International Amaldi Conferences

of Academies of Sciences and National Scientific Societies on Scientific Questions of Global Security

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XVII International Amaldi Conference of Academies of Sciences and National Scientific Societies on Scientific Questions of Global Security

14-16 March 2008, DESY, Hamburg

Proceedings

Union of the German Academies of Sciences and Humanities
represented by the Academy of Sciences and Humanities in Hamburg

Editors: Klaus Gottstein, Götz Neuneck

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XVII International Amaldi Conference of Academies of Sciences and National Scientific Societies on Scientific Questions of Global Security

(DESY, Hamburg, Germany, 14-16 March 2008)

Summary

The XVII International Amaldi Conference took place on the campus of the German Electron Synchrotron (DESY) in Hamburg under the auspices of the Hamburg Academy of Sciences and at the joint invitation of the president of the Union of German Academies of Sciences and of the Chair of the Amaldi Conferences at the Accademia Nazionale dei Lincei in Rome, Prof. Edoardo Vesentini. Organisational support was given by the Institute for Peace Research and Security Policy at the University of Hamburg, the Center for Science and Peace Research of the University of Hamburg, and by DESY. Sponsors were the Stifterverband für die Deutsche Wissenschaft, the Stiftung Friedensforschung and the Alfred Toepfer Stiftung.

Sixty scientists and scholars from 15 countries (Canada, China, the Czech Republic, France, Germany, Iran, Israel, Italy, Japan, Korea (South), Norway, Poland, Russia, the United Kingdom and the United States) attended the three-day conference.

In honour of Prof. Wolfgang K. H. Panofsky, co-founder of the Amaldi Conferences who passed away on September 24, 2007, the conference was opened by a newly established “Panofsky Lecture” delivered by his old friend and long-standing associate in arms control and government advising activities, Richard L. Garwin.

The topics on the agenda were:

1. Nuclear Policies of the Nuclear Weapon States,
2. Safe Fuel Supply for Civilian Nuclear Power Stations and the Risk of Nuclear Proliferation,
3. The Future of Non-Proliferation,
4. The Risk of Nuclear Terrorism,
5. New Military Technologies such as Directed Energy Weapons.

Also discussed were

- problems of offering independent scientific advice in questions of security policy,
- the role of the nuclear option in regional conflicts,
- methods of detection of clandestine nuclear activities,
- options for the future of nuclear energy and nuclear weapons.

Apart from the presentation of papers there was a panel discussion on these topics.

A special feature of the conference was the participation of young scientists who served as *rapporteurs* on the results of the individual sessions, thereby having the opportunity to give an assessment of the problems and the suggested solutions from the point of view of the younger generation. This novelty was widely acclaimed, was recommended for perpetuation in future Amaldi Conferences and is hoped to contribute to a permanent regeneration of the Amaldi Conferences.

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Preface

It is my great pleasure to present here, on behalf of the Union of German Academies of Sciences and of its President, Professor Günter Stock, the Proceedings of the XVII International Amaldi Conference of Academies of Sciences and of National Scientific Societies on Scientific Questions of Global Security. This Conference was held, from March 14 to 16, 2008, on the campus of the German Electron Synchrotron (DESY) in Hamburg under the auspices of the Hamburg Academy of Sciences and at the joint invitation of the Chair of the Amaldi Conferences at the Accademia Nazionale dei Lincei in Rome, Prof. Edoardo Vesentini, and of the President of the Union of German Academies of Sciences, Prof. Gerhard Gottschalk till December 2007 and Prof. Günter Stock as of January 2008.

The purpose and the goal of the Amaldi Conferences is to inform a sufficient number of members of academies and of scientists nominated by academies, on questions of security and arms control in order to keep up to date a reservoir of independent experts in these fields who are able and ready to discuss these questions with government experts, supplying new ideas and independent advice. To secure political neutrality the Amaldi Conferences do not pass resolutions and publicize only the issues discussed whereas the proceedings contain all the papers submitted as well as accounts of the discussions.

Topics treated at previous Amaldi Conferences under the particular political aspects of the day were, *inter alia,* the future of nuclear weapons, the technical problems of the prevention of nuclear proliferation, the conversion of military research establishments to civilian use, particularly in the former Soviet Union, the control of conventional arms trade, the detection and defusing of landmines, and the verification of the non-production of chemical and biological weapons.

The particular conference the proceedings of which are recorded here is number seventeen in a series which started in 1988 as the result of an initiative by Dr. Frank Press, then President of the U.S. National Academy of Sciences (NAS), and Dr. Wolfgang K.H. Panofsky, then chair of the Committee of International Security and Arms Control (CISAC) of NAS. They suggested in 1986 that European Academies and scientific societies should join the talks then already underway for some time between CISAC and a corresponding committee of the Academy of Sciences of the USSR on questions of arms control and disarmament. Due to the understanding and enthusiasm of Prof. Edoardo Amaldi as Vice-President and soon afterwards President of the Accademia Nazionale dei Lincei, the proposal by Press and Panofsky was immediately accepted by the Italian academy. The first conference of the type suggested took place in Rome in 1988. It was a success, and Professor Amaldi and the Lincei were hosts to another such conference in 1989. After Amaldi's untimely death these conferences were named Amaldi Conferences in his honour and continued in Rome (1990), Cambridge (1991), Heidelberg (1992), Rome (1993), Warsaw (1994), Piacenza (1995), Geneva (1996), Paris (1997), Moscow (1998), Mainz (1999) Rome (2000), Siena (2002), Helsinki (2003), Trieste (2004). The proceedings of these conferences were widely circulated and brought to the attention of governments and scientific and cultural societies.

The letters of invitation to the seventeenth Amaldi Conference (Hamburg, 2008) were sent to the Presidents of the academies and national scientific societies of most of the countries traditionally participating in the Amaldi Conferences. The main topics of a preliminary agenda were mentioned. The Presidents were asked to nominate scientists able to contribute to discussions on these topics. Fifteen countries responded. Sixty scientists and scholars from Canada, China, the Czech Republic, France, Germany, Iran, Israel, Italy, Japan, Korea (South), Norway, Poland, Russia, the United Kingdom and the United States attended the three-day conference.

The preliminary agenda for the XVII Amaldi Conference was arrived at in a two-step-process. A tentative draft was designed by members of the German Amaldi Committee at a meeting in Hamburg on 27 April 2007. This draft was submitted to Prof. Vesentini as chair of the Amaldi Conferences who discussed it with members of the Italian arms control committee and modified it following suggestions made by Prof. W.K.H. Panofsky who was in Rome at the beginning of June 2007. Finally, the preliminary agenda of the XVII Amaldi Conference envisaged discussions on the Nuclear Policies of the Nuclear Weapon States, on Nuclear Proliferation and the Risk of Nuclear Terrorism and on New Military Technologies such as Directed Energy Weapons, and on all the sub-topics coming under these headings. The problem of offering independent scientific advice in questions of security policy was also one of the topics. Also discussed at the conference were the role of the nuclear option in regional conflicts, methods of detection of clandestine nuclear activities, and options for the future of nuclear energy and nuclear weapons.

Apart from the presentation of papers there was a panel discussion on these topics.

The scientific programme of the Hamburg Amaldi Conference was opened by a special "Panofsky Lecture". Wolfgang K.H. Panofsky had died on September 24, 2007, at age 88. Not only had he been a nuclear physicist of world-wide reputation and an advisor to several U.S. Presidents on questions of nuclear arms control and disarmament, he may also be considered to have been, together with Edoardo Amaldi, one of the two fathers of the Amaldi Conferences. When informed in April 2007 in our congratulations on his 88th birthday that another Amaldi Conference was due to take place in the near future, he expressed enthusiasm and, as mentioned above, influenced the programme of that conference in a very substantial way later that year. Up to his last days he had maintained a keen interest in the Amaldi meetings. It is hoped that the opening by a "Panofsky Lecture" will become a tradition in future Amaldi Conferences. The Panofsky Lecture in Hamburg, the city where Wolfgang Panofsky ("Pief") had lived in his boyhood until his forced emigration, with his parents, to the United States, the city where he was Honorary Senator of the University, was delivered by Richard L. Garwin, his old friend and long-standing associate in arms control and government advising activities.

This volume contains all papers submitted to the conference. In some cases the authors have slightly changed the titles of their contributions, as compared to the titles that appear in the original programme, in order to fit them even better to the intended messages. The volume also reproduces transcriptions of the introductory speeches and of a number of discussion remarks. Some of the latter were edited by their authors after transcription, some were edited by the transcribers, by Prof. Neuneck and by the undersigned who accepts the responsibility for any mistakes that might have been introduced by this process. Included are also the programme of the conference, and the list of participants.

A special feature of the conference was the participation of young scientists who served as rapporteurs on the results of the individual sessions, thereby having the opportunity, in the Tenth Session, to give an assessment of the problems and the suggested solutions from the point of view of the younger generation. This novelty, due to the initiatives of Götz Neuneck and Martin Kalinowski, was widely acclaimed, was recommended for perpetuation in future Amaldi Conferences and is hoped to contribute to a permanent regeneration of the Amaldi Conferences. By the way, the report of the Tenth Session may thus serve as a summary of some of the main results of the conference.

There is no record of the Eleventh Session in which there was a general discussion on the topics of this conference and on the future of the Amaldi Conferences. However, most of it was taken up during the Open Meeting of the International Organizing Committee of the Amaldi Conferences right after the official end of the conference. We are very grateful to Dr. Richard Garwin for writing a report on that meeting which he chaired. In this meeting experiences gained from the conference just ended and procedures for initiating future Amaldi Conferences were discussed and adopted. This will be very helpful for the organization of future Amaldi Conferences. For this reason Dr. Garwin's report is reproduced at the end of these proceedings.

Our sincere thanks are due to Prof. Albrecht Wagner, Head of the DESY Directorate and Member of the Hamburg Academy of Sciences, for the permission to use the DESY auditorium, the DESY Guesthouse and the DESY restaurant and to Dr. Frank Lehner and the DESY staff for the technical arrangements that made this conference on the DESY site and the printing of these proceedings possible. Mrs. Katharina Lehner, Ms. Cinthia Heanna and Mr. Michael Schaaf deserve our thanks for their painstaking and often difficult work in transcribing the audio recordings of the discussion remarks and of some of the presentations.

Prof. Heimo Reinitzer and Prof. Cord Jakobeit, President and Vice President of the Hamburg Academy of Sciences, derserve our gratitude for extending the auspices of the Hamburg Academy of Sciences to the XVII Amaldi Conference.

Participants in the preparatory meetings in Hamburg of the German Amaldi Committee were Michael Brzoska, Peter J. Croll, Constanze Eisenbart, Klaus Gottstein, Martin Kalinowski, Götz Neuneck, Hartwig Spitzer. They gave their time and their ideas to the preparation of a successful conference. Special mention deserves Goetz Neuneck without whose continued support and suggestions this conference would not have been as successful as it turned out to be. After 20 years of service as German representative with the Amaldi conferences I am very happy that the Presidium of the Union of German Academies of Sciences appointed Prof. Neuneck as my official successor as Representative of the Union of German Academies of Sciences with the Amaldi Conferences. This is a promising signal for the future thriving of the Amaldi Conferences and of the work of the German Amaldi Group.

Organisational support to the conference was given by the Institute for Peace Research and Security Policy at the University of Hamburg under the leadership of Professor Michael Brzoska and Professor Götz Neuneck and the Center for Science and Peace

Research of the University of Hamburg led by Professor Martin Kalinowski. Financial support was generously supplied by the Stifterverband für die Deutsche Wissenschaft, the German Research Association (Deutsche Forschungsgemeinschaft), the Deutsche Stiftung Friedensforschung and the Alfred Toepfer Stiftung F.V.S. We are very grateful to all of these institutions.

Klaus Gottstein
Representative of the Union of German Academies of Sciences with the Amaldi Conferences
(till December 2008)

XVII International Amaldi Conference of Academies of Sciences and National Scientific Societies on Scientific Questions of Global Security

(DESY, Hamburg, Germany, 14-16 March 2008)

Programme

Thursday, 13 March 2008

16:00 Tour of DESY

18:00 Informal Get-together

Friday, 14 March

9:00-9:30 **Opening Welcome**

Prof. Albrecht **Wagner**, Director of DESY

Prof. Cord **Jakobeit**, Vice President of the Hamburg Academy of Sciences

Prof. Edoardo **Vesentini**, Chair of the Amaldi Conferences

9:30-10:30 **First Session**
(**Chair**: Albrecht **Wagner**)

Albrecht **Wagner** (Germany): Introduction to the Panofsky Lecture: Pief's Contributions To Physics, a Brief Survey, Introducing the Panofsky Lecturer, Richard Garwin

Richard **Garwin** (USA): Panofsky Lecture: Pief's Contributions to Arms Control and Nuclear Disarmament

11:00-12:00 **Second Session**
(**Chair**: Edoardo **Vesentini**)

Spurgeon **Keeny** (USA): The Relationship between Scientists and Policy-Makers in the Field of Arms Control

John **Boright** (USA): Academy Influence on the G8 Agenda

12:00-12:30 **Third Session:** Regional Conflicts and the Nuclear Question
(**Chair**: Constanze **Eisenbart**)

Rudolf **Avenhaus** (Germany): On the Conflict about Iran's Nuclear Program: a Game-Theoretical Analysis

13:30-15:30	Continuation of Third Session
	Yair **Evron** (Israel): Regional Nuclear Deterrence Relationships: Stable or Unstable?
	Saideh **Lotfian** (Iran): Regional Security from the Perspective of Iran (with emphasis on the nuclear issue)
	Aharon **Zohar** (Israel): Iran; the Oil and the Bomb
	Mark **Suh** (South Korea): Prospect of the Six-Party-Talks and Peaceful Resolution of the North Korean Nuclear Issue
16:30-18:00	Boat Trip through Hamburg Harbour to the City Hall
18:00	Reception by the First Mayor of the City of Hamburg in the Town Hall

Saturday, 15 March

9:00-13:00	**Fourth Session**: Safe Fuel Supply for Civilian Nuclear Power Stations and the Risk of Nuclear Proliferation (**Chair**: Spurgeon **Keeny**)
	John **Simpson** (UK): Strategy Options for the UK's Separated Plutonium.
	Tatsujiro **Suzuki** (Japan): The Nuclear Fuel Cycle and Proliferation.
	Rudolf **Avenhaus**/Thomas **Krieger** (Germany): A Quantitative View on Verification of Arms Control and Disarmament Treaties.
11:00-12:30	**Fifth session**: Continuation of Fourth Session (**Chair**: Henri **Korn**)
	Boris **Myasoedov** (Russia): Proliferation Concerns Connected with Nuclear Fuel Cycle Developments.
	Ole **Reistad** (Norway): Report on International Project on the Minimization of HEU in All Nuclear Fuel Cycles
	Adele **Buckley** (Canada): Nuclear Renaissance-Protocols to Verify Safety, Terrorism Protection and Safeguards, in Preparation for International Agreements.
13:30-14:00	Continuation of Fifth Session
	John F. **Ahearne** (USA): Internationalization of the Nuclear Fuel Cycle.
14:00-15:00	**Sixth Session**: Detection of Clandestine Nuclear Activities (**Chair**: Alex **Keynan**)
	Jerzy **Mietelski** (Poland): Monitoring of Plutonium in the Air
	Martin **Kalinowski** (Germany): Detection of Clandestine Nuclear Weapons Production and Testing by Analyzing Air Samples.

15:30-16:00 Continuation of Sixth Session

Christopher **Watson** (UK): Radiological Detection of Nuclear Material.

16:00-17:30 **Seventh Session**: The Risk of Nuclear Terrorism
(**Chair**: John **Simpson**)

Wu **Jun** (China): The Analysis of Nuclear Terrorism Risk
Francesco **Calogero** (Italy) The threat of nuclear terrorism

17:30-18:00 **Eighth Session**: New Military Technologies
(**Chair**: Richard **Garwin**)

Götz **Neuneck** (Germany): Strike Technologies / Laser Weapons

<u>Sunday, 16 March</u>

9:00-10:00 **Ninth Session**: Thoughts on the Nuclear Future
(**Chair**: Vladimir **Nekvasil**)

Harald **Müller** (Germany) The Future of the Non-Proliferation Regime,

Andrew **Mack** (Canada) The Risks of "Break-out" in a Nuclear-Weapon-Free World Compared to the Risks of the Nuclear Status Quo.

10:00-10:30 **Tenth Session**: Reports by young scientist-rapporteurs on the salient results of the individual sessions. Discussion.
(**Chair**: Götz **Neuneck**)

11:00-12:30 Continuation of Tenth Session

14:00-15:30 **Eleventh Session**: Panel and general discussion on the topics of this conference and on the future of the Amaldi Conferences in general
(**Chair**: Martin **Kalinowski**)

15:30 Closing of the Conference

15:30-16:00 Coffee

16:00-18:00 Open Meeting of the International Organizing Committee of the Amaldi Conferences

Photo of Participants

Group photo of the participants at the
XVII International Amaldi Conference of Academies of Sciences and of National Scientific Societies on Scientific Questions of Global Security, DESY, Hamburg, 2009

By courtesy of Marcel Dickow, see http://amaldi2008.desy.de/e103/

XVII International Amaldi Conference of Academies of Sciences and National Scientific Societies on Scientific Questions of Global Security

(DESY, Hamburg, Germany, 14-16 March 2008)

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Contributions to the discussion

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Opening Session

Opening Remarks by Albrecht Wagner, Director of DESY

Ladies and Gentlemen,

It is my great pleasure to welcome you at DESY, which together with the Hamburg Academy of Sciences hosts this year's Amaldi Conference. I would like to start by saying Edoardo Amaldi is known to me as a particle physicist who has played a fundamental role in the foundation of CERN. So, I am very grateful to him and particle physicists owe him a lot. Today, you are at DESY and, for those of you who were not here yesterday, I would like to describe in two words where you are.

DESY is a national research laboratory focusing on the understanding of the innermost structure of matter in two research areas: particle physics and structural research with X-rays. DESY is serving a broad user community of 3000 scientists from 45 nations from all around the world, while pursuing also it own research. Although DESY is nationally funded by the German government and the government of the state of Hamburg and - for our outstation near Berlin - the state of Brandenburg, it serves a very international user community.

The topic of this conference is something I am not an expert in - therefore I will not say much about it, except stressing the major importance of these discussions. I believe that discussions in this field are very, very important – as are the interactions between countries, also between countries who normally would not speak to each other. In that sense I wish you a very productive meeting, very good discussions and very forward looking results and with this I hand over to the Vice President of the Hamburg Academy of Sciences, Cord Jakobeit.

Welcome Address by Cord Jakobeit, Vice President of the Hamburg Academy of Sciences

Thank you very much, Professor Wagner.

Honorable President Vesentini,
Dear members of the XVII Amaldi Conference,
Ladies and gentlemen,

I would also like to extend a warm welcome to all of you: to DESY, first of all, but also to the XVII Amaldi Conference here in the city of Hamburg. I want to welcome you in the name of the Union of the German Academies of Sciences, which after 1992 in Heidelberg and 1999 in Mainz, is hosting this conference in Germany for the third time. I am here to replace our President, Prof. Reinitzer, who had to undergo knee surgery and who sends his best wishes and great apologies. This year's conference takes place under the auspices of the Hamburg Academy, which is the youngest of the eight academies in Germany.

Some of you have come a long way, from places such as Iran, Israel, Japan, India, Pakistan, South Korea, Russia and the U.S. and from several European countries. Hamburg is also a very diverse and multiethnic place and I hope that the insight you will gain from this conference will be matched by your hopefully positive impressions from the city.

Scientific questions of global security – this has been the major emphasis and topic of the Amaldi Conferences for the last twenty years. The end of the east-west confrontation notwithstanding, topics such as the future of nuclear weapons, the technical problems of the prevention of nuclear proliferation, the risk of nuclear terrorism, the control of conventional arms trade, the detection and defusing of land mines, the verification of the non-production of chemical and biological weapons etc., have been with us over these last two decades with different emphasis of course. And they have not lost their urgency and actuality as demonstrated by the many unsolved conflicts in this world. Therefore, I take it as a sign of hope that you have united here to discuss and think about possible ways out of these military and political impasses. As a scientist, there is little more rewarding than devoting one's time and energy to the most challenging issues of mankind.

The objectives of the Amaldi Conference are close to what we as the Hamburg Academy of Sciences and I personally perceive of as very urgent topics. Therefore we were glad to take this year's conference under our auspices with a special mandate from the Union of the German Academies of Sciences. We are also glad to demonstrate our commitment and interest in these matters with a symposium we will host along with several other institutions in less than two weeks time. This symposium on March 27th will commemorate one of the largest demonstrations, indeed the largest demonstration in Hamburg in the post-war years, that took place some fifty years ago in April of 1958, when more than a hundred thousand people demonstrated in front of the Hamburg Town Hall – which, by the way, you are going to see tonight at the reception. This demonstration against a then much discussed possible nuclear armament of the *Bundeswehr*, the German Armed Forces, and against the nuclear arms race of the two superpowers will be at the center of this symposium in two weeks time by linking a historical context with questions about nuclear proliferation of today.

As an academy which was also founded in 2004 to pool scientific activities of the region, we are looking with great interest at the many scientific institutions and the research activities in Hamburg that deal with issues of peace and conflict research in a larger sense, such as the Institute for Peace Research and Security Policy at the University of Hamburg; the various institutes at the Helmut Schmidt University here in Hamburg, one of the two Universities of the Armed Forces in Germany; the recently founded Carl Friedrich von Weizsäcker Center for Science and Peace Research; and the Institute for Theology and Peace; to name just a few. We hope that we will be able to launch a scientific project in the area of peace and conflict research at the Hamburg Academy of Sciences soon. And we think that the Academy might be in a good position to act as an umbrella, a focal point for these many regional research activities in peace and conflict research matters.

You will open this XVII Amaldi Conference commemorating the late Wolfgang K. H. Panofsky, who passed away last September. He undoubtedly played a critical role in bringing the Amaldi Conferences to life. Sad as this loss may be, I think you are closing a circle when you took Hamburg as a place to honor the life and the achievements of Wolfgang Panofsky, delivering the first Panofsky lecture today. Wolfgang Panofsky's father, one of the most important art historians of the 21st century, was successfully teaching at the Hamburg University when the National Socialist, the Nazi party, forced him to resign and to emigrate to the United States. Wolfgang Panofsky was fourteen years old at that time. I do not know the biography of Wolfgang Panofsky well enough to be able to tell you how much he suffered from this experience of loss and separation from his mother country. But I am afraid that the city of Hamburg had a lot of sad memories for him. Probably also good memories, I hope. The more I am happy today that you are honoring him for his many achievements as a renowned scientist, especially for his merits in the field of disarmament and in the responsible and reflected handling of atomic energy, in the very city he and his family were chased out of. As a political scientist who is very much interested in issues of regime effectiveness and compliance, I am of course tempted to comment on the deplorable state of the nuclear nonproliferation regime, which is seemingly heading into crisis. But I will leave it to your expertise and hope to learn from what you have to say about these issues. It would be great if this conference could in later years be seen as one of the many elements of the yet unfinished mosaic to come closer to the old vision of a complete abolition of all nuclear arms. Helmut Schmidt, the former German chancellor and ever the old pragmatist, once remarked that the one who has visions should go see the doctor. I much rather admire people who relentlessly work towards coming closer to what an old vision once promised.

Ladies and gentlemen, let me again express my great respect for your work and efforts here at the beginning of your deliberations. I can only thank you for your commitment and relentless efforts to work for a more peaceful world. I wish you all the best for a good, informative and insightful conference. And I hope that you have a few happy days here in Hamburg. Thank you very much for your attention.

Introductory Remarks by Edoardo Vesentini, Chair of the Amaldi Conferences

On November 20, 2004, in a short farewell speech at the conclusion of the XVI Amaldi Conference in ICTP Trieste, I said, speaking for myself - but I presumed to represent the position of many of us - that I look forward, with moderate optimism, to the future, to the real existence XVII Amaldi Conference. But I also said that all of us would do our best to make it possible.

In the three years which lapsed since the meeting in Trieste, moderate optimism seemed to be really too optimistic and the possible continuation of the series of our meetings seemed to be out of our reach. The fact that we are here today and the XVII Amaldi Conference has just started is quite an achievement, sort of miracle, which is essentially due to the generosity of our German colleagues. It is a pleasant duty for me to express our gratitude to all of them, thanking in particular Professor Jakobeit, Vice President of the Hamburg Academy of Sciences, and Professor Albrecht Wagner, Chairman of the board of the directors of DESY, where we are here today. Special thanks go to our old friend Klaus Gottstein, who has taken on himself the burden of the organization. In the long series of the Amaldi Conferences that began in Rome, in 1988, this is the first one in which Pief Panofsky is not with us. All of us here, and in particular those who had the privilege of sharing his friendship, are going to miss his intellectual integrity and his advice in a world in which many of our certitudes - which were also his certitudes -, seem to be fading away. In his talk at the Amaldi Conference meeting in Geneva 1996 he said that, notwithstanding the many recent criticisms of science and scientists in general, the members of the Academies in particular have a high credibility both with the public and the respective governments. Now, that certitude is no longer universally shared in our society. But then he added in the same speech that putting questions of international security and arms control by Academies, acting either singly or in concert, continues to be important, and that the original Amaldi Guidelines remain generally valid. Those set at the time of Frank Press, Pief Panofsky, Edoardo Amaldi and all the founding fathers of our small community remain our guidelines. Also under this respect it is particularly fitting that the XVII Amaldi Conference and perhaps other future Amaldi Conferences begin with the Panofsky lecture. Thank you.

First Session - The First Panofsky Lecture

Chair: Albrecht Wagner

Introduction to the Panofsky Lecture:
Pief's Contributions To Physics, a Brief Survey
Introducing the Panofky Lecturer, Richard Garwin

Albrecht Wagner (Germany)

Ladies and gentlemen,

It's my great honor to introduce Richard Garwin. But before I do so I should point out that I agreed with him that I will review the scientific work of Pief Panofsky. Richard Garwin will review what Pief did in arms control and other domains. Let me therefore start by picking up something Professor Jakobeit said:

Pief Panofsky was born in Berlin in 1919 and then grew up as a boy here in Hamburg. He went to one of the most prestigious schools in Hamburg, the Johanneum, and as you heard he had to leave together with his family in 1933 for the United States. His father had a dual appointment at that time. He was the founder of modern art history and of course tried to influence his children and to introduce his love for art into his children, but probably he overdid it. Pief told me that he went to the museum with his father, where they would stand in front of one painting for four hours. That is definitely too much, so whatever you do with your children, don't overdo it. His father also probably did not have the sense of working with his fingers. Therefore he called his two boys, who both were in science, "the plumbers" - *die Klempner*. And Pief was actually very proud, he considered this as a title of honor being called a *Klempner* by his father.

He was fifteen when he arrived in the United States and did not even bother to go to high school, but went straight into Princeton University. So it is not astonishing, with such a head start, that he graduated, got his PhD, at the age of 23 at Caltech while working in the field of x-rays. Jesse DuMond, who was his thesis advisor, became his father in law afterwards. By the time he graduated, at the age of 23 (we are writing 1942) there was already war and Pief went and worked on military projects. I think the project which influenced and impressed him the most was that he had to measure the yield of nuclear weapons and was actually a close witness to the first atomic explosion. After the war Pief went to Berkeley, where he worked with Luis Alvarez on the design of a Proton LINAC. That was the time of the McCarthy era in the United States and the staff of LBL had to sign a non-communist oath, which Pief did, but he did not approve of it. He therefore left Berkeley for Stanford, where he stayed ever since on the physics faculty.

At Stanford he laid the foundation for an impressive number of Nobel Prizes by providing the facilities first at MARK III, where Hofstadter did his study of nuclear structure, and later when he built the project M, the project "Monster" as it was called, which today we call lovingly the SLAC LINAC, a two miles linear accelerator on which a number of Nobel Prizes were gained both for understanding of the deepest structure of the proton and for the discovery of the J/Psi and the tau Lepton.

The SLAC LINAC construction was started in 1961. This was the time when Pief became the director of SLAC, which he remained until 1983. For 23 years he was guiding the laboratory in an absolutely remarkable way. I think many things have been said about Pief as leader - those of you who knew him know that he did it with patience, with energy, with foresight and with a lot of creativity. He had a unique understanding of physics together with a unique understanding of what is technically doable. That of course was very important for a laboratory which covered both experiments and theory.

From my personal point of view, and from the point of view of the laboratory that I represent, Pief has been very instrumental in many critical moments in the history of DESY. In the very early times he recommended to the founding father of DESY, Willibald Jentschke, to ask for more money than Jentschke originally intended. This became a famous story because Jentschke each time asked more and he got it. Later on, he was instrumental when the question was how DESY should move on after the first project. Jentschke sampled the opinion of several of his scientific colleagues and friends and assigned a weight factor to the opinion of the different people and Pief's opinion got a very large weight factor. You will not be astonished that the University of Hamburg, to which DESY is strongly linked, awarded in 1984 an Honorary Doctorate to Pief Panofsky and in 2006 Pief became an honorary senator of the University of Hamburg. This was the last time he was actually visiting Hamburg with his wife Adele and we had lots of interesting and inspiring discussions with him.

I can recommend to you a book Pief wrote about his life - "Pief Remembers" - which describes his way through physics and through arms control. The Leitmotiv of Pief was by Voltaire: "Love truth but pardon error". I think this motto guided him. Pief was also motivated enormously by his conscience and responsibility as a scientist for society. And this has let him become so engaged in projects you are discussing. This part of Pief's life will be covered by Richard Garwin.

It is my great pleasure and honor to introduce Richard Garwin, who was born in 1928 in Cleveland, Ohio and received his PhD from the University of Chicago in 1949. It would probably take too much time if I would try to mention all the things he has done in his life. He was among the directors of the IBM Watson Laboratory and held many other positions there too. He was teaching at a number of universities, he was professor of public policy at the Kennedy School of Government at Harvard, and of course in addition he has played and is still playing a very important role as an advisor to many people, among them presidents of the United States and always on the topic of military technology, arms control etc.

He has an incredibly broad spectrum of scientific interests and achievements, ranging from understanding weapons to computers, which is not astonishing if you work at IBM, to communication, again linked to that. But then I find things like his work on *solid helium*, on the detection of gravitation or radiation etc. Also the interests and breadth of his work are illustrated by more than 500 publications and, what is less usual, 46 patents.

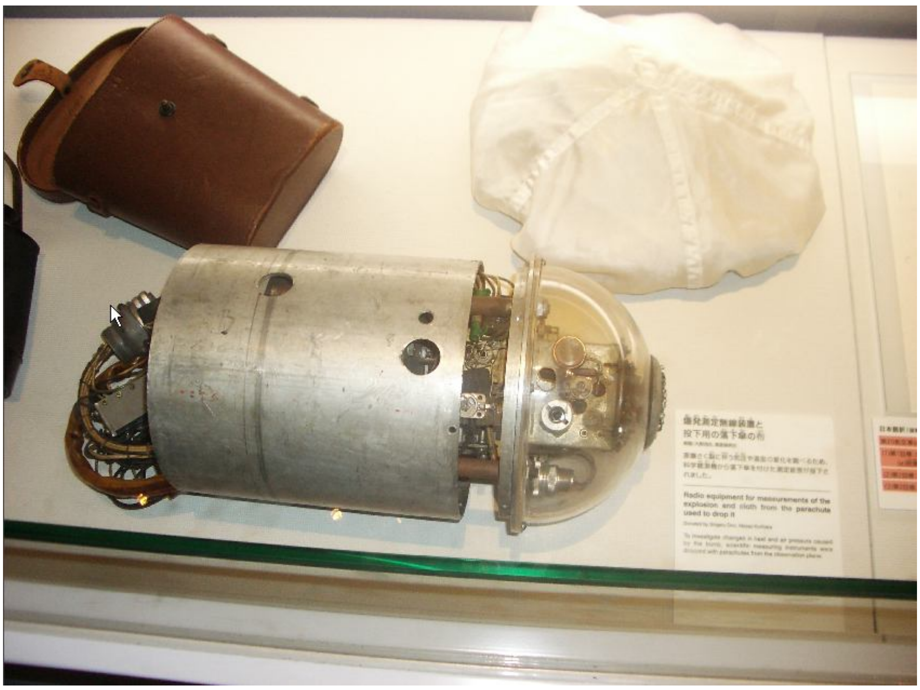
He has been advising Presidents of the United States, he has been on the Defense Science Board, he was member of the scientific advisory group to the joint strategic target planning staff, chair of the arms control and nonproliferation board and I could continue. He is presently member of the JASON Defense Advisory Committee. He has been working on the council of the Institute for Strategic Studies and is a long and an all time member of Pugwash. He received many honors which I will not read to you.

Let me quote once more Voltaire who said: “It is dangerous to be right in matters on which the established authorities are wrong.” I think both Pief and Richard Garwin have been facing that danger and have tried to defuse it by educating authorities so they are a little more right. Richard Garwin, thank you very much for coming, the floor is yours!

The First Panofsky Lecture
Pief's Contributions to Arms Control and Nuclear Disarmament

Richard L. Garwin (USA)

W.K.H. Panofsky (Pief) was a great man in his field of high-energy physics, in his creation and operation of accelerators and a laboratory that led to 3 Nobel prizes for work he promoted as Director, in his teaching and service to the physics profession, and in his contribution to national and international security. In this presentation I shall review Pief's work in national and international security, especially as I saw it when we were both members of the President's Science Advisory Committee (PSAC), of its Strategic Military Panel, an advisory panel to Henry Kissinger, National Security Assistant to President Nixon, and of the Committee on International Security and Arms Control of the National Academy of Sciences (CISAC). This covers the period from the late 1950s through 2007.



Radio equipment for measurements of the explosion and
cloth from the parachute used to drop it. Hiroshima Peace Museum.
(Photo courtesy of Ben Rusek, NAS CISAC)

We are fortunate to have Pief's own views of these efforts in his 2007 autobiography "Pief Remembers: Panofsky on physics, politics, and peace." It may be useful to see these from a different perspective. Pief's experience in the technical aspects of security in the Nuclear Age began at Los Alamos during the war. There he worked on a parachute-borne device to determine the yield of the nuclear weapons under development by responding to the pressure pulse and transmitting the signal by radio to a receiver on a nearby aircraft. This drew on his prior work on a "firing error indicator" (FEI) for anti-aircraft gunners in training – work done with Alex E.S. Green under Jesse DuMond, whose daughter, Adele, Pief would later wed.

Recruited to Berkeley by his Los Alamos colleague Luis Alvarez after the war, Pief worked with him on the proton linear accelerator and the "Materials Testing Accelerator" (MTA). This was to compensate for a supposed uranium shortage by accelerating deuterons against a uranium target in order to breed plutonium for nuclear weapons. Pief's broader national security work probably began with the "Screwdriver Report", his response with Robert Hofstadter to the task of detecting "one cubic inch" of weapon material -- plutonium or highly enriched uranium (HEU) that might be smuggled into a United States port, concealed in a packing case. Despite the mild radioactivity of the uranium and the enormous rate of emission of alpha particles from 20 curies of plutonium, the "Screwdriver Report" nevertheless judged quantitatively that detection sensitivity and shielding was such that the only sure way of fulfilling the task was to disassemble the packing crate with a screwdriver. In a 1946 hearing of a committee of the U.S. Senate, Robert Oppenheimer responded to a Senator's question as to how one might detect a smuggled nuclear weapon, "... my most important tool would be a screwdriver to open the crates and look." In 1955 Pief was involved in a much broader task for the Air Force Scientific Advisory Board – to explore means for countering the delivery of nuclear weapons against the United States – a task that was to occupy him the rest of his life.

In 1958 the first opportunity presented itself for actual negotiations with the Soviet Union to explore the possibility of verifying a ban on nuclear explosive tests, and a Conference of Experts convened in Geneva to explore the matter. On the basis of its report, negotiations began in the Fall of 1958 on a ban of all nuclear weapon tests. Spurgeon Keeny will discuss this further, but I just note here that the first Conference of Experts was regarded by pro-testing scientists and officials in the United States as too optimistic on detection of clandestine nuclear explosions, and a second Conference of Experts was convened in 1959 to explore this further. From 1961-64, Pief was a member of the President's Science Advisory Committee (PSAC) attending two-day plenary meetings in Washington each month and in a typical month several two-day sessions of a subcommittee or PSAC panel. He notes,

"Because I had to teach freshman physics on Wednesday mornings, my wife would pick me up from my return flight to San Francisco on Tuesday evenings, drive to the Stanford lecture hall and work with me to prepare the demonstrations needed for the next day's classes. We then went home and early on Wednesday mornings I gave the lectures and accompanying demonstrations, usually to three classes in succession."

Pief is remembered for his effectiveness in teaching and for his dedication to that profession, as indicated by this example.

In June of 1961, Pief chaired a PSAC panel to evaluate technical factors on the need for nuclear testing and also to assess whether the Soviet Union had or had not conducted any secret nuclear tests during the moratorium on nuclear testing which was then in place. There was much public interest in this report, and properly so. It concluded that "It was feasible for the Soviet Union to have conducted secret tests, that there was no evidence that it had done so (or had not done so), and that there was no urgent technical need for immediate resumption by the United States." This conclusion was not universally shared, and was especially criticized by the Department of Defense. Thus, after the demise of PSAC in 1973 the technical questions of the necessity for or the technical benefits of nuclear testing and the possibility that it might be done covertly continue to recur, and were addressed by Pief, particularly via the instrument of the National Academy of Sciences' Committee on International Security and Arms Control (CISAC) which played a key role in such later analyses.

In the modern world, after the signing of the Comprehensive Test Ban Treaty (CTBT) in 1996, it was submitted to the U.S. Senate for ratification September 25, 1997, but it was only brought up for a vote on October 13, 1999, where it failed of ratification. President Clinton set up a special advisor, former chairman of the Joint Chiefs of Staff, General John Shalikashvili, who in April 2000 requested the National Academy of Sciences to conduct a study on technical issues regarding the CTBT. Although that study was completed and approved by the authors December 2000, discussions over the classification of the Report, together with the required approval process within the Academy delayed publication of the Report until July 2002. This study, chaired by John Holdren, in which Pief played a leading role, compared three possible future worlds -- one without any restriction on nuclear testing; a world where a CTBT is obeyed by everyone; and a world where a CTBT is in existence but evaded to the extent possible without detection by the worldwide system established for monitoring the CTBT. This technical and military analysis concluded that U.S. national security is served better with a CTBT than without one, even if extreme evasion efforts continued.

Now I turn to Pief's work in the Strategic Military Panel (SMP) of the President's Science Advisory Committee and his activities in the group led by Paul Doty that advised Henry Kissinger as President Nixon's national Security Advisor and, to a lesser extent, when Kissinger was both Secretary of State and National Security Advisor. Pief's work was characterized by a dedication to scientific correctness and thoroughness, compatible with producing a coherent report in time to do some good. In this he exemplified the best of technical advisors, not falling into the policy-only trap or into the technical-only trap, without proper concern for timeliness or understandability.

For years the SMP had the task of assessing the state-of-the-art and deployed capability of ballistic missile offense and defense, on both the U.S. and the Soviet sides. This was very helpful in bringing realism to the two sides. It was all too easy to postulate effective defenses on the U.S. side, as unfortunately the U.S. Army often did, in fulfillment of its obligation to provide plans and programs for such defenses and to implement them if judged desirable by the President of the United States. But because the SMP had the job of assessing Soviet missile defenses and of U.S. capability to penetrate them, it was familiar with the techniques that offensive nuclear weapons could use to confuse, deceive, or overwhelm the defense until it was too late for the defense to destroy them.

Each year, therefore, the SMP prepared a Top Secret assessment for the President. In the 1960s this meant advising on a series of attempts to develop a credible anti-ballistic missile defense system. First to be examined by SMP was the 1961 proposal of NIKE-ZEUS -- an evolution of the Army-developed and deployed air defense systems (NIKE-AJAX and NIKE-HERCULES). However, it suffered from the problems associated with mechanically steered radars of inadequate agility to cover a large threat and also inadequate traffic-handling capability, even if there were only pure warheads and no decoys.

The Army then proposed (in 1965) the NIKE-X system of ballistic missile defense, which would have multiple phased-array radars and many interceptors to protect the entire country. Its fatal flaw was the ability of an adversary to focus the attack on a small region of the country and thus to exhaust the local supply of interceptors.

The next proposed was the SENTINEL system in 1967; it used NIKE-X technology and aimed to provide a "light area defense" of the United States against a small number of Chinese intercontinental ballistic missiles. Furthermore, the planned Sentinel system was to have two layers. One, a 5-megaton exo-atmospheric interceptors (the Spartan); and second, a short-range interceptor that would engage the nuclear-armed reentry vehicles in the upper atmosphere -- the Sprint interceptor missiles. The SMP's final assessment of the Johnson Administration effort was that the Sentinel system would not work for reasons that were both technical and strategic, particularly the ability of the offense to deploy many light-weight decoys that could not be discriminated by the ground-based radar and would thus require more interceptors than could be deployed. By the time the discrimination would be effected by the slowdown of decoys in the atmosphere, it would be too late to launch the nuclear-armed interceptors to destroy the warheads.

But there was a deeper reason for the failure of such a system. It was intended to defend the entire U.S. population against nuclear-armed ICBM attack by the Chinese. It thus required more anti-missiles than could be afforded. Consequently, the offense could choose the regions that were not defended by Sprint missiles rather than the regions that were defended, still destroying as many millions of people as if there had been no defense at all.[1]

In July 1965, Pief wrote the members of the SMP a memo, "Changes in the AICBM Picture", that is, changes in the status of understanding of anti (intercontinental) ballistic missiles in the world and particularly in the United States. Pief argued that the technical situation had changed since 1961, with the recognition of a new longer-range kill

[1] The SMP had the most experienced and best-qualified technical people to be found, without attention to their partisan political or philosophical bent, including over the years Hans Bethe, Lewis M. Branscomb, Sidney D. Drell, Dan Fink, myself, Marvin Goldberger, Richard Latter, Pief, Jack P. Ruina, Kenneth M. Watson, Albert D. Wheelon, and Jerome B. Wiesner. Some of the Panel members were experts in radar, some in nuclear weapons. Others specialized in intelligence as applied to the Soviet threat, and others in system analysis and computing. Still others were experts in the interaction of rockets and nuclear explosions with the atmosphere, important in determining the detectability of missiles, the disruption of radar capability by the effects of nuclear explosions on the atmosphere, and the like. In the earliest days of the SMP there was much attention to "wake effects" and discrimination.

mechanism from interceptors with exoatmospheric burst of their nuclear warheads, and with better discrimination of decoys from warheads within the atmosphere. Pief noted the vulnerability of the 1961 system (and potentially the 1965 system) to a "decoy-only" attack with multiple decoys launched by small missiles to exhaust the interceptors protecting a portion of the country -- incidentally a proposal I had made in 1953 while I was working on Project Lamp Light, on the air defense of the United States and Canada.

Here are some further examples of the work of the PSAC Strategic Military Panel: On September 25, 1967, Marvin Goldberger, at the time chairman of the SMP, wrote on behalf of the SMP that the Panel did not find Secretary of Defense Robert S. McNamara's arguments for the Sentinel system convincing and that such an ABM system should not be deployed ("except for domestic political considerations beyond our competence").

In May 1967, Drell and Panofsky, as members of the SMP, had written Spurgeon Keeny, staff of the Office of Science and Technology with chief responsibility for strategic military matters, a memo "Bilateral Strategic Weapons Freeze", copied to Marvin Goldberger as chair of the SMP and to Donald F. Hornig as President Johnson's Science Advisor. Keeny was at the same time and had long been a senior staff member of the National Security Council, providing that body a unique competence in technical matters and an invaluable link to PSAC.

When President Nixon took office January 20, 1969, one of the first decisions of his administration was to refocus the light ABM deployment of the Johnson Administration, in view of the quite unexpected popular opposition to the proposal to defend only 12 or so localities in the United States. It had been expected that the public would clamor to have the defense extended to their locality, but instead the prospect of the certain deployment of nuclear-armed interceptors in their neighborhood brought strong opposition. Although the Nixon Administration was philosophically favorable to the deployment of an effective and heavy defense against Soviet nuclear-armed missiles, it was politically infeasible to move in that direction and so the argument for the full-scale development of the technology and its initial deployment shifted in favor of a limited defense of one wing of Minuteman ICBM silos -- that is, 150 of the total of 1000 silos -- a task for which the Sentinel System was ill-suited, despite the change of name to Safeguard. Note that the modified deployment did nothing to directly protect the population.

President Nixon had chosen as his National Security Advisor Prof. Henry Kissinger of Harvard University, who although capable, confident, and energetic, knew little about science or technology, but nevertheless rather than taking advantage of the powerful mechanism of the President's Science Advisory Committee and the President's Science Advisor chose to cut PSAC out of direct contact with the president. For instance, the President's Science Advisor at that time, Lee DuBridge, forwarded to the president a report of the Strategic Military Panel signed by its chair, Sid Drell, and a copy of that report, now declassified and available in image form, bears Kissinger's marginal note, "We must get PSAC out of strategy." Fortunately, a good personal friend and Harvard colleague of Kissinger's was Prof. Paul Doty, a noted biochemist and long-time member of the President's Science Advisory Committee. Doty suggested, and Kissinger agreed, that Doty should lead a group of technical colleagues, most of them members of the PSAC, to provide informal advice on request to Kissinger as National Security Advisor.

The group initially was constituted by Doty, Drell, myself, George B. Kistiakowsky, Pief, George W. Rathjens, and Ruina.

We would meet with Kissinger in the White House Situation Room (with maps of crisis areas on the wall, and behind a curtain the military staff involved in crisis communications) nominally at about 6 pm, but it was often 7 pm or later before the National Security Advisor could make room for us in his schedule. We would discuss briefly and leave with him a highly classified paper that we had prepared for him over the previous month, and we would of course respond to any current questions he had. We would meet with him the next morning for breakfast at about 7:30 am to go over issues he wanted us to study for the next month's meeting and for further discussions of the paper of the previous evening.

The group had expertise not only in nuclear weapons and radar and military systems such as air defense and missile defense and strategic submarines and antisubmarine warfare, but also in space, intelligence, biology and biochemistry and biological warfare, and several other academic and security-oriented fields. Kistiakowsky, who had succeeded James R. Killian as President Eisenhower's Science Advisor, soon left the group because of philosophical differences with Kissinger over Vietnam, and Rathjens soon resigned because of his opposition to the bombing of Cambodia. The rest of us stuck it out, feeling that the influence that we could have was worth the likely rejection of our advice.

An important topic on which we spent considerable time in analysis and discussion was that of multiple independently targeted reentry vehicles for strategic ballistic missiles (MIRVs) and the question of whether they should be banned in a Strategic Arms Limitation Treaty. At that time the United States had tested but not deployed MIRVs, and the Soviet Union had not tested. U.S. unilateral intelligence resources ("National Technical Means") could verify with high confidence the absence of MIRV testing, and one option for a SALT agreement would include a ban on testing or deployment of MIRVs. Kissinger decided not to include this because he felt that he had enough difficulties overriding military preferences by severely limiting ballistic missile defense, and he did not want to jeopardize that achievement by proposing to limit MIRVs as well. At one point in 1974 Kissinger is quoted as saying, "If I'd realized what a MIRVed world meant, I would have been more serious about obtaining a MIRV ban."

A flavor of our activity, for instance, is in a paper of February 1971, on "Collateral Constraints on Surface-to-Air Missiles as Anti-Ballistic Missiles, and Implications of Hard-Site Defense" (Hard-site defense (HSD) is the use of specialized interceptors or even guns or small rockets to destroy reentry vehicles containing nuclear warheads before they can approach the silo or other hardened target to within lethal range -- a distance at which an explosion could destroy or disable a target). Far from rejecting ABM, the Doty Group concluded that if there were to be a Strategic Arms Limitation Treaty (SALT) that limited ABM systems, United States' interests would be better served if the treaty banned hard-site defense, but that in the non-SALT context of a continuing arms race, HSD might become valuable as a way to preserve the nuclear deterrent and that R&D work for the design and advanced technology of HSD should continue to be supported at that time. But the Group viewed with concern the political risk of introducing a demand to permit hard-site defense at that stage in the negotiation.

Of current note, in view of the UK program to begin the construction of a replacement for its Trident submarines and the beginning of consideration in the United States of a similar program, is a report prepared April 1971 by Doty, Drell, Garwin, Ruina, and Panofsky, "An Evaluation of the Undersea Long-Range Missile System (ULMS)." This was a technical paper for Kissinger that reviewed the proposal for ULMS (that was eventually funded and became the Trident submarine with the Trident-II missile). It did not conclude that ULMS was necessary or even desirable and although it provided a full but concise evaluation of ULMS and of a converted Poseidon to carry the ULMS missile, as competitors, it argued that if there were urgency in providing the ULMS system, "ULMS should not be thought of as a replacement for worn out Polaris boats. Polaris boats have an indefinite life or can be assumed to operate for at least another 20 years". "If an urgent need for ULMS developed, the 8-yr lag before first delivery could be shortened by redesigning the Poseidon conversion to accommodate the missile designed for ULMS ... In this way some boats with ULMS missile capability could be on station in less than half the time required to produce ULMS boats. All the advantages (of ULMS) apply equally to redesigned Poseidon."

Political arguments over the program were later to overwhelm the technical arguments that would have brought increased and more flexible capability sooner via the converted Poseidon submarines than via the Trident route. The work of the SMP as well as of PSAC was terminated by President Nixon in 1973 and for nearly a decade the White House had no continuing independent scientific advice. However, in the Carter Administration this was partially reversed. An interesting example is the technical analysis of a possible nuclear test, possibly from a ship or barge in the "South Atlantic".

The "South Atlantic Event"

On September 22, 1979, one of the VELA satellites in 100,000-km radius circular Earth orbit detected with its two whole-Earth light sensors a double-peaked flash. Although differing in detail, the signal resembled that from some of the atmospheric tests that the 12 VELA satellites had detected over the years. Agencies of the U.S. government responsible for analyzing and interpreting such detections attempted in the immediate aftermath to determine whether this was indeed an atmospheric nuclear explosion or an artifact of the system. It was reported to the President as a likely nuclear test.

A few days after the event, President Carter's Science Advisor, Frank Press, at the suggestion of Spurgeon Keeny, convened a panel, chaired by Jack Ruina of MIT, that included myself, Pief, and Luis Alvarez, among others, to review the information that had by then accumulated. Keeny had reviewed the data with Secretary of Defense Harold Brown before it was released to the intelligence community. We began our work and, with these people experienced in treating large amounts of data from particle physics, requested much information from the VELA system that had NOT originated with nuclear explosions. We found many such "zoo events". In this activity, Pief showed his insistence on reviewing all available information, keeping an open mind toward all hypotheses, and searching for ways of analyzing the data best suited to determining whether the records were indeed the double-humped light output of a nuclear explosion. The report of the Ruina Panel is publicly available on my website at http://tinyurl.com/yww4vf. The key to the determination was provided by Panel member F. Williams Sarles, who plotted the data in the "phase plane" of one light sensor vs. the other, differing nominally only in sensitivity. However, the two sensors, having the same view of the Earth, did behave differently, thus indicating that they could not have been viewing the same event on or near the Earth; in this regard the signal differed from any of the detections of a true nuclear test.

The panel concluded, "Although we cannot rule out the possibility that the signal was of nuclear origin, the Panel considers it more likely that the signal was one of the zoo events, possibly a consequence of the impact of a small meteoroid on the satellite". Apparently, the light source in question was close to the satellite and thus viewed differently by the two light-detectors. One of the many micro meteors that strike satellites could have liberated a small piece of reflective insulation that traversed the field of view of the VELA satellite, the double-hump in time occurring because the flake of insulation was spinning as it passed the field.

Pief followed the VELA detection puzzle through the years, and received occasional updates that in fact provided no new information to confirm that VELA had detected a nuclear explosion. Nevertheless, the so-called "detection" continues to be accepted in some U.S. government circles as an attempt to hide a test of a low-yield nuclear weapon.

The Stanford Arms Control Program

In the late 1960s, Stanford University was a center and victim of student turmoil, especially protests against the Vietnam War. As a concerned senior faculty member, Pief was much involved in general and in particular with one case of a professor who had been brought up for discipline by the university.

Beyond suffering in silence and working in general to calm the unrest, Pief and his SLAC colleague Sid Drell -- also Professor of Physics and former member of the President's Science Advisory Committee -- wanted to show students that there were other more important and more general topics of concern, to the solution of which they might contribute if they turned their interest and their talent in that direction. Pief and Drell organized and co-taught a famous arms control course beginning in the very early 1970s, and Pief was very active in creating the Stanford arms control program, which eventually became in the late 1980s the Stanford Center for International Security and Arms Control.

Two such charismatic teachers attracted many students to this course, among them James B. Timbie, who has been an important senior official in arms control and national security in the Department of State.

JASON Work

The JASON Defense Advisory Group was formed in 1960, initially attached to the Institute for Defense Analyses, a federally funded research contractor. There was a perception by senior scientists advising the U.S. government that the expertise accumulated during the Second World War was a waning resource, and that scientists involved in real technical work for the government would be needed to replace the aging coterie of those who had worked on technical problems during World War II. This was dubbed the JASON group, which met in the summertime for six weeks or so, and typically had a couple of field trips and a three-day meeting in Washington, DC

Spring and Fall. Pief contributed to many Jason reports. Most had to do with his areas of expertise -- charged particle accelerators as weapons or for the production of tritium, or monitoring of proliferation. We note a 2003 JASON report which was a return to his roots -- the Screwdriver report -- as an analysis of prospects for detecting a concealed nuclear weapon. Technology had evolved since the study more than 50 years earlier, so that by the use of conventional high-energy x-rays from a portable electron accelerator, together with modern particle detectors, it is indeed technically feasible to scan the 7,000,000 cargo containers entering the United States each year to detect an intact smuggled nuclear weapon, or to identify a small fraction of containers that would need further scanning or even unpacking to ensure the absence of a weapon. But it would be necessary to build the extensive system to perform the scanning, preferably in the ports of shipment rather than on arrival, and to communicate, store, and interpret the information from the scan and other data relating to the container.

Pief also contributed to several other reports dealing with a nuclear test ban or of programs of stockpile stewardship -- maintaining nuclear weapons safe and reliable without nuclear explosion tests. The Jason mode is such that it is difficult to discern the contribution of individual authors, but Pief's participation was always much esteemed.

The National Academy, CISAC and the Soviet Union

The year 1980 was a difficult and perilous time during the Cold War. The Soviet Union had invaded Afghanistan in December 1979, and President Jimmy Carter cancelled U.S. participation in the 1980 Moscow Olympics. In 1979 the United States possessed some 25,000 nuclear warheads and the Soviet Union several thousand more. These were loaded on bombers and missiles and aimed mostly at targets in the opposing nation. Ronald Reagan was about to be elected President of the United States and Leonid Brezhnev was the longtime General Secretary of the Soviet Union, to be succeeded on his death in 1982 by Yuri Andropov and then by Konstantin Chernenko. Mikhail Sergeyevich Gorbachev assumed that position in March 1985.

Formal negotiations initially planned in the administration of President Lyndon B. Johnson, resulted in Richard M. Nixon's administration in the 1972 ABM Treaty and the Limited Offensive Agreement, but the building and deployment of nuclear weapons continued. Non-official contacts between scientists in the Soviet Union and the United States continued discussions of nuclear hazards and of means of controlling the nuclear threat. Perhaps the most important of these was SADS (Soviet-American Disarmament Studies) led by Paul Doty beginning in 1964 and ending in 1975. These contacts were for the most part under the sponsorship of the American Academy of Arts and Sciences (Boston), supported by the Ford Foundation. In 1980 the US National Academy of Sciences began to explore a more formal but still unofficial relationship with the Soviet Academy of Sciences, and such meetings began in 1981 at a pace of two per year in the Soviet Union or in Washington.

The US CISAC thus created was chaired initially by Marvin L. Goldberger, then president of CalTech. The Soviet counterpart was chaired for two years by Nicolai Inozemtsev, Director of the Institute of World Economy and International Relations, and after his death for a long time by Evgenij P. Velikhov. It had as members, among others, Roald Z. Sagdeev, Georgi A. (Yuri) Arbatov, and Evgenii Primakov. Initially, Igor Tamm was a member and after his release from internal exile Andreii D. Sakharov.

Our early sessions discussed some details of nuclear forces, of crisis and arms-race stability, and the relationship between defenses and offensive forces. Pief was an active participant in all of these and later succeeded Goldberger as chairman.

In 1982 and 1983 there was much talk in the Western press about directed energy space weapons (DEW): lasers and particle beams as a new means of defense against nuclear-armed missiles. These were seriously discussed between our groups. In early 1983 there was such a bilateral discussion at a meeting in Washington, with very detailed analysis of the effectiveness and vulnerability of space-based DEW that led to the judgment that they would not be militarily effective. One week later, on March 23, 1983, President Reagan gave his television speech announcing the Strategic Defense Initiative (SDI) calling for the scientists "who gave us the nuclear weapons to give us the means to render them impotent and obsolete" by intercepting them before they could reach their targets. It was clear that the defense was to be non-nuclear and largely dependent on DEW, including a nuclear-explosion-pumped x-ray laser weapon! The SDI announcement provided further focus to our bilateral discussions.

When Mikhail Gorbachev assumed the Soviet leadership in March 1985, he felt the need to hear from capable, honest people outside the power structure of the military, the administration, or the Party and worked closely for a year or more with Arbatov, Primakov, Sagdeev, and Velikhov, so we were sure that our bilateral analyses were brought to the attention of the Soviet leadership by individuals capable of interpreting them. Probably to the disappointment of many in science and engineering in the Soviet Union, Gorbachev did not follow the United States into a major SDI defensive program but decided that he could defeat SDI with means that were asymmetric, and at some 1% of the cost to mount an SDI system. That was probably the most exciting aspect of the CISAC bilateral with Soviet counterparts, and Pief played a big role.

Pief with CISAC and Soviet counterpart at STRATCOM HQ
(E.P. Velikhov, et al. July 1991)

The major reports of CISAC bear Pief's stamp of thoroughness, clarity, and integrity. I have added a brief excerpt or summary of each report:

- Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities (2005):
"1. Present and foreseeable technological capabilities exist to support verification at declared sites, based on transparency and monitoring, for declared stocks of all categories of nuclear weapons -- strategic and nonstrategic, deployed and nondeployed -- as well as for the nuclear-explosive components and materials that are their essential ingredients. Many of these capabilities could be applied under existing bilateral and international arrangements without the need for additional agreements beyond those currently in force."

- Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty (2002):
"The worst-case scenario under a no-CTBT regime poses far bigger threats to U.S. security -- sophisticated nuclear weapons in the hands of many more adversaries -- than the worst-case scenario of clandestine testing in a CTBT regime, within the constraints posed by the monitoring system."

- The Future of U.S. Nuclear Weapons Policy (1997):
"In any case, the regime of progressive constraints constituting the committee's proposed near- to midterm program makes good sense in its own right -- as a prescription for reducing nuclear dangers without adverse impact on other U.S. security interests -- regardless of one's view of the desirability and feasibility of ultimately moving to prohibition."

- Management and Disposition of Excess Weapons Plutonium: Reactor-Related Options (1995):
"Separated weapon-usable material -- highly enriched uranium or plutonium of any composition aside from almost pure Pu-238 -- should be provided security comparable to that provided nuclear weapons in storage -- the 'stored nuclear weapons standard'. The initial goal of disposition of excess weapons plutonium should be to degrade it to a condition in which its security needs are comparable with those of spent reactor fuel itself -- the 'spent-fuel standard'."

- The Future of the U.S.-Soviet Nuclear Relationship (1991):
"Instead, we seek an appropriate balance between the positive and adverse effects of nuclear weapons in the face of many uncertainties. We recommend, in furtherance of a new nuclear policy, that:
(1) In the agreements that follow the Strategic Arms Reduction Treaty (START), the United States and the Soviet Union should reduce the number of nuclear warheads in their strategic forces to 3,000-4,000 actual warheads, a reduction of as much as a factor of 3 below anticipated START levels. The remaining strategic forces of both sides should be made more survivable, both by eliminating the most vulnerable forces (in particular MIRVed ICBMs) and by reducing the vulnerability of retained forces. "

These studies, available to read and download at www.nap.edu constitute a tangible and enduring part of Pief's legacy.

Pief and the Amaldi Conferences

Pief's involvement with the Amaldi Conferences was intense and better known to some here than to me. But it would be good to record his role in creating the Amaldi Conferences. By 1986, it was clear that the principal purpose of CISAC was being achieved -- that the interaction with our Soviet counterpart group had paid off in better informed scientists on both sides who, especially on the Soviet side after the accession of Mikhail Gorbachev, were having a substantial impact on Soviet policy. CISAC then asked whether it would be possible to influence other national academies, particularly in Europe, to play such a role with their governments. To explore this further, CISAC prepared and hosted a "European meeting" in Washington June 28-30, 1986. Ten CISAC members and eleven European scientists took part in this meeting, including Klaus Gottstein, Francesco Calogero, and Carlo Schaerf. On their return to Italy, Calogero and Schaerf reported to Edoardo Amaldi, then Vice President of the Accademia Nazionale dei Lincei. Amaldi was very much in favor of this initiative and set up a Working Group on International Security and Arms Control (SICA). The first informal meeting was held at Rome at the Lincei June 1988, and then an international conference, "International Security and Disarmament: The Role of the Scientific Academies" was held in Rome in June 1989.

There was good interaction at the CISAC "European meeting," and I believe that following the meeting the Royal Society did step up its activities with the government of the United Kingdom, as did the French Academy of Sciences with that of France. As indicated, Edoardo Amaldi was particularly inspired by the proposal and hastened to create not simply an interaction between the Accademia dei Lincei with the Italian government, but on a grander scale hoped to have a continuing involvement among the academies for contributions to their national security. When Amaldi died unexpectedly in December 1989 Prof. Giorgio Salvini was elected to succeed him as President of the Academy and of the SICA group as well, and the international meetings were named henceforth, "Amaldi Conferences."

Pief and China

Pief first went to China in 1976 with his wife, Adele, for a two-week visit to which, characteristically, he gave his all -- touristically, diplomatically and to collaboration in High Energy Physics. The result was his intense involvement in advancing China's participation in High Energy Physics. He was proud of his unique status. Chinese leaders proposed to Pief that he become an advisor to the Chinese Academy of Sciences, but Pief did not think it appropriate to be a formal advisor to a foreign country, and instead a section in the annual agreement between the US Department of Energy and the Chinese Academy of Sciences provided for his services as an unpaid consultant in the field of High Energy Physics. SLAC thus played a leading role with Chinese scientists resident at SLAC in the design and construction of the Beijing Electron-Positron Collider.

Pief's excellent relations with scientists in China and with high government officials there, encouraged him to suggest to the Chinese that they create a mechanism to work with the NAS CISAC to better understand the threats nuclear weapons posed to their security and how to bring them under control. Since Pief then chaired CISAC, it was natural that he should propose such an interaction with the Chinese. Rather than the

Chinese Academy of Sciences, which does not have a role in nuclear weapons, the Chinese Academy of Engineering Physics was the counterpart of the US NAS, and so a productive interaction began with the Chinese Scientists Group for Arms Control, under the leadership of Hu Side, head of the Institute of Applied Physics and Computational Mathematics (IAPCM), the design branch of the Chinese nuclear weapons program. The CSGAC-CISAC bilateral continues to this day and will have its 20th anniversary this year.

The first bilateral talks between Chinese scientists and the CISAC delegation led by Pief. 20 years ago.

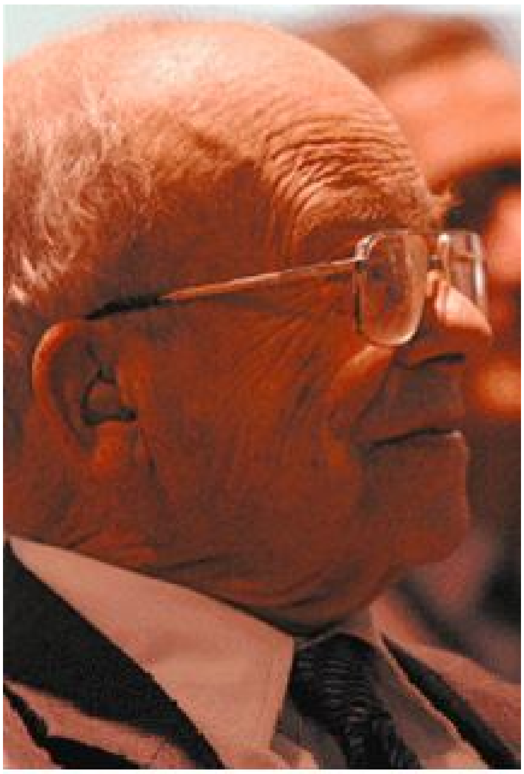
Pief was welcomed by the leaders of COSTIND in China.

Pief with CISAC and CSGAC in Beijing, ~ 2003

Evidently it is valued by both sides. It permitted frank discussions of the prospective Comprehensive Test Ban Treaty and the drawing of a balance between the security benefits and the costs to the nuclear weapons program and the potential hazards of a collapse of the CTBT regime.

While this brief review covers only part of Pief's role, it makes clear that he was one of the most important founders of the tradition of American science advising in national security matters. He had a unique combination of breadth of interest, focus, energy, and talent that led to his becoming one of the great scientific advisors in the first half-century of the nuclear age. He made full use also of his energy and intellect in trying to make the world's decision makers better informed in the national self interest and in the interest of the world's inhabitants.

In this approach he was my personal hero, for his dedication, his good spirit, his ability, his insistence on integrity, and his readiness to take pencil in hand to commit ideas to paper as informative and persuasive prose. I am honored to have had the opportunity to present at this Amaldi Conference the first Panofsky Lecture, which cannot possibly do justice to such a great man.



W.K.H. “Pief” Panofsky
* 1919 – † 2007

Discussion of Richard Garwin's Lecture

Erwin Häckel *(Germany): Dr. Garwin, just a brief question relating to the VELA satellite incident on the south Atlantic nuclear or not nuclear flash. You referred to the findings of your panel that the evidence was at least questionable. I wonder, is there now, 30 years later, any historical evidence that your finding was correct or not?*

Richard Garwin: No, as I indicated, no additional evidence has turned up in support of the hypothesis that it was a nuclear test. Pief was particularly interested in this, so we received updates from further intelligence. What's so remarkable is that nobody has come forward saying that they were involved, providing any details, writing their memoires now that it is long gone. Many had believed the conspiracy theory and thought it was a collaboration of an Israeli nuclear device with the South Africans, helping them move the bar to whatever. There is a lot of non-information. A South African minister once quoted the existence of an Israeli-South African program, but he was just repeating what he saw in the press. The way President Nixon was persuaded that the US public was behind his bombing of Hanoi harbor when it was not, this was disinformation that was published by the White House and his supporters. So, it is hard to find the reality in these cases. What is clear is that the conference of experts which defined the various sensors that should be on a satellite for the detection of tests in the atmosphere and in space resulted in the VELA satellites. They successfully detected the 43 nuclear explosions before the South Atlantic event. You may ask: how would you know if it's in the South Atlantic if these sensors view the entire world's surface? Well, logically it must be that there were other sensors that were looking elsewhere and the only place unlooked at by the other sensors was the South Atlantic. That doesn't give you high confidence that it actually took place and that it took place there.

Second Session - The Relationship between Scientists and Policy-Makers in the Field of Arms Control

Chair: Edoardo Vesentini

The Relationship between Scientists and Policy Makers in the Field of Arms Control

Spurgeon Keeny (USA)

The question of the relationship of scientists to policy-makers in today's high technology world is extremely complicated. Since scientists interact at all levels of the government bureaucracy that influence policy, I will address my remarks to the much narrower question of the direct involvement of scientists with the US President who has the final say on US arms control policy. Even this is a challenging assignment, given the fact that since World War II there have been eleven US Presidents with very different styles interacting with sixty years of history.

Rather than give a bare-bones summary of this interaction over this span of personalities and time, or attempt some all-encompassing generalities, I think it would be more interesting and useful to recall in some detail a few illustrative case studies with which I had direct involvement. At the outset, let me emphasize that the access of scientists to presidents is not an end in itself; their advice must be judged objectively as to whether it is based on sound science and subjectively as to whether it advances arms control in a problem-solving manner or serves to undercut arms control by creating or exaggerating problems.

The most impressive positive example is found in the initial phase of the half-century long history of the Comprehensive Test Ban Treaty, which remains a work in progress. By the mid 1950's, President Eisenhower had concluded that with the testing of multi-megaton nuclear weapons, nuclear warfare had become militarily unacceptable. At the same time, the Cold War was heating up and Eisenhower was faced with dire estimates of the Soviet threat and the growing public concern about fall-out from atmospheric nuclear tests.

Seeking independent advice, Eisenhower appointed James Killian as his full-time Science Advisor supported by a Presidential Science Advisory Committee made up of a group of prominent scientists, many of whom had played critical roles in World War II military projects. As one of its first assignments, the committee at Eisenhower's request examined the feasibility of a ban on further nuclear testing. The committee concluded that such a ban would be in the net security interest of the US and could be adequately verified.

On the basis of this advice, Eisenhower proposed a meeting of scientists from the US, UK and USSR and their principal allies to examine the verifiability of a test ban. This led to the Conference of Experts, which met in Geneva in the summer of 1958. The delegations were made up of senior scientists including several Nobel Laureates and specialists from the weapons laboratories and the intelligence communities. I found myself as the staff director of the US delegation. The US delegation had no instructions other than to obtain an objective assessment of a ban's verifiability and to report directly to the President's Science Advisor in Washington.

Despite existing international tensions, the conference proceeded in a professional collegial fashion and agreement was soon reached on the ability of a hypothetical world wide system with some 160 control posts, using existing techniques, and supplemented with the right to undertake on-site inspections to detect and identify atmospheric and under-ocean tests with yields above one kiloton. The problem of underground tests proved more difficult since at the time there had been only one such test, Ranier, with a yield of about 2 kilotons. Nevertheless, the seismologists concluded, on the basis of US data, that tests above 5 kilotons could be detected and probably identified against the background of natural seismic events.

Based on the Conference's report, Eisenhower decided, over the objection of many of his political and military advisors, to propose that the three nuclear powers negotiate a comprehensive nuclear test ban. These negotiations, which began in the fall of 1958 in Geneva, were of a much more conventional type, with senior diplomats representing each side but still with senior science advisors on each delegation or on call.

Before the negotiations got very far, technical problems developed when the US delegation, on instructions, introduced new technical information which questioned the findings of the Conference of Experts. An additional underground nuclear test and further analysis led some US seismologists to conclude that the identification limit of underground tests might be twice as high as previously estimated. More significantly, a group of US scientists led by Edward Teller had challenged the overall findings of the Conference of Experts on the grounds that methods of evasion were available that would permit undetected testing at very high yields. This could be accomplished either by testing in huge underground cavities or testing in outer space, even behind the moon, with an accompanying rocket to record data and communicate it back to earth.

While these evasion scenarios did not conflict with physical principles, they did involve enormous practical problems, tremendous costs and probably telltale collateral evidence. Nevertheless, the President's Science Advisor decided that these claims should be reported and examined internationally to avoid the inevitable charge that scientists favoring the test ban were suppressing unfavorable information. Consequently, technical working groups were set up to consider the problems in parallel with the formal negotiation.

The first working group addressed the problem of tests in space, which had not been addressed by the Conference of Experts. The US group led by Panofsky included some of the scientists who had proposed testing in space. Panofsky put the US group to work calculating the distance as a function of yield at which various sensors on satellites could detect radiation from a nuclear explosion above background radiation. Although the distances were enormous indicating the difficulty of such testing, Federov, who led the Soviet group, at first objected for ideological or political reason to putting any limits on the capabilities of detection, but Panofsky persisted successfully.

The second working group was tasked with analyzing the problem of evasion by testing in large underground cavities. The US side co-chaired by Panofsky decided that the concept should be presented by Hans Bethe since he was internationally recognized as a strong supporter of the ban and a scientist whose credentials and integrity were beyond question. After Bethe completed his typically elegant lecture on the theory behind the decoupling phenomenon, Federov, who was chairing the session, simply said as I recall, "Thank you Dr. Bethe, and does anyone else want to present any of Dr. Teller's ideas to improve the treaty?" While this irony was not the problem-solving response that Panofsky would have liked, I don't know what response we expected to get. The result of this working group was a third working group.

The third working group was called to explore what research programs might be undertaken to improve the ability to detect and identify seismic events. The US group led by Frank Press, who subsequently became President Carter's Science Advisor and then President of the National Academy of Sciences, came well prepared with the results of meetings of key US scientists in the field. At the outset, the working group appeared to be making progress in defining a joint research program on how one might improve seismic detection and identification. Unfortunately, unbeknownst to the participants, a US U-2 spy plane had just been shot down over Sverdlovsk. This led to the blow-up of the Paris summit. Shortly thereafter the Soviet delegation announced, I thought rather regretfully, it had been recalled. Thus ended for all intents and purposes progress on the CTB during the Eisenhower presidency.

The test ban issue resurfaced under President Kennedy, but soon bogged down over the modalities and number of annual on-site inspections of suspicious seismic events. Khrushchev offered two or three inspections, but Kennedy wanted seven or eight inspections. Jerry Wiesner, Kennedy's Science Advisor, was unable to persuade Kennedy to propose five as a reasonable compromise. Despite suggestions, Khrushchev also declined to propose five. I concluded at the time that Kennedy was not prepared to bargain for a test ban because he judged, probably correctly, that he would not be able to obtain Senate ratification. It turned out that Krushchev was having his own domestic problems at the same time.

Public concern over atmospheric contamination increased with the resumption of testing after a voluntary moratorium of a few years. The Soviets conducted gigantic sixty-and thirty-megaton atmospheric tests while the US conducted a megaton-plus test at 400 kilometers altitude over the Pacific, which had far-reaching communications effects and disabled at least one civilian satellite and potentially endangered Soviet astronauts in space. Moreover, the Cuban missile crisis created international alarm over the real possibility of nuclear war. In this environment and without further scientific preparation or support, veteran diplomat Averill Harriman was dispatched to Moscow with a very small delegation. In little over a week he completed a pre-arranged deal to ban future nuclear testing in all environments except underground. The widely acclaimed Limited Test Ban Treaty helped reduce the level of world-wide anxiety by showing that the US and Soviet Union could still arrive at constructive agreements. As far as arms control was concerned, however, the agreement simply drove testing underground, where many more tests were conducted in the following twenty years than had been conducted in the previous twenty years.

More than thirty years passed before an international comprehensive test ban was negotiated with US leadership under President Clinton. Unfortunately, despite the support of the Joint Chiefs of Staff and the directors of the nuclear weapons laboratories, the United States Senate failed to ratify the treaty. Claims had been made by some US scientists, again led by Edward Teller, that the treaty would prevent tests necessary to protect the aging US nuclear weapons stockpile. It was also claimed that new weapon developments could be based on very small nuclear tests with yields measured in kilograms of high explosive rather than kilotons, which could not possibly be detected under the treaty. These misleading claims provided grounds for voting against the treaty to Senators who were anxious to withhold from Clinton credit for a major international accomplishment. One hopes that the Senate will revisit this issue in the next administration. Ratification by other key states, however, will still be needed for the treaty to enter into force.

The strategic arms control negotiations provide many interesting insights into the interaction of scientists with arms control policy. Under President Johnson, the initial thinking about strategic arms control developed largely within the government involving parallel activities in the newly created Arms Control and Disarmament Agency (ACDA) and the Department of Defense. President Johnson strongly supported the idea of early negotiations with the Soviet Union. It was originally planned to announce that negotiations with the Soviet Union would begin in the fall of 1968, but the day before the announcement was to be made Soviet troops moved into Czechoslovakia and the joint announcement was cancelled. President Johnson still wanted to open negotiations before his term expired, but time ran out.

To the surprise of many, the newly elected President Richard Nixon and his National Security Advisor Henry Kissinger decided to go ahead with the negotiations. In so doing, they explicitly excluded the President's new Science Advisor and the President's Science Advisory Committee from the development of a US negotiating position. They were apparently concerned that naive scientists would limit their freedom of action.

In developing the US position, however, difficult technical issues soon arose between CIA and the Defense Intelligence Agency over the extent of the Soviet threat to be controlled. Independent science advisors to DIA had concluded that the Soviet ABM system included not only the large Moscow site but also the internetting of the numerous nuclear-armed SA-5, and even SA-2, air defense sites, constituting a nation-wide capability. In addition, it was argued that the giant Soviet SS-9 missiles already had a MIRV capability, thus greatly increasing the existing Soviet threat. CIA argued that the evidence did not support either of these conclusions. This led to interminable arguments in the verification panel chaired by Kissinger, who had by now taken over as the arbiter of the US policy position and on which I now represented the Arms Control and Disarmament Agency. In the process, Kissinger realized he needed independent scientific advice on these and other issues. Rather than call on the Science Advisor, he met with the informal group described by Garwin. He arranged with me, however, to handle their clearances and other arrangements so that the group would have no official tie to the White House. In the end, Kissinger was persuaded that CIA was correct, possibly influenced by his secret panel, and negotiations began.

The US negotiating team was led by Ambassador Gerard Smith, director of ACDA and a senior diplomat with a strong delegation, including Harold Brown, then President of Cal Tech, and other technical experts. I chaired the interagency backstopping committee, but Kissinger and his staff dealt with all important decisions. In fact, Kissinger completed the final deal backchannel with the Soviet leadership without the knowledge of the US delegation or anyone else in the US government other than

President Nixon. It is interesting to note that the resulting ABM Treaty was ratified by the Senate with only two dissenting votes and the interim SALT I Agreement received overwhelming Congressional support.

Another important illustration of the interaction of science advice and strategic arms control policy came fifteen years later, on March 23, 1983, when President Reagan announced the Strategic Defense Initiative (SDI), which would provide a shield that would in his word make nuclear weapons "impotent and obsolete". This concept had been developed by a group of scientists led by Edward Teller working with the then Presidential Science Advisor, George Keyworth. It consisted of a wish list of unproven directed energy weapons, including a nuclear explosive-pumped x-ray device and various space-based kill devices.

The announcement came as a complete surprise to most knowledgeable non-government scientists as well as to all but a very small group of very senior government officials, some of whom strongly opposed the announcement. I remember the day before the announcement, I received calls at the National Academy of Sciences from several very senior physicists asking if I had any idea why they were being summoned to the White House for a command performance Presidential announcement.

This is an excellent example of direct scientific advice to a President on arms control policy-related issues. Unfortunately, the science was flawed and misleading. The program popularly labeled "star wars" was roundly criticized by most knowledgeable scientists, with Garwin and Panofsky playing leading roles. But the damage was done. Over the next twenty-five years and with the expenditure of well over a hundred billion dollars, the program's grandiose objectives shrank as reality sank in. Nevertheless, the present President Bush arbitrarily withdrew from the ABM treaty that had been in force for over thirty years in order to deploy a few problematic interceptor missiles against an equally problematic North Korean threat. Now free from the solemn treaty obligations entered into by President Nixon to make strategic arms control possible, President Bush plans to deploy ten more problematic interceptor missiles in Eastern Europe against the non-existent Iranian threat.

Finally, on a more encouraging note, let me conclude with an illustration of scientific policy advice developed entirely outside of government that had a direct impact on arms control policy. In 1975 when I was not in government, I was asked by the Ford Foundation to chair a study on the future of civil nuclear power, which was, of course, closely tied to the issue of nuclear proliferation. I managed to persuade some twenty distinguished scientists, including Garwin and Panofsky, as well as economists and political scientists to join in a year-long study group, with the somewhat presumptuous aim of preparing an agreed report in time for the then unknown next president. I think we were all pleasantly surprised when everyone signed off on the resulting 400-page book titled "Nuclear Power: Issues and Choices". Among the many substantial conclusions and recommendations was the recommendation that reprocessing should be deferred indefinitely since, given the availability of uranium, it offered no economic advantage, and significantly increased the risk of nuclear proliferation.

The published book was on President Carter's desk before he took office, and soon after his inauguration the entire group met with him for ninety minutes in an extended discussion. Carter, a graduate in nuclear engineering from the Naval Academy, was the only president with scientific training; and he was clearly impressed. The following day he gave the Japanese prime minister a copy of the book, and reportedly said that if he wrote a book on the subject, this would be it. In fact, he not only carried out some of the recommendations but initiated the International Nuclear Fuel Cycle Evaluation (INFCE) study in an effort to engage the international nuclear community in a critical review of the nuclear fuel cycle. This approach, however, was doomed to failure since many of the foreign representatives at the conference had vested interests in the nuclear fuel cycle as did some of the US participants enlisted in the outreach program. The report did, however, influence the US nuclear program, which cancelled the Barnwell reprocessing plant and the Clinch River breeder. The study may have had an impact elsewhere. I know there was a German version published with the somewhat misleading title, "Das Veto".

I hope these examples have illustrated the range of ways scientific advice has played a major role in the arms control policy process. While scientific advice has often been indispensable to policy making, it has not always advanced the case for arms control but has sometimes provided opponents of arms control with arguments as well. Science advice in the US has usually been the best the scientific community could provide. On occasion, however, advice reaching the highest levels has involved wild extrapolations or simply misleading information, as in the case of the Strategic Defense Initiative.
Policy-makers should feel an obligation to seek the best scientific advice available to them on arms control and other issues. For its part, the scientific community in every nation has an obligation to volunteer advice if it believes its political leaders are unaware of technical considerations or have received misleading scientific advice. I know it was in this spirit that CISAC in the mid 1980's encouraged European scientific bodies to become more involved with their governments in arms control and other security issues. This effort was influential in the original formation of the Amaldi Conferences. I am glad to see the organization thriving after seventeen years. Much work remains to be done.

Academy Influence on the G8 Agenda

John Boright (USA)

Thank you very much; it is a real pleasure to be here. I wanted to apologize ahead of time, I am here only today and there are a lot of you I'd like to talk to. I'll explain later why I am leaving. I don't have a very long talk, so maybe you can forgive me a one minute excursion on to the question of Pief Panofsky, particularly since I have missed all of the celebratory events for Pief. In 1970 I finished the particle physics PhD at Cornell and had become very interested in these questions of arms control and proliferation and didn't know what to do. I applied some places for a post-doc, one of them being Stanford. And I went there and interviewed with the legendary Pief Panofsky. It turns out unbeknowance to me, there was an Arms Control and Disarmament Agency and through some context originated actually by Spurgeon Keeny I was asked if I would be interested in coming to Washington to interview. And in fact I did two days after returning from Stanford and walked into the office, and there in the arms control and disarmament agency was Pief Panofsky sitting there. And I felt literally surrounded by this man. And I knew they were identical twins and I thought they were maybe deployed. The staff later at the Academy of Science on in their summary of Pief said they were sure that given his level in intensity of activity that he could be followed by infrared satellites. I think that gives you some idea of what a remarkable man he was.

I want to talk about the question of advice from a very current perspective and to give you some idea of two converging lines of work that are multilateral rather than national or bilateral, which is a lot of what has been discussed. One forum that brings together national leaders of the major countries is what used to be called the economic summit, then the G7 and then the G8. This has been going on for many years and it is taken quiet seriously. Initially it focused on economic issues. The economic summit is hosted in turn by each of the now eight countries participating, the eight being the U.S., Canada, Japan, Italy, the United Kingdom, Germany, Russia and France, but now broadened by five others: China, India, Brazil, Mexico and South Africa. The G8 – again starting with focus on global economic issues – has been broadening the range of issues that it addresses and has started over the last several years to address some security issues and, in various ways, nuclear proliferation. On the other hand the academies of sciences over the last ten years have had a tremendous – I think - search of collective activity. They have formed an association of all the science academies of the world, called the Inter Academy Panel, which now is up to 97 academies with parallel networks of medical academies called the Inter Academy Medical Panel and of engineering academies – some point different case – and there is some double counting there in between the academies of science and of medicine, but there are something over a hundred and fifty academies, that have now a very active and very organized cooperation. The goal of the cooperation is to really complete a transition from academies as primarily or even exclusively and purely scientific organizations to what we would broadly say is national service organizations. In a major part of that concept of national service is being able to and recognized as a source of advice to, in the first instance, their own country on many of the real challenging problems that society has to deal with, whether it is health, or agriculture, or higher or other education and so on. The academies have been working very, very actively. And I'd be glad to talk later about some components of that. They have even set up a branch organization to do in-depths of studies, partly at the request of Kofi Annan, who felt there was no way to use the existing UN organizations to get truly objective and independent advice on major issues. There is a parallel organization, for those of you who may be interested, I have a little handout and would be glad to talk later. It is called the Inter Academy Council. It is headquartered in Amsterdam and it has a board made up of fifteen academy of sciences presidents from around the world, U.S. and China are co-chairs and others include Iran, Turkey, France, the African Academy of Sciences, Brazil, Japan, Chile, India, Germany - which is always a special case organizationally-, and again I'd be glad to talk about the German participation which has been very important in this and so on.

Based on the work of these global networks, a suggestion was made by the Royal Society of London that the academies of the countries that participate in the G8 summit should offer advice collectively on issues that were to be on the agenda for an upcoming summit, and in this case it was three years ago. Tony Blair hosted the summit; his focus was on assistance for Africa and on climate change. The academies of those thirteen countries, plus some others from Africa in case of this question of capacity building in Africa, worked together to agree on relatively brief statements on those two topics. I have here copies of the series of statements for anyone who would like to see it. So, for the Glen Eagle summit two statements were adopted and provided. The next year, the summit was hosted in St. Petersburg and again under the chairmanship of the academy of the host country, in this case the Russian Academy of Sciences. The academies again worked out two completely agreed relatively brief statements on major issues that were scheduled to be on the agenda for the St. Petersburg summit. In this case, one of them was on the energy sustainability and security and the other one was on common efforts to deal with pandemic diseases. Then last year the summit was hosted in Germany, and again this process was used to reach agreement on two statements that were understood to be on the summit agenda as essentially proposed by the host government, Germany, again one on energy, which was sustainability, energy efficiency and climate protection; and a separate one on the title, which was promotion and protection of innovation. I have copies of these six statements here if anyone would like to see them as examples. Japan is hosting the summit this year. I am on my way to the preparatory meeting for the academy input. In varying degrees, these statements have had some impact on the actual discussions at the summit and the conclusions reached. In the case of Germany, the chancellor Merkel gave quite direct attention to the statements, met with the presidents of several academies, had a discussion and there is a direct relationship in the climate case between what was recommended by the academies and what reached finally the joined declaration of the governments. In the case of Japan, again there is a strong interest in climate and also in the broader aspects of global health that go beyond cooperation on infectious disease. Again, it is a topic that I'd be glad to consider further.

So, the question is that on the one hand the economic summit has been addressing security issues including proliferation, and on the other hand the academies have now developed a mechanism for making inputs in general, not necessarily on the security side. The question is, do we have an opportunity here, collectively? That's what I wanted to address and explain a little bit of the background of that. That question is to whether this is a real opportunity. I think it involves really three points. One, is whether the governments want to put particular issues on the summit agenda and therefore pay attention to them and perhaps move forward with recommendations. Secondly, whether our academies are prepared to provide policy relevant inputs on topics including security. That's a mixed bag. I think, as you have heard previous talks in the example of China, the Chinese academy of sciences has not really wanted to address security issues.

The same applies to India, for example. On the other hand, for the Russian Academy, for the U.S. Academy, for the Royal Society, which is the academy for the United Kingdom, and so on, some academies do. That is a second question: do the academies even believe that this is part of their mandate to address. There also is a question of principle. Given the very active engagement of academies in a full partnership involving all academies of the world, there is a question to the degree to which is appropriate for a subset of them to be functioning without the inclusion of the others and to take some of the issues, such as assistance to Africa: there are many countries not represented at the G8 summit, which have a tremendously important role and impressive track record of assistance to Africa, the Netherland, the Scandinavian countries for example. So, there is a question of how far we want to go with this subset having adopted the principle of a globally inclusive process. Finally, there is an intriguing question: if both of these answers come out yes, should the science community, in this case represented by academies, be essentially passive and respond to the agenda proposed by the governments. In this case the process is that the host government has the primary role in setting the agenda for a summit. Or should the academies move somewhat earlier and more creatively to suggest agenda items or perhaps more focused follow on implement action on pass the agenda items. The host country for the next summit will be Italy, by the way, just to irrigate our thinking on this, the year after that it is Canada, and the year after that it is the United States. Those are the next three summits. There has been some discussion on this. After providing input to the Glen Eagle summit three years ago, the academies met in London and talked about the process, and indeed met with the Deputy Foreign Minister of the FCO, the Foreign Affairs Minister of the UK, and discussed that particular topic with him and he was quite emphatic that academies should be proactive and should try to provide inputs earlier in the process of prioritizing economic summit agendas. We don't have a very broad calibration of the views of the other governments on that, and I must say the U.S. government would be one of the most difficult ones to foresee right now, since we are going to have a new administration within months, which is very likely to change attitude on many things even if it is a republican administration. We do believe that there is pretty clear evidence that the Canadian and Brazilian governments, for example, would be quite interested in having more proactive inputs from science community. That is the general context of this question if perhaps the science community can use economic summits as a mechanism to help to inform global policy on major international issues, including international security.

Discussion of Spurgeon Keeny's and John Boright's Lecture

Götz Neuneck *(Germany): If we combine both talks, the historical perspective and the future, I think it is evident that the last sentence of Spurgeon Keeny's talk is absolutely correct, that much has to be done – or is to be done. One concrete question for John Boright: The G8 several years ago initiated what they called 10 plus 10 over 10, a program to reduce the threats in major nuclear weapon states, but also in other countries concerning chemical weapons, for example. A lot of money was promised for that, governments assigned money in different fields with different outreaches, but till now no independent panel has ever made any assessment of what has been achieved in this period, or what can be achieved, let's say, over ten years. A concrete proposal here would be to start some kind of process to look at what really has to be achieved in terms of increasing security or safety on nuclear materials, the disarmament of submarines, and so on. So, would that be a proposal that would still fit in the agenda of the G8?*

John Boright: Oh, frankly, that's exactly the kind of comment and thinking that I hoped to hear here. As you may remember, what I included in my remarks just now was the possibility of reviewing progress on commitments that had been made at the summit. I think, again, not to overstate the degree of consensus on something that has been discussed only very briefly among academies but, in fact, several of the academies in the internal discussions have emphasized that maybe what's primarily lacking in this broad area of policy addressed by summits is indeed exactly what you said. It's an independent review of the degree of progress. I spent twenty-five years in the U.S. government, and now twelve years out of the U.S. government, and I am acutely aware of the natural inevitable tendency of governments to describe the part of the glass that's full. Whatever fraction is full. That will be the answer to a review of where we are on that issue. I personally think that this possibility of a methodical review by an independent group would in fact be very valuable. I certainly welcomed that comment.

Christopher Watson *(UK): I'd like to follow up this very interesting comment with Götz Neuneck, because it seems to me that it highlights one of the problems with the specific academy input to this debate, which is that academies collectively around the world do not have a monopoly of wisdom in this area. The particular cases of the 10 plus 10 over 10 program is one, in which in the U.K. at least academic bodies have had almost zero input and have rather limited information. I am here by accident, because I am not an academic, but I have been very closely involved in the U.K.'s 10 plus 10 over 10 program. There is a lot published about it, but very little academic discussion on it. So, it seems to me that to have an input to the governmental process which relates entirely on academies would be insufficient.*

John Boright: I think we both have something to say on that. That's absolutely right, but one of the key characteristics of the way academies work – and certainly ours very much, in this case –, academies are conveners but they convene whatever expertise they need. In the case of our academy, in fact, it is a very extensive advisory process with some six thousand panel members on every issue you can imagine during any given year. And, in fact, even less than twenty-five percent of that six thousand are academy members. And to take the case of CISAC: It has had, as Dick Garwin and Spurgeon can list for you in great detail, the benefit of the involvement of former leaders in government, military generals, nuclear weapons lab leadership and high level policy makers. So, your point is absolutely correct, but it's one that academies at least try in their imperfect way to deal with.

Spurgeon Keeny: I thought it would be interesting to give one example where national science academies did get involved in a major collective effort to influence security policy. It was initiated in the Pontifical Academy of Sciences where a group, including its President Carlos Chagas and Cardinal Koenig of Austria, decided in the early 1980s that the Vatican should be persuaded to make a statement on the threat of nuclear war and the need for nuclear arms control. At an organizing meeting, as the representative of Frank Press, then President of the US National Academy of Sciences, I found myself together with Yevgeniy Velikhov of the Soviet Academy, M.G.K. Menon of India, and Max Perutz of the Royal Society designated as a committee to draft a short statement on the subject that all academies would find it possible to support. On the basis of our draft statement, the Vatican decided to hold a conference to which they invited, as far as I know, every national science academy or equivalent institution. Most of which were represented by senior scientists at the conference. After extended discussion, the statement with minor changes and a strong call for action was unanimously approved by the conference and presented to the Pope in a private audience. The Vatican issued the statement as a official document but of course not ex cathedra. As far as I know, this is the only document formally endorsed by representatives of essentially all national academies of science on a controversial security issue.

Erwin Häckel *(Germany): In listening to the two talks – or in fact the three talks we heard this morning, it seems to me that there is a sort of a business cycle, boom and bust cycle, with regard to the role of scientists providing independent advice to governments. Over several decades, especially in the United States, but also in the Soviet Union, it was obviously high time for scientists in the nuclear field to offer advice in arms control and strategic matters, and as Mr. Keeny mentioned in his talk, this is apparently no longer the case in recent years. Whereas, on the other hand, there is now a new – if I might say so – fashion of scientific advice, which is now in the global climate change business. Now, the question is interesting: why is that the case? My theory is – it is not really a theory but a kind of hunch – that governments tend to approach scientists to seek their advice if they try to circumvent or overcome and overrule some established interests, some vested interests in the bureaucracy, in the economy, in the business community. I wonder if one of the panelists would care to comment on that impression – which is in fact not more than an impression.*

John Boright: Absolutely. Each country has its own political institutions and decision making process. In the case of the United States, frankly, scientific advice is sought sometimes in Congress, where a similar situation exists of really fairly strongly held opposing views and, in some sense, a compromise is reached: well, let's have the academy examine it and try to give us some more hopefully common ground, factual and analytical. But that is just an expression of various components of national political decision making, and there is absolutely a tendency to when someone believes that the advice will be supportive of what they think they should do, they are more often more likely to ask for the advice. And of course, the scientific advice is absolutely not definitive, it is part of a process and it does not address some of the political context that high-level decision makers are going to take into account including, in many cases very dramatically, the political feasibility of moving forward with what seems to be the right way.

Spurgeon Keeny: I would like to venture some generalizations in response. I think there is no question that during the last seven years in the United States that there has been a serious decline in interest at the senior levels of government in the views of the scientific community. In general, however, I think it fair to say that over time since World War II the level of scientific competence in government has tended to increase so that, rightly or wrongly, the government has developed increased confidence in its ability to deal with the scientific component of policy issues. In the early days after World War II, presidents and top government officials had little knowledge of the scientific components of major policy issues confronting them and little confidence in the input from the government bureaucracy. At the same time, you had a remarkably qualified scientific community that was seized with these issues. Senior scientists who had played critical roles in World War II were very concerned with the consequences of the weapons they had helped create. They were available and served as effective advisors. With the passing of that uniquely qualified generation of scientists, the nature of the scientific community's relations with policy gradually changed as the governments own competence increased. Within thirty years, the Secretary of Defense under President Carter was Harold Brown, a physicist, who had been Director of the Livermore Weapons Laboratory, and subsequently under President Clinton was Bill Perry, a mathematician/physicist, both of whom had previous experience in US/Soviet arms control negotiations. The problem of maintaining contact with the second and third generation of cutting- edge scientists and stimulating their interest in security related problems was recognized some time ago by the Defense Department which organized the so called Jason Group to increase its interaction with the academic scientific community. With this increased understanding, participants are also in a position to pursue interests in security policy as well. The Amaldi Conferences and other such activities provide an opportunity to engage a new generation of international scientists, who are prominent in their respective fields, in the major security issues facing the international community today.

Third Session - Regional Conflicts and the Nuclear Question

Chair: Spurgeon Keeny

On the Conflict about Iran's Nuclear Program: A Game-Theoretical Analysis

Rudolf Avenhaus (Germany)

Abstract

The conflict between the International Community on the one hand and the Iran on the other about the latter´s nuclear program is modeled as a non-cooperative two-person game with vector-valued payoffs in normal form. With the help of dominance considerations the game can be reduced to a two-by-two game which has two Nash equilibria in pure strategies one of which is payoff-dominant to the other. It is argued, however, that the pupose of this model (and similar ones) is not so much the presentation of concrete results, but rather the demonstration of an analytical tool which can be used in international negotiations.

Problem Formulation

In a simplified manner, the very nature of the ongoing conflict between Iran and the International Community (IC) on Iran's nuclear program may be captured in terms of a game between two parties each of which attempts to maximize the values it associates with the outcome of the game defined in terms of the payoff from its moves given the moves of the opposing party. This describes what in Game Theory is called a non-cooperative two-person game with vector valued payoffs in normal form.

It is assumed that the essence of the moves of Iran can be described in terms of three optional actions: whether or not it

- remains a party to the Non-Proliferation Treaty (NPT),
- fulfils treaty obligations of not developing nuclear weapons, and
- enriches Uranium.

Thus, there are essentially five pure strategies, that Iran may pursue as shown in Figure 1.

The four pure strategies that are available to the IC vis-à-vis Iran, also shown in Figure 1, have been analyzed in detail in a separate paper.[2] They include

- using military force to destroy Iran's nuclear facilities,
- accepting Iran as a nuclear power,
- robust diplomatic engagement of Iran in combination with flexible sanctions, and
- negotiations with Iran aimed at regional stability (Grand Bargain).

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[1] A slightly modified version of this paper has been published by R. Avenhaus and R. K. Huber in *PINPoints* 28, pp 13-16, IIASA, Laxenburg, Fall 2007

[2] R. Avenhaus and R. K. Huber: Zum Atomstreit mit dem Iran: Eine spieltheoretische Betrachtung von Handlungsoptionen (in German). *Europäische Sicherheit* 56, February 2007, pp 29-32

The payoffs to both parties are expressed in terms of two vectors with three components the values of which express for Iran the prospects of securing

- steady income from the export of gas and oil in the long term by developing an independent nuclear power supply including the full nuclear fuel cycle,
- national security through either appropriate guarantees by the IC or a national nuclear deterrent capability, and
- the status as the dominant regional power,

and for the IC the chances that

- Iran will not become a nuclear weapon state,
- regional stability is maintained, and
- supply of oil and gas from the region is assured.

The payoffs are measured on a nominal scale featuring five classes which, for ease of comparison, are assigned numerical values indicating the payoff as being either *very negative* (-2), *negative* (-1), *neutral or status quo* (0), *positive* (+1), or *very positive* (+2).

Figure 1 presents the payoff matrix for the normal form of the game between the IC and Iran. Each field of the matrix describes a specific combination of the opponents' strategies. The payoff vectors resulting from each strategy combination are listed in the lower left corner of each field for the IC, and in the upper right corner for Iran.

Analysis

By comparing the payoff vectors of each party it will be realized that the second and third strategy of the IC is dominated[3] by the fourth,. For Iran, the first strategy is dominated by the second, and the third and fourth by the fifth. Thus, by eliminating the dominated strategies of both sides the five by four normal form game shown in Figure 1 is reduced to the two by two reduced game shown in Figure 2.

Of course, each single value attributed to the elements of the payoff vectors may be subject to debate. It should be stressed, however, that the purpose of this exercise is not primarily to determine realistic payoffs and equilibrium strategies. Rather, we want to demonstrate a method that permits, based on plausible value judgements, gaining some first insights from a deliberately simplified model of the conflict between the IC and Iran. In other words, we want to present an analytical tool which can be used in international negotiations. Nevertheless, a few remarks seem appropriate to explain the value judgement of the authors.

The non-formal analysis presented in the *Europäische Sicherheit* justifies the assessment, shown in the first row of the matrix, that the use of military force by the IC would very likely result in the worst payoff to Iran in each of the components of its payoff vector regardless of the strategy option it chooses. This would also be true for the second and third component of the IC's payoff vector because of the forceful response to an IC attack that must be expected from Iran and its supporters. However, as expressed by the values of the first component of IC's payoff vector prospects of Iran not becoming a nuclear power are considered to be good, at least in the short run, regardless of its strategy. For the first two of the Iranian strategy options it is assumed that the IC would use military force pre-emptively, for the other three in

[3] Dominance means that, all other component values being equal, at least one component of the payoff vector of the dominating strategy is assigned a higher value than the components of the dominated payoff vector regardless of what strategy the opponent uses

response to Iran not fulfilling the obligations of an NPT signatory state or terminating NPT membership. In the latter cases Iran can be assumed to have had sufficient time to harden and hide some of its nuclear facilities so that a later resumption of the nuclear program can not be definitely excluded.

If the IC pursues a grand bargain and Iran continues enrichment while fulfilling its NPT obligations, including submission to a rigorous verification regime in exchange for security guarantees by the IC, the possibility of Iran eventually becoming a nuclear weapon state can be considered as highly unlikely (+2) and the status quo would be preserved with regard to both stability in the region (0) and oil and gas supplies from the region (0). For Iran, all components of the payoff vector would be positive in this case, albeit somewhat less for the third component related to its status of a dominant regional power.

If Iran were to terminate NPT membership while the IC pursues negotiations in good faith to eventually reach a grand bargain, the consequences would be highly undesirable for the IC with a view to Iran reaching a nuclear military capability and, because of the reactions to be expected from other states in the region, for both regional stability and the flow of oil and gas from the region. For Iran, the deterrence capability that comes with nuclear power status implies a high degree of national security (+2), while ensuing sanctions by the IC would reduce the income generated from oil and gas exports significantly (-1) and diminish at least temporarily Iran's chances of becoming the dominant power in the region (+1).

The implications of the reduced form of the game shown in Figure 2 may be analysed by using the method of preference directions which identifies, by means of directed arrows, which of its two strategies one side prefers given the strategy of the opponent. It will be realized that IC prefers the Grand Bargain over the use of military force if Iran remains a member to the NPT fulfilling its obligations, including submission to a rigorous verification regime in exchange for security guarantees by the IC: (+2, 0, 0) > (+2, -2, -2). The opposite is true if Iran were to terminate NPT membership: (+1, -2, -2) > (-2 -2, -2). If on the other hand the IC uses military force, both of Iran's strategy option are equivalent: (-2, -2, -2) ~ (-2, -2, -2). If the IC pursues a Grand Bargain, Iran would prefer not terminate the NPT and being allowed to enrich uranium under IC control: (+2, +2, +1) > (-1, +2, +1).

It will be noted that the reduced form game has two Nash equilibria[4] denoted in Figure 2 by asterisks: the first one is the strategy combination in the upper right hand field of the matrix (Military Force, Termination of NPT), the second one in lower left hand field (Grand Bargain, Adherence to NPT, Fulfillment of obligations and Enrichment). The second equilibrium is payoff-dominant because for both parties the payoff vectors are preferable to those of the first equilibrium. Thus, provided the payoff vectors reflect a realistic assessment, both sides should have a strong incentive to adopt strategies the implementation of which does, however, require a good deal of subsequent cooperation between Iran and the IC which our non-cooperative game model does not address.

Also, it must be pointed out that the payoff dominance of the second equilibrium depends on whether the IC can muster the military capability to successfully deny Iran reaching its objectives as expressed by the payoff vector (-2, -2, -2). Thus, the question arises as to how the credibility of IC's military capability would affect the outcome of the game. Theoretically,

[4] A Nash equilibrium is defined as a pair of strategies with the property that any unilateral deviation does not improve the deviator's payoff.

not much should happen even if the IC had no military capability at all, because eliminating the first row in the normal form matrix of Figure 1 would not affect any of the observed dominance relationships among the strategies of both sides. Therefore, the reduced form of the game shown in Figure 2 would leave the IC with only the strategy "Grand Bargain", and the one by two reduced game with one equilibrium that is identical to payoff-dominant equilibrium in the previous two by two game.

However, from a practical point of view it seems by no means certain that Iran would adopt the equilibrium strategy in this case. If one takes a closer look at the payoff vectors in the second row of the reduced matrix in Figure 2 it will be realized that choosing to terminate NPT membership rather than the equilibrium strategy would cost Iran only a relatively small loss in payoff compared to the IC. While IC may react to Iran's termination of NPT membership by implementing an embargo thus delaying Iran's nuclear program temporarily, the IC would end up with the worst possible situation with regard to reaching its strategic objectives as expressed the payoff vector (-2, -2, -2).

Interpreting these results one may conclude that part of a robust diplomacy, and ensuing negotiations with Iran aimed at eventually concluding a "Grand Bargain", must be the visible build-up of a credible deterrent in form of a military capability to effectively threaten Irans's nuclear program and cope with the aftermath of an eventual attack. Currently, a sufficient capability of that kind is not available to the IC.

Concluding remark

In conclusion, three remarks on the limitations of the foregoing analysis shall be added. First, it is a simplification to represent the IC as one player: In fact we have in mind the Western IC, and there are other states with different views and objectives. Second, since negotiations between two parties such as Iran and the IC will be accompanied by sequential moves from both sides, it would seem more appropriate to describe the conflict by a game in extensive form. In particular, a Grand Bargain strategy of the IC would require such a description. On the other hand, additional assumptions would have to be made in this case which themselves may be questionable. And third, for sake of simplicity we have limited the payoff vectors to three components for each side. However, in reality there may be many more objectives that need to be taken into account. As a consequence, more than two equilibria might be obtained making an interpretation of the results of a game analysis more difficult.

Iran / IC	Adherence to NPT; Fulfillment of Obligations; No Enrichment	Adherence to NPT; Fulfillment of Obligations; Enrichment	Adherence to NPT: No Fulfillment of Obligations; No Enrichment	Adherence to NPT; No Fulfillment of Obligations; Enrichment	Termination of NPT
Military Force	$\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$ $\begin{pmatrix}+1\\-2\\-2\end{pmatrix}$	$\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$ $\begin{pmatrix}+2\\-2\\-2\end{pmatrix}$	$\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$ $\begin{pmatrix}+1\\-2\\-2\end{pmatrix}$	$\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$ $\begin{pmatrix}+1\\-2\\-2\end{pmatrix}$	$\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$ $\begin{pmatrix}+1\\-2\\-2\end{pmatrix}$
Acceptance of Iran's Nuclear Armament	$\begin{pmatrix}-2\\0\\0\end{pmatrix}$ $\begin{pmatrix}+2\\+2\\+2\end{pmatrix}$	$\begin{pmatrix}+2\\0\\+1\end{pmatrix}$ $\begin{pmatrix}+1\\0\\0\end{pmatrix}$	$\begin{pmatrix}-2\\+2\\-1\end{pmatrix}$ $\begin{pmatrix}-2\\-2\\0\end{pmatrix}$	$\begin{pmatrix}+2\\+2\\-1\end{pmatrix}$ $\begin{pmatrix}-2\\-2\\-1\end{pmatrix}$	$\begin{pmatrix}+2\\+2\\+1\end{pmatrix}$ $\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$
Robust Diplomacy and Flexible Sanctions	$\begin{pmatrix}-2\\0\\0\end{pmatrix}$ $\begin{pmatrix}+2\\+2\\+2\end{pmatrix}$	$\begin{pmatrix}+2\\0\\+1\end{pmatrix}$ $\begin{pmatrix}+1\\0\\0\end{pmatrix}$	$\begin{pmatrix}-2\\+2\\-1\end{pmatrix}$ $\begin{pmatrix}-2\\-2\\-1\end{pmatrix}$	$\begin{pmatrix}+2\\+2\\-1\end{pmatrix}$ $\begin{pmatrix}-2\\-1\\-1\end{pmatrix}$	$\begin{pmatrix}+2\\+2\\+1\end{pmatrix}$ $\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$
Grand Bargain	$\begin{pmatrix}-2\\0\\0\end{pmatrix}$ $\begin{pmatrix}+2\\0\\+2\end{pmatrix}$	$\begin{pmatrix}+2\\+2\\+1\end{pmatrix}$ $\begin{pmatrix}+2\\0\\0\end{pmatrix}$	$\begin{pmatrix}-2\\+2\\-1\end{pmatrix}$ $\begin{pmatrix}-2\\0\\0\end{pmatrix}$	$\begin{pmatrix}-2\\+2\\-1\end{pmatrix}$ $\begin{pmatrix}-2\\0\\-1\end{pmatrix}$	$\begin{pmatrix}-1\\+2\\+1\end{pmatrix}$ $\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$

Figure 1: Normal Form of the Two-person Game between Iran and the International Community (IC)

(Red: Dominated strategies of Iran. Blue: Dominated strategies of IC)

IC \ Iran	Adherence to NPT; Fulfillment; Enrichment	Termination of NPT
Military Force	$\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$ $\begin{pmatrix}+2\\-2\\-2\end{pmatrix}$	$\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$ $\begin{pmatrix}+1\\-2\\-2\end{pmatrix}$ *
Grand Bargain	$\begin{pmatrix}+2\\+2\\+1\end{pmatrix}$ $\begin{pmatrix}+2\\0\\0\end{pmatrix}$ *	$\begin{pmatrix}-1\\+2\\+1\end{pmatrix}$ $\begin{pmatrix}-2\\-2\\-2\end{pmatrix}$

Figure 2: Reduced Form of the Normal Form Game given in Figure 1
(The arrows indicate the preference directions, the asterisks the equilibria)

Discussion of Rudolf Avenhaus' Lecture

Hannes Ridesser *(Germany): What was very interesting for me when I heard your speech was the frame, and the main frame I saw was the frame of fight, which means there is no real space for a deviation from the initial idea and the initial target. That means if Iran moves away from the idea of the big need for nuclear weapons, it would be seen as a failure. I think that this would not be a failure but a wonderful advantage for Iran to get out of the jacket of the enemy. But it would be considered as a failure while it would be, I would say, a kind of co-evolution. How can we find different frames, different initial ideas of discussions of the game theory?*

Rudolf Avenhaus: I think it was more a comment than a question. You can develop it. Let me just say one thing to your last question: My model does not describe a bargain which has a time aspect, nor a sequence of actions. I said this would be very difficult to model because you have to make so many assumptions that it is very questionable whether you would get an applicable result. So the art is to get essential features and try to draw some conclusions from that.

Erwin Häckel *(Germany): Although I cannot claim to really understand the intricacies of your model, I have one problem with one of your assumptions, which is that you assume that the payoffs for different decisions are objective values or values that can be objectively determined, whereas from historical experience and from every day experience we realize that the decisions which countries make in such instances are very unstable and evolving; over time, they may turn out to be erroneous, exactly the opposite of what they were presumed to be, like in the cases of South Africa, or Iraq, or Pakistan. What was the value of their nuclear armament; they charged it wrongly and brought themselves down by their nuclear programs.*

Rudolf Avenhaus: I would not use the word objective. I mean, the figures we put here are assumed values as seen by the Iran. Very bad, or good, or whatever, as seen by the Iran and vice versa by the international community, but of course there is a big assumption behind it and in that sense I support your comment. This knowledge about the payoffs has to be common knowledge. These are the figures as the Iranians see it, as the international community sees it, but both of them have to know them. And this is a very difficult assumption of course. Let me say only this at this moment.

Regional Nuclear Deterrence Relationships: Stable or Unstable[1]

Yair Evron (Israel)

This lecture assesses the stabilizing or destabilizing effects of proliferation on two regional strategic relationships: the Middle East and the Indian subcontinent. After describing briefly the Indian-Pakistani relationship, it then turns to a short analysis of the impact of Israel's nuclear posture on strategic developments in the Middle East, and finally it elaborates more extensively on the possible implications of the potential nuclearization of Iran. Some policy–oriented conclusions regarding different steps that could be taken to lessen the dangers resulting from such nuclearization will conclude this discussion. A secondary theme discussed in the paper is the "usefulness" of a nuclear posture for the strategic objectives of a state.

A useful analytical framework to assess the consequences of proliferation to various regions is to take as a starting point the superpowers' nuclear relationship during the Cold War and identify its basic structure and mechanisms, and then assess their relevance to a regional nuclear relationship. This approach will be used in the following discussion of the possible effects of proliferation in the Middle East.

The Superpowers' Central Balance of Nuclear Deterrence

The superpowers mutual nuclear relationship evolved gradually from the early 1950s and persisted for some forty years until the end of the Cold War and the disappearance of bipolarity. It developed over time and underwent several phases. The notion of stable mutual deterrence developed slowly, and a search for measures designed to enhance nuclear stability began only in the late 1950s and continued thereafter through the development of second strike capabilities and advanced elaborate command and control systems on the one hand, and arms control and Confidence and Security Building Measures (CSBMs) on the other hand. But during the 1960s and 1970s there were several major superpowers crises that could have led to nuclear exchanges. Indeed, even in the phase of relative stability there were periods of severe competition – both political and also in arms buildup. And, in the first half of the 1980s, tensions yet again led both rivals to seek capabilities that would allow them to "win" the arms race, though these efforts appeared not unlikely to change the basic balance of deterrence.
Thus, one of the main lessons of the nuclear era has been that it was replete with dangerous points and that at various times decision makers on both sides erred and misconstrued the intentions of their rival. The stability of the "central balance of deterrence" has, therefore, always been a product of trial and error and of continued efforts to overcome dangerous situations and manage crises as they arise.

A structural analysis of the superpowers' balance of deterrence suggests that there were several basic characteristics that contributed eventually to its relative stability. Some of them were specific and context conditioned, some technical, and some related to the nature of societies and regimes. Altogether these could be divided into several subsets: political relations between adversaries; historical conditions; stability of societies and regimes; technical systems; characteristics of the nuclear weapon systems; strategic doctrines; and cognitive issues. There is broad agreement that some of these factors

[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

were essential and in their absence, the likelihood of escalation to the nuclear level would have been high. In contrast, there are many disagreements concerning first, whether the central balance of deterrence was indeed all that stable; second, which factors were essential for the creation of deterrence stability and whether they – or some of them – were dependent on the specific context of the superpower relationship; and third, whether regional nuclear deterrence relationships could be stabilized, were similar factors to obtain therein.

The following, in various degrees of importance, is a list of the conditions for stability, as derived from the “central balance of deterrence": bipolarity ; stability of regimes and effective control over nuclear systems; socialization as to processes of learning in the nature of nuclear weapons; second strike capability; command, control, and intelligence systems (the current full title is command, control, communications, computers, intelligence, surveillance, and reconnaissance – C^4ISR); no direct territorial friction; elaborate systems of decision making in situations of crisis; open channels of communication; and arms control agreements and various CSBMs.

Lessons from the Indian-Pakistani Nuclear Relationship

India and Pakistan apparently succeeded in developing small arsenals of nuclear weapons already in the late 1980s or early 1990s (with India having fissile materials and components for the assembly of nuclear weapons much earlier). More precisely, it was assumed they had these capabilities though they did not explicitly admit it. In 1998 India and Pakistan tested nuclear weapons and thus became declared nuclear powers. *En route* to this status, several major crises bordering on escalation to the nuclear threshold took place between them. In 1990, because of the situation in Kashmir, limited military confrontation began escalating and the possibility of a major war was imminent. At the height of the crisis, Pakistan took initial steps towards the assembly of some nuclear weapons. Only substantial and intensive American diplomatic intervention defused the crisis.

In the post-crisis analysis, two interpretations emerged. One, it was the nuclear moves Pakistan undertook that ultimately deterred India from attacking.[2] Conversely, and more convincing, India was not deterred by Pakistan's nuclear signaling. Rather, India in any event was not seeking war, but was drifting towards it in response to Pakistani terrorism in Kashmir and extreme domestic pressures. Thus, once the US intervened and succeeded in convincing Pakistan to stop backing military activity in Kashmir, India was ready to forgo the military option. Furthermore, the Indian leadership was not at all aware of the Pakistani nuclear signaling, and to the extent that the nuclear issue was raised, Indian leaders did not consider it a sufficient deterrent against military action.

Several conclusions can be drawn from the 1990 crisis. First, the existence of some nuclear capabilities did not deter the escalation that led to the crisis. Second, the two adversaries had different interpretations of the effects of Pakistan's nuclear moves. Third, the crisis was managed only through very active outside diplomatic intervention, which led to limited resolution of its overt cause, namely the Pakistani backing of the

[2] Several observers have argued that nuclear deterrence has in fact operated in the crisis and led to its diffusion. See for example Devin T. Hagerty, "Nuclear Proliferation in South Asia: The 1990 Indio-Pakistani Crisis" *International Security* 20, no. 3 (1995-96): 79-114. For an opposed view see George Perkovich, *India's Nuclear Bomb* (Berkeley: University of California Press, 1999).

insurgency in Kashmir. Fourth, the existence of democratic regimes does not guarantee against miscalculations. On the contrary, weak democratic governments such as those the two countries had at the time are less likely to behave rationally than strong authoritarian regimes.

In 1999, after the two states were already open nuclear powers, the Kargil crisis erupted, some of whose basic characteristics were present four years later when the 2002 crisis erupted. The crisis escalated rapidly and the concern over it prompted Washington once again to intervene diplomatically to defuse the crisis.[3]

A post-crisis analysis suggests that the two adversaries interpreted the implications of the nuclear factor differently. The Pakistani military leadership assumed that its nuclear capability would deter India from escalation and would allow it to conduct limited war in Kashmir and support a terror campaign in India. The Indian leadership assumed that the only way to force Pakistan to halt its military campaign in Kashmir was by military escalation, and was not deterred by the potential Pakistani nuclear threat. India thus planned a limited war, which presumably would not cross the assumed Pakistani tolerance threshold. However, there was no common understanding concerning the red line whose violation would trigger Pakistan's use of nuclear weapons. In addition, and contrary to the 1990 crisis, Pakistan both before and during the evolution of the crisis had an authoritarian regime, while India remained a democracy. This change of regime in Pakistan, however, was not necessarily a factor leading to instability. Indeed, during the crisis itself, the Indian government was under increased domestic pressure to toughen its stance and escalate. The common factor was the strong American intervention. Its ability to influence and pressure both India and especially Pakistan was greater than in the former crisis. Both adversaries moved closer to the US, and Pakistan became even more dependent on it.[4]

Generally speaking, the introduction of nuclear weapons into the Indian subcontinent did not deter the two rivals from dangerous escalations. Thus, nuclear weapons did not create conflict stability in the region. The deeper sources of the conflict continue to serve as potential trigger for possible future crises. Preempting such crises require resolution or management of the underlying political tensions coupled with extensive measures related to their nuclear assets and various CSBM .Indeed, following the last crisis the two countries moved towards a cease-fire in Kashmir; they are developing strategic doctrines that might alleviate to an extent the dangers involved in nuclear

[3] There have been many accounts of the Kargil and 2002 crises. For a very detailed account of the 2002 crisis see Steve Coll, "The Stand Off," *The New Yorker*, February 13, 2006 and the interview with him, "The Nuclear Edge," *The New Yorker*, February 13, 2006. For another very good account and for the argument that the nuclearization of the Indian subcontinent has contributed to the crises, see for example Pervez Hoodbhoy and Zia Mian, "The Indian–Pakistani Conflict: The Failure of Nuclear Deterrence," *Znet*, November 24, 2002. For an assessment of the Indian-Pakistani nuclear relationship see Michael Quinlan, "India-Pakistan Deterrence Revisited," *Survival* 47, no. 3 (2005): 103-16. For an account of the American diplomatic effort in the crises, see Strobe Talbot, *Engaging India* (Washington D.C. Brookings Institution Press, 2004).

[4] For some general accounts of the Indian and Pakistani nuclear programs and strategies see the various contributions in Jasjit Singh, ed., *Nuclear India* (Delhi: IDSA, 1998); Perkovich *India's Nuclear Bomb*; Peter Lavoy, "Pakistan's Nuclear Posture: Security and Survivability" (Washington, D.C.: Nonproliferation Policy Education Center, 2007); Syed Rifaat Hussain, "Analyzing Strategic Stability in South Asia with Pathways and Prescriptions for Avoiding Nuclear War," *Contemporary South Asia* 14, no. 2 (2005): 141-53; Waheguru Pal Singh Sidhu, "India's Nuclear Use Doctrine," in Peter Lavoy, Scott Sagan, and James Wirtz, eds., *Planning the Unthinkable* (Ithaca: Cornell University Press, 2000).

crises ; and they have adopted some CSBM. The relationship remains however tense and the complicated domestic situation in Pakistan adds to the concern about nuclear developments there.

The Iranian Nuclear Posture

Iranian strategic leaders likely perceive security threats from different directions, some of them emanating, at least potentially, from nuclear powers: Iraq (until 2003 perceived as a potential nuclear power), the US, Israel, Pakistan, and Russia.
Until the American occupation of Iraq in 2003, the primary strategic threat that Iran faced was from Iraq, and this was probably the principal cause for the renewal of its nuclear project. Since the American invasion of Iraq and the destruction of the Iraqi armed forces, coupled with the fact that the Iraqi WMD capability ceased to exist, the potential Iraqi threat has disappeared in the short and medium terms. Iran's current nuclear development is probably aimed at deterring the US, balancing other nuclear regional threats, and deterring Israel. However, beyond deterrence Iran is pursuing an aggressive regional foreign policy and issuing threats *vis-à-vis* Israel, and is most likely searching for a dominant role in the Middle East. This is already perceived by several regional states – including the Gulf countries, Egypt, Israel, and Turkey – as a threat to their national interests.[5]

The "usefulness" of an Iranian nuclear deterrent

While deterring a potential Iraqi nuclear threat (which might have been) developed during the long and bloody war between the two countries appears to have some rationality, it is doubtful that developing a nuclear deterrent against the US will serve any rational strategic Iranian objective. The notion of *minimal deterrence* would be irrelevant here because of the enormous disparities between the sides and because the US could always use superior conventional capabilities to suppress Iranian capabilities. Indeed, by developing a nuclear capability Iran would expose itself to a deterrence "game" which she is going to lose .

The Israeli Ambiguous Nuclear Posture [6]

From the inception of its nuclear project, Israel adopted an ambiguous posture. The ambiguity was not a calculated policy, but rather the result of a gradual development under some particular constraints. Ultimately, the ambiguous posture proved to be very successful in mitigating various counterproductive effects. Because of the volume of international news and data on the Israeli nuclear capability that has appeared over time,

[5] There have been several attempts to gauge the intentions of the Iranian leadership in pursuing its nuclear program. See for example Ephraim Kam, *A Nuclear Iran: What Does it Mean, and What Can be Done*, Memorandum No. 88 (Tel Aviv: Institute for National Security Studies, 2007).

[5] For studies of the Israeli nuclear posture see Shai Feldman, *Israeli Nuclear Deterrence* (New York: Columbia University Press,1982); Yair Evron, *Israel's Nuclear Dilemma* (Ithaca: Cornell University Press, 1994);and Yair Evron,*Weapons of Mass Destruction in the Middle East* (Washington D.C.: The Henry Stimson Center, Occassional Paper No. 39); and Zeev Maoz, *Defending the Holy Land* (Ann Arbor: University of Michigan Press, 2006) part 3; for the history of the nuclear project until the end of the 1960s, see Avner Cohen, *Israel and the Bomb* (New York: Columbia University Press, 1998); for the history of the diplomatic negotiations between the US and Israel on the nuclear project see Zaki Shalom *Israel's Nuclear Option* (Brighton: Sussex Academic Press and the Jaffe Center for Strategic Studies,Tel Aviv University, 2005).

part of the opacity surrounding the project has been eroded. As a result, there are currently no doubts internationally concerning the existence of a nuclear capability. However, Israel does not officially recognize the existence of its nuclear capability and refrains from providing official details about it. Israel also adheres to some basic understandings with the United States regarding its nuclear behavior.

However, the posture of ambiguity is still an important one in several respects. There is considerable difference between an explicit nuclear doctrine (and declared deployment) and a posture of ambiguity. In addition, the posture of ambiguity also signals self restraint and caution.

Tradition of Responsible Behavior

Over the years, Israel faced several very serious security challenges. While from time to time the nuclear factor was referred to implicitly, there was nevertheless a deliberate policy of avoidance of relying on explicit nuclear deterrent threats. The only time – during the 1973 War, under conditions of great stress – that the possibility of an explicit nuclear threat was raised in internal debate, the Israeli "kitchen Cabinet" rejected it.[7]

Avoidance of Nuclear Coercive Diplomacy

One of the most dangerous uses of nuclear diplomacy (and, historically in the superpowers' context, also not effective) is political *coercion*, namely, the use of nuclear threats in order to secure political objectives. Israel has avoided this tactic, and in fact, precisely because of its relative regional political isolation (which has gradually been changing) its ability to resort to nuclear coercion is inherently much more constrained than that of other regional powers.

Effects on regional stability

This could be measured mainly by two criteria: successful deterrence and thus avoiding war; and enhancing resolution of conflict.

Deterrence

The main purpose of the Israeli nuclear posture has been deterrence. However, an account of the history of the Arab-Israeli conflict does not suggest that the nuclear image of Israel has indeed deterred armed violence against it. Of the five Arab-Israeli wars (not counting the 1969-70 War of Attrition and the 2006 Lebanon War), two – the 1973 War and the Lebanon war of 1982 – took place after it could have been assumed by Arab leaders that Israel already had a nuclear capability. Since Israel initiated the 1982 Lebanon War, the relevant case of Israeli deterrence is the 1973 War. Generally speaking the outbreak of the war has demonstrated the failure of Israeli deterrence. Various observers and analysts have suggested that the image of an Israeli nuclear capability did affect Egyptian and Syrian behavior during the war by inducing them to conduct a limited war. However, an analysis of the war[8] demonstrates that the Egyptian

[7] Seymour Hersh in *The Samson Option* (Faber & Faber, 1991), claims that Israel decided on nuclear signaling in 1973 and this affected Egyptian behavior. I disagree with him. See Evron *Israel's Nuclear Dilemma.*

[8] See Evron, ibid.; Maoz, *op.cit.*

and Syrian strategic leaderships conducted a limited war because of their perception of Israel's *conventional* superiority, and not because of concern about a possible Israeli *nuclear* capability.

Since the Israeli-Egyptian peace agreement of 1979, the absence of Arab-initiated wars against Israel has not been due to the existence of the Israeli nuclear deterrent, but rather to a lack of concerted Arab interest in initiating a general war (due to Egypt's and Jordan's lack of political interest therein); the political process between the sides; and Israel's conventional capabilities.

Resolution of conflict – the peace process

It has been argued that Israel's nuclear image was a determining factor in inducing Arab regimes to seek peace with Israel. The evidence on that is not clear. The key to the peace process was the Israeli-Egyptian dialogue from 1977-79 culminating with the peace treaty. It appears that the two main factors that contributed to it from the Egyptian side were the Egyptian realization of Israel's military victory in 1973 (though after the initial Egyptian military success and difficult combat for both sides) and Israel's readiness to return the Sinai to Egyptian sovereignty. Additional factors were the weakening of pan-Arabism, Egyptian willingness to reorient politically towards the US, and major Egyptian economic considerations. The nuclear factor might have played a role as well, but most probably only as a secondary factor.

The Israeli-Jordanian peace agreement of 1994 had nothing to do with Israel's nuclear capability. Israeli-Jordanian relations have long been characterized by the understandings of both states of some important shared or coincidental strategic interests. The actual formal peace came after a long period beginning in the mid 1970s of peaceful coexistence and even cooperation in various areas, and ultimately became possible with the beginning of the Oslo process.

The Israeli-Palestinian peace process, beginning in 1993, had nothing to do with Israel's nuclear capability.

Finally, it is likely that the existence of Israel's nuclear capability is an *additional* factor in various Arab leaderships' assessments of the costs/benefits involved in a continued conflict with Israel. It could also serve as one of the arguments by Arab leaderships *vis-à-vis* extreme sectors within the populations calling for abrogation of peace agreements and the overall peace process.

The previous discussion on deterrence and the peace process leads to the conclusion that Israel's nuclear posture has not contributed significantly to regional stability. It has neither deterred wars, nor has it – by itself – led to the peace process. In all, the basic and most fundamental regional developments occurred without any reference to the nuclear factor.

Instability

There is a series of arguments that Israel's nuclear developments contributed to regional *instability.* This relates primarily to two issues: further regional proliferation and the outbreak of wars.

Nuclear proliferation

One of the recurrent themes in the debate about the possible effects of proliferation has been the "chain reaction effect", namely, that states would "go nuclear" as a response to adversaries' nuclearization. Since Egypt was the leading foe of Israel until the 1970s, its expected reaction to Israel's nuclearization would have been a response in kind. In fact however, Egypt, out of a combination of rational reasons, declined to invest its efforts in a nuclear weapons project. The Iraqi nuclear effort might have been partly motivated by the Israeli capability, but probably more so by several other factors: hegemonic ambitions in the Gulf and the Middle East in general; the ongoing conflict with Iran; and a belief that nuclear development is a key to overall modernization and regional prestige.

This account does not invalidate the general "chain reaction" argument. It does, however, suggest that it should always be considered within the specific historical context.

Triggering War

From the mid 1960s, the Israeli nuclear project became a subject of debate and concern in Egypt (and to a lesser extent in Syria). President Nasser raised the possibility of preventive war designed to destroy the Dimona complex. Several analyses of the 1967 crisis have suggested that one of the main reasons for the Egyptian escalatory moves was the desire to destroy Dimona, or to force Israel by diplomatic means to abandon the nuclear project.

However, a careful analysis of the crisis and its causes suggests that the roots of the crisis were very different: inter-Arab competition; the Egyptian desire to correct the results of the 1956 Sinai Campaign; escalation along the Israeli-Syrian border; and Egyptian defense commitments to Syria.[9] Moreover, although Dimona did concern Egypt, during the American-Egyptian diplomatic dialogue in 1965 on the Middle East arms race the Egyptians did not raise the issue (it was actually the American side that referred to it and tried to calm Egyptian concern). More significantly, in the diplomatic negotiations during the 1967 crisis itself, Egypt did not raise the Israeli nuclear development as one of the conditions for resolving the crisis. Finally, the evidence presented in *Foxbats over Dimona* is clearly not persuasive and far from substantiating its case. Thus, although Dimona caused concern in Egypt (and probably the USSR as well), the 1967 crisis did not result from it.

In conclusion, the Israeli nuclear posture had only a very limited impact on either stability or instability in the region. The logic of political and strategic developments was determined primarily by other factors.

Israeli-Iranian Mutual Nuclear Deterrence

Presently, Israel and Iran – as leading regional powers – perceive each other as major adversaries. The extreme ideological stance that Iran has adopted *vis-à-vis* Israel, Iran's

[8] The literature on the 1967 War is very extensive. See for very useful detailed account Michael Oren, *Six Days of War*,(Oxford University Press, 2002).

support and encouragement of armed hostilities against Israel, and its effort to sabotage the peace process has turned Iran into one of Israel's staunchest enemies. Iranian nuclearization, therefore, appears as a major existential threat to Israel. In turn, the Israeli international diplomatic efforts against Iranian nuclearization and the implied military threats to destroy the Iranian nuclear facilities have enhanced Iranian hostility toward Israel. A potential source for confrontation might result from a clash between Israel and a neighboring state allied to Iran, or between Israel and a sub-state armed organization (Hezbollah).

There is no scientific way of assessing the probability that an extreme Iranian regime would attempt the first use of Iranian nuclear weapons out of an ideological drive to destroy Israel. Hypothetically, a regime that is totally devoted to the pursuit of its extreme ideological objectives and is even ready to sacrifice part of its population might entertain this option. This presumably might become a more viable option if Iran accumulated an arsenal with several dozens of bombs and credible delivery vehicles and, on this basis, might hope that using all of them against Israel would destroy all of Israel's nuclear capabilities. If some remained, then Iran would be ready to absorb a limited Israeli counterstrike. However, in view of Israel's widely assumed large nuclear arsenal and numerous delivery vehicles, including various protected platforms that form a second strike capability, it appears highly improbable that even a fanatic leadership would choose such a policy. The dangers are enormous, not only to Iran as a country but first and foremost to the regime itself. No regime, even if endowed with the most extreme ideology, chooses to commit suicide.[10] Moreover, Iran must consider not only Israel's second strike capability, but also the high probability of a devastating American response.

Putting this scenario aside, an analysis of the various factors and conditions affecting Israeli-Iranian strategic relations after a possible Iranian nuclearization would lead to the conclusion that they will suffer from inherent instabilities. *The political context* of Israeli-Iranian relations is already very tense and it is not likely that these would be bettered by Iranian nuclearization. In addition, several leading Arab states as well as Turkey are extremely concerned by the possibility of Iranian nuclearization and one or more of them, might decide to "go nuclear" as well, thus creating a multipolar nuclear relationship, thus making decisions in times of crisis very difficult. Creating credible *second strike capability* and efficient *command and control* systems are very expensive and complex tasks. While it is likely that Israel have such capabilities, Iran lacks them. This might lead to mutual mistakes and anxieties. If these are projected into a highly tense political relationship loaded as it were with the possibility low level continued violence along Israel's borders, the dangers involved in Middle Eastern proliferation are obvious.

Measures to Enhance Stability

The first measure to enhance stability involves political relations. There are sufficient reasons why Israel should have an interest in securing peace with Syria and managing its relationship with the Palestinians, but, in addition, such developments would considerably curb the dangers resulting from a nuclearized Iran. The second measure

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[10] For some analyses pointing out the rationality and pragmatism of the Iranian leadership, see David Menashri, *Post Revolutionary Politics in Iran: Religion, Society and Power* (London: Frank Cass, 2001), chs. 7 and 8; Shireen T. Hunter, *Iran after Khomeini* (New York: Praeger, 1992).

involves American and international efforts that could contain further proliferation in the Middle East, including the extension of defense guarantees to regional countries and the strengthening of the global nonproliferation regime, which might constrain proliferation inclinations. On the other hand, global drifting towards wider proliferation, be it even to *status quo* powers, might enhance regional tendencies towards proliferation.

In addition, establishment of direct communications between Israel and Iran could serve as an important mechanism in readdressing dangers involved in the nuclearization of Iran. This presumably will have two functions: first, improving the overall relationship between Israel and Iran in order to reduce threats of friction leading to escalation. Whether such an improvement is possible, given the significant gaps between the two countries, remains to be seen. Second, even in the absence of political improvement, communication designed to manage critical crises should be developed. Third parties could also play a role in communicating between the parties. Were American-Iranian relations to improve, the US could act as a crisis manager, receiving and delivering messages between the two adversaries. Alternatively, a neutral organization might act as a conduit.

There is a difference between two types of crisis management: first, when an impending potential crisis is monitored and attempts are made to defuse it before it materializes; second, dangerous escalations in which there is an immediate development requiring response. The hot line established between the superpowers was designed to contend primarily with the second type. Ultimately, in order to preempt potential catastrophic results of the second type, direct lines of communications are necessary.

Deterrence relies to a certain extent on uncertainty. However, both sides should perceive the other as primarily a rational actor. Contrary to the famous formulation of the "rationality of irrationality" and to notions of "crazy states," nuclear deterrence should be conducted primarily as a rational instrument, and hence exercised only in the most critical circumstances. These observations should reflect also on various scenarios for "last resort" and battlefield uses.

Mutual "learning" about the strategic intentions and doctrines of the adversaries is an important factor in stabilizing nuclear relationships. This should come in addition to much more learning on the nature of nuclear weapons and the implications of nuclear deterrence.

An additional important possible issue is the question of "no first use", which requires a separate analysis. An agreement for no first use policy would arguably serve the strategic interests of both parties. It could be materialized either through formal agreement or through unilateral steps, such as a declared doctrine for no first use.
Finally, the improved political relations between several leading Arab countries and Israel might serve as a more congenial context for a new attempt at forming a regional security regime. Initial steps towards it were made during the Arms Control and Regional Security (ACRS) negotiations conducted in the 1990s. A revival of the idea and steps towards it are clearly dependent on several prior political moves, but initial thinking about it might contribute to some of the measures suggested above.

Concluding Observations

Nuclear relations between Israel and Iran would be inherently unstable due to several contextual conditions. Chief among them are: the nature of the Middle East state system in a conflict-ridden region with several foci of violence; the extreme ideological position of the current Iranian leadership against Israel and the likelihood that it would also try to apply coercive diplomacy *vis-à-vis* its neighbors; the lack of socialization in nuclear affairs primarily on the part of Iran, though to a lesser extent on the part of Israel as well; the inherent problems of C^4ISR systems in the Middle Eastern context; the difficulties in successfully communicating nuclear tolerance thresholds and consequently in formulating rational strategic responses; the absence of any direct channels of communications; and the lack of crisis management mechanisms.

The example of the India-Pakistan nuclear relationship demonstrates first, that the introduction of nuclear weapons does not by itself lead to more cautious behavior on the part of adversaries. Second, the existence of nuclear weapons might even encourage irresponsible behavior, on the assumption that the adversary would be deterred from conventional retaliation for fear of crossing a nuclear threshold. Third, there is a high probability that nuclear signals will not be understood and that mutual misperceptions would lead to nuclear escalation. Fortunately for both India and Pakistan, the United States intervened and helped the parties to deescalate. Moreover, both India and Pakistan are currently trying to establish various CSBMs designed to reduce the fear of another dangerous escalation.

Nuclear optimists argue that the introduction of nuclear weapons immediately or ultimately stabilize conflict relations (though some suggest that such stabilization depends on several additional conditions). In contrast, nuclear pessimists regard nuclear weapons as not inherently stabilizing conflict relationships, with life in a nuclear world (or regions thereof) as necessarily permeated by the threat of nuclear escalation. Only great and focused efforts could contain such threats.

Regional Security from the Perspective of Iran, with an Emphasis on the Nuclear Issue[1]

Saideh Lotfian (Iran)

I will discuss regional security from the perspective of Iran, and will also comment on security issues concerning the crisis over Bushehr nuclear reactor under construction in cooperation with Russia, as well as other nuclear facilities in Iran. It has been argued that long-term security in the Middle East is ultimately dependent on respect for territorial integrity of all states as a first step in trust-building, encouraging active participation of all regional states, promoting extensive regional trade, fostering closer political ties and peaceful resolution of conflicts.

Since western analysts often pass judgment on uncertainties perceived in Iran's foreign policy intentions and capabilities, I will try to briefly discuss possible answers to three major questions related to Iran's foreign policy objectives and behaviors in the context of regional security. These questions are as follows: 1- What are the major conflicting issues related to regional security from the standpoint of the Iranian government? 2- What is Iran's view on regional security? 3- What can be done in order to deal with sources of instability in the Middle East, and more specifically what can be done in order to de-escalate the nuclear crisis?

To answer these questions, I will focus on four interrelated foreign policy issues, which are of major concern for Iranian decision makers. The first issue has to do with the security of Iraq, because Iraq is a neighboring country and what happens there has a drastic impact on Iran's national security. The second foreign security issue for Iran is the U.S. plans for the region— the Bush administration's plans not only for Iraq, but for the entire so-called Greater Middle East. The next challenging security issue is the controversy surrounding Iran's nuclear power program, particularly its uranium enrichment plant. Finally, the fourth foreign policy concern has to do with the failure to bring peace between the rival factions involved in the protracted Palestinian-Israeli conflict. On the Iraqi security issue and also U.S.'s long term plan for Iraq, Iranian government officials have repeatedly said that putting an end to the crisis in Iraq is Iran's number one priority. At the same time, they have expressed their uneasiness about what they call the U.S. imperialist design for the region. They actually view U.S. military presence in Iraq as part of a grand strategy designed by the U.S. government to redraw the map of the Middle East in a way which would be detrimental to Iran's national interest. There are many Iranian key decision makers who have stated that the U.S. presence in Iraq is for the purpose of first controlling Iraqi oil resources, and secondly for changing the balance of power in the region in order to protect its reliable ally, namely Israel.

The nuclear issue, which was developed as a result of Iran's civilian nuclear reactor program, and more specifically because of the uncertainty surrounding its enrichment facilities, is also at the top of the agenda for Iran's foreign policy makers. Iranian government has constantly defended its right to engage in peaceful nuclear activities under the Non-Proliferation Treaty (NPT). As a signatory of the NPT, it has the right to utilize nuclear power to ensure its energy security. Since mid-1980s, the Iranian government has consistently said that Iran is opposed to the proliferation of nuclear

[1] This paper has been revised by the author. The information may differ from the audio content.

weapons, but supports access to peaceful nuclear technology for all NPT states. In the debate over the best way to end the nuclear standoff, Ahmadinejad, the president of Iran, has said that Iran will not accept the option of nuclear fuel supplied by other countries. He has insisted that Iran should have uranium enrichment facilities on its soil. While, the issue of permanent suspension of Iran's nuclear power reactor program is non-negotiable, Iranian leaders have tried to reassure the international community by indicating their opposition to the military use of nuclear power. Some have referred to an important *Fatwa*, which is a religious ruling by a high-ranking religious authority on an issue in Islamic law. This *Fatwa* on the prohibition of the use of nuclear weapons was restated most recently on 9th of November 2007 during a Friday prayer sermon. You must understand that Tehran's Friday prayers function as very important platforms for the religious and political leaders to introduce or emphasize Iran's foreign policy agenda. Ayatollah Emami Khashani who is close to Ayatollah Khamenie pointed out that since killings of innocent people is forbidden in Islam, "the production of nuclear bomb or even having it in mind is forbidden by the Islamic *Sharia*" (law).[1] He clearly emphasized the fact that this is the view expressed by Muslim scholars, who believe that the use of nuclear weapons is forbidden in Islam. Ayatollah Khamenei himself was reported as saying: "As it has repeatedly been announced, Iranian nation is not after nuclear arms. Americans too know the issue pretty well but since they can not explicitly deny absolute rights of the nation, they start leveling charges to convince the world public opinion." He maintained that Iranians are opposed to nuclear weapons "on ideological and Islamic ground but are determined to continue using peaceful nuclear energy."[2] Minister of Defense Najjar pointed out that "Iran has never been pursuing a program to develop nuclear weapons as it is against the country's religious, humanitarian and defensive doctrines."[3] Ahmadinejad remarks on this issue were more clear-cut when he called "claims that Iran is pursuing nuclear bomb" to be falsehood.[4] However, these reassuring pronouncements have not reduced the level of tensions because of the atmosphere of mistrust that exists between various parties involved in conflicts in the Middle-East.

More recently, strong language used by Iranian president Ahmadinejad and some of his key advisors have played very well in the hands of some Israeli officials and neoconservative politicians in Washington, who have portrayed Iran as the greatest threat to western interests in the Middle East. For his part, Ahmadinejad has stated that the Iranian nation is willing to establish relations with all states except Israel. He has criticized Israel's obsession with security by saying that Israel, in the name of security, continues its occupation of Palestinian lands, puts into action its unlawful policy of targeted killings of its opponents, and defiantly refuses to sign the NPT instead of keeping its nuclear weapons. In fact, many Iranian officials have made statements critical of Israeli policies in recent months in reaction to reports that Israel was encouraging the Bush Administration to go to war against Iran to stop its nuclear program. There is no time here to examine the Iranian harsh rhetoric on Israel, and compare them with the extreme anti-Iranian rhetoric of the Israelis (most notably Israel's former defense minister and the current transportation minister, Shaul Mofaz) who have called for a military strike on Iranian nuclear facilities. From all these relentless statements, it is clear that the Iranians feel threatened by Israel's war rhetoric and the Israelis see Iran as a source of threat.

I want to spend some time on the third question on preventive actions, because Iran is not the first country that has shown an interest in nuclear reactor programs, and is not the last country which will invest in a nuclear energy program. There is always the fear that other Middle Eastern states might become interested in the military use of nuclear power, and will decide to follow the example set by Israel as the first nuclear-capable state in the region. There are nine useful preventive measures, some of which have been discussed in other forums as well as in the morning sessions. These measures include:

1- Ratifying the No First Use of nuclear weapons treaty in order to restore confidence in the minds of the non-nuclear weapon states which might become interested in acquiring nuclear deterrence capability;

2- Strengthening the nuclear disarmament and non-proliferation regime;

3- Removing the obstacles for the creation of a nuclear weapon free zone in the Middle East;

4- Using multi-lateral approach for the resolution of inter-state conflicts;

5- Providing economic incentives for democratization. Countries that actually start the process of democratization have to be rewarded; and economic incentives ought to be extended to those government leaders who have allowed the creation of a strong civil society as a step toward democratizing their societies;

6- Encouraging the establishment of a reliable regional security system. If it is not possible for the entire Middle East to have a region-wide security system, it might be advisable to divide the region into various subsystems and work on the creation of sub-regional and on sub-systemic security systems. For example, one for the Persian Gulf, one for the Red Sea, and so on;

7- Enhancing conventional arms control efforts. We should not forget the fact that there is a connection between conventional arms transfers to the region and the interest shown by some regional countries to actually try to acquire unconventional arms capability. More specifically, I am referring to what seems to be a renaissance of arms trade, a reminiscence of the Cold War's arms transfer policies of the great powers. The major weapons producing states (e.g., France, Russia, U.K, U.S.) have all become actively involved in selling military equipment to the oil-rich countries in the Middle East. The arms race has been a major obstacle to regional economic integration and political unity. Every weapon system which is transferred to one country becomes a major security concern for the neighboring countries. If a neighboring rival country does not have a lot of resources or does not have access to the international arms markets, they might become interested in developing chemical, biological or even, in some cases, nuclear weapons capability;

8- Creating a balance between legitimate concerns for energy security and the threat of nuclear proliferation. It is true that most Middle-Eastern countries are oil-rich, but it is also true that they are concerned about their energy security. Their oil and gas resources will run out one day and they do not want to be in a position where they do not have access to the energy needed for development. Of course, the acquisition of nuclear power reactors has also become a status symbol; and has become a matter of national pride. If Iran has a nuclear reactor, Saudi-Arabia wants a nuclear reactor, Egypt, Turkey and the UAE want their own nuclear reactors. A chain-reaction has already started in that region;

9- Addressing sentiments of insecurity and vulnerability of all regional states. This last measure, which I think is the most crucial one, calls for taking into consideration the threat perceptions of the Middle Eastern states. For the most part, Iran sees itself as a victim of U.S. power play, and a prey in the historic great power competition over the region's energy resources. Iran finds itself in a position whereby it has to deal with first the dual containment and possibly preemption policy of the Bush Administration. Secondly, Iran sees itself as a victim of the Iraqi invasion caused partially because of the Arab-Iranian rivalry. It is an undeniable fact that Iran had to fight an eight-year deadly war with Iraq, a neighboring Muslim country. Even today, it feels threatened by its neighbors. In fact, Iran sees itself as a country surrounded by actual and potential hostile countries. Iran might be viewed by some regional actors as an expansionist and an aggressive state, but the Iranian government's self-perception is that it is a misunderstood, isolated and excluded state which has been denied its fair share of influence in the Persian Gulf and in the other parts of the Middle East. Over the years, Iran's self-image has been translated into a number of foreign policy goals: 1) Iran feels obligated to defend the Muslim societies fighting for their survival; 2) Iran wants to become a potential power balancer and a major regional player in pursuit of peace; 3) Iran would like to reduce the U.S. presence and influence in the region, because it feels threatened by the U.S.—which in the minds of Iranian leaders is actually viewed as one of Iran's neighbors because of the presence of American military forces in Afghanistan, Iraq, and in the waters of the Persian Gulf. Last, Iran wants to assert its sovereignty over a score of disputed territories all around the Iranian borders.

Iranian policy statements are chiefly viewed by the outsiders as an indication that Iran is an aspiring regional hegemonic power, which might eventually dominate the region and intervene in the internal affairs of its neighbors, especially if the American forces leave the region. However, Iran's real concern is that it must protect itself against the American imperialist aspiration to weaken Iran and even change the regime. There are neoconservatives in Washington such as Michael Ledeen, who have been calling for the regime change in Iran.[5] The Bush administration is now using Iran's nuclear power program as an escape goat to justify U.S. plans for deploying missile defense systems in Europe, beginning with the deployment of interceptors and radars in Poland and Czechoslovakia. Basically, the Washington's announcement of a perceived missile threat from Iran is viewed by Iranian leaders as a convenient excuse used by the U.S. in order to reduce the chances of criticism by Russia, PRC and its NATO allies. Again, Iran sees itself in the midst of a great power rivalry for world dominance. Iran has had experience with these kinds of rivalry in the Cold War era.

Given the shortage of time, I briefly come back to the discussion of Iran-Israel tension which has been influencing regional security. Both countries want regional hegemony because they both want to feel more secure. They feel that if they have the upper hand, it gives them the capability to reduce the chances of being influenced and of being invaded by other actors in the region. Israel wants to maintain its nuclear monopoly in the Middle East. To neutralize all its regional rivals, the Israeli government wants to contain any state which might give support to anti- Israeli groups, including Hamas and

Hezbollah. Israel does not believe Ahmadinejad when he said Iran wants to ensure regional stability, and does not believe the Iranian president when he says that he simply wants to create a stable environment in which Iran can be certain about its access to the global oil market, and when he talks about the fact that Iran is not after nuclear weapons. Israel says Iran's *Shahab-3* missiles with a range of over 1000 km can reach Israeli territory. Yet, the point is that Iran is also concerned about Israeli *Jericho-3* missiles with a range of over 4000 km reaching the Iranian targets. Attitudes of both states, both governments, could be changed through peaceful and patient diplomatic efforts from all sides. I emphasize that we need multilateral diplomatic efforts not only for resolving the nuclear crisis, but also for resolving the conflicts that exist between Iran and the other regional players. Thank you.

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[1] "Thought of Making Nuclear Bomb Forbidden in Islam: Kashani," *Mehr News Agency (MNA)*, 9 November 2007.
[2] "Supreme Leader: Iran does not Seek Nuclear Weapons, *Islamic Republic of Iran News Agency (IRNA)*, 3 June 2008.
[3] "Defense Minister: Iran Never Seeks Nuclear Weapons," *IRNA*, 10 December 2007.
[4] "Claims that Iran is Pursuing Nuclear Bomb, a Sheer Lie," *IRNA*, 24 September 2007.
[5] See for example, Norman Podhoretz, "The Case for Bombing Iran," *Commentary*, June 2007.

Discussion of Yair Evron's and Saideh Lotfian's Lecture[1]

Götz Neuneck *(Germany): Thank you, Saideh, for your overview on different climates, views and perspectives on Iran. I have a little bit of a problem with the Iranian official strategy. I think there are two parts. The first one is the past nuclear history. One can see more or less, the government provided a lot of information in the last few years. The other issue is the nuclear enrichment question. I wonder if there are so many statements, Fatwas, proposals or ideas including soft measures, why Iran is not putting something into the discussion such as the Additional Protocol. If there is not really the intention to develop nuclear weapons, why not signing, for example, the CTBT, putting some pressure on Israel to do the same and including the Additional Protocol, which could give the IAEA much more opportunities to control the non-nuclear weapons status of Iran. So maybe you can comment a little bit about the balance of how to use arms control not as an old method, but a new method to bring back some fuel into the discussion and to the relations and to give some confidence about future developments.*

Erwin Häckel *(Germany): Taking together the two presentations, which were obviously not entirely in unisense with each other, I wonder if each of you could comment on a question which you did not address directly but sort of skipped intentionally. What in your opinion would be the effect of Iran having nuclear weapons on the national security of both countries? And please do not argue whether or not Iran is going to have weapons, just consider the theoretical, the hypothetical possibility that this could take place.*

Saideh Lotfian: I answer the second question first and then move to the first one, because the second question concerns a hypothetical case. I believe that if Iran or any other country in the region acquires nuclear weapons capability, that event would fundamentally destabilize the entire region. The reason is that any country which acquires nuclear weapons would encourage its neighbors and its rivals to get hold of the same capability. A number of Middle Eastern countries have financial resources at their disposal in order to persuade some actors in the international community to provide them with the technology and the knowhow they need in order to have nuclear capability. Reportedly, Saudi Arabia had become interested in buying ready-made nuclear weapons from the nuclear capable states in the same way that they actually bought some intermediate-range ballistic missiles from China in the late 1980s. The real security threat is that the emergence of more regional nuclear weapon states would mean more instability in the Middle East. Therefore, we have to work towards creating a nuclear weapon free zone before it is too late. It is easier to persuade the only nuclear capable state in the region, Israel, to agree to the creation of such a zone, but if you have two or three countries the task would become much more difficult.

Turning to the first question, it is true that I did not discuss domestic politics, and it is also true that a wide range of views on Iran's nuclear program have been expressed. In the continuum of views, we observe people from the National Front, created by Iran's Prime Minister Mossadegh in the late 1940s as a liberal nationalist political movement, which was initially involved in gaining popular support for the oil nationalization.

[1] This discussion has been revised by one of the speakers. The information may differ from the audio content.

Although the leaders of the movement are not active in Iranian politics now, they have spoken against Iran's nuclear reactor program and have even called for a temporary suspension of the construction of the Bushehr power plant. There is also, as of now a minority of scholars and politicians on the extreme end who have called for having the same capability that Israel has. This second group supports the idea of horizontal nuclear proliferation and nuclear deterrence needed for the security of the Middle East. However, most Iranians have expressed their aversion to nuclear weapons. Moreover, there is the issue of the impact of the U.S. policies towards Iran's role in the region on Iran's foreign policy decision-making. The nuclear talks were initially held between Iran and the EU-3, or between the European countries and Iran, and later between P5+1 and Iran. The important point is that the U.S. is a major factor in the success of these talks, and the problem is that Iran does not trust the Americans while the U.S. does not trust the Iranians. The direct participation of the U.S. in these nuclear talks would be positive for the trust and confidence building needed in any negotiation. Finally, let me address the whole issue of CTBT, and the reason why Iran did not ratify the CTBT. Iran ratified the CWC (it took only fifteen minutes for the Iranian Parliament to ratify the CWC), but nobody can actually insist on the ratification of CTBT at the moment, simply because Iranian leaders are saying that unless the U.S. ratifies the CTBT, they are not going to do that. Similarly, the Iranian political leaders are saying that if other countries (such as the US) have nuclear enrichment programs, Iran as a signatory of the NPT is also entitled to have the same capability on its own territory.

Yair Evron: Several points in response to the questions: First of all, I think if Iran becomes a nuclear power, and here I totally agree with Prof. Lotfian, then there is a quite considerable possibility that several additional Middle Eastern countries might seriously consider and possibly even go ahead with their own nuclear programs. Saudi Arabia is one of them, and on the background of very close Saudi and Pakistani relations some news, of pieces of data that have appeared here and there, the possibility of Pakistani transfer of technology, nuclear technology and so on to Saudi-Arabia is of very high probability. According to some observers the United Emirates are considering this possibility, and Egypt and Turkey. So we have several countries that might decide to go on the nuclear path. Let me just add a somewhat paradoxical, but still valid point, that is that the Arab countries which presumably should have seen the Israeli nuclear capability as a major threat, in fact consider the Iranian possible development of a nuclear capability as a much greater threat. This is because they consider this primarily as a political instrument that Iran might use for achieving a hegemonic position in the Middle East. This is a very serious threat when you discuss these things with Saudis or people from the Gulf, Egyptians and Turks. So, we have to bear this in mind. Finally, in terms of if Iran becomes a nuclear power, it seems to me, and here again I agree with Prof. Lotfian, it seems to me that the main reason for Iran pursuing a nuclear weapon capability - and I am confident that they have tried and are still trying to do that - was first of all the Iraq factor. After all, Iran and Iraq fought for nine long years that terrible war, and Iraq used chemical agents against Iran and all the rest of it. And, secondly, the United States. So the Israeli nuclear capability, I think, was not very high on the priorities of the Iranian regimes when they considered the possibility of nuclearization. Finally, if Iran becomes a nuclear power, then it seems to me, within the Middle East, beyond the possibility of further proliferation is that there would emerge an unstable nuclear relationship between Israel and Iran. As I said in my paper - and Prof. Lotfian in fact referred to it in several ways -, there is a need for a major investment in measures to reduce the instability inherent in this relationship, because the possibility of inadvertent war or even purposeful war is quite considerable and much more than in the superpower context. And finally a footnote to what Prof. Lotfian remarked about the need for diplomatic relations: I think Israel is very much interested in a direct dialog with Iran. The Iranian regime unfortunately is very, very negative in its position *vis à vis* Israel.

***John Simpson** (UK): I have a question for Prof. Lotfian which is quite simple, and that is: what is the peaceful purpose of the enrichment program? The reactor, the Arak reactor, which is being built or planned is a heavy water reactor and therefore does not need enriched uranium. The existing Bushehr reactor will be supplied with fuel by the Russian Federation and any fuel going into it will have to be licensed by the Russian Federation. Thank you.*

***Michael Brzoska** (Germany): I have two questions, one for Prof. Evron: How far can one go with only analyzing nuclear relations in a regional perspective, because several of the examples brought in the bigger powers. And is it possible that one cannot? Would it be possible in a crisis that major nuclear powers would stay out and not try to either support or stop one of the regional powers? And I also would like, maybe briefly, to hear whether you see that link in the 73 crisis on that issue. And Prof. Lotfian: You portrayed Iran's policies as very much status quo with respect to international law, international order. But I hear especially in reactions to Security Council decisions on sanctions that it is really a Iranian position to question the legitimacy of the international order, also as it withstands to the regional situation. So, to what extent is Iran content with thinking in terms of legal international provisions and to what extent does Iran think they need to be changed?*

Saideh Lotfian: Let me answer the first question which has to do with the nuclear fuel cycle. The idea behind having a uranium enrichment facility has to do with the goal of having an independent nuclear power program. The fact is that the Iranian government has said that they cannot put their trust in the hands of the Russians, because Russia had a policy of delaying the construction of the Bushehr reactor, and they do not think they can be one hundred percent sure that Russia will continue supplying, uninterrupted and at a reasonable price, the fuel that they need for the Bushehr and other reactors which have been planned for construction in the future. The argument that they make is that they want to have reliable fuel supply, and the most reliable fuel supply source that you can have is the one which is from your own enrichment facilities situated in your territory. However, I think this is an issue which is negotiable. The Iranian side, this is my personal opinion, if provided with strong incentives would agree to some type of multilateral arrangement which would ensure the supply of fuel and would agree to the suspension of fuel enrichment on Iranian territory. Turning to the second question, I have to say that Iran has shown, at least in the public statements of its key leaders, a great deal of respect for the United Nations. Iran has a preference for multilateral diplomacy through the OIC and the NAM, but has never discontinued its ties with the UN over the years. In recent months, it has been particularly very positive concerning the continuation of Iran's cooperation with the IAEA, because as you know the only way Iran can have access to the technology that it needs is through the IAEA. The United Nations General Assembly has always provided a very valuable forum for the Iranian heads of state to communicate with other heads of states.

Yair Evron: Just very quickly about the projection of the international system into the region of the Middle East. I think we live in a different international system. 1973 was a system of bipolar situation America–Soviet Union, and very possibly every major crisis in the Middle East soon escalated to the level of the superpower relationship, and this is the main reason why both, the United States and the Soviet Union, made major efforts in different ways, sometimes in conflicting ways, to manage these crises, both 67 and 73. However, now we live in a different kind of situation in which the system of alliances does not exist, Iran is not allied to the Soviet Union, there is no Soviet Union; Israel is allied to a large extent to the United States, but this is a single power and not very reliable. In other words, I do not think a crisis in the Middle East would escalate beyond the Middle East, even a nuclear crisis, so this is a different situation from what used to be the situation during bipolarity. This is a major debate that should be further pursued. I do think that the United States and the international community at large have a very important role to play in the Middle East, I agree with Prof. Lotfian on that, that there is a need for a major effort in crisis management in the Middle East, which would be partly shared, or the United States and the international community should be part of it. One of the main things is to create a system of communication between the Iran and Israel, because if we have a nuclear relationship between the two without direct communications and without any mechanism for crisis management and with, I would argue, quite radical policies of Teheran, then the dangers of escalation are very serious.

Iran; the Oil and the Bomb[1]

Aharon Zohar (Israel)

There is a story told about a man who wanted to buy a hand watch. So while he was strolling through the main street of the city, he saw a window shop packed with hand watches. He was happy, entered and he saw the seller. He asked him: can I buy a hand watch? The seller said: but I am a circumciser. He looked at him and said: If you are a circumciser, how come that your window is packed with hand watches? The circumciser looked at him and said: what would you expect me to put there?

This is dedicated to those who still expect Iran to admit that it develops a military nuclear capability on one hand, and to my Iranian friends who still think that everybody believes them. Going to the point, I would say this and it will be demonstrated through this idea of Iran's oil crisis. How come that Iran, that is the richest country in the world regarding oil and gas reserves combined, is developing a nuclear capability? Talking about combined oil and gas reserves, Iran is the first in the world; it is the second to Saudi Arabia regarding oil reserves; and second to Russia regarding natural gas reserves. In 2005 Iran produced around 5 % of the global oil production. 86 % of the export of Iran is oil and gas, mainly oil that consists 28 % of the GDP. Iran oil reserves will last over 90 years. I do not believe that anybody in this hall will live so long. Most of the oil and natural gas in the world is concentrated in the strategic crescent covering Iran, Saudi Arabia, Iraq and Russia.

The major Iranian oilfields are concentrated north of the Persian Gulf, while oil pipeline and nuclear sites are dispersed throughout the country. Bushehr is probably the most known nuclear site of Iran, but Natanz, and other nuclear sites are not less import.

Despite of the fact that Iran has the largest oil and gas reserves, it suffers from an acute oil crisis. What are the reasons for it? First, on the demand side, the oil prices in Iran are about 15 times cheaper than in the US: 9 cents per liter. Despite of this, Iran was rationing few months ago the oil supply to its own inhabitants. The reason is that Iran imports more than 50 % of its gasoline. In addition, Iran has an electrical installed capacity of 47,000 Megawatts and electricity is extremely cheap in Iran.

Electricity rising demand due to the rising standard of living and population growth are the reasons Iran gives for going nuclear on one hand, and reduced dependency on others, on the other hand.

As I said before, Iran has the largest oil and gas reserves in the world that will last at least for 90 years.

Talking about supply it has been severely constrained because of the fact that Iran imports at least half of its gasoline demand. The use of income of oil revenues for other purposes and sanctions that reduced Iran's ability to maintain its old oil refineries are influencing Iran oil industry.

[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

Iran is fully dependent on oil import. Oil prices are affecting Iran's intentions to go nuclear, and the fact that many countries are dependent on Iran's oil and gas resources are magnifying the problem by far.

Discussion of Aharon Zohar's Lecture

***Richard Garwin** (USA): If Iran wants to have nuclear energy in order to spare its oil, it is going about it in a very inefficient fashion. The Shah wanted to have 20 reactors by the turn of the century (by the year 2000), and now Iran has one nearly operational reactor with fuel supplied by Russia. Why would Iran not look favorably upon the acquisition of a strategic stockpile of low enriched uranium so that they could have either the fuel or the LEU for ten years of operation? Why would they not be spending their money now to build multiple reactors rather than requiring the technology as a matter of pride, which is inhibiting their acquisition of nuclear power?*

Miloš Jovanović *(Germany): I would like to hear a comment from Mr. Zohar on something that Ms. Lotfian said in her presentation. She said that Iran is trying to get ready for the time oil is finished which is one of the reasons why they are doing the nuclear research and why they want to use it for several resources now. You said of course that the oil reserves would be enough for the next 90 years, so that would be a very long strategic thing, but you said that it is with the current production which will surely increase. I would like to hear your comment on that argument that they are trying to get ready for the time after the oil and they are not the only state in the region that is doing that.*

Aharon Zohar: Regarding the first question: I will hand it over to to Ms. Lotfian.
Regarding the second question: As we know, oil reserves will last not more than 50 years. I am talking about 90 years regarding the current production rates of Iran…

***Saideh Lotfian** (Iran): Answering the second question; I still feel that the Iranian government is obligated to ensure energy security and I do not simply advise the government to spend too much money on nuclear powered generation capacity, but the point is that 90 years is a short time. It is a lifetime, and what will happen to the next generation? There are other countries, including the U.S., there are major oil producing countries that are looking forward in advance and trying to diversify their energy sources. We cannot criticize the Iranian government for being concerned about the preparation for the time that they will not have oil and gas resources to export and get the money and finance their development projects. But we could criticize the Iranian government for that hazardous way of trying to get the technology that they need.*

Referring to the first question: It is true that the Iranian nuclear power program started under the Shah, at that time the Iranian government had the advantage of benefiting from U.S. advice. Right now, because of the fact that Iran has been under a sanction regime, they actually buy whatever is available, any technology which is related to the nuclear energy program and if they have access to it, they buy it. Basically, you could see investments which are wasteful, and investment which are not needed, but it has to do with the fact that they have been under sanction. I think that one thing that should be included in that investment package for Iranians when they are at the negotiating table *has to do with technology which is needed for the development of solar and wind energy, rather than relying too much on the nuclear power sector.*

Aharon Zohar: Just to remind you: a generation is 25 years. Oil prices jumped by four times during the last fifteen years and I am curious to see what will happen when Europe and the US will face a growing oil shortage.

Adele Buckley *(USA): Nuclear power to actually construct and operate is very expensive, and if the Iran is subsidizing the electricity price it seems to me that this is going to get – without doing arithmetic – a terrible problem where they are going to be kind of jumping out of the frying pan into the fire. I am asking myself why is it they are not putting that money into making oil refineries for instance.*

John Boright *(USA): It is really rather a comment than a question because the answer is not good for my own country either. It is kind of shocking to hear a whole discussion about energy with nobody mentioning the most effective investment that anybody can make, which is in energy efficiency. If any of our countries are serious about reducing dependency and being independent, that is the number one thing to do!*

Aharon Zohar: I am not responsible for the Iranian policy. The topic of my lecture is not saving energy; the topic is the oil crisis of Iran.

Saideh Lotfian*: The comment made by Adele is very important and in fact the Iranian government is under heavy criticism for the fact that they have not invested in refining capacity and we still rely on refineries in Abadan, which was basically built by the Shah. But the point is that Iran is under sanction, as I mentioned, and because of the secondary sanctions, oil companies do not invest in either refining or in other oil projects in Iran. And again I would say that that would be an item on the agenda for the negotiators who are dealing with the Iranian government. Iran gets some of its gas from Turkmenistan and this winter, which was harsher than normal, Turkmenistan for a few weeks actually refused the transport of gas to Iran, and there were rationings of gas in several provinces and it made life very difficult for the people. The government actually utilized that issue to tell the public that there is a need for the nuclear power, without discussing the fact that they should have put their money in the late eighties in investing in the refining capacity and other sources of energy. These are all issues which have to be debated publicly in Iran.*

Michael Brzoska *(Germany): What I was missing in your presentation was a kind of cost calculation that Iran is really losing money by building nuclear power instead of selling oil at the international market for $110 per barrel now. And what follows if that is true, that Iran is losing money on that, is of course the irony following John Boright that the higher the oil prices, the larger the economic incentive for Iran to build nuclear power. And therefore we are, I think, in a sense, by not trying to save energy and not trying to save oil stimulating Iran to build nuclear power. Would you agree with that?*

Aharon Zohar: I am not responsible, as I said, for the Iranian calculations, but as we all know the costs of building nuclear capabilities for electricity purposes, assumed this is the way they are following - which I do not believe -, the costs are enormous to a country that has the largest oil and gas reserves in the world. There is no country in the world that has such reserves.

Saideh Lotfian: *The oil price has gone up, that is true, and Iran's foreign reserves in foreign banks have gone up because the oil prices have gone up, but the point is that Iran imports petroleum and the cost is much higher. The final analysis is that the costs of living have gone up because we have to pay more for the imports of commodities that are not produced domestically. So it is not always good news that the price of oil goes up. It does not make the Iranians happy because then they have to pay more for industrial goods and for the technology that they need to import from other countries.*

Prospect of the Six-Party-Talks and Peaceful Resolution of the North Korean Nuclear Issue[1]

Mark B.M. Suh (South Korea)

Since the early 1990s the North Korean nuclear issue does not only endanger peace and stability on the Korean peninsula as well as of the world, it is also threatening the non-proliferation regime. The first nuclear crisis 1993/94 was resolved peacefully through direct bilateral talks between the US and the Democratic People's Republic of Korea (DPRK, hereafter North Korea) on the basis of the Geneva Framework Agreement in October 1994.[2] Unfortunately, however, it failed to be fully implemented and was nullified by the US and North Korea in December 2002. Consequently, North Korea withdrew from the NPT on 10 January 2003 and started to build up its nuclear capabilities. In order to provide a platform for dialog in this second crisis, the Chinese government initiated the Six-Party Talks process in August 2003. This multilateral approach is seeking a step-by-step diplomatic solution to the complex issue and to help build a peace mechanism in and for the region.

Can the Six-Party Talks find an answer to the Korean question and bring about permanent peace in Korea? Although the verifiable and complete denuclearization of North Korea has been agreed upon by all parties in September 2005, why is there lacking enthusiasm in implementing the agreements and bringing North Korea back to the NPT as a non-nuclear state?

Changing the Political Environment

After more than 13 months of delay and some serious setbacks, the second meeting of the fifth round of the Six-Party Talks finally resumed in December 2006 in Beijing, but ended without even setting the dates for a next meeting. Most observers believed that it was the end of the Six-Party Talks.

Prior to that, the first meeting of the 5th round of the Six-Party Talks in November 2005 had also ended without any progress and conflicted with the North Korean precondition that the US financial sanction against North Korea must be lifted first of all. The process was practically dead with neither North Korea nor the USA willing to make any compromises to break the deadlock.

To make the situation even worse, North Korea escalated further by carrying out seven missile tests on July 4th 2006 and ultimately conducting the first nuclear test on 9 October 2006, however, with a prior short warning. The US blamed mainly China for not doing enough to prevent these dangerous developments and demanded to pressurize North Korea to give up its nuclear ambitions. China though, after trying to influence the North Korean leadership by giving massive economic aids and advising not to make the situation worse by such provocative acts, took renewed initiatives to bring the US and North Korea back to the talks.

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[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

[2] More about the background of the Agreement see Joel S. Wit, Daniel B. Poneman and Robert L. Gallucci, The First North Korean Nuclear Crisis: Going Critical. Washington, D.C.: Brookings Institution, 2004.

Some significant changes also occurred on the side of the US. Since the November 2006 mid-term elections, during which the Democrats emerged as a majority in both Houses, the Congress renewed pressure on the President for early resumption of the negotiations with North Korea. Since the election, the US repeatedly assured North Korea that it had no intention of invading North Korea and did not seek a regime change any more. It also began to talk directly with North Korea in Beijing within the framework of the Six-Party Talks and promised to offer some dramatic political and economic rewards to North Korea in return for a complete denuclearization.

The Six-Party Talks process got moving again, when the first-ever direct talks between the US and North Korea outside of Beijing took place in Berlin, Germany, on 16-18 January 2007. This was made possible because US President George W. Bush had indicated willingness to sign a peace treaty with the North through South Korean President Roh Moo Hyun on 18 November 2006 in Hanoi, Vietnam. It was seen as a sign of a new US policy towards North Korea. The most important fact for this change was the determination of the concerned parties (especially the US and North Korea) to find a negotiated solution instead of prolonged military confrontation. North Korea demanded to prove that the US indeed changed its hostile policy against North Korea.

The Banco Delta Asia (BDA) Problem

The freezing of 50 North Korean accounts through US-American financial sanctions, especially the Banco Delta Asia (BDA), a bank in Macao, in October 2005, was regarded by North Korea as an act of US hostile policy against North Korea. The BDA is a private bank in Macao which was founded in 1954 and had been dealing with North Korea since the 1970s. North Korea wanted this freezing to be undone as a symbol of the new US policy. Those 50 frozen North Korean accounts, with a total of 24 Million US Dollars in the BDA, consisted of 20 from North Korean banks, 11 from trading companies, 9 from individuals but 8 from Macao companies trading with North Korea and two Macao individuals who dealt with North Korea.

North Korea denied that these accounts had anything to do with wrong doings such as counterfeiting money or drug trafficking or selling weapons of mass destruction as the US claimed. Half of the total money in question, about 12 Million US Dollars, proved to be money from the Hyundai Group of South Korea, which pays North Korea regularly for the Geumgang Mountain Tour Project in North Korea. Other parts of the money are believed to be from selling gold reserves. In addition, North Korea claims that the 10 accounts of Macao companies and individuals have nothing to do with North Korea at all.

Although the first meeting of high ranking officials on the issue between the US and North Korea took place in Beijing during 19-20 December 2006 outside the Six-Party Talks, there was no concrete agreement or solution on the issue. The second meeting of this kind also took place in Beijing from 29-30 January 2007, but again, no agreement was found. North Korea expressed its disappointment and accused the US for not keeping its word. The North Korean state media made it known that according to the Berlin meeting of 16-18 January 2007, the US had promised to lift the sanction within one month.

It was only during the Six-Party Talks in Beijing in 13 February 2007 when the US announced to release the 24 Million Dollars in BDA in the near future. This enabled the Six-Party Talks to move forward and the parties agreed on the first step to implement the denuclearization plan for North Korea at the last minute. The BDA issue had been the major cause of escalation and confrontation over the nuclear issue for more than a year, but it became the very symbol of the changed US policy towards North Korea.

Although the US decided to free all the North Korean money from the BDA, it was confronted with an unexpected problem in transferring the money to North Korea. The Bank of China refused to accept the money and to transfer it to North Korea. The two main reasons were:

- The decision on the BDA was made outside of the Six-Party Talks process and China was not consulted, therefore it was not willing to accept this bilateral decision.

- China demanded that not only North Korea but also the BDA, a Chinese private bank, must be rehabilitated as well.

This deadlock could only be resolved when Russian President Putin decided to help President Bush in order to save the Six-Party Talks. First, the money was transferred by the BDA in Macau to the Federal Bank Branch in New York. Then the money was transferred to the Russian Central Bank in Moscow, which finally sent it to a Russian private bank in Krasnoyarsk in Siberia. North Korea finally acknowledged the receipt of the money on 25 June 2007 and officially announced that the BDA problem had been solved. The Six-Party Talks began to move again and resumed in Beijing eventually leading to the Agreement on the Second Implementation Plan on October 3, 2007.

Contrasting Interests of the Involved Countries

One of the reasons for the slow phased development in the Six-Party Talks is the different and contrasting interest of the parties on the issue. As long as the denuclearization of North Korea is not the top priority of all parties, the process will experience ups and downs and might take long time to realize the complete denuclearization of North Korea.

North Korea

North Korea's main target is the very survival of the regime. It believes that the nuclear capabilities are essential for deterring US invasion as well as for strengthening the regime. Since the nuclear test, it feels more secure than before from an invasion led by the US. The government is assuring the people that it had to suffer mainly due to the efforts of becoming a nuclear power. It has been celebrating its nuclear success and telling people that it can and will now pay more attention to the economic recovery and the well being of the people. On the other hand, it is offering the US to trade off the nuclear program for full normalization of relations and economic compensation.

The North Korean leadership has decided to abandon the nuclear option in exchange for some political concessions from the US: Not only ending the Korean War and recognizing the DPR Korea as a normal state, but stopping regular military maneuvers in South Korea as the first step towards mutual accommodation. Economically, it also expects a valuable reward: The resumption of deliveries of heavy oil which were stopped in 2003, with North Korea desiring much larger amounts of about one million tons this time. Furthermore, since the 1994 Geneva Framework Agreement was a purely bilateral deal with the US but later abandoned unilaterally by the US, this time it decided on a multilateral deal with 6 countries involved in the negotiation. The promised two light-water reactors (LWR) also remain on North Korea's agenda.

North Korea is very desperate now to get rice and fertilizer aids from the South which have been delayed since early 2008. Winters are harsh and the rice from the South would help the people very much. The fertilizers from the South were essential for farmers of the country since 2000 and are much needed for planting crops such as rice, corn, potatoes and vegetables. With the success of the Six-Party talks North Korea hopes to receive help from the US as well as from South Korea again.

If, however, the US fails to solve the pending issues by delaying the normalization of relations with North Korea, it is likely that North Korea could react by proliferating nuclear capabilities to other countries. Nevertheless, the North Korean leadership is interpreting the process as a great success of Kim Jong Il's military-first policy and as a victory in the war against the US, the most powerful country in the world, finally ending the 58 year long Korean War. North Korea is likely to move on only slowly by matching the US actions to normalize relations and meantime expects to be regarded as a nuclear power by the international community, an equal partner in the Six-Party Talks.

The USA

Since the nuclear test of North Korea in October 2006, the US government showed interest in starting direct dialogue with North Korea to solve the nuclear issue.[3] With the loss of the Republican majority in the Congress in November 2006 and subsequent sacking of chief neo-cons hostile to North Korea, especially D. Rumsfeld and J. Bolton, voices for a negotiated solution to the North Korean nuclear issue became louder.[4] The first sign was Bush's proposal to then South Korean President Roh Mu Hyun on 18 November 2006 in Hanoi that the US was willing to sign a peace treaty between the US, China, North and South Korea finally ending the Korean War, if North Korea completely gave up its nuclear programs and returned to the NPT as a non-nuclear state. President Bush also promised to provide security guarantees to North Korea as well as to join South Korea in helping North Korea financially and economically.

Secretary of State C. Rice and US-Envoy C. Hill started to seek dialogue with North Korea and allowed direct bilateral negotiations as an equal partner, not calling the North Korean regime a member of the "axis of evil" anymore. The turning point was the Berlin meeting where the chief negotiators of the US and North Korea agreed on basic issues. The basic principle of the Bush-led US policy, namely "disarm first then talk", had been given up and a tit-for-tat approach was adopted, as North Korea had been

[3] For more about background about the Six-Party Talks and Bush's Policy on North Korea, see Charles L. Pritchard, Failed Diplomacy: The Tragic Story of How North Korea Got the Bomb. Washington, D.C.: Brookings Institution, 2007.

[4] Victor D. Cha and David C. Kang, Nuclear North Korea: A Debate on Engagement Strategies. New York: Columbia University Press, 2003.

demanding. The US agreed to act according to the agreement reached in Beijing, and North Korea promised to move forward accordingly. This time the solution is not only between the US and North Korea like the Geneva Framework Agreement in 1994 but a multilateral agreement of the six member countries. This can be seen as a major shift in the US policy towards North Korea and the turning point in the Six-Party Talks process.

A further major reason for the change of the US policy is caused by the fact that China appears to have less influence on North Korea than expected and is benefitting from the situation. In fact, the US isolation policy led to North Korea being more dependent upon China, politically and economically, so eventually North Korea could have become a province of China. Therefore, the US decided to no longer withhold South Korea from helping North Korea. The US believes that further isolation and sanctions of North Korea might deepen the already dominant Chinese involvements in North Korea and divide the two Koreas permanently or lose North Korea to China. This recognition of the US administration about the Chinese intention brought about the radical changes in dealing with North Korea in addition to the South Korea-US Free Trade Agreement which increased South Korean impact on the US North Korean policy.

With the change of government in the US in early 2009, it is likely that the nuclear problem can be solved soon and finally succeeds in bringing back North Korea into the NPT regime as a non-nuclear state, which could strengthen the NPT in the end.

South Korea

No other country is more eager about an early success of the Six-Party Talks than South Korea. South Korea worked hard with China, the US and North Korea to find a solution to the nuclear issue through the process of the Six-Party Talks and to prevent an escalation of the crisis. Being situated on the peninsula, it is directly affected by the nuclear program of the North and by the prolonged military confrontation between the US and North Korea since the Korean War.

It is likely that South Korea will bear the major burden of economic compensations to the North as in the previous case. South Korea already delivered 50 000 tons of heavy oil to North Korea when it shut down the Yongbyon nuclear reactor, and will supply another 950 000 tons oil or equivalent in electricity once North Korea completely disables the major nuclear facilities. The US and other countries, except Japan, will join South Korea to provide help for North Korea promised in the Six-Party Talks.

Unfortunately, with the change of government in South Korea in February 2008, the relations between North and South Korea are rapidly worsening. All official dialogues have been stopped and even private contacts are restricted. The 10 year old Mount Geumgang Tour Project has been stopped in July and the Kaesong Tour Project as well. The Kaesong Industrial Zone near the border in North Korea is now the only surviving economic cooperation project between the North and South. Although South Korea played an active role in bringing about a solution to the problem until February this year, it is doubtful whether the current government is able to have any active role in the near future and collaborate with the US to solve the problem.

China

China, the host country of the Six-Party Talks, worked hard to bring about a solution. It was forced by the US to put pressure on North Korea in order to abandon its nuclear ambitions, but China was reluctant to further isolate North Korea. Although China clearly stated that it cannot and will not allow a nuclear armed neighbor, it had no other choice but to support North Korea's interest. China's utmost interest was to successfully host the 2008 Summer Olympics and therefore did not want to anger the US nor North Korea and wished to sustain peace in the region. The Chinese leadership repeatedly urged North Korea not to test the missiles and the nuclear device, but North Korea acted according to its own interest. At one time North Korean leader Kim Jong Il refused to receive a personal message from the Chinese President and even to meet the special envoy of President Hu Jintao.

After the nuclear test in October 2006, China did not use its veto to block the UN resolution against North Korea in contrast to the past. This was misinterpreted by the US hawks as a change of policy in China. To save the Beijing Summer Olympics, China went along the US's and Japan's initiative in the UN and agreed on the resolution, but it did not implement economic sanctions against North Korea as the US requested. In fact, China increased its export of oil and other important goods to North Korea since the passing of the resolution. Nevertheless, China's influence on North Korea has decreased since then and appears to have much less influence on the North Korean leadership than the US believed. North Korean leadership now distrusts China as being too close to the US and South Korea, its main enemies.

China's main interest is to keep the status quo on the peninsula, which are a divided Korea and a China-friendly regime in North Korea. Since the nuclear test, some Chinese scholars even suggested a regime change in North Korea through a military coup or installation of a China-dependent fraction. However, North Korea believes in its own nuclear capabilities and it no longer needs the Chinese protection against the US aggression. China is suspicious of the US and North Korea for striking a deal outside of the framework of the Six-Party Talks. It is interested in influencing the issue on its own terms.

China has been urging the U.S. to provide security guarantees and economic aids as well as diplomatic incentives for North Korea in order to solve the problem peacefully for the benefit of the region and the world. China continues to play an important role in sustaining the Six-Party Talks and bringing about a success eventually. In the long run, it is interested in institutionalizing it as a political forum to safeguard the regional stability in the future.

Japan

Japan was and is the most reluctant partner in the Six-Party Talks dealing with North Korea. It made known from the beginning that it is only interested in talking about the abduction issue. Without solving this issue first, it repeatedly stated that it would not help North Korea at all. But the other five partners including North Korea wanted to focus on the nuclear issue at the Six-Party Talks instead. Although some feared that

Japan could block any agreement on the nuclear issue, it has so far agreed on the final agreement. The abduction issue will be dealt with within the Japan-North Korea study group along with the normalization issue.

Accordingly, North Korea must seek to normalize relations and deal directly with Japan. The first direct contact took place in Beijing 2007 during the Six-Party Talks for only one hour, but there was no progress. Then Japanese Prime Minister Shinzo Abe said in Tokyo that his country would not yet join in giving aid to the North. Japan said it wanted to resolve the issue of abductions of Japanese citizens, which Pyongyang had admitted but not yet addressed to Tokyo's satisfaction.

Japan has been accused of using the North Korean nuclear issue for its own domestic purposes. It joined the US in developing the Missile Defense (MD) System as well as increasing its defense budget and elevating the defense agency to a full-fledged defense ministry. It expanded its military cooperation with the US at the expense of regional harmony not only concerning North Korea. Some observers in South Korea and China view Japan as the major factor for instability in the region.

It was Japan and the US who initiated the UN Resolution against North Korea after the nuclear test. They wanted even harsher actions against North Korea including military sanctions. Now Japan is unhappy with the new US accommodation with North Korea and is reluctant to normalize relations. It has been the harshest implementer of the UN resolution against North Korea and still upholds its sanctions.

Japan demands the release of the abductees and a solution to the missile issues before relations with North Korea can be normalized. It feels uneasy about the current direct dialogue between the US and North Korea as well as the US humanitarian aid to North Korea. A denuclearized North Korea lies in the interest of Japan because of a peaceful future in the region, so it is advisable to pay more attention to the present and future instead of to the past. Mutual distrust and lack of confidence are the key problems in the process.

Russia

Russia participated actively in the process and offered some alternatives to the energy issue. It is very likely that when the North Korean denuclearization process has reached a certain point, Russia might deliver electricity to North Korea directly and help by modernizing North Korea’s power plants.

Since President Putin took office in 2000, relations between Russia and North Korea have been improving gradually. Furthermore, personal friendship between President Putin and Kim Jong Il are becoming an important factor. Solution to the old debt problem is expected to be solved in the near future; this would elevate the relations and expand further into the economic sector. North Korea views Russia as a socialist brother state who can be trusted unlike China.

Russia is keen on helping North Korea to solve its energy problem and it favors closer cooperation between the two Koreas and an eventual reunification of the nation.

Current Status of the Talks

After 5 years of ups and downs, the third meeting of the 5th round of the Six-Party Talks in Beijing succeeded by reaching an implementation plan for denuclearization of North Korea on 13 February 2007 in Beijing – now known as the 2.13 agreement.[5] North Korea agreed not only to freeze but to completely shut down and disable its nuclear facilities and programs in exchange for economic and energy aid as well as political concessions, such as normal relations with the US and Japan. It is a step-by-step plan to resolve the problem: North Korea commits itself to shut down its nuclear facilities and to seal them together with nuclear experts from the IAEA within two months. In return, the other 5 countries will provide 50 000 tons of heavy oil initially, and when North Korea has successfully disabled all nuclear facilities, additional 950 000 tons of heavy oil or an equivalent in other forms of energy, such as electricity, are to be supplied to North Korea.[6] The major gain for North Korea, however, is the promised political recognition from the US and Japan.

This was only the initial step of a multi-phased implementation plan to denuclearize North Korea and to finally end the more than 15-year old nuclear crisis with the US, leading to an eventual termination of the long "forgotten" Korean War and giving peace a chance on the peninsula. Under the agreement, five working groups were to meet and to work out solutions: denuclearization, normalization of US-North Korea relations, normalization of North Korea-Japan relations, economy and energy cooperation, and peace and security in Northeast Asia. This certainly was a breakthrough and a landmark agreement, although neo-conservatives like John Bolton already expressed their displeasure and called for rejection of the agreement under US President Bush.

The complete list of North Korean nuclear activities, as agreed in February 2007, was submitted by North Korea to the Chinese government on 26 June 2008 after a six months delay. The next day, President Bush responded promptly by stating publicly that the US was taking necessary step to remove North Korea from the list of states sponsoring terrorism. The North Korean leadership expected this to happen on 11 August 2008 – 45 days after its announcement. When there was no action by President Bush until 14 August, North Korea announced that it was preparing to restart the reactor and reprocessing the spent fuel accusing the US for not keeping its promises. North Korean leader Kim Jong Il also disappeared publicly and rumors about his ill health began to make the headlines.

President Bush finally announced on 11 October 2008 that the US was removing North Korea from the list of states sponsoring terrorism. North Korea immediately responded positively about the decision and resumed the disabling process of the nuclear facilities getting the Six-Party Talks process moving again.

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[5] See Mike Chinoy, Meltdown: The Inside Story of the North Korean Nuclear Crisis. New York: St. Martin's Press, 2008.

[6] The US has been seeking for a substitute of Japan to supply the heavy oil promised in the Six-Party Talks. Australia has recently stated that it is willing to supply 200 000 tons of heavy oil which Japan refuses to deliver. New Zealand and EU also indicated their willingness to supply heavy oil to North Korea.

Prospects of a Nuclear-Weapon Free Korean Peninsula

The future of the Six-Party Talks is brighter than ever these days, but there are still some challenges on the road. The ongoing military exercises of the US and South Korea, such as the RSOI and Foal Eagle as well as many other routine exercises are viewed by North Korea as signs of war-preparations and hostile policies towards North Korea. It regards its own nuclear capabilities as a response to these threats and a legitimate act of self-protection, so it is clear that North Korea will not give up its nuclear potentials unless the US really changes its policy against North Korea.

Not all parties involved are eager to speed up the process of the Six-Party Talks and make the Korean peninsula nuclear-weapons free. North Korea aims to use the nuclear issue to achieve its political goal of being accepted and recognized by the arch enemies. Paradoxically, it now wishes to concentrate on rebuilding the already shambled economy with the help of enemies and friends. Solving the energy problem could be the first step towards a rapid economic reconstruction of North Korea.

The US, on the other hand, is likely to convince the American public that the implementation plan is a diplomatic success of its own, and thus gain free hands to fully concentrate on Iran and the Middle East. The calculated escalation by North Korea has been a nightmare for the Bush administration who wanted to use North Korea as a new enemy in order to build the Missile Defense (MD) System in Japan and to keep the status quo in Korea. Now it has to talk with a so-called rogue state and seek a way out without breaking its own promises. It is fully aware that without accepting security interests of North Korea, it is unlikely that North Korea will ever give up its nuclear capabilities.

It is likely that the Six-Party Talks will agree on the verification protocol to conclude the second phase of the implementation by early 2009. Under the new US administration from early 2009, the third phase of implementation is expected to be negotiated which completes the denuclearization of North Korea in the near future. Whether North Korea can rejoin the NPT as a non-nuclear state before the 2010 Review Conference of the NPT depends on the decision of the US government.

Although much depends upon what happens between the US and North Korea and other partners of the Six-Party Talks, the prospect of a nuclear-weapon free Korean peninsula looks better than ever. All parties must build confidence by overcoming the remnants of the Cold War and by implementing the agreement reached by the Six-Party Talks step by step.

In order to build confidence and reduce mutual distrust as well as to ensure smooth implementation of the 9.19 and 2.13 agreements, a few actions of the Six-Party-Talks States could be taken:

1. South Korea should expand its economic aid to North Korea, that is, not only provide rice and fertilizer but it should also help reform the agriculture and chemical industry to increase the food production, so North Korea can be self sufficient in the long run.

2. North and South Korea should seek ways to peacefully co-exist and recognize each other as sovereign states.[7] The overall relations of the divided nation should be changed from confrontation to peaceful co-existence. The 1992 basic agreement by the two Koreas could be the foundation for a legal framework of mutual recognition and in establishing normal state-to-state relations.

3. Japan should discuss about the already agreed issue of normalizing relations with North Korea and the abducted Japanese issue should be discussed on bilateral level only. Other members of the party should win over Japan that a non-nuclear North Korea must be the top priority, as it is of interest for all as well as Japan.

4. Refrain from conducting US-South Korea joint military exercises in South Korea, especially as long as the Six-Party Talks are in progress. As in 1994, postponing or canceling the military exercises is essential in building confidence and reducing tensions on the Korean peninsula. These exercises are counter-productive to the diplomatic efforts through the Six-Party Talks in order to solve the nuclear problem peacefully.

[7] For more details about the complicated relations between the two Koreas, see Don Oberdorfer, The Two Koreas: A Contemporary History. New York: Basic Books, 2001.

Discussion of Mark Suh's Lecture

Christoph Pistner *(Germany): I have a question concerning the open points in the declaration of the North Koreans that you mentioned, especially concerning the HEU program. I mean there are basically two options. There has been a HEU program or there has not been a HEU program. If there has been one, do you feel that the North Koreans will at some point in time be willing to declare that they had one? And if there has not been an HEU program, do you think that the U.S. will be willing to accept at some point in time that there had not been one?*

Hannes Ridesser *(Germany): This was very very interesting because it showed the danger of placeholder conversations, of speaking continuously about weapon developments and so on, while in fact what they want is to be recognized, they want to be in a normal relation with their surrounding countries and they do not want, of course, to be demonized. I immediately had to think about the speeches that had a similar situation of also being in danger of talking a lot about weapon systems while failing to talk about fear. This is very common between, for example, Israel and Iran: fear of invasion. Coming from this perspective is the new topic of talking with each other how they can help each other out of the situation of being afraid of invasion.*

Mark Suh: The first question on HEU: I did not have time to go into details. It is a little complicated. The beginning of the second crisis in 2002 was exactly because of this HEU question. James Kelly visited North Korea and he accused them "you violated the Geneva Framework Agreement by having this HEU program". North Korea refused "we do not have it and we did not violate it". This issue became so serious and ended up as the nuclear crisis as we see now. But there is little evidence in support of the American accusations: 1) North Korea imported 20 centrifuges from Pakistan. A.Q. Khan was the dealer and he managed to sell 20 of them to North Korea; 2) North Korea managed to import thousands of aluminum pipes, which can be used as centrifuges. But they used it for missiles as a rocket, and they really produced ballistic missiles – they are very good at that – to be exported to other parts of the world. The North Koreans insist that they never had a HEU program, and they will never do it and they have no intention to do it. I asked the North Koreans what happened with the centrifuges they imported. They explained that they imported the centrifuges to study them and also use them for different purposes, such as commercial uses. That is why the evidence for the HEU agitation from the U.S. is very weak, because the above mentioned evidence is too weak. In my impression, North Korea does not have the electricity to get 3000 to 5000 centrifuges to run to enrich uranium for years to get enough material to have a nuclear bomb. I think they chose a plutonium bomb because it is cheaper for them, and despite being technically more difficult, they managed to solve the problem. The HEU issue is likely to remain on the agenda because it is embarrassing for the U.S. The key problem for the second crisis is practically almost like the Iraq case – it is no longer valid since there is no clear evidence. In some way, it is difficult when the US insisted on having the HEU issue on the list and North Korea said they could not include it because they never had it; this really delayed the dialogue process. It might pop up again, but so far I do not think North Korea has tried HEU or will go in that direction.

Let us go back to the first crisis. You remember North Korea signed the NPT in December 1985. According to the NPT you have to sign the Safeguards Agreement with the IAEA within six months, but North Korea did not do this until 1992. The signing of the Safeguard Agreement was delayed for seven years to allow IAEA

inspections. When the IAEA entered North Korea in 1992, they conducted an *ad-hoc* inspection according to the list that North Korea provided first. There were two problems which really became a crisis (over which a military conflict almost emerged), but the key issue was the amount of plutonium that North Korea admitted having. You would be surprised how much they admitted having – this was the only fissile material they had – 98g! But according to the IAEA inspectors, North Korea had at least 148g. This is clear evidence of North Korea's capability of producing plutonium.
The second issue was a time issue: According to the North Koreans, they produced plutonium in the late eighties; but according to the IAEA inspectors, North Korea had done some experiments already in the mid-eighties, so it must have more plutonium in some place hiding. What happened was a demand for special inspections - for the first time ever - by the IAEA. North Korea refused this demand and declared that it would withdraw from the NPT. Pugwash and some others worked very hard to hold North Korea within the NPT, and North Korea decided to remain in it. This is the main reason why the treaty was and could be extended indefinitely in the 1995 NPT Review Conference. Since 10 January 2003, North Korea is no longer a party to the NPT, but it has already agreed that it is willing rejoin as a non-nuclear state when the political circumstances change. North Korea most of all expects political compensation from the US.

Saideh Lotfian *(Iran): I just want to mention the importance of the solution of the North Korean nuclear crisis through diplomatic means because I believe that it will have a positive impact on the nuclear crisis in which Iran is concerned. That will show basically that diplomacy works; it will strengthen the arguments of those who are supporting diplomatic means rather than military options. It will also remove North Korea from the supply side of basically the nuclear equation. Mark already talked about Syria, the suspicious Syria-North Korean connection which led to the Israeli air strike against the suspected sites within Syrian territory. Basically the NPT will be strengthened, so the non-proliferation regime will be strengthened and the next step would be the creation of a nuclear weapon-free zone in the Korean Peninsula. So I would see it as a positive step.*

Aharon Zohar *(Israel): I also subscribe to the idea that it would be helpful if the Iranian issue would be settled diplomatically rather than by other means. It seems to me that it would be helpful if the United States engaged in direct negotiations with Iran in order to resolve the issue. I do think, however, past experience suggests that negotiations by themselves will not help. I think a combination of the carrot and stick is required in this context, with the background of previous attempts at resolving the Iranian issue. And finally, connected with the whole issue whether Iran has been, had or is contemplating a nuclear weapons project, I just wanted to mention that the investment that Iran is making in ballistic missiles of different kinds and different types – and investing a lot of money in these projects – suggests that Iran is contemplating a nuclear weapon option, because otherwise it would be rather a major expenditure to invest in ballistic missiles unless you are contemplating the possibility of putting nuclear warheads on them. Otherwise in terms of cost-effectiveness it does not make any sense if you are not developing a nuclear capability. The joint effort of missilery and the enrichment does create a major suspicion about the Iranian intentions.*

Fourth Session - Safe Fuel Supply for Civilian Nuclear Power Stations and the Risk of Nuclear Proliferation I

Chair: Spurgeon Keeny

Strategy Options for the UK's Separated Plutonium

John Simpson (UK)

I am about to present you with a problem to which at the moment we do not have a clear solution. The problem is that the United Kingdom at the moment has 103 tons of separated plutonium stored at Sellafield, some of it non-UK owned and no strategy for its disposition. The amount that the UK is holding, by far the largest separated civil plutonium stockpile in the world, is greater than the amount of weapons grade plutonium that the United States and the Russian Federation are currently committed to dispose of through their collaboration agreement. So the question that I am addressing to you today is what the UK government should do with it.

How did we get to this situation? I was one of the working parties which recently produced a report on this for the Royal Society. We got into this situation because the U.K. has been reprocessing nuclear fuel from its power reactors for the last 55 years. But all these civil nuclear activities are now all coming to a close. The fast reactor program which was supposed to burn this plutonium was halted in 1994. The last of the UK's indigenous first-generation Magnox gas cooled reactors, the source of the bulk of this plutonium, is scheduled to close in 2010. The last indigenous second-generation advanced gas cooled reactor is scheduled for retirement in 2023. The only light water reactor in the United Kingdom, Sizewell B, commissioned in 1995, has a scheduled retirement date of 2035. Finally, the United Kingdom government has agreed to its privatized utilities building new light water reactors and if they do the first one could be commissioned by 2020. But it will not subsidize their operations: they will be built only if they can be justified on commercial grounds.

Other legacies of the UK's national nuclear program include the Thermal Oxide Reprocessing Plant (THORP). This is scheduled to close in 2010, when reprocessing of non-U.K. fuel on a commercial basis is due to terminate. However, there are question marks over this because THORP has been inoperative for about two years due to waste discharge problems and is not clear when and if it is going to reopen. If it does not reopen, the only way to satisfy the existing contracts is going to be a flag-swapping exercise where existing Magnox reprocessed material is returned to its contractees, and their own used fuel is stored indefinitely at Sellafield.

A Magnox reprocessing plant has been running since the early sixties and is scheduled to close in 2012. By then the residual material held in storage facilities at reactor sites should have been reprocessed. This would place a cap on the stockpile as all U.K. reprocessing will have ceased. In theory, the stockpile will then start to drop very slowly as a result of the separated plutonium going through the Sellafield MOX plant,. This plant has a design throughput of 120 tons per annum. The current production rate is less than 40 tons and we have not been able to find a convincing answer as to why this is so. And no one seems very optimistic that it is going to rise above 40. Yet repatriation of fuel to overseas customer is, as a matter of non-proliferation policy, in MOX form only. It is probably going to take to 2023 to clear the backlog of MOX destined for overseas customers, assuming it operates at a 40 tons p.a. capacity. What this would mean is that conversion of UK separated plutonium to MOX cannot begin before 2023 unless additional capacity is added.

What is the alternative to MOX as a plutonium disposal route? Is it direct geological disposition? It would appear that the separated plutonium is unlikely to be acceptable for geological disposition by the UK regulator in its current power form. Moreover, a UK intermediate level waste store is not estimated to be going to be available in the U.K. before 2040, and a high level waste one before 2075. And at that point I think my eldest grandchild will be about ninety.

Another issue is physical security. At the moment the plutonium is held in an above ground store. Separated plutonium powder could therefore be released in aerosol form after an explosion or fire, thus forming a potential health hazard. The material itself appears to be held in double stainless steel cans and since 9/11 there has been greatly upgraded physical and personnel security at the plant and facility. Also, a new so-called special products and residues store has been built adjacent to the Sellafield MOX plant. It also appears that all the weapon grade plutonium, including material transferred in 2000 to Sellafield from the military stockpiles at Aldermaston and elsewhere, has been blended down.

So, in summary what is this legacy problem the UK is confronted with? First of all, there will be 100+ tons of separated plutonium at Sellafield by about 2012, when the existing UK Magnox reactors and the reprocessing plant are scheduled to close. There is currently no UK government policy on what is to be done with this. Geological disposal will not be available until about 2075. It would appear that all the current MOX capacity is going to be engaged until 2023 in converting the contracted overseas material into MOX for repatriation. The separated plutonium is currently in powder form, and thus appears vulnerable to terrorist attempts and dispersion or burning and possibly theft.

The majority of this material could be converted into low or high specification MOX after about 2023 to combat this threat, or earlier if additional MOX capacity was built. While this would significantly enhance its resistance to terrorism and theft, economic considerations suggest that this would only be viable if it is in the form of high specification MOX for burning in a reactor. This can only happen if new power reactors are to be built in the UK. At the moment the government has only given the green light for such a new build, and it is not clear that it will be commercially attractive. The only other option is to burn some of the MOX to the spent fuel standard in the Sizewell B light water reactor. Yet when the planning hearings on Sizewell B took place, it is reported that there was a commitment by the then Head of the nationalized Central Electricity Generating Board – this was before Mrs. Thatcher’s privatization activities – that Sizewell B would not burn MOX.

Technically, the operational life of Sizewell B could probably extended from its current forty years to sixty given what is happening elsewhere in other European states with the operating lives of similar reactors. If it was licensed to burn MOX, it could do so for a period of 12 to 32 years, depending on whether its lifetime can be extended. This would enable it to consume between 6 and 16 % of the U.K. stockpile through to 2055 assuming a 33 % MOX loading; this however would still leave about 84 % of the stockpile to be disposed of in a geological depository after 2075. If there was no new build and no burning in Sizewell B, there appeared to be no alternatives but to store it, possibly with or without high level waste surrounding it or mixed with it, or to export it. If however there is a new build, of, say, four new 1000 Megawatt reactors commissioned for operations at 33 % MOX load from 2023 onwards, the stockpile could be reduced by 2065 to a bare minimum of contaminated material which is unsuitable for conversion into MOX. (At some stage in its life, some of the plutonium came into contact with polythene, and at the moment there is no clear vision of how to separate it in an economic manner) . Given the U.K. government's commitment to geological disposal of spent fuel arising from any new built, all the former stockpile of separated plutonium in their MOX fuel could then be disposed of geologically in a safe and secure manner- that is as soon as the high level waste facility and the relevant immobilization technologies are available.

What therefore are the alternative policy options that appear to confront the U.K. government in this situation?

First of all, there is the option favored by many governments: doing nothing. This does not cost a great deal. It would involve taking no action on licensing Sizewell B to burn MOX or persuading the utilities to burn MOX in new build reactors. There would only have to be some work to sustain the enhanced level of physical protection on the plutonium store.

Secondly, convert the plutonium into low grade MOX after 2023 (i.e. MOX not designed to be burned in a specific reactor, but providing greater resistance to the effects of fire or explosion than in its current powder form). This might possibly mean enhancing the capacity of the current MOX plant in order to accelerate this process.

A third option, if there is no new built, is to export stocks of high specification MOX after 2023. After all, this is what the UK is already doing – exporting such material back to Japan, back to Switzerland, back to Germany. Under this option it might be burned in specific non-U.K. reactors, for example in France. Whether this is acceptable both domestically in the U.K. and internationally is, however, open to question.

Fourth, convert the plutonium to high specification MOX after 2023 and burn it in Sizewell B. However, only part of it can be burned in Sizewell B even though its capacity could be enhanced by increasing the percentage of MOX in its fuel loading. .

Five, if new build did occur, convert the maximum percentage of plutonium to high specification MOX in it after 2023. This would enable the majority of the plutonium to be burned as MOX in reactors in the UK by about 2055.

Lastly, and this is something that in fact is not discussed in the Royal Society study, mix the plutonium with the large amounts of U.K. high level waste or put a jacket of high level waste around it, and store it in this form until a suitable geological disposition facility is available in 2075.

So I think this leaves us with a number of open questions which I look forward to your thoughts on:

1) Is indefinite non-geological storage of separated plutonium, with no high level waste mixing, an acceptable basis for UK nuclear security policy in respect of this material?

2) Should the United Kingdom regard the used fuels standard as the basis for plutonium disposal policy, this being apparently the basis for the disposal for the weapon grade material coming from the United States and the Russian Federation?

3) If MOX burning in four plus new 1000 MW reactors is the only satisfactory way of attaining the used fuel standard nationally, should any additional costs of using MOX fuel be classified as waste disposal costs not generating costs? Would this allow the British government to subsidize the burning of the plutonium as MOX in these reactors without moving from its stated position of not subsidizing their economics?

4) If there is no new build in the U.K., what would be the security or other implications on the sale or lease of its plutonium stocks to other countries? Would this be domestically or internationally acceptable?

Finally, the existing U.S. - Russian Federation arrangements for disposal of some of their weapon grade plutonium may offer lessons for the United Kingdom. It would be interesting to hear the thoughts on this of those who have been involved with this in the United States. And, and this moving into very uncharted territory, could GNEP – the Global Nuclear Energy Partnership that President Bush initiated – have an internationally accepted role in disposing of the United Kingdom's stockpile? I await your thoughts on this and other options.

Discussion of John Simpson's Lecture

Richard Garwin *(USA): Thank you for the excellent presentation. I think that matters are even worse than you suggested. As Spurgeon Keeny indicated, he and I have worked on the "spent fuel standard" in the context of disposition of excess weapon plutonium. The problems are very similar to those of the civil plutonium, except that we acquired the plutonium in a different way. But once you get the plutonium, or the plutonium oxide, you have a very serious problem.*

The Sellafield MOX plant was built in 1996 and it was supposed to have a capacity of 120 tons of fabricated MOX a year, presumably using up about six tons plutonium per year to do this. It never produced more than 2.6 tons of MOX in any year. In the first four years it produced 2.6 tons of MOX. And now the U.K. is exporting some of the plutonium from the Sellafield MOX plant to France for fabrication at the Melox plant. I think the solution is in export. I think that countries should not have to solve their problems themselves, especially since, in this case, it has been done so incompetently in the Sellafield MOX plant and there is no indication that it will get any better.

My own solution to the waste problem also is to change the international rules so that there can be competitive commercial mined in geologic repositories. And the use of reprocessing in the Global Nuclear Energy Partnership does not significantly reduce the need for repository because the separated material needs to go underground also. To have Sizewell B, under the best of circumstances, licensed to use MOX, and use up only 6 % or 16 % of the total does not solve the problem. The problem has to be attacked by all of the light water reactors elsewhere or by the direct disposition as being pioneered at Livermore of glass vitrification or ceramic-ification of the plutonium oxide and direct disposal, which is going to cost money. You are right, you have a problem, you have identified the problem, there is no identified solution, but the world has to solve this problem and move on.

John Simpson : I agree completely.

Christopher Watson *(UK): I find myself in a slightly embarrassing position in this subject, because attentive readers of the Royal Society Report on this will discover that I was one of the reviewers of this report – that I did not contributed to it, and therefore I feel free to express my dissents to quite a lot of comments made in the report. First, and most important, related to timescales, and I think most of John's excellent report was concerned with dates. The crucial date relates to the lamentable performance of the Sellafield MOX plant and I think the report failed to emphasize sufficiently the scandalous nature of the failure to achieve the plant throughput. I think that is actually a total remediable situation provided that Great Britain is prepared to swallow some of its national pride and make use of the excellent technology which exists across the channel in France. And I think with a little bit of help from our French colleagues we could quite quickly get SMP up to its planned throughput. I think that ought to be absolutely top on our list of priorities, because if we can quickly get SMP up to its designed throughput, there is no reason why we should not address this problem converting it all to – and for heaven's sake – full specification MOX, not any half grade stuff. Having produced that, the second failure of the report is to recognize the international dimension of this activity, which is strange because Britain has been exporting and will continue to export MOX to places that are as far away as Japan. There is no difficulty, in principle, in exporting MOX; the problem is that the most obvious market for that MOX is France. And the report totally fails to recognize the*

willingness – maybe even enthusiasm – of France to receive MOX from any available source, because of the very large number of reactors on the continent which already burn that stuff. Therefore the inadequacies of the British nuclear reactor program are irrelevant. What matters is that within Europe and within perfectly terrorism-wise respectable countries there are lots of countries willing and able to burn MOX. So I see no obvious reason why we should not adopt that as our number 1 strategy.
Number 2 is that, if for some reason all that does not work, I can see no reason not to live with the spent fuel standard argument and to use artistic HLW, as it means I am creating the material in a suitable and sustainable standard form. Any terrorist who wants to get over plutonium would be out of his mind to try and reconstitute it from the spent fuel standard material and therefore that has to be a perfectly reasonable interim solution for the problem while we wait for those repositories to come along.

Christoph Pistner *(Germany): You did not really come up with an explanation for why the SMP is not really producing MOX at the moment, but could you perhaps give us an idea about when the SMP would really switch over to produce low spec MOX just as a disposition option, would you expect it to be able then to produce more MOX than it is producing at the moment? I mean, is the problem of low production rates specifically because of the high specification MOX you need for the reactor, or are other technical problems underlying there?*

John Simpson: The switch over date appears to be somewhere around 2023. But given the way these things work I think you have to allow some leeway aside on that. I am not sure that I can answer your question technically – I am not a scientist; I am a political scientist. I just take the information which is being offered to me. I do not know if you (Watson) can answer the question as to what the problems of the MOX plant are specifically. I am not sure that it will necessarily make a major difference in the throughput as to whether or not you are going in for low specification MOX or high specification MOX.

Christopher Watson*: Very quick on that. I am not myself an expert on MOX production, but my understanding is that Britain attempted to scale up a very small scale plant to a full production scale without thinking it through. There are a lot of silly design details where it got wrong – design details which our French colleagues did not get wrong, and therefore there is no difficulty in principle and I do not think it relates to the difference between the quality of the MOX, it is just a general poor standard design of a full production facility.*

Nuclear Renaissance: Its Expectations, Realities and Security Implications[1]

Tatsujiro Suzuki (Japan)

Because of increased energy security and climate change concern, there is an increasing expectation that nuclear power capacity worldwide will be doubled or tripled in the coming decades. This, so-called, "nuclear renaissance", and its expectation, has already had significant impacts on nuclear fuel markets and may encourage diffusion of sensitive nuclear fuel cycle technologies. On the other hand, there are many issues to be overcome if nuclear renaissance is to be realized. Therefore it is important to assess the realities of such expectations and those international implications. This paper will look at the expectations of "nuclear renaissance" and its realities and assess those international implications, with particular emphasis on the Asian perspective.

This paper will review recent trends in nuclear power development, especially in the Asian region, and identify key issues that need to be overcome if "nuclear renaissance" will be realized.

Nuclear Renaissance I: Need for Replacement Orders in Advanced Countries

At the end of 2007, there are 439 units of nuclear reactors (total capacity of 371.7GW) are operating in the world supplying roughly 16% of world total electricity generation. Its capacity has not grown much in the last 20 years. This paper will briefly look at the markets in the US and in Europe. As many of existing reactors will face the end of life in the coming decades, replacement orders will be needed not to increase dependency on fossil fuels and carbon emissions. According to the recent estimate by Schneider and Froggatt (2008), 262 units (208 GW) may have to be replaced between 2008 and 2025[2]. This will lead to a high expectation of "new reactor orders" in the advanced countries, such as in the US and Europe. Without such replacement orders, share of nuclear power generation will decline which is now considered not desirable for both energy security and reducing greenhouse gases.

Under the liberalized market, however, financial risk of ordering nuclear reactors needs to be overcome for private utility companies. The US introduced a series of new policy measures under the Energy Policy Act of 2005 to reduce financial risks associated with ordering new reactor orders in the US[3]. Thanks to these policy measures, now more than 30 reactors are planning to apply for licensing for new reactor construction. The UK government recently released a White Paper on Energy 2007[4] in which the government confirms the importance of keeping the nuclear energy option for the country. The White paper also suggests several policy measures to facilitate new orders, but no direct financial assistance is suggested.

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[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

[2] Mycle Schneider & Antony Froggatt, "World Nuclear Industry Status Report 2007," Commissioned by the Greens-EFA Group in the European Parliament, January 2008.

[3] Wall Street Utility Group, "The Energy Policy Act of 2005: The Implications for Nuclear Energy," September 2005. Published on Nuclear Energy Institute's website. http://www.nei.org/

[4] UK Department of Trade and Industry, "Meeting the Energy Challenge, White Paper on Energy 2007," http://www.dti.gov.uk/energy/whitepaper/page39534.html

Nuclear Renaissance II: Meeting High Energy Demand in Asia

China, India, Japan and South Korea have all committed to support major nuclear power expansion plans over the next two to three decades. While nuclear share of electricity could decline from 19% in 2001 to 12% in 2025 globally, developing countries will likely to increase nuclear electricity from 7% to 17%, according to the International Energy Agency (IEA)[5]. China, India, Japan, and South Korea would add around 45,000 MW of nuclear electricity generation capacity by 2025. 20,000 MW nuclear capacity came online since 2000 and mostly in Asia. So it is not surprising that those countries will plan to build such capacity in the next two decades or so.

Some ASEAN countries such as Vietnam and Indonesia have also expressed their interest to introduce nuclear power by 2020 or so. Australia recently also published a government report suggesting 25 reactors by 2050. For those who will try to introduce nuclear power, they need to build industrial and regulatory infrastructure, such as human resource, safety culture etc., to support growing nuclear power programs. For such countries, modular-type small reactors, such as the one under demonstration in South Africa, may be more fitting to their needs.

Issues to be overcome

In order to realize global resurgence of nuclear power, there are tow important issues to be overcome.

(1) Safety and Public confidence (improved decision making process)

Safety concerns remain one of the highest barriers for local communities to accept the sitting of nuclear power facilities, including waste storage or disposal facilities. For the long-term sustainable growth of nuclear power, it is essential to establish public confidence on nuclear safety. So-called "risk-based" safety regulation is one possible solution for an effective and transparent safety regulatory regime. Since the 1980s, the US Nuclear Regulatory Commission (NRC) has been working to establish such regulations, with well-established safety regulation by the private industry. "Risk-based regulation" means that safety regulation puts emphasis on the areas with higher probability of accidents (higher "risk"), and reduces regulatory requirements in less important areas. In order to implement such regulations, industry must prove which areas should be the focus, and thus transparency of plant safety has been increased. Such regulation also provides incentives to utilities to improve their performance. As a result, US nuclear power performance has improved significantly during since the 1990s.

But that is not good enough to gain public confidence. For example, public confidence could be easily eroded by non-technical incidents such as data falsification incidents, such as the ones in Japan and in UK. Once confidence is lost, it takes a long time to recover, and that will affect local decisions to accept new nuclear facilities - or even the continued performance of existing facilities. Especially after the recent major earthquake in Niigata, seismic safety concern needs to be carefully addressed, as many Asian nations are also facing major earthquake risks. Japan's lessons from the Kashiwazaki-Kariha nuclear power plants need to be shared among nuclear industry

[5] International Energy Agency (IEA), "World Energy Outlook 2006," http://www.worldenergyoutlook.org/2006.asp

worldwide in order to improve safety measures against severe earthquakes. Eventually, better social decision-making process may be needed to gain long-term public confidence in nuclear policy.

(2) Spent nuclear fuel and radioactive waste management

Unless spent fuel and radioactive waste management issues are resolved, the financial and political risks of nuclear power will never be resolved. There are two primary policy choices with regard to spent fuel management: one is the "Once-through" option which directly disposes of spent fuel to a repository, and the other is the "Recycling" option, which recovers uranium and plutonium from spent fuel, to be then recycled into reactors while the remainder of the spent fuel is disposed of as waste. While, in principle, these two options are mutually exclusive, in reality, both options are now merging. This is because "interim spent fuel storage" is an essential step to both options. Eventually, many nations may pursue a "mixed strategy", i.e. combination of "once-through" and "recycling" after long term "interim storage". In short, regardless of future policy choices, it is essential for all countries to secure interim storage capacity of spent fuel and waste. If spent fuel storage capacity is not secured, utilities may have to take reprocessing option which will lead to possible large stockpile of plutonium. This is exactly the case for Japan, which is now about to start large commercial reprocessing plant (800 tonsHM/y) in Rokkasho village, which may increase her plutonium stockpile of current 43 tons to more than 70 tons in 2012[6]. This has already caused serious international concern, especially among Asian neighboring countries. In order to avoid such accumulation of plutonium, securing storage capacity for spent fuel is essential.

For final disposal of nuclear waste, in addition to various technical options currently being considered, improved decision making process might be necessary to gain public confidence as described above.

International Implications: A Multilateral Response?

Finally, in order to have sustainable nuclear power growth, it is essential that such expansion of nuclear power will not lead to increased proliferation risk of nuclear weapons. The biggest proliferation risk comes from nuclear fuel cycle facilities, such as enrichment and reprocessing, which can produce weapons-usable material (WUM, i.e. highly enriched uranium [HEU] and plutonium). Expansion of nuclear power can naturally lead to proliferation of sensitive facilities and technologies.

In this context, there have been various proposals to have tighter control over nuclear fuel cycle activities since Mr. ElBaradei, Director General of the International Atomic Energy Agency (IAEA) proposed “multilateral approaches” to nuclear fuel cycle facilities. Those proposals include the following key components: 1) tighter control over WUM; 2) improving nuclear fuel supply assurance; 3) multilateral control over new fuel cycle facilities; 4) and proposals suggesting taking back spent nuclear fuel to supplier countries. In February 2006, the United States government announced the new Global Nuclear Energy Partnership (GNEP) in which new "partners" (advanced nuclear countries) will provide nuclear fuel supply guarantees to those countries which give up

[6] Tadahiro Katsuta, Tatsujiro Suzuki, "Japan's spent fuel and plutonium management challenges," International Panel on Fissile Material (IPFM) report # 2, September 2006. http://www.fissilematerials.org/ipfm/site_down/ipfmresearchreport02.pdf

having such nuclear fuel cycle facilities on their own. The GNEP also proposes to accept spent fuel and waste from those recipient countries and to develop advanced fuel recycling technologies. But the scope and the content of the GNEP have been changing and it has not made much progress yet. Russia also proposed International Nuclear Fuel Cycle Center (INFCC) which provides "complete fuel cycle service" and now is renamed as "Global Nuclear Power Infrastructure (GNPI)." It is similar concept to GNEP, and has expressed its close cooperation with IAEA. There are other proposals made by six enrichment suppliers, UK, Japan, Germany, etc. The common factor of these proposals is to use "fuel supply assurance" as a key incentive to give up nuclear fuel facilities. It seems that tighter control on sensitive facilities/technologies would be unavoidable.

However, similar proposals made in 1970s and 1990s have never been realized. What are the possible conditions for multilateral approach to be realized? I will argue the following three conditions.

Universality: Any new proposal which could lead to discrimination among countries who would like to pursue nuclear energy. If the proposal would divide countries into "have" and "have not", regarding nuclear fuel cycle technologies/facilities, strong opposition from countries who have not yet had nuclear fuel cycle technologies. Currently, only Japan, as a non-nuclear weapon state, has been allowed to have both enrichment and reprocessing facilities for civilian purposes. Naturally, other advanced nuclear countries like S. Korea feel "discriminated" since they have been "denied" to have such sensitive facilities of their own.

Or, on the contrary, such proposal may encourage nations to develop their own fuel cycle technologies/facilities. In fact, after the GNEP proposal, already at least six countries (Argentina, Iran, Australia, Canada, Kazakhstan, and Ukraine) have expressed their interests in pursuing enrichment technologies. Therefore, it is essential that multilateral approach should be based on a rule of "universality".

Complete transparency: If any country or a group of countries would like to develop nuclear fuel cycle facilities, it is essential that those facilities need to be under the international safeguards. Besides, it is desirable that any new facilities should share the highest level of transparency. Transparency can be achieved through many measures which can increase international confidence associated with those nuclear fuel cycle facilities. Complete transparency can also contribute to improved safety and security measures applied to those facilities.

Economic viability: Countries who would like to pursue nuclear fuel cycle facilities should assess their economic viability first. IAEA and/or IEA could help determine its economic viability in order to assess needs and rationale of the proposed facility or program. Without economic viability, such facilities could generate international concern about its motivation.

Those three conditions are necessary conditions but may not be sufficient for multilateral approach to be successful.

Conclusion

It seems that global interests in nuclear power will increase, due to higher energy prices and pressure from climate change problems. Especially in Asia, such pressures are high so that expectations of nuclear power growth may lead to rapid expansion of nuclear power in the region. But in order to realize such high expectations, there are four major issues to be overcome. They are: financial risk and competitiveness of nuclear power, safety and public confidence, spent fuel and radioactive waste management, and finally nuclear non-proliferations. It seems unavoidable that nuclear fuel cycle facilities will have to be under some "multilateral arrangement" in order to minimize proliferation risks associated with those facilities. It would be a good time for all countries in the Asian region to discuss the necessary conditions for such multilateral arrangement to succeed in the region.

Discussion of Tatsujiro Suzuki's Lecture

Richard Garwin *(USA): About two years ago, about one hundred American environmental organizations got together and approved dry cast storage of spent fuel reactors. Is that likely to happen in Japan as well? I noticed you said that there is a political problem and that it was approved at only one site.*

Tatsujiro Suzuki: It is still difficult to find a new dry cast storage site. But even if you find it, this will not become the alternative to reprocessing because the local committees impose the continuing reprocessing as a condition to accept dry cast storage, since this is the guarantee that the spent fuel will be removed after a certain period of time. So, it is a self-conflicting problem.

Richard Garwin*: Right. You should add to your three criteria: reality. I noticed that you quote the words that the U.S. would have a right to seek return of technologies and equipment. That means nothing. I mean, if it were intended to mean something, you'd say the U.S. has the right to return, not to seek return.*

Christopher Watson *(UK): I think in both of the last two papers, one feature discussion which has not been highlighted – which is important – is whether in the long run we want this plutonium anyhow. The British stockpile was accumulated on the premise that before too long we were going to move to a fast reactor-based program. Both Russia and Japan are talking as if that is seen as possibly a long-term planning, in which case having good sensible interim storage arrangements, be there in dry cast form or as plutonium stockpile, seems a perfectly sensible interim measure. Would you agree with that?*

Tatsujiro Suzuki: Yes, I agree. But there are two *momenta*. To the technical experts – the engineering committee - doing nothing is not the wise way of dealing with this problem. They want to do something about it. They are considering many options to come up with a different type of reprocessing, like UREX, or whatever it is that they have been proposing. But as Dr. Garwin said, that does not solve the fundamental problems. Then just leaving it like that is a better way of dealing with the problems, but the technical committee does not want to do that. And sometimes the public also sees a similar thing. If the government says: "oh, we do not have to do anything, just leave it like that", it looks very stupid. And if the government says: "ok, we will develop new technologies to deal with this problem", the public might say: "ok, we are making some efforts to do it". And that is the substantial problem we are dealing with right now. When we suggest dry cast storage as the best option, the public say that is lazy. That is the problem we have to solve: how are we going to convince the public and the local community that leaving as it is is the best option. It is very difficult.

Andrew Mack *(Canada): This is just a very quick point that goes to the issue of politics, which I think is one of the things which is incredibly important. About twenty years ago there was a huge debate in Australia about whether or not Australia ought to mine and export uranium. And at that time, there was a big conference being held, and the Secretary of the Labor Party was there and it was put to him that of all the countries in the world which would be ideal depositories for dry cast storage, Australia, which was politically stable, geologically stable, large and very empty, would be a great place to have it. In addition, there were various opportunities to make large amounts of money* *doing this at the same time. The response from the Secretary of the Labor Party was very interesting. He said: listen, at the moment, we have had an enormous political problem in digging up something and sending it away that is not dangerous; what you are suggesting is bringing something back which is very dangerous – or what is perceived as being very dangerous, and politically there is no way that it will work. And I think as always the politics of these things are often more important than the technical problems.*

Spurgeon Keeny *(USA): I'll just comment that we certainly understand the political dimensions of the storage in the case of Yuka Flats, which would appear to me as the ideal place in the United States, but where the local political force says: no way. So it is completely up in the air in the United States. And with regard to this Indian agreement, I will just note that we do not have the final word on that yet, and it still has to go through congressional review; and has to depend on IAEA agreement; and it also has to get the agreement of the Nuclear Suppliers Group. So I think it is by no means certain whether that really will go forward. Personally I think that it would be no loss if it does not go forward.*

A Quantitative View on Verification of Arms Control and Disarmament Treaties

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Abstract

The problem of optimizing efficiency and effectiveness of the verification of arms control and disarmament treaties is discussed from the point of view of systems analysis. The term "optimization" implies a quantifiable formulation of verification objectives and it is argued that non-cooperative game theory offers an appropriate framework for such a formulation. Examples supporting this thesis are given both in the context of the original Non-Proliferation Treaty (NPT) verification regime and with reference to extended Safeguards under the new NPT verification protocol.

1 Why quantitative analyses?

Verification has become a crucial issue in international negotiations on Arms Control and Disarmament treaties: Whereas in earlier years the opinion was held that agreement on principles should first be found, and that thereafter the details of verification could be worked out, today verification is taken into account from the very beginning, as for example the Chemical Weapons Convention negotiations demonstrated (see, e.g., Avenhaus et al (2006)).

Formally the problem of verification may be described as follows: The inspected party, in this case a sovereign State, may have some incentive to violate its commitments deliberately and in a clandestine way, a possibility that necessitates the regime's verification measures. The Inspectorate, acting on behalf of a community of participating States, e.g. the United Nations, will wish to deter such illegal activity and, should that illegal activity nevertheless take place, detect it with the highest possible probability and speed. The potential violator knows that, by virtue of the inspection regime, a violation brings with it the risk of detection and may incur punishment in the form of sanctions or even military intervention. Therefore, if a State chooses illegal behaviour, it will wish to avoid detection with the highest possible probability, or at least delay it for as long as possible.

It is because the preferences and strategic alternatives of the protagonists may be stereotyped in this way that routine inspection activities can, in principle at least, be treated quantitatively. Indeed, they must be treated this way, since routine inspection activities involve inspection efforts and sampling costs whose sizes have to be justified in a rational way. In fact, it is possible to calculate and optimise the effectiveness of inspections and to quantify the idea of deterrence. The underlying concept is that of non-cooperative game theory together with its "solution", the so-called *Nash equilibrium* (Nash (1951)). This concept was formulated by the American Nobel laureate John Nash in the early 1950s. It proposes that protagonists in a conflict situation will choose their strategies so that neither has an incentive to deviate unilaterally from his or her choice. This deceptively simple definition is the foundation of the theory and is recognised as a necessary condition for rational behaviour.

Of course one might object that verification regimes are largely cooperative in nature, serving to bolster mutual international trust through voluntary submission to external scrutiny. But non-cooperative game theory, despite its name, by no means excludes cooperative behaviour. For example in the famous *prisoners' dilemma* (e.g., Myerson (1997)) there exists a mutually preferable, cooperative alternative, which however, because it violates Nash's rationality condition, is not acceptable. In a "verification game", on the other hand, one quite generally observes the situation in which the Inspectorate carries out some inspection plan and the State, acting upon its own best interests, behaves legally. This cooperative behaviour may be reached even if the State has some real incentive not to cooperate, and if it is, we have a suitable definition of deterrence: a Nash equilibrium in an inspection regime in which the State's equilibrium strategy is to behave legally.

2 Non-Proliferation Treaty-Verification

In the framework of verifying the peaceful use of nuclear energy, i.e. under the Nuclear Non-Proliferation Treaty, this sort of quantitative analysis has been used only at a rather technical level. It has been applied for instance to derive optimal inspection sampling plans at specific facilities for given reference periods and hypothetical violation scenarios. It has not yet been applied to optimize the distribution of inspections on different facilities within one State for given reference periods and total inspection effort for that State. One reason for this hesitance may be that game theory has a reputation for mathematical abstruseness and limited practical applicability. This reputation is ill-deserved, as we would like to demonstrate subsequently.

There was, however, another, more important hindrance to the use of game-theoretical optimization: According to the original Verification Model Agreement (IAEA (1972)) the verification effort to be spent in the single States was determined on the basis of the State's peaceful nuclear fuel cycle size. This led to a situation where more than 80% of the IAEA's inspection resources were spent in the three States Canada, Germany and Japan, which were never suspected to clandestinely acquire nuclear weapons. At that time no one was happy with the situation, but at the same time no one wanted to tackle the problem of evaluating States' incentives in order to change such an undesirable inspection effort distribution. Carl Bennett, one of the fathers of safeguard systems analysis, summed things up by saying "they are looking for a technical solution of a political problem".

The Additional Protocol (IAEA (1997)), the model for which was agreed upon by the Board of Governors of the International Atomic Energy Agency (IAEA) in May 1997, seeks to introduce new subjective elements into the nuclear safeguards regime, a regime which had hitherto been founded on the quantitative principle of material accountancy. Some of these elements have been the subject of considerable controversy ever since. The objective was to strengthen safeguards following the failure to detect Iraq's illicit nuclear weapons programme. At several occasions the claim was made that any attempt to quantify the effect of the new measures within the overall IAEA safeguards verification regime would be pointless and should be avoided. But at the same time, there seemed to be very general consensus that the additional measures would serve to improve the effectiveness and efficiency of safeguards. For a systems analyst this was an absurd State of affairs: claiming improvement or optimisation while at the same time denying the need for a measurable objective is obviously self-contradictory. This confusion actually contributed to the long, difficult and at times cross-purposeful discussions that characterised the debate between IAEA member States and the Agency over the Additional Protocol.

One important example for the above mentioned problems is the possibility of false accusations. These can never be avoided in detection systems based on variable sampling procedures, nor can they easily be clarified, and they may lead to serious consequences in a political environment. In general, the detection probability of variable sampling procedures is a monotonically increasing function of the false alarm probability. Thus it might happen that, in the interest of a higher detection probability, more an more tests are performed while the increasing false alarm probability is ignored.

Let us illustrate this with a very simple example. Consider n tests, each with non-detection probability β and false alarm probability α. Then, given the independence of data, the total detection and false alarm probabilities $1 - \beta_{total}$ and α_{total} are

$$1 - \beta_{total} = 1 - \beta^n \qquad \text{and} \qquad \alpha_{total} = 1 - (1 - \alpha)^n \, .$$

For $\alpha = \beta = 0.05$ (as usually and formally required) and $n = 2$ we get

$$1 - \beta_{total} = 0.9975 \qquad \text{and} \qquad \alpha_{total} = 0.0975 \, ,$$

i.e., the performance of two tests instead of one test increases the detection probability from 0.95 to 0.9975, but the false alarm probability becomes twice as high.

It should also be mentioned that more sophisticated examples demonstrate convincingly that in general it is not true that a detection system performs the better, the more information is collected. For example, in case of the establishment of a nuclear material balance in a facility for some reference time, intermediate physical inventories worsen the overall detection probability of diverted material. They may however decrease the detection time (see, e.g., Avenhaus and Canty (1996), p. 166 ff). One verification objective can only be improved at the expense of the other.

3 Inducing legal behaviour: One State

The reluctance to define one's terms is not new, in fact it lurked within the old nuclear verification system. It can be illustrated by the paradigmatic example of a storage facility consisting of N sealed items of nuclear material. Suppose a subset of n sealed items on inventory is checked by the Inspectorate. If the number r of broken seals is much smaller than the total number N of seals, then the probability of detecting at least one broken seal $1 - \beta$ is given approximately by

$$1 - \beta \approx 1 - \left(1 - \frac{n}{N}\right)^r \, . \tag{1}$$

The number r of broken seals represents the so-called significant quantity of the verification objective (see, e.g., Avenhaus and Canty (1996), p. 17 ff); of course its actual value is not known to the inspector, rather it is that amount of falsification which is significant in the spirit of the NPT. But just how large should the subset be for effective and efficient safeguards? Traditionally, one solves the problem by allowing the inspector to work for a given amount of time. If the time needed to check one seal is known, then the number of seals he can check is also known. His *effectiveness*, expressed as the probability of detecting illegal activity, is then a function of purely technical quantities - the size of the inventory, the inspection time per item and total time available. But is this *efficient*? Is the inspector wasting some of his time, or should he be investing more of it? "How much is enough?" as the American verification theorist Allan Krass asked many years ago (Krass (1985)).

The answer is that the Inspectorate should invest that amount of verification effort which will deter the State, through the risk of timely detection, from illegally breaking a seal, no more and no less. But herein lies a difficulty: in order to treat the question of deterrence, we are forced to introduce the subjective aspects associated with perceived risk, namely the preferences of the inspected party for legal versus illegal behaviour. If we do so, formal methods will help us come to a common understanding. It is argued by many, however, that an international verification organisation like the IAEA has no business doing this sort of political analysis. Instead, the point of view is taken that the detection capability is an external variable that must be determined bureaucratically. Typically, some ad hoc measure, such as X percent detection probability for violation strategy Y, is specified which determines the overall inspection effort required for its achievement. This of course begs all questions regarding efficiency, and any further treatment of the matter is sterile.

An alternative is to try to arrive at a genuine quantification of the problem, and we will now show how it can be done. Let the utilities - which in the jargon of game theory reflect the preferences of the State - be ordered as follows: a negative value $-b < 0$ for detected illegal behaviour (the perceived likely sanctions), zero for legal behaviour, and a positive value $+d > 0$ for undetected illegal behaviour (the incentive, whatever that might be, to violate the agreement). The latter value may be arbitrarily small, but should never be exactly zero. This would be tantamount to saying that the inspection regime is superfluous, in contradiction of the international consensus that there is a genuine risk of clandestine violations. The normalisation to zero for legal behaviour is convenient and thoroughly consistent with the meaning of utility. Let furthermore be $1-\beta$ the probability of detecting an illegal action. Then the State's expected utility, if it decides to behave illegally, is

$$-b \cdot (1-\beta) + d \cdot \beta \,,$$

and the potential violator will clearly be inclined to behave legally if it perceives this expected utility to be less than zero,

$$-b \cdot (1-\beta) + d \cdot \beta < 0$$

or, equivalently,

$$1-\beta > \frac{1}{1+\frac{b}{d}} \,. \tag{2}$$

Thus we get a condition for the probability of detection required for deterrence and, in turn with (1), a condition for the time which an inspector has to spend in the facility in order to check n seals,

$$n \approx N \cdot \left(1 - \left(1 + \frac{d}{b}\right)^{-1/r}\right) .$$

It turns out that the larger the ratio of perceived sanctions to perceived benefits of illegal behaviour, the smaller is the amount of effort that should be invested by the Inspectorate to achieve its goal, perfectly understandable from the common sense point of view.

So far IAEA analysts have hesitated to consider the explicit use of subjective parameters for the design and planning of its routine inspections measures. Rather it has preferred simply to impose criteria that require necessary non-detection probabilities β, typically, $\beta < 0.05$. Using inequality (2) implies that such a requirement is tantamount to saying that $d/b > 19$ independent of the State under consideration. The State's incentive to misbehave is about 20 times larger than its own perception of the consequences of detection. While this might be true for some situations, it is certainly not a reasonable - nor efficient - assumption to made in general.

As already mentioned, this way of looking at things has been criticized on the grounds that it is impossible, or worse, impolitic, to estimate utilities of parties to a treaty. But all we have really done is to relate, via the condition for legal behaviour, a technical result (which connects the probability of detection with the time the inspector has to spend in the facility) to the reality of the situation to which it is being applied. If, for example, a State's incentive to break a seal is known to be much smaller than its perceived consequences of detection, a good inspection plan would be to make the inspection time very small. Then, just a single token seal check would be both efficient and effective. If, on the other hand, the utilities are indeed inaccessible, or even taboo, then at least we know why we cannot define effective and efficient verification and that the subject should best be dropped. In either case quantification has helped us.

4 Inducing legal behaviour: Two States

Let us consider now two States. Since we assume that a given inspection effort has to be spent for these two States, game theoretical methods - instead of purely decision theoretical ones in the case of just one State - have to be used in order to determine the optimal inspection strategy.

Returning to the new Protocol: In the additional verification measures, it is even explicitly stated that qualitative elements like the motivation of States are to be taken into account. What can this be if not a recognition of the fact that different States may have different motivations? The sort of analysis just undertaken should therefore be all the more relevant. Thus if we extend the previous paradigm to two States each possessing one storage facility, these motivations are expressed by different utilities for each State. We will show, that a formal analysis provides, under reasonable assumptions, a condition for legal behaviour of both States which generalises the considerations in section 3 (see Avenhaus and Canty (1996), p. 139 ff).

Let the utilities introduced above for the two States be b_i and d_i, those of the inspection authority for the corresponding cases be $-a_i < 0$ and $-c_i < 0$, and the detection probabilities $1 - \beta_i$ $(i = 1, 2)$. Let us assume, furthermore, that just one State can be inspected and that the i-th State is inspected with the probability p_i $(i = 1, 2)$, $p_1 + p_2 = 1$, and that the i-the State behaves illegally with probability $q_i (i = 1, 2)$. Then the expected payoffs to the three parties inspection authority, first and second State, are

$$
\begin{aligned}
I_0((p_1, p_2), q_1, q_2) &= \sum_{i=1}^{2} [\,(-a_i \cdot (1-\beta_i) - c_i \cdot \beta_i) \cdot p_i - c_i \cdot (1-p_i)\,] \cdot q_i \\
I_1((p_1, p_2), q_1) &= [\,(-b_1 \cdot (1-\beta_1) + d_1 \cdot \beta_1) \cdot p_1 + d_1 \cdot (1-p_1)\,] \cdot q_1 \\
I_2((p_1, p_2), q_2) &= [\,(-b_2 \cdot (1-\beta_2) + d_2 \cdot \beta_2) \cdot p_2 + d_2 \cdot (1-p_2)\,] \cdot q_2 \,.
\end{aligned}
$$

Then the Nash equilibrium $((p_1^*, p_2^*), q_1^*, q_2^*)$ which - as already mentioned - is defined as a strategy combination with the property that any unilateral deviation does not improve the deviator's payoff, is given by the inequalities

$$I_0((p_1^*, p_2^*), q_1^*, q_2^*) \geq I((p_1, p_2), q_1^*, q_2^*) \quad \text{for all} \quad p_1, p_2 \in [0, 1]$$

and

$$I_i((p_1^*, p_2^*), q_i^*) \geq I_i((p_1^*, p_2^*), q_i) \quad \text{for all} \quad q_i \in [0, 1] \quad \text{and} \quad i = 1, 2 \,. \tag{3}$$

In case of legal behaviour, i.e., $q_1^* = q_2^* = 0$, both States' payoffs are zero, i.e., $I_i((p_1^*, p_2^*), q_i^*) = 0$ for $i = 1, 2$, therefore we get from (3)

$$0 \geq [\,(-b_i \cdot (1-\beta_i) + d_i \cdot \beta_i) \cdot p_i^* + d_i \cdot (1-p_i^*)\,] \cdot q_i \quad \text{for} \quad i = 1, 2 \,,$$

which leads to the (not unique) equilibrium inspection probabilities

$$1 \geq p_i^* \geq \frac{1}{1-\beta_i} \cdot \frac{d_i}{b_i + d_i} \quad \text{for} \quad i = 1, 2 \,.$$

Because of $p_1 + p_2 = 1$ a necessary condition (but not sufficient) for legal behaviour is

$$1 \geq \frac{1}{1-\beta_1} \cdot \frac{d_1}{b_1 + d_1} + \frac{1}{1-\beta_2} \cdot \frac{d_2}{b_2 + d_2} \,,$$

which is a generalization of (2).

But now, the required detection probabilities (and hence inspection efforts) for each State are inextricably bound up with both States' utilities! The bureaucratic solution is all the more arbitrary. The inclusion of subjective preferences thus seems unavoidable: There is no purely technical solution to a political problem! It should be mentioned that in addition to the technical capabilities of the inspection authority, expressed by the detection probabilities, and the political incentives of the States, expressed by the utilities, also the technical capabilities of the States to acquire nuclear weapons, can and have to be taken into account.

5 Concluding Remarks

There are, roughly speaking, two types of applications of formal methods which are relevant to the context of verification of international arms control and disarmament and environmental treaties. These might be called operational and conceptual. The first of these involves solving the technical problem of implementing inspections given constraints of time and/or manpower. If, for example, an inspector has a given time at his disposal for some facility in a calendar year, then optimal inspection procedures during one visit, or optimal distributions of inspection visits over time, can be determined (see Diamond (1982)). Moreover, the best statistical evaluation techniques can be derived whenever actual measurements are performed and statistical errors (for example false alarms) cannot be avoided. Here, subjective preferences of inspected parties need not be taken into account explicitly.

The conceptual type of application deals with the analysis of the constraints themselves, as pointed out above. Now the questions to be addressed are: How much time can an inspector spend for a major verification task? How should the overall manpower and budget of a verification authority be distributed between States with different motivations? And finally, to repeat the all important question, how much verification is enough? Here, necessarily, one must resort to utility functions which express the preferences of the parties involved. Even if they cannot be estimated numerically, the analysis of their interrelationships and their influence on the efficiency and effectiveness of verification measures is indispensable for understanding what verification really means.

Of course it is difficult to get diplomats and politicians interested in the type of thinking just outlined. Howard Raiffa, the former Director of the International Institute for Applied Systems Analysis (IIASA) in Laxenburg near Vienna, has described the general problem many times and very convincingly. We can only repeat his plea for our case, namely that both parties, practitioners and analysts, approach each other in the interest of really solving the vital problems of verification (Raiffa (1991)).

6 Literature

Avenhaus, R., Kyriakopoulos, N., Richard, M. and Stein, G. (Eds) (2006). *Verifying Treaty Compliance - Limiting Weapons of Mass Destruction and Monitoring Kyoto Protocol Provisions* (Springer Verlag, Berlin and Heidelberg).

Nash, J. F. (1951). Non-cooperative Games, *Annals of Mathematics* 54, 286-295.

Myerson, R. B. (1997). *Game Theory - Analysis of Conflict* (Harvard University Press, Cambridge, MA, third Printing).

IAEA (1972). The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-proliferation of Nuclear Weapons, INFCIRC/153 (corrected) (IAEA, Vienna).

IAEA (1997). Model Protocol Additional to the Agreement(s) between the State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (corrected) (IAEA, Vienna).

Avenhaus, R. and Canty, M. J. (1996). *Compliance Quantified - An introduction to data verification* (Cambridge University Press, Cambridge).

Krass, A. S. (1985). *Verification: How Much is enough?* (Taylor and Francis, London and Philadelphia).

Diamond, H. (1982). Minimax Policies for Unobservable Inspections, *Mathematics of Operations Research* 7, No. 1, 139-153.

Raiffa, H. (1991). Contributions of system analysis to international negotiation, in *International Negotiations - Analysis, Approaches, Issues*, ed. V. Kremenyuk (Jossey Bass Publishers, San Francisco).

Discussion of Thomas Krieger's Lecture

***Richard Garwin** (USA): I found this very interesting. If you give up your very nice separation with 1-β > 1/1 + b/d for the single state and you divide both sides by 1-β, you have something which is not separated but is in precisely the same form, so call that φ; and φ1 for one state is less than 1 is your criterion, and for two states φ1 + φ2 is less than 1. So just a trivial modification, but it extends the single state solution to the two states. On the lower right there, divide by 1-β, so that formula is 1/1-β x 1/1+b/d < 1, call that φ1. So φ1 + φ2 < 1. Precisely the same result. But you say that the IAEA has not been acting rationally.*

Rudolf Avenhaus: We do not say it this way. But let me repeat, as Mr. Krieger said, the procedure was always to postulate values for the detection probability 1-β, including false alarm probabilities for variable sampling. And this was just, let me say, statistical tradition: if you do tests or so, you use α=β=0.01 or 0.05 and this was done. But this is not adjusted to the situation where you have adversaries, therefore we said implicitly, as on the right hand side of the formula mentioned by Dr. Garwin, the IAEA made assumptions about it. So if d/b is 20, then it would be rational. But they did not say that. What our message is, is that if you have more than one state with different interests you cannot do it this way anymore. In fact, the Additional Protocol gives room to such extended considerations. But is has not been done explicitly so far.

***Christopher Watson** (UK): Thank you for the very interesting paper. My problem with it is how you determine the parameters b and d. The cost of detection is comparatively readily quantifiable; but the benefits, which so often are being political benefits, I thought were normally unquantifiable. So how do you arrive at that figure?*

Thomas Krieger: That is a good question. Actually, what we do in order to make such a quantitative analysis possible, is that we simply have to assume that both the gain and the cost of being detected can be measured in the same units. We need this to make a quantitative model. It is a problem.

***Christoph Pistner** (Germany): Obviously the outcome of your analysis is clearly that for an efficient verification system you need a state specific approach. But, if I got you right, one of your major conclusions was that, for the political system to be effective, we would probably need some universal system, which would mean that we have to treat all the states equally. There seems to be some contradiction to getting an effective verification system if at the same time we want to have a universal political system. Could you elaborate on this a little bit?*

Rudolf Avenhaus: You see, this is precisely the problem we were dealing with. In the beginning, in the original model agreement in 1972 or so, it was the idea that all states were considered equal. This was explicitly stated. The problem was already seen there. This led to the unsatisfactory situation mentioned: the three states Canada, Japan and Germany consumed 80 % of the total available verification effort. This is just an analysis of the problem. I cannot say more about it.

***Martin Kalinowski** (Germany): I think that this is a very interesting analysis and I understand that one of the motivations to undertake it is to make the safeguards systems more efficient, in particular with countries that are not under suspicion and are not* *under inspection as much as countries that are under suspicion. But as a first guess, though quantifying d and b is very difficult, I think that as a first approximation the ratio of d to b is the same for countries that are not suspected of violating the treaty as for countries that are suspected. For a country like Germany, to build a nuclear weapon or to divert some of the plutonium would not mean much gain, and also the punishment would not be so hard. So neither d nor b would be big. But for countries like Iran or North Korea, or countries that tend to be suspected of not complying with the treaty, the cost would be high and at the same time the gain would be high. The ratio is the same. How can you treat this? What does not get into this consideration that I just made is the size of the nuclear program. If a country has a lot of nuclear activities that are under inspection, then the costs for the inspections are high. And if a country that has almost nothing under inspection and has maybe a hidden trail program and is a proliferating country, the costs for the inspection are low, but the risk for the inspectorate is high.*

Rudolf Avenhaus: Your last comment is clear. This is a very simple model and you can extend it to more states and to states with more facilities and so on, then things get more complicated, but one knows how to do it. It is a technical problem. But the problem of the estimation of the ratio b/d for different states with different motivations remains, and there is no easy answer to it. Of course we thought about how it could be done and probably the best thing is to have a kind of, let me say, engineering approach. You do not think about the figures as such, but you take the total available effort and you see what can be achieved and how you can distribute it, and it makes sense in a general way. You do not consider the ratios in an isolated way because then you get nowhere and you never have some kind of certainty. A kind of engineering approach, where you play with technical and political parameters simultaneously, seems to be the best thing.

Christoph Pistner: *Just one more technical question to understand your model. Do I get it right that you are assuming within this model that the whole inspection effort is fixed? So you are saying that you have a total time for inspections, and you have to divide it between the countries. So you are not saying that one state has one reactor and we have a total inspection time for this state; and another state has two reactors, so we would have double the inspection rate for it. That means that part of your problem comes out of the assumption that you have a given total inspection time that you want to divide between the different countries, right?*

Thomas Krieger: Right in the sense that the *expected* effort in all countries is positive. But there are other models where the inspection effort is distributed on different countries in a deterministic way.

Fifth Session - Safe Fuel Supply for Civilian Nuclear Power Stations and the Risk of Nuclear Proliferation II

Chair: Henri Korn

Proliferation Concerns Connected With Nuclear Fuel Cycle Developments[1]

Boris F. Myasoedov, Yuri K. Shiyan, Ivan G. Tananaev (Russia)

In connection with the growth of cost on hydrocarbon source of energy (gas, mineral oil, coal), a great interest in development of world nuclear energy is being enlarged, called now as a "Nuclear Renaissance". Many countries that do not have nuclear power plants (NPPs) are considering building one and many nations that already operate one or more NPPs are considering adding more NPPs and expanding their nuclear facilities with fuel fabrication and uranium enrichment.

Energy demand in Russia is expected to increase by 1.5 times up to 2016 as compared to that in 2006, and to double by 2020. The strategy for nuclear power engineering development in the first half of the 21st century is based on the following principles: nuclear fuel breeding, comprehensive safety and competitiveness.

At present, 31 power units operate at 10 NPPs in Russia. According to the National Program approved in Russia started from 2007, at least two nuclear power units of 2 GW total capacity are to be built annually. As a result, by 2015 10 new power units will be put into operation of 9.8 GW total installed capacity. It will lead to the growth of NPPs share in the total volume of generated electric power up to 18.6%. After 2015 3-4 power units are planned to be built annually.

The potential large expansion of nuclear power evokes growing proliferation concerns in terms of the potential capability to manufacture nuclear weapons. The same technologies that are needed to enrich uranium so that to fabricate reactor fuel and to separate plutonium from spent fuel to be used in mixed oxide reactor fuel (MOX) can be used to produce the fissile material needed for nuclear weapons.

Russia proposed new conceptions for solving the problem of proliferation due to potential manufacture of nuclear weapons which are discussed in the current article.

International Uranium Enrichment Center (IUEC)

The interest in nuclear energy development is growing worldwide and this trend exacerbates a problem of NPPs assured supply with nuclear fuel. Creation of nuclear facilities for uranium enrichment, and reprocessing of nuclear spent fuel in some countries, which haven`t had these technologies, enhances risks of nuclear weapons proliferation.

[1] This paper was submitted by the authors for the conference records. The information and subject may differ from the audio content.

Creation of international system of assured nuclear fuel supply for NPPs countries, which in good faith meet requirements of the Nonproliferation Treaty (NPT) promotes reduction of these risks.

Over the past years some initiatives on strengthening of nuclear non-proliferation regime have been put forward, for example, the initiative of Russian Federation President Vladimir Putin (St-Petersbourg Summit of January 25, 2006), where he stated: "The key element of this infrastructure should be creation of system of international centers for providing nuclear fuel cycle services including enrichment under the IAEA control".

The goals of the initiative are as follows:

- enhancement of a role of nuclear power sector to ensure global energy security;
- development of global nuclear energy infrastructure through creation of a network of international nuclear fuel cycle centers;
- granting of nondiscriminatory and guaranteed access to production and service of nuclear fuel cycle for countries, which develop the nuclear energy production.

The international legal basis of IUEC:

- Declaration by ROSATOM at the 50th Session of the IAEA General Conference on IUEC establishment at the "Angarsk Electrolysis Chemical Complex (AECC)" site in September 2006;
- Verdict by Kazakhstan Republic on joining the IUEC Russian initiative in October 2006;
- Verbal Note of the Russian Ministry of Foreign Affairs to IAEA of January 2007 with request to include the AECC in the list of the Russian facilities under IAEA safeguards;
- Approval of the Russian Federal Low № 13-FZ in February 2007 which enables to set up a holding company in the nuclear sector of Russia (OAO "Atomenergoprom" is 100% state-owned company), and to protect the rights of ownership of legal entities in nuclear materials, equipment and storage facilities;
- Intergovernmental Agreement between the Russian Federation and the Kazakhstan Republic of August 2007 on the IUEC establishment;
- Registration of IUEC as a legal entity in September 2007; registration of the IUEC shares issue in November 2007;
- Decision of the Government of Armenian Republic about involvement of the "Armenian Nuclear Electric Power Station" in the IUEC activities in November 2007;
- Registration of the IUEC Moscow branch in December 2007;
- The Russian Federation Government Resolution about including the IUEC in the list of the Russian nuclear fuel cycle facilities under the IAEA safeguards within the framework of the Agreement INFCIRC/327 in Russian Federation in December 2007.

The main documents that regulate the IUEC creation are: the Intergovernmental Agreement between the Russian Federation and the Kazakhstan Republic on the IUEC creation which came in to force in August 2007. This Agreement was signed by the Head of ROSATOM S.V. Kirienko and the Minister of Energy Natural Resources B.S. Izmukhambetov in the presence of the Presidents V.V. Putin and N.A. Nazarbaev on May 10, 2007 in Astana. During the IUEC Constituent Assembly the agreement between the OAO "TENEX" and the AO "NAK "Kazatomprom" was signed about the IUEC creation.

The intergovernmental agreement between the Government of Russian Federation and the Kazakhstan Republic on creation of the IUEC determined:

- the main goals and conditions of the IUEC activities;
- the executive bodies and authorized organizations;
- a form of establishment and IUEC location;
- the main requirements for countries-participants, which organizations could be IUEC shareholder (observance of nonproliferation obligations);
- prohibition of IUEC participants access to Russian enrichment technologies;
- application of IAEA safeguards to IUEC nuclear materials.

The first stage of the IUEC development was the formation of this organization according the agreement between the OAO "TENEX" and the AO "NAK "Kazatomprom" (06.08.2007). The primary distribution of shares was the following: the OAO "TENEX" – 90%, and the AO "NAK "Kazatomprom" – 10%. The IUEC signs agreements on fabrication of enriched uranium products with the AECC. The nuclear materials produced by the IUEC should be under the IAEA safeguards.

The second stage of the IUEC establishment provides for the reform of nuclear sector:

- creation of the "Atomenergoprom";
- restructuring of state-owned facilities into share-holding companies;
- establishment of IUEC nuclear material stockpiles to ensure their guaranteed supplies.

The third stage of IUEC establishment provides for:

- joining the IUEC by organizations of countries concerned on the basis of separate intergovernmental agreements. The IUEC is open for all countries which are IAEA members, observe nonproliferation regime requirements and share the goals and objectives of these organizations.
- redistribution of shares in the IUEC nominal capital.

Leasing of fuel materials

The Russian legislation is modified now for procurement of a mechanism for nuclear fuel leasing. At present nuclear fuel produced in Russia and used in foreign nuclear reactors could be returned back for long-term storage, reprocessing or disposal without back-off of radioactive waste and materials.

Leasing of transferable NPPs

Projects of modular Nuclear Power Plants (NPPs) with low power are being developed in Russia. These NPPs could operate during long time (up to 10 years) without a fuel handling. Metric and mass of transferable reactor units allows their transportation as a ready mode on a river and marine boats, or railway vehicles. Interest grows in Russia for energy generation by nuclear power plant of low capacity (<300 MW): high demand in self-contained power supply of the extracting enterprises and population in the remote areas of the country; the big conceptual decisions groundwork for small NPPs made in 60-80 years of the last century; revival in development of atomic engineering within the accepted Federal Program (see table 1, and fig.1, and 2).

Table 1
The most perspective projects of Small NPP

Small NPP	**Power capacity**			**Refuelling interval, years**	**Fuel enrichment, %**
	Electricity, MW	**Cogeneration**			
		Electricity, MW	**Heat, Gcal/h**		
ABV-6	2x8.5	2x6	2x12	12	19.5
SVBR-10	2x12	2x6	2x25	12	18.7
Uniterm	2x6.6	2x2.5	2x17.2	25	19.5
KLT-40C	2x38.5	2x19.5	2x73	3	17.4
Ruta	-	-	60.2	3	3
VVER-300	300	220	450	2	3.3
VBER-300	2x340	2x215	2x460	1.5	19.5
VK-300	-	250	400	2	4
SVBR-100	4x101.5	4x95	4x130	8	16.5

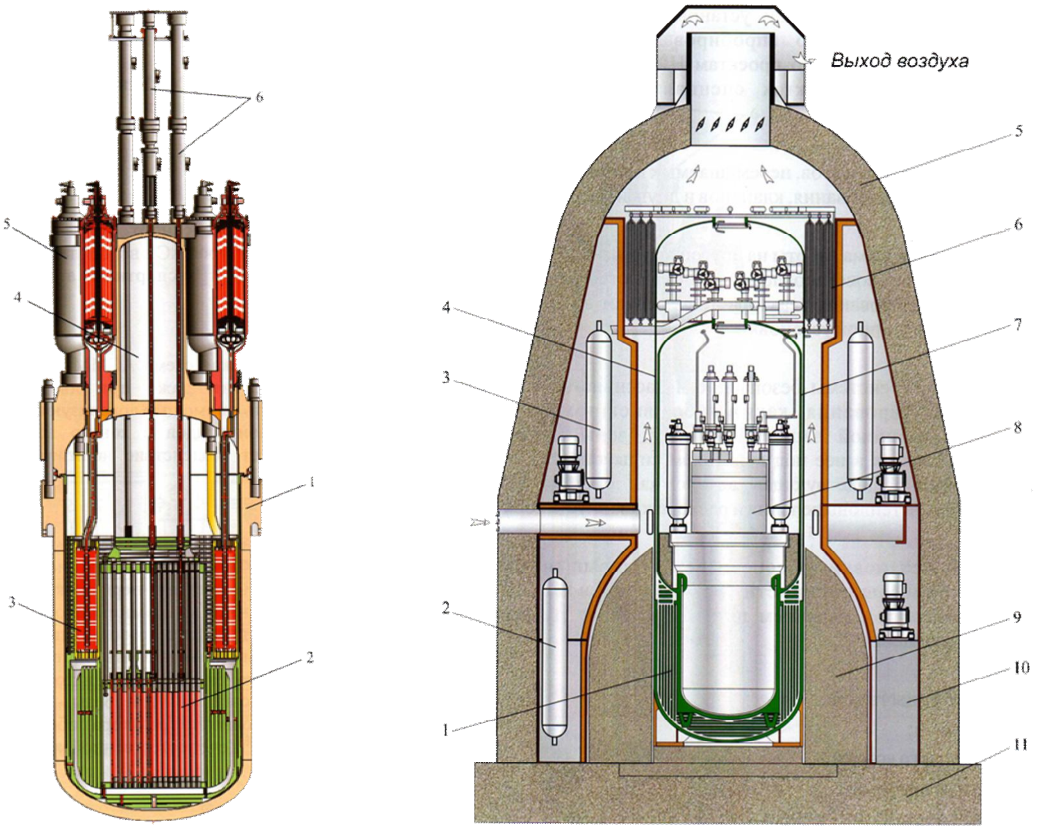

Fig. 1. Small NPP Uniterms

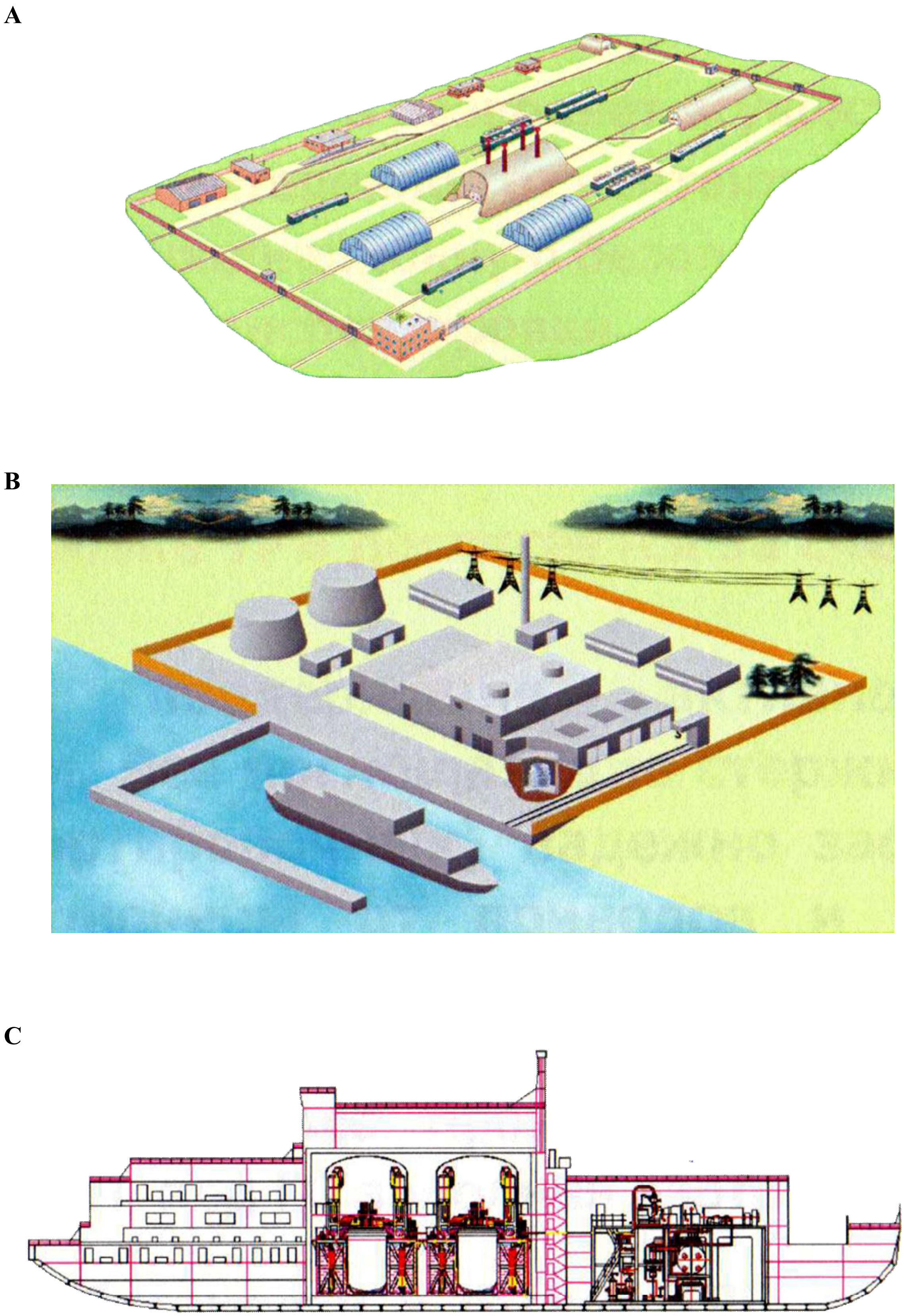

Fig. 2. Small-size NPP site variants: A.- land NPP; B.- Coastal NPP; C.- floating NPP

Modular small-size NPPs in integrated style provide high fuel cycle protection against proliferation. Problems of small-size NPPs physical protection are as follows:

- high charges for guard personnel and engineered safety features;
- special hardware development to provide remote control of protective barriers with space systems use;
- development of special accountability and control systems for nuclear materials in small NPP fuel cycle.

Problems of technical support of nuclear fuel cycle are as follows:

- technologies for transportation of the integrated reactor, SNF;
- necessity to double energy capacities for the period of integrated reactor (core) replacement.
- Russia suggests to use small capacity modular NPPs for the countries which do not plan to develop own fuel cycle. However, some new problems with physical protection and transportation must be solved.

Closed fuel cycle including pyrochemical processes and new reactor development

Russia has a unique experience of development and operation of NPP power units with fast neutron reactors (20-year successful operation of the BN-350 power unit and operating BN-600 unit 3 at Beloyarsk NPP).

The basic approaches to spent fuel (SF) reprocessing include:

- materials needed for utilization (reprocessing only in case of the use of materials in fuel cycle; excluding recovery of basic fissile components for stockpiles);
- partitioning and recycling instead reprocessing (all components must be introduced in closed fuel cycle; technologies flexibility and modules principle; minimization of wastes (and storage and disposal costs); and nonproliferation (inherent barriers).

Key technologies of the Fast Reactor closed fuel cycle with MOX fuel:

- Pyroelectrochemical reprocessing (recycling through molten salt);
- Vibropacking technology (crystalline particles with getter);
- Remote controlled automated technologies for fuel pins and fuel assembly manufacturing.

The Research Institute on Atomic Reactors – RIAR (Dimitrovgrad) is a center of non-aqueous methods development (see fig. 3).

The main steps in development of pyrochemical processes are as follows:

- pyrochemical investigation - from early 1960-s; demonstration of fluoride volatility reprocessing technology – 1970s;
- demonstration facility for pyrochemical MOX-fuel production for fast reactor – from late 1970-s;
- pyroelectrochemical reprocessing experience – 1990-2003;
- preparation for industrial application – from 1990-s;
- studies of transmutation cycle, nitride fuel and other applications – from 1990s.

Fig. 3. The Research Institute on Atomic Reactors – RIAR (Russia, Dimitrovgrad)

The RIAR current status of pyrochemical development for oxide fuel had been presented below. In the field of basic research:

- properties of U, Pu, Th, Np, Am were studied;
- knowledge of physical chemistry and electrochemistry of basic fission products were accumulated;
- chemistry of nitride fuel recycle methods was developed.

The essentials of technology and equipment have been developed for the oxide fuel reprocessing and fabrication processes. The process was tested with 6700 kg of pure fuel from different reactors and more than 30 kg of BN-350 and BOR-60 irradiated fuel. The essentials of technology have been elaborated and a feasibility study has been completed for the BN-800 large-scale plant. As the readiness of technology is high, work is under way on industrial implementation of U-Pu fuel. The BOR-60 operation is based on vi-pack fuel. The design of the CFC facility is in progress. 30 FAs have been tested included 15 fuel assemblies that are being irradiated in BN-600. Upgrading of MOX fuel production facilities of the BN-600 hybrid core is in progress.

Basic research in the field of the molten salt systems is allowed for the development of technological processes for production of granulated uranium and plutonium oxides and mixed uranium and plutonium oxides. A distinctive feature of the pyrochemical technology is a possibility to perform all the deposit production operations in one apparatus, to wit - a chlorinator-electrolyzer.

Pyrochemical reprocessing consists of the following main stages:

- dissolution of initial products or spent nuclear fuel in molten salts;
- recovery of crystal plutonium dioxide or electrolytic plutonium and uranium dioxides from the melt;
- processing of the cathode deposit and production of granulated fuel.

Fuel rods with granulated fuel are fabricated by vi-pack technique according to the standard procedures (in glove boxes or hot cells) that has been used at RIAR for 30 years.

The main advantages of the vi-pack technique and vibro-packed fuel rods are as follows:

- simplicity of the process due to the reduced number of process and control operations, that makes the automation and remote control of the process easier;
- possibility of the use of granulate in any form; both in the form of a homogeneous composition and mechanical mixture;
- reduced thermo-mechanical impact of vi-pack fuel on the cladding (as compared with a pelletized core);
- more flexible requirements for the inner diameter of the fuel rod claddings.

Stages for implementation of closed fuel cycle with MOX fuel from the RIAR view are as follows:

- hybrid core of the BN-600 reactor (1500 kg of MOX fuel and 50 FAs annually), as pilot project for technology implementation and collection of industrial and irradiation statistics;
- creation of MOX production lines for the BN-800 reactor with power grade Pu (up to 12 ton of MOX fuel and about 400 FAs annually) on the basis of Krasnoyarsk or MAYAK and RIAR cooperation with minimization of capital expenses;
- construction of the BN-800 closed fuel cycle (on MAYAK/Krasnoyarsk or near reactor) or for the next commercial BN reactor, as integrated plant with reactor, on the basis of developed technologies.

Acknowledgments:

Authors are grateful to Prof. Valentin Ivanov and Dr. Alexander Bychkov for valuable discussions of the results discussed.

Discussion of Boris Myasoedov's Lecture

***Richard Garwin** (USA): In the global infrastructure that Russia is proposing, when you take back spent fuel, is there in mind a geologic repository involved for the waste or will Russia continue to put the dissolved material into the ground as has been done before in the form of soluble materials?*

Boris Myasoedov: Yes, as I mentioned, Russia established this international Uranium Enrichment Center and in the future we hope that it will be able to reprocess the fuel after radiating in a foreign reactor. Reprocessing means that fissile material will be separated and the radioactive waste will be disposed in Russia. In Russia we now only use interoperation of radioactive waste in some very stable matrixes, like natural minerals. We just stopped putting the liquid waste directly into the ground. So, only solidification or other matrixes, and after the disposal of this matrix in some special underground place.

***Franco Calogero** (Italy): Could you say something about the eventual elimination of highly enriched uranium from peaceful activities, in particular from research reactors and from nuclear propulsion submarines and icebreakers, whether that is a prospect in the medium and long-range future to eliminate all of these activities as being incompatible with non-proliferation and possible terrorism.*

Boris Myasoedov: Yes, if I understand your question, Russia in Soviet times built a lot of scientific centers with so-called scientific reactors in the former Republics of the Soviet Union. But now we have a special program to return all fissile materials and some of these steps are now concluded. For example, some of the fissile materials from the Ukraine and other republics will return and be reprocessed in Russia. We also have a special program for solving the problem about the reactors from submarines; this program was supported by many nations and we appreciate very much their financial help. Now about 60% of all those reactors are finished, and their spent fuel goes to the Mayak, which is a reprocessing plant in Russia responsible for reprocessing this kind of fuel. It also concerns some of the Russian submarines and icebreakers.

***Klaus Gottstein** (Germany): You said, if I understood correctly, that the International Uranium Enrichment Center will be private. Who will be the private owner of that center and what influence will the government have on its market policy, the admission of customers, and so on?*

Boris Myasoedov: I believe John Ahearne, who will present a summary of our joint projects, will give more details about this center. Maybe it is not exactly private. It is not a governmental organization; it will be an open company in which representatives of other countries will be entitled.

***Erwin Häckel** (Germany): I wonder if you could identify those countries which now return their spent fuel to Russia, or from which Russia is ready to accept returned fuel.*

Boris Myasoedov: Yes. As you know, in Soviet times we built a lot of nuclear power plants in Bulgaria, in some eastern countries, and in Finland, and their fuel, which was produced in Russia, after being used on these power plants, was returned for reprocessing. It was done in the cases of Finland, Hungary, Bulgaria and some others.

Now Russia is open for reprocessing all fuels, even those that were not produced in Russia. So, we are ready to reprocess all fuel; including both storage and reprocessing.

Christopher Watson *(UK): Two questions about your program to have a unified center within Russia. The first is the physical location. You mentioned in your slides Angarsk, and that is of course the appropriate center for enrichment, but many other parts of the fuel cycle activity would presumably not be at Angarsk. So, where would they be? The second question is: what is the present status of the negotiations with the IAEA on having IAEA inspection of this facility? There have been a lot of statements about the discussions being ongoing, but a number of potential customers are worried about whether or when they will actually reach a conclusion.*

Boris Myasoedov: Of course in Russia we have several centers for enrichment of uranium. One of them is Angarsk; it is situated in the western part of the country. Before, as I mentioned, it was a completely closed enterprise, but now due to an official act of the Russian government it is under inspection of the International Atomic Energy Agency. Concerning other nuclear facilities in Russia, we have three reprocessing places: Tomsk, Krasnoyarsk and Mayak; but only Mayak has a capability of about 150 tons per year. In this reprocessing plant we do the reprocessing of fuel, as I mentioned, from nuclear submarines, from some power stations, and now we are developing the construction of a new reprocessing plant in Krasnoyarsk – but it is only under construction. Concerning your question about the inspection of the International Atomic Energy Agency: yes, in the functions of the international center the regular inspections of the IAEA are included for Angarsk, not for Mayak.

Adele Buckley *(USA): My question concerns the transportation. You said it was a problem to be solved. Could you tell us what discussions have been so far and what progress are you making?*

Boris Myasoedov: Yes, it is a special question. The transportation is one of the important stages in the fuel cycle. As concerns Russia, we have some special development, very good containers and good safety during the transportation. But concerning the transportation in the international way, it must be discussed and must be decided with the participating countries. This question is under discussion.

Nuclear Renaissance – Verification of Performance[1]

Adele Buckley (Canada)

Global demand for electricity virtually guarantees an increase in nuclear energy capacity. There are legitimate misgivings – increase in the threat of proliferation, generation of dangerous long-lived waste, no certainty about plant safety, and potential for nuclear terrorism. Today's control system is dangerous and inadequate to mandate sound operation, prevent accidents and apply full safeguards.

Every nuclear reactor must be seen as having a global presence, but there is not a binding agreement that requires international oversight of all nuclear reactors. The IAEA Additional Protocol for Application of Safeguards is directed solely at verifying that there are no activities leading to nuclear proliferation. The sound regulatory regime developed by IAEA relies on the expertise and reliability of national regulators, and is *voluntary*. The productive way forward is to promote universal adoption and enforcement of an international agreement on safety, security and safeguards.

Power utilities operate under a national regulatory system. Compliance with regulations, and demonstration of compliance by regular interaction with the regulatory agency is part of the cost of doing business. Where nuclear power is concerned, a regulatory system must include every nation, including Nuclear Weapons States, binding all to *the same regime*. The evident and legitimate regulatory agent is the IAEA. The time to begin is *now*, taking advantage of the lead time before new nuclear power plants come on –line, working in parallel on new verification protocols and the terms of an international treaty. Workable, stringent processes have been developed to meet the needs for verification and inspection for environmental technologies. Models from this domain may provide cross-fertilization for improvement of inspection and verification under IAEA. For unassailable credibility, the regulatory authority and inspection team interacting with a specific plant must be a true third-party to it. Resources available to individual national regulators vary greatly, and therefore IAEA will be required to provide training and support, possibly through designated subcontractors within each country. As in environmental regulatory compliance a system of "user-payment" is the only viable financial model.

It is vital for the international community to work toward a legally binding international regime that addresses *all factors.* To this end, governments, institutions, the private sector and civil society must take up their respective responsibilities.

Nuclear Renaissance

Every nuclear reactor has a global presence; a problem or an accident anywhere in the world can have short and long term effects far beyond the borders of the country of origin. Access to energy is a key to development and prosperity, and nuclear-generated electric power is a favored choice for the future energy mix of India, China, U.S. and others. This has been labeled as the nuclear renaissance, and will lead from over 400 reactors today to an estimated 500 - 600 nuclear reactors, even taking into account

[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

retirement of some reactors. Finland is building a 1600 MW reactor; Ontario Power Generation (Canada) is soliciting proposals for new nuclear power.

There are legitimate misgivings – increase in the threat of proliferation, generation of dangerous long-lived waste, availability of sufficient cooling water, no certainty about plant safety, and potential for nuclear terrorism. Considering cradle to grave true costs, it is extremely expensive. Further, taking into account the entire life cycle of nuclear power, the greenhouse gas emissions (much-touted as "zero") are several times higher than would be obtained by renewable energy.

Like it or not, the reality is that the nuclear energy renaissance is underway, without significant progress in the degree of physical protection against terrorism or the guarantee that safeguards are sufficient. Though improvements have occurred, nuclear safety has been an issue since the beginning. The International Atomic Energy Agency (IAEA) and its most active member states recognized this and staged a major international meeting, participants from 57 countries, in Moscow in Feb 27-Mar 3, 2006 on "Effective Nuclear Regulatory Systems: Facing Safety and Security Challenges"; proceedings[2] were published in Sept., 2006. The paper on behalf of the Chinese National Nuclear Safety Administration[3] says "According to the national nuclear development program, nuclear electricity supply capacity will reach 40 GW(e) by 2020….,,, it will be necessary to build two or three 1000 MW(3) units every year."

IAEA has held international conferences on strategies critical to nuclear safety, beginning in 1991. The Convention on Nuclear Safety has 56 contracting parties, and "Conference on Effective Nuclear Regulatory Systems…" in 2006 showed that the regulators know what is required, but they must "walk the walk", not just "talk the talk". The next such conference will be in three years. *This pace is much too slow.*

Of particular note is the conference keynote address by Dr. ElBaradei where he said "…every regulatory body has a unique design, based on national laws and the industry it must regulate….no two regulatory bodies have the same enforcement tools at their disposal. …civil society and public at large are increasingly recognized as important stakeholders in the work of the regulatory body."

This paper discusses the urgent need for continuous improvement and enforcement in the global nuclear regulatory system, and proposes verification methodologies that may assist in this. It also calls for the effort of the nuclear disarmament movement to support rapid and credible implementation and enforcement.

Failure to Assure Safety – An Example

There are a number of nuclear power plants in the northeastern United States that are very close to large population centers, and where an accident could have consequences for many persons in that area of the United States and Canada. Although the national regulatory system in the United States is well structured, the intent to enforce safety seems lacking, and there have been recent protests from citizens and other governmental

[2] STI/PUB/1272, 331 pp.; 20 figures; 2006, ISBN 92-0-110606-8

[3] G. Li, X. Hao, B, Tang, Nuclear Safety Regulations and Review of New Nuclear Power Plants in China, p. 255, Proceedings "Effective Nuclear Regulatory Systems…" IAEA STI/PUB/1272

authorities. In November, 2007 the New York Attorney General[4] and five other state Attorney Generals submitted a letter to the Nuclear Regulatory Commission (NRC) expressing concern "..NRC's failure to address safety issues including …seismic activity in the re-licensing of nuclear power plants is irresponsible". Citizens petitioned[5] to halt flaws in nuclear plant re-licensing when a U.S. Federal Audit showed that the Nuclear Regulatory Commission (NRC) staff did not verify the authenticity of technical safety information submitted by nuclear power plant operators. The Office of the Inspector General stated it was …"difficult to distinguish between licensee-provided data and NRC staff's independent assessment methodology and conclusion".

If these failures to ensure safety occur in a rich, developed country, would it not be even more likely that new users of nuclear power will tend to "cut corners" and compromise safety?

The Current Role of IAEA

The IAEA's mandate[6], dating from 1956 and whose Statute was last changed in 1963, says that all states that are member states of the United Nations, can be members[7] of the Agency, providing that they fulfill their obligations in good faith. IAEA has a strong internal structure and an expert professional staff. Where nuclear energy is concerned, the IAEA's role is to be a provider of expert guidance, developer of safety and security standards[8] (available for adoption by national regulatory agencies), sponsor of international conventions and supporter of new science and technology.

IAEA's Additional Protocol[9] for the Application of Safeguards is directed solely at verifying that there are no activities leading to nuclear proliferation. Only the NNWS (Non Nuclear Weapons States) are required to allow IAEA to enter their facilities containing nuclear materials for inspection and verification. IAEA INFCIRC/193 defines the terms and conditions of a safeguards activity in Article 7.

> a. In implementing safeguards under this Agreement, full account shall be taken of technological development in the field of safeguards, and every effort shall be made to ensure optimum cost-effectiveness and the application of the principle of safeguarding effectively the flow of nuclear material subject to safeguards under this Agreement by use of instruments and other techniques at certain strategic points to the extent that present or future technology permits.
>
> b. In order to ensure optimum cost-effectiveness, use shall be made, for example, of such means as:
>
> i. Containment as a means of defining material balance areas for accounting purposes;
>
> ii. Statistical techniques and random sampling in evaluating the flow of nuclear material;

4 Environmental News Service (ENS) Nov 16, 2007
5 Environmental News Service Jan 3, 2008
6 http://www.IAEA.org
7 http://www.IAEA.org/statute
8 International Commissions on Radiological Protection (ICRP) is the authoritative organization to publish nuclear safety (radiological protection) goals which are the bases of IAEA safety guidelines
9 Model Protocol Additional to the Agreement(s) between States(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540

iii. Concentration of verification procedures on those stages in the nuclear fuel cycle involving the production, processing, use or storage of nuclear material from which nuclear weapons or other nuclear.

The Euratom safeguards[10] are applied in conjunction with those of the International Atomic Energy Agency under tripartite agreements concluded between the Member States, the Community and the IAEA. The Euratom Treaty introduces an extremely comprehensive and strict system of safeguards to ensure that civil nuclear materials are not diverted from the civil use declared by the Member States. The EU has exclusive powers in this domain, which it exercises through of a team of 300 inspectors who enforce the Euratom safeguards throughout the EU.

Nuclear Weapons States (NWS) have no obligation to implement safeguards, and three out of the five NWS do not have safeguards inspection. However, to assist IAEA, Britain and France voluntarily participate[11] in safeguards inspection. This safeguards work is especially valuable for reprocessing plants, and assists in the developing methodology for safeguards procedures for the NNWS. United States and Russia have not volunteered for safeguards inspection; one reason offered is that it would be very expensive.

Signatories to the Non-Proliferation Treaty that have nuclear materials for peaceful uses expect to be examined under the safeguards regime, because IAEA has an operational role with respect to Safeguards. It has authority as the responsible international inspection agency, and, from time to time, it reports non-compliance to the Security Council. *However, IAEA has no comparable operational role where nuclear safety is concerned, and the same is true regarding physical protection against terrorism, so that is where the weakness of the international system lies.* It is a useful precedent that IAEA delegates safeguards inspection to Euratom, as it could extend its authority through similar tripartite agreements to deal with nuclear safety.

Multilateral Nuclear Approaches and GNEP

When it became evident that a number of states would be considering means to develop their own nuclear energy capability, and in particular their own fuel cycle facilities, the IAEA appointed an expert group to consider Multilateral Nuclear Approaches (MNAs). These deliberations were reported in IAEA INFCIRC/640, February 2005. The two dominant factors:

(1) Assurance of non-proliferation, and
(2) Assurance of supply and services

A multilateral approach to non-proliferation would reduce the risk by requiring the presence of a multinational team to prevent such actions as theft of fissile material, diffusion of sensitive technologies to unauthorized entities, or development of clandestine parallel programs. However, the risk remains that the host country would expel multinational staff, and terminate its safeguards agreement under the NPT. Assurance of supply could be acceptable, but there would need to be strong incentives for the host country to give up this degree of sovereignty. A most critical step noted by

[10] http://europa.eu/scadplus/treaties/euratom_en.htm
[11] Personal communication, Professor John Simpson, Mountbatten Centre for International Studies, University of Southampton

the expert group is devising effective mechanisms for assurances of supply of material and services, commercially competitive, free of monopolies, of political constraints, and including backup sources of supply.

At the subsequent G8 meeting in 2006, in St. Petersburg, Russia, Presidents Bush and Putin endorsed the GNEP (Global Nuclear Energy Partnership) for promotion of additional use of nuclear energy *and* for a plan to prevent proliferation by having a centralized nuclear fuel supply. The January/ February 2008 report from GNEP Watch[12]: Developments in the Global Nuclear Energy Partnership" has the headline - Canada and South Korea join the GNEP as the US Congress Scales it Back.

Proposal for a Universal System of Inspection and Verification

We need a new, and *universal,* regulatory system directed solely at all aspects of nuclear energy for peaceful uses. This would include:

- Individual nuclear plant sites - addressing all designs and types of reactors for nuclear power generation
- Central fuel enrichment facilities
- Naval nuclear reactors
- Research reactors
- Nuclear waste[13]
- Measures that protect against potential nuclear terrorism

The system would include ways of sharing expertise internationally. It would incorporate, enlarge and support the work of IAEA.

An expert team would design a General Inspection and Verification Protocol. All signatories to an international agreement would commit to working within the framework, which would incorporate international standards. Technology Specific Verification Protocols would be necessary to deal with specifics of the inspection and

[12] Report prepared monthly by Miles Pomper in Washington DC, for the CIGI Nuclear Energy Futures Project.

[13] Strategies for disposal of nuclear waste have created many years of controversy, because, in addition to low-level radioactive waste, the waste product of nuclear energy production is highly radioactive and long-lived.. Nevertheless, the technical community has accepted the viability of secure centralized storage in a deep geological repository. No country has yet implemented such storage. In Canada, the Nuclear Waste Management Organization (www.nwmo.ca) was given a mandate by the Government of Canada, reviewed every aspect of the situation with the input of world renowned experts, and issued a report in November 2005 (The Government of Canada is beginning to take action on the report.) The central recommendation is adaptive phased management of the waste, with use of a deep geological repository. Adaptive management gives the flexibility to adapt to experience gained in earlier years of waste storage, and, most importantly, to also adapt to societal and technological changes. During the Phase I program, there is provision for an optional step – relatively shallow storage with opportunity for retrievability, followed by later deep storage. There would be continuous monitoring, sequential and collaborative decision making. NWMO says that such storage could only be implemented, in Phase 1, at the earliest in 2035, and the final deep storage could be operational by 2065. While this work seems thorough and rational, the delay in starting and the proposed time scale requires that more information be available to the ordinary informed citizen. It is not known whether or not IAEA considers nuclear waste disposal a priority. The regime of certification and inspection of nuclear waste storage sites would be best managed by a user-pay type of system, so that there is an ongoing method of financing the continuous monitoring required for such sites.

verification. This would accommodate all technical elements of all types of nuclear technology, existing and future, as deployed throughout the world.

An international agreement to inspect and verify would not be reliant on the Non-Proliferation Treaty, nor would it require that those countries presently outside it join the NPT regime. This would be a legally binding agreement. Such an agreement could provide the opportunity to limit the power of the GNEP (Global Nuclear Energy Partnership) to modify international nuclear trade rules to accommodate situations like the proposed deal between U.S. and India.

Credibility and Safety through Third Party Verification

The only viable system of inspection is one which has the absolute confidence of all members of the international community. This requires involvement of recognized certifiable experts in nuclear power plant technology, and in the methodology of inspection and verification. The vital characteristic, in addition to expertise, is that the inspection team must be a third party[14] to

- the owner of the nuclear power plant
- the management of the nuclear plant
- subcontractors to the owners and managers, *and*
- the government of the country in which the nuclear plant is sited

International law must be recognized and enforced by the government. The government is the regulator, and often is also the owner, and therefore would be in a conflict of interest position as the inspecting agency. It is particularly desirable that the inspection team should have no link to the government of the country. This is a more onerous demand than the requirement for other types of electricity generators (e.g. coal-fired plants) but it is vital to the achievement of international credibility for the system. Pragmatically, true third party verification would probably be achieved incrementally, especially in countries without a democratic government.

A regular, periodic inspection of *every* plant and *every* nuclear reactor in a massive task, and could not be carried out by the IAEA staff alone with its own resources. Therefore, the IAEA would be obliged to train and authorize others to carry out protocols of inspection that were authorized by IAEA. These protocols would be highly technical and so would the level of expertise within the group of authorized subcontractors to IAEA

Implementing such an inspection system would require expansion of IAEA, so that it could manage the inspection/verification system. The means of funding is proposed in a later section.

Verification Models from other Sectors

It is time for the nuclear electricity generating plant to enter the mainstream of the regulatory system for electricity generators. There are legal requirements (regulations) that the plant must fulfill and there are voluntary standards. Both of these categories have their national and international levels However, it is hard to ascertain whether or

[14] Third party means absence of conflict of interest, so that there is no organizational, government, or any link whatsoever between the inspection team and the plant under inspection.

not there are true international standards for nuclear plants, and, in any case, compliance is voluntary. National standards vary greatly, but ideally should be as good or better than those modeled by IAEA safety standards.

Citizens have been encouraged to believe that nuclear power is an important energy solution to combat climate change. From this viewpoint, nuclear energy is a technology that may create an environmental benefit. However, how can the population be assured of reliable and safe performance of the technology? National regulators and their nuclear operators could consider procedures and programs that have been developed to meet the need for verification of performance of environmental technology, and for verification of emissions reduction for greenhouse gases. Examining workable rigorous processes from another domain may provide cross-fertilization for improvement of inspection and verification by IAEA.

Model One: Environmental Technology Verification (ETV)

For assurance of environmental performance, some countries have established a generic system that gives systematic and documented proof of a technology as being sound in terms of its claims of operation within its individual environment.

- Environmental Technology Verification (ETV) (Operating under the US EPA[15])[16]:

The following information is extracted (and condensed) from the US ETV website - "In the 1990s, the US EPA recognized that the lack of an organized and ongoing program to produce independent, credible performance data would be a major impediment to the development and use of innovative environmental technology. Thus, the US ETV program, established in 1995, is a program to accelerate the implementation of environmental technology through objective verification and reporting of technology performance. The Environmental Technology Verification (ETV) Program develops testing protocols and verifies the performance of innovative technologies. Such data are needed by technology buyers and permitters, both in the United States and abroad, to make informed technology decisions. Since its inception in 1995, ETV has verified almost 400 technologies and developed more than 85 protocols. The goal of ETV is to provide credible performance data for commercial-ready technologies to speed their implementation for the benefit of purchasers, permitters, vendors and the public.

The ETV Program operates mainly through cooperative agreements between EPA and private nonprofit testing and evaluation organizations. These ETV verification organizations work with EPA technology experts to create efficient and quality-assured procedures that verify the performance of innovative technologies. Vendors and others in the private sector, as well as federal, state and local government agencies, cost-share with EPA to complete priority ETV protocols and verifications. The efforts of ETV centers are guided by the expertise of stakeholder groups."

- ETV Canada[17] – Environmental Technology Verification (operated by ETV Canada and OCETA[18] under license from Environment Canada) The following information is extracted from their website:

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[15] United States Environmental Protection Agency

[16] www.epa.gov/etv

[17] http://www.etvcanada.ca

"ETV Canada offers an assessment process for verifying the claims associated with projects and programs, as well as technologies and technological processes. ETV verification provides the marketplace with the assurance that environmental performance claims are valid, credible and supported by quality independent test data and information. A comprehensive 3-part strategy for ETV Canada has been implemented

1. Technology Verification
   - Working closely with technology innovators and qualified verification organizations
2. Performance Benchmarking
   - Based on the development of credible stakeholder-driven performance criteria and the transparent reporting of performance information
3. International Harmonization of Protocols and Test Methods
   - Building on the established ETV Generic Verification and Test Protocol and related decision-support tools"

The model presented by ETV Canada is comprehensive in that it addresses a range of processes and classifies inspection and verification in a way that the entire nuclear power industry could use to verify safety, and presence of technical systems to prevent damage from terrorism.

- European Union (EU): A consortium, is conducting a Specifically Targeted Research Project for developing an ETV system for the European Union. The EU is proceeding with this work because environmental technology verification [ETV] is recognized for its importance in most highly-industrialized countries, e.g. the United States, Japan, and Canada. The Environmental Technologies Action Plan for the European Union [COM(2004) 38 final] called for the development of a European ETV system. At present the PROMOTE consortium is conducting a Specifically Targeted Research Project for developing an ETV system. PROMOTE receives financial support by the 6th Framework Programme of the EU.[19]
- China is adopting a system of ETV that has its roots in the Canadian ETV system. China began a process of adaptation after a program of assistance provided by CIDA, the Canadian International Development Agency. Other countries, e.g. South Korea, are at various stages of implementing ETV.
- Harmonization: international discussions have been ongoing for several years, so that acceptance in one jurisdiction would be recognized in all. The third international conference on harmonization of EPV (Environmental Performance Verification), in France, November 2007, emphasized inclusion of developing countries and had participants representing international organizations such as UNEP and OECD. EPV systems originating in North America (US EPA and ETV Canada) were held up as models.

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[18] OCETA Ontario Centre for Environmental Technology Advancement

[19] http://www.cen.eu/cenorm/businessdomains/technicalcommitteesworkshops/workshops/ws32-promote.asp# CWA/ETV-SGS N012 CWA Business Plan 07 Mai 2007

Model Two: Carbon Emissions Trading System

Cap-and-Trade Emissions Trading puts a significant price per tonne on emitted carbon dioxide – ranging from $15 to $30 and higher, and the financial transactions that are already taking place have potentially large monetary value. A rigorous and credible system of verification is therefore an essential element for success in using this as a tool to mitigate the effects of greenhouse gas emissions (resulting in climate change). In this situation, the presence of expert third party verifiers is essential. All stages of a project are subject to internationally agreed quantitation methodologies (originating with IPCC[20]) for calculating all emissions associated with it – e.g. for manufacturing components, transportation to the site of operation, actual energy-consuming operation of the project. The business-as-usual situation, the baseline, is compared to the proposed emissions reduction, and emission credits are then calculated before, during and after a project. There are two major stages:

1. VALIDATION – before commencement of a project: independent review of carbon emissions savings to be achieved. At this point there should be also an element that requires Production and use of a Monitoring Plan, so that all participants agree on how the emissions data is to be generated and recorded.
2. VERIFICATION – independent review of data and information collected during the project, to establish actual savings of Greenhouse Gas in the project compared to the pre-project Baseline

The greenhouse gas verification process must be unassailable in its credibility, and for that reason the examinations of the validation and verification agencies must be meticulous. This is costly, and can only be justified for as a venture involving trading between corporations that are major emitters and major emissions reducers.

Model Three: Fissile Materials Cutoff Treaty (FMCT)

FMCT, when and if it comes into force, signals a major step toward nuclear disarmament. Also, the treaty would require a comprehensive regime of inspection and verification, involving all countries that have any of the range of materials classified as fissile materials; the evident inspection and verification authority is IAEA. This would be an inspection system for both nuclear weapons states and non-nuclear weapons states. Thus, it would set in place a precedent for universality which could be a model, and could be extended to apply to inspection and verification of all aspects of nuclear power generation.

Resources and Funds

As expressed by Louise Frechette, former UN deputy secretary-general, distinguished fellow at CIGI[21], in the Globe and Mail, Oct 26, 2007, there is a problem with resources and funds:

"The IAEA suffers from a chronic shortage of resources to carry out all its responsibilities under the NPT and related conventions. It can barely cope with its inspection and technical assistance workload as it is and would be hard pressed to meet the needs arising from a nuclear renaissance."

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[20] IPCC Intergovernmental Panel on Climate Change, operating with a mandate from the United Nations

[21] Centre for International Governance Innovation www.cigionline.org

IAEA, the appropriate management entity, must have authority not only over proliferation safeguards, but also over safety and terrorism prevention. IAEA, while retaining oversight, must train and authorize subsidiary organizations. Thus
IAEA requires increased funding, *and* as in environmental regulatory compliance, a system of "user-payment" is the only viable financial model

The Task for the International Community prior to Opening of New Nuclear Power Plants

It is evident from the history of developing the programs cited here as potential models that a number of years are required for planning and implementation. Present planning would see nuclear power plants come on stream only after a lengthy process of permitting, designing, building and commissioning, so that it will be well into the next decade before new nuclear reactors are present on the global scene.

There should be two parallel activities:

1. In preparation for new international agreements on stronger measures for inspection and verification, *BEGIN NOW TO PREPARE VERIFICATION PROTOCOLS.* For this purpose, it would make sense to assemble an expert international team for this work [example: IPCC Intergovernmental Panel on Climate Change].
2. *NEGOTIATIONS SHOULD BEGIN NOW.* The structure and details of a new universal international regulatory require an expert international team, and it should be identified, commissioned and begin its work.

The international community has to work in concert, beginning now, to produce a legally binding system that addresses all factors relating to the nuclear renaissance. Governments, institutions, the private sector and civil society must take up their respective responsibilities. Within civil society, the nuclear disarmament movement would have special empathy for this mission, and should participate vigorously.

Discussion of Adele Buckley's Lecture

Rudolf Avenhaus *(Germany): I agree with your statements about the shortage of funds of the IAEA, but on one point I must correct you. It is not true that there are no inspections of the IAEA in nuclear weapon states. There are inspections of the peaceful part of the nuclear fuel cycle at least in the United States, in the U.K. and in France. I do not know the details about how much, and so on, but there are inspections and there are and there were also inspections on bilateral agreements with the IAEA, for example between the United States and India. All this is not enough, I agree, but in principle these tools exist.*

Adele Buckley: That is good to know for a person like me because I am not professionally active in those areas and I was not able to find that out in time for this. I do not know if that is voluntary or mandatory. What is going on in the nuclear weapon states, is that mandatory or voluntary?

Rudolf Avenhaus*: It is mandatory, but they determine the sites of the inspections themselves.*

Adele Buckley: So, it is kind of "half-mandatory".

Erwin Häckel *(Germany): I think there is nobody who would not agree with you that it is desirable to have a global verification system for nuclear safety on the highest possible level of standards. However, the major problem is that there is no agreement on what the highest possible level is. There is not even an agreement in all member states. Take this country, Germany: there is no agreement in the federal system on what the standards for optimal safety should be. If you try to extrapolate it on the international level, if you could reach an agreement among all IAEA member states, it would be on the lowest common denominator. You would never reach the highest possible level. That also does not seem to be very desirable; the fact is that many nation-states probably provide a higher level of safety assurances than could ever be reached on the international level.*

Adele Buckley: This is to me a very important point. I would think that the national level would be governed by national regulations, and that it would be the highest level that states could achieve, and it would be mandated within such an inspection system that that must be also part of what is done; it would need a third party to assure that the national regulation were actually being done. But, on the other hand, where there were deficiencies, the lowest possible denominator is better than perhaps nothing at all. In any case, of course, these are all things that are the best to do, and we have heard several times this morning of things that are desirable, and yet you do not know how to tackle them. But you at least have to express what is needed and try to get to a point which approaches that, rather than just hide your head in the sand and hope that it will go away.

Christoph Pistner *(Germany): You said that the IAEA already has a problem with coping with the situation as it is now with the inspections and all the work they have to do, and that they should start to prepare for this possible nuclear renaissance. This seems like a very critical thing to do. I just wonder what the reasons are why the IAEA* *is not doing that already. How is it that there are no preparations for that, for a possible nuclear renaissance in the future? Do you have any information on that?*

Adele Buckley: Maybe someone else does, but I would imagine it is this resource problem, isn't it? They already have a workload which is quite significant and cannot really be fulfilled 100% on the present resources. This is sort of ridiculous because there is a huge amount of money put into nuclear weapons and other related situations. Why cannot the IAEA have sufficient resources to do its work? But I do not know the answer. Maybe someone else does.

John Simpson *(UK): Can I just clarify the situation over nuclear weapon states inspection? There is a difference between the two European nuclear weapon states and the other three, because the two European nuclear weapon states are subject to EURATOM safeguards. What that means is that everything other than specific weapon plants and facilities are open to EURATOM inspection. There is no difference between the way the U.K. and France and the other EURATOM states – the non-nuclear weapon states – are inspected other than this specific point. In the case of both the other three states and the U.K. and France – though in the latter it is almost irrelevant given the EURATOM context – they accept voluntary IAEA safeguards. But in implementing these safeguards the IAEA tends to opt, because they are nuclear weapon states, to apply IAEA safeguards only to types of plant that nuclear weapon states alone operate, but which they think, looking to the future, they may have to safeguard in non-nuclear weapon states. So they concentrate on enrichment and reprocessing plants, as part of a strategy of developing concepts and practices for safeguarding those plants. As far as the question of the impact of a nuclear renaissance on safeguards is concerned, the IAEA is already in the situation where you have to give very early information on the plant that you are building so that they can safeguard it effectively and offer advice on safety etc., thanks largely to changes in safeguards procedures made after 1991 in response to the Iraq situation. So it is not clear what specific changes you are suggesting should be implemented .*

Adele Buckley: To me the difference seems to be that there are going to be countries with nuclear power that never had it before. Those would be the most difficult, serious ones to look at first. But I think that there are plenty of places where safety is perhaps not as good as it should be. If there is a universal system where everybody has to do the same and it is not voluntary – it is legally binding – it would be safer than presently. I am not aware that there is any universal system which mandates what is to be protected against nuclear terrorism and what is to be set up within the plant for that purpose. Each individual country decides on their own what is best whether anyone agrees that that is a good system or not. It is just a national situation, as opposed to an international one. So it would be better if there was some oversight on that topic as well.

Christoph Pistner*: It is not really a question, but a remark in response also to what Prof. Haeckel already said. In Germany we have a discussion about what to do with the oversight of nuclear power plants. In the current system it is the state's responsibility to have the immediate oversight of the safety of the nuclear power and there have been some debates about whether it would be better to have the federal government to be responsible for that immediate oversight, since it only has a general oversight of the nuclear power plants safety. And there are good arguments on both sides; it might even be better to leave the responsibility to the states, because they are much closer to the* *reactors and they know the situation in the reactors much better than the federal ministry does. So there are arguments in both directions; it might even be worse if you are too far away.*

Adele Buckley: That is an interesting point. All I wanted to do was to draw some attention to this situation, which is not being discussed nearly as much as the necessity of nonproliferation and safeguards. These are all important as we are trying to protect the citizens of the world from whatever dangers we all are aware of.

Internationalization of the Nuclear Fuel Cycle[1]

John F. Ahearne (USA)

Two factors are driving discussion of the nuclear fuel cycle: growth in nuclear power and potential expansion of enrichment facilities. These are related.

Nuclear Renaissance

After decades of being viewed as unattractive, at least in the West, nuclear power is becoming more acceptable, partially due to the increased concern about global warming.

In October 2007, the IAEA issued "Energy, Electricity and Nuclear Power Estimates for the Period up to 2030." The report noted that "Nuclear power's share of worldwide electricity production rose from less than 1 percent in 1960 to 16 percent in 1986, and that percentage has held essentially constant in the 21 years since 1986….Nuclear electricity generation has grown steadily at the same pace as overall global electricity generation.

There were 435 operating nuclear reactors around the world as of the end of 2006, including 103 in the United States, 59 in France, 55 in Japan and 31 in Russia. Twenty-nine plants were under construction, including seven in Russia and 15 in various Asian countries.

Of the 30 countries with nuclear power, the percentage of electricity supplied by nuclear ranged from 78 percent in France to 19 percent in the United States and 2 percent in China, where energy consumption has burgeoned in recent years."[2]

The IAEA predicted that "'Much of the growth will be fueled by energy-hungry economies like India, China, South Korea, and Japan. Nuclear power's prominence as a major energy source will continue over the next several decades."[3]

China and India have booming economies, booming populations and growing energy demand. The IAEA analysis is based on the argument that these countries need to develop all the energy sources they can.

In the report, the IAEA makes low-case and high-case projections, taking into consideration various different scenarios.

"In the low estimates, the present barriers to nuclear power development are assumed to prevail in most countries….:
-Low economic and electricity demand growth rates in OECD countries;
-Public opposition to nuclear power, leading to policy decisions not to consider the nuclear option…;
-Institutional and financing issues preventing the implementation of previously planned nuclear programmes, in particular in countries in transition and in developing countries;

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[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.
[2] *The Economic Times,* 27 October 2007.
[3] *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030*, IAEA Reference Data Series No.1, 2007 Edition.

-Inadequate mechanism for nuclear technology transfer and nuclear project funding in developing countries.

The high estimates reflect a moderate revival of nuclear power development that could result in particular from a more comprehensive comparative assessment of the different options for electricity generation, integrating economic, social, health and environmental aspects. They are based on a review of national nuclear power programmes….”[4]

The predicted nuclear growth is large in both projections but the projections do differ significantly. In the low-case, nuclear power production is estimated to expand by at least 25 per cent between now and 2030 and by as much as 93 per cent in the high case.

Out of the 31 new nuclear power plans under construction at the end of 2006, half of them, 16 in all, were being built in developing countries, with most of those in China and India.

"China…was planning a five-fold expansion by 2020….Nevertheless, with China growing so fast, nuclear power would still amount to only four per cent of total electricity [generation] by 2020…. As for Japan and South Korea, the problem was not so much a booming population, as a lack of indigenous oil and gas resources. For them, nuclear power is attractive for energy security reasons, and for Japan in particular it is attractive in reducing greenhouse gas emissions…."

For the IAEA, the picture was much more complex in Europe…

"In the high-case projection, which assumed that Britain would replace all of its old, retiring nuclear power plants with new ones and that Germany would keep it plants running, nuclear capacity was projected to expand by 20 per cent by 2030. But if Britain replaces its retiring nuclear power plants with other sources of energy…and if Germany and Belgium were to phase out their nuclear programmes, …[there is] a decrease in nuclear capacity of 40 per cent by 2030."[5]

Developing countries

Studies of developed and developing countries show that electricity is critical for GDP growth. Coal is polluting, gas is expensive. Nuclear also is expensive – to build – but not to operate and it is clean.

To understand some of the issues faced if nuclear power is to expand in developing countries, the experience of India was presented at a 2006 conference.

"The Indian Department of Atomic Energy (DAE) claimed nuclear would be favorable compared with coal by 1990s. This did not happen. There were enormous cost and time overruns in all but one nuclear power station. Nuclear power is more expensive than coal for real discount rates. Indian costs do not include spent fuel management, which is subsidized by DAE. The DAE is positive about reprocessing and claims that India's

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[4] *Ibid.*, pp. 6-7.
[5] *The Economic Times,* 27 October 2007.

approach would be one-half of world costs. This probably is correct because of lower labor rates and easier regulations.

The DAE forecasts 20,000 MW of nuclear by 2020 and 275,000 MW by 2052 with much of the growth based on breeder reactors, including MOX fuels. Their 1250 MW prototype breeder with a 1.05 breeding ratio is scheduled to be operating in 2010. The predicted cost is about $1300/KWe. The estimated breeder electricity costs will be higher, but not significantly more than those of the current Indian reactors. The amount of Indian uranium is tight unless new mines are opened but there is public resistance to that.

In summary:
It is unlikely that India will be a major customer for new foreign reactors. For example, French reactors are too expensive.
Nuclear power will be a major part of planning but not for electricity generation.

Lessons:
-Nuclear power increases in developing countries will be slow
-Don't trust predictions.
-Lower labor costs but weaker regulations and licensing lead to safety concerns."[6]

Proliferation concerns

Is there link between nuclear power and nuclear weapons? Many commenters have noted that countries that developed nuclear weapons do not appear to have linked the weapons programs to the nuclear power programs. However, Carson Mark, former head of the Los Alamos Laboratory theory division, many years ago did link nuclear power to nuclear weapons noting that the capability to handle radioactive material that is needed for nuclear power is also what is needed for nuclear weapons.

A nation seeking to acquire nuclear weapons needs the nuclear explosive material and the knowledge and means to detonate that material in a weapon. It is generally assumed that the knowledge is available or fairly readily acquired. The difficulty of acquiring the nuclear explosive material remains the greatest barrier for a nation seeking to develop its own nuclear weapon (setting aside external political, diplomatic, and military pressure that may serve as obstacles). How can a country obtain that material? One way is from countries that have stockpiles of such material. But such transfers are not permitted by international agreements such as the NPT and the NSG criteria.

However uranium enrichment and nuclear fuel reprocessing facilities used for peaceful nuclear energy objectives (serving civilian NPPs) also can be used to produce the material for weapons. Almost all current and planned NPPs use fuel made with enriched uranium. When mined, uranium has less than 1 % of U-235, the isotope used to produce fission power. For use in a NPP, the percentage must be increased to 3-5 % using enrichment facilities. These plants are expensive and technologically challenging. However, going from the LEU needed for a power reactor to the HEU usable for nuclear weapons is much less a challenge than building the enrichment plant.

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[6] Presentation at The Future of Nuclear Energy conference, Chicago, Illinois, November 1-2 2006.

Once running these plants can be used to enrich the uranium to much higher percentages, making highly-enriched uranium (HEU), an excellent material for a nuclear bomb.

Nuclear fuel reprocessing facilities separate the portions of used nuclear fuel that can be recycled into new reactor fuel, primarily plutonium. Although more challenging to use in weapons than HEU, the separated plutonium can be used in a nuclear bomb.

Today, eleven countries enrich uranium: Brazil, China, France, Germany, India, Japan, Netherlands, Pakistan, Russia, UK, and the United States have operating facilities, and Iran is trying to bring a new facility online. Two consortia—Eurodif (in France) and Urenco (in Germany, Netherlands, UK and soon the United States)—and two nations—Russia and the United States—provide commercial uranium enrichment services for other countries.

Seven countries reprocess irradiated nuclear fuel: China, France, India, Japan, Pakistan, Russia, and the UK. Only France, Russia, and UK offer commercial reprocessing services to other countries. Reprocessing, or regeneration, currently is only under consideration by countries with mature nuclear complexes.

The continued growth in nuclear power has raised proliferation concerns that new entries into the nuclear power world would want to build enrichment facilities to provide the fuel for their reactors.

Uranium enrichment services are needed to make fuel for almost any new reactor, so it is reasonable to argue that an enrichment facility is part of a new civilian nuclear energy program.

The possible spread of enrichment capability is a greater proliferation concern than the spread of reprocessing capability because it is possible to design very simple bombs based on HEU and clandestine production of HEU using enrichment facilities is hard to detect. To encourage the growth of NPPs but discourage the spread of enrichment facilities, , the Director General of the IAEA, Russian President Putin, and US President Bush have proposed systems to assure the needed fuel for countries planning to build NPPs and remove the incentive to construct enrichment facilities.

Presidents Putin and Bush stated:
"We are prepared to support expansion of nuclear energy in the following ways, consistent with national law and international legal frameworks. These efforts build on, reinforce, and complement a range of existing activities, including the work at the IAEA for reliable access to nuclear fuel, the initiative of the Russian Federation on developing Global Nuclear Infrastructure, including the nuclear fuel center in the Russian Federation, the initiative of the United States to establish the Global Nuclear Energy Partnership, the IAEA International Project on Innovative Nuclear Rectors and Fuel Cycles, and the Generation IV International Forum." [7]

DG ElBaradei has said: [8]

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[7] Declaration on Nuclear Energy and Nonproliferation Joint Actions, 3 July 2007:

[8] Statement to the Board of Governors on Assurances of Nuclear Fuel Supply:

"If we really want a more proliferation resistant system, all enrichment and reprocessing systems should be regional or multinational. To achieve this, we first need to establish an assurance of supply mechanism…."[9]

There is an international concern on expanding enrichment facilities but not on constraining peaceful uses. Last year a meeting was held at the IAEA by a joint US/Russian committee[10] to which countries were invited who might be users of a fuel assurance program.

While supporting the concept of fuel assurance but with some questioning its need, the representatives made clear that they would not give up rights under the NPT.

Illustrative examples:

From a Middle Eastern country: "Today, however, the guarantee of fuel supply as a back up measure is a basic requirement, especially in case of its interruption for political reasons."

From an Asian country: "The existing market for fuel has functioned well. Even though supply disruption occurred by several reasons, utilities purchased nuclear material from alternative sources"

From an African country at the 19 September 2006 IAEA Special Event:
"When the [IAEA] Expert Panel's Report was discussed in the Board of Governors last year, [my country] emphasized that any decision taken in this regard may not place any unwarranted restrictions on the inalienable right of States to the peaceful application of nuclear energy…. In addition, we should guard against the notion that sensitive technologies are safe in the hands of some, but pose a risk when others have access to them."

From a South American country: "The importance of nuclear power's potential for sustainable energy development, as well as for areas such as medicine, improving conservation of foods, etc., is being revisited and there is a clear tendency to its increased use in the future…. [However] [n]o new system based on discrimination against those who comply with the international rules on non-proliferation has a chance to be considered legitimate."

[9] The above description is based upon background material for a joint US/Russian Academies of Sciences committee on the international fuel cycle.
[10] Several or the Russian members are in attendance at this conference.

Safeguards

Safeguards are critical to constrain weapons growth. Enrichment plants are hard to detect, reprocessing is easier.

IAEA safeguards are the world's standard, if access is allowed.

A.Q.Khan demonstrated a weakness in safeguards can be exploited by a dedicated insider and an extensive world-wide network.

There are two types of safeguards problems:

(1) A nation state trying to develop nuclear weapons or helping another state to develop nuclear weapons.
(2) Protecting stores of HEU or separated plutonium.

For (1), the protection is provided by the IAEA, especially with the Additional Protocol. For (2), the state storing the material can increase physical protection and install an effective material control and accounting system.

The US and Russia have been cooperating on increasing physical protection for Russian facilities.

But the best protection is to prevent production of more weapons usable material. That is the goal of the fuel assurance programs.

Discussion of John F. Ahearne's Lecture

***Richard Garwin** (USA): I have a question for Dr. Buckley: In regard to the user pays for the safeguard's inspection from the IAEA, which I agree is the proper basis, do you have any incentives for the development of automated systems, remote monitoring, so that the user would pay less if they installed such systems than if there were only manual inspections?*

***Adele Buckley** (Canada): This is a new thought to me. Certainly you would have to have a price structure in such a user pay system, and of course it would not be the same payment for every site, and there would not be the same payment for an international enrichment facility. There would definitely be a whole range and if you could do something remotely, it would probably save a lot of money. All the initial costs for developing, inventing, installing and commissioning would be plenty, but after that it would save money.*

John Ahearne: The comment I would make is that there is some question about the program the United States has offered, the Global Nuclear Energy Partnership. It has several real difficulties. The first difficulty is that our Congress is not supporting it, they are not funding it. A second problem is that we have discussed with a number of countries what it really takes to have a fuel assurance program to work. The most valuable incentive that we have detected is after they have used the fuel, they can give it back. The take back of the fuel is a critical element, particularly for countries that are just starting into the nuclear power world. They see taking care of spent fuel as a real problem. And so if the countries assuring the supply are willing to take it back, which Russia has done for years for the fuel and the supply, this would be a different matter. The United States has only done that for the HEU fuel for the research reactors, and although the United States has its program for fuel assurance, there is no plan at the moment to take spent fuel back. As was mentioned by Spurgeon Keeney earlier, we have been having a tremendous difficulty trying to develop a repository at Yucca Mountain in the United States. And the idea of taking foreign fuel is just not going to get anywhere in our Congress. So the GNEP has some positive features: it is basically predicated on the belief that one eventually is going to have to go through reprocessing and so there is a lot of work being done on new technologies. But they are a long way from actually coming to fruition, so I am afraid that in my country the rhetoric is far outpacing the reality.

***Adele Buckley**: This is just the response to the last comment. In Canada there is the discussion of getting a fuel enrichment facility. This would, from an economic viewpoint, be a value added to the uranium that comes from Canada. That would be just great. But there is a statement by the government and then a citizen opposition… Definitely, it would never be possible to take back fuel. Just another one on a long string of problems.*

Eliminating HEU as Reactor Fuel – Addressing the Need for Acceleration by Measuring HEU Inventories and Progress on Minimization[1]

Ole Reistad, Styrkaar Hustveit (Norway)

In 1980, the International Fuel Cycle Evaluation (INFCE) study led representatives from 59 states to realize that the widespread use of high enriched uranium (HEU) in various types of applications posed significant proliferation risks, and a push was instigated to minimize the civilian use of HEU and reduce the number of sites with HEU. Yet, there is confusion with regards to the scope as well as the progress of ongoing activities: which materials and facilities are actually covered, at what pace they are converted, with what progress for HEU elimination as such and what are the prospects for complete elimination of the use of HEU fuels. This study establishes the basis for measuring in relation to the entire HEU-fueled universe (all fuel cycles). The conclusions are that currently, 294 reactors and isotope production facilities employ HEU fuel or target material, out of which 154 are used for naval propulsion. These facilities are in annual need of more than 3,500 kg HEU for naval propulsion, more than 900 kg HEU in research reactors, and 40-50 kg HEU for isotope production in civilian facilities, in addition to several tons of various attractiveness levels in other types of reactors. Of particular concern is material with high enrichment levels and low radiation barriers being stored or handled in batches of significant quantities, such as HEU target waste and certain types of fuel from other isotope production, research reactors/ critical assemblies and naval fuel. In all 48 civilian research reactors have completed the conversion to LEU as a result over continued international assistance over three decades. This represents a decrease in HEU consumption of 278 kg – or 19% compared to the amount of HEU consumed in 1978 in similar facilities. The establishment of baseline measurements for assessing the results of the current HEU minimization effort calls for additional focus on the scope and methodology for HEU minimization. The justification for addressing only 54% of the remaining HEU-fueled research reactors as part of the international minimization programs should be addressed together with a heightened focus on facility decommissioning. Materials with specific weapons-relevant properties should be given higher priority compared to bulk HEU material. 130 HEU-fueled reactors with HEU consumption of 450 kg have been shut down since 1978. There should be no need to convert all the remaining 130 HEU-fueled research reactors, as decommissioning and dismantling should play a more prominent role in the future HEU minimization effort. As other sectors reduce their HEU fuel inventory, there is a need to evaluate the risks associated with the continued use of large quantities of weapons-grade HEU fuel for naval propulsion.

1. Introduction

Highly enriched uranium (HEU) is an essential ingredient in most nuclear explosive and non-explosive applications. HEU is also considered more apt than plutonium for use in an improvised nuclear device (IND). Thus, a recognized objective internationally has been to minimize the use of HEU and reduce the number of locations with HEU. Yet, nearing the 30 year anniversary of this objective, the number of HEU-fuelled installations in operation remains high, HEU is still being used in large quantities, and significant quantities of HEU is still to be found in a large number of unsecured

[1] This paper was submitted by the authors for the conference records.

locations worldwide. This paper analyzes the technical content of a possible HEU cleanout, and, on this basis, suggests future measures for achieving a real clean-out in all nuclear non-explosive applications. The different location and types of HEU-fuelled facilities are discussed; a) propulsion reactors, b) power-related reactors, c) research reactors (steady-state reactors, critical and subcritical assemblies and pulsed reactors). For each of these areas, the present use of HEU is discussed together with the status of current HEU conversion and minimization efforts and the prospects for accelerated HEU phase-out. On the basis of the available technical data and the number of currently operating reactors, annual HEU consumptions are assessed and predictions towards 2020 given.

1.1. Scope and limitations

The concept 'HEU clean-out' has earlier been applied in various ways; covering only civilian facilities or all types of HEU with emphasis on weapons material as this constitutes the largest single category of HEU. In this paper, the term 'HEU-clean-out' has been used to comprise all HEU-fuelled facilities (i.e. non-explosive applications). In addition, one has to assume that large amounts of HEU reside at various fuel fabrication, fuel reprocessing and storage facilities, these are not included in the scope of this paper. Similarly, spent fuel at HEU-fuelled facilities is not discussed in any depth, this is only briefly considered together with each of the categories of facilities in chapter 2.

This study is criteria-based; such as enrichment level and HEU consumption in the assessment of priority measures. The risk associated with HEU fuel may vary considerably with regard to these properties, in addition to e.g. irradiation time or burn-up, and fuel composition. The two former attributes has been discussed recently [1], with the conclusion that the 20% limit for fuel enrichment for converted facilities should be upheld as a sharp limit. Thus, in this paper all applications using fuel enriched above 20% will be discussed. Regarding the various types of facilities, there are obvious differences in risk in relation to the annual consumption of HEU vs. all facilities at the site, the various types of applications and the amount of fresh and spent material moved in and out of the core and stored at the site. As there in principle is no difference in risk with respect to the fact if the material is being used for civilian or military purposes, all facilities has been included.

2. The HEU-fuelled Universe

The present concern for HEU in research facilities could be traced back to the International Fuel Cycle Evaluation (INFCE), launched in 1977 and completed three years later. It was realized then that the widespread use of HEU in different types of applications posed significant proliferation risks. The INFCE study led representatives from 59 states to agree that: "The trade in and widespread use of highly enriched uranium and the production of fissile materials constitute proliferation risks with which INFCE is concerned." [2]. The INFCE study recognized that there were over 140 HEU-fuelled research reactors with significant power-output (between 10 kWt and 250 MWt) in operation in more than 35 countries, each year producing in excess of 1700 MW and consuming more than 1200 kg U-235. As then, the current HEU-fuelled universe includes far more facilities than research reactors, including propulsion reactors, breeder reactors and isotope producing facilities play a significant role regarding HEU in fresh fuel, as in-core or target material or spent fuel.

2.1. Research reactors

Most nuclear research facilities, in many cases small and compact, yet versatile, allows for wide-ranging and multiple use. A research reactor is a reactor used as a research tool for basic or applied research or for training: *"a nuclear reactor used mainly for the generation and utilization of neutron flux (...) for research and other purposes."* [3]. Facilities commonly known as critical and subcritical assemblies, pulsed and fast burst reactors are included in this definition. Research reactors come in variants less than ~W to well above ~MW. The generated fission heat is normally not used for electricity production or other purposes. As the complete status and existence of the different types and location of the existing HEU-fuelled research reactors are not well-known, a summary of the information available has been listed in Appendix 1. As seen in Table 2.1, still almost 140 research reactors facilities remain in operation that fully or partly use HEU, with a nominal power of 1100 MW in total. In this assessment, all types of reactors are included, also military reactors. However, there are no military facilities registered among the high-flux facilities having nominal power above 1 MW, except for the isotope and Pu-production reactors discussed in chapter 2.3.

The pulsed reactors come in all different types and sizes, some also being steady state reactors operating in pulsed mode. The nature and number of the pulsed modulus vary with reactor size and external need; from a limited number pulses a day or pulses with a regular frequency using for example rotors in the core. Thus, the actual number of fissions – fuel consumption – is low, most facilities have lifetime cores. The existing pulsed reactors are found in Russia (at least 8 civilian and military facilities), Uzbekistan, the United Kingdom and the United States (one military facility in Sandia). An example regarding the amount of HEU installed in a pulsed facility, is the Russian BIGR pulsed reactor at the Institute of Experimental Physics at Sarov (VNIIEF); containing 833 kg of 90% HEU as part of the core [4]. In critical assemblies chain reactions may be sustained by means of apt core configuration and appropriate controls. Sub-critical assemblies use the same reactor designs and configuration, but they are incapable of sustaining a chain reaction, either due to the assembly geometry or due to a limited amount of fissile material in the core. Usually also such facilities have life-time cores, examples on fissile material inventory are e.g. 56 kg in the Japanese FCA Tokai assembly (enrichment 20-93%) and 39 kg in the US ATRC assembly (enrichment 93%).

		Russia & NIS	China	Europe	US	Other	Total
Critical assemblies		34	2	6	1	2	45
Pulsed reactors		14	0	1	3	-	18
Steady-state reactors	0,03 – 0,25	1	4	6	3	12	26
	0,25 – 1 MW	1	-	-	1	2	4
	1 – 2 MW	-	-	1	4	2	7
	2 – 10 MW	7	1	1	2	2	13
	10 – 250 MW	9	1	8	4	2	24
Total		66	8	23	18	22	137

Table 2.1: HEU-fuelled research reactors in operation – 2007

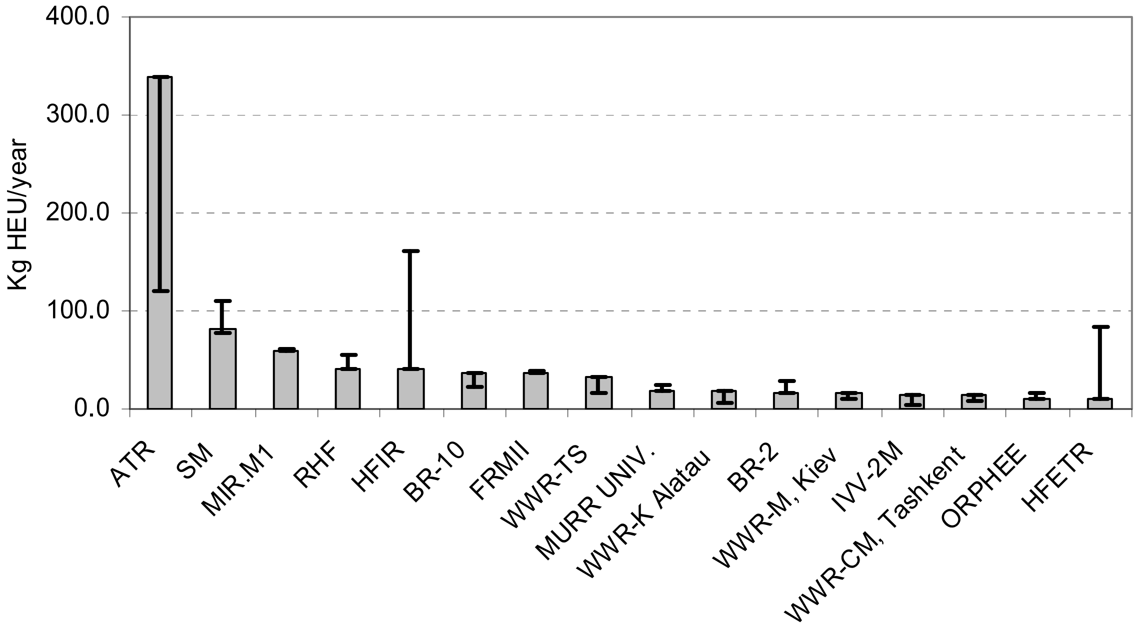

Figure 2.1: HEU Consumption in research reactors – 2006

The HEU consumption varies considerably for the steady-state reactors in Table 2.1. To a certain extent, for the individual facility, this information has been attempted removed for the public domain, most notably from the IAEA Research Reactor Database (RRDB). As the basis for Figure 2.1, the data in RRDB on nominal power, average burn-up and availability has been applied to calculate the annual consumption of U-235. The error bars indicate the span (min./ max.) of consumption estimates for each reactor given in various sources. [5] [6] [7] [8] Sources of uncertainty come from lack of relevant information in the IAEA RRDB and/ or because of data on availability not corresponding with the actual situation. For example, the ATR reactor is said in the current version of the RRDB (last updated 2001 by US competent authorities) to operate 24/7 52 weeks each year, which results in unrealistic results for its fuel consumption. It has also been claimed that the figures for availability reported to the IAEA are larger than the actual situation in order for justifying continued operation. For 2006, the facilities discussed in Figure 2.1 constitute, using the RRDB values for all facilities, 94% of the total consumption of HEU in research reactors.

Another area related to research reactors where HEU is being consumed, and in increasing quantities as seen in Figure 2.2, is the production of Mo-99 – the basis for producing Tc-99, the most widely used radioactive isotope in nuclear diagnostics. Mo99-production may involve HEU or LEU as fissionable target material, though there are also other technologies available, such as solution reactors with fuel permanently dissolved in a liquid, and neutron activation techniques using Mo-98. When using fission, Mo-99 is produced from the reaction U235(n, f)Mo99, with 6,1% yield. The product are often assessed in 6-day Ci; the amount of Mo-99 remaining 6 days after being transported to medical companies worldwide. The main production centres using HEU-based technology, covering currently almost 90% of the Mo-99 used for medical purposes [9], are left to four; the BR-2 reactor, also using HEU in its driver fuel, the Dutch High Flux Reactor (HFR), NRU at Chalk River in Canada and the South-African SAFARI reactor. In Figure 2.2, figures for the yield when producing 6-day Ci from

HEU using the Cintichem process have been used to assess the overall amount of U-235 – as HEU (36% enriched in the case of South-Africa, 90% for the others) – consumed in this process. The calculations are based on a 10% efficiency loss when extracting the Mo-99 from the targets after irradiation and an annual 1% gain through technology improvements. The main feature is the growth; in figure 2.4 the annual growth has been assumed to be 10%. While this technology only a few years ago involved tens of kilograms of HEU, the annual consumption may soon reach 100 kg of HEU. At the same time, a significant increase in the use of non-HEU based technology has to take place to compensate for the large increase in the global Mo-99 market.

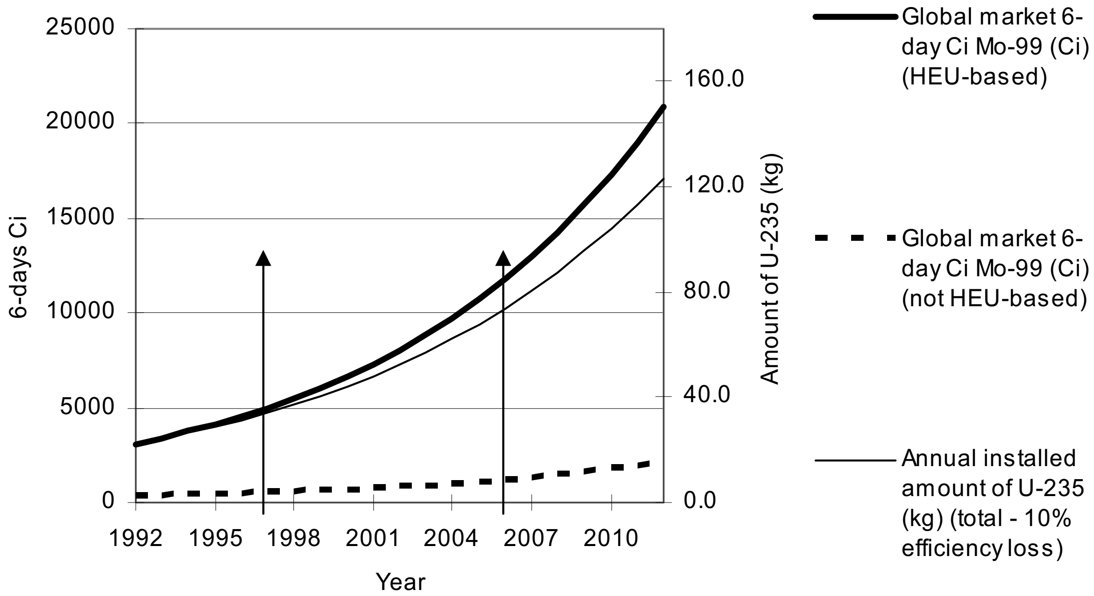

Figure 2.2: Projected Mo-99 production market size and U-235 consumption in research reactors – based on 10% annual growth and market size figures for 1996 and 2005

Two facilities heavily involved in isotope production are also the Russian light-water reactors *Ruslan* and *Ludmila*. As these are military facilities part of the Mayak complex, very little about their operational status, power level and fuel is publicly available. However, generally considered to be about 1000 MWt and using HEU to spike-up the flux in the isotope-producing regions, the U-235 consumption has been assessed to 230 kg, or 750 kg HEU annually. [10]

2.2. Propulsion reactors

In nuclear propulsion; marine vessels such as cruisers, aircraft carriers, submarines and space reactors, HEU has traditionally been the preferred reactor fuel. A somewhat exotic HEU application is found in Northwest-Russia, as fuel for the nuclear-propelled icebreaker fleet; also used as test beds for the development of Russian nuclear submarines. [11] [12] As seen in Table 2.2, the HEU-fuelled nuclear propulsion inventory presently includes 152 reactors in three countries; France has seemingly left this exclusive club, as all current naval reactors reportedly are LEU fuelled except possibly the reactor in *L'Inflexible* which will be decommissioned in a few years (it has not been included in Table 2.2 and Figure 2.3). There are no indications which direction China is taking their nuclear propulsion program, until now the country is, as earlier pointed out, believed to have their propulsion reactors operating on LEU cores. [13] Earlier, also other countries such as Argentina and Brazil have aimed for a nuclear propulsion capability as part of their defence-related installations, as India probably is doing at the moment.

The present consumption (2006) of U-235, as fuel initially enriched above 20%, for the world's civilian and military nuclear-propelled fleet has been calculated in Figure 2.3. The basis is an assessment of a) the annual consumption of cores for each generation of vessels (one to four) which generally correspond to the reactor generations, and b) a core inventory. The core inventory are traditionally not public available, thus, these figures are in most cases based on available data on core-life and burn-up, and assumed operational activity.

	Russia		US	UK
	Civilian	Military	Military	Military
Nominal reactor power < 250 MW	9	30	79	14
Nominal reactor power > 250 MW	-	2	18	-

Table 2.2: HEU-fuelled Propulsion Reactors in Operation – 2006

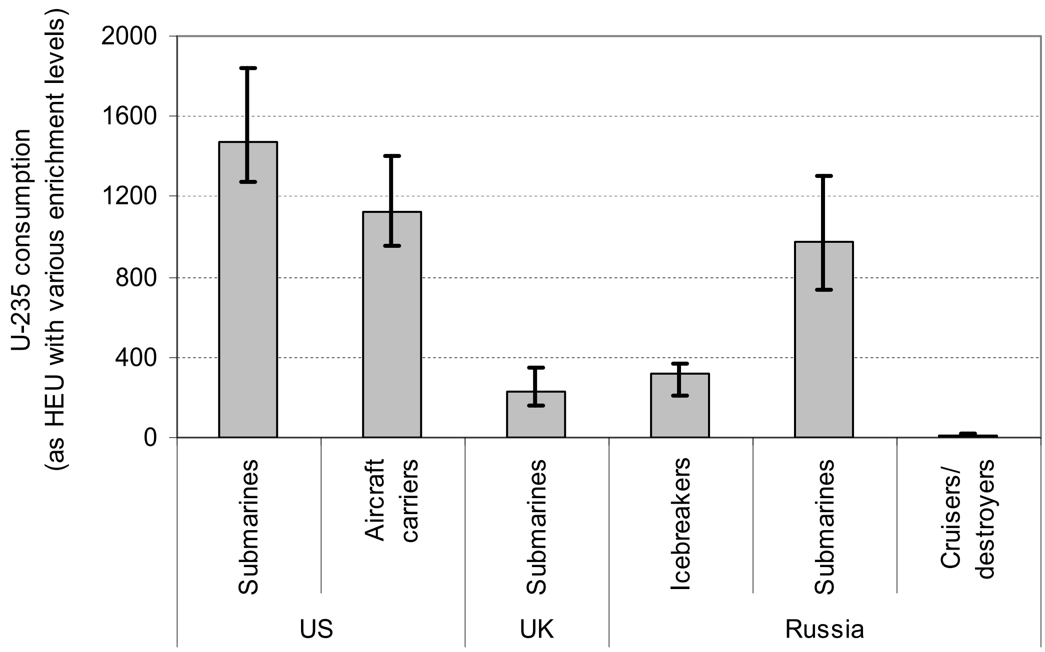

Figure 2.3: HEU consumption in naval propulsion facilities 2006

As the United States started early to use weapons-grade HEU – 97,3% enriched – and currently has by far the largest nuclear fleet; the United States naval facilities dominates the picture. A major component is the carriers; probably with several reactors with high nominal power and large inventories of fuel. In total, the United States has 93 reactors currently in operation, consuming about 2600 kg U-235, out of which 40 % are consumed in the operation of the aircraft carriers as seen in Figure 2.3. The UK Navy had in 2006 13 naval reactors consuming approximately 230 kg U-235, initially enriched to the same level as for the United States naval reactors. Russia is in a peculiar situation as probably only civilian vessels uses 90% enriched HEU, while the submarines and surface vessels probably use medium-level HEU fuel (20-45%). A possible hypothesis is that the Soviet Union, out of concern for the overall operational reliability (redundancy) historically preferred to equip their vessels with two reactors, hence having no need for optimizing fuel efficiency and packing. [11] The most recent 3. generation vessels have one reactor (OK 650 B/ VM-5). There is, however, little data available to indicate the initial core load, operational capacity or any other information if and how the reduction in reactor power has been compensated when using a single reactor configuration. Due to low operational activity and only a few commissioned vessels after 1990, probably less than 20 cores have been consumed by this reactor generation. For 2006, the HEU consumption figures are 0,3 tons (90% enriched) for the civilian fleet. The figure for the Russian submarine fleet is somewhat less than 1 ton U-235 (20-45%).

Regarding space propulsion, both the Soviet Union and United States both have used HEU-fuelled reactors. [14] None such facilities are currently in operation. According to the five year plan for the United States DOE Nuclear Criticality Safety Program, NASA continues to be interested in benchmark experiments for their proposed space reactor to power the Jupiter Icy Moons Orbiter [15]. As the concept of using HEU in space missions have some appealing features with respect to the weight and endurance of the power facility, it has been suggested that the main problem today is rather to have countries completely renounce the option than that the technology is reintroduced any time soon.

2.3. Power-generating reactors

While today's commercial power reactors use low-enriched UO2 or mixed oxide (MOX) fuels, the question if HEU has any role in the development of new reactor systems, particularly fast reactors, has been raised at several occasions. Several countries have in the past built prototype fast breeder reactors that have used or use HEU fuels. Today, as given in Table 2.3, only one breeder reactor fuelled with HEU is currently in operation (the Russian BN-600). In addition to these facilities, there are a number of fast reactor research facilities, such as the Russian *BR-10* and *BOR-60* facilities, the neutron sources *RSV Tapiro* and *YAYOI* which in this paper are included in chapter 2.1.

Country	Facility	Reactor type, nominal power (MW)	U-235 consumption (kg.) (% initial enrichment)	Comments
Russia	Seversk, AD-4	Pu-production, (approx. 2000 MW)	200 (90%)	First criticality 1965, projected shut-down 2008
Russia	Seversk, AD-5	Pu-production, (approx. 2000 MW)	200 (90%)	First criticality 1967, projected shut-down 2008
Russia	Zheleznogorsk	Pu-production, (approx. 2000 MW)	200 (90%)	First criticality 1964, projected shut-down 2011
Russia	BN-600	Fast breeder, 600 MWt	4000 (HEU, 20-25%)	First criticality 1973

Table 2.3: HEU-fuelled Breeder and Pu-production reactors in Operation 2007 and U-235 Consumption

The operational HEU-fuelled breeder and Pu-production facilities have a very different profile in their HEU consumption; while only part of the fuel for the Russian BN-600 is enriched just above 20%, the Pu-production facilities use 90% enriched HEU. Regarding the Russian production reactors, HEU fuel has been claimed to account for 10% of the power generation according to [15], with 30% burn-up and a nominal effect on 2000 MWt, each facility uses about 200 kg HEU (90%) annually. Russia has now agreed to close the Pu-production facilities in Seversk and Zhelenogorsk in 2008 and 2011, respectively.

Limiting new reactor designs, including breeders, to LEU will place few if any limitations on developing future advanced power reactor designs. [10] None of the designs under development today, either through the IAEA's International Project on Innovative Nuclear Reactors and Fuel Programs (INPRO) or through the Generation IV International Forum (GIF) program, call for the use of HEU. The Russian program, like others worldwide, does not envisage the use of HEU in new generations of fast breeder reactors [16].

While there are only a few fast HEU-fuelled reactors in operation, the decommissioned fast facility BN-350 in Kazakhstan has caused considerable concern the last years as large amounts (~of HEU enriched to 26%) has been stored. In October 2005, the removal of this material was initiated by the government of Kazakhstan in close cooperation with NTI [17].

3. The HEU Minimization Agenda – Facility Conversion and Shutdown

The two main avenues for minimization of HEU-fuelled facilities are *decommissioning* and *conversion*. When considering the progress in HEU minimization since the INFCE-study was completed, these two processes have, as seen in Figure 3.1 resulted in an equal decrease of HEU consumption regarding research reactors. Thus, a main issue for the future is to design the global research reactor sector in a way that makes it possible to decommission outdated, not justified and under-utilized HEU-fuelled reactors of various types and sizes. The sudden increase in 2004 was due to the commissioning of the German FRM-II reactor. As the limited need for using HEU in breeder reactors already has been discussed, these facilities will not be further addressed here. When considering the development described in Figure 3.1 and 3.2, there is a need for considering the future potential for conversion vs. decommissioning.

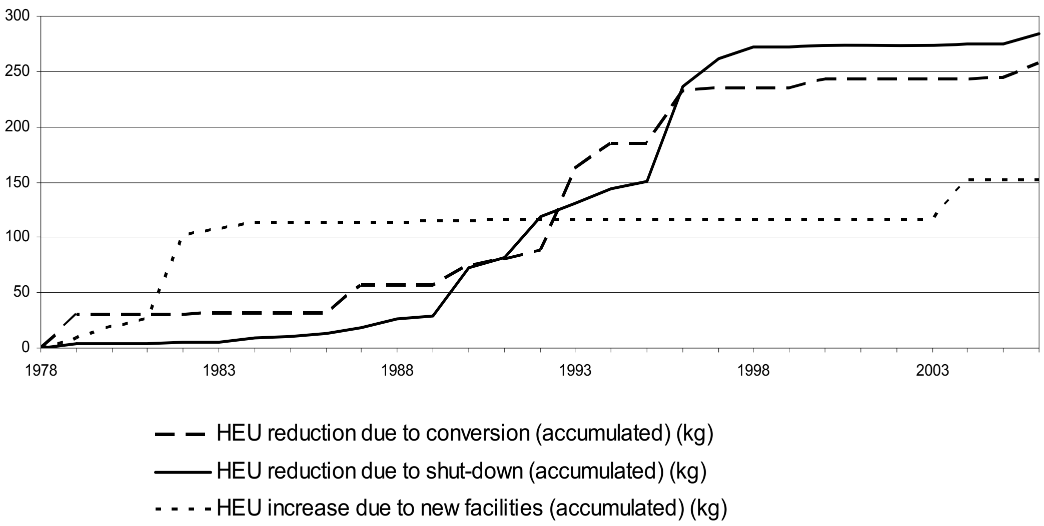

Figure 3.1: Changes in U-235 Consumption for Research Reactors – Conversion vs. Decommissioning 1978 – 2006

Large efforts have been on-going since before the INFCE-study was finished to convert existing facilities. Regarding the civilian sector, the United States initiated the Reduced Enrichment for Research and Test Reactors (RERTR) program in 1978 to develop the technical means to convert HEU fuelled research reactors to the use of LEU and assist in the conversion process. A corresponding effort was initiated in the Soviet Union aiming at reducing the enrichment levels in foreign supplies to 36%. The Global Threat Reduction Initiative (GTRI) was launched in May 2004 in cooperation with the International Atomic Energy Agency (IAEA), but is a United States program operated out of the United States Department of Energy's (DOE) National Nuclear Security Administration (NNSA) with strong support from a number of countries. Today the GTRI includes all United States programs to protect and also assist in the removal of vulnerable material; also the RERTR program. These programs are the initiative responsible for the projected decrease in HEU consumption as a result of conversion as described in Figure 3.1.

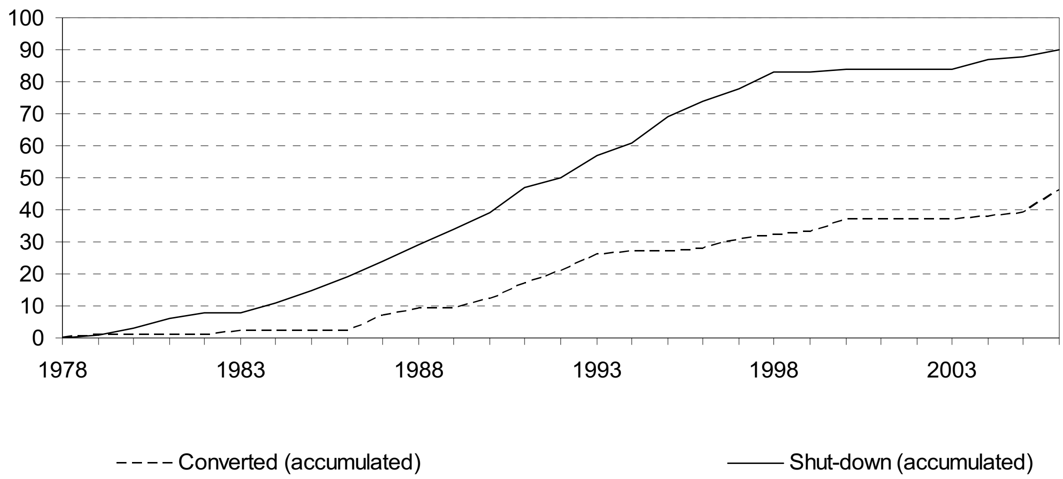

Figure 3.2: Changes in Number of HEU-fuelled Facilities – Conversion vs. Decommissioning 1978 - 2006

The decommissioning option, despite its successes as described above, has no international programs as support, and has to be approached by addressing the possible incentives and the individual reactors. A recent initiative less concerned with conversion and more with minimization and clean-out was taken by the Norwegian government at the NPT Review Conference in 2005 [18]. In June 2006 an international symposium was held in Oslo with the objective of establishing international consensus on relevant technical issues related to HEU minimization, and for reaching agreement on the way forward for a concerted international effort within the framework of existing international agreements, organizations and assistance programs. [19] The results of the international conversion programs described above was taken note of; e.g. that most small and intermediate sized reactors can be converted without significant technical impediments or loss in reactor performance, and that new power reactor concepts can be developed without the use of HEU. Regarding HEU-fuelled high-flux facilities, it was agreed that the justification of those should be evaluated closely and in the view of further development of the concept of shared facilities or centres of excellence.

The GTRI has assessed the individual reactors in the RERTR – perspective as seen in Figure 3.3; the possibility for conversion, and has concluded that 49 reactor may be converted with existing fuels, 26 needs new high-density fuels and 54 facilities are outside the scope of the GTRI program and have therefore not been assessed in this context. Before assessing the different categories in Figure 3.3, additional assumptions may be added as a basis for establishing the future agenda for HEU minimization: There is no reason for having HEU in low-power reactors below 1 MW, as the main purposes with these reactors are education and training, testing of instrumentation and, if suitable, neutron radiography. However, most of these facilities do have life-time cores are of less concern when considering some of the criteria mentioned in chapter 1.1. Thus these facilities do not constitute an independent need for a conversion program. Since the Pu-production reactors have a well-defined shut-down date, those will not be further discussed below.

3.1 Research reactors

Out of the facilities listed in Figure 2.1, the WWR-reactors and HFETR are examples of reactors possible to convert with existing fuels, while the conversion of the other facilities is dependant on the development of new fuels (see Figure 3.3). The development of high-density fuels was restarted in the second half of the 1990-ties as the funding of the RERTR increased substantially. The main avenues chosen then was to continue the effort on silicide fuel, which had shown promising results with densities up to approximately 6 gU/ cm^3, and other dispersion fuel types containing U-Mo and U-Zr-Nb alloys. The Russian program insisted focusing on the a uranium-oxide cermet fuel, which turned out to be a failure; partly due to the fact that Russian fuel fabricators did not had the ability produce the fuel at a reasonable cost. The most advanced LEU fuel available today is a dispersion fuel – U_3Si_2Al with density 4.8 Ug/cm^3. Today this fuel type has been in use for over a decade.

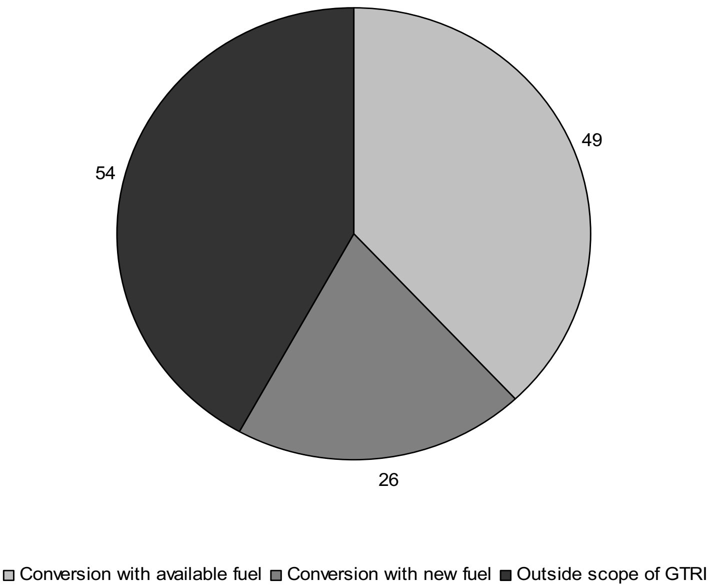

Figure 3.3: GTRI categories of HEU – fuelled research reactors - 2007

The other candidate high density fuel is a UMo alloy, often referred to as monolithic fuel. For some research reactors, for example the large HFIR research reactor in the US, U-Mo monolithic fuel with a density up to 16 g/cm^3 is needed for conversion to LEU. The expectations for a break-through have been large; in 2000 U-Mo 6 Ug/cm^3 dispersion fuel was planned to be qualified within the end of 2003 and 8–9 Ug/cm^3 by the end of 2005. In 2003, the failed progress in the development of high-density fuel led to an initiative to extend the May 2006 deadline for the acceptance of spent fuel from HEU-fuelled facilities. Scientists from France, Russia and the US have confirmed that U-Mo dispersion fuel with moderate density (5.4 gU/ cm^3) and high density (8 gU/ cm^3) failed to pass radiation tests in 2004. The objective now is to complete the development and qualification of high density fuels within 2010 and the actual conversion within 2014 for most facilities. However, even if this fuel becomes available, there exist reactors which cannot be converted to LEU without changes in fuel geometry, such as the German FRM-II reactor.

Even if accepting the current schedule for conversion of the current high-flux facilities, a large number of facilities will remain HEU-fuelled also beyond 2014. In Figure 3.4, all projected conversions –primarily all US HEU-fuelled civilian facilities – are included, in addition to published decommissioning dates. A radical shift in the HEU consumption in 2014 is noted, however, for most existing HEU-fuelled facilities no conversion or decommissioning date has been set. The main reason is that 1) a large part of these facilities has not been part of any minimisation program until recently, such as non-steady-state reactors and critical assemblies, 2) they are said to be outside scope, being for example military facilities – as seen in Figure 3.3.

At the moment there are some discrepancies between the scope of the GTRI and the RERTR program. The latter program includes currently 12 critical assemblies on their list of candidates for conversion, however, no rational for this decision, or the lack of decision regarding any other of these life-time facilities given in Appendix 1, has been registered. Therefore, a priority task should be to assess the need for these facilities and create a new initiative within the GTRI for addressing all facilities of these types as soon as possible in the context of HEU minimization, and then also include decommissioning as an option.. There should no need for using HEU in pulsed reactors, critical and subcritical assemblies except in very special cases. These facilities are installations which may be replaced by adequate tools for computer modelling; probably only a few facilities would cover the need for being able to physically building and adjusting a physical mock-up of critical material. Most HEU-fuelled critical facilities are no longer needed because neutronic codes for standard reactor types are well tested, and computers are now fast enough to make detailed virtual simulations of the reactor in question. However, conversion is not an option as the various options for simulating criticality disappears with different configurations or fuel materials.

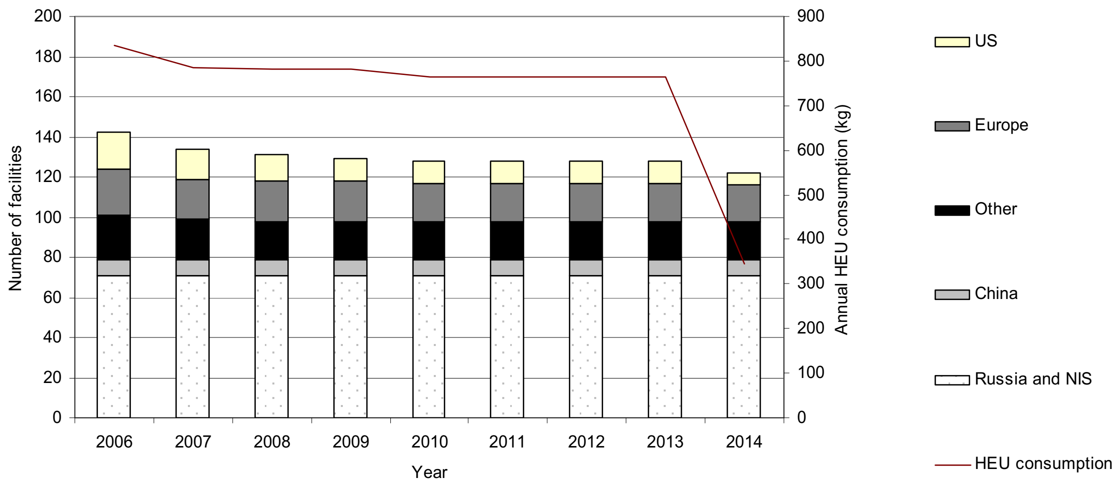

Figure 3.4: Projected Development Regarding the Conversion of Research Facilities 2006 - 2015

When the facility of which the critical assembly are a mock-up has been decommissioned or converted, the assembly loose its main justification. In addition, the research focus of nuclear engineering has changed; the development and testing of new reactor and fuel materials and power plants designs solutions has given place for standardization, exit strategies and aging considerations, thus, the small innovative facilities with exotic fuels are less needed. The increasing concern for safety and security, in particular when considering HEU-fuelled facilities, also for dismantling and decommissioning activities, makes it even more difficult to sustain the continued operation of the HEU-fuelled facilities. Decommissioning cost may even be a driving force for continued operation as no governmental funds has been set aside for this purposes.

While the objectives for conversion as discussed above not include considerations on the justification, these have implicitly been introduced of the IAEA. The IAEA has dedicated resources to issue guidance documents for the strategic planning for research reactors in order to establish a strategic plan which *"provides the rationale for the future for the facility"*. [20] The IAEA has also made clear that it will only *"support requests for new facilities or equipment for research reactor utilization if they are accompanied by a strategic implementation plan clearly demonstrating that the items requested are necessary to achieve the plan."* [21] Today more proliferation resistant solutions should be considered in addition to the possibility of having shared facilities or centres of excellence. The US has now constructed an alternative source of high flux, the Spallation Neutron Source, which will be their *"frontier research facility for neutron scattering to analyze structure of matters and materials.*" [22] Such projects are in the multibillion class and thus beyond the scope of most states or even regions. On this basis, there is an obvious need for developing arrangements for sharing access to new high-flux facilities based on alternative technology. Another proposal is to consider how to get the most optimal results of the available experimental set-up – without using HEU – thus, how to develop LEU-fuelled high-flux facilities and or improve the experimental apparatus. [23]

The large unknown in this scenario is if the decommissioning effort will speed up in the years to come. When considering the age of the facilities in the two categories of facilities targeted for conversion the years ahead (see Figure 3.3) – as seen in Figure 3.5 and 3.6, the majority of those for which the new fuels are being developed will in average soon pass 40 years of operation. There is an obvious need for regions, such as EU, or individual countries, to establish schedules for decommissioning or conversion. Regarding the former, there is – at the strategic level of research reactor capabilities – a growing concern among operators is how to justify existence in a shrinking market with lower governmental subsidies.

Figure 3.5: Year of first criticality - research reactors which can be converted with existing fuels

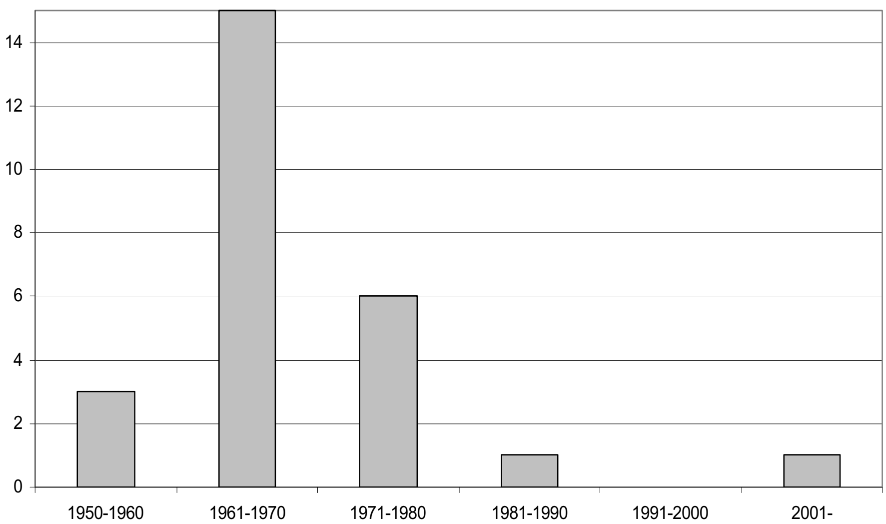

Figure 3.6: Year of first criticality - research reactors which require new fuels for conversion

A the isotope demand is increasing with 5-10% pr. year, the argument for having one new high –flux reactor for isotope production online by 2010-15, and another by 2015-2020 has been made. However, the emerging Mo-99 production activities in Argentina, Romania, Indonesia, Australia and US, at the University of Missouri, have shown that there are no fundamental a priori technical impediments for establishing new production capacities producing ^{99}Mo based on LEU, and that the emerging norm is to use LEU technology. The current lack of progress regarding conversion has led the US DoE to engage the US National Academy of Sciences to assess ways and means to provide new options for how to alleviate the current dependence on HEU in the production of Mo-99 for domestic use in the US. There are no specific plans with the four main producers to convert to LEU targets. One of the main objectives for Mo-99 production should be that all future production will be established on the basis of LEU technology. This is the focus of an IAEA Coordinated Research Program which seems to succeed in getting potential producers globally together for an efficient dissemination of the available knowledge on isotope production processes, target fabrication and waste handling.

3.2 Military Naval Reactors

The military naval reactors are the area with most reactors and the largest amount of material being spent in 2006. If projecting the use of HEU into the period between 2006 and 2020, as seen in Figure 3.4, there are no plans to reduce the use of HEU in the United States, United Kingdom or Russia, while France is about to phase-out their reliance on HEU in their military vessels. France made a decision in the seventies to run their new Rubis submarine on LEU fuel. The Rubis-class is the smallest nuclear submarine ever built with a displacement on 2500 tons. The US, Russia, and the UK have shown no interest in similar initiatives with respect to their navies or, in the case of Russia, its icebreaker fleet. The United States long-term plan seems to introduce one Virginia-class submarine every year until 2020, while reducing the number of Los Angeles-class by one every year. The influence on the annual consumption is small as seen in Figure 3.1; the overall level on 2,6 metric tons will remain constant. The replacement of the *Vanguard*-class in UK will have effect only well beyond 2020. The United States has reserved 180 tons of HEU for naval and other reactor fuel. UK has stated that none of their HEU stocks will be declared excess as the material has been set aside for their submarine program. Russia is assumed to have reserved 100 tons of HEU for naval reactors. The main arguments for maintaining high enrichment levels are compact cores and high endurance, in the most recent cases the reactor does not need to be refuelled as core life-time corresponds to the life time of the vessel itself.

The United States Navy was challenged in 1995 to assess the potential for conversion of the submarine cores to LEU, and the options adjusting endurance or/ and core volume were assessed. The main conclusion was that LEU-fuelled reactors would, among other elements, cause greater occupational radiation exposure, generate more waste and have considerable economical consequences. To preserve the longevity of the core, the core volume had to be increased threefold. Subsequently the pressure vessel, the reactor compartment and the size and the cost of the vessel itself would have to increase correspondingly, according to the assessment construction costs would increase “about 28% for aircraft carriers and 26% for submarines – about $1.1 billion pr. year” [24]. The assessment was made without any reference to the possibly larger implications of continued operation on HEU. However, the most important inherent problem with the assessment was, due to the high level of secrecy surrounding the design and operation of these installations, the lack of details. The conclusion in one of the few open-source studies on conversion of nuclear-propelled reactors was that the dimensional increase are sufficiently small that they can easily be compensated for by the use of an integral reactor design as used in the French Rubis. [25] The UK is currently amidst to make a decision on what to do when the operational life-time of the naval reactor in the Vanguard-class boats end in mid 2020-ties.

The UK should include an assessment of the potential for using LEU when designing the replacement for the PWR-2 in Vanguard - class. The potential content of an effort to consider the potential for conversion of nuclear submarines would be to 1) assess the French approach; rational and relevance for other countries, 2) complete an independent assessment on a) fuel design, b) impact on pressure vessel, reactor compartment and, subsequently, on the operational parameters. The United States probably has with the recent introduction of life-time cores a considerable advantage regarding optimization of operational costs and, possible, directly related properties such as diving depth and endurance, compared to for example Russian vessels. However, continued effort should be put into translating design modifications into operational properties in a transparent way to pave the way for an evaluation of the pro et contras regarding continued operation with HEU fuel. As long as the area of military propulsion is not addressed at all, this may affect the support for the US-led effort in the civilian nuclear sector. The most promising area is the Russian icebreaker technology as more space is available and, due to intensive operations, the fact that these vessels are being refuelled quite frequently already (several vessels a year). A naval reactor using LEU has already been developed as a basis for the Russian floating power concept where a prototype is being constructed at the moment, and one study has been completed showing the potential for converting these reactors to LEU using high-density fuel types. This study should have a follow-up with respect to other types of Russian-designed naval reactors. Regarding a future Chinese and Indian nuclear-propelled navy, the current UK deliberations are potentially extremely important, as would be a signal to evaluate more closely LEU-fuelled submarines for the near future.

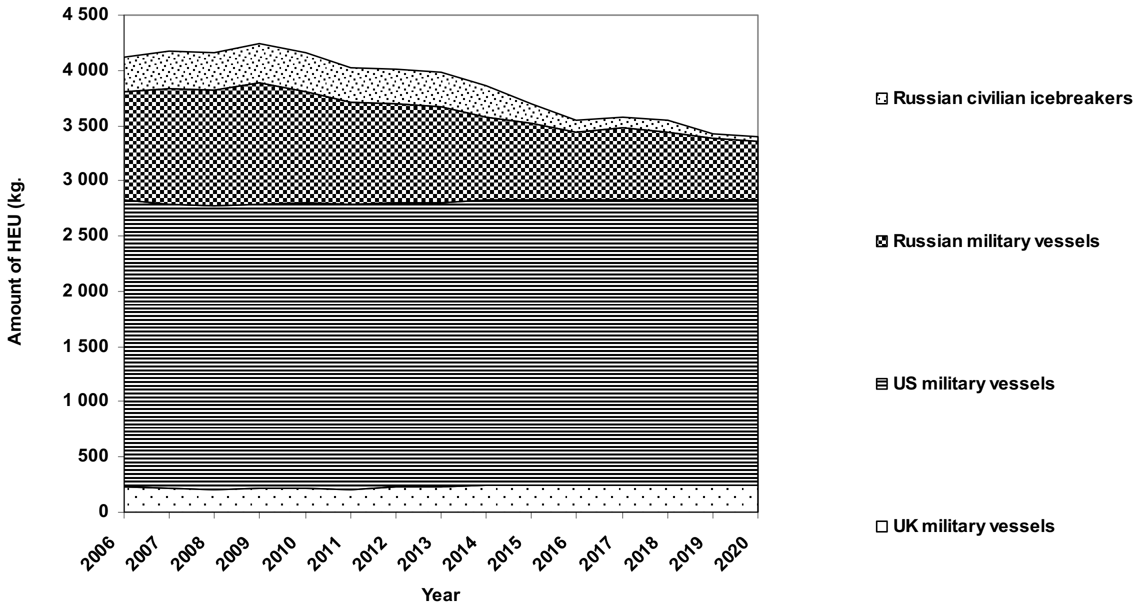

Figure 3.7: Projected HEU consumption in naval propulsion facilities 2006 - 2020

When considering the role of decommissioning for use of HEU for propulsion, Russia stands out – possibly involuntary – as promising case. While HEU minimization seems not to be of main importance to the Russian government in other areas, the decline of HEU consumption in the Russian Navy will continue as old vessels are taken out of service and the introduction rate of new vessels remains low. The question is if Russia will aim to construct new military vessels with higher endurance – probably life-time cores – if not convinced otherwise. A credible scenario for the nuclear icebreakers is to include the commissioning of the brand new vessel, 50's Victory, recently completing trial journeys outside St. Petersburg, and another vessel in 2012. The present icebreaker fleet will retire completely within 8 years according to an estimate made in 2000. [10]

4. Conclusions and Recommendations

Today, when considering all military and civilian HEU-fuelled facilities, there are over 300 civilian and military HEU-fuelled facilities consuming approximately 10 metric tons of HEU. A large part of this material remains as HEU after being used as fuel or target material. The main contributor is nuclear propulsion, in particular military naval vessels, and other various types of facilities in Russia and the United States. Isotope production and civilian research reactors in other countries represent areas of considerable importance when aiming for an all-encompassing HEU clean-out in non-explosive applications. A considerable amount of efforts and resources are spent as part of international conversion efforts, most notably the GTRI initiative. The objective is to convert all civilian facilities by 2014. However, without any radical change in the international approach to the continued operation of HEU-fuelled facilities, in particular in Russia, a large number will continue to be in operation in 2020.

The current initiatives address only civilian facilities using fuel and reactor conversion as its primary tool for achieving HEU minimization. The justification of HEU-fuelled high-flux facilities should be evaluated closely as developing further the concept of shared facilities or centres of excellence, and increased emphasis should be put on decommissioning. New power reactor concepts can be developed without the use of HEU. There is a need for further consideration on the conversion of targets for large Mo-99 production facilities. The main impediment is lack of commitment in countries with advanced nuclear fuel technology infrastructure to decommission or convert HEU-fuelled facilities and fund the relevant international activities, such as the GTRI and the G-8 Global Partnership. When considering the future prospects for having more reactors converted, a relevant conclusion is that the international community at the moment is not able to prioritize its need for flux and related services with its need for reduced risk of diversion of HEU, and that countries like the United States, Russia and the United Kingdom see no significant proliferation risk associated with the use of large quantities of HEU in the military sphere.

When considering past experiences, reactor decommissioning has been the most important instrument in reducing the number of HEU-fuelled facilities and the HEU consumption. A separate program for the decommissioning of the HEU-fuelled facilities should be initiated, thereby providing other alternatives to the relevant sites in stead of the continued operation of old and outdated facilities. This might be one element in the revitalization of the GTRI-initiative for establishing a program covering all types of facilities worldwide.

5. Acknowledgements

This paper has been written as part of the effort with the International Panel on Fissile Materials (IPFM) (www.fissilematerials.org) to develop the technical basis for practical and achievable policy initiatives to secure, consolidate, and reduce stockpiles of highly enriched uranium and plutonium. The authors would therefore like to express our gratitude for the continued exchange of opinions and knowledge with the members of IPFM, in particular Dr. Matthew Bunn, Dr. Alexander Glaser, IPFM co-chair Frank von Hippel, and Ms. Cristina Chuen has also been instrumental in sharing her knowledge and information on the HEU minimization efforts. Any mistakes, errors and inconsistencies are the sole responsibility of the authors.

6. References

[1] Glaser A; On the Proliferation Potential of Uranium Fuel for Research Reactors at Various Enrichment Levels; Science & Global Security; Volume 14, No. 1; 2006; p 1-24. (2006).

[2] International Nuclear Fuel Cycle Evaluation; Report of INFCE Working Group 8, Advanced Fuel Cycle and Reactor Concepts; International Atomic Energy Agency; 1980; p 43.

[3] Code of Conduct on the Safety of Research Reactors, IAEA, 2004.

[4] Frank von Hippel, *HEU* in Critical Assemblies, Pulsed Reactors and Propulsion Systems, Oslo (technical workshop), June 18, 2006, http://www.nrpa.no/symposium/ (accessed at May 2, 2007).

[5] Albright D, Berkhout F, Walker W; Plutonium and Highly Enriched Uranium 1996 World Inventories, Capabilities and Policies; Oxford University Press; 1997; p 486-489.

[6] Matos J E; Relationships Between the RERTR Program and the U.S. Spent Fuel Acceptance Policy; WM'98, Tucson, Arizona; March 1-5, 1998.

[7] Civiak R L; Closing the Gaps, Securing Highly Enriched Uranium in the Former Soviet Union and Eastern Europe; Federation of American Scientists; 2002.

[8] Meyer M; A Global Overview of High Density U-Mo Fuel Development Efforts; Oslo Symposium on Minimisation of Highly Enriched Uranium in the Civilian Nuclear Sector; 2006.

[9] von Hippel F. and Kahn L; Feasibility of Eliminating the Use of Highly Enriched Uranium in the Production of Medical radioisotopes; Science and Global Security, Volume 14, 2006.

[10] Bukharin O; Securing Russia's HEU Stocks; Science and Global Security, Volume 7, 1998,.

[11] Reistad O, Mærli M B, Bøhmer N; Russian Naval Nuclear Fuel and Reactors: Dangerous Unknowns; The Nonproliferation Review; Vol. 12, No. 1 March 2005; p. 163-197.

[12] Bukharin O; The Russian Icebreaker Fleet (2006); Science and Global Security, Volume 14, 2006, pp. 25-31.

[13] Ma C, von Hippel F; Ending the Production of Highly Enriched Uranium for Naval Reactors; The Nonproliferation Review; Vol. 8, No. 1 Spring 2001; p 86-101.

[14] Voegeli N; Spave Nuclear Reactors: History and Emerging Policy Issues; The Nonproliferation Review; Vol. 14, No. 1 March 2007; p. 163-175.

[15] United States Department of Energy; Nuclear Criticality Safety Program, Five Year Plan; October 2004; http://www.deprep.org/2005/AttachedFile/tb05f01b_enc2.pdf accessed 10.05.2007.

[16] Massimo Salvatores, Advanced Fast Reactor Development Requirements: is there any need for HEU?, Oslo (technical workshop), June 18, 2006; http://www.nrpa.no/symposium/ (accessed at May 2, 2007).

[17] IAEA-TECDOC-1452 (2005); Management of high enriched uranium for peaceful purposes: Status and trends; International Atomic Energy Agency; June 2005.

[18] Nuclear Threat Initiative, Government of Kazakhstan and NTI Mark Success of HEU Blend-Down Project; October 8, 2005; http://nti.org/c_press/release_Kaz_100805.pdf accessed 11.05.2007.

[19] NPT/CONF.2005/MC.III/WP.5 (2005), Combating the risk of nuclear terrorism by reducing the civilian use of highly enriched uranium, Working paper submitted by Iceland, Lithuania, Norway and Sweden to the NPT Review Conference in New York, 2005.

[20] Harbitz O and Aas K (Chair's Summary), International Symposium on the Minimisation of Highly Enriched Uranium (HEU) in the Civilian Sector, June 20, 2006. For more information on the HEU Symposium, see http://www.nrpa.no/symposium/ (accessed May 5, 2007).

[21] IAEA-TECDOC-1212 (2001); Strategic Planning for Research Reactors; International Atomic Energy Agency; Vienna; 11 May 2001.

[22] Yanglai Cho (2000), Spallation Neutron Source, http://www.akpa.org/article/ycho.pdf (accessed at October 11, 2006).

[23] Glaser A (2006); The Role of Neutron Scattering Simulations In Identifying Optimum Strategies to Convert Research Reactors to Low Enriched Fuel; Presentation at The International Workshop on Advanced Monte Carlo Simulations in Neutron Scattering, October 3-4, 2006 Paul Scherrer Institute, Switzerland (http://www.princeton.edu/~aglaser/talk2006_psi.pdf), accessed at May 2, 2007.

[24] US Navy (1995) US Naval Nuclear Propulsion; Report on use of Low enriched uranium in naval nuclear propulsion.

[25] Ippolito T (1990); Effects of variation of uranium enrichment on nuclear submarine reactor design; Master Thesis, Massachusetts Institute of Technology, Dept. of Nuclear Engineering, 1990.

Appendix 1: List of operational HEU-fuelled Research Reactors*

Country	Name of facility	Type of facility	Civilian/ military	First criticality	Power level (MWt)
Argentina	RA-6	Steady state	Civ.	1982	0.5
Belarus	YALINA-Booster	Critical assembly	Civ.		
Belgium	BR-2	Steady state	Civ.	1961	100
Canada	Slowpoke Alberta	Steady state	Civ.	1977	0.02
Canada	Slowpoke Saskatchewan	Steady state	Civ.	1981	0.02
Canada	Slowpoke-2 Halifax	Steady state	Civ.	1976	0.02
Chile	RECH-2	Steady state	Civ.	1989	
China	HFETR Critical	Critical assembly	Civ.	1979	0
China	Zero Power Fast Reactor	Critical assembly	Civ.	1970	0.00005
China	HFETR	Steady state	Civ.	1979	125
China	IAE	Steady state	Civ.	1984	0.027
China	MJTR	Steady state	Civ.	1991	5
China	SD	Steady state	Civ.	1989	0.033
China	SH	Steady state	Civ.	1991	0.03
China	SZ	Steady state	Civ.	1988	0.03
Czech Republic	LVR-15 REZ	Steady state	Civ.	1957	10
Dem. P.R. of Korea	IRT-DPRK	Steady state	Civ.	1965	8
Former Yugoslavia	RB	Critical assembly	Civ.	1959	
France	Eole	Critical assembly	Civ.	1965	
France	MASURCA	Critical assembly	Civ.	1966	0.003
France	MINERVE	Critical assembly	Civ.	1959	0.0001
France	Pile Azur	Critical assembly	Mil.	1962	0.0001
France	ORPHEE	Steady state	Civ.	1980	14
France	RHF	Steady state	Civ.	1971	58.3
France	SILENE	Steady state	Mil.	1974	0.001
Germany	FRMII	Steady state	Civ.	2004	20

Ghana	GHARR-1	Steady state	Civ.	1994	0.03
Hungary	BUDAPEST RES. REACTOR	Steady state	Civ.	1959	10
India	APSARA	Steady state	Mil.	1956	1
Iran	ENTC MNSR	Steady state	Civ.	1994	0.03
Israel	IRR-1	Steady state	Civ.	1960	5
Italy	RSV Tapiro	Steady state	Civ.	1971	0.005
Jamaica	UWI CNS SLOWPOKE	Steady state	Civ.	1984	0.02
Japan	FCA Tokai research establishm.	Critical assembly	Civ.	1967	0.00002
Japan	KUCA Kyoto University	Critical assembly	Civ.	1974	0.000001
Japan	KUR	Steady state	Civ.	1964	5
Japan	UTR KINKI	Steady state	Civ.	1961	0
Japan	YAYOI	Steady state	Civ.	1971	0.002
Kazakhstan	WWR-K CA	Critical assembly	Civ.	1972	0.0001
Kazakhstan	EWG 1	Steady state	Civ.	1972	60
Kazakhstan	IGR	Steady state	Civ.	1961	10
Kazakhstan	WWR-K Alatau	Steady state	Civ.	1967	6
Mexico	TRIGA MARK III	Steady state	Civ.	1968	1
Netherlands	LFR	Steady state	Civ.	1960	0.03
Nigeria	NIRR-0001	Steady state	Civ.	2004	0.03
Pakistan	PARR-2	Steady state	Civ.	1989	0.03
Poland	MARIA	Steady state	Civ.	1974	30
Russia	BOR-60	Breeder	Civ.	1969	60
Russia	659	Critical assembly	Mil.	1963	0.0001
Russia	1125	Critical assembly	Mil.	1975	0.0006
Russia	FM	Critical assembly	Civ.	1971	0.00001
Russia	Astra	Critical assembly	Civ.	1981	0.0001
Russia	BFS-1	Critical assembly	Civ.	1961	
Russia	BFS-2	Critical assembly	Civ.	1969	
Russia	BR-1	Critical assembly	Civ.	1965	0.00005

Russia	CA MIR.M1	Critical assembly	Civ.	1966	0.0001
Russia	Delta	Critical assembly	Civ.	1985	0.0001
Russia	Emphir-2M / EFIR-2M	Critical assembly	Civ.	1973	0.0001
Russia	FM MR	Critical assembly	Civ.	1971	0.0001
Russia	FS-1M	Critical assembly	Civ.	1970	0.000002
Russia	ISKRA	Critical assembly	Civ.	1996	0.0002
Russia	Kvant	Critical assembly	Civ.	1990	0.001
Russia	MAKET	Critical assembly	Civ.	1976	
Russia	Nartsiss-M2	Critical assembly	Civ.	1983	0.00001
Russia	FS-2	Critical assembly	Mil.	1972	
Russia	FS-4	Critical assembly	Mil.	1976	
Russia	FS-5	Critical assembly	Mil.	1987	
Russia	RF-GS	Critical assembly	Civ.	1962	0.00001
Russia	SF-1	Critical assembly	Civ.	1972	0.0001
Russia	SF-7	Critical assembly	Civ.	1975	0.0001
Russia	SGO	Critical assembly	Civ.	1968	0.00001
Russia	SO-2M	Critical assembly	Mil.	1976	
Russia	FM PIK	Critical assembly	Civ.	1983	0.0001
Russia	STEND-2	Critical assembly	Mil.	1969	0.002
Russia	STEND-3	Critical assembly	Mil.	1967	0.002
Russia	STEND-4	Critical assembly	Mil.	1967	0.0005
Russia	STEND-5	Critical assembly	Mil.	1967	0.0005
Russia	Strela	Critical assembly	Civ.	1968	0.00001
Russia	T2	Critical assembly	Civ.	1965	2E-07
Russia	BARS-4	Pulsed	Mil.	1984	
Russia	BARS-5	Pulsed	Civ.	1986	0.01
Russia	BARS-6	Pulsed	Civ.		
Russia	BIGR	Pulsed	Mil.	1977	
Russia	BIR-2M	Pulsed	Mil.	1965	

Russia	FBR_L	Pulsed	Civ.	1981	
Russia	GIR 2	Pulsed	Mil.	1993	
Russia	HYDRA (IIN-3M Gidra)	Pulsed	Civ.	1972	0.01
Russia	IBR-2	Pulsed	Civ.	1977	2
Russia	IBR-30	Pulsed	Civ.	1970	0.01
Russia	Igrik	Pulsed	Civ.	1975	0.03
Russia	VIR-2M	Pulsed	Mil.	1980	
Russia	Yaguar (NHUAR)	Pulsed	Civ.	1990	0.01
Russia	ARGUS	Steady state	Civ.	1981	0.02
Russia	BR-10	Steady state	Civ.	1958	8
Russia	IR-8	Steady state	Civ.	1981	8
Russia	IRT, MEPhI	Steady state	Civ.	1967	2.5
Russia	IRT-T, Tomsk	Steady state	Civ.	1967	6
Russia	IVV-2M	Steady state	Civ.	1966	15
Russia	MIR.M1	Steady state	Civ.	1966	100
Russia	OR	Steady state	Civ.	1989	0.3
Russia	RBT-10/2, Minatom	Steady state	Civ.	1984	7
Russia	RBT-6, Minatom	Steady state	Civ.	1975	6
Russia	SM	Steady state	Civ.	1961	100
Russia	WWR-M	Steady state	Civ.	1959	18
Russia	WWR-TS	Steady state	Civ.	1964	15
Russia	R-1	Critical assembly	Mil.	1992	
Switzerland	AGN 211 P	Steady state	Civ.	1959	0.002
Syrian Arab Republic	SRR-1	Steady state	Civ.	1996	0.03
UK	VIPER	Pulsed	Mil.	1967	0.0005
UK	IMPERIAL COLLEGE (CONSORT)	Steady state	Civ.	1965	0.1
Ukraine	WWR-M, Kiev	Steady state	Civ.	1960	10
US	ATRC	Critical assembly	Civ.	1964	0.005
US	Fast-burst FBR	Pulsed	Mil.	1964	10

US	SPR-II	Pulsed	Mil.	1967	0.005
US	SPR-III	Pulsed	Mil.	1975	0.01
US	ACRR	Steady state	Civ.	1967	4
US	ATR	Steady state	Civ.	1967	250
US	HFIR	Steady state	Civ.	1965	85
US	MITR-II	Steady state	Civ.	1958	4.9
US	MURR UNIV.	Steady state	Civ.	1966	10
US	NBSR	Steady state	Civ.	1967	20
US	NRAD	Steady state	Civ.	1977	0.25
US	NTR General Electric	Steady state	Civ.	1956	0.1
US	OSTR, STATE UNIV.	Steady state	Civ.	1967	1.1
US	UWNR UNIV.	Steady state	Civ.	1961	1
US	WSUR, ST.UNIV.	Steady state	Civ.	1961	1
Uzbekistan	Photon	Pulsed	Civ.	1975	1.5
Uzbekistan	WWR-CM, Tashkent	Steady state	Civ.	1959	10
Vietnam	Dalat Research Reactor (DRR)	Steady state	Civ.	1963	0.5

The list of facilities is an extract from the HEU Facility Database (HEU-FD) at the Norwegian Radiation Protection Authority (NRPA) covering facilities established after 1978. All illustrations are based on data in HEU-FD. The main source of this database is different versions – 1989 to 2001 – of the IAEA Research Reactor Database and other open-source information as indicated in this paper. For further information on specific information on any of the facilities in Appendix 1 or other relevant facilities, please contact the authors.

Sixth Session - Detection of Clandestine Nuclear Activities

Chair: Alexander Keynan

Monitoring of Plutonium in the Air[1]

Jerzy W. Mietelski (Poland)

Plutonium isotopes are one of the most radiotoxic radionuclides when inhalation exposure is considered. For example, the most common Pu isotope, the ^{239}Pu, is characterised by inhalation dose conversion factor equal to $1.2*10^{-4}$ Sv/Bq and $2.1*10^{-4}$ Sv/Bq for adults and infants, respectively [1]. It means, that inhalation of only about 10 kBq of this isotope in form of well dispersed aerosols (i.e. having aerodynamic diameters of about 1 μm) results in doses in range of single Sv, so causing acute radiation sickness if obtained during short time. However, this dose will be obtained during many years of persistent of Pu isotopes in bones and liver. Nevertheless dose of range of 1 Sv is not a small one, anyway. Such tiny plutonium aerosol can be generated as results of nuclear terrorism: explosion of so called dirty bomb (conventional explosives mixed with a radioactive material) or attempt to detonate a home-made plutonium A-bomb of low yield. It can be also partially produced during a shot down of a nuclear warhead.

Systems for radioactive monitoring of the air which exist in many European countries are mainly oriented for measurements of gamma-emitters, which are relatively easy to measure and which provide enough information for decision makers in case of any accidental releases from nuclear power-plants or from other possible minor or remote nuclear accidents. The majority of plutonium isotopes emit practically only alpha radiation. Some of monitoring laboratories are doing also radiochemical analyses for determination of many other radionuclides, among them plutonium. The typical analytical process, which includes radiochemical separation of Pu and then alpha spectrometric measurements, takes about two weeks from end of aerosol collection to final results of measurement. This is for sure to long time for any reasonable decision in case of future true emergency situation. The need of developing much shorter methods is urgent. The plutonium is just a case among many other alpha-emitters like polonium, uranium, thorium, but the dose-conversion factors are the highest for Pu isotopes. This topic was undertaken in US recently and some much rapid procedures are already developed. However, their introduction to European laboratories is very limited, if any at all. The case of murder intoxication of A. Litwinienko using polonium isotope showed how all security systems are blind for alpha emitters.

To recognize properly emergency situation when it will happen the normal background levels as well as their variation and also the isotopic compositions are important to be recognized first. Very important for this topic is also geographical variation - present and past background levels of Pu concentration in air of all Europe.

Together with some members of Polish network for air monitoring which is coordinated by CLRP (Warsaw) and NAEA (Warsaw) as well as with German (PTB,

[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

Braunschweig) and Czech (NRI, Prague) Institutions our Institute form kind of informal cooperation platform to study question of present sources of Pu in air of Europe. It is very likely, that this platform will be significantly extended in close future and converted into a pan-European consortium.

The aim of presently conducted work within this informal platform is to understood sources and pathways of plutonium in air. Besides simply monitoring of background values of Pu activity the isotopic ratios and their variation are the key questions. The work is still in progress.

Brief characterisation of plutonium

Plutonium (Pu) is a transuranic element with Z=94 and rather complicated chemistry [2-4]. It is considered a man-made (anthropogenic) and it was discovered in 1940 by Glenn Seaborg and co-workers in products of nuclear reaction [5]. Although later it was found, that Pu exists in ultra-traces naturally within the Earth crust [6]. All Pu isotopes are radioactive. The natural levels of Pu activity on Earth surface are orders of magnitude lower than man-made ones. There are six Pu isotopes present in the environment [6]. They have mass numbers from 238 to 242 and 244. The most important are ^{239}Pu and ^{240}Pu, which has half-life time of about 24 or 7 thousands years, respectively. They both emit alpha particles of energy equal to 5.15 MeV and thus one cannot distinguish between them while the most common method, the alpha particles spectrometry is applied as detection system. It is common to present the sum of their activities, what is written: $^{239+240}$Pu. To distinguish ^{239}Pu from ^{240}Pu the mass spectrometry (ICP MS, TIMS, AMS,…) is needed. Using alpha particles spectrometry the ^{238}Pu is usually also detectable, but it is hard to detect by mass spectrometry due to problems with mass interference caused by much more common in all kind of samples uranium (^{238}U). The isotope ^{241}Pu has in environment usually higher activities than ^{238}Pu. This is a beta radiation emitter and can be measured by liquid scintillation spectrometry for example [7]. However, the detection limits for this method are higher then for semiconductor alpha spectrometry, so it is not so easy to detect. It is relatively short lived and thus hard to detect by mass spectrometry as well. The isotope ^{242}Pu in environmental levels is detectable only by mass spectrometry, however since it is in wide use in radiochemical laboratories as radiochemical tracer with much higher activities it is very rarely measured in environmental samples.

Sources of plutonium in air

Plutonium was released to environment in well recognized situations: atmospheric nuclear explosions (1945-1980, with the maximum in 1963 – see Fig. 1), reprocessing of spent nuclear fuel, Chernobyl accident (1986), accidental re-entries of satellites having Pu on board (1963 - SNAP 9A, 1978 – Cosmos 954) and accidents with strategic bombers equipped with nuclear bombs (Palomares, Thule) [6,8,9].

Therefore the general assumption is made, that plutonium in air comes now mainly from resuspension of contaminations present in environment from past releases or accidents. Different sources of Pu have their specific isotopic composition which is like a fingerprint. For example global fallout has very low (equal to about 0.03) value for activity ratio ^{238}Pu/$^{239+240}$Pu. Higher values of such Pu isotopic ratio is typical for plutonium originated from spent fuel. There are several potential sources of traces of spent fuel in air over Europe. First, one can think about resuspension of tiny soil particles at the area with high Chernobyl plutonium deposition. Chernobyl plutonium has specific isotopic composition, for instance the activity ratio of ^{238}Pu to $^{239+240}$Pu is close to 0.50 [10], however some variation of this value was observed [11,12]. The highest Pu deposition are localised almost exclusively close to Chernobyl. Although along all the tract of initial plume the traces of Chernobyl Pu are noticeable. In a distance of about 500 km from Chernobyl (North-Eastern Poland) this fallout do not exceeds 50% of global fallout [10]. Approximate map of exclusively Chernobyl-origin $^{239+240}$Pu deposition in Poland based on forest litter measurements is presented in Fig. 2 [10]. Another possibility for explanation of traces of spent fuel Pu in air over Europe is so called sea spray from North Sea, where some Pu discharged from nuclear fuel reprocessing installation in Sellafield is still present [13]. This source has also specific value of this ratio which is in range of 0.18 – 0.21. The Baltic Sea can be excluded as the source of Pu with high ^{238}Pu/$^{239+240}$Pu ratio since the global fallout is dominant component there [14,15]. Measuring different isotopic ratios one can calculate proportion between different sources. Using only one isotopic ratio it is possible only to get the proportion between two sources [16]. To distinguish plutonium origin having three potential sources we have to measure another plutonium isotope ratio, for instance the ratio between ^{239}Pu and ^{240}Pu. It can be done by means of mass spectrometry. Usually, plutonium is accompanied by ^{241}Am, which has not very much different environmental properties. These isotopes originated predominantly from a decay of ^{241}Pu, which isotope has relatively short half life time of 14.1 years. Proportion between ^{241}Pu (which is hard to detect directly) and other plutonium isotopes is also specific for given source, therefore proportion between ^{241}Am and $^{239+240}$Pu can be also used for distinguishing between different Pu sources.

Despite our general assumption on Pu origin from resuspension we cannot exclude other plutonium sources. Each operating nuclear power plant or in general nuclear reactor can release ultra traces of radioactivity. However plutonium is so not volatile element, that it is rather unlikely source. Some plutonium might come from stratosphere where traces of plutonium can still present after past nuclear explosions or accidental burn of satellites during their re-entries into atmosphere. Plutonium was used also in some industrial application as fire alarm sensors, for example. High temperature deconstruction of larger amount of such sensors in some cases can be detected as well.

Experimental experience

Our laboratory conducts environmental studies on Pu since 1993 and since 1990 we are doing monitoring of the air for gamma-emitters. Our radiochemical procedures applied for Pu analyses [16] follow the general ideas of that applied by IAEA group for Chernobyl project [17]. Background values of plutonium (^{238}Pu, $^{239+240}$Pu) concentration in air are studied in a retrospective way for air filters which were collected in Kraków since 1990 [19,20]. Samples are the sets of Petryanov type filters exposed on weakly basis in ASS-500 high efficiency aerosol sampling station. The airflow through single filter is about 50 000 m^3. To measure plutonium a collection of more than 10 filters is used. Therefore sets of quarterly collected filters are subjects of our investigation. Since 2003 we are exploiting two ASS-500 stations and thus six weeks sets are used for newer sets. In addition, since August 2005, the dry and wet atmospheric precipitation is collected in monthly basis in a collector of 2 m^2 area and then is analysed for activity of radionuclides, among them plutonium. Rain water (or melted snow) containing also dry deposition is collected into large barrels, where it is acidified with nitric acid and later it is successively evaporated to dryness and then analysed. All our samples are analysed in conventional, long lasting radiochemical procedure which consist of full decomposition of matrix (mineralization), then Pu oxidation step adjustment, ion-exchange separation and NdF_3 alpha sources preparation [18]. The results of our measurements from years 1990-1995 (Figs 3 & 4) were partially already published during local Polish conference [20], the analyses for sets of filters from years 1996-98 and 2001-2003 are being conducted now and the results are expected soon, during the Spring of 2008. Some piloting results for single quarterly collected sets of filters from 1995 and for precipitation from 1996 were also published in the past [19].

In general, the measured activity concentration for $^{239+240}$Pu in air (Fig. 3) is about 10 nBq/m^3. The ^{238}Pu has activity concentration of an order of magnitude lower level. Results show seasonal variation of both: activity concentration and isotopic composition (Fig. 4). The latest ratios use for attempt of identification of sources. What is the most noticeable is not a constant ^{238}Pu/$^{239+240}$Pu isotopic ratio, which is usually higher than European global fallout value equal to about 0.03 . Similar non-uniform and higher than global fallout values of this Pu isotopic ratio was reported for results from Germany [21] and from Czech Republic [22]. Explanation of this observation is main of the scientific challenges studied by our informal collaboration platform of laboratories.

Besides described above retrospective and current monitoring of Pu in air some more unusual samples were analysed [23]. They were two cabin filters from Boeing 767 airliners of LOT Polish airlines, which were exploited mainly on the North Atlantic route from Warsaw to Chicago, New York or Montreal. Filters were obtained after two years of exploitation, after their routine exchange. The air for cabin in airliners is taken from outside. It is pressurized by fan in jet engine, than its mixed with some recycled air from cabin, its humidity and temperature is adjusted and it is filtrated. Therefore the material stopped on filters contain aerosols which are mixture of low stratospheric dust collected during high-altitude flight, some dust collected at intermediate or low altitudes during take-off, landing and taxing as well as some anthropogenic dust from cabin. However, relatively high concentration of cosmogenic radionuclides (^{7}Be, ^{22}Na) suggests high altitude flight as the main source of radionuclides, among them plutonium. The cabin filters show low Pu activity with relatively high ^{238}Pu/$^{239+240}$Pu activity ratio, close to 0.20 [23].

Initial results for atmospheric precipitation for years 2005 and 2006 are presented in Fig 5. Large seasonal variation is suggested.

Conclusions

Although contemporary levels of Pu in the air are low and they seems to be meaningless from dosimetric point of view they recognition seem to be important. Presented analyses are not completed and results are preliminary.

Understanding of present sources of Pu and the pathways of its aerosol transport are of large importance for any future emergency situations.

For general nuclear security reasons monitoring of alpha emitters, among them plutonium, should be established in European countries. The proper fast analytical methods should be developed and suitable instrumentation or equipment should be places in selected laboratories.

References

1. ICRP (1993). Age-dependent doses to members of the public from intake of radionuclides, ICRP Publication 67, Ann. ICRP 23, No 3-4.
2. Choppin G.R. (1988). Chemistry of actinides in the environment, *Radiochimica Acta* 43, p. 82-83.
3. Choppin G.R., Morgenstern A. (2001). Distribution and movement of environmental plutonium. Plutonium in the Environment, Ed. A.Kudo, p. 91-106, Elsevier, Amsterdam, …, Tokyo, 2001.
4. Myasoedov B.F., Pavlotskaya F.I., (1989) Measurements of Radioactive Nuclides in the Environment. Analyst, vol. 114, p.255-263
5. Seaborg G.T., Mc Millan E.M., Kennedy J.W., Wahl A.C. (1946). Radioactive element 94 from deuterons on uranium. Phys. Rev. 69, p. 366-367.
6. Taylor D.M. (2001). Environmental plutonium- creation of the universe to twenty-first century mankind. Plutonium in the Environment, Ed. A.Kudo, p. 1-14, Elsevier, Amsterdam,… , Tokyo, 2001.
7. Parus J.L., Raab W., Radoszewski T. (1993) Liquid scintillation counting of plutonium and/or americium concentrations. Liquid Scintillation Spectrometry 1992, ed. J.E.Noakes, F.Schönhofer, H.A.Polach, *Radiocarbon* 1993, 233
8. UNSCEAR (1977): Ionizing Radiation Sources and Biological Effects; Raport to the General Assembly with annexes, UN. Pub.,1977, New York .
9. UNSCEAR (1982). Ionizing Radiation Sources and Biological Effects; Raport to the General Assembly with annexes, UN. Pub.,1982, New York .
10. Mietelski J.W., Nuclear spectrometry applied to studies of bioavaibility of radionuclides from "fuel like hot particles" in forest environment Report IFJ 1921/B (habilitation thesis), IFJ Kraków 2003, (in Polish)
11. Pietruszewski A. Bojanowski R. (1990). Plutonium in the Air at Warsaw after Chernobyl Accident. In: *Proceedings of the International Symposium on Post-Chernobyl Environmental Radioactivity Studies in East European Countries*, *Kazimierz nad Wisłą, 17-19 Sept.1990,* 118-126, Lublin, UMCS Press.
12. Pavlotskaya F.I. and Myasoedov B.F. (1991). Plutonij v Potchviach (Plutonium in Soils) *Priroda 5,* 57-61 (in Russian).
13. Kershaw P.J., Leonard K.S., McCubbin D., Aldrige J.N. (2001). Plutonium: the legacy of Sellafield, Plutonium in the Environment, Ed. A.Kudo, Elsevier, Amsterdam, …, Tokyo, 2001. p. 305-328.
14. Skwarzec, B. (1999). Polonium, uranium and plutonium in the Southern Baltic Ecosystem. Czechoslovak Journal of Physics, 49. Supplement 1, 461-466.
15. Suplińska, M.M, (1992). Studies on plutonium concentration in the sea bottom sediments. Operational and research activities of Central Laboratory for radiological Protection in the years 1990-1991, CLOR, Warszawa, 68-70.
16. Mietelski J.W., Wąs B. (1995) Plutonium from Chernobyl in Poland, *Applied Radiation and Isotopes*, 46 (11), p. 1203-1211.
17. LaRosa J.J., Cooper E., Ghods-Esphahani A., Jansta V., Makarewicz M., Shawky S., Vajda N. (1992). Radiochemical methods used by the IAEA's Laboratories at Seibersdorf for the determination of ^{90}Sr, ^{144}Ce and Pu radionuclides in the environment

samples collected for the International Chernobyl Project, *J. Environ. Radioactiv.* **17**, 183-209.
18. Sill C.W. (1987). Precipitation of actinides as fluorides or hydroxides for high resolution alpha spectrometry. *Nuclear Chem. Waste Mgmt.* **7**, 201-215.
19. Mietelski J.W., Kozak K, Wąs B., Jasińska M., Krupa J.O. Plutonium Isotopes Concentration in the Ground Level Air and Rain Samples from Krakow. Proceedings of 13-th Radiochemical Conference; 19-24-th April 1998, Marianskie Laznie-Jachymov, Czech Republic, Czechoslovak Journal of Physics, vol. 49. Supplement 1. , 1999, p.115-117
20. Mietelski J.W., Gaca P. Plutonium isotopes in air 1990-1993. Abstract P-28, Book of Abstracts of the Fourth National (Polish) Conference on Radiochemistry and Nuclear Chemistry, Kraków, 9-11 May 2005 (in Polish).
21. Wershofen, H., Arnold, D., 2005. Radionuclides in ground-level air in Braunschweig-Report of the PTB trace survey station from 1998 to 2003. PTB-Ra-45, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany.
22. Hölgye, Z., Filgas, R., 1996. Concentration of $^{239,240}Pu$ and ^{238}Pu in the surface air of Prague in 1993, 1994 and 1995. Journal of Radioanalytical and Nuclear Chemistry, Letters 214, 303-308.
23. Mietelski J.W., Gaca P., Grabowska S.. Study of Radionuclides Content at ca. 11 km Altitude by Use of Cabin Filters from Airliners. *Book of Extended Synopsis, International Conference on Isotopes in Environmental Studies, Aquatic Forum 2004, Monaco, 25-29 Oct. 2004,* IAEA –CN-118, p. 411-412 (2006).

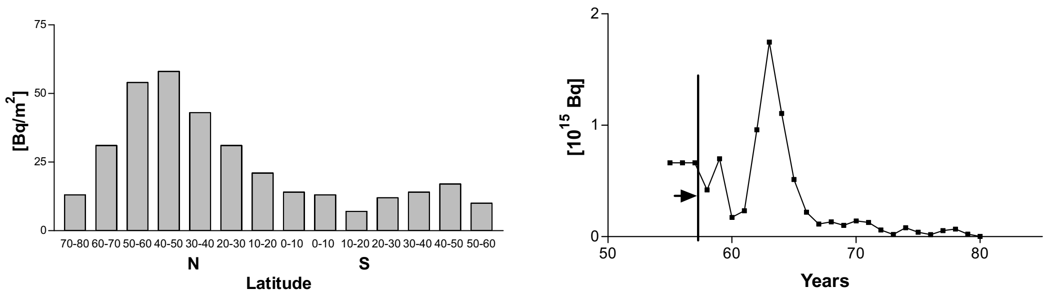

Fig. 1. (Left) The mean cumulated $^{239+240}Pu$ deposition for 10 degree latitude belts and (Right) history of releases in globe-scale; data from UNSCEAR reports [8,9].

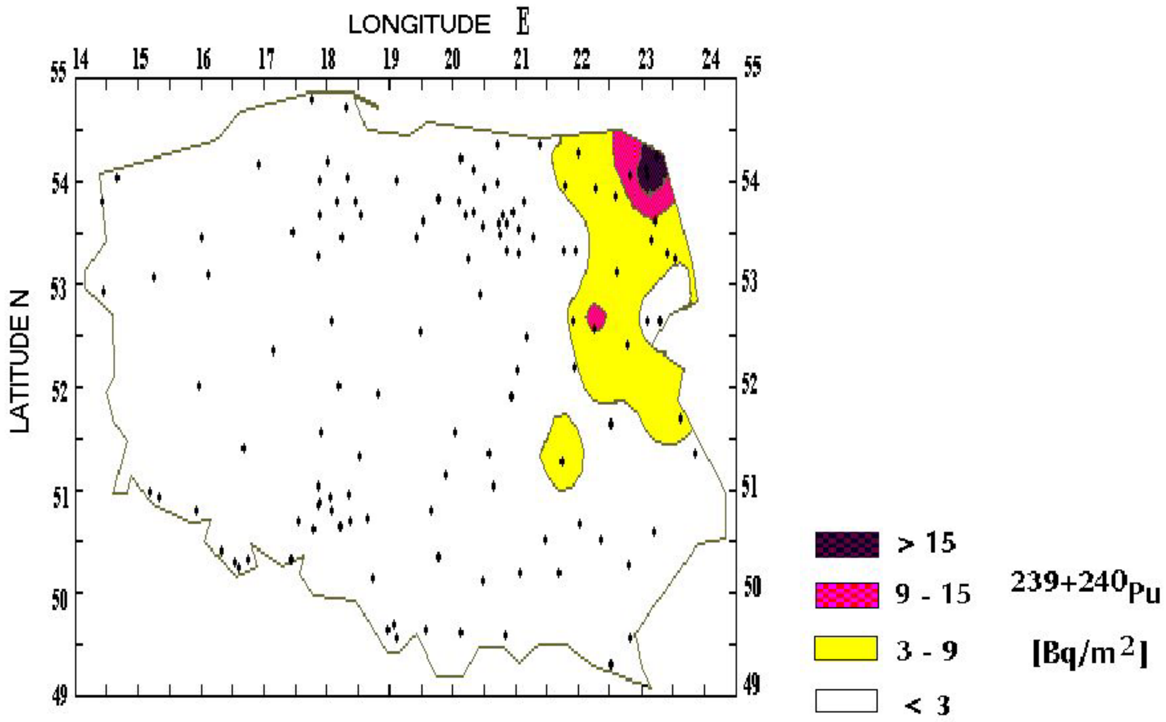

Fig. 2. The approximate map of exclusively Chernobyl-origin deposition of $^{239+240}$Pu in Poland [10].

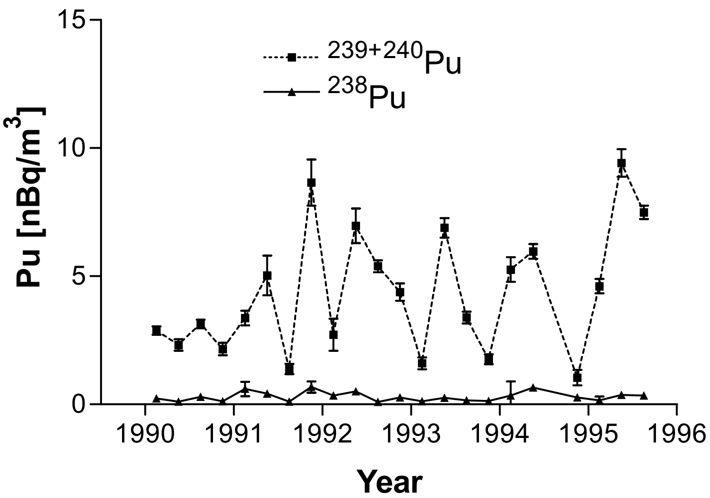

Fig. 3. Activity concentration of Pu isotopes in ground level air of Krakow, results from retrospective study for years 1990-1995 (results 1990-1993 were already published in [20])

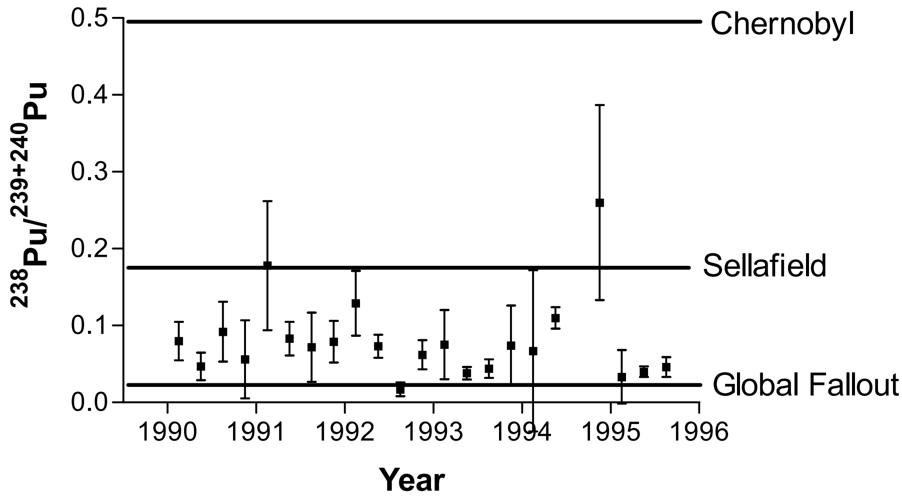

Fig. 4. Activity ratio for Pu isotopes in ground level air of Krakow, results from retrospective study for years 1990-1995 (results 1990-1993 were already published in [20])

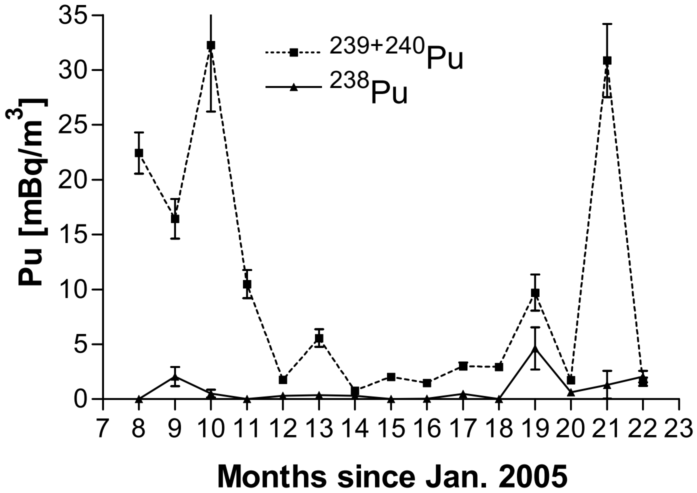

Fig. 5. Initial results for monitoring of Pu in atmospheric precipitation (rain, melted snow and dry precipitation) in Kraków.

Discussion of Jerzy Mietelski's Lecture

Erwin Häckel *(Germany): Just a very small question regarding the fallout from nuclear explosions: I wonder if all of the material has meanwhile sunk to the earth, or if there is still aerosol in the air around.*

Jerzy Mietelski: This is a very good question. We did this analysis of the carbon filter from the airplane. This carbon filter from the airplane was mostly collected at the altitude of eleven kilometers on the North Atlantic route. This gives some general information about the possible plutonium content in the stratosphere. We still cannot exclude that some of the plutonium is still precipitating. Generally in the [inaudible] you can find that practically the global fallout ended in the 1970s, but of course the question is what does it practically mean.

Christopher Watson *(UK): One of the useful things that could come out of your measurements would be new and improved information about the effects of ingestion of plutonium for human beings. My impression – and that was reinforced by the recent Royal Society study done on plutonium disposition, is that there is very limited information on that subject. Am I correct and is there any prospect of getting better information in the future?*

Jerzy Mietelski: Generally speaking, if you look at the incorporation of plutonium to the normal public, there is really very little data about this. There are some results about the workers of the nuclear installations; I know that in the U.S. there is now a project about the levels of plutonium in people from Hanford. There is also Russian data from Mayak about the exposure of the people who died from lung cancer, as far as I remember. There are also some papers from Great Britain regarding Sellafield, and I heard also of some German papers. But the majority of the papers with concern to the normal public are only on the global fallout of plutonium. Despite the fact that one of the papers was done from the autopsy material from the lungs of the people from Belarus, they also found only the material from global fallout. We just started this analysis of the human bonds from Poland, which are for the general public – not workers of any nuclear industry, and from the first results we see the effects of the global fallout proportion, but we have just started.

I know only the paper by Bunzl and Kracker from Germany, where they have some people from Bavaria – I think – and some people from Belarus that they compare and they found that the results from Belarus are not very different from the results from Bavaria.

Detection of Clandestine Nuclear Weapons Production and Testing by Analysing Air Samples[1]

Martin B. Kalinowski (Germany)

The verification of arms control treaties is essential for their success. Most critical are situations in which states are not fully cooperative with the inspecting party and in particular, if the inspectors have no access to - or not even knowledge of - the site of activities banned under a treaty. In these cases, the inspectors rely on remote sensing technologies. For the Comprehensive Nuclear-Test-Ban Treaty (CTBT) it was possible to design a verification system that relies on a global remote monitoring system to provide the first evidence of a clandestine nuclear test. On-site inspections would follow as a second step.

In this paper, the emerging capabilities of analysing air samples are described with their benefit for remote verification of nuclear arms control treaties.[2] These are eminent in two applications. Firstly, krypton-85 and other radioactive isotopes could be used to verify the Nonproliferation Treaty (NPT) because they can indicate unreported production of plutonium. This is not yet put into practise. In part 1 of this paper, the technical capabilities are discussed. Secondly, radioactive debris from nuclear explosions will be used to verify the CTBT. This is covered in part 2 of this paper.

Detection of clandestine nuclear weapons production by atmospheric krypton-85

The methodologies and procedures for detecting non-reported nuclear activities relevant to the NPT have made significant progress since the Additional Protocol was negotiated. During the intrusive inspections in Iraq, new methods have been applied. The International Atomic Energy Agency (IAEA) has gained a legal foundation for enhanced inspections by the member states agreeing on the Additional Protocol in 1997. It has opened the doors for the nuclear inspections capabilities to become more effective and powerful. This is of high importance, since the most significant gap and biggest challenge for verification of nuclear non-proliferation is the detection of clandestine weapons-usable materials production.

The urgency in fixing this verification gap became obvious for the first time with the shock caused by revealing the clandestine nuclear weapons program in Iraq in 1990. The next blow was the expellation of the IAEA inspectors by North-Korea leaving the IAEA with no means to verify whether this country is separating plutonium. In 2002 Iran’s unreported uranium enrichment facilities have become known and were then put under on-site inspections and while Iran promised not to build again any unreported facility, there are no operational verification means in place to detect remotely any highly enriched uranium (HEU) or plutonium production that an NPT member state might operate somewhere clandestinely.
This verification gap is causing distrust in the IAEA nuclear safeguards system and probably increases the escalation dynamics related to Iran's nuclear program. Therefore,

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1 This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

2 Office of Technology Assessment: Environmental Monitoring for Nuclear Safeguards, Congress of the United States, Washington DC, September 1995. Kalinowski, M.B.; Feichter, J.; Nikkinen, M.; Schlosser, C.: Environmental Sample Analysis. In: R. Avenhaus, N. Kyriakopoulos, M. Richard, G. Stein (eds.): Verifying Treaty Compliance. Springer Berlin, Heidelberg 2006, pages 367-387.

part 1 of this paper focuses on the question how scientific research could contribute to closing the verification gap. The goal is to provide the IAEA inspectors with tools for remote detection of clandestine nuclear-weapons-materials production.

Ever since Iraq's clandestine nuclear program shocked the non-proliferation community in 1990, the IAEA tried to improve its nuclear safeguards system. First, the major 93+2 program was set up.3 It resulted in the 1997 Additional Protocol.4 Although it expanded the legal basis for more comprehensive safeguards activities, hardly anything has so far been achieved in providing the IAEA with technical means to detect clandestine activities from a distance.

Environmental sampling is still restricted to the locations that are routinely visited by inspectors anyway. Satellite imagery has been demonstrated as a powerful tool to detect clandestine facilities.5 Consequently, the IAEA established an analysis unit for satellite imagery. However, this tool is used mainly for investigation of known facilities, in particular for preparing inspections and for verifying building outlines as compared to those stated in facility declarations. Though uranium enrichment facilities have a few features that can be observed in satellite imagery (size of buildings, heat generation), this technology is not at all capable of providing an indication of clandestine reprocessing for plutonium (or uranium-233) separation. The operation of the plutonium (or uranium-233) production reactor might be detected by satellite image analysis.

		Satellite images		Air samples	
		Visible light	Infrared	Stand-off	Regional network
Plutonium production	Reactor	Yes	Yes	Yes	Yes
	Reprocessing	No	No	Yes	Larger facilities
Uranium enrichment	Conversion	No	No	Yes	Larger facilities
	Calutron/EMIS	No	Yes	Yes	No
	Gas diffusion	Yes	Yes	Possible	No
	Centrifuges	No	No	Unlikely	No

Table 1: *Detectability of various process steps in the production of fissile materials.*[6]

3 The 93+2 program owes its name to the fact that it started in 1993 and was planned for a duration of 2 years so that it would produce sufficient results by the time of the NPT Review and Extension Conference in 1995, in order to provide satisfying answers to the critical issue of clandestine activities. The officially stated goal of the 93+2 program was to enhance the efficiency and effectiveness of nuclear safeguards.

4 Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (corrected), approved by the IAEA Board of Governors on 15 May 1997.

5 B. Jasani and G. Stein (eds.) Commercial Satellite Imagery - A Tactic in Nuclear Weapon Deterrence, Springer, 2002.

6 This table is modelled after Table 9.1 in: International Panel on Fissile Materials, Global Fissile

Environmental sample analysis might add on satellite image analysis and might even close some of their gaps. Table 1 gives an overview on how the capabilities based on air samples and satellite images compare to each other with regard to the relevant steps in production of nuclear weapons-usable materials.

In 1997 and 1998, a technical committee was brought together by the IAEA in order to study the technical possibilities of Wide Area Environmental Sampling (WAES) under the NPT Additional Protocol. The committee confirmed earlier findings that krypton-85 would be the best suited tracer for plutonium production.[7] This radioactive isotope is a by-product of breeding plutonium as well as uranium-233. It is released into the atmosphere during chemical separation of spent fuel or special breeding targets. Therefore, it is a good indicator for plutonium separation.

However, the IAEA expert committee concluded that WAES was not feasible due to the enormous costs. According to this study, a network of monitoring stations with 25 km grid size, operating continuously, would be needed to cover relevant parts of the globe. Even if regions which lack the required infrastructure for clandestine reprocessing facilities were omitted, the whole system would require hundreds or even thousands of expensive detectors. The report8 of the technical committee was printed by the IAEA but has never been released to the public, although it is often referred to and even quoted in publications by experts who had served as committee members.9
In spite of the lack of transparency, the following became known about the study. The simulation methods applied were outdated and the study was clearly biased against WAES; accordingly, the conclusion was that WAES is infeasible. The requirements on WAES defined by the study were far too demanding. New sensor technologies were not taken into account. In particular the ultra-sensitive trace analysis of krypton-85 allows for a radical cost reduction. The proof of principle for using atmospheric krypton-85 to detect plutonium production at a distance was given by a case study on the German pilot reprocessing plant at Karlsruhe.[10]

Progress in safeguards methodologies based on environmental sampling is not only urgently needed with regard to the Model Additional Safeguards Protocol related to the NPT. It would at the same time address verification issues for a Fissile Materials Cutoff Treaty (FMCT). For both treaties, further scientific-technical work is required and would support political progress in non-proliferation and disarmament of nuclear weapons. Even without a formal agreement, it would be highly beneficial to develop and demonstrate verification means that could be used as national technical means or by

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Material Report 2007, Chapter 9: Detection of clandestine nuclear material production. www.fissilematerials.org

7 Kalinowski, M.B.: Measurements and Modelling of Atmospheric Krypton-85 as Indicator for Plutonium Separation. In: C. Foggi, F. Genoni (eds.), Proc. Workshop on the Status of Measurement Techniques for the Identification of Nuclear Signatures, Geel, Belgium, 25-27 February, 1997, EUR 17312 EN, pages 67 72.

8 Use of Wide Area Environmental Sampling in the Detection of Undeclared Nuclear Activities, Member State Support Programs to the IAEA, STR-321, 1999.

9 For example P.W. Krey, K.W. Nicholson, Atmospheric sampling and analysis for the detection of nuclear proliferation, Journal of Radioanalytical and Nuclear Chemistry 248, No. 3 (2001), pp. 605-620.

10 Kalinowski, M.B.; Sartorius, H.; Uhl, S.; Weiss, W.: Conclusions on Plutonium Separation from Atmospheric Krypton-85 Measured at Various Distances from the Karlsruhe Reprocessing Plant. Journal of Environmental Radioactivity 73/2 (2004), 203-222.

NGOs and independent citizens to detect clandestine nuclear activities, especially those related to fissile material production.

A new opportunity occurred when the IAEA Board of Governors decided in 2004 to call for help in exploring novel technologies and verification approaches to detecting clandestine activities. The IAEA started its Novel Technologies Program[11] and collected technical proposals from member states. In April 2005, the IAEA organized a workshop on detection of uranium enrichment. In September 2005, the IAEA hosted a Technical Meeting on Noble Gas sampling and monitoring, and in August 2006 another one on Laser Spectrometry Techniques. The purpose of these meetings was to explore future research and development needs for applying these new methods to nuclear safeguards under the NPT Additional Protocol.

Visionary thinking combined with cutting edge science and technology is required to identify practical procedures for remote environmental sampling. This can only be achieved by a group that is not bound by diplomatic constraints and short term approaches. To address these needs and to support the IAEA in developing new verification methodologies, the International Network of Engineers and Scientists Against Proliferation (INESAP) facilitated the establishment of an independent Group of Scientific Experts (iGSE).[12] This network of specialists is attempting to follow the precedence set by the highly influential work of independent expert groups who supported progress towards a nuclear test ban treaty in the past.[13]
The goal for the iGSE will be to develop and demonstrate technologies and procedures for remote sensing and other novel methodologies that allow detection of clandestine nuclear-weapons-usable materials production. The expected outcome will be technical progress in related verification methodologies, their demonstration in field exercises, and the public availability of new measurement results as well as of conclusions that can be drawn with respect to production of plutonium and highly enriched uranium (HEU) production. The unique features of this project are the combination of the required expertise; the independence of scientists from governmental, diplomatic and organizational interests; and ensured unrestricted publication of the results.
The technical areas to be considered by the iGSE should focus on the issues with the greatest urgency and the best prospects for significant progress. Therefore, environmental sampling is selected as the first topical focus.

The most promising new sensor technology is a novel ultra-sensitive trace analysis of krypton-85.[14] It will allow for radical cost reductions in any concepts of sampling and analysing air for nuclear safeguards. The technology is now being developed at the Carl Friedrich von Weizsäcker Center for Science and Peace Research at the University of

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11 J. Whichello, D. Parise, and N. Khlebnikov: IAEA Project on Novel Techniques. INESAP Information Bulletin No. 27, pages 27-30. http://www.inesap.org/bulletin27/art07.htm

12 iGSE: Detection of Clandestine Production of Nuclear-Weapons-Usable Materials. Project Summary INESAP Information Bulletin No. 27, pages 4-8. http://www.inesap.org/bulletin27/art01.htm

13 The Group of Scientific Experts (GSE) was formed in 1976 at the Conference on Disarmament in Geneva. It coordinated and focused the worldwide development of verification technologies and analysis methods for a comprehensive nuclear test ban treaty. Most importantly, it demonstrated them in technical experiments called GSE Technical Tests (GSETT-1 in 1984, GSETT-2 in 1991, and GSETT-3 started in 1995).

14 Kalinowski, M.B.; Daerr, H.; Kohler, M.: Measurements of krypton-85 to detect clandestine plutonium production. INESAP Information Bulletin No. 27, pages 9-12. http://www.inesap.org/bulletin27/art02.htm

Hamburg. It is based on an atom trap and, therefore, called atom trap trace analysis (ATTA). This method is highly selective and sensitive because only krypton-85 atoms are selectively guided by laser beams that are finely tuned to the atomic energy levels into a magneto-optical trap where they rest for up to a second while they are identified by their fluorescence quanta. One by one they are counted. The first such device has been built at the Argonne National Laboratory and went operational in 1999. It is used for ground water and ice core dating studies and had not been previously considered for safeguards applications.

The research project at the University of Hamburg has two goals. The efficiency of counting krypton-85 atoms will be increased and the instrument will be optimized for applications in the field. The main advantage of ATTA in comparison to the traditional beta counting method is the required sample size. In order to achieve the wanted minimum detectable concentration with one-hour beta counting a sample volume of 100 liter air or more has to be taken. This needs to be pre-processed in the field in order to reduce the volume of the shipping container. The pre-processing removes the noble gas fraction from the air by cryo-adsorption. Since this requires liquid nitrogen, a carrier gas and electric power in the field, sample taking is too expensive for large scale routine applications. In contrast, ATTA could be successfully applied to samples of 1 liter. This would be very cost-efficient. If applied as random sampling during routine inspections, the air sampling would cause almost no additional costs.

Regarding Wide Area Environmental Sampling, the future improvements in implementing a sampling scheme based on ATTA could raise the usefulness and quality of krypton-85 sampling in comparison to the monitoring scheme that was previously studied and discarded due to its high costs.

Shorter sampling periods could reduce the detection thresholds by one order of magnitude. Mobile air samplers could be used instead of having stationary monitoring sites. The mobility would allow the inspection agency to undertake surprise measurements on very short notice.

However, it still remains unclear to what extent and under what conditions remote sampling in combination with transport modelling can detect clandestine plutonium separation of significant quantities with sufficiently high detection and low false alarm probability. In order to evaluate this, simulation studies are under way at the University of Hamburg in cooperation with the Max Planck Institute for Meteorology and the Meteorological Institute of the University Hamburg.[15] The study is carried out as task under the German Support Program for the IAEA.[16]

Atmospheric transport simulations will be used to determine optimum procedures for location-specific and wide area environmental air sampling to detect clandestine reprocessing activities. Based on the results on sensitivity and source attribution, the inspection procedures will be optimized in order to achieve maximum detection probability with optimum source location.

The goal is to provide the IAEA with all information and technology required to implement this krypton-85 tracer approach and to close the safeguards gap regarding the detectability of clandestine plutonium production.

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15 Kalinowski, M.B.; Feichter, J.; Roß, O.: Atmospheric krypton-85 transport modelling for verification purposes. INESAP Information Bulletin No. 27, pages 17-20. http://www.inesap.org/bulletin27/art04.htm

16 Task C.38 Simulation of Atmospheric Noble Gas Concentrations to Assess Sampling Procedures for the Detection of Clandestine Reprocessing

For detecting unreported production of highly enriched uranium, the task is even more challenging, because the signatures are weaker. In fact, they appear to be too weak to be even detected with a stand-off system in close vicinity of the release point. In this inspection scenario, the IAEA would apply a mobile system that could sense the off-gases of industrial facilities from outside their fence. Even under the assumption of a source strength that is 100 times larger than commercial uranium centrifuge enrichment plants, the emitted concentration would be too low. For a LIDAR (laser radar) system tuned at the most sensitive excitation energy for the UF6 molecule, the detection limit is three orders of magnitude below the expected concentration right above the stack.[17]

Detection of clandestine nuclear weapons test by atmospheric radioxenon

The Comprehensive-Test-Ban Treaty (CTBT) has been negotiated at the Conference on Disarmament in Geneva between 1993 and 1996. It was opened for signature in September 1996. Though the CTBT has been signed by 178 states and ratified by 144 (as of March 2008), it is not yet in force due to its specific conditions for entry-into-force. However, the Preparatory Commission for the CTBT Organisation has a mandate to establish the International Monitoring System (IMS), the International Data Centre (IDC) and prepare the procedures for On-Site Inspections (OSI). This is carried out by the Provisional Technical Secretariat (PTS) based in Vienna, Austria. The goal is to have the completed verification system in place and ready to operate as soon as the CTBT enters into force.

The CTBT has several provisions for verification of compliance. The International Monitoring System consists of four networks with different sensor technologies: seismic, hydroacoustic, infrasound and radionuclides. In addition, the CTBT allows for confidence building measures, consultation and clarification as well as On-Site Inspections.

The purpose of the International Monitoring System (IMS) sensor network is to detect signals that are indicative for nuclear explosions, as well as to identify and to locate nuclear explosions underground, underwater or in the atmosphere. The IMS network will consist of 321 stations in order to monitor the whole globe. 250 of these have already been built by March of 2008. It has sub-networks with four different sensor technologies. The seismic network will consist of 50 primary and 120 auxiliary seismological stations; the hydroacoustic network comprises 11 stations to monitor all oceanic waters; 60 infrasound and 80 radionuclide stations are being set up.[18] More precisely, the radionuclide network consists of three components: 80 particulate stations, 40 noble gas systems[19] collocated with particulate stations and 16 radionuclide laboratories.[20] The radionuclide component is essential in providing the proof that an

17 Bösenberg, J.: Kalinowski, M.B.: Detectability of Atmospheric UF6 and HF as Indicators for Uranium Enrichment with Lidar. INESAP Information Bulletin No. 28. To be published in April 2008.

18 Hoffmann, W., R. Kebeasy and P. Firbas (1999): Introduction to the verification regime of the Comprehensive Nuclear-Test-Ban Treaty. Physics of the Earth and Planetary Interiors, 113, 5-9.

19 The number of 40 noble gas systems is a compromise after some delegations were hesitant during the Geneva negotiations to agree to this technique at all. A noble gas test experiment performed at the Institute of Atmospheric Radioactivity in Freiburg, Germany, convinced all interested parties of the advantage to have noble gas systems. It is up to the Conference of States Parties to decide after Entry into Force of the CTBT to increase the numbers of noble gas systems.

20 Schulze, J., M. Auer and R. Werzi (2000): Low level radioactivity measurement in support of the CTBTO. Applied Radiation and Isotopes 53, 23-30.

explosion detected by other means is of nuclear nature and not a chemical one.[21]

The radionuclide stations will take daily samples, conduct the measurement in the field and send the data to the International Data Centre in Vienna. Upon receipt, the pre-analysis is done automatically and then reviewed by analysts for quality control. The results are sent to the member states and stored in a database. The detectors are designed to achieve a high sensitivity. The agreed requirements are to reach a detection limit of at least 30 µBq/m3 for Ba-140 and 1 mBq/m3 for Xe-133.

Atmospheric and underwater tests release a large amount of radioactivity and will easily be detectable. The challenge is to detect traces from underground explosions. Even if they are designed for full containment, there is always a risk that the containment fails and radioactivity is released unintentionally into the atmosphere. In addition, operational activities after the nuclear test inevitably cause the release of radioactivity. More than 500 tests at the Nevada Test Site were followed by operational releases within a few days or weeks after the explosion measured at the point of release.[22] The isotopes that are most likely released are gaseous non-reactive fission products. Due to their fission yield and half-lifes, there are four CTBT relevant noble gas isotopes, Xe-135, Xe-133m, Xe-133 and Xe-131m.[23]

The challenge of monitoring atmospheric radioxenon concentrations results from the fact that many nuclear facilities release the relevant isotopes as normal operational release.[24] This results in frequent detections of elevated concentrations. In order to avoid false alarms, it is important to be able to discriminate between reactor emissions and releases from nuclear explosions. It has been shown that isotopic ratios can be utilized for source discrimination.[25] If only a single isotope is measured with the others being below the detection limit, it is still possible to associate the detection to a possible source region by atmospheric transport simulations.[26]

The announced nuclear test undertaken by North Korea on 9 October 2006 was a chance to demonstrate the functionality of the radioxenon monitoring system.[27]

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21 Kalinowski, M.B.: Comprehensive Nuclear-Test-Ban Treaty CTBT Verification. In: R. Avenhaus, N. Kyriakopoulos, M. Richard, G. Stein (eds.): Verifying Treaty Compliance. Springer Berlin, Heidelberg 2006, pages 135-152.

22 C.R. Schoengold, M.E. DeMarre, E.M. Kirkwood. (1996). Radiological effluents released from U.S. continental tests 1961 through 1992. United States Department of Energy - Nevada Operations Office, DOE/NV-317 (Rev.1) UC-702, Las Vegas, August 1996.

23 De Geer, L.-E. (2001): Comprehensive Nuclear-Test-Ban Treaty: relevant radionuclides. Kerntechnik 66/3, 113-120.

24 Kalinowski, M.B.; Tuma, M.P.: Global radioxenon emission inventory based on nuclear power reactor reports. Submitted to Journal of Environmental Radioactivity in March 2008.

25 Kalinowski, M.B.; Pistner, Ch.: Isotopic signature of atmospheric xenon released from light water reactors. Journal of Environmental Radioactivity, Volume 88/ 3 (2006), 215-235. http://dx.doi.org/10.1016/j.jenvrad.2006.02.003

26 Gerhard Wotawa, Philippe Denier, Lars-Erik DeGeer, Martin B. Kalinowski, Harri Toivonen, Real D'Amours, Franco Desiato, Jean-Pierre Issartel, Matthias Langer, Petra Seibert, Andreas Frank, Craig Sloan and Hiromi Yamazawa: Atmospheric transport modelling in support of CTBT verification - Overview and basic concepts. Atmospheric Environment 37 (18) 2529-37.

27 Kalinowski, M.B.; Ross, O.: Data analysis and interpretation of the North Korean nuclear test explosion of 9 October 2006. INESAP Information Bulletin No. 27, pages 39-43. http://www.inesap.org/bulletin27/art12.htm

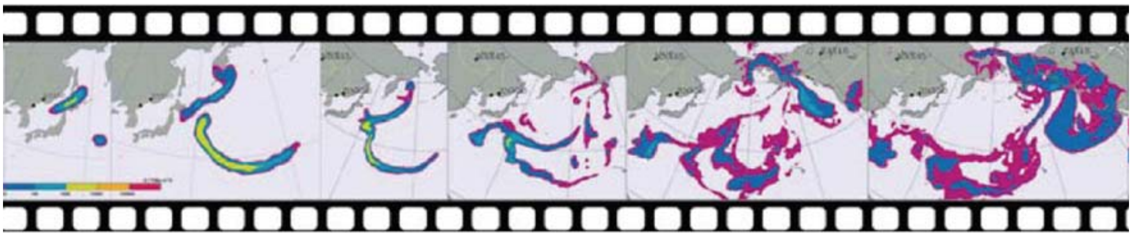

Figure 1: *"The above film strip shows from left to right the movement of the xenon-133 plume interms of calculated ground level concentrations assuming a surface emission of 1015 Becquerel at the time and coordinates of the 9 October event . The scene on the far left illustrates how the plume starts travelling to the east, while the shots on the far rights how the plume arriving at the Yellowknife station (CAX16)."*[28]

On 26 February 2008, Tibor Tóth, the Executive Secretary of the Provisional Technical Secretariat said: *"We also need to continue building up the noble gas technology. Data from this technology were crucial in the context of the declared nuclear explosion in the DPRK in October 2006."*[29]

Several seismic observatories all over the world recorded an event that took place in the North East of the country at 1:35 UTC on that Monday with a seismic body wave magnitude of 4.1±0.1. The Provisional Technical Secretariat (PTS) of the CTBTO PrepCom determined the location and time of the event from seismic signals received at the IMS stations. This was reported in the daily Reviewed Event Bulletin (REB) to the member states. Seismic analysis can in principle conclude if a seismic event was caused by an explosion or by an earthquake. In this case the signals were week, but nevertheless indications are strong that the event was an explosion. However, the low yield estimated to be in the range of 0.5-0.8 kt TNT raised the question whether the explosion was caused by chemical explosives or by a nuclear one.

Seismic signals cannot be used to make this distinction. In order to proof undoubtedly the nuclear character of an explosion it is necessary to detect radioisotopes produced in the nuclear fission processes and relate them with atmospheric transport modelling (ATM) to the geographic region of the explosion as demonstrated in Figure 1. This was successfully achieved even though the IMS network of noble gas stations was far from being complete. At that time there were only ten stations under experimental operation and not a single at close distance. The success is described by the PTS with the following words:[30]

> *"According to ATM calculations, the debris would reach the nearest operating noble gas station in Yellowknife, Northern Canada, on 22 October 2006 with two peaks on the 23rd and 27th. Interestingly, alternative forward ATM calculations with up to two days delay in release times predicted the same double peak signal. This indicates that the peak pattern at Yellowknife*

28 Idid.

29 Provisional Technical Secretariat of the CTBTO PrepCom: Press Information PI/2008/05, 26 February 2008. www.ctbto.org

30 Paul R.J. Saey, Andreas Becker and Gerhard Wotawa: North Korea: a real test for the CTBT verification system? Part II: noble gas observations. Spectrum Issue 10, August 2007, pages 20-21.

was rather shaped by the geographical conditions (i.e. mountain ranges in Alaska and Northern Canada) than by the release time of the device. The station in Yellowknife detected, as predicted, above background levels of xenon-133 on 21 and 25 October with somewhat lower values between 22 and 24 October, thus resembling the calculated double peak pattern. Backtracking calculations were evaluated to exclude other known sources of noble gas from facilities closer to the station. Consequently, the ejection of xenon-133 characteristic for a one-kiloton nuclear explosion on the Korean peninsula at the time of the REB event was the most realistic source scenario to explain the observed concentration pattern in Yellowknife."

Though the IMS system together with atmospheric transport modelling (see Figure 1) delivered a strong indication for the North Korean explosion being of nuclear nature, this is still not a robust proof.

The doubts whether North Korea has in fact tested a nuclear device were addressed by a short statement based on national technical means of the USA. It is quoted in full length here:[31]

"Analysis of air samples collected on October 11, 2006 detected radioactive debris which confirms that North Korea conducted an underground nuclear explosion in the vicinity of P'unggye on October 9, 2006. The explosion yield was less than a kiloton."

Unfortunately, no details were provided about what exactly the US air plane collected on its flight over the Japanese Sea. The word "confirm" indicates that the findings of the sample analysis might not have been clear enough to legitimate the use of the stronger word "proof".

Fortunately, a Swedish team had quickly after the explosion offered to South Korea to take air samples with their mobile noble gas extraction unit and analyse them for radioxenon with a device called SAUNA in their laboratory in Stockholm. They succeeded in detecting all relevant isotopes but Xe-135 in five samples taken on the west cost close to the Demarcation line between the two Korean states between 11 and 14 October.[32]

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31 Office of the Director of National Intelligence, Public Affairs Office: Statement by the Office of the Director of National Intelligence on the North Korea Nuclear Test. ODNI News Release No. 19-06, Washington, 16 October 2006.

32 Ringbom, A., Elmgren, K., Lindh, K.: Analysis of radioxenon in ground level air sampled in the Republic of South Korea on October 11 - 14, 2006. Report FOI-R-2273-SE, Stockholm 2007.

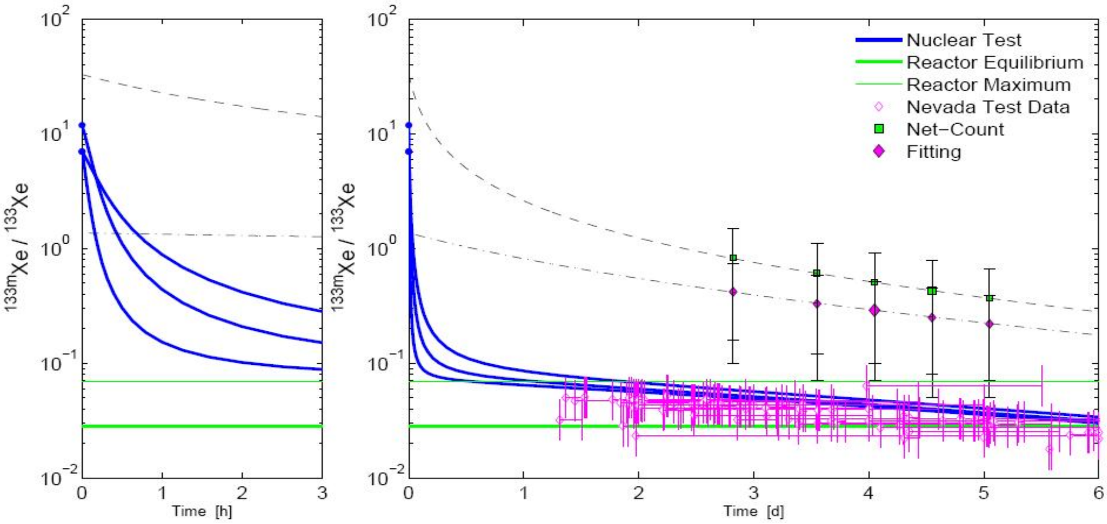

Figure 2: Isotopic ratio of Xe-133m/Xe-133 as it develops over time after the explosion. The data from samples taken in South Korea in October 2006 are put in perspective with historic data from the Nevada Nuclear Test site and simulated curves that follow the radioactive decay for various scenarios.

Air trajectories indicated that a plume released from the explosion site would have reached the air sampling point at the time when radioxenon was detected a few days after the explosion. At first glance, the isotopic ratios including Xe-131m appeared like those emitted from nuclear power reactors while the ratio of the isomers Xe-133m and Xe-133 indicated an explosion as described below. It took a couple of more months before the ambiguity was erased and a clear picture emerged. The Swedish team continued air sampling for four more months to analyse the typical background on the Korean peninsula. These measurements revealed that the Xe-131m concentration measured in October 2006 is at the typical background level in that area. Accordingly, it was not part of the plume freshly released by the nuclear explosion but it remained from releases of nuclear reactors during the previous weeks. This occurs with this particular isotope because it has the longest half-life of the relevant four isotopes (11.9 days).

With this insight, only the two isomers Xe-133m and Xe-133 remained for an analysis of their activity ratio. Figure 2 shows the measured and reconstructed data for the five samples with elevated concentrations in October 2006. Two different analysis approaches were used and reported by the Swedish team. The operationally used net count method and a more precise fitting method. The latter provides lower concentration values. Each method was able to determine the activity concentration of both isomers for one of the five samples (indicated by thicker marks in Figure 2). This paper uses a reconstruction of the missing values according to the radioactive decay law.

Figure 2 demonstrates how the activity ratio of Xe-133m/Xe-133 develops over time after the explosion. It puts the measured data points in perspective with simulated ratio curves[33] as well as historic data as reported from the Nevada Test Site.[34] The solid blue simulation lines apply for nuclear explosions under the assumption that the gaseous

33 M.B. Kalinowski, Ch. Pistner (2006).

34 C.R. Schoengold, M.E. DeMarre, E.M. Kirkwood. (1996).

radioxenon remains in contact with the precursor nuclides (no fractionation). The dashed black curves follow simply the radioactive decay of both isomers assuming full fractionation. The green lines mark the equilibrium and the maximum ratio that occur in nuclear reactors. The Nevada data lie in the range of the reactor ratios and suggest that no discrimination is possible a few hours after the explosion when the blue curves resulting from nuclear explosions bent down towards the reactor domain. However, the Korean data are found clearly above this range. This can be explained by an early fractionation of the gaseous from the non-volatile fission products. Within one hour, the radioxenon must have been emitted from the underground explosion leaving the particle bound precursor nuclides behind. Until that time, the ratios have followed one of the blue non-fractionated explosion scenarios. From the time of emission, the activity ratios followed the dashed line of decay without ingrowth of the precursors. This resulted in activity ratios well above the reactor domain and render source discrimination possible even five days after the explosion. A clear proof is found that the North Korean explosion of 9 October 2006 was of nuclear character. The Swedish team itself was the first to reveal this result.

This demonstrates that isotopic ratios can successfully be utilized for source discrimination, even if only the two different isomers Xe-133 and Xe-133m were quantified per sample.

Conclusions

Improving verification capabilities is an important contribution that scientists can make to help to solve a problem that could otherwise lead to the escalation of a conflict. In particular, closing the verification gap related to clandestine nuclear-weapons-materials production is of high urgency. Together with other new technologies and inspection procedures this will hopefully provide the IAEA with the technical capabilities of the IAEA to detect any possible clandestine activities in countries like Iran. As a result, trust in verification could be gained and further escalation of conflicts about suspect nuclear programs could be prevented and the danger of preemptive measures could be minimized.

CTBT verification would remain inconclusive unless radioactivity is detected. It needs to be taken into consideration that radioactive emissions frequently occur from legitimate sources. The risk of false alarms has to be minimized by smart analysis methods. Their basic principles have been developed and their applicability has been successfully demonstrated for the North Korean nuclear test of October 2006.

These new verification technologies will have to be put in perspective to the long-term goal of a nuclear-weapons free world. Environmental monitoring activities will play an important role in facilitating future treaties like the proposed Nuclear Weapons Convention and gain importance if less nuclear facilities are present.

Discussion of Martin Kalinowski's Lecture

***Francesco Calogero** (Italy): Martin, I am trying to play devil's advocate: The Korean explosion was about one kiloton – a little less. So that is one million kilograms of TNT, a very major enterprise to do it with TNT. And now you say there was suspicion that it might be that, rather than a real nuclear explosion, and the proof is that some radioactivity has been detected. But if one imagines the North Koreans having engineered such a big conventional explosion, why could they not at the same time release some radioactive materials just to mimic it more effectively? Or what I am saying makes no sense?*

Martin Kalinowski: The biggest problem in this is the timing because the radio-xenon is short-lived. The four isotopes have half-lives between nine hours and twelve days, so the production of this radio-xenon needs to be done almost at the same time as the explosion is done. That's quite difficult. And also the capture of the noble gases from the reprocessing activity is not very easy. There needs to be a quite unique extraction from a huge air stream. The air stream of a reprocessing facility needs to be ten thousands m^3 per hour. That is a large air stream. You want to get out only the noble gases; that's a high technical challenge. None of the commercial reprocessing facilities is undertaking this endeavor because it is so difficult.

***Erwin Häckel** (Germany): I would like to raise a point, which is more of a comment rather than a question, relating to wide area environmental sampling, which you did not go into very deeply but mentioned in the beginning. I seem to remember during the negotiations for the Additional Protocol in the 1990s, wide area environmental sampling was given a very strong prominence. In retrospect it seems to be the case that an unproven technology was advertised much more widely than it really deserved, which is a bit of an outrage in that respect. That still raises the question: would it not be possible not to establish a global system of such monitoring stations for environmental sampling, but instead surrounding a suspicious country such as North Korea or Iran, for that matter, with such stations that would, of course, be much less expensive. Could that be effective?*

Martin Kalinowski: In the study that you refer to and that I refer to – done in the 1990s for the International Atomic Energy Agency – nobody assumed a global network of stations because from the beginning this was clearly too expensive since the distance at which you can still distinguish fresh emissions from background variations is not very large. At that time one thought that 25 km would be the required distance between two stations in a network assembly. I think 100 km, or maybe a few hundred kilometers, would suffice, but still this is too dense a network to be implemented globally. As a result, in that study done in the 1990s the experts considered only one region – it was the Middle East – and they even considered that in parts of that region, where there is, for example, a desert or a sea, it would not be needed to have detection stations located in these regions without infrastructure. So one can do away with part of the network and reduce the number of stations needed. But still it was considered to be too expensive. One of the reasons why it was considered too expensive is because the requirements were set very high. It was demanded that there be a 95 % probability of detecting a single release related to a larger campaign of producing plutonium. In my view this is unrealistically strict because even a 10 % detection probability would help since there would not be a single activity of producing plutonium. If a country produces plutonium, it will do this again and again, so that multiplies the chances of being detected. Also the meteorological models that are applied were not appropriate. Gaussian Plume Models are relevant for distances of up to 10 or 15 kilometers and do not provide meteorologically correct concentrations at larger distances. So that is the reason why we are now using a different approach and different models.

Rudolf Avenhaus *(Germany): In the second part, and now again, you mentioned atmospheric transportation models, but not in the first part. If you measure krypton-85 in the air and you want to infer from these measurements plutonium production, are you not also very dependent on such models, size and direction of the wind in order to get reliable results?*

Martin Kalinowski: Of course. I am not sure I really got your question, but of course the meteorological conditions are relevant.

Rudolf Avenhaus*: But you need models; that is the question. Can you develop models that give you the appropriate certainty from where the krypton is coming, to which degree, in order to prospect…?*

Martin Kalinowski: But meteorological data is available at high resolution in time and in space, if you use analysis data which is very accurate and that you need only if you have real cases. We are now doing a model study of principle, and therefore with our meteorological model we generate the weather data like pressure, temperature, wind directions, so we calculate that ourselves. They are guided by real analysis data that we get from the European Center of Medium-Range Weather Forecast.

Rudolf Avenhaus: *I was thinking when you presented the data of the WAK, you had a measuring point close to it and then far in the south at Freiburg. The wind is going in one direction, I mean.*

Martin Kalinowski: It is not. The wind is turning and you were able to see this from the plumes that were released in the model from the North Korean test site. There is not a single plume always traveling in one direction getting broader and broader. It goes back and there are wind shears at different heights. One thing is that it changes directions a lot, but parts of this plume stay together for a long, long time and are transported over thousands of kilometers and remain with the maximum concentration and there are plume centers at the detectable level even at the distance of Yellowknife compared to the release point in Asia.

Jerzy Mietelski *(Poland): This report from the United States was found on the eleventh of October, so two days after the explosion, and in Alaska they were found later. So it means that it was some airborne instrumentation on the airplane or something like this?*

Martin Kalinowski: Yes, the U.S. used their airplanes and sent them on the Japanese Sea and they made predictions of where the plume would go with their meteorological models and then they sent the airplanes to the center of the plume. The station in Yellowknife, which is part of the International Monitoring System for the Comprehensive Nuclear-Test-Ban Treaty, is a ground based station – also the South Korean air sampler from Sweden was based on the ground. But your point is interesting because the idea that we propose to the International Atomic Energy Agency instead of using a network of stations, we propose that if they assume there is a country that has a clandestine reprocessing facility and they have some idea about where this might be located, then they can do their own atmospheric transport modeling to predict a plume. They do not need the time of the release, but they still can assume maybe a continuous release and look at the concentrations in the next couple of days. And then they can select a moment where the meteorological conditions are very favorable, no high wind speeds, no high turbulences, and the plume rests within the region for a couple of days and stays with a high concentration, at that time they would call complimentary access and send the inspector exactly into the center of the predicted plume. That is a completely different scheme and much more likely to be successful at low costs. The second scheme that we suggest to the agency is a routine sampling procedure that every time an inspector visits a nuclear facility not only takes his swipe samples from the surfaces, you also take some air samples – and that is a spot sample. The current meteorological situation is transporting air to this location, to this sampling point by chance from maybe even other countries in the region.

And before we end this session, I just want to advertise also this special issue of the INESAP Information Bulletin, because it covers information about iGSE, the independent group of scientific experts, and has several articles on krypton-85 and other remote detection methodologies to detect clandestine nuclear operations. I have some copies with me here but it is also available as pdf on the Internet.[1]

***John Simpson** (UK): I recollect that in the mid-90s in discussing these issues of wide area sampling with the IAEA, the positive aspect of any form of wide area sampling was seen to be the deterrent one; that in practice those who were being sampled in a sense would not know whether what they were perhaps doing illegally was going to be detected or not. And this in turn would have the deterrent effect, even if in practice the sampling system was really a very weak one. I am just wondering, you talked about the problem of costs and how expensive this was going to be in the form that we discussed, what sort of money are we actually talking about here and have you any feel for where there might be a midpoint between the ideal sampling system and the sampling system which would be less than ideal technically, but which would still have a deterrent effect?*

Martin Kalinowski: If you deployed fully automated autonomous devices in the field that would just send the data electronically once per day to the Agency, the investment costs would be half a million to one million US$, and the operational costs would be in the order of maybe one to three hundred thousand US$ per year for one station (one unit). This is based on the experience with the Test Ban Treaty Organization. From this you can immediately see that this would be too expensive, even if you think of a small network. If you had one laboratory, with one analysis unit, it might also have an investment cost of maybe up to one million US$ – maybe less, but then you can have this very cheap sample taking in the field; this is so cheap that I cannot even give a number. That is what we recommend, and the deterrence is given by the fact that the country will not know at what time a complimentary excess inspection is called for. At anytime the inspector might go into the place where the plume has its maximum. So there is no way of knowing: "the next station is in this wind direction, so I will produce plutonium only if the wind is blowing into this direction".

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1 http://www.inesap.org/sites/default/files/inesap_old/pdf/INESAP_Bulletin27.pdf

Richard Garwin *(USA): But that's on the assumption of continuous release. What operations do correspond to continuous release?*

Martin Kalinowski: Good point. The reprocessing campaign, the dissolution of spent fuel in acid takes about a couple of hours, so the release is expected to have ended after three or six hours at most. The plume would spread and travel over nearby regions – nearby means hundreds of kilometers distance – and stay there or travel over these regions within a couple of days. So if there is one release once per week, as a first guess I would say at a distance of two to three hundred kilometers, fifty percent of the time you have elevated concentrations. Not at one point, but at the point where the maximum is for a given time. This we still have to calculate with our model; I can tell you more about this maybe next year. But this is of course an important point. Eventually it is a question of probability; if the inspector does not know when the release takes place, so he might select the wrong time and has therefore a certain probability of missing the plume because there was no release at the assumed time. This probability factor that I just mentioned is one half of the chance to detect the plume if the inspector does not know when the dissolution takes place.

Detecting Nuclear and Radiological Materials[1]

Christopher Watson (UK)

Good afternoon ladies and gentlemen. I first want to express my appreciation to the organizers of the Amaldi Conference for inviting me and also to the Royal Society for giving me the privilege of attempting to summarize a symposium workshop that they held last December. I have the task of trying to condense a two day meeting into a twenty minute presentation – which means I will have to talk rather fast.

The Royal Society, as I am sure you are all aware, is the oldest scientific society in continuous existence in the world and provides independent expert advice to scientific community, to business and to government. In 1988 it established a committee on the scientific aspects of international security SAIS – of which I have the privilege of being a member – and its remit is to consider the scientific and technical aspects of international security, including arms control, counterterrorism, non-proliferation etc. Last year they decided to hold an international workshop on the detection of nuclear and radiological materials, and to bring together some seventy international experts in that area so they could exchange views on neutral ground. They were particularly interested in covering the interdisciplinary aspect of it, and getting people ranging from high-energy physicists to medical physicists, nuclear engineers, radio chemists, etc to talk to each other, to see if we could bring new and interesting ideas to bear on the subject. The meeting took place on 10th and 11th of December, and there is an official summary of its conclusions, of which there are copies just by the door, and I invite you to take one on your way out. While you are doing that you might also like to take copies of the report on the management of plutonium, about which John Simpson spoke earlier.

I should perhaps emphasize that I am myself not an expert on radiological detection. I have a broad interest in the topic of nuclear terrorism, but my background is not particularly on the instrumentation side. So I am sure that some of the questions, which you will want to put me, I will not ne able to answer. I will try to set the information that I am presenting in the context of my general views on problems of terrorism, non-proliferation and the like. Those views are of course my own, and do not necessarily represent those of the Royal Society or even SAIS.

Why is this subject of special current significance? First of all, there is a growing international concern about the illicit trafficking of nuclear and other radioactive materials, because of its implications for nuclear weapons proliferation and, very specifically, for nuclear terrorism. There is an awareness that the scale of the problem is growing rather fast. For example, in the IAEA database of reported international incidents involving theft or lost of radioactive material, since 1993 there have been 332 entries, of which 86 occurred in 2006 alone; and of those some 20 involved highly enriched uranium or plutonium – fortunately in subcritical quantities, but the trend is alarming. Second, there is a great international interest in the subject which is called nuclear forensics. Third, there is a specific interest within the U.K. Ministry of Defense in improving the technology in this area: it has to be admitted that this was in part motivated by the 2006 Litvinenko case. Since I discussed that at some length with my Russian colleges over dinner last night, I do not propose to go into that in any detail

[1] This paper has been revised by the author. The information may differ from the audio content.

today! But more widely, there are concerns in the U.K., the U.S. and – I am sure – worldwide about the subject of nuclear terrorism. In fact, I tried to discover the scale of that interest by typing the words "nuclear terrorism" into Google, and I got 2,990,000 hits. So it is clearly a topic of current interest.

What are the specific nuclear and radiological threats that are now of concern? You will all be familiar with these… First of all, the acquisition of a nuclear explosive device such as a nuclear weapon; secondly, the acquisition of nuclear material with which the terrorist could build an improvised nuclear explosive device; thirdly, acquisition of radioactive material with which they could construct a radiological dispersal device - the so called 'dirty bomb'; fourth, the sabotage of nuclear installations (locations or transport), both involving specifically nuclear material and radioactive material; and last, use radiological materials to harm key individuals. Of those five, naturally, the highest priority attaches to the theft of either nuclear weapons or fissile material. Those are both overwhelmingly the most important, but are also the most difficult. The others all have the potential to be a matter of great public concern, and therefore governments are naturally and appropriately concerned about them.

I think what our conference highlighted was that if we have any hope of addressing these problems, we have to have a multi-layered defense system. There is no one gadget which, by magic, can reliably detect all these illicit activities. For that multi-layered system to work, a key input is intelligence – and intelligence of all kinds: military, human, technical, and so on, and I will be saying quite a lot more about that during this talk. I said multi-layered defense, and that is because it has three main layers. The first is physical protection: the object of the exercise there is to make it difficult for unauthorized persons to gain legitimate or illicit access to nuclear or radioactive materials, or to remove them without the owner authorizing it or, at least, being aware that it has happened. So everything that has to do with nuclear material accountancy, physical protection, and so on, comes under that heading. The second layer is detection and that is characteristically done at a number of key points in the transfer of the material from where it ought to be to where it ought not to be, typically at points such as the exits of nuclear facilities, airports, ports and alike, where hopefully the flow of the material has to be channeled and can therefore have the maximum chance of being detected. The third layer of defense, if all the others have failed and the material has somehow gotten out into the world and some harm has resulted, is at least to be able to attribute the material that has just caused the harm to some unambiguously identified source, and either to bring the perpetrators to justice or, in the most extreme case, to take appropriate military action.

Let us now focus on the second layer of detection, and on the techniques which are currently deployed. The existing techniques are relatively primitive, and they typically involve two levels of interrogation. The first is a primary screening, which is done with cheap and cheerful equipment typically at airports and so on, monitoring for both gamma rays, using PVT plastic scintillators, and for neutrons using moderated helium-3 gas tubes. Those devices are fine as far as they go. They do not identify the specific isotope –with luck they identify the presence of some nuclear material giving rise to radiation above the background level, which will raise the alarm, and then bring into play the second layer screening with slower procedures using more sensitive equipment, which has a chance of detecting which radioisotopes are involved. These include instruments such as sodium iodide (NaI) scintillators or cadmium zinc telluride

(CdZnTe) semiconductor detectors. What is wrong with that? Well, there are lots of things wrong with that. The first is that the primary screening detectors are very susceptible to shielding of the source. A few centimeters of lead works wonders in preventing them from detecting material as it moves. Secondly, they currently give rise to a rather high number of false positives, due to normal naturally-occurring radioactive material. For example, instruments which monitor transport containers raise a false positive in somewhere between one and three percent of all containers. When you multiply that by the number of containers that you are having to process, that is an awful lot of false positives and it requires an awful lot of time to try and find out whether there really is radioactive material in it or not. The primary devices are not very fast, so if a lorry is driving rapidly past the detector, it might move too fast to provide even a minimum signal; and because of the adverse effects of the inverse square law, they have to be placed rather close to the source of radiation to have a chance of picking it out. Typically, these devices operate with a range of not more than ten meters. That starts to become a problem for large containers, and it certainly becomes an acute problem if, for some reason, the material of interest has got through the first layer of protection, and you are now trying to search a much wider area to discover where it has gone to, and you are then reduced to either driving around urban district or flying over it attempting to monitor for this missing material. Under those conditions, detecting it at a range of more than about hundred meters is very difficult, and that makes the whole process of search slow and not very efficient. Secondly, as regards to secondary screening, the detectors are not particularly good at detecting the most important materials, such as pure U235 or weapons grade plutonium, and they are not very good at providing a sufficiently accurate measurement of the isotopic composition to facilitate the forensic process. So there are lots of things that are not right with the current system, and it was therefore very appropriate for the Royal Society to invite the experts to try to come up with something better. During the two days, quite a lot of ideas were discussed, and I simply present those to you without attempting to be very selective. It is up to you to decide what is the right direction for the security community to move in. During the next few years, I think that everybody is agreed that the best instruments around - what they called "the gold standard" - are the germanium detectors, which produce beautiful high resolution gamma spectra. They are very expensive and they require very special cooling facilities, but there are real hopes that both the price can be brought down and the cooling arrangements can be simplified, so that they can be made more widely available. And certainly for aerial surveys of a region they are the instrument of choice, because with their high resolution they are much the best at picking up rather weak signals. There is also scope for low cost neutron detectors with improved energy resolution, using scintillators which either have better advanced deconvolution algorithms or are impregnated with new neutron-sensitive dopants. A third idea is to buy a bit more time in which to make the measurement, by embedding gamma and neutron detectors in so-called 'smart containers', and requiring people to transport goods across state boundaries in one of these special smart containers, so that the detectors then have the entire duration of journey of that container to make the measurement.

Looking a bit further into the future, there are all sorts of ideas around, and I am in no position to judge how good they really are. Muons were much discussed at the meeting. They of course have the advantage that they penetrate through much larger thicknesses of shielding and are therefore good, both when the terrorist has deliberately tried to shield his way out of the problem, and when dealing with large containers with a lot of extraneous material packed around. The problem is that supplies of muons with the necessary energy (measured in hundreds of MeV), are not very widespread unless you happen to be at CERN. But there are always cosmic ray muons, and if you have got enough time, you could hope to use those, and there was one enthusiastic participant at the meeting who was telling us exactly how that could be done. Following the same line of thought as the smart container for sea transport, there was the suggestion that aircraft should be equipped with detectors, which again would have the entire duration of the flight in which to pick up something that was a potential cause of concern.

Looking still further into the future, there is always a scope for better scintillators; nanotechnology and semiconductors advances, such as quantum dots and organic semiconductors, were among the ideas that were thrown up. The balance between passive detection and active detection also needs to be reviewed. There are various things you can do if active detection is permitted. The worry about that is, of course, that to get a good interrogation you need to use a relatively large dose of radiation, and the danger is that you end up causing grievous consequences for somebody who is hidden away in that container.

Looking at the overall picture, and standing back from the detail, the general feeling at the meeting was that the physics of all this is relatively well understood, and the chances of a real breakthrough in detection are not very great – and therefore what we really need to do is to build better systems, which incorporate all the existing technology, and so greatly increase our chances of detection of malfeasances. This involves networking of various different kinds: data networking; information networking; and exchange of view across the international community as to what the real threats are, so that we can focus the attention on the most likely events; and to develop expertise in the IT systems involved in networking in this area, and make use of all the standard technology on that. There was a feeling that there is a lot of scope for improving the deployment systems for those systems which are not just located at a port or at the exit to a facility. Unmanned aerial vehicles were identified as a good and cheap device for doing scans of areas when searching for things; helicopters and manned deployment systems for work in urban areas, where shielding by buildings was likely to be a problem. As regards satellite systems – well, we thought about them, but we decided that they have rather limited scope. As were mentioned earlier in this meeting, they do have some role and particularly by focusing attention on facilities where something strange is going on, satellite images do have a role.

What measures can be taken either internationally or nationally at the government level to strengthen all these approaches? The first thing is to reach a common understanding on what the threats are. At this conference, we had a certain amount of discussion on that, and I think there is a fair measure of consensus at the broad bush level; but reaching agreement at a detailed level about what the real threats are is less easy - there are lots of things that are either nationally specific or where there are very different national perceptions, so there is a great role for experts to get together and agree on a common assessment of the relative magnitudes of different threats. Secondly, to make nuclear forensics work, there is a vast need for better nuclear data. If you want to know whether a particular bit of polonium comes from Sellafield, or La Hague, or somewhere else, you need to have accurate background information about the isotopic composition of the materials released by those bodies. Those two are perhaps perfectly happy to release it, but other countries that might be releasing such material into the environment may be more reluctant to make that data available. So there are quite difficult sensitivities about how you share information without compromising national security, and there is a lot of scope for getting agreement among scientists about the meaning of measurements made in this area, so that they can all trust each other's measurements and share their technology. Within governments, the same thing applies, but on a slightly smaller scale. Many of you, I am sure, will be aware that in your own country different agencies have different responsibilities in this area and they do not always talk to each other. So getting a good inter-agency communication is often very important. Getting good communication between the policy makers and scientists is also very important. Last, but absolutely not least, good public education: this is an area where there is a tremendous amount of misperception by the public on what the relative risks are. So we all have a very real responsibility to communicate to our own societies what the real risks are, and what we are doing to minimize them.

Summing it up what were the key points: first of all, we all agreed on the need for a multi-layered defense against nuclear security threats. We are hopeful for some improvements in detector technology, but not vast improvements. There is a need for great improvement in the system approaches, better international coordination and better coordination at the national level as well.

Thank you very much!

Discussion of Christopher Watson's Lecture

Richard Garwin *(USA): What do you have in mind for portable muon generators?*

Christopher Watson: Good question. I have no idea. I think our colleague who was pushing this was relying on cosmic muons. If somebody did have a nice idea for a portable machine, great.

Constanze Eisenbart *(Germany): Mr. Watson, could any of your planned measures have prevented the poisoning of Litvinenko? I mean, there was a very small amount of nuclear material that was necessary to kill one man.*

Christopher Watson: I think that is a very special case. It is very special because we are talking about a pure alpha emitter, a low energy alpha emitter at which all the normal means of detection would fail to pick out. You will only pick it out if you know you are looking for it. After the event, the majesty of the British nuclear forensic system came into play and they knew exactly what they were looking for, eventually, and they found it everywhere. It is not difficult to discover once you know you are looking for low range alphas. But I am afraid that is one of those ones where only the third layer in the system is very much used and sadly it has to lead to closure. What it has done though is that it concentrated the minds wonderfully on what we ought to do: to improve nuclear forensics and capabilities generally and worldwide, and how important it is in terms of reassuring the public that we are protecting them against this particular sort of nuclear hazard.

Richard Garwin*: Actually, there are in fact reasonable means of finding efficiently and economically pure alpha emitters on surfaces. If you looked at the cloud chamber yesterday in the exhibition – there was a spark chamber and a cloud chamber – you could see short fat tracks, which were alpha particles, and that means that an alpha emitter on a surface gives rise to dense ionization in the air, which can in fact be drifted into an air detector. Georges Charpak has been working on such things, and I have seen them operate, and I have proposed that they be deployed for this purpose. So you could with an electric field that would not be palpable pick up these bursts of ionization that come off people who have even a little bit of contamination and drift them for many tens of centimeters into the detector.*

Christopher Watson: Great, thank you.

Martin Kalinowski *(Germany): Thank you very much. I enjoyed your talk. My question is: if I look at the list of participants of the workshop that you organized at the Royal Society, there were a few participants from the United States. I would like to know whether you can give us an assessment of how the development in the United States in homeland security is maybe ahead of us in Europe. Do you see a difference in the knowledge on how to detect nuclear materials in the United States as compared to Europe, and do you see a difference of deployed systems? Is there something we have to catch up on here?*

Christopher Watson: Very good question. I think I would say that, in terms of instrument technology, there was not much to choose between the two communities. Both were highly intelligent, informed, imaginative people doing good work. I think it is true to say that the U.S. since 9/11 has thrown itself into this problem on a scale which we in Europe have not really yet addressed. The fruits of that are due very soon. The targets which the American Agencies of this have set themselves for monitoring at ports in particular and at airports are frighteningly ambitious. Whether they will actually achieve them, I have no idea. But at least they are talking big, whereas the European equivalence are talking more modestly and taking it in a step by step approach.

Seventh Session - The Risk of Nuclear Terrorism

Chair: John Simpson

Analysis on the Risk of Nuclear Terrorism[1]

Wu Jun Zhang Songbai (China)

In the past decade, the risk of terrorist incidents involving weapons of mass destruction has increased. No doubt, terrorist groups try to explore the use of weapons of mass destruction, including nuclear explosive devices, to carry out terrorist attacks. Based on the analysis of events a calculation of the relative probability may occur in four ways. The probability of a nuclear terrorist incident triggered in four ways with the relative probability of success of each and the relative risk sizes have been assessed with an analysis model. The results show that the risk of the use of radioactive material by terrorists to produce a "dirty bomb" is slightly larger than for the other three ways, and needs particular attention.

Introduction

The phenomenon of terrorism as a kind of human conflict has had a long history. Modern terrorism was formed after the Second World War, and became a human threat in the 1960s. In this period, most terrorist events happened in the context of colonialism, dependency, and the emergence of new independent nations. The number of terrorist events obviously increases, and the means of terrorism are changing. The targets of terrorism extend beyond national territories, and become international in character. International terrorism is created.

After 1970, some organizers of terrorism have formed an international network. In the 1980s, almost 4000 terrorist events happened, 30% more than in the 1970s, and the death toll is twice that of the 1970s. In the 1990s, the casualties of terrorist events are increasing[2]. The terrorist has become an enemy of humanity.

Some experts who did research on terrorist groups thought that terrorist groups, even those short of resources and technology, could obtain weapons of mass destruction (WMD). As the technology of WMD is proliferating and the economy globalizing, to obtain crude WMD is not so difficult as before. The events in 1995 when terrorists used sarin gas to attack people in Tokyo, and the Oklahoma explosion after that made people realize that terrorist use of WMD might be possible. In the past decade, the events relating terrorists to WMD have increased[3]. There is more evidence that terrorists try to get WMD including nuclear weapons.

1. Nuclear Terrorism

Nuclear terrorism is the horrible action of using the potentially harmful application of radiation material, of nuclear material, to achieve a political purpose[4]. Although the probability of nuclear terrorist events is still very low, the risk of nuclear terrorism is increasing, and the danger is getting bigger. After the 9/11 events, the IAEA reappraised

[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

the risk of nuclear terrorism in the world, and issued a new warning on the threat of it. The IAEA pointed out that, to deal with this unconventional threat, there should be some special responses[5].

The threat of nuclear terrorism exists in four facets:

- Steal nuclear bombs and explode them.
- Steal, smuggle, or purchase nuclear material, and assemble crude nuclear explosive devices, and explode them.
- Attack a nuclear power plant or other nuclear facility, causing a huge radiation release.
- Distribute radiation material or construct a “dirty bomb”.

2. The means of nuclear terrorism

The explosion of a nuclear weapon in a big city is a very dangerous terrorist event. The simplest way is to steal a nuclear weapon and explode it. Normally, nuclear weapons are protected very well in the nuclear weapon states. Some experts still worry about nuclear weapons safety in some states. These weapons could become terrorists’ targets.

Tactical nuclear weapons are easy to handle by terrorists because of their physical character and the policy of their use. Tactical nuclear weapons are normally small, and they are deployed on the battlefield or theater of operations. They are not stored together and not protected well. They are easy targets for terrorists.

Another way to get a nuclear weapon is that terrorists steal or smuggle nuclear material and build a crude nuclear explosive device. This device could be made from plutonium, or could be made from highly enriched uranium. From the point of view of technology, it is not easy to make a nuclear weapon from plutonium which must be an implosive type weapon. It would be much easier to use highly enriched uranium for making a “gun type” nuclear explosive device. There are 250 tons of used military plutonium, and 208 tons of used civilian plutonium. Since 1993, more than ten events of nuclear material smuggling happened.

The simplest way to make a nuclear weapon is to put two or more highly enriched uranium pieces together, so that the total mass gets much higher than critical, that is a “gun type” weapon. It looks crude, but the theory is easy to understand, and so is the production. It is the easiest way for terrorists to make a nuclear weapon.

There are about 1850 tons of highly enriched uranium and 20 tons of enriched uranium from civilian use in the world. In the civilian field, highly enriched uranium is used in about 100 research reactors, and these reactors play an important role in medical treatment, in industry, and in other fields. A lot of these reactors are using uranium enriched to more than 90%. The highly enriched uranium is a threat regarding nuclear weapon proliferation and nuclear terrorism.

Some highly enriched uranium reactors are modified to use uranium enriched to less than 20%. But the uranium for this kind of reactor could still be used for a nuclear explosive device. We know that its mass must be higher than critical. One can calculate that criticality cannot be reached for uranium with less than 5 % ^{235}U. Thus, uranium with 5% ^{235}U cannot be used to make a nuclear explosive device.

For 100% ^{235}U, the critical mass is about 50 kg. For 10% ^{235}U, the critical mass is 3808 kg. This means that to make a nuclear explosive device one needs about 3.8 tons uranium of 10% ^{235}U without reflecting layer. A reflecting layer could reduce the critical mass. Assuming 20cm thickness of reflecting layer the critical mass would be 15 kg for uranium of 100% ^{235}U. If ^{235}U is 20%, to make a nuclear explosive device, 333 kg enriched uranium with 20cm thickness layer would be needed, and 2157 kg for enriched uranium of 10% ^{235}U.

The use of an implosive design is technically more difficult. Considering the mass of the reflecting layer and of the explosive, an improvised nuclear device should weigh more than 3 tons for uranium with 20% ^{235}U.

If terrorists have some technical capability and some tons uranium metal of more than 10% enrichment, it is possible for them to make an improvised nuclear device. If the implosive design is used, the needed enrichment is less.

Attacking a nuclear power plant or a nuclear facility is another way of nuclear terrorism. There are 5 forms of attacking a nuclear facility[5]. (1) Attacking a nuclear power plant directly, releasing a huge amount of radiation. (2) Destroying a key component of a nuclear power plant. (3) Stealing spent fuel from a nuclear power plant, and using it for terrorist action. (4) Attacking nuclear material or radiation sources in transfer, and release radiation. (5) Attacking other nuclear facilities.

Another way of nuclear terrorism is to make a “dirty bomb”. It is simple. Any radioactive material from a nuclear reactor, such as spent fuel, could produce this kind of weapon without the application of any chemistry. An important aspect is the need for a special method to secure safety during treatment, and to prepare aerosols of the radiating material to cause the maximum damage. Relatively, radiation sources are the material that is easy to get for terrorists. Radiation sources are widely used in industry, in agriculture, in medical sanitation and other economic fields. There are millions of radiation sources in the world. In China, there are 60-70 thousand radiation sources in use, and more than 10 thousand radiation sources are out of use [7]. Because of their low radiation, normally they would not create severe damage to people. Some are high radiation sources like cobalt-60, cesium-137, strontium-90, iridium-192. They are normally used in γ ray radiation processes, in medical radiation treatment, in non-destructive assay with γ rays, in nuclear batteries and in americium-beryllium neutron sources in surveying oil. Terrorists could obtain them.

3. Nuclear terrorism risk evaluation

The nuclear terrorism risk could be considered as a series of terrorist incidents. It includes the probability of terrorist incidents and the hazards associated with these events. The risk of nuclear terrorism could be defined as:

$$R\left(\frac{Destruction}{Time}\right) = P\left(\frac{Number\ of\ Events}{Time}\right) x\ T\left(\frac{Destruction}{Time}\right)$$

To analyze the risk of terrorism, the effect of nuclear terrorist attack needs to be identified, but also the possibility (probability) needs to be estimated, and the scale of destruction by a single incident needs to be evaluated.
The security situation of weapons-grade (WG) and reactor-grade (RG) nuclear material is different. With weapons-grade material explosive devices could be built directly, especially with weapons-grade uranium. Therefore, the probability for building a nuclear bomb is different for the two materials.

The probability of getting WG material and RG material are P (WgM) and P (RgM). The probability for setting up nuclear explosive devices is P (IND|WgM) and P (IND|RgM). The probability for successful transfer of nuclear explosive devices to the target is P (S|IND). The probability P(IND) for a nuclear terrorist incident caused by simple nuclear explosive devices is

$$P(IND) = P(S \mid IND) * [P(WgM) * P(IND \mid WgM) + P(RgM) * P(IND \mid RgM)]$$

Attack on major facilities includes attacks on nuclear materials transport, spent fuel reprocessing facilities, and nuclear material storage facilities, causing serious damage to the environment.

If each attack on nuclear facilities has the probability P ($S|NI_l$), the probability for every possible way of attack on nuclear facilities, causing radioactive effects, is P (NI_l), the probability for an attack on nuclear facilities by terrorists is P (NI) :

$$P(NI) = \sum_{i=1}^{8} P(S \mid NI_1) * P(NI_1) + \sum_{j=2}^{5} P(S \mid NI_l) * P(NI_l)$$

i = 1,2…8 represents 8 different ways to attack nuclear reactors.
j=1,2,3,4,5 are the five different types of nuclear facilities

We divide various radiation sources into α and β, γ. The probabilities of the source transport to targets are different. Stolen (or purchased) I- and II-source probability is P(RSklm).The probability to build "dirty bombs" is P(RDD|RS). The probability of transferring a "dirty bomb" to its target and exploding it is P(S|RDD). The probability for a nuclear attack by terrorists is:

$$P(RDD) = P(S \mid RDD) * P(RDD \mid RS) * \sum_{k=1}^{2}\sum_{l=1}^{2}\sum_{m=1}^{2} P(RS_{klm})$$

k=1,2 means theft and purchase; l =1,2 is class I or class II source, m = 1,2,3 represents the sources α, β and γ.

The risk of nuclear terrorism in four ways can be expressed as

$$R_n = P_n * T_n$$

.

n = 1,2,3,4 are the four ways mentioned before.

Since a nuclear terrorist incident has not yet occurred and the relevant data are scarce, the numerical estimate is uncertain. We use an event tree analysis and probability analysis to analyze the risk of the four ways from the probability of the occurrence of terrorist incidents. These are to steal and to explode nuclear explosive devices, to steal or to smuggle nuclear material to produce crude nuclear explosive devices and explode it, to attack nuclear facilities and to use radioactive materials to make "dirty bombs" and explode them.

The relative probability of incidents reflects the security situation of nuclear explosive devices, nuclear materials, nuclear facilities and radioactive sources. As the statistical data show that nuclear material, radioactive sources and radiation events are relatively numerous, the probability for potential attack on nuclear facilities, for potential terrorist incidents with "dirty bombs" and for attacks on nuclear facilities is higher than the probability for incidents with nuclear explosive devices.

The probabilities of the four potential types of nuclear terrorism triggering a nuclear incident are different. Access to adequate nuclear material to produce nuclear explosive devices and successfully explode them is much more difficult than attacking nuclear facilities. Although the probability of a successful attack on nuclear facilities triggering a nuclear terrorist incident is very small, the probability of exploding a nuclear explosive device is even much lower.

Although the destruction caused by a single terrorist incident with a nuclear "dirty bomb" is much less than the destruction by nuclear explosive devices, also by improvised nuclear explosive devices, the probability of terrorists triggering successfully a "dirty bomb" is much higher than the probability of attacking nuclear facilities and probability of terrorists exploding nuclear explosive devices. In the four nuclear terrorism facets, the risk of nuclear terrorism by "dirty bombs" is higher than the other three ways. The risks of attacking a nuclear facility and of terrorists making an improvised nuclear explosive device produced by illegal nuclear material are almost the same. The risk of the explosion of a nuclear weapon is minimal.

4. Discussion on the risk of nuclear terrorism

The probability for using nuclear weapons to carry out terror attacks is very low, but the consequences would be very serious. Many experts believe that there are some hidden troubles in Pakistan's nuclear weapons' safety. India's nuclear weapons are in an unknown situation. North Korea conducted nuclear tests, but the nuclear-weapon situation in North Korea is not fully understood by outsiders. Smuggling of nuclear material in the 1990s is an indisputable fact. From the technical perspective, clandestine manufacture of nuclear weapons by highly enriched uranium stolen from a reactor is feasible. Therefore, strengthening the safety of weapons and nuclear materials, especially highly enriched uranium, is a major step in preventing nuclear terrorism.

A uranium-235 concentration between 5% and 20% is sufficient for making gun-type nuclear explosive devices. Given the widespread existence of uranium in civilian reactors, and the relatively lax management, there must be sufficient vigilance to prevent such materials from falling into the hands of terrorists.

Radioactive waste and radiation sources are widely distributed. Technically and practically it is possible for terrorists to gain access to radioactive materials and to make dirty bombs. But the direct casualties are relatively low, the harm can be identified. Strengthening the control of radioactive material, in particular the control of radioactive sources, is the key to preventing nuclear terror.

Diagnosis of nuclear materials technology can effectively strengthen the management of nuclear materials. With regard to terrorist use of lowly enriched uranium for nuclear attacks, it is very important to identify the source. One can deter the smuggling of nuclear materials to terrorists and the proliferation of dealers, but can also promote nuclear materials management and security.

The risk of terrorist attacks on nuclear facilities in times of peace is relatively smaller than other risks of nuclear terrorism, because in general simple attacks are taken into account when designing nuclear power plants and other nuclear facilities, and they have a self-protection function. However, large-scale attacks and undermining the internal staff are the key challenges to the protection of nuclear facilities.

For the prevention of nuclear terrorist activities, the key way is to strengthen the supervision of nuclear and radioactive materials. Radioactive source tracking is an important step to deal with the risk of nuclear terrorist attacks.

With respect to the characteristics of radioactive terrorist activities, research and analysis of the risk of nuclear terror, and of the consequences of terrorist attacks is very important for predicting and forecasting technological challenges.

Nuclear terrorist activities could cause tremendous property damages and personnel casualties, but more important is the social and political confusion. Psychosocial effects will follow the elimination of the consequences of nuclear terrorist incidents. The experience of psychosocial interventions is seriously needed to deal with nuclear radiation incidents, and to develop effective measures to improve a deep awareness of the importance of information exchange to prevent nuclear terrorism.

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[2] Ian O. Lesser “Countering the New Terrorism”, ISBN 7-5011-5490-2/D.866.

[3] Charles D. Ferguson “The Four Faces of Nuclear Terrorism”, ISBN 1-885350-09-0, Monterey Institute of International Studies, 2004

[4] Rajesh M. Basrur, Hasan-Askari Rizvi, Nuclear Terrorism and South Asia, SAND98-0505/25, February, 2003

[5] Pan Ziqiang,, “Nuclear and radiation terrorism management”, Science press agence, ISBN 7-03-014708-1, April 2005 P.22.

[6] Nuclear and radiation terrorism management PP.29

[7] Nuclear and radiation terrorism management. P.41

The Risk of a Nuclear Catastrophe[1]

Francesco Calogero (Italy)

1. Introduction: various types of nuclear catastrophes

Nuclear catastrophes may be of different types. A rough taxonomy lists, in a rough order of decreasing impact: (1) a major nuclear war involving a large number (hundreds, thousands) of nuclear explosions; (2) a military conflict in which few (say, a one-digit number of) nuclear explosions take place, mainly against civilian targets (cities); (3) the military (so-called "surgical") employment of few nuclear explosions against specific targets, such as deeply-buried bunkers housing key installations, trying to minimize "collateral damage" to civilians; (4) the destruction of a city by a nuclear explosion produced by a terrorist commando; (5) the deliberate radioactive contamination on a significant scale of an inhabited area (so-called "dirty nuclear bomb" or, more properly, "radioactive dispersion device"); (6) the accidental explosion of a nuclear weapon, or other accidents involving nuclear weapons; (7) a serious accident in a civilian nuclear installation, typically in an electricity-producing nuclear reactor. I review below quite tersely these 7 types of events. I then focus on item (4), the treatment of which constitutes the main topic of this contribution. And I then complete this presentation with a terse mention of the risk of nuclear-weapon proliferation, a topic that should never be forgotten given its impact on the future of our civilization inasmuch as it largely influences the likelihood that some of the catastrophes listed above shall eventually happen; and with the opposite prospect of progress towards the achievement of a nuclear-weapon free world.

1.1. A major nuclear war

During the Cold War enormous nuclear arsenals have been built and deployed, mainly by the USA and the Soviet Union, now Russia. They comprised several tens of thousands nuclear warheads, most of them having explosive yields hundreds of times larger than those of the two bombs that destroyed Hiroshima and Nagasaki (6 and 9 August 1945; themselves with yields of 10-20 kilotons, namely equivalent to the explosive energy released by 10-20 million kilograms of high explosives such as TNT). Given the size of these arsenals, and the enormous effects of nuclear explosions – including, in addition to blast and heat (killing people and causing large-scale fires), immediate nuclear radiation and delayed radioactivity (fallout) – the possibility of an all-out nuclear war involving the two major nuclear-weapon countries entailed the prospect of an abrupt end of our civilization, possibly even the extinction of *homo sapiens*. The present arsenals have been somewhat – but not yet drastically – reduced with respect to those of the Cold War time. The prospect of a major nuclear war involving the two nuclear superpowers has instead decreased substantially – although many nuclear-armed missiles with intercontinental ranges are still kept on quick-reaction alert entailing the capability that their launch be decided and executed within minutes. A worrisome recent development is the return – by the current leaderships in the United States and in Russia (Bush and Putin) – to antagonistic postures playing up to nationalistic feelings and based on unilateral rather than cooperative attitudes to national and international security. It is perhaps justified to hope that a new

[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

administration in the United States, and to some extent in Russia as well (with Medvedev becoming more independent from Putin), might lead soon to a reversal of this unfortunate trend.

1.2. Few nuclear explosions in the context of a military conflict

A military conflict in which very few nuclear explosions take place, mainly against civilian targets (cities), would entail the immediate death of millions of people, the delayed death – after weeks and months of suffering – of many more, and of course major economic losses. It might typically occur in the context of confrontations among countries with nuclear weapons, such as the conflict over Kashmir pitting India and Pakistan against each other, or a military development in the Middle East leading to the employment of nuclear weapons, presumably in a situation in which the leadership of Israel – the only country in that region having now an operational nuclear arsenal – feels the very survival of their country at risk. Clearly any prospect of additional nuclear-weapon proliferation in the extended Middle East region will increase the risk of nuclear catastrophes in that region, while on the contrary the establishment and implementation of a nuclear-weapon-free zone agreement covering that region – or a weapons-of-mass-destruction-free zone agreement, also encompassing chemical and biological weapons – would essentially eliminate that danger, especially if it were achieved in the context of a transition from the present conflictual circumstances to a universally accepted settlement of existing controversies, including the mutual recognition of all States in the region (including Israel and a Palestinian State).

1.3. Few nuclear explosions pinpointed on specific military targets

This scenario has been contemplated relatively recently, mainly in the context of envisaged attempts to destroy underground bunkers containing installations considered of crucial strategic relevance, such as those producing materials essential for eventual or ongoing nuclear-weapon proliferation: for instance, centrifuges enriching uranium – say, in Iran – or nuclear reactors producing plutonium – say, in North Korea. The effectiveness of such actions is moot, as well as the illusion that they might be achieved with relatively minor "collateral damage". It is moreover – hopefully – widely understood that any military employment of nuclear weapons – breaking a taboo that prevailed for over six decades (Hiroshima and Nagasaki, August 6 and 9, 1945, were the only instances of the use of nuclear weapons "in anger") – would represent a major blunder, certainly with very bad repercussions – for instance in terms of nuclear-weapon proliferation. Fortunately it appears that the possibility of undertaking such initiatives is somewhat less talked about now than it was in the recent past. In any case it is useful to remind any decision-maker contemplating the responsibility of ordering such actions that whoever were to do so would be considered a "war criminal" in terms of international law as currently interpreted by the International Court of Justice: a judgement likely to affect the rest of the life of that person, and likely to go down in history.

1.4. Destruction of a city by a nuclear explosion produced by a terrorist commando

It has been and is my assessment that the likelihood that such a catastrophe occur is significant – and can be significantly affected by some countermeasures that might and should be taken, while it is only marginally influenced by other, rather useless, types of countermeasures now being contemplated and undertaken. The bulk of this presentation will be devoted to this topic. Clearly to make such an assessment, and to evaluate the more adequate countermeasures, it is necessary to understand and discuss the easiest route, for the possible perpetrators, to achieve the goal of destroying a city via a nuclear explosion. The risk that by doing so one might provide useful hints to them, turning concern into self-fulfilling prophesy, should not be neglected: this suggests caution in treating these matters, both in terms of the information provided and the kind of media used to advertise these possibilities. But excessive self-restraint carries the opposite danger of forswearing the responsibility to issue warnings that, if heeded, might instigate initiatives likely to decrease significantly the probability that such a terrible disaster occur.

Another component of this issue – that will be ignored below, since I do not feel competent to provide in this direction any nontrivial information – deals with the reasons and sentiments motivating the possible perpetrators of such a hideous act, aimed at killing in a flash millions of civilians and other millions after weeks and months of suffering. Suffice here to state that the argument often used in the past – according to which terrorists, being politically motivated, would never use such tactics, likely to alienate the sympathies of most people – are now considered to be invalid by most competent observers.

1.5. Radioactive-dispersion device

This refers to the possibility of the deliberate dispersal, "in anger" (i. e., with the specific purpose to harm people), of radioactive materials. It seems to me that this threat has been given more play than it really deserves. Indeed the likelihood that many (say, thousands) of people would die within weeks due to the radioactive contamination caused by such an event is moot, mainly because of the difficulty of getting hold, handling and properly dispersing a quantity of radioactivity likely to produce such results. It is undoubtedly possible to achieve in this manner a major media impact, and as well a very significant economic impact if such an event will occur on a significant scale in a major city, and also quite a few casualties resulting from the panic that might ensue – also due to the widespread fear of radioactivity, compounded by the inability of humans to feel its presence (although simple and cheap instruments to detect and measure it exist). The countermeasures to be adopted are quite obvious, and should be in any case undertaken independently of the terrorist threat: monitor and protect carefully all radioactive sources, educate the public to understand (quantitatively!) what radioactivity is, what the dangers associated with it are, and how it can be measured (also making widely available simple instruments to do so).

1.6. Accidents involving nuclear weapons

Of course, due to the existence of nuclear weapons, a nuclear catastrophe could occur accidentally rather than being intentionally caused. Two scenarios are relevant with respect to this risk.

The first and most dramatic – as it might trigger a nuclear war – might be caused by the accidental launch of a nuclear-armed delivery vehicle – typically a long-range missile carrying nuclear warheads. Careful procedures – including the psychological screening of the men who are in charge of these missiles – have of course been envisaged to minimize this risk. But some such danger of course lingers, especially in the context of nuclear postures – such as those still prevailing in the USA and Russia – maintaining the option to decide and execute the launch of some intercontinental nuclear-armed missiles within minutes. The reasonableness to maintain such postures should be questioned by public opinions and by political leaders.

An additional worrisome element possibly entailing malign interventions rather that inadvertent mistakes is the possibility that the computer network controlling the launches of missiles – as well as the influx and assessment of the information determining the eventual decision to launch – be penetrated and tampered with by insiders and/or by outside hackers, with catastrophic consequences. Clearly such possibilities cannot be completely ruled out as long as nuclear weapons exist, and in particular as long as some of them are deployed on long-range delivery vehicles such as missiles (unstoppable once launched) in a quick-response alert mode.

The second type of risk is the accidental explosion of a nuclear weapon due to a mishap. Serious accidents involving nuclear weapons – but none of them causing an actual nuclear explosion – occurred during the height of the Cold War, when nuclear weapons were routinely flown on bombers, some of which were always kept in the air.

Finally, no discussion of accidents involving nuclear weapons can omit at least a mention of the submarines carrying nuclear-tipped missiles, that constitute an important component (due to its “invulnerable” character) of nuclear arsenals. The dramatic loss of such submarines with their entire crew is unfortunately a possibility that has indeed materialized.

1.7. A serious accident in a civilian nuclear installation

Minor accidents occur routinely in nuclear installations: some of them might entail the release of minute quantities of radioactivity. Given the idiosyncratic fear of public opinions with respect to radioactivity the management of nuclear installations tries occasionally to hide such events, rather than dealing with them with complete transparency. Such a tendency tends of course to increase rather than to decrease the concern of public opinions. Occasionally (rarely) an important accident occurs: the major instance was Chernobyl, mainly due to a quite irresponsible behaviour of the managers of that nuclear installation. However, even in that case, no nuclear explosion occurred. In fact the probability that a nuclear explosion occur in a nuclear reactor is extremely tiny, for all practical purposes it can be considered an impossibility: even as a consequence of deliberate sabotage, the occurrence of a real nuclear explosion in a nuclear reactor (with effects comparable to those produced by a nuclear-explosive device) is extremely unlikely, perhaps just impossible. But electricity-producing nuclear reactors, after they have been operating for quite some time, contain very large quantities of highly radioactive material, and the release of even part of it – due to an accident (now rather unlikely) or to sabotage – would certainly constitute a major disaster. This is what happened in Chernobyl: accidentally, but due to such an irresponsible behaviour of the management of the reactor that the event could even be categorized as unintentional sabotage…

But the enormous, qualitative difference should be emphasized among the consequences, on one side, of a nuclear explosion in an inhabited area such as a city (deliberately produced with the intent to harm) and, on the other side, of the release of radioactivity due to even a major accident – some kind of (non nuclear) explosion – in a nuclear reactor or in an installation where radioactive spent fuel elements of a nuclear reactor are stored.

2. Nuclear terrorism

This second section focuses on the risk that a small subnational group acquire the technical capability to destroy large part of a large city with a nuclear explosion, causing an enormous human catastrophe, probably worst than what happened on August 6, 1945, in Hiroshima and three days later in Nagasaki. If and when a terroristic commando will demonstrate such a capability, such an event – a nuclear explosion in a city – and the prospect that such a catastrophe be repeated – will put into question the very survival of our civilization.

What could and should be done to lessen this risk is then tersely outlined.

2.1. The most likely procedure for a terrorist commando to destroy a city

A small subnational commando – provided it acquires a sufficient quantity of (weapon grade, i. e. uncontaminated and containing, say, at least 90% U-235) Highly Enriched Uranium (HEU) – is quite likely to be able to manufacture a primitive nuclear explosive device, itself quite likely to destroy large part of a large city, killing promptly very many people (at least several tens of thousands, but more likely hundreds of thousands or even millions), leaving in its wake as many or even more who will suffer for days weeks months before dying, and causing an immense economic damage. To reach this conclusion – which has the nature of a scientific/technological truth – one must realize that a primitive nuclear explosive device is much easier to manufacture than a nuclear weapon produced for employment in a military context by a State: the nuclear explosive device need not be transportable nor sturdy (most likely, it will be clandestinely manufactured in a rented locale in the target city), it need not be reliable (most likely, its yield will be *a priori* unpredictable, but with a significant probability to be of the order of that of the Hiroshima bomb), it need not have any security/safety gadgets (but given the low radioactivity of Uranium it can be manufactured without any health risks), and most likely it will be exploded via a timer allowing ample time for an easy getaway. The ease to manufacture such a device is implied by the fact that a nuclear explosion is produced whenever a supercritical mass of HEU is assembled sufficiently fast (namely in a time of the order of, say, a millisecond), possibly with a tamper around it in order to reduce the critical mass and to facilitate the supercritical mass remaining assembled for a sufficiently long time so as to guarantee that a cosmic ray neutron, or an internally produced neutron, start the chain reaction and that the chain reaction involves a sufficiently large number of nuclei before it gets stopped by the explosive disassembly of the device.

All the additional materials besides HEU needed to manufacture such a device are easily available in the open market (except possibly for some conventional explosives, easily available in the black market if they are indeed needed). And no previous expertise in the manufacture of nuclear weapons is needed (although it would of course facilitate the task), nor any knowledge of nuclear or material sciences beyond what an intelligent bricoleur may easily get from the open literature (available in books and via internet). This explains why this task can presumably be performed by a small commando of individuals, who need not muster any exceptional skills. While this is not the place to go into additional details, I suggest to any reader who doubts that this assessment is scientifically or technologically correct, to consult experts on the manufacture of nuclear weaponry – but make sure that the question being asked is the proper one, namely not the difficulty to build a *nuclear weapon*, but the difficulty to manufacture a *nuclear explosive device* of the type likely to be realized by terrorists in order to destroy a city. And I invite those of you who are interested but sceptic to read the appropriate literature. Let me just quote here a sentence from a paper entitled "The technical opportunities for a sub-national group to acquire nuclear weapons", written by a former director of the Sandia Laboratory in the United States, where the US nuclear weapons are manufactured:

"While not entirely straightforward, designing and fabricating a nuclear explosive device of the type described here is unlikely to confront a sub-national group with insurmountable difficulties".

And I should add that in his paper this author is actually discussing a somewhat more reliable nuclear explosive device than the gadget I mentioned above – as being one the yield of which would be *a priori* unpredictable, but with a significant probability to be in the kiloton or multi-kiloton range (the yield of the Hiroshima bomb was about 13 kilotons, produced by the fission of about one kilogram of HEU; about 60 kilograms of HEU were contained in that bomb).

Fortunately there is a barrier to be overcome before a subnational terrorist group acquire the capability to destroy large part of a large city via a nuclear explosion, namely the difficulty to get hold of the required quantity of HEU. This explains why a nuclear catastrophe has not yet happened. But complacency in this respect is, in my opinion, unwise. I have however become convinced that the scepticism about the likelihood of a catastrophe of new type happening is so widespread and overwhelming, that the threat of a nuclear explosion in a city caused by a subnational commando is unlikely to be taken adequately seriously before a catastrophic instance of it happen. Indeed the main rejoinder I hear by individuals who try to downplay this risk is: if you say it is so easy to do, why it did not yet happen?

Let me repeat: I believe the reason why it did not yet happen is because it is difficult for a subnational group to get hold of the sufficient quantity of (weapon-grade uncontaminated) HEU. And I do not pretend to be able to provide any reliable expertise on this aspect of the problem, which has to do mainly with intelligence. But it seems to me the following facts motivate serious concern.

One hundred kilograms of weapon-grade HEU are more than enough to manufacture easily a primitive nuclear explosive device. Once this amount of HEU is acquired by a terrorist commando, smuggling it anywhere is a trivial task, facilitated by its small volume (less than ten litres) and marginal radioactive signature. On the other hand I do not believe that HEU can be manufactured by a terrorist commando, indeed few States have the capability to produce it; and I discount the likelihood that any state provide a terrorist group with a large enough quantity of such material – hoping not to be overly optimistic in this respect. But this amount of HEU – less than *one hundred* kilograms – must be compared with the existing stocks of this material, which in Russia alone probably still exceed *one million* kilograms, dispersed over many sites (perhaps up to one hundred?).

Of course these considerations do not apply only to Russia, which is however the country where there is the largest stock of HEU.

2.2. Preventive countermeasures

Obviously the first priority to prevent the acquisition by terrorists of the capability to manufacture a nuclear explosive device is to impede that they acquire a sufficient quantity of HEU.

Some steps to improve the accounting and physical security of this material have been taken, mainly in the context of cooperative activities among the United States and Russia (and some of the other New Independent States formed after the disappearance of the Soviet Union), funded by the United States under the Nunn-Lugar legislation; but many experts believe that much less than enough has been and is being done.

Some progress has also been made in eliminating HEU: indeed the oversized stocks of HEU left over after the end of the Cold War make the elimination of large quantities of it – hundreds of metric tons – insignificant from a military-strategic point of view (except as regards the risk of its use by terrorists!); while the down-blending transformation of HEU into LEU (Low Enriched Uranium) containing, say, 3-5% U-235, which is the standard fuel for most commercial nuclear reactors, can be performed easily hence cheaply. (LEU cannot be used to manufacture nuclear explosive devices, and transforming LEU back to HEU is a task beyond the capabilities of most States, let alone a terrorist group). The most important development of this kind is the so-called "HEU Deal", agreed at the beginning of the 1990's, that regulates the down-blending to LEU in Russia of 500 metric tons (half a million kilograms) of Russian HEU and the sale of this LEU to American utilities via the United States Enrichment Corporation (USEC), a previously federally-owned institution that was privatized just when this deal was initiated. This arrangement is meant to entail that this entire operation be conducted "at no cost to the American taxpayer". But this caused the security motivations to eliminate *as much HEU as possible as quickly as possible* acquiring secondary importance with respect to the commercial aspects of this deal. Indeed, mainly for commercial reasons (namely, not to affect adversely the market price of LEU), the implementation of this deal has been spread over a quite long time period (20 years) – hardly consistently with a proper appreciation of the danger entailed by the prospects of nuclear terrorism based on the availability of HEU. Moreover, again just due to controversies about financial aspects, this program suffered various delays.

Anyway so far the HEU Deal caused the elimination by down-blending of over 300 metric tons of Russian HEU (estimated by USEC to correspond to the elimination of over *twelve thousand* nuclear warheads), and it seems to proceed now at a steady rate entailing the elimination of 30 metric tons of HEU per year. This is a positive result, although much more could and should be done, indeed a faster rate of elimination (by as much as a factor of five) would have been feasible – certainly technologically and also in terms of Russian willingness – if adequate funds were made available (even on a temporary basis) to support an acceleration of the elimination of the 500 metric tons of HEU declared by Russia to be in excess of their military needs. An extension of the project so as to eliminate additional quantities of Russian HEU can/should now be envisaged, perhaps via a different sort of financial arrangement. Unfortunately – and in my opinion most unwisely – the USA and other affluent countries do not seem as committed to address this question as it should be implied by the lip service paid to the risk of nuclear terrorism, for instance at the meeting of the G8 group of nations (or G7+1: Canada, France, Germany, Italy, Japan, UK, USA + Russia) held at Kananaskis in 2002, where the formula 10+10/10 (ten plus ten over ten) was advertised, meaning an agreement "in principle" to devote 10 billion US dollars by the USA, plus 10 billion US dollars by the other countries, over the next 10 years, to promote various developments meant to alleviate the risk of the use by terrorists of means of mass destruction. But these commitments have not been and are not being fully implemented.

A study advocating faster progress in the elimination of HEU and suggesting political and financial arrangements to this end was completed some years ago. It originated in the Pugwash context – then was commissioned by the Swedish government and performed by an international expert group. [G. Arbman, F. Calogero, Paolo Cotta-Ramusino, Lars van Dassen, M. Martellini, M. Bremer Maerli, A. Nikitin, J. Prawitz, L. Wredberg, "Eliminating Stockpiles of Highly Enriched Uranium: Options for an Action Agenda in Co-operation with the Russian Federation", Report submitted to the Swedish Ministry for Foreign Affairs, SKI Report 2004: 15, ISSN 1104-1374, available on www.ski.se] The main idea of that study is to offer financial incentives – possibly in the form of loans without interest – to Russia (and possibly to other countries of the former Soviet Union; but most of the HEU is in Russia) in order to promote additional elimination of HEU besides that already agreed with the USA. The hope was that other affluent countries (Europe, Japan, Australia, Canada,...), besides the USA, become involved in this enterprise; but, for various reasons, this has not (yet) happened. Perhaps some developments in this direction – at least in the bilateral USA-Russia context – are now in progress. However, the foundation of the HEU Deal was a Russian decision – taken at the beginning of the 1990s and sanctioned by the Duma – to declare 500 metric tons of HEU redundant to any military employment. But – in spite of the obvious military irrelevance of most of the remaining stock of HEU still possessed by Russia– it seems now unlikely that Russia will agree to additional elimination of its HEU, due to the changed geopolitical setting: much improved financial circumstances of Russia mainly thanks to the raise in the price of oil and gas, deteriorated strategic relations among Russia and Western countries (*in primis* the USA), resurgent nationalism in Russia with the standard associated tendency to ignore rational considerations.

Less than fully reasonable is – in my opinion – also the attitude of the USA, where – while 217 metric tons of HEU have been declared unnecessary for national security needs, and about half of them have been already down-blended to LEU – an enormous quantity of HEU has instead been set aside to guarantee the availability of fuel for nuclear-powered submarines into the remote future.

Also in this connection it should be mentioned that much useful work has been done by professor Frank von Hippel of Princeton University and by others, towards the eventual total elimination of the use of HEU from non-weapon activities worldwide, namely from all research reactors and from all the reactors used for naval propulsion (icebreakers and submarines). Indeed technological developments – including in particular the development of much more compact LEU fuel elements –make such a development possible. Clearly the eventual, complete phasing out of HEU from all human activities will be a must for the survival of our civilization, that is incompatible with the availability of a material allowing to a small group of individuals the capability to destroy a city. But let me emphasize that the total elimination of weapon-grade HEU does by no means entail a renunciation to peaceful nuclear activities, including the utilization of nuclear energy to produce electricity, a task which does not require any use of HEU.

Finally let me note that more attention has been and is devoted, rather than to the elimination of HEU, to the elimination of Plutonium, the (only) other material suitable for the construction of a nuclear explosive device. This is due to certain industrial and commercial interests which stand to gain (especially in Europe) from investments made in this direction rather than towards the elimination of HEU, and as well because this problem is technically more challenging (hence intellectually more interesting) than the elimination of HEU. But this misplaced focus is unfortunate, not only because there is still more HEU around than Plutonium, but especially because it is so much more difficult to build a nuclear explosive device with Plutonium than with HEU that the likelihood that a Plutonium device be manufactured by a sub-state terrorist commando is moot. («Most people seem unaware that if separated U-235 is at hand it's a trivial job to set off a nuclear explosion, whereas if only plutonium is available, making it explode is the most difficult technical job I know». Luis W. Alvarez, key physicist in the Manhattan project, and subsequently Nobel laureate in physics, in his memoirs published in 1987, one year before his death).

2.3. Defensive countermeasures

Enormous investments (totalling hundreds of billions of dollars) have been and are being spent by the USA to build a defensive shield against (nuclear-armed) missile attacks. The declared rationale for this investment is the need to defend against the embryonic nuclear-weapon capabilities of "rogue States". It is indeed recognized and advertised by the USA that such a shield will never be effective against an adversary possessing a nuclear-weapon arsenal as large and advanced as that deployed by Russia. But some in Russia nevertheless perceive it as an attempt to eliminate the retaliatory capability of Russia hence to make the threat of an American first-strike against Russia more likely or at least more credible. The response by Russia is to modernize its nuclear-weapon complex, and to be less disposed to reductions in its nuclear weaponry, namely to progress in nuclear disarmament. This pattern is becoming more and more an impediment to that transition from confrontation to cooperation of the USA and NATO with Russia (and also with China), that should have been the natural consequence of the end of the Cold War. There are indeed ugly symptoms of a return towards a Cold War climate in the relations among these two sides, mainly due to developments interpreted in this context as "provocative" by Russia – such as the planned deployment of radar and "defensive" missile bases in Eastern Europe. This is not the place for any further elaboration of these topics. The only point to be made here is that the defensive shield – irrespective of whether it will ever provide any reliable protection against nuclear-armed missiles – is obviously totally irrelevant against the nuclear threat by terrorists. As recently stated (Testimony to Congress, July 2007) by William Perry, a former (from 1994 to 1997) U. S. Secretary of Defence: "The centrepiece of our government's strategy for dealing with a nuclear attack is the National Missile Defence system…But the greatest danger today is that a terror group will detonate a nuclear bomb in one of our cities. Terrorists will not use a ballistic missile to deliver their bomb…".

More relevant to our topic here are defensive measures specifically meant against terrorism, being earmarked to impede the entry of weapons and dangerous materials into a country. A major effort in this direction is made by the USA, involving expenditures totalling billions of dollars. The idea is to install instrumentations and personnel at airports and all ports of entry, capable to monitor hence impede that any dangerous item enter the USA. While an investment in this direction has no negative implications (from the security point of view; it might have some negative economic impact, due to the delays it is likely to entail), it seems to me to be relevant rather as a Keynesian intervention to stimulate employment even if consisting of quite useless actions (like, as Keynes suggested, employing a work force firstly to dig holes in the ground and then to fill them), than in terms of its effectiveness – at least with respect to the goal of impeding, to a terrorist commando who had acquired enough HEU to manufacture a nuclear explosive device, to transfer it to the target city and set up shop there to perpetrate their hideous deed. I believe it is possible – indeed easy – to block such a commando if by intelligence it has been identified – before or after it enters the country. I consider instead pie in the sky the hope to create an impenetrable shield making it impossible – or even quite difficult – to introduce in a major American city a quantity of HEU sufficient to manufacture easily there a nuclear explosive device capable to destroy it. The motivation of this opinion of mine comes from the very small volume of such material (of the order of ten litres) and its quite marginal radioactive signature – to be compared with the enormous amount of goods that enter daily, by an extremely large number of legal ports of entries, in the USA – not to mention the significant quantity of materials, for instance tons of forbidden drugs, that enter every year via illegal routes.

Finally, it should be noted that there begins to be serious consideration in the USA of the measures to be taken if a city is hit by a nuclear explosion (in particular, one caused by terrorists): see, in particular, the report entitled "The Day After: the action in the 24 hours following a nuclear blast", the text of which is available on the web (http://cisac.stanford.edu/publications/day_after_the_action_in_the_24_hours_following_a_nuclear_blast/).

2.4. How likely is it that this catastrophe will happen?

The title of this section is the natural question that is evoked by any discussion of this unpleasant and scary subject. The only contribution I can usefully provide to this question is to outline – as I tried to do above – the technical facts that underlie this issue. This treatment is I believe useful inasmuch as it identifies some fundamental realities, and it also serves to identify measures that should certainly be taken: devote resources and efforts primarily towards the elimination of HEU – *as much of it as possible as quickly as possible* – and as long as HEU exists, as stop-gap measure, also devote efforts and resources to improve its physical security. But I do not know if there is anybody who can provide a reliable reply to the question stated above. My hunch – based on the technical data I know, as reported above – is that the probability is significant; hence it motivates a quite serious concern. So, I am quite concerned, and I expect a catastrophe to occur any day. But a more specific assessment of the relevant probability requires an expertise on the precise workings of the terrorist archipelago including an insight – mainly based on intelligence – that I do not muster. However, it appears that my concern is shared by the authors of the report mentioned at the end of the preceding section, who are presumably much better informed than me on these matters given their previous jobs in government.

3. Nuclear-weapon proliferation

In this section I will tersely review the main facts relevant to the current regime concerning the so-called "horizontal" proliferation of nuclear weaponry (the "vertical" nuclear-weapon proliferation refers mainly to the nuclear arms race involving the two so-called nuclear superpowers, the USA and the Soviet Union, now Russia). This terse review is meant for readers who are unfamiliar with these topics and wish to get a brief survey of the main relevant facts. As already mentioned above the motivation to present it here is because clearly a collapse of the nuclear non-proliferation regime – entailing the emergence of programs for the acquisition of nuclear weapons in many new countries – would make the occurrence of nuclear catastrophes much more likely, indeed essentially inevitable: a bleak future for humankind.

I will then end by tersely outlining the prospects that humankind achieves an alternative future, a world without nuclear weapons and without the raw materials to produce them; focussing in particular on some, hopeful, recent developments.

3.1. The nonproliferation regime

The main pillar of the nuclear-weapon nonproliferation regime is the Non Proliferation Treaty (NPT). It entered into force in 1970, and it was made into a permanent treaty – with no time limit – in 1995. The NPT identifies five nuclear-weapon countries: USA, Soviet Union (now Russia), United Kingdom, France, China. Their commitments under the treaty are not to transfer nuclear weaponry to other countries or help other countries to acquire such weapons, and to get eventually rid of their own nuclear arsenals – although no specific time limit is set by the treaty for this achievement. All other countries are identified as non-nuclear-weapon countries, and their commitment is not to acquire nuclear weaponry. The right by all countries to have access to peaceful nuclear technology is moreover affirmed by the treaty, and non-nuclear-weapon countries are committed to accept a verification regime administered by the International Atomic Energy Agency, based in Vienna, to certify that their peaceful nuclear activities are not diverted towards the acquisition of a nuclear-weapon capability.

All countries but three (or maybe four, including North Korea) are now party to the NPT: the three exceptions are India, Pakistan and Israel. The first two have recently acquired a nuclear-weapon capability, and they have demonstrated it by performing experimental nuclear explosions – underground, in order not to violate the Treaty that prohibits all nuclear explosions not taking place underground, to which these two countries, as most others, are parties. Israel has a deliberate policy of opacity concerning its nuclear-weapon capabilities, but it is certain that it has acquired a nuclear arsenal, presumably meant to be used – or threatened to be used – only in exceptional circumstances, when the very survival of that country is perceived to be at risk.

Other important components of the international nuclear-weapon nonproliferation regime are several nuclear-weapon-free zones, covering a large portion of the globe. Generally the nuclear-weapon-free zones exclude altogether the presence of nuclear weapons in the countries that are parties to them, while the NPT is generally interpreted to allow the presence of nuclear weapons (belonging to a nuclear-weapon country) in a non-nuclear-weapon country provided the hosting country cannot decide by itself to use such weapons. At present the only country that deploys its nuclear weapons in the territory of other countries is the USA. A few hundred American nuclear bombs, to be eventually delivered by aircraft, are now deployed – in the context of the Atlantic Alliance (NATO) – in six European countries: United Kingdom, Belgium, the Netherlands, Germany, Italy and Turkey. At the peak of the Cold War, many different types of American nuclear weapons were deployed in Europe, including mines and artillery shells, and several types of missiles besides bombs for aircraft; their total number reached a peak exceeding seven thousands warheads. The American nuclear weapons now present in Europe are meant to have a purely political (symbolic) significance: some NATO documents state that any decision to use them would take months to be implemented. The idea that the negative impact of such a symbol – in the context of the worldwide nuclear weapon non-proliferation regime – outweigh now its positive implications seems to be gaining ground on both sides of the Atlantic.

The nuclear non-proliferation regime based on the NPT has had a remarkable success in containing the spread of nuclear weapons. Indeed, at the end of the 1960' it appeared that many countries would acquire nuclear weapons: several countries already had more or less embryonic nuclear-weapon programs, which were terminated when these countries became parties to the NPT; and many more countries would have been forced to start such programs once their competitors and neighbours acquired such capabilities. Moreover the NPT provided the appropriate framework for the complete elimination of the nuclear weaponry of countries that became parties to this treaty *after* having acquired such arsenals: this was in particular the case of South Africa after the political transition to majority rule, and of Kazakhstan, Ukraine and Belarus after the dissolution of the Soviet Union (each of the arsenals of strategic nuclear weapons that fell under the control of the first two of these three countries when the Soviet Union disappeared were much larger than the combined arsenals of the three "lesser" nuclear-weapon countries, United Kingdom, France and China).

But unfortunately there is now an impending risk that the nuclear-weapon nonproliferation regime collapse.

3.2. Viability of the nonproliferation regime

The main symptoms of stress of the nuclear-weapon nonproliferation regime have been the open acquisitions of nuclear weaponry by India and Pakistan, greeted in both countries by signs of broad popular support. Another gloomy indication have been the developments in East Asia, where North Korea has acquired (and demonstrated) a nuclear-weapon capability in clear violation of its commitments under the NPT of which this country was a party, although at one point it declared the intention to abandon that treaty. This has opened the prospect that other countries in that part of the world – in particular Japan and South Korea – could opt out of the NPT and acquire a nuclear-weapon capability. This would be particularly easy, from a technological point of view, for Japan, a country that could quickly manufacture a significant nuclear-weapon arsenal if it decided to do so. Fortunately a strong opposition to nuclear weaponry – underscored by its Constitution – has characterized Japan as a consequence of the Hiroshima and Nagasaki traumas. But it could be overcome by the fear of a nuclear-armed North Korea. Hopefully, however, recent developments justify some hope that the crisis with North Korea be overcome in the context of the six-country negotiations involving North and South Korea, China, Japan, Russia and the USA, entailing a complete and verified renunciation by North Korea of any nuclear-weapon ambition and the consequential re-entry of this country as "normal" member of the international community.

Yet another worrisome development concerns the acquisition by Iran of a large-scale capability to enrich uranium, a technology that Iran claims to be developing for peaceful purposes but that in fact also has a clear nuclear-weapon potential —as explained above (once such a capability has been acquired, it can be used to produce LEU for peaceful uses as well as HEU for nuclear weapons; justifying the concern that once such a capability has been acquired Iran might walk out of the NPT and acquire nuclear weapons). In spite of contrary statements by Iran, this concern finds some foundation in aggressive pronouncements of certain components of the Iranian political leadership, including its President, and also on dubious aspects of its past activities that have motivated doubts in the context of the verification activities by the IAEA. The future unfolding of this crisis is for the moment unclear.

But it is in any case rather evident that the fundamental underlying reason of the risk that the international nuclear-weapon non-proliferation regime collapse is the unwillingness of the nuclear-weapon countries – *in primis*, the two nuclear-weapon superpowers, USA and Russia – to make serious progress towards fulfilling their part of the NPT bargain, namely the eventual elimination of their nuclear-weapon arsenals. It is in fact obvious that only in the context of a nuclear-weapon-free world – in which no country reserves the privilege to possess its own nuclear arsenal – the arguments for acquiring nuclear weapons that demagogues raise and public opinion now eagerly listen to in various geopolitical contexts – based on the powerful rejoinder: "why should we exercise restraint if others do not?" – could be effectively countered. To bolster the nuclear non-proliferation regime an overall global consensus must be internationally established, founded on a universally shared norm and entailing a cooperative framework based on a common interest: to prevent any country, and any subnational group – if necessary by force, with the backing of the entire international community – from acquiring nuclear weaponry and/or the capability to manufacture nuclear-explosive devices.

3.3. A nuclear-weapon free world: Desirable? Feasible?

This is not the place for a detailed analysis of this issue. Suffice here to note that – while many influential individuals, especially in or near the leadership of the nuclear-weapon countries (and in particular the most influential of these countries, namely the USA), still believe that the prospect of a nuclear-weapon-free world is utopian, hence that any policy motivated by this goal is naïve hence misguided – the recognition of the obvious truth that the achievement of this goal is in fact the only alternative to eventual widespread nuclear-weapon proliferation with catastrophic consequences has been steadily making progress and is now understood and internalized by more and more people, including individuals who played key roles in the development of nuclear weapons, who shaped the thinking about their political and military roles and who served in positions of high responsibility in supervising their management.

Past milestones in this thinking were: two collective books produced in the context of the Pugwash Conferences on Science and World Affairs [*A nuclear-weapon free world: Desirable? Feasible?*, edited by J. Rotblat, J. Steinberger and B. Udgaonkar, Westview Press, 1993 (also translated in many languages including Russian, Japanese, Spanish, Arabic, Korean,…and published in as many countries); *Nuclear Weapons: the Road to Zero*, edited by J. Rotblat, Westview Press, 1998]; two documents issued respectively by the Canberra Commission and by the Committee on International Security and Arms Control (CISAC) of the U. S. National Academy of Sciences ["Report of the Canberra Commission", August 1966; "The Future of U. S. Nuclear Weapons Policy", National Academy Press, Washington, D. C., 1997].

Important examples (all easily googable) of recent developments are: two articles by a bi-partisan quartet composed by two former US Secretaries of State, a former US Secretary of Defence and a former US Senator [George P. Shultz, William J. Perry, Henry A. Kissinger and Sam Nunn, "A World Free of Nuclear Weapons", *The Wall Street Journal*, January 4, 2007 and January 17, 2008]; the reply to the first of these two articles by Mikhail Gorbachev ["The Nuclear Threat", *The Wall Street Journal*, January 31, 2007]; the remarkable remarks by Arnold Schwarzenegger, Governor of California (October 10, 2007); the support that these developments have evoked by most of the former U. S. Secretaries of State, Secretaries of Defence and Special Assistants to the President for National Security; and various significant recent developments along these lines in other countries, including: the specific proposal ("Laying the Foundations for Multilateral Disarmament", February 5, 2008) presented at the Disarmament Conference in Geneva by the British Minister of Defence Des Browne, offering the UK's Atomic Weapons Establishment at Aldermaston to host a technical study of the verification of the elimination of nuclear weapons, to be performed jointly by experts of the 5 official Nuclear-Weapon Countries; and the decision by the Australian government to establish a new Canberra Commission. Pronouncements supporting progress towards the total elimination of nuclear weaponry can also be found in the following developments (to mention just a few): the very recent French White Paper on Defence; several recent interventions by leading British politicians, including the Prime Minister; and a bipartisan group of four eminent statesmen including a former Secretary General of NATO (article in *The Times* of London); an analogous intervention in Italy (an article in the major Italian newspaper signed by four top politicians from both sides of the political spectrum and by myself as token representative of the scientific community: *Il Corriere della Sera*, July 24, 2008); the electoral platforms issued by both candidates to the November 2008 presidential elections in the USA; and several statements issued by NGOs worldwide, such as, for instance, that issued by the Executive Committee of the Pugwash Conferences on Science and World Affairs and that promulgated by the Luxembourg Forum, an international group of experts based in Moscow – taking its name, just as the Pugwash Conferences do, from the location of its first meeting – who convened an international conference recently (June 2008) in Rome.

Collectively, these developments suggest that the prospect of the transition to a Nuclear-Weapon-Free World is graduating from desirable utopia to practical politics. Clearly in this respect a crucial role will be played by the new American Presidency.

Discussion of Wu Jun's and Francesco Calogero's Lecture[1]

Erwin Häckel *(Germany): When speaking about the risks of nuclear terrorism I would like to express a voice of caution and restraint. Nobody in his right mind would belittle the risk of nuclear terrorism. However, if we consider the first sentence of Mr. Wu's presentation, which said that nuclear terrorism is the most dangerous possible event at present time, I think this is a statement that we should be very careful and cautious to present. If we compare the risk of nuclear terrorism in terms of probabilities, or in terms of damage and casualty, I think it is very difficult – if not impossible – to compare it to other large scale risks, such as interstate war, conventional war or nuclear war, civil war, organized genocide, large natural disasters, large infectious pandemics. All of these are not unlikely, they are within our empirical experience and they can cause damage and casualties in numbers that compare easily to a nuclear explosion. In addition to that, in comparison to nuclear terrorism, with regard to most of these risks we do not have countermeasures at hand, and we don't have really widespread public awareness of these risks. So again, I do not want to belittle the risk of nuclear terrorism, but we should keep it in perspective and realize that the proportions of other risks to mankind should be taken into account.*

Francesco Calogero: But it is precisely because there are countermeasures that are not being used, that one should emphasize this risk – because if there is a risk to which there is no countermeasure, then all you can do is pray. But if there is a risk of a major catastrophe – like destroying a city – and there are obvious things that should be done and have not been done – like eliminating more highly enriched uranium – then I think one should emphasize this. Everybody should cry out for the fact that the opportunity to eliminate much more highly enriched uranium has been lost because it was considered more important to make a deal focused on commercial interests – such as keeping the price of low enriched uranium sufficiently high – instead of giving priority to the risk that New York, or Moscow, or Berlin be largely destroyed by a nuclear explosion.

John Simpson: I am sure many politicians are only too well aware of this.

Spurgeon Keeny *(USA): I was struck by the conclusion of Jun Wu that attacks on nuclear facilities was a much lower concern and probability as is considered by Calogero as well. It seems to me that nuclear facilities are ready made devices, they are there for the taking and I have not made a detailed study of it, but I am certainly aware that the security at lots of facilities is awfully poor. One does not even like to talk about it, it is so bad. To take one example, until recently in Japan there were not even guards with side arms at their main facilities, and maybe someone can comment on this who is more familiar with it, but that guards are still not there, they are just in the vicinity. I just wonder, are we really avoiding it – and I am not referring to Japan alone, but at the most likely place where there is to be a terrorist attempt to create a major incident, at a nuclear reactor or other facility?*

Wu Jun: When I calculated the risk of attack of nuclear facilities, we calculated this for the attack of nuclear power stations, spent fuels and research reactors. Nuclear power

[1] This discussion has been revised by one of the speakers. The information may differ from the audio content.

stations are normally well designed and well protected. I think the Chinese and American standards can offer protection against missiles. And even if this kind of attack happens, the costs will be lower than in Chernobyl, because Chernobyl is a huge area, and the release of radiation is huge. The costs for the dead people we calculated are 10 million. Spent fuel facilities are normally located outside of towns, in areas like deserts. In those areas, the only effect would be that they would be "dirty", but the costs would be low. It would be easier to identify it. Research reactors are dangerous, but they work with small amounts of material.

Francesco Calogero: I would not argue that the probability of destroying a city is higher than that of sabotaging of a nuclear installation. And I think a major sabotage could be much worse than Chernobyl. But I think that one should make an effort to remember what a Hiroshima-type explosion is, what could happen if a real nuclear explosion takes place in downtown Manhattan, or downtown London, or downtown Moscow. That is something completely on a different scale than what could be produced by an act of sabotage in a nuclear installation. So, one is talking about something on a completely different scale. The relative probabilities of these two kinds of events, I cannot say; I doubt anybody can make a reliable assessment. And of course, every effort should be made to make the two things as improbable as possible, and certainly there should be an effort on defending all nuclear installations. But do not forget what a real nuclear explosion in a city has been and would be. That is something completely out of scale, compared to a major accident or sabotage in a nuclear installation.

Christopher Watson *(UK): A few points for Francesco. The first is on the relative importance of uranium and plutonium. Broadly, I think I would agree with you, but I think you slightly understated the risks represented by plutonium. If you look at the history of recent proliferative countries that since the original big five have gone down the nuclear route, quite a good portion of them have at least explored the plutonium route as their preferred way to go, implying that people coming new to the subject thought that they could solve this problem. Maybe they were wrong and maybe Alvarez was right. But I would like to hear Dick Garwin's view on that, because I suspect that the difference and difficulty of the uranium route or plutonium route is not as great as you presented it.*

The second point is on getting rid of unnecessary uranium. Of course the "Megatons to Megawatts" program ought to move faster and should now be accelerated. The sums of money are really quite large and the disruptive effects on the international uranium economy are quite marked, and so it is not going to be easy to get agreement on getting rid of these last few hundred tons. I think I also agree with you that even more urgent than those few hundred well protected tons is the few tons of less well protected uranium, and particularly research reactors and naval vessels. Both of those I have the feeling that you underestimate the difficulty of the task. The research reactors are the proud possession of small facilities, small organizations that have no wish to lose their facility and they are certainly not prepared to simply close them down. If you pay every penny of the cost of converting them to medium enriched uranium, they might be willing to go down that route; but even so, they do not like to be told, so it is a politically difficult task. It is not surprising that, although everybody recognizes that it is important, it has not happened very fast. As a glance to the naval vessels, it is not altogether accidental that, although in the early generation of naval vessels they were *all low enriched uranium, the most recent naval vessels have tended to move to high enriched. And it has to do with getting that last knot of speed out of your submarine, and submariners care deeply about that last knot of speed and it is not going to be very easy to persuade them by governmental agreement for good. And the same thing applies with less certainty to the icebreaker case. I wish you well on those two fronts, which are very important, but I do not think it is obvious.*

***Richard Garwin** (USA): In response to the invitation to comment on the plutonium route for improvised nuclear weapons: this is not a country team. A country team might be expected to do a reasonable job with analysis, given that has been done, but the fact is that they do not. The North Koreans made a nuclear weapon, which they exploded in October 2006, and they told other countries shortly before the test that it would be a four kiloton weapon, and it was almost surely less than one kiloton – perhaps half a kiloton. The Indian scientists, in my opinion, did not do a very good job with their plutonium weapon, so it is not so easy; in fact, surprisingly poor performance on their part. As for the naval vessels and the research reactors, it is the fresh fuel which is the real problem. The exposed fuel for the naval vessels was highly irradiated and very well sequestered in the reactors, and the fresh fuel supply line is tightly controlled for most of the existing systems – although I do not know the case in Russia at the moment. Research reactors often have a spare core or two, fresh fuel usually less than critical mass though – fast critical mass of highly enriched uranium, and typically it is not in pure metal form, so it would have to be physically separated into the uranium component and the aluminum component or whatever. But that could be done reasonably well, however they would have to acquire a critical mass under these circumstances.*

Francesco Calogero: I just want to add one thing: on the issue of highly enriched uranium and plutonium, my nightmarish concern is a group of people that build a nuclear explosive device in an apartment downtown. Two, three, five persons. And that is something completely different from even the North Korean or Pakistani team. It is no question that a state can eventually acquire the capability to use Plutonium, but I think that for such a small group as I envision it is really much more difficult to produce a real nuclear explosion – not a radioactive-dispersal device – using plutonium. Whereas, unfortunately, it is my understanding that, even for such a small team of incompetent people – I mean, intelligent people but not necessarily weapon specialists – it is possible to produce a Hiroshima-type explosion in an apartment if they just had available a sufficient quantity of weapon-grade HEU. So that is a major difference. Regarding the question of altogether phasing out highly enriched uranium, I always emphasize that this is, in some sense, not the immediate goal. Yet it seems to me our civilization cannot survive with a material around which provides to a small group of just few people the capability to destroy a city. That is incompatible. So, eventually, highly enriched uranium should not be around: it should not be around in research reactors, it should not be around in naval vessels. I understand that France now is beginning to redesign its nuclear-powered submarines using much-less-enriched uranium. So this is possible and it is being done, there is a R&D activity in this direction. I think this is a very desirable development. It will not be easy but it ought to be done. And efforts in this direction should be supported with high priority. Much effort is instead focused on an impossible task: preventing 100 kg of HEU from entering, say, the United States. If a group of terrorists will manage to acquire this amount of HEU, it is unfortunately most likely that they will be able to bring it wherever they want – for instance to New York – because it is such a small quantity compared to the amount that enters legally. Moreover, the amount of materials that enter illegally the United States is enormous. Preventing the introduction of such an amount of material by erecting barriers is just an impossible task.

Andreas Henneka *(Germany): As a political scientist, I was quite happy to see in the paper of Prof. Calogero something about the elimination of nuclear material, not only about the detection or the controlling. Could you maybe elaborate a little bit more about the possibilities of scientific experts about the elimination of nuclear issues?*

Francesco Calogero: The answer is very simple: Highly enriched uranium can be downgraded to low enriched uranium. Going from low enriched uranium back to highly enriched uranium is a very difficult technological task that only very few countries master – certainly not the terrorists. So, if you just downgrade the uranium from, say, 95 % highly enriched uranium to 3-5 % low-enriched uranium, then you have a material that can be used to produce electrical energy, but cannot be used to produce nuclear explosions. This is feasible; in fact it is being done. There is a big project to do this and it is a very positive development, but it should be on a larger and faster scale than it has been done until now.

Adele Buckley *(USA): I have not heard anyone speak much about transportation. I do not know if there would be a terrorist opportunity during the transport from Russia to the U.S. for instance. Is the central enrichment facility to make only low enriched uranium, or is it sometimes to make highly enriched uranium and transport it somewhere? It seems there is some opportunity there to at least put it on the list of possible terrorist problems. And then on a lighter note: if you think of the novels that describe some dirty bomb, which is making a whole area impossible to live in for years and displaces many people… Is this an impossible event, or what is the dirty bomb possibility?*

Francesco Calogero: To the first issue: the highly enriched uranium is downgraded in Russia, and it is low enriched uranium that is transported from Russia to the United States.

Matthias Engler *(Germany): Mr. Wu Jun told us that one could build an explosive device with 300 kg of 20 % enriched uranium. Usually low enriched uranium is considered to be unsuitable to produce an explosive device. Maybe the experts could give us a number what is reasonable to think about in terms of enrichment, what could be sufficient to build a nuclear explosive device: 20 %, 50 %?*

Wu Jun: First, for the gun-type nuclear explosive device, it is a pre-initiation problem, because for every kilogram of uranium 238, we normally have thirteen neutrons. For the implosive nuclear device, normally the timescale is a thousand times of the gun-type nuclear device. We can use normal calculation: in four kilograms nuclear weapons are about 200,000 neutrons per second; but if we use 600 kilograms uranium of 20 %, there are about 8,000. So the timescale for the weapon grade plutonium, the pre-initiation probability is about 10 %. If we use the gun-type nuclear weapon, the probability is about 20 to 50 %. Even in these quantities, it is still very dangerous.

Saideh Lotfian *(Iran): I wonder if there are any databases on the number of nuclear terrorist acts that have failed. I know of several databases on terrorist acts, so we know that they have increased: for example, in 2006 there were more than 6000 such acts. If we have the data to support the assumption that the risk of nuclear terrorism has gone up, I would be interested to know about the databases that exist.*

Francesco Calogero: Well, I think the IAEA is keeping a list, a database. And I guess there is a feeling that many thefts and smuggling episodes are being reported. But you really have to look at how serious they are; whether they really involved highly enriched uranium, and so on. In any case I doubt it is very significant to look at this kind of database, because the issue is about a single event: whether it would be possible for someone to acquire clandestinely 50kg, 100kg of highly enriched uranium. I think it is rather improbable that the terrorist group would be able to assemble 20g here, 50g there… After all, the major protection that one can hope for is from intelligence, and the more involved is the acquisition process, the more likely it is that it will be discovered. Obviously the really dangerous events are those that are not discovered. There were quite a number of discoveries of minor transfers of radioactive materials from Russia towards Europe through Eastern Europe, while next to nothing was discovered in the southern border of Russia. But of course everybody knows that it is the southern border of Russia that is much more porous. If nothing is reported from there, this does not imply that nothing is happening. One should rather worry that if nothing gets discovered there, it may rather be due to much less efficiency there in preventing the smuggling.

Wu Jun: I think this is a very important issue. If we track where the material comes from, it would create a very important database. Also, for every facility in every country there are nuclear forensic issues. So first we should set up the databank. I remember a U.S. scientist recommended us to make it, to write a paper about it. But we still don't know how that would be, because for some countries that information is kept in secrecy.

John Simpson: I am not sure that was it. Were you [Lotfian] asking a question about terrorist incidents, or smuggling incidents? I understood you were asking about terrorist incidents that had failed.

Sadeh Lotfian*: Both smuggling and also incidents that have failed. As I said, I know of several databases created about the terrorist activities, both the ones that have succeeded and the ones that have failed. And there is a criticism that these databanks actually are not complete. So I was wondering if they have included the terrorist incidents in those databanks, whether they are separate databases, or simply nuclear incidents, to find the trends, and find the weaknesses.*

Wu Jun: The IAEA, Stanford University and the Monterey Institute have such databases. I know that these three databases have some differences.

John Simpson: One problem with the databanks is that the IAEA databank only has in it reports which come from governments; whereas the other databanks, of course, being independent operations, can also include material from newspapers or other reports. So that is why I think there are significant differences.

Erwin Häckel *(Germany): Just a brief comment: I do not want to belittle the threat of nuclear terrorism, in fact I think major effort along what Francesco (Calogero)* *suggested should be made to contain the danger of possible smuggling of nuclear materials, of highly enriched uranium, into the hands of terrorist organizations. Speaking of that, I think we should ponder for a minute about the intentions of terrorist organizations to use nuclear weapons or nuclear devices in pursuit of their objectives. 9/11, which was a major event – and a historical event in some respect – was committed with the most primitive instruments, like these plastic knives or something like that, leading of course to whatever happened. I can imagine a terrorist organization that would like to use a nuclear device in order to destroy the whole international system. I might also argue that for the purpose of many other terrorist organizations the use of a nuclear device might not be productive for their own objectives. And again I qualify what I am saying by arguing that possibly even one event of the use of nuclear device would be sufficient to apply all the possible countermeasures beforehand. But I still think that we should consider also the intentions of different terrorist organizations. Thank you.*

Francesco Calogero: In the past this was a traditional argument, that terrorists have political goals and therefore they will not want to produce a major catastrophe that would alienate public opinions, and therefore it is not likely that they will use such drastic means as destroying a city with a nuclear explosion. It seems to me that after 9/11 this argument has lost cogency. In addition, one must recognize that there have been instances in which people have tried this. The Japanese sect did use chemical weapons, they did use some kind of biological weapons, and they did try and set up a program to produce nuclear devices. They were very far from being able to achieve this goal, but they did try. So maybe it will not be terrorists in the usual sense of political terrorists who try this, maybe they will be crazy people. But the risk is there and so I think that everything possible should be made to lessen it, as a very high priority, because one cannot have confidence that it will not happen. There have been also instances in the United States of terrorists – you might say political motivated, you might say they were a crazy group – who would not recognize the federal government of the United States, considering it an occupying force. One might say they are crazy, but they were prepared to perform major acts of violence; and you might have insiders from such groups in sensitive installations and institutions, so I think the danger is real. Still I believe the most serious danger is from politically motivated groups such as those who produced 9/11. I don’t think they would hesitate from doing something as terrible as destroying a city. Moreover there is a perverse attraction in being able to use the ultimate weapon, in demonstrating the capability to perform such a terrible act.

John Simpson: I refrain from making any comments on this discussion, but I do think that the point that Erwin has made is a very relevant one which is if you look at this from the point of view of a terrorist group, what are the benefits to be derived from going down this road, as against roads they are much more familiar with? As you pointed out, that minimum cost, and in a sense minimum effort can generate a roughly similar consequence, certainly politically as well as economically.

Eighth Session - New Military Technologies

Chair: Richard Garwin

High Energy Lasers: A Sensible Choice for Future Weapon Systems?[1]

Götz Neuneck and Jan Stupl (Germany)

Introduction[2]

In 1916 Albert Einstein postulated the effect of stimulated emission of radiation and thereby laid the theoretical foundations of modern laser technology. However, it was not before 1960 that the first laser, a ruby laser, was built by T.H. Maiman. Today, lasers are widely employed in both civilian and military settings. Examples for civilian applications include CD-players, medical lasers, industrial laser welding and laser induced fusion experiments. Militarily, lasers are used as range finders, communication devices and target designators for laser guided weapons.

The output power of modern day lasers ranges from milliwatts to megawatts (in cases where they deliver continuous output power), or even petawatts (10^{15} W) for short pulse lasers. In military terms, lasers with continuous output powers greater than 20 kW are classified as High Energy Lasers (HEL). Output powers in the range of kilowatts or even megawatts allow the creation of laser beams with potential harmful intensity over distances of up to several hundred kilometers. These beams can be used to heat up targets, which then may lead to structural failure of the target object.

The first military applications of lasers were developed in the mid to late 1960s, and massive financial amounts have been spent on further research and development (R&D) since. Today, a number of research programs focus specifically on laser based directed energy weapons (DEWs). In 2005, more than half a billion US dollars is spent on R&D on DEWs by the United States (US) alone.[3] Other industrial countries such as France or Germany are conducting research in the field of HELs as well. Others, such as Russia, have done so in the past and might still have significant expertise in this field.

The aim of this article is to explore existing and planned military applications of HELs. In particular, we attempt to answer whether and to what extent investments in these weapons are sensible in the context of contemporary international security. Firstly, we will briefly examine the different military applications of laser technology. We will then introduce the technical characteristics of HELs. This scientific background is necessary in order to be able to address important security policy questions that arise from the development of HELs. These policy questions will be subject to analysis in a following section. Finally, we will survey some current HEL weapon projects. In particular, we

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[1] This paper was submitted by the authors for the conference records. The information and subject may differ from the audio content.

[2] This article is based on a paper given by the authors at the Spring Summit 2005 of the Deutsche Physikalische Gesellschaft (German Physical Society) in Berlin. The authors thank Jürgen Altmann, Achim Maas, Björn Michaelsen and the Editor of *Security Challenges* for their helpful comments. We also thank Prof's Emmelmann (Hamburg University of Technology) and Spitzer (University of Hamburg) for their support of experimental work in this field.

[3] For further information see table 2 and note (n.) 22.

will examine two advanced HEL projects in the US, the Airborne Laser and the Tactical High Energy Laser.

Military Applications of Laser Technology

Military laser applications can be usually divided into DEW applications and sensor applications. Some lasers, however, fit into both categories. Laser weapons are termed DEW when the energy of the laser beam is directly responsible for inflicting damage on a target object. Lasers may also be used as active sensors. This means that information is gathered using a laser beam which is emitted and then partly reflected back onto the sensor. In case the intensity of this beam is sufficient to damage a target, a sensor laser could be used as DEW as well. Table 1 summarizes important military applications of contemporary laser technology.

Sensor applications	*Example*	*Status*
target illumination	laser-guided bombs	first built 1968
range finding	fire control in tanks	deployed 1976
communications	submarine communications	R&D
LiDAR / LaDAR (laser radar)	verification of chemical WMD	R&D
Directed energy weapons		
blinding lasers	British and Chinese prototypes	Illegal (since 1995),but in use several times before
point defense	defense against artillery	prototype
missile defense	airborne laser	R&D

Table 1: Military Laser Applications

Sensor Applications

The first laser-guided bombs were built for the US Air Force in 1968.[4] They are the oldest example of military use of laser technology. However, it was not before the Gulf War of 1991 that these weapons became more widely known to the general public. Laser-guided bombs rely on the principle of so-called target illumination. The target is lit up by a laser spot of distinct wavelength and modulation. A detector inside the bomb identifies this signal, and, using control flaps, the bomb is automatically guided to the designated target.

Another form of sensor application is laser range-finding. A pulse is emitted by a laser, which is part of a sensor package. The pulse is partly reflected by the target onto the sensor where it is detected. Because the speed of light is finite, there is a certain delay between the emission of the laser pulse and its detection which depends on the respective distance. Measuring this delay, the sensor’s built-in electronics are able to calculate the distance to the target. This kind of laser range-finding is used in fire

[4] National Museum of the United States Air Force, ‘Texas Instruments BOLT-117 Laser Guided Bomb’, October 2002, http://www.wpafb.af.mil/museum/arm/arm21.htm – viewed April 2005; GlobalSecurity.org, ‘BOLT-117 (Bomb, Laser Terminal-117)’, March 2005, http://www.globalsecurity.org/military/systems/munitions/bolt-117.htm – viewed April 2005.

control systems of tanks since 1976, for example.[5] Initially rather narrow, the application of distance measurement has been widened over the years. A notable development is the so-called 'laser radar'. Laser radars employ concepts similar to those of conventional radars. Laser radars are also known as LiDAR or LaDAR. The abbreviations initially stood for Light Detection and Ranging and Laser Detection and Ranging, respectively. This is misleading, however, as the acronym 'LiDAR' is used for several different applications. Generating three-dimensional maps for cruise missiles navigation using a generalized method of range-finding is one example. It is also possible to determine the speed of moving objects using the Doppler frequency shift. Using a multi-spectral signal allows for gathering of information on the atmospheric composition as the amount of back-scattered energy depends on the wavelength of the beam and the composition of the atmosphere. One possible application of a multi-spectral LiDAR is the detection of chemical warfare agents within the atmosphere.[6]

Sensor applications are also used in the field of communication. One interesting development in this regard is the recent attempt to use lasers in submarine communication.[7] Certain wavelengths have only a small absorption in water. This means that communication could be possible without the submarine having to surface. And even if the submarine has to surface for the technology to work, laser communication would still be advantageous since it would draw less attention and is easier to secure than undirected radio transmissions.

Lasers as Directed Energy Weapons

In order to use laser beams as weapons, a certain amount of laser output power is necessary. The output power depends heavily on the actual target. For so-called soft targets, the minimum power to cause harm can be very low. Blinding lasers, for example, are designed to blind the human eye temporarily or permanently.[8] As the eye is very sensitive, these weapons require only a small amount of output power. Blindness can be caused in several ways: Apart from burning the retina, a laser pulse can also rupture blood vessels inside the eye or cause a process of slow decline of the retina. At a distance of a few meters, even an output power of a few milliwatts can damage the eye because the ocular focuses the beam onto the retina. This dramatically increases the intensity of the beam. Blinding lasers were used in the Falklands conflict and in the Iran/Iraq war of the 1980s.[9] However, in 1995, these weapons were officially banned under International Humanitarian Law.[10] If the aim is to destroy hard targets rather than to blind the enemy, however, the laser requires an output power many orders of

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[5] GlobalSecurity.org, 'M1 Abrams Main Battle Tank', March 2004, http://www.globalsecurity.org/military/systems/ground/m1-intro.htm – viewed 30 April 2005.

[6] Further information about LiDAR applications can be found at P S Argall & R J Sica, 'Lidar (Laser Radar)', in T G Brown et al, (eds), *Optics Encyclopedia: Basic Foundations and Practical Applications*, volume 2 G-L , Wiley-VCH, Weinheim, D, 2003, http://pcl.physics.uwo.ca/pclhtml/pub/LidarPapers/Argall-Encyc-Optics.pdf, pp. 1305–1322.

[7] W P Risk, T R Gosnell & A V Nurmikko, *Compact Blue-Green Lasers (Cambridge Studies in Modern Optics)*, Cambridge University Press, Cambridge, UK, 2003, http://www.loc.gov/catdir/samples/cam034/2003268603.pdf , pp. 8 - 12.

[8] A Peters, 'Blinding laser weapons: The need to ban a cruel and inhumane weapon', *Human Rights Watch Arms Project*, vol. 7, no. 1, September 1995, pp. 1–49.

[9] J H McCall, Jr, 'Blinded by the Light: International Law and the Legality of Anti-Optic Laser Weapons', *Cornell International Law Journal*, vol. 30, no. 1, 1997, pp. 1–44 here: pp. 5 – 6; Peters (as in n. 8), p. 3.

[10] For further discussion see below.

magnitude higher than that of blinding lasers. As mentioned, this article will focus specifically on HELs. The US Department of Defense (DOD) defines HELs as lasers with a continuous output power greater than 20 kW or a pulse energy in excess of 1 kJ.[11]

Technical Properties of HEL Weapons

HEL weapons are based on the propagation of a high intensity light beam from the weapon to the target. In order to use a laser as weapon, different processes have to be linked. The first is to actually create the laser beam. The beam energy then needs to be sent through the atmosphere. Finally, the beam energy must interact with the target. The target may be damaged or destroyed only if the whole process technology is successful.

From a military point of view, the use of HEL weapons has both advantages and disadvantages.[12] Some advantages from a military point of view include the following:

- The laser beam travels with the speed of light, i.e. 300 000 kilometers per second. In the vacuum of outer space the beam travels in a straight line. In favorable approximation this is also true for the propagation in the atmosphere. Compared with projectile weapons, targeting is simpler and evasion more difficult.

- Laser beams can be deflected by mirrors. Because mirrors are lighter than heavy gun towers, targeting is easier and quicker.

- The use of optical apertures with sizable diameters leads to collimated (nearly parallel) beams over distances from several hundreds to even thousands of kilometers. It has been suggested to combine this ability with space-based mirrors so that large parts of the world can be covered by only a few HELs.

- ‘Ammunition’ is only needed for certain laser types, e.g. chemical lasers. Many lasers only need electrical energy to operate. No further ammunition is needed if sufficient electrical energy is provided by a vehicle on which the laser is mounted.

- An attack with HELs does not leave fragments of weapons or ammunition. This makes it more difficult to identify the attacker.

Some potential disadvantages of the military use of HEL applications include the following:

- The target has to be in the line of sight of the laser if no further mirrors are used.

- Every optical aperture causes diffraction effects to the beam. As a consequence, the beam has a divergence. The beam diameter expands with distance and the intensity (power per area) decreases. This means that every laser weapon has range limits.

[11] US Defense Threat Reduction Agency, ‘Section 11: Lasers and Optics Technology’, in US Department of Defense, *Developing Science and Technologies List*, Ft. Belvoir, US, 2000, http://www.dtic.mil/mctl/DSTL/Sec11.pdf.

[12] G Neuneck, ‘Physik und Abrüstung - Neue Waffentechniken und Rüstungskontrolle’, *Physik in unserer Zeit*, vol. 32, no. 1, 2001, pp. 10–17; K Tsipis, ‘Laser weapons’, *Scientific American*, vol. 245, no. 6, 1981, pp. 51–57.

This is true even in the vacuum of space, as the beam still has to leave the laser through an aperture and has to start off with a finite size.

- Interactions between the beam and the atmosphere further reduce the beam's range. Absorption and scattering lead to reduced intensity. Additionally, the beam heats up its own path in the atmosphere. This means that the air's index of refraction is changed depending on the beam intensity. If the temperature difference between the centre and the outer parts of the beam is sufficient, the result is so-called thermal blooming, also known as thermal lens. This leads to higher beam divergences, compared to an ideal, so called diffraction-limited beam divergence, which is caused only by diffraction. Turbulence induces similar effects. Also, for long distances, there is an upper intensity limit for beams propagating within the atmosphere. Above a critical intensity, additional non-linear effects set in and the degrees of absorption and diffraction become a function of intensity. In other words, the higher the intensity, the higher the portion of the energy is absorbed and the less the damage that is inflicted upon a prospective target.[13]

- Today's high power lasers have low energy efficiency and require large and costly energy sources. Small batteries cannot store sufficient energy yet.

- The damage mechanism is highly dependent on the physical properties of the target. Compared to conventional explosives, it takes relatively long to destroy the target. The exact timeframe depends, among other things, on the target's reflectivity. If it is too high, the target might not be destroyed at all because most of the energy is then deflected.

- There are some countermeasures which work especially against lasers. For example, the scattering of the beam in the atmosphere can be raised artificially using a smoke screen; the reflectivity of the target can be improved by special coatings.

Despite these disadvantages and doubts about the feasibility of HEL weapons, several R&D programs are in progress.

Some Policy Questions Regarding Military HELs

Military HELs as a New Technology

Military HELs are relatively new and constitute a new type of weapon. As with any new technology, the first important question is whether and how HELs will proliferate in the future. Since there are a great number of laser applications in material processing, the first impression is that proliferation of HEL weapons might be fueled by the existence of industrial lasers. However, the equipment used in laser material processing is relatively expensive and has to be modified significantly before it can be used in a military setting. In addition, the output power of industrial lasers is usually smaller than

[13] US Department of Defense, *Defense Science Board Task Force on High Energy Laser Weapon Systems Applications (SuDoc D 1.107:2002017434)*, Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, 2001, http://www.acq.osd.mil/dsb/reports/
rephel.pdf, p. 103; P E Nielsen, *Effects of Directed Energy Weapons*, National Defense University Press, Washington, D.C., US, 2003, http://www.ndu.edu/ctnsp/Nielsen-EDEW.pdf, p. 129.

ten kilowatts. The availability of these lasers could nonetheless facilitate research for governments keen on obtaining military HELs.

Another key question that needs to be addressed is whether and to what extent a possible future use of HELs may lead to political instabilities or to escalation of an existing conflict. One example of a potentially destabilizing event is the deployment of a ground- or space-based laser anti-satellite (ASAT) weapon. In the aftermath of an attack with an ASAT weapon, the country attacked and others may be uncertain as to whether a future satellite failure is due to technical reasons or the result of an attack by a hostile power. In time of crisis, the existence of such a weapon alone might be enough to trigger further military escalation of a conflict. It is interesting to note in this context that the US first tested HELs for use against satellites in October 1997 to examine whether a ground-based HEL can blind satellite optics.[14]

Furthermore, it is also important to examine the likelihood of technological arms race. In theory, an arms race may be initiated by the deployment of an HEL missile defense system. Countries that feel threatened by an HEL system could either try to develop such a system themselves or attempt to compensate it with other weapons. Viable options in the latter respect may include the development of technologically advanced missiles that circumvent the system altogether. Another alternative could be the deployment of a high number of missiles with the aim to 'overload' an HEL defense system. It is evident that both efforts have the potential to cause negative spill over effects on other states and to result in an arms race.

Arms Control and Disarmament

As briefly mentioned above, the use of blinding laser weapons is illegal under international humanitarian law. In particular, these weapons violate the 1995 Fourth Protocol to the Convention on Prohibitions or Restriction on the Use of Certain Conventional Weapons Which May be Deemed to be Excessively Injurious or to Have Indiscriminate Effects.[15] This protocol outlaws the use and transfer of laser weapons which are intended to cause blindness. Additionally, the signatories are obliged to take the necessary steps to prevent blinding caused by other laser weapon engagements.[16] The protocol is not applicable where collateral blinding occurs as a result of the otherwise legitimate use of military laser applications. As a consequence, the protocol might be applicable to HEL weapons only, if they are especially designed for blinding purposes. Nevertheless, the protocol seems to have had some positive effects so far. Open marketing of blinding lasers has stopped and many laser R&D programs have been aborted after the adoption of the protocol.[17] Indeed, the protocol could constitute

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[14] B S Lambeth, *Mastering the Ultimate High Ground: Next Steps in the Military Use of Space*, RAND Project Air Force, Santa Monica, CA, US, 2003, http://www.rand.org/publications/MR/MR1649/MR1649.pdf, p. 102.

[15] For the full text and a list of signatories see ICRC, 'treaty database of the International Committee of the Red Cross', http://www.icrc.org/ihl.nsf/WebFULL?OpenView – viewed May 2005.

[16] The US is a special case. While they took part in the negotiations, they have not signed the protocol. Instead, there has been a unilateral declaration by the US Secretary of Defense which prohibits the use of laser blinding weapons in the US military. This declaration is considered as legally binding by scholars of international law, too; see L Doswald-Beck, 'New Protocol on Blinding Laser Weapons', *International Review of the Red Cross*, no. 310, January-February 1996, p. 285; A Stallard, 'Blinding Laser Weapons. Lethal or otherwise?', May 2003, http://www.bark.net.au/Globalisation/gloart10.htm – viewed 10 October 2005.

[17] Compare Ibid. and W M Arkin & A. Peters, 'US Blinding Laser Weapons', *Human Rights*

the first step towards a comprehensive ban of all laser weapons. This would be a first step toward preventive arms control, a concept which was developed to ban the introduction of new destabilizing weapon systems.[18] Whether and to what extent a complete ban is realistically achievable is another question, of course.

A first step towards a ban of HEL weapons would be to set limits on some of their technical parameters such as output energy or brilliance. It is also necessary to investigate the differences between laser tools, e.g. in material processing, and laser weapons to write appropriate definitions and guidelines to be able to unambiguously distinguish between them. Braid et al. and Altmann have made some suggestions how to tackle this problem.[19] Restricting HEL tools permanently to the interior of buildings would prohibit their use as offensive weapon.

If agreement on arms control measures was to be reached, the important question of verification remains. As far as long range (several hundred kilometers) laser weapons are concerned a ban appears to be verifiable relatively easily. These weapons need large optical apertures in order to prevent energy dissipation by diffraction. The resulting optical elements would require a diameter of one meter or more and need special coatings. As there is no other field of application for specially coated large diameter optics apart from long range HEL weapons, looking for these optics or indicators of their construction would be a good way to verify a ban.

The detection of a laser engagement or the source of such an engagement is a different problem. The beam itself is not visible on a radar screen and there are no remainders of ammunition after the attack. If the aim is to limit the intensity of laser beams within the atmosphere, verification may be possible by observing the scattered radiation due to interaction with the atmosphere. If the distance to the laser source is known, the beam diameter can also be calculated. Braid et al. and Prilutsky and Fomenkova have demonstrated that the intensity can be estimated using both quantities.[20]

Watch Arms Project, vol. 7, no. 5, May 1995, http://www.hrw.org/reports/1995/Us2.htm.

[18] Information on the concept of *preventive arms control* can be found in R Mutz & G Neuneck, 'Rüstungsmodernisierung und qualitative Rüstungskontrolle', in E Bahr, G Krell & K von Schubert, (eds), *Friedensgutachten 1989*, Institute for Peace Research and Security Policy at the University of Hamburg, Hamburg, D, 1989, pp. 129–139; W Liebert & G Neuneck, 'Wissenschaft und Technologie als Faktoren der Rüstungsdynamik', in E Müller & G Neuneck, (eds), *Rüstungsmodernisierung und Rüstungskontrolle: neue Technologien, Rüstungsdynamik und Stabilität*, Militär, Rüstung, Sicherheit 69 , Nomos, Baden-Baden, D, 1991, pp. 45–60; Idem, 'Civil-Military Ambivalence of Science and the Problem of Qualitative Arms Control: An Example of Laser Isotope Separation', in H-G Brauch et al., (eds), *Controlling the development and spread of military technology: lessons from the past and challenges for the 1990s*, VU Univ. Press, Amsterdam, NL, 1992, pp. 43–57; T Petermann, M Socher & C Wennrich, *Präventive Rüstungskontrolle bei Neuen Technologien. Utopie oder Notwendigkeit?*, Studien des Büros für Technikfolgen-Abschätzung beim Deutschen Bundestag 3, Edition Sigma, Berlin, D, 1997.

[19] T H Braid et al., 'Laser Brightness Verification', *Science and Global Security*, vol. 2, no. 1, 1990, http://www.princeton.edu/%7Eglobsec/publications/pdf/2_1Braid.pdf, pp. 59–78;
J Altmann, 'Verifying Limits on Research and Development - Case Studies: Beam Weapons, Electromagnetic Guns', in J Altmann, T Stock & J-P Stroot, (eds), *Verification After the Cold War: Broadening the Process* , V.U. Press, Amsterdam, NL, 1994, pp. 225–234.

[20] Braid et al. (as in n. 19); O F Prilutsky & M N Fomenkova, 'Laser Beam Scattering in the Atmosphere', *Science and Global Security*, vol. 2, no. 1, 1990, http://www.princeton.edu/%7Eglobsec/publications/pdf/2_1Pilutsky.pdf, pp. 79–86.

HEL Weapon Projects – A Brief Survey[21]

United States

Several HEL projects in the United Sates are underway, mainly conducted by the military. A list of some projects and their funding can be found in Table 2.[22]

Discussions as to whether place HEL in space initially originated in the 1980s. More recently, however, they have sparked renewed interest. The *Space Based Laser* (SBL) program as part of the missile defense projects of the second Bush Administration is primarily intended as a tool to intercept incoming ballistic missiles. The aim of this project is to fit satellites with chemical hydrogen-fluoride (HF) lasers (wavelength[23] $\lambda = 2.7\mu m$) together with high performance large diameter optics and fire control systems. It would then be possible to employ these SBLs to intercept intercontinental or medium range ballistic missiles primarily in the boost-phase of their ballistic trajectory. In the past it was also planned to apply SBLs against other satellites (as anti-satellite (ASAT) weapons).[24] However, according to the Defense Science Board, a federal advisory committee established to provide independent advice to the Secretary of Defense, for technical reasons, it has not been possible yet to launch such satellites into space.[25]

From a military point of view, a missile defense system based in outer space is appealing for several reasons. Firstly, the interactions between the beam and the atmosphere would then be reduced to a minimum. Also, positioning a missile defense system in space would substantially increase its range. Nevertheless, a space-based system also faces significant difficulties. It has been estimated that in order to reach adequate protection from hostile theatre ballistic missiles, the US would require a minimum of twenty satellites in different orbits.[26] In light of the fact that each repair would require astronauts or robots to be sent into orbit, the maintenance of these satellites may prove to be extraordinary difficult. Another problem is energy supply, as the built-in power supply will cease after time, which will also require space launches to refill or repair the space-based system. Since 2002, no funds have been allocated for the SBL program in the unclassified part of the US Department of Defense's budget.[27] However, this does not necessarily imply an end of the research for space-based HELs *per se*. Some authors believe that the HEL research can proceed in 'black programmes'

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[21] The following information has been gathered through public sources. Apart from the US, it is quite difficult to find information about military laser research. The reason for this could be a more restrictive handling of this information in other countries or just the result of smaller defense budgets.

[22] The numbers are the result of our research conducted using a search engine of the US DOD's budget office, which has been available until March 2005. Our result for the ABL is identical with a publication of the United States Government Accountability Office, 'Defense Acquisitions: Status of Ballistic Missile Defense Program in 2004' (as in n. 29). Sources for the funding of the THEL can be found in n. 60.

[23] Wavelengths greater than 0.8 µm are part of the infrared, making the beam invisible for the eye.

[24] US Space Command Director of Plans, 'United States Space Command Long Range Plan – Implementing USSPACECOM Vision for 2020', March 1998, http://www.fas.org/spp/military/docops/usspac/lrp/toc.htm – viewed 14 October 2005, pp. 20, Fig. 5-2; W H Possel, 'Defense - New concepts for Space-Based and Ground-Based Laser Weapons', *Occasional Paper - Center for Strategy and Technology*, no. 5, Air War College, Air University, Maxwell Air Force Base, United States 5, July 1998, http://www.au.af.mil/au/awc/awcgate/cst/csat5.pdf – viewed 14 October 2005, p. 11.

[25] US Department of Defense, *Defense Science Board Task Force on High Energy Laser Weapon Systems Applications,* (as in n. 13), p. 129.

[26] Possel (as in n. 24).

[27] J Lewis & J Cowan, 'Space Weapon Related Programs in the FY 2005 Budget Request', 26 March 2004, http://www.cdi.org/news/space-security/SpaceWeaponsFY05.pdf – viewed 25 October 2005.

or under different budget titles. Hitchens et al. note, for instance (especially mentioning the SBL), that the current US administration is willing to classify controversial projects in the face of congressional and public opposition.[28]

Another project currently under research and development is the Airborne Laser (ABL) program. Also aiming for ballistic missile defense, the intention of the project is to use a Boeing 747 airplane as a flying platform for a multi-megawatt HEL. The estimated range of an ABL is between 200 and 600 kilometers. The ABL would circle around hostile missile bases and destroy launched missiles in their boost phase. The ABL will employ a chemical oxygen-iodine laser (COIL) (wavelength $\lambda = 1.315\ \mu m$). At the moment, about 500 million US dollars are spent per year for the construction of a first prototype.[29] Further details of the ABL will be introduced below.

The Tactical High Energy Laser (THEL) is intended for point defense. Its primary task would be defending a limited area against mortars and artillery rockets. The program has already resulted in the development of a field tested prototype. This prototype managed to destroy mortars and rockets in a test environment.[30] The THEL is a ground-based chemical laser (deuterium-fluoride DF, wavelength $\lambda = 3.8\ \mu m$). The system consists of several portable, container-sized units. Current research is aimed at building a more mobile version, the MTHEL.[31]

The ZEUS system is a laser application used to defuse mines and unexploded ordnance (UXO) from safe distances.[32] The system's main part is a standard industrial laser, which is mounted onto a modified 'hummer' all-terrain vehicle. A beam director, an adjustable mirror, is used to guide the beam onto its targets. In the best case scenario, the explosives would burn but not explode. The range of the system is about 300 meters, the output power is only a few kilowatts. A prototype has been used in Afghanistan and is currently being tested in Iraq.[33]

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[28] T Hitchens et al, 'Space Weapons Spending in the Fiscal Year 2006 President's Request- A Preliminary Assessment', 10 February 2005, http://www.cdi.org/PDFs/FY06-1.pdf – viewed 14 October 2005.

[29] United States Government Accountability Office, 'Defense Acquisitions: Status of Ballistic Missile Defense Program in 2004', Report to Congressional Committees GAO-05-243, March 2005, p. 59.

[30] J Schwartz, G T Wilson & J M Avidor, Tactical High Energy Laser, in S Basu & J F Riker, (eds), *Proceedings of SPIE on Laser and Beam Control Technologies*, volume 4632, SPIE, June 2002, pp. 10-21, http://www.st.northropgrumman.com/media/SiteFiles/mediagallery/factsheet/SPIE_Manuscript_Tactical_high-energy_laser.pdf.

[31] US Department of Defense*, Defense Science Board Task Force on High Energy Laser Weapon Systems Applications* (as in n. 13).

[32] ZEUS is a registered trademark of Sparta Inc., Lake Forest, CA, US.

[33] N Shachtman, 'Call it a comeback: Laser Hummer', 2005, http://www.military.com/soldiertech/0,14632,Soldiertech_Laser,,00.html – viewed May 2005.

Program	SBL	ABL	THEL	ZEUS
Laser	HF	COIL	DF	Nd:YAG
Applications	missile defense / ASAT	missile defense / ASAT (?)	defense against artillery	mines / UXO
Range	Global	200-600 km	5 km	300 m
Funding 2005	n.a.	approx. 500 Mio. USD	approx. 50 Mio.USD	private (Sparta Inc.)
Status	n.a.	construction of prototype	testbed	tests in Iraq

Table 2: HEL Projects in the US

Laser DEW Programs Outside the US

Several other countries have also conducted R&D of laser DEW. These include France[34], Israel[35], China, Germany and Russia. Reports about Russian HELs tend to be inconsistent. Some authors have claimed that the output powers of systems tested by the former Soviet Union ranged from 20 kW to 1 MW.[36] After group of US scientists, led by Frank von Hippel from Princeton University, had visited a Soviet ballistic missile defense test site at Sary Shagan/Kazakhstan, it became clear that the Soviet Union had been conducting laser experiments for tracking satellites before 1989. This system featured a 20 kW CO_2 laser. The laser was coupled with a beam director and controlled by a simple (1960s) computer.[37]

China also seems to have developed DEWs. In early 1995, a Chinese company, Norinco, introduced a blinding laser weapon, the ZM-87, on an arms fair in the Philippines. According to a corresponding fact sheet, the ZM-87 permanently damaged the eye in a range of about 3 km and temporarily damaged it within a distance of up to 10km.[38] In October 1995 China signed the Blinding Laser Protocol (and ratified the instrument in 1998). A recent visit to Norinco's web pages revealed the absence of any advertising of blinding laser weapons.

[34] France looked into the technology of chemical lasers, too. There has been research using a DF-laser with a beam director. The project was named latex (laser associé à une tourelle expérimentale), see B Anderberg & M L Wolbarsht, *Laser Weapons: The Dawn of a New Military Age*, Plenum Press, New York, NY, US, 1992; quid.fr, 'Armes ? faisceaux de particules et lasers', quid.fr, 2000, http://www.quid.fr/2000/Q055040.htm – viewed October 2005.

[35] Israel works together with the US on the THEL. The aim of the co-operation was to build a defense system against Katyusha rockets. Companies from Israel contributed the radar and the control system. Further information can be found in section 6.2 and in Schwartz et al (as in n. 30)

[36] Anderberg & Wolbarsht (as in n. 34), p.133-4.

[37] F von Hippel, 'A visit to Sary Shagan and Kyshtym', Science and Global Security, vol. 1, no. 1-2, 1989, http://www.princeton.edu/~globsec/publications/pdf/1_1-2vonHippelA.pdf, pp. 165–174.

[38] Peters (as in n. 8), p.11.

Germany reportedly attempted to develop a gas-dynamic CO_2 laser for air defense purposes in the late 1970s.[39] The companies involved in this project were Diehl and MBB. However, it proved impossible to establish whether the project delivered any results or whether and when it was cancelled. Today, the company Rheinmetall-DeTec focuses on DEWs based on medium energy lasers. It plans to use pulsed solid state lasers against optical sensors.[40] According to the company's 2003 business report, the project is funded by the German Ministry of Defense.[41] Aside from Rheinmetall, Diehl, the European Aeronautic Defense and Space Company (EADS) and the German Aerospace Center (Deutsches Zentrum für Luft und Raumfahrt DLR) currently engage in a joint project to examine properties of a future medium energy laser weapon.[42] The project, entitled Medium Energy Laser weapon - COIL (MEL-COIL), accomplished the construction of a prototype COIL, which is located at the Federal Office for Defense Technology and Procurement and aims to assess air defense capabilities.[43] The laser developed in the course of this project has reached output powers in the 'higher kilowatt' range.[44] The MEL-COIL uses the same kind of laser as the ABL, namely a COIL.[45]

Two Advanced HEL Projects in the United States

The ABL and THEL are currently the most advanced projects. The following sections will thus examine both applications in more detail.

Airborne Laser

The ABL is intended to be employed as missile defense system. As indicated, in theory, a modified Boeing 747 aircraft would patrol in range of an enemy's missile bases and engage any missiles launched during their boost phase. The problem is, of course, that, depending on the size of the hostile country and the range of the ABL, the aircraft might have to fly in hostile air space. Since its speed is significantly slower than that of tactical combat aircrafts, the laser-fitted aircraft is vulnerable to attack.[46] As a consequence of diverging laser beams and the limited laser intensity delivered, the beam would have to be focused on the respective missile for several seconds. Missiles consist

[39] Anderberg & Wolbarsht (as in n. 34).
[40] G Wollmann, 'Direct energy weapons close gap: Dr. Gerd Wollmann on laser technology and high-power microwave', 2003, http://www.rheinmetall-detec.de/index.php?lang=3&fid=716 – viewed May 2005.
[41] Rheinmetall DeTec AG, 'Business report 2003', 2004.
[42] Aviation Week, 'Germans Come Closer To a Laser Weapon', *Aviation Week Show News ILA 2004*, May 2004, http://www.aviationweek.com/shownews/04ila/images/sn_ila04_3.pdf – viewed May 2005, p. 13.
[43] Deutsches Zentrum für Luft-und Raumfahrt e.V., 'Institute und Einrichtungen: Institut für Technische Physik', March 2003, http://www.dlr.de/tp/publikationen/handout/handout/itp_ handout.pdf – viewed May 2005.
[44] Bundesverband der Deutschen Luft- und Raumfahrtindustrie e. V., 'EADS-LFK erforscht Lasertechnologie - Deutscher Know-how-Vorsprung mit MEL-COIL', LRI Fakten - 03/2004 Informationen aus der Luft- und Raumfahrtindustrie , March 2004, http://www.bdli.de/index.php?option=com_docman&task=docclick&Itemid=108&bid=14&limitstart=0&limit=12 – viewed 19 October 2005.
[45] Wehrtechnische Dienststelle für Waffen und Munition (WTD91), 'Mittelenergie-Lasertechnik', Bundesamt für Wehrtechnik und Beschaffung, April 2004, http://www.bwb.org/C1256DF2004FF94C/vwContentByKey/W25YAC4W930INFODE – viewed May 2005.
[46] Another option would be to destroy all possible threats to the aircraft in advance. As these would include all sorts of surface-to-air weapons, this does not seem to be a viable choice.

of a warhead and the booster. The warhead is located on the top of the booster, the latter providing the acceleration. Since the warhead mounted on the missile's top is designed to withstand extreme temperatures during re-entry into the atmosphere, the laser beam is probably incapable of destroying it, even if it tracks it for several seconds. The laser would be therefore rather employed to heat up the metal skin of the booster. In theory, the forces at work during acceleration will then tear the missile apart. If the missile is powered by liquid fuel, which is highly pressurized, this internal pressure would further accelerate this process.[47] However, this also means that the warhead would remain intact and could potentially detonate in the following crash. This problem is called 'short fall problem' and could still lead to catastrophic collateral damage.[48] 'Short fall' might endanger people living in the flying area of the ABL.

Technical Properties of the ABL

In order to raise the temperature of the missile's hull to a critical point it is necessary to focus a laser beam of sufficient intensity on the same spot for several seconds. Because of diffraction effects and interactions with the atmosphere, however, the beam is only focusable to a certain degree. As a consequence, it is imperative to supply an output power of several megawatts.[49] The ABL's laser is a COIL.[50] The invention of COIL dates back to the 1970s, but as its working principle is complex, other lasers can be used more easily if output powers in the kilowatt range or below are required. Hence COILs have not matured into a standard tool so far. In a COIL, several toxic chemicals (e.g. hydrogen peroxide) react with each other in order to deliver the energy which is needed to create the beam. To ensure the safety of the crew, it is necessary to seal off the crew compartment airtight from the actual laser.

Since all of the laser's optical elements are extremely sensitive to misalignment, it is planned to use an automated sensor-actor system to work against the vibrations in the airplane. An adaptive optics system using a deformable mirror is supposed to compensate turbulence in the atmosphere between the ABL and the target. Turbulence otherwise distorts the beam. To finally shape and direct the laser beam, a 1.5 m diameter telescope will be used. The telescope will be gimbal-mounted on the aircraft's nose (see Figure 1). The engagement of the ABL begins as soon as the missile passes the cloud cover. The missile is detected by a system consisting of three other lasers and several infrared sensors.[51]

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[47] G Forden, 'Ballistic Missile Defense: The Airborne Laser', *IEEE Spectrum*, vol. 34, no. 9, September 1997, pp. 40–49.

[48] Idem, 'Laser defenses: What if they work?', *Bulletin of the Atomic Scientists*, vol. 58, no. 05, September/October 2002,, http://www.thebulletin.org/past_issues/058_005.htm, pp. 48–53.

[49] The diameter of a laser beam, which has the wavelength λ, will expand to at least $L\lambda/D$ with distance L, where D is the diameter of the laser aperture. If one assumes the distance to be L = 500 km and is using the values of the ABL, hence wavelength λ = 1.315 µm and diameter D = 1.5 m, the beam diameter will be at least 0.44 m.

[50] For more information about this particular chemical oxygen-iodine laser see D K Barton et al., 'Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues', *Reviews of Modern Physics*, vol. 76, no. 3, 2004, http://www.aps.org/public_affairs/popa/reports/nmd03.cfm, pp. 1– here: p. 301.

[51] Detailed information about the design of the ABL can be found in Ibid. and in Forden, 'Ballistic Missile Defense: The Airborne Laser' (as in n. 47).

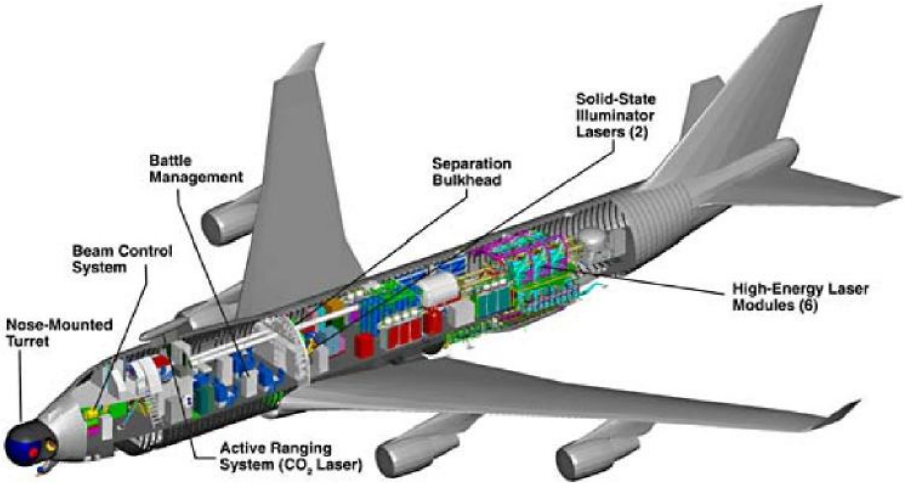

Figure 1: Planned ABL setup. Source: Boeing website.

The ABL - Will it Work?

All systems of the ABL have to be perfectly coordinated in order to use the aircraft for effective missile defense. This is a very complex task. A first test of the ABL system was originally scheduled for 2002 but postponed due to technical difficulties.[52] According to a recent congressional statement by the director of the US Missile Defense Agency, the first tests of the laser system on the ground are now scheduled for 2006.[53] If successful, the COIL will then be integrated into an aircraft. A first complete test is envisaged for 2008. At the moment, however, the planned compensation for the vibrations in the airplane poses a major challenge, as vibrations hamper both the technical operation of the laser and the targeting itself.[54]

The American Physical Society (APS) formed a study group on boost-phase intercept systems in order to assess US missile defense projects. In its report it concludes that the ABL may have 'some capabilities' against liquid-propellant inter-continental ballistic missiles (ICBMs). To arrive at these conclusions, the APS 'made reasonable estimates' and 'adopted the best-case scenario' in case of doubt.[55] The APS, for example, estimated the necessary flying areas of the plane. The results make it seem unreasonable to use the ABL against large countries, because the plane would have to enter hostile air space. Figure 2 (next page) sheds more light on this particular issue. Examples for possible fields of application are missiles launched from Iran and North Korea. In Iran,

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[52] United States Government Accountability Office, 'Defense Acquisitions: Status of Ballistic Missile Defense Program in 2004' (as in n. 29).
[53] Statement before the Strategic Forces Subcommittee of the Senate's Armed Services Committee on April 7th 2005, H A Obering, 'Missile Defense Program and Fiscal Year 2006 Budget', April 2005, http://www.senate.gov/~armed_services/statemnt/2005/April/Obering% 2004-07-05.pdf – viewed May 2005.
[54] misselthreat.com, 'Airborne Laser (ABL)', 2005, http://www.missilethreat.com/systems/abl_usa.html – viewed May 2005; United States Government Accountability Office, 'Defense Acquisitions: Assessments of Selected Major Weapon Programs', Report to Congressional Committees GAO-05-301, March 2005; United States Government Accountability Office, 'Defense Acquisitions: Status of Ballistic Missile Defense Program in 2004' (as in n. 29).
[55] Barton et al. (as in n. 50), p. XXII.

only a small part of the flying area is outside the country, whereas in case of North Korea, the ABL could eventually patrol over the South China Sea and the Sea of Japan.

The APS study also shows, that even with optimistic assumptions, the ABL would be ineffective against solid-propellant ICBMs.[56] Nevertheless, the ABL program is pushed forward, with a planned budget of 4.4 billion US dollars between 2006 and 2011.[57]

ABL Applications apart from Missile Defense?

Missile defense based on ABL applications appears to be very difficult. But are there any other possible applications of a flying HEL that justify its R&D budget? One possibility is the destruction of satellites in space. Using the ABL against surveillance satellites could be less difficult because satellites are much more vulnerable than warheads which are built to sustain re-entry into the earth's atmosphere. The optical sensors on board the satellite are built to detect weak signals from the surface. As a consequence, a high power laser beam should be able to overload and eventually destroy the sensors. Furthermore, several attempts can be undertaken in order to destroy the sensors of a specific satellite. It is difficult to decide whether it is possible to track a satellite using the sensors of the ABL alone, because a satellite is more difficult to detect by the ABL's sensors than a boosting missile. If other tracking devices are used outside the ABL, this task seems to be achievable.

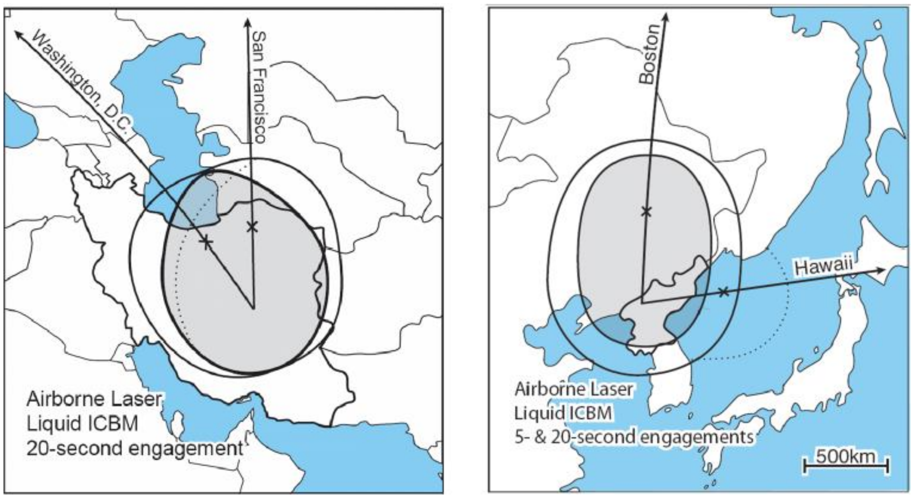

Figure 2: <u>Left:</u> Necessary flying area (shaded) for an intercept of liquid-propellant ICBMs launched from Iran against San Francisco or Washington D.C., if the available time for the intercept is 20 s. If there is less time available, the ABL has to be stationed closer to the missile base. <u>Right:</u> Flying areas for 5 s (shaded) and 20 s engagements against liquid-propellant missiles launched from North Korea, heading for Boston and Hawaii. Source: APS report on Boost-Phase Intercept (as in n. 50, p. 139, 141).

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56 Barton et al. (as in n. 50), p. XXII; solid-propellant ICBMs are using a different hull material from liquid-propellant missiles, which is more heat-resistant.

57 US Department of Defense, 'FY 2006/FY 2007 budget estimates: vol. 2 - Missile Defense Agency', March 2005, http://www.dod.mil/comptroller/defbudget/fy2006/budget_justification/pdfs/rdtande/MDA_PB06_07_Budget_Submission.pdf – viewed May 2005.

Tactical High Energy Laser

In contrast to the ABL, research on the Tactical High Energy Laser (THEL) has already resulted in the development and production of a prototype. Originally intended to be employed as defense against small short-range artillery rockets (Katyusha), the prototype has also been tested against mortars and large-calibre rockets.[58] The THEL system consists of radar, laser, beam director, optical tracking unit and computer-controlled command and control unit (see Figure 3). The radar is used to scan simultaneously the entire surroundings of the guarded area. As soon as e.g. a mortar round is detected, the beam director is aligned to it to use its superior optical tracking system. The laser can be activated automatically or with human intervention. A computer continues tracking until the target is destroyed or reaches it destination. Similar to the ABL, the THEL uses a chemical laser. Several toxic chemicals are used to produce chemically excited deuterium-fluoride. This delivers the necessary energy to create the laser beam. The exact output power of the THEL is classified. However, given that the US Department of Defense has described the THEL as HEL, it is likely that its output power exceeds 20 kW.

The beam director of the THEL shows a high degree of maneuverability.[59] Hence, the use of the THEL against ground targets should be possible in principle, if the control system is modified accordingly. However, the whole THEL system is not movable during its operation. As a consequence, the US DOD initiated a R&D program to develop a mobile version of the system called mobile THEL (MTHEL).

At the moment it is unclear whether the MTHEL program has any future. In the 2005 budget of the US DOD, the MTHEL program is funded until 2009. A first test was scheduled for 2007.[60] Until 2009, 340 million dollars have been allocated. In the 2006 budget, however, the program is noted as cancelled. The remaining 2005 funding is to be used for limited tests, the production of an initial engineering design, and the preparation of the THEL for storage.[61]

Nevertheless, on 4 May 2005, Northrop Grumman (NG), the main contractor of the MTHEL program, held a press conference entitled ‘Directed Energy: Out of the Lab - Onto the Battlefield’. According to Reuters, NG recommended use of the THEL in Iraq to guard against ‘insurgents mortar and rocket fire’. Reuters further reported that, according to NG, US Army officials had ‘balked’ at deploying the THEL so far for

[58] Northrup Grumman, ‘Press release: Northrop Grumman-Built High-Energy Laser Destroys Large-Caliber Rocket in History-Making Test’, Northrop Grumman, Redondo Beach, CA., US, May 2004, http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=57129 – viewed May 2005.

[59] Northrop Grumman, ‘Press Kit Lists: Tactical High Energy Laser - Media Gallery’, 2005, http://www.st.northropgrumman.com/media/MediaGallery.cfm?MediaType=Videos&PressKit=23 – viewed May 2005.

[60] US Department of the Army, *Supporting data FY 2005 president’s budget submitted to OSD - descriptive summaries of the research, development, test and evaluation army appropriation, budget activities 4 and 5 - Vol. II*, edited by Office of the Secretary of the Army (Financial Management and Comptroller); Department of the Army , February 2004, http://www.asafm.army.mil/budget/fybm/FY05/rforms/vol2.pdf – viewed May 2005, p. 24, 27-28, 33.

[61] Idem, *Supporting data FY 2006/2007 president’s budget submitted to OSD - descriptive summaries of the research, development, test and evaluation army appropriation, budget activities 4 and 5 - Vol. II*, edited by Idem , February 2005, http://www.asafm.army.mil/budget/fybm/FY06-07/rforms/vol2.zip, p. 21.

logistics and safety reasons.[62] At the same press conference NG also promised that these concerns could be addressed and announced the development of a smaller point-defense HEL weapon within two years. On 4 May 2005, Army officials involved in the matter were unavailable for comments for Reuters, but on 10 May 2005, a US Army officer was quoted in stating that no decision had been announced by the Pentagon about a deployment of the THEL.[63]

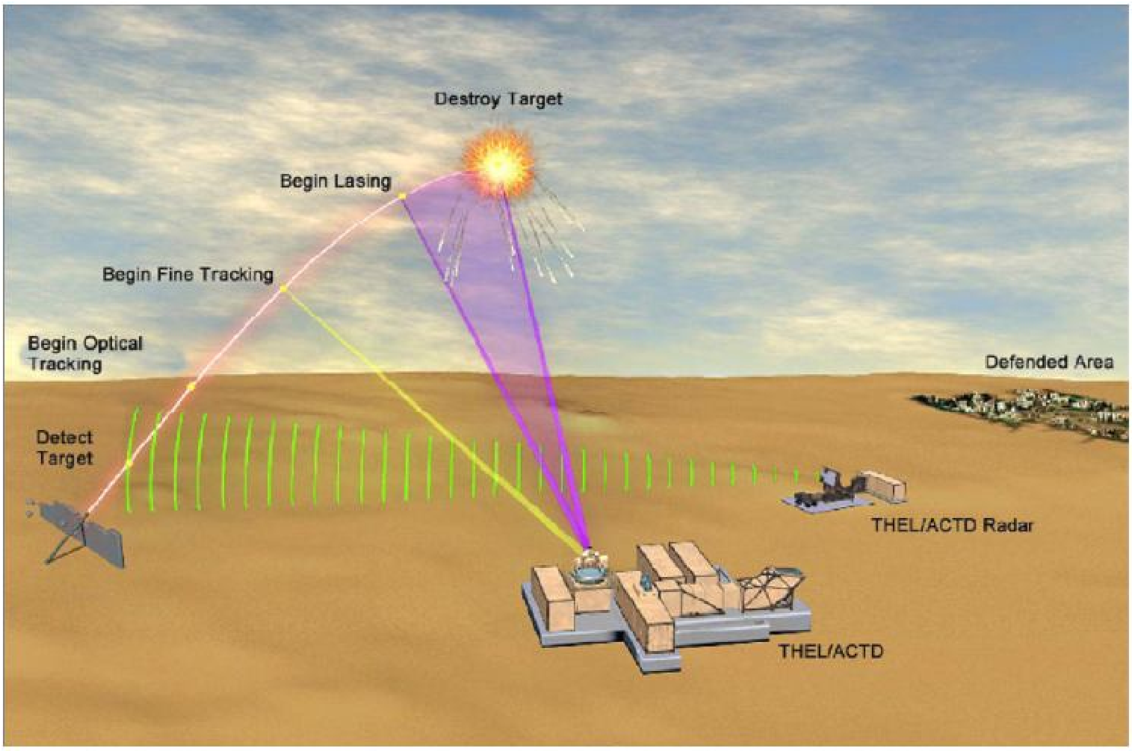

Figure 3: Progress of a THEL Engagement. Source: Shwartz et al. (as in n. 30).

It seems that at the time of writing (October 2005), a deployment of the THEL in Iraq has not occurred. A major concern is probably the supply of the laser's chemical fuels. These fuels cannot be produced on site and this creates a severe logistical problem. The fuels also represent a security hazard as the chemicals used are highly toxic. This can cause problems during the transport of the fuels and also on the deployment location. One source reports that the THEL is capable of shooting down a maximum of twelve targets per minute, i.e. it takes at least five seconds to shot down one mortar round.[64] As a consequence, it would be possible to overwhelm one system with a coordinated attack, if, for instance, several mortars were fired simultaneously from different directions onto the THEL. Hence the possibility of a successful attack on the THEL's fuel tanks has to be taken into account. And a successful attack which might be as hazardous as an attack with chemical agents.

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62 Reuters, 'US Army balks at sending laser weapon to Iraq', 5 May 2005, http: //www. reuters. com/newsArticle . jhtml?type=topNews&storyID=8390401 – viewed May 2005.

63 defensetech.org, 'RAY GUN TWO STEP: LASERS TO IRAQ?', May 2005, http: //www. defensetech.org/archives/001540.html – viewed May 2005.

64 M Becker, 'US-Armee erwägt Einsatz von Laserwaffe im Irak', *Spiegel Online*, May 2005, http://www.spiegel.de/wissenschaft/mensch/0, 1518,355681,00.html – viewed 12 May 2005.

Conclusion

Since the invention of the laser, R&D has been funded to explore possible military applications. So far, High Energy lasers (HEL) in the form of directed energy weapons (DEW) have not been deployed on the battlefield. HELs, however, have matured enough to run in test mode. Hence, it has been possible to build DEW prototypes like the THEL. There are several existing HEL projects, especially in the US. It can therefore be expected that HEL weapons will be introduced in a combat situation sooner or later. Whether these weapons will have the promised capabilities (e.g. as missile defense systems) is uncertain since major technical, logistical and military problems remain to be solved.

As far as short-range HEL weapons are concerned, solutions to these problems cannot be ruled out in the long run. However, as far as long-range weapons are concerned, there are certain physical limits, which cannot be bypassed. As a consequence, it seems unlikely that projects like the ABL will work under every condition, especially not if an adversary can employ effective countermeasures. Nevertheless, the appearance of HEL weapons raises several important policy questions by itself. In addition, it has to be investigated, which other applications might become available beside the advertised ones. Such applications may include weapons designed for blinding, arson and anti-satellite (ASAT) warfare. A potential use of HELs as ASAT weapons, for instance, might be destabilizing for international security and could trigger a technological arms race in outer space. Given these arguments, from our point view, further investment in HEL DEWs does not seem to be a sensible choice.

Discussion of Götz Neuneck's Lecture

Spurgeon Keeny *(USA): Could you say something about what the other side can do to respond and overcome any of these measures, assuming they could be actually converted to an operational system? I know many of the critics in the United States feel that we have spent 120 billion dollars on it so far and produced very little and there is quite a range of ideas that another country, such as Russia, could undertake that would largely negate many of these ideas.*

Götz Neuneck: I think there is a short answer: If they are scared about that, concerned about that, they might have a look at the presentation of Jan Stupl to learn what the most useful countermeasures are. These countermeasures are quite trivial in a sense. I mentioned them: one is to mirror the skin of a missile. This is not too easy but it is doable, you can use ablative materials, but then you have to put it outside of the missile and I am quite sure that missile engineers wouldn't have any problems looking for a special painting that reflects light. Another possibility is also to spin the missile, especially during launch. This is doable, it is not too easy, but you can do it. And you can, of course, combine all these three methods, and then I am quite sure that there might be even more ideas. I am sure that Dick Garwin knows more on that. I would say it is useless to spend so much money on it, but you know there are other projects in the missile defense area where we have the same problem with countermeasures. We all know that the current missile defense system does not work against a country which uses very simple countermeasures. The problem is to convince the American tax payer.

Hartwig Spitzer *(Germany): Two brief questions. I believe you mentioned that a length of time of something like at least 8 seconds would be necessary to have the beam directed upon the target, which would of course require following the target. I wonder if that is a problem. The second question relates to the direction against short-range missiles. I did not really understand the problem. What is the problem with the defense against short-range missiles?*

Götz Neuneck: The problem is that you have to follow the missile for some time. It is not clear what the real output energy of the laser is; but if one makes some calculations, it is at least between 20 seconds and even more. The airborne laser would have only a limited amount of energy on board, so it can only shoot a limited time. The problem in fact is to deliver the energy to a missile if it is in higher altitudes. At the beginning, you have a very dense atmosphere, so that the laser cannot work very efficiently. You have some kind of critical time. At the beginning the missile is deep and very slow, so you can see it quite well, but unfortunately the laser might not be very effective. But if the missile is moving and propelling itself, it has to be easier. It is not so complicated for the laser to follow that; it is a big flashlight. You receive a reflection from the missile and you will actually see it, but of course the aircraft is also moving, so it is not trivial but I think it is doable. The problem in this event is: what is inside the missile? It would be also another countermeasure to cool the missile, then the assumptions here, which are always best case assumptions, are also that the tanks are quite empty, so if the tanks are full, the energy would distribute it and would not harm. You know you need a critical moment and for that you have only several minutes – even less, depending on the missile. And of course the skin of the short-range missiles is always much thicker than the skin of an intercontinental ballistic missile. This adds to the problem.

Hannes Riedesser *(Germany): What I wondered when I heard about the airborne lasers is: how could this be a defense weapon? It has such a limited range that it can only be used as a first strike support weapon in a known area of engagement; you have to know where the danger is coming from. It will never be used over United States' soil. It will be used in foreign countries.*

Götz Neuneck: There is a long debate on what is offensive or defensive. I mean, it is quite easy: you can say a shield is defensive and a sword is offensive, but as a fighter you can combine both. This is certainly the deepest problem for the missile defense debate we currently have. Certainly this aircraft is an additional element of the U.S. global missile defense system. It is only applicable for small countries and you also need not only one aircraft, but one might be in repair, maintenance or whatever; you need four of them. Another very basic problem is the survivability of defensive systems because they also will be attacked. You have to protect this kind of airborne laser additionally. This makes it very complicated, but nevertheless we have to convince others, we have to convince people who are running the budget in the U.S. at the moment.

[unknown speaker]*: Maybe this is a good follow up question to the question before this one. I was just wondering about the simulations that you showed us. It was a best case scenario of course; it seemed to me as if the aircraft was already in the air when the missile started in this simulation. Now you showed us that when the laser does not have enough time to have a continuous shot at the short range missile, they will not do much harm. Have there been any calculations on the question of the missile launch, its getting detected and then the aircraft launches, then how much time that would take?*

Götz Neuneck: The short-range ballistic missile flies for maybe two, three or four minutes. You do not have any time, the aircraft already has to be in the air. For the intercontinental missile it is quite the same. You have to be on patrol all the time.

Francesco Calogero *(Italy): I think at the beginning you have shown the type of laser antipersonnel weapons, which are already operational and maybe deployed. You mentioned the blinding one. Is this not forbidden by international conventions?*

Götz Neuneck: Yes. There is a protocol under the Conventional Weapons Convention CWC, I think it is the fifth (or fourth) protocol from 1995. It prohibits the deployment and transfer of weapons designed to blind the naked eye; and calls upon avoiding collateral blindness using other lasers. But the convention says that you only prohibit that if the system is built to blind people. The airborne laser is not built to blind people. There are other lasers, even range finders, you know. This is the first problem. The second problem is that not all states have signed the treaty. I think one good thing is that when this protocol came into conclusion, there was a strong tendency to introduce blinding weapons into military forces. And this protocol prevented that. The U.S. did not sign this protocol, but they comply with it. There is a letter – I think it was from Bill Cohen – saying that the U.S. military forces would not introduce that. But there is still some research; it is a complicated issue. I would say the protocol until now has been effective, but you never know. As many arms control treaties, it does not prevent further developments in this field.

***John Simpson** (UK): I wonder if you could say something about the impact of the weather upon these systems, particularly ground based systems.*

Götz Neuneck: Where is Jan Stupl? He knows these technical details much better than me.

Jan Stupl (Germany): The weather would be a big problem. If you are on the ground and you are inside a thunderstorm, you can forget about it, basically. If it's just a bit humid, then it's more difficult than compared to dry weather. Weather is an important factor. For the ABL is over most of the weather, because it is flying at 12 kilometers altitude there it is not so much of a problem, but it could be a problem if the missile is launching in a very humid atmosphere, then you need more time than you would need in a dry atmosphere.

Richard Garwin (USA): I would like to make some comments. First some technical comments and perhaps I can show you something. On the active denial system that Götz mentioned, which is a 100 kilowatt 3 mm wavelength mobile system for the battlefield, on March 3rd of this year on the American CBS television program "60 minutes" there was a 20 minute segment about the active denial system and it showed people who were paid to do this – and some who were not paid to do it but were government officials – being illuminated at a distance of more than a kilometer from this vehicle that has an antenna a couple of meters square. It produces an intense burning sensation of the skin, but if it is turned off or you get out of the beam, which is quite small, then there is no damage. It turns out that if you used just an umbrella with aluminum foil, then you do not need to know the frequency. With micro-perforation, you could still see through it and the millimeter waves cannot get through it at all. But it has to be a big enough umbrella, so as to cover. In order not to have to have the umbrella too big you could wear aluminum foil trousers and boots, so that you only would have to cover a part of you. However, that could show some intent to remain in the area if you come with an aluminum foil umbrella. I have made this point for many years in a number of reports on nonlethal weapons done for the Council on Foreign Relations.

The kinetic energy kill-weapons initially in the star war days of 1983 were imagined to be rail-gun launched bullets that would go thousands kilometers through space and attack and strike ballistic missiles, but it is impossible either to aim that well, to fly that well or to predict that well where the target will be, unless it is a satellite. So the only possibility is to have these kinetic kill vehicles equipped with homing devices. And that is what you saw operate effectively from one of the sea-based kinetic-kill interceptors. That is part of the missile defense system that the United States has used to destroy a satellite that was about to reenter the atmosphere.

A rather political point I would like to mention on the airborne laser, is that it is so much easier and more effective in killing satellites which are totally predictable. The airborne laser knows exactly where it is to a meter accuracy with its global positioning system GPS; it knows where the satellite is to meters accuracy. It has the tracking laser on it, so it can refine its knowledge; and there is no problem to heat a satellite – even a hundred degrees temperature increase in a satellite is likely to kill it. It is a totally different matter from blinding or dazzling a satellite, which, as Dr. Neuneck said, can be done with milliwatt or watt lasers.

On the question of the shortfall – that is if you have a successful intercept, you might regret it because it might fall short. The average population density in Europe is a factor 100 smaller than the population density in a target city, so it is true that on average one hundred people might be killed by a nuclear weapon explosion at a random spot in Europe. But if you can reduce the effectiveness of any military weapon by a factor of 100 or 1000, and besides make it so they do not kill the people they are wanting to kill, but other people, this would be really quite a matter of deterrence. So it is far from my role to say something approving about a ballistic missile defense system. But the question of shortfall does not bother me. I take issue with my friends on this.

Another technical point on the adaptive optics: It is really quite striking that as you make a larger and larger telescope mirror for astronomy purposes, or for any purposes, on the Earth surface, once you get beyond about 15 cm in diameter, the accuracy, the sharpness does not improve even though the diffraction limit goes down as 1/radius. So you might imagine that if you had an apparatus of 15 cm diameter at ground level, if you made a 150 cm apparatus the resolution would be ten times better – but it is not. What you are doing is simply collecting a hundred times as much light, but each element of the telescope, even 15 centimeter diameter, is just as blurred. And unlike a telescope in a vacuum, these images do not add coherently to sharpen themselves; they add incoherently. So if you could move a portion of the mirror every 15 cm by a wavelength or less in order to compensate for the effect of the turbulence, you could regain the sharpness. And that is what has been done in the adaptive optics system for astronomy for the last ten years. In fact, they can use their standard mirrors and re-image the system on a smaller mirror in the telescope, so you have typically an adaptive optic corrective mirror which is only itself 10 cm in diameter, but will correct a mirror two or three meters in diameter because of the optical systems.

On the blinding lasers: even though it is not forbidden to use lasers that will accidently blind people, the people who manufacture laser target designators or laser rangers really do not want the bad publicity of blinding people. So they have a big incentive to make so called eye-safe lasers. The blinding comes not because the eye or the cornea is heated; the blinding comes because the eye lens focuses even a small power laser light into a point on the retina that will then boil – or pulsed lasers cause shock. But if the laser is eye-safe in a sense that does not penetrate the water of the eye, then it does not cause damage at that level and would have to have a factor of 10 to the 5^{th} or 10 to the 6^{th} times that power level in order to cause damage.

And now I would like to show you, with the miracle of modern computers, how you can find more about these topics. On the screen you can go to Google. I put in the Google search box *nuclear terrorism.* You see that looking at the two words *nuclear* and t*errorism*, and requiring them to be in the same file, there are 631,000 such files available on the internet. And if I would now add quotation marks beginning and after – so I am looking at the phrase *"nuclear terrorism"* – you see there are 345,000. It helped some, but to explore all those 345,000 it will take you a long time. So you might want to see what Dick Garwin has to say about it, then you can put in *Garwin "nuclear terrorism".* Now there are 2,060; but I can tell you, I did not write 2,060 papers on nuclear terrorism and post them on the internet. Most of these are people who are referencing, or talking about me, or criticizing what I have to say on nuclear terrorism, and you might want to read those things too. But in order to see what I have to say, you have to remember my website, which ends with fas.org/rlg/. So in Google if you will put “site;” and then the last portion of the URL that you are looking for – you could put “site;mil” to see what the American military has to say – if you do this, there are only 6; not 340,000, not 2,060, there are only 6. That is, in the Google search box you put *site:fas.org/rlg/ “nuclear terrorism”*

And so you could see what I have to say. Some of these six are only in fact the titles, but also it searches within the file, so anything that I say that has “nuclear terrorism” as a term within the document will be found in this way, as well as files on my site that actually reference other things. So here is nuclear weapon proliferation, nuclear terrorism and Iran.

Let me go back. I told you you could see what the U.S. military has to say about nuclear terrorism.: *site:mil “nuclear terrorism”*

This displays 537 documents. Do any of them talk about me and nuclear terrorism? Try *site:mil “nuclear terrorism” garwin*

Yes! There are 10 documents. It is really a marvelous way to research things, not necessarily that I have anything to do with.

Let us search for “microwave weapon” *site:mil “microwave weapon”* ; this retrieves 47 “hits,” the first of which is “Trends of Microwave Weapon Development”. The problem with microwave weapons to compete with lasers is that they need an enormous antenna, because otherwise you could make megawatts easily of microwave power – much more easily than laser power, but the beam broadens with distance. If you would have a few meter diameter mirror, microwave is in the centimeter range, the visible lasers are in the one micrometer range and there is a factor of 10,000 between them. The energy is diluted by a factor of 10 to the 8^{th}, one with respect to the other. In fact, you could make a hundred meter diameter microwave weapon antenna in space, it has to be accurate to a fraction of a centimeters rather than a fraction of an optical wavelength, but a factor 100 in mirror diameter only compensates by a factor of 10 to the 4^{th} of the 10 to the 8^{th}. So microwave weapons really are only good for a damaging, for deceiving, jamming, overwhelming communication channel; they are not good for destroying things.

Now you could look for “particle beam weapons”, there are 588 hits with *site:mil* Some of these are very useful because they are at the U.S. military universities; these are captains, majors doing their master thesis and amassing the information available in order to have a coherent view about such things.

I have written about particle beam weapons as well. That is really interesting because initially particle beam weapons, you might think of an accelerator laboratory that you are going to have a beam of protons or electrons which will go through space. There is no atmosphere there, so no absorption, but the unfortunate thing is that there is a magnetic field even though it is a small magnetic field, it in fact keeps protons less than 10 GeV from striking the Earth’s surface, it bans them by 90 degrees. In order to have a chance you would have to have a multi GeV proton beam, which would then be deflected by many kilometers. It is a much bigger energy particle than is needed to destroy a target, so it is totally useless. What you do – this is a 1981, a pre-star wars you will see, it is asking what is the benefit of directed energy weapons; it is in fact a reasonable thing to look at. Let us see what it says about particle beams: space-based

ASAT beam weapons, "because there are relatively few satellites and a satellite is in general very soft they are natural targets for destruction by energetic particle beams, but the only particle beam useful in space is the hydrogen atom beam…."

The acceleration of negative hydrogen ions-- that is, a hydrogen atom with an electron attached to it-- was first done by Luis Alvarez, who made the tandem electrostatic accelerator which doubles the energy available from an 8 million volt or 10 million volt prudential difference, because he starts at ground with a negative hydrogen ion and accelerates it to a mid-terminal at a physical potential of 10 million volts, goes through a little bit of gas so that there is now a positive hydrogen ion coming out, which is accelerated through the same potential and so the accelerator will only need 10 million volts, which now gives 20 million electron volts energy. Anyhow, you can read all about this and you can read it from your preferred domain if you use the site "particle" in the Google search box. For instance, *site:fas.org/RLG/ " hydrogen beam" "particle beam"*

For the particle-beam weapon, negative hydrogen ions would be accelerated in a linear accelerator, deflected in the desired direction, and then the second electron would be "stripped" away in a gas cell to yield the hydrogen-atom beam that would not be deviated by the Earth's magnetic field.

Ninth Session - Thoughts on the Nuclear Future

Chair: Vladimir Nekvasil

Regime Crisis: The Precarious State of the Nuclear Non-Proliferation Treaty at the End of the Bush Administration[1]

Harald Müller (Germany)

This paper deals with the issue of regime stability of the non-proliferation regime with the NPT at its center. It first derives conditions determining regime stability from insights into the nature and evolution of international regimes. It then screens the practice of NPT members for their contributions to, or detractions from, these conditions. In this context, it also looks at the repercussions of the recent American-Indian nuclear agreement. It continues with describing the consequences if present trends prevail. It concludes with a look at the "bright side of life", enumerating some countertrends which may lead to a re-stabilisation of the regime.

Conditions of regime stability

International regimes, such as the one built around the Nuclear Non-Proliferation Treaty, are stable only under certain conditions. Regimes, as normative orders that force states to do certain states and prohibit others, are a principal deviation from an order built on self-help, that is, national strength, only. Particularly if the norms that provide their structure are of a legal character, they point into the direction of a different type of international order than the classical "Westphalian system". Balances of power are replaced by the rule of law, arms races are substituted for by agreed limits on arms and on their employment in war and peace, and the right to make war is severely circumscribed and confined to self-defence and military actions collectively agreed.[2] The nuclear non-proliferation regime attempts to provide a building block to such a system in the very area of the greatest destructive potential mankind was capable of developing. Since providing order in that area is probably necessary to the survival of mankind in an age of ever growing interdependence (on the one hand) and destructive power (on the other), the relevance of the maintenance of this regime should be beyond dispute.[3]

Regime stability hinges on two aspects from the perspective of member states: It should serve their security interest, that is, it should be vitally useful; and it should be fair and just, that is, it should comply with fundamental moral norms of justice which are available in all world cultures, though with nuances of differences.[4] This aspect of fairness and justice is grossly underrated by realist and rationalist theories of international relations. Morale and, within it, the notion of justice, is, however, a

[1] This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

[2] Hasenclever, Andreas / Peter Mayer / Volker Rittberger (1997): Theories of International Regimes. Cambridge: Cambridge University Press.

[3] William Walker, Weapons of Mass Destruction and International Order," Adelphi Papers no. 171 (London: International Institute for Strategic Studies, 2004).

[4] Mayer, Peter 2006: Macht, Gerechtigkeit und internationale Kooperation. Eine regimeanalytische Untersuchung zur internationalen Rohstoffpolitik, Baden-Baden: Nomos

powerful action and policy driver across cultures and should be accorded due concern in both analysis and politics.[5]

The structure of the NPT regime

The structure of the non-proliferation regime is straightforward and simple[6]: Proliferation should stop; the obligation of non-nuclear weapon states (NNWS) consists thus of a) renouncing all attempts to obtain these weapons, and b) to have the benign effects of this renunciation verified by the International Atomic Energy Agency (IAEA).[7] The second imperative of the regime is to undo the effects of proliferation to far. This is the stipulation implied by Art. VI which obliges the nuclear weapon states (NWS) to disarm. The International Court of Justice (ICJ) has, in its advisory opinion of 1996, confirmed that the somehow convoluted and vague language of this article means that the NWS have to bring to a conclusion negotiations of a treaty or a series of treaty that lead(s) to the complete elimination of nuclear weapons.

The logic behind the structure of the NPT is equally simple: Either all (who can afford it) or none. States left to their own devices in an anarchic environment are well advised to get what they can – notably the most powerful weapon of their era –, if others are supposed to do the same. Only if no one possesses it – and this can be verified with a reasonable degree of reliability – can states be expected to refrain from acquisition for ever. The NPT is thus an experiment. Those who live up to their renunciation undertaking watch those who have promised to disarm. If the latter one's don't make good on their promise, the former ones will deviate from their own, even if the result leaves everybody worse off.

The practice of regime members

The validity or a regime is created and maintained through the practice of the members. This practice over the last decade gives reason for concern. Four members, Iran, Libya, North Korea[8] and, apparently, Syria,[9] have breached their basic undertaking as nuclear weapon state not to seek nuclear weapons. Of these four, only Libya has returned to good standing, giving up for good, in 2003, all weapons activities (and also activities in the realm of chemical and biological weapons and of missiles). The Treaty community has not found a reliable way to deal with these blatant cases of non-compliance, and the UN Security Council has not acted in a convincing way as the stalwart of the regime, due to strategic and geoeconomic divergences of interests among its permanent members.

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[5] Shapcott, Richard 2001: Justice, Community and Dialogue in International Relations, Cambridge: Cambridge University Press

[6] Goldblat, Jozef 2002: Arms Control: the new guide to negotiations and agreements, 2. Aufl., London, Chapter 6

[7] David A. V. Fischer: History of the International Atomic Energy Agency: The First Forty Years. Vienna, IAEA 1997; Dirk Schriefer/Walter Sandtner/Wolfgang Rudischhauser (eds.), 50 Jahre Internationale Atomenergie-Organisation IAEO. Ein Wirken für Frieden und Sicheheit im nuklearen Zeitalter. Baden-Baden, Nomos-Verlag 2007

[8] Joseph Cirincione, Deadly Arsenals. Tracking Weapons of Mass Destruction, Washington, D.C., Carnegie Endowment for International Peace 2005

[9] Leonard S. Spector/Avner Cohen, Israel's Airstrike on Syria's Reactor: Implication for the Nonproliferation Regime, in: Arms Control Today, http://www.armscontrol.org/act/2008_07-08/SpectorCohen.asp

The nuclear weapon states have failed to comply with their commitment to take "systematic steps" towards nuclear disarmament. They have discarded the political consensus achieved during the NPT Review Conference in 2000, enshrined in the "Thirteen Steps" towards nuclear disarmament. The US has refused to ratify the CTBT, and China, in response, has not done so either. The ABM Treaty has been abandoned by Washington, a Treaty on the Cut-off of fissile material production for weapons purposes is not even being negotiated. The only arms control treaty of that ere, the Moscow Treaty, is a very weak document, lacking any verification measures and any interim steps and reduction rules towards its final goal. It will be terminated in 2012, the very moment when the two parties are obliged to have finally reached the reduction goals. China is slowly expanding its nuclear arsenal, while the United States, Russia, the United Kingdom, and France are modernizing theirs.[10]

As a response to the Iranian construction of an enrichment plant and to the much heralded renaissance of nuclear energy, President George W. Bush, in a February 2004 speech, decreed that sensitive nuclear technologies, contrary to the letter of Art. IV of the NPT, should be confined to present technology holders and should not be allowed to emerge in any new country. Non-nuclear weapon states from Egypt to Indonesia, from South Africa to Italy see a new discrimination coming, in addition to the one between nuclear and non-nuclear weapon states, by the abolition of the basic principle enshrined in Art. IV, that the unhindered development of the peaceful uses of nuclear energy is an "inalienable right" of Treaty members.

The quest for universality and the Indian case

At the same time, non-NPT party India, having tested nuclear weapons in 1998 and having declared herself a nuclear weapon state, became a partner of the United States in civilian nuclear energy, pursuant to the US-Indian nuclear agreement that has been signed but not yet ratified at the time of writing. The language of this agreement runs counter to the "Principles and Objectives" adopted by the NPT Extension Conference in 1995, and to the valid guidelines of the Nuclear Suppliers Group. While it is certainly worthwhile to cultivate relations with the emerging world power and large democracy India, unilaterally violating existing commitments in the non-proliferation regime is too high a price for this achievement. The fact that the agreement does not contain clear and progressive disarmament steps (because the US, of course, wanted none) can only exacerbate the disillusionment of non-nuclear weapon states about the merits of the NPT: a new nuclear weapon state de-facto accepted with no prospects of nuclear disarmament discards the goal of universality which the NPT community so far has embraced.[11]

The Indian case is a textbook example how the nuclear weapon states eschewed their political responsibilities for the sake of narrow and short-term perceived national interests. In the sixties, when India felt threatened by the new nuclear weapon state, China, India asked the US, the UK and the UdSSR for a nuclear umbrella no one

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[10] Hasenclever, Andreas / Peter Mayer / Volker Rittberger (1997): Theories of International Regimes. Cambridge: Cambridge University Press.

[11] Harald Müller/Carsten Rauch, Der Atomdeal. Die indisch-amerkanische Nuklearkooperation und ihre Auswirkung auf das globale Nichtverbreitungsregime.Frankfurt/M, Hessische Stiftung Friedens- und Konfliktforschung, HSFK Report 6/2007

accepted. During the negotiations which led to the conclusion of the NPT, India wanted a clear and unequivocal disarmament undertaking by the nuclear weapon states with a specified time-table. This was not accepted, and India's nuclear inferiority was inscribed in the Treaty, which proved unacceptable to the Indian political elite. During the seventies and eighties, India explored the possibility to get a permanent UNSC seat without becoming a nuclear weapon state. These attempts were completely ignored by the Permanent Five. In the eighties, India made two further attempts to get a politically binding program for nuclear disarmament. The nuclear weapon states rejected these proposals.

In the run-up for the NPT extension 1995 and during the CTBT negotiations 1996, India made it clear that neither was acceptable without nuclear disarmament. The NWS did not listen. When India saw the window of opportunity for a change of status closing because of indefinite extension of the NPT and the successful conclusion of the CTBT (at the time New Delhi did not expect Washington to become the show stopper for the test ban), India, under the nationalist BJP leadership, developed its arsenal. Altogether, India is certainly no white angel, but also no villain. It wants an equal seat at the table of power. It tried several alternatives to nuclear weapons. No one worked because of the established NWS' stubborn refusal.

The regime in the eyes of its members

The utility calculus of the leading state, the United States, appears to be dramatically changed. The NPT is reduced to an instrument for legitimizing US unilateral policies towards states it regards as its foes. It is neither taken as containing obligations that should influence America's strategies, doctrines or military posture. Nor is universality, the inscribed ambition of the NPT, any longer the guideline for US policy – at least not under Bush. Proliferation is acceptable if it concerns US friends and allies, such as Israel, India or Pakistan. It is unacceptable if it concerns US foes such as Iraq, Iran or North Korea. In the latter cases, the US reserves the right to act forcefully in a unilateral manner and without a UN Security Council mandate. Russia and China, in turn, prevent the more determined and effective use of the Security Council for enforcement policy out of geostrategic or economic interests that override, in their view, the guardianship role the Council enjoys under the NPT.

For non-nuclear weapon states the positive utility calculus that made the NPT attractive is very much in doubt. As compliance policy is not consequently pursued and thus no reliable guarantee that the Treaty will reach its goal, and as universality has been given up by leading countries, the security gain which the NPT promised – to keep the number of nuclear weapon states at five and reduce it eventually to zero – proves elusive. For the Arab states who believed the NPT would be useful for exerting pressure on Israel to give up its nuclear capacity, it is particularly disappointing that the United States has completely ceased the (already weak and merely rhetorical) efforts to persuade Israel to make concessions on its nuclear capability. Doctrinal developments which give nuclear weapons not less, but more missions, extending their deterrence and retaliation functions beyond nuclear threats and attacks to all weapons of mass destruction, to conventional contingencies, to preventive strikes or even to securing strategic resources devalues another purported gain from the NPT, the security guarantees given by nuclear weapon states in its context. Economic gains from nuclear cooperation are lacking, while attempts to curb rights derived from Art. IV foreshadow even less utility in the future.

This lack of utility cannot be easily divorced from feelings of injustice which come with it. The NPT has been an unequal treaty from the beginning. Disarmament was meant over time to eliminate this inequality. The lack of compliance with the disarmament obligation thus deepens the feeling of injustice which has been lingering in the NPT community from the beginning.

Non-nuclear weapon states note the unequal treatment of regime members and non-members, and the unequal enforcement towards those who have not complied or are not complying. They also have misgivings that non-compliance by non-nuclear weapon states is enforced, while non-compliance by nuclear weapon states is outrightly denied by them and carries no consequences at all. Attempts to constraint Art. IV rights do not only reduce utility but add to the feelings of unfairness that is growing. In a nutshell, the NPT in its present shape is perceived as profoundly unfair and unjust.[12]

Consequences

The deep misgivings about regime utility and justice divide the treaty community. With the community divided, it is neither capable to further strengthen the regime nor to face rule-breakers with a united front. Never was this as evident as during the 2005 NPT Review Conference that did not even agree on its agenda until well into its last week and which ended in quarrels and without a final consensus declaration which is the goal of all these conferences. The refusal of the nuclear weapon states to commit to disarmament was reciprocated by the rejection of the non-aligned state to agree to any measure that would have improved the non-proliferation toolbox available in the regime context as, inter alia, giving the NPT some organisational structure or agreeing to a procedure to respond to withdrawals from the NPT.[13]

This development is doubly fatal: First, would-be proliferators can find shelter behind the solidarity of the non-aligned who would rather confront the perfidious nuclear weapon states than the "rogues" in their own ranks. Second, in the balance between protagonists of a move towards nuclear weapons and defenders of a non-nuclear posture, the weakening of the regime lowers the barrier towards decisions to take steps up the nuclear ladder, promoters of nuclear weapons are thus strengthened, and opponents are weakened.

In regions where the risk of proliferation looms large, the lack of a determined response due to a weakened regime might help to engender and/or to accelerate the build-up of a nuclear proliferation chain. In East Asia, this might affect Japan, South Korea, and Taiwan. In the Middle East, beyond Iran Saudi-Arabia, Egypt, Syria, and even NATO member Turkey. Security-driven proliferation, in turn, might trigger status-motivated emulation: self-confident middle powers may wish to get even with their peers. This "status chain" might include Indonesia, Malaysia, Thailand and Vietnam; South Africa, Nigeria and Algeria; Brazil, Argentina, Chile and Venezuela. Within one generation, the

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[12] Fahmy, Nabil 2006: An Assessment of International Nonproliferation Efforts after 60 Years, in: The Nonproliferation Review 13 (1), 81-87

[13] Harald Müller, Vertrag im Zerfall? Die gescheiterte Überprüfungskonferenz des Nichtverbreitungsvertrages und ihre Folgen, Frankfurt/M, HSFK-Report 4/2005

world might face 20 to 30 nuclear weapon states, with dire consequences to strategic stability and to the danger of nuclear terrorism, as each new nuclear weapon program enhances the number of access points of non-state actors to fissile materials or even full-fledged nuclear weapons which might have less safety and security features than those of established nuclear powers.

Conclusions and outlook

The NPT is an unequal treaty. Non-compliance by the NWS makes it even more asymmetrical. Moreover, non-compliance is unequally enforced. Moslem countries note in addition the –unequal treatment of India and Pakistan and the unequal treatment of India/Israel/North Korea versus Iraq and Iran; however, Arab countries nevertheless are worried about the Iranian program).

Decision making is seen as unilateral, or club-wise, but not universal-multilateral. The Zangger Committee and the Nuclear Suppliers group both have some members from the non-Western world, but the West dominates. In the IAEA Board of Governors, the membership criterion of the most advanced users of civilian nuclear energy also biases membership in favour of industrialised states. The G-8 which has recently developed to an important body concerned with proliferation and non-proliferation, the strongest and most advanced industrialised countries are exclusively among themselves. Due to the composition of the UN Security Council, they dominate this body as well. As a consequence of these arrangements, non-Western, non-NNWS have hardly a chance of participating in the decisions most decisive for the development of the regime.

In terms of its input dimension – who is allowed to take part in shaping the regime – as well as its output-dimension – who gets what out of the regime, the Treaty and the broader regime are seen (even by an increasing number of supporters) as unjust.

The non-proliferation regime is a miracle of world history: To convince a vast majority of states who could afford a nuclear weapon program not to embark on it, but to renounce the most powerful weapon of the time is no minor achievement.. But taken for granted by the great powers, it is threatened by terminal erosion if present trends continue. This erosion can only be stemmed, when the two concerns of the majority of member states will be fulfilled:
–a significant contribution to their national interest
–a desire for participatory and substantial justice

The "utility" factor requires stronger security guarantees, more tangible benefits in the civil uses of nuclear energy and a convincing way to deal with non-compliance, withdrawals, and non-members. The „justice" factor requires determined steps towards nuclear disarmament and the opening of „clubs" to more encompassing and inclusive decision-making on the core issues of the regime. If no remedies are available on either front, regime decay could be inevitable.

Not all news, of course, are bad. The abandonment by Libya of its nuclear weapons ambitions was a stunning success for non-proliferation. On North Korea, the six-party-talks might still achieve a peaceful solution of the East Asian nuclear crisis and lead to the emulation of the Libyan example by the leadership in Pyongyang. The harsh rhetoric by the US has largely subsided, and the nuclear weapon states have begun to re-affirm their undertaking to achieve nuclear disarmament. Most remarkable is the campaign led by the former leading US statesmen Kissinger, Shultz, Perry, and Nunn to revive the vision of a nuclear weapon free world, and to move in this direction through a series of discrete arms control and disarmament steps.[14] The two US presidential candidates have expressed their intention to revive nuclear arms control, and this promise has been echoed by new Russian president Medwedew. The British foreign and defence secretaries have likewise emphasized their country's obligation to move towards nuclear disarmament. As the disappointment about the lack of disarmament has been the major source of cleavage within the regime, this revival of the idea of nuclear disarmament among the nuclear weapon states addresses a central risk of the regime crisis. The world has seen a turn to the worse in the late nineties; confronted with the clear risk of non-proliferation regime erosion and the danger of a nuclear stampede, it might now engage in a turn to the better.

[14] George P. Shultz, William J. Perry, Henry A. Kissinger, Sam Nunn, "A World Free of Nuclear Weapons," *Wall Street Journal*, January 4, 2007, p. A15

Discussion of Harald Müller's Lecture

Francesco Calogero *(Italy): Thank you, Harald, for the very strong presentation. I think it is useful to present this very stark view. You certainly have only looked at the half empty part of the glass. I just want to mention two developments which go in the positive direction. The two I would emphasize are the most important ones. The first one: next year there will be a different administration in the United States, which will be - I would say - certainly better, much better in this respect than the present one. That is a major important development that we should hope for - and of course, try to influence it. The second one is the fact that, because of that recent development in the United States, at least the discourse about the eventual elimination of nuclear weapons as required seems to be in a different status in the sense that very similar politicians and influential people are now at least talking about this as something serious and needed. I think it is not only propaganda. It comes from the recognition of the catastrophic prospect of proliferation. At least these two developments I think are important and that should give us some hope for a positive development.*

Harald Müller: Thank you very much, Francesco. I was too afraid of my chairman to add three sentences about the silver-line at the horizon. But I fully agree with you. I would add even one more indication that maybe the trend is now slowly going in the right direction and that indication is a rather remarkable shift in the rhetoric by the Bush administration during the Non-Proliferation [Treaty] Review preparations. Since Christopher Ford took responsibility, he is not tiring of emphasizing that, yes, the United State has a disarmament obligation and he is addressing that subject in a very sophisticated way - I would say that world disarmament is a sanctified goal, but we must be aware it is a bumpy road and we must pursue it in a way that we do not enhance instability and insecurity rather than fostering it. Of course this line of argument is meant to emphasize the hurdles and to show how difficult, if not impossible, disarmament in practice will be. But of course it is engaging the right discussion because as we discuss this problem we may be able to devise ways to eliminate the hurdles or go around them. The same emerges from the British government, and you know that Secretary Beckett, when she was Foreign Secretary, gave this famous speech in Washington. The U.K. government is actually following that up, supporting and financing studies on nuclear disarmament. All this shows as you say that maybe a learning effect has appeared but we have lost seven precious years under the worst U.S. administration in living memory. I think we will have a lot of work to basically put aside the ruins which this policy has left behind.

Christopher Pistner *(Germany): Could you elaborate on what you think about the U.S.-India deal and its prospects. Are there still any stumbling blocks? Will the deal still be changed in some way or will it just go through as it is proposed currently?*

Harald Müller: The deal, of course, is facing resistance in both capitals, and it may be that the resistance is even larger in India, where one of the coalition partners is communist and opposed principally on very nationalist grounds. We have also not yet seen the assent by the Nuclear Suppliers Group, where obviously some of the member states are playing a delaying game, postponing the decision year by year, because they do not want to oppose it outright and they do not want to approve it. We have also not seen an agreement between India and the IAEA, which is a basic condition for the congressional approval of this deal to go forward. I think the jury is just out whether it will ever get through.

Yair Evron *(Israel): Thank you very much, Harald, for your excellent presentation. I have three comments. First of all, just very briefly mentioning the Israeli case that you have* *referred to. I discussed it in my own lecture, I just wanted again to make a note that because of the Israeli ambiguous nuclear posture, I think the ambiguity somewhat mitigates the adverse effect of the Israeli nuclear capability. The second point is more general, and this has to do with the motivations of different countries to become nuclear. You have connected them to a large extent with the fact that the members of the club refuse to disarm - or at least take very partial steps in this direction. It seems to me that the motivations of different states in different subsystem of the international system have more to do not with the question whether the members of the club do have a nuclear capability or not, do disarm or not, but with more immediate security threats that they perceive in their own regions. So there is also this element of injustice or discriminatory character of the NPT; nevertheless I think the main motivation has to do with regional threats. Finally, I think in these terms defense commitments and the question of security guarantees is a very important and critical issue. Thank you.*

Harald Müller: Thank you very much, Yair. Let me just contradict your second point. You are right, but you are even more wrong. It is quite right that every single country that has acquired nuclear weapons so far had security concerns that were basically focused on its own national security - which is necessarily a regional thing, but how these concerns are addressed of course depends on the overall security environment; depends on the examples you see; depends on what is projected in terms of the utility of nuclear weapons. Here I submit the nuclear weapon states bare heavy responsibility. Of course, if you had a movement coming from the top towards nuclear disarmament with all the pressure - which, for example, the United States can put behind policy - showing at the same time by which different means - for example, defense commitments by the United States - that the security concerns of states could be addressed, then I think all those who have nuclear weapons could be persuaded. And I remind you that, with the exception of Israel, every single case when nuclear weapons have been acquired was a response to a threat in which at least one nuclear weapon state has been involved. This is something we cannot ignore.

Erwin Häckel *(Germany): For once I am surprised, Harald, that I am perhaps not so gloomy as you seem to be. You suggest that in recent times there has been a deterioration in the stability of the non-proliferation regime. I wonder if that really is the case. I wonder if the principles that are basic to the regime have really been accepted so strongly and unequivocally and universally as you assumed. I would argue that the nuclear powers were dishonest about their disarmament commitments from the beginning. I would argue that the nuclear powers have been highly selective in their attitudes towards certain proliferators in past decades. And I would argue that the non-allied states from the beginning were very reluctant to accept their obligations in terms of safeguards. So, I wonder if there has really been much basic change in the regime.*

Harald Müller: Of course it has always been my ambition, Erwin, since I first met you to stand on the gloomiest side of you. I think you are painting too much a picture of continuity. First of all, if it is true - and it may be true - that the nuclear weapon states entered the NPT in bad faith, what does this really mean? We say today the North Koreans were cheating by entering the NPT with the intention to use the umbrella of the treaty to go nuclear. What you are saying about the nuclear weapon states is they are North Korea from the other side. What does this mean for the rest? Secondly, I would argue that the proof of this pudding befalls only in the last ten years. Non-allied states and other non-nuclear weapon states have accepted throughout the Cold War that this was an unusual situation, which was impeding immediate disarmament. After 1989, the hopes were enormous - and they were justified - that now the disarmament train was running. After 1996, all of a sudden it stopped and this created frustration that was never there before. Your remark about the non-allied, I must say, I just do not understand.

Aharon Zohar *(Israel): If Iran will stop or be stopped from obtaining nuclear capabilities, will it stop the chain of force?*

Harald Müller: It is always very hard to make a statement with 100 % probability. I think if Iran stops for good its nuclear activities, the chances that we will not see a proliferation chain in the Middle East are tremendously good. I was myself rather surprised - if not shocked - about the degree of concern, which I met in Cairo the last time I was there, about the Iranian developments. Quite remarkable. I have seen the nervousness of Saudis in conferences. I think those two countries are very, very likely to follow suit if Iran goes openly nuclear. I think those two would stop this from happening if Iran didn’t.

Nuclear 'Breakout': What are the real risks?[1]

Andrew Mack (Canada)

On January 15, 2008, George Schultz, William Perry, Henry Kissinger and Sam Nunn made their second appeal in a year for the world to move towards the abolition of nuclear weapons. Writing in the *Wall Street Journal* they argued that, 'With nuclear weapons more widely available, deterrence is decreasingly effective and hazardous.'[2]

What was needed the authors suggested was a step-by-step approach to global nuclear disarmament. Given that each of them had long been supporters of nuclear deterrence this *volte face* surprised many observers.

In fact of all the countries in the world to gain from global nuclear disarmament the US would clearly benefit most. Currently at least four states have the ability to launch devastating nuclear strikes against the US with nuclear weapons—and there will surely be more in coming years.

In a genuinely nuclear-weapon free world this threat would disappear completely. The US would be freed of the threat of nuclear annihilation—and in addition would become the unchallenged conventional military power. If states like North Korea bought into this disarmament bargain they would lose their 'nuclear equaliser'. Absent this deterrent they could no longer count on the US not attacking them.

But there was a curious omission in the Schultz *et al* OpEd—there was no mention of the critically important challenge posed by the threat of nuclear 'breakout'.

A central concern of opponents of complete nuclear disarmament has long been that, in an ostensibly disarmed world, a 'rogue' state would renege on its treaty commitments, secretly build a nuclear arsenal, and then 'breakout' of the abolition treaty.

This paper critically analyses some of the most discussed risks of nuclear 'breakout' from a denuclearised world. It argues that while these risks are real, they must be measured against the risks inherent in a turbulent international system where states retain large arsenals of nuclear weapons indefinitely. It is the *balance* of risks which should the critical factor in determining whether or not a nuclear-free world will enhance global security.

The paper suggests that the risks of abolition have been considerably overstated by opponents of nuclear disarmament, and that the security arguments for retaining nuclear weapons have become less compelling as the prohibitionary norm against nuclear use has grown, and as the risks of war between industrialised states have declined.

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1 This paper was submitted by the author for the conference records. The information and subject may differ from the audio content.

2 George P. Schultz et al, 'Towards a Nuclear-Free World', Wall Street Journal, January 15, 2008.

How Might Breakout Occur?

How might ‘breakout’ happen in practice? There are at least four possibilities.

First, an existing nuclear weapon state could cheat in the global disarmament process by retaining a secret cache of nuclear weapons and/or fissile material during the disarmament process.

Second, a state could create a clandestine program to produce weapons grade fissile material or use separated ‘reactor-grade’ plutonium from civilian power reactors to make nuclear weapons.

Third, stolen fissile material may be smuggled to, or otherwise acquired by, a ‘rogue’ state or a terrorist group and used to produce a bomb.

Fourth, states that felt sufficiently threatened could, of course, withdraw from the global disarmament regime and create a nuclear weapons program legally and with no attempt at concealment.

A much-cited reason for concern about ‘breakout’ derives from the fact that the ‘nuclear genie is out of the bottle’ and that ‘nuclear weapons cannot be disinvented’. Nuclear arsenals may be destroyed, but the knowledge needed to rebuild them will persist. Opponents of global nuclear disarmament believe that, since there is no foolproof means to prevent cheating, honest disarmers would, sooner or later, find themselves at the mercy of unscrupulous nuclear cheats.

Security planners in nuclear weapons states (NWS) fear that if they destroyed all of their nuclear weapons they would give up the only credible deterrent against nuclear threats from ‘rogue’ states that cheated on their treaty commitments.

Nuclear weapons are also seen by some states as the best deterrent against the threatened use of chemical and biological weapons.

Thus for critics, the risks of nuclear disarmament are simply too great to be entertained seriously. Only when relations between nations are so benign that states will no longer require *any* military forces, will getting rid of *all* nuclear weapons become a realistic option.

However, while the pro-nuclear arguments should be carefully weighed, they are eminently contestable. For example, the argument that creating a nuclear abolition convention is impossible or undesirable because ‘nuclear weapons cannot be disinvented’ is, in itself, unpersuasive. Chemical weapons cannot be disinvented either, but that did not prevent the creation of the Chemical Weapons Convention. Indeed, as Nobel Peace Prize winner Joseph Rotblat has noted:

> The 'disinvention' argument is an argument against disarmament in general; if accepted it would mean that there should be no disarmament of any kind of weapon.[3]

The claim that it is impossible to have complete confidence that states would not cheat on their treaty obligations is true, but it is not a compelling argument against seeking a nuclear-free world. States which are signatory to the Nuclear Nonproliferation Treaty (NPT) and the Chemical Weapons Convention may cheat on these treaty obligations, but this fact did not preclude these agreements from being successfully negotiated and implemented, nor did it mean that they were of no security value. The point of a creating a nuclear abolition treaty is not that it would create a world free of risk, but one in which the *balance* of security risks is decreased.

Policies for Avoiding 'Breakout'

Creating confidence that the parties to a Nuclear Weapons Convention would not be able to cheat on their obligations *and* that if cheating did occur the consequences would be of less concern than is generally believed, would be critical to its successful negotiation and implementation.[4]

Clearly the verification task associated with such a Convention would be highly demanding. The international community would need to be adequately assured that the NWS have not only dismantled *all* their nuclear weapons, but also that *all* the fissile material these weapons contain (and any other stocks of fissile material) would have to be identified and dealt with in such a manner that it is no longer a source of proliferation concern.[5]

In addition, intrusive verification regimes that can reliably detect the clandestine production of fissile material and weapons would have to be established. Detection would have to be timely enough for effective preventive action to be taken by the international community.

The following sections examine the four major sources of 'breakout' risk in a disarmed world. The conclusion argues that much of the concern about the risks and consequences of 'breakout' has been overdrawn.

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3 Joseph Rotblat, 'Overcoming the Obstacles to a Nuclear-Free World', *INESAP: Information Bulletin*, no. 5, April 1995.

4 Since no such convention is currently being negotiated it may seem inappropriate to capitalise 'nuclear weapons convention'. The term is, however, increasingly commonly used in this form in the arms control and non-governmental agency disarmament communities and is capitalised here for this reason.

5 Fissile material can either be 'burned' or disposed of as waste. High-enriched uranium (HEU) can be diluted and used as fuel in light-water reactors. Plutonium can be mixed with uranium and 'burned' as Mixed-Oxide Fuel (MOX).

‘Breakout’ risks I: retention of undeclared nuclear weapons and/or fissile material by nuclear weapons states

When states have very large numbers of nuclear weapons, cheating at the margin is of little strategic import. If a country claims that it has 20 000 nuclear weapons, but has hidden a hundred more, the extra weapons do not confer any significant strategic advantage. Deterrence based on *mutual* assured destruction will remain robust. However, if all NWS are supposed to have disarmed and one state retains a secret one-hundred bomb nuclear stockpile—enough to destroy every major city in Europe, Russia and the United States—cheating could matter very much indeed.

Could the international community be wholly confident that a Nuclear Weapons Convention would prevent the NWS from cheating? Could even the most intrusive inspection regime guarantee that no nuclear weapons/fissile material had been hidden? There are good reasons for scepticism.

The verification problem is complicated by the fact that the NWS have not been required to declare all of their nuclear weapons inventories or facilities, nor to submit them to International Atomic Energy Agency (IAEA) inspection.[6] There is thus no *internationally* verified assessment of the size of either the nuclear weapons stockpiles of the NWS, or their stockpiles of fissile material.

Given that no NWS state is sure how many weapons other NWS states possess, determining that there has been no cheating would be very difficult. This is especially so given that no verification system, however intrusive, could provide confidence that all of the declared and undeclared nuclear states—the P5 and the ‘outer three’—had in fact destroyed all of their stockpiles.

So-called National Technical Means (NTM) of verification, which were used extensively to verify strategic arms control agreements in the Cold War era, would be of little use in determining whether or not states have met their obligations to denuclearise by eliminating all their stocks of plutonium or high-enriched uranium (HEU). NTM use a variety of remote sensors to detect missile launches, monitor missile telemetry and count missile launch platforms. NTM sensors can also detect the existence and operation of clandestine nuclear reactors and spent fuel reprocessing plants, but not nuclear *warheads* or caches of fissile material.

There are no guarantees that even a highly intrusive in-country verification regime would detect carefully hidden bombs or fissile material. It is true that fissile material (plutonium or HEU) has radioactive ‘signatures’ which, unless well-shielded, can be detected by commercially available sensors even when hidden. But this is over relative short ranges. There is a great deal of research underway on passive and active detention of ship-bourne nuclear devices. But there are no long-range, high-sensitivity, remote-detection capabilities capable of detecting the presence of nuclear weapons.

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6 Although not required to do so under the NPT, the NWS have provided the IAEA with lists of civil nuclear facilities at which they will accept safeguards.

Non-nuclear weapons states (NNWS) that were members in good standing of the NPT would not have a comparable opportunity to cheat on a Nuclear Weapons Convention, since all activities of potential proliferation concern which they had pursued would have been monitored by the IAEA from the outset. The weapons-relevant nuclear material inventories of the non-nuclear-weapon NPT states are declared, verified and subject to surveillance.

How real is the risk that the nuclear powers might successfully hide either some nuclear weapons, or sufficient fissile material to build them? It is certainly true that the retention of unaccounted for fissile material or nuclear weapons could go undetected by international inspections. But the possibility of being caught this way would not be the only disincentive to cheating.

No state contemplating cheating could be certain that its transgression would not be revealed *from within*. Any attempt to hide nuclear weapons and/or fissile material would be known by a considerable number of citizens of the state in question. If just one individual refused to go along with the deception and 'blew the whistle', all would be revealed. This is in no sense a fanciful idea—nuclear 'whistle-blowing' is already a fact:

> Israel's nuclear weapons program had its Mordechai Vanunu, Russia's State Institute of Organic Chemistry and Technology had its Dr Mirzayanov, and Saddam Hussein had his defector son-in-law, Lt. General Hussein Kamel Hassan.[7]

Governments contemplating cheating could not know in advance whether or not their violations would be revealed by 'whistle-blowers'. Revelations of such a gross violation of a major international treaty would also make the government in question liable to severe sanctions by the international community. Thus the risk of being caught cheating is appreciable, *even* if remote detection of clandestine weapons/fissile material is difficult, if not impossible. These risks of detection may in themselves, constitute a sufficient deterrent to this form of cheating.

To provide a material incentive for whistle-blowers the international community could offer substantial rewards for information leading to proof of treaty violations. A one million dollar reward offer that led to the revelation of a clandestine bomb program would be an extraordinarily cheap form of surveillance.[8]

'Breakout' risks II: clandestine nuclear weapons production facilities

A second source of 'breakout' concern arises from the fact that states might build clandestine nuclear facilities in order to make nuclear weapons—as did Iraq. The most

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7 Christopher E. Paine, Thomas B. Cochrane and Robert S. Norris, 'International Arrangements for the Transition to a Nuclear-Free World' in *Background Papers*, Canberra Commission on the Elimination of Nuclear Weapons, Canberra, August 1996, p. 154.

8 Some form of sanctuary might also have to be provided for 'whistle-blowers' since in some states such activity could be seen as treasonous and thus be highly dangerous for the individuals involved.

time-consuming, expensive and technically challenging stage of nuclear weapons manufacture is the production of the fissile material, in the form of either plutonium (Pu), or HEU.

Assuming that all civilian nuclear facilities would be under effective safeguards, producing nuclear weapons via the plutonium route would require a would-be 'breakout' state to operate a clandestine reactor to produce Pu, and a reprocessing plant to separate the Pu from the spent reactor fuel.

But building an underground reactor or reprocessing plant in a remote location will usually require the construction of roads, considerable excavation, the provision of electricity, water supplies and so forth. Some or all of these preparations would be detectable by surveillance satellites. And even if the construction of such a reactor went unnoticed, its *operation* might still be detected. The heat signature of an operational reactor, even one located underground, is, in principle, detectable by remote infra-red sensors. And this is only one of a range of techniques by which clandestine operations can be revealed.

IAEA-sponsored remote-detection field trials, based partly on experience gained in Iraq, have proved successful. According to one report, 'effluent signatures can ... detect reactors over...hundreds of kilometers'.[9] The operation of reprocessing plants may also be detected at considerable distances. When spent fuel rods are cut up and irradiated fuel is dissolved during the separation process, radionuclides are released which can be collected remotely by 'large volume air sampling', and subsequently analysed.[10]

Other chemicals released into the environment can also help indicate the presence of a reprocessing operation. Some of these may be airborne; others may be contained in liquid discharges which enter the ground water. Sampling of radioactive and other traces in ground water and river bed sediments is one of the most promising and cost-effective means for remotely detecting clandestine reactors or reprocessing plants. Fish and shellfish, which can act as bioconcentrators of radionuclides, may provide a further source of data on radioactive discharges.

Clandestine uranium enrichment facilities are more difficult to detect than Pu production or reprocessing facilities. But in the enrichment process, 'some enriched uranium will inevitably be released into the environment' and this can, in principle, be detected.[11] Traces of the uranium intended for enrichment could also provide valuable intelligence—providing the uranium did not occur naturally in the enrichment

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9 G. Andrew, 'Prospects for Environmental Monitoring in International Safeguards' in *International Safeguards 1994*, p. 420.

10 Such sampling needs to be undertaken in conjunction with accurate meteorological observations which will indicate the strength and direction of winds taken at the time of collection. Unlike most aquatic sampling, airborne samples can be taken from outside the territory of a suspect state. One problem with such sampling is that the activity which is detected may not have come from the suspect state, but from a more distant one.

11 Andrew, 'Prospects for Environmental Monitoring', p. 422.

facility location. Unusual chemicals associated with the enrichment process which are released into the environment may provide further useful verification data.

Proliferator states can, of course, take countermeasures to try to prevent detection of clandestine facilities. Underground reactors could be sited beneath other heat-generating industrial plants and/or in urban areas. This would obviate the need to create new electricity and water supplies and would help hide the reactor's heat signature. Emissions from reprocessing plants and reactors could be reduced, though not eliminated, with high-efficiency filters, or the weapons plants could be co-located with legitimate civilian nuclear facilities to confuse environmental monitoring analysis. In addition, as a 1995 Office of Technology Assessment report on environmental monitoring noted:

> ...it is relatively easy for a small, covert facility to minimise liquid run-off, and in dry areas there may not be sufficient rain to wash out and concentrate material that settles out from the atmosphere... Effective air monitoring requires a great many stations...Hence air monitoring can be quite expensive.[12]

Nevertheless, as one official noted:

> ...it seems very unlikely that, even with such countermeasures, over a period of time, all indicative emissions from facilities can be prevented.[13]

Other 'cues' that a state was building nuclear weapons might include:

- intelligence provided to the IAEA by nuclear supplier states that a potential proliferator state was seeking to acquire weapons-relevant materials or technologies;
- national intelligence assessments based on NTM or human intelligence provided to the IAEA by member states;
- 'whistle-blowing' from within the proliferator states (see above).

Any suspicious data could provide the basis for 'special' or 'challenge' inspections of the locality in question by the IAEA, or what other inspection body may have been set up under the terms of the disarmament treaty.

There can be no guarantees that a 100 per cent detection rate of clandestine facilities could ever be achieved. But this is not the point. Deterring would-be proliferators requires first, that there is some reasonable probability that the cheating will be detected, and second, that the detection will incur very considerable costs.[14]

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12 Office of Technology Assessment, *Environmental Monitoring for Nuclear Safeguards*, Congress of the United States, Washington DC, September 1995, p. 7. This is the most up to date and comprehensive overview of environmental monitoring for nuclear safeguards in the public domain.

13 Ibid. p. 420.

14 In some cases desperation may impel political leaders to seek nuclear weapons almost without regard to the risks of getting caught. That of course is a risk that the international community already faces under the NPT regime.

‘Breakout’ risks III: civilian fissile material inventories

A third source of ‘breakout’ concern lies with the large and rapidly growing inventory of weapons-useable plutonium, mostly from civilian power reactors. Hundreds of tons of *separated* Pu has already been produced from the nuclear waste generated by the operation of civilian reactors by 2010. Only a small percentage of this Pu will be disposed of by being blended with uranium to make mixed-oxide fuel (MOX) and ‘burned’ in light-water reactors.

Civilian stocks of HEU are of lesser proliferation concern than both separated and unseparated plutonium because the quantities are *far* smaller.

The central concern here is not that fissile material might be *diverted* during the production process, which has been the traditional focus of IAEA safeguards activities, but that states which possess civilian plutonium might simply withdraw from the Nuclear Weapons Convention and use their fissile material quite openly to make nuclear weapons. There would unlikely to be any legal barrier to such a course of action since any treaty banning nuclear weapons would, like the Nuclear Non-Proliferation Treaty, almost certainly contain a clause permitting states to withdraw if they perceived their ‘supreme national interests’ to be jeopardised. States that have both the technical expertise to make nuclear weapons *and* large stockpiles of Pu are sometimes called ‘virtual’ nuclear weapons states. They are able to ‘go nuclear’ *far* more quickly than states that would have to produce fissile material from scratch.

In a world in which nuclear weapons had been banned, but in which large quantities of civilian fissile material remained under national control, the current global division of nuclear weapons states and non-nuclear weapons states would be replaced by a new division between *‘virtual’* nuclear ‘have’ and ‘have-not’ states.

The risk of ‘breakout’ using extant civilian fissile material would be largely eliminated if all fissile material production were ceased and existing stockpiles destroyed. Proponents of a comprehensive ban on fissile material argue that existing Pu stocks could be mixed with high-level radioactive wastes, vitrified and disposed of, or mixed with low-enriched uranium to form MOX fuel and ‘burned’ in power reactors. HEU stocks could simply be diluted to a safe level and used as reactor fuel. HEU and Pu production facilities would, of course, be closed. This is not, however, the only way to remove fissile material stocks from national control. One obvious alternative, which would continue to permit the use of fissile material for civilian purposes, would be the creation of an international fissile material storage and control regime. The stored material would be returned to member states for legitimate energy purposes as needed.

It seems clear that major changes in the attitudes of states still committed to the plutonium economy will be needed before either a comprehensive cut-off ban or an effective international plutonium management regime can be put in place.

'Breakout' risks IV: nuclear terrorism

A denuclearised world would certainly make the acquisition of nuclear weapons by terrorists more difficult than is currently the case. The implementation of a Nuclear Weapons Convention and its associated verification/safeguards regime would considerably reduce the 'loose nukes' problem in the former Soviet Union which is seen as the most likely source of stolen fissile material for terrorist organizations.

Terrorist organisations do not, themselves, have the scientific, technological, material or financial resources necessary to produce fissile material, which requires either a large uranium enrichment program, or the construction of both a nuclear reactor and a reprocessing plant to extract the Pu from the spent reactor fuel. The costs of such programs are measured in hundreds of millions, if not billions, of dollars, and their creation would almost certainly require the acquiescence, if not outright cooperation, of the government of the country in which they were to be built. Moreover, as argued earlier, the production of fissile material is vulnerable to remote detection.

The fact that it might *in principle* be possible for a terrorist group to make nuclear weapons does not, however, mean that this is likely to happen in practice. There are a number of engineering problems and potential hazards involved in bomb-making that suggest few, if any, terrorist organizations, would be able to overcome.

The only way that terrorists could acquire fissile material would be either to steal it, or to buy material illicitly acquired by others. While this might, as argued above, be much more difficult once a Nuclear Weapons Convention and a Comprehensive Fissile Material Cut-off Convention were in place, the material could be acquired well before either treaty were signed and implemented. So the issue of illicit acquisition remains relevant to 'breakout', not only for terrorist organisations, but also for proliferator states that cannot create their own fissile material.

But despite much alarmist media coverage, there have thus far been no seizures of smuggled weapons-grade fissile material in quantities large enough to make a nuclear weapon. In fact, much of the seized smuggled nuclear material has no relevance to the manufacture of nuclear weapons at all.

Moreover those who worry about nuclear terrorism often forget that terrorists already have access to mass-casualty weapons whose construction poses no technical challenges. A container ship loaded with thousands of tons of fertiliser-diesel explosive and detonated in the heart of a major city could kill tens of thousands of people.

Finally, it should be obvious that however much the international community is concerned about nuclear terrorism, maintaining nuclear arsenals cannot help to resolve the problem. Terrorists operate from hiding; unlike states, they do not present themselves as a target for nuclear weapons. If their presence were to be revealed, they would indeed become military targets, but the weapon of choice would never be nuclear-armed.

State retention of nuclear weapons is more likely to increase rather than decrease the risks of non-state nuclear terrorism, and nuclear weapons have no utility should strategies to prevent nuclear terrorism fail. Thus concern about the dangers of nuclear terrorism cannot, in itself, be an argument against global nuclear disarmament.

Dealing with 'Breakout'

What options would the international community have in dealing with cases of nuclear 'breakout'? One possibility, which has been canvassed by a number of analysts, would be to create a UN-controlled nuclear force which could only be used in response to nuclear use (not revelation of possession) by a 'breakout' state.[15] Nuclear retaliation by the United Nations would require authorisation by *all* of the Permanent Members of the UN Security Council (UNSC), and the support of the majority of the Council as a whole.[16]

The point here would be to have multi-nation control over firing authorisation of nuclear missiles. The platforms that carried the nuclear weapons could remain under national control. American submarines might carry the missiles, for example, without the US being able to fire them independently. Unauthorised launchings could be prevented by Permissive Action Links[17] on the missiles. Launch authorisation would be 'multi-key' and would require receipt of authorisation codes from *all* the permanent members of the UNSC.

Such an International Nuclear Deterrent Force (INDF),[18] would have obvious limitations. Gaining consensus to use nuclear weapons among a diverse body of states would be difficult if not impossible; if a Permanent Member of the UNSC were the violator—a not improbable scenario—it would be impossible. This, however, may be less of a problem than critics believe since, as will be argued below, there will be few strategic incentives for *major* powers to seek to re-acquire nuclear weapons in a non-nuclear world.

The fact that it could be very difficult to gain multi-nation consent to authorise nuclear use is wholly appropriate. It *should* be difficult to authorise such use. It is true that a 'breakout' state contemplating the use of nuclear weapons would be aware of the political constraints on INDF retaliation, but unless such a state is a permanent member of the UNSC it could not be certain that there would *not* be nuclear retaliation. In such uncertainty lies deterrence.

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15 See, for example, Richard Garwin, 'Nuclear Weapons for the United Nations' in eds Joseph Rotblat, Jack Steinberger and Bhalchandra Udgaonkar, *A Nuclear-Weapon-Free World*, Westview, Boulder CO, 1993.

16 I assume that by the time a Nuclear Weapons Convention were to be in place, the permanent membership of UNSC would be more representative of the international community than it is today.

17 PALs are currently not fitted on US submarines, although they are on other strategic weapons.

18 See *An Evolving US Nuclear Posture*, Second Report of the Steering Committee Project on Eliminating Weapons of Mass Destruction, Stimson Center, Washington DC, December 1995, p. 32.

An INDF should not be seen as a permanent fixture of the global security system, but rather as a final stage in the move towards a completely nuclear-free world. This is not least because other means of deterring and dealing with nuclear 'breakout' may be more efficacious in the long-term than countervailing nuclear deterrence.

What incentives would states have to 'breakout' of a Nuclear Weapons Convention? Clearly some of the current motives for nuclear acquisition would no longer apply:

- In a denuclearised world, states would no longer need nuclear weapons to deter the nuclear arsenals of other states—which is their most important function today.
- Global and regional influence would no longer be a motive for acquiring nuclear weapons. If nuclear weapons were legally and normatively proscribed for *all* states, 'breakout' would attract international odium, not prestige or influence.

But other current motives to acquire nuclear weapons would remain. Perhaps the most important of these would the incentive for small and medium powers to acquire or maintain nuclear weapons as 'strategic equalisers' in confrontations with conventionally more powerful adversaries.[19] Historically this has been an important acquisition motive for a number of states. Israel, for example, originally sought nuclear weapons because of the quantitative military imbalance between itself and its Arab enemies. North Korea wanted nuclear weapons in part because it was rapidly being overtaken militarily by South Korea. Taiwan's repeated attempts to acquire nuclear weapons technologies in the past were prompted, not only by a desire to have a countervailing deterrent against China's nuclear arsenal, but also to create an 'equaliser' to the potential threat from China's huge conventional forces.

The issue of states that perceive themselves to be so threatened by powerful adversaries that they might feel impelled to 'breakout' from a Nuclear Weapons Convention is important and needs to be addressed.[20] But while the problem is real, it should not be exaggerated, since it currently affects only a tiny handful of states.

It is also important to remember that the problem of small would-be proliferator states seeking nuclear 'equalisers' exists whether or not there is a Nuclear Weapons Convention in place. North Korea and Iraq are obvious recent cases in point. Yet no serious analysts believed that the use or threatened use of nuclear weapons would have been an appropriate response to the North Korean nuclear crisis. But even if one

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19 The more militarily powerful states are, *ceteris paribus*, the better they are able to defend themselves with conventional weapons. Indeed the US, the world's most powerful state, has greater geostrategic interest in genuine nuclear disarmament than any other state. Currently the US can be effectively destroyed as a functioning society by the four other declared nuclear powers. In a nuclear-free world these threats would no longer exist while the US would retain unchallenged conventional military hegemony.

20 It should also be noted that the withdrawal of the US 'nuclear umbrella' from states like South Korea and Japan will almost certainly increase their sense of vulnerability. This problem should not be exaggerated however. Washington has promised North Korea that, once it comes into full compliance with IAEA safeguards, the US will undertake not to use or threaten to use nuclear weapons against it. This means in effect that the US 'nuclear umbrella' will no longer protect South Korea from conventional threats from the North. Yet South Korea has not sought to compensate itself for this anticipated removal of US nuclear protection by acquiring its own nuclear weapons.

accepts that nuclear weapons may be effective in certain contexts, this has to be set against the overall costs and risks of nuclear retention.

If there were no other strategies for seeking to prevent the small state ‘breakout’ problem, the case for retaining nuclear weapons would be strengthened. In fact there are many such strategies. Preventive strategies include various arms control options and positive and negative security assurances. Where prevention fails sanctions, including military sanctions, can be employed.

One of the most important tasks for proponents of abolition is to demolish the illusion that the possession of nuclear weapons is a guarantee against conventional attack. The historical evidence demonstrates that it is not. US nuclear weapons did not prevent Vietnamese revolutionaries from attacking US forces in the Vietnam war; nor did they deter China from attacking the US during the Korean war. Israeli nuclear weapons did not deter Egypt from attacking Israel during the Yom Kippur War. Russian nuclear weapons did not deter the Afghan resistance, nor did they prevent a Russian defeat, and British nuclear weapons did not dissuade Argentina from invading the Falkland Islands.

Finally, there is the question of aggression. What are the risks that states would pursue a ‘breakout’ strategy, motivated not by the sort of defensive concerns as discussed above, but because they harboured aggressive designs against other states? This pervasive concern has frequently been invoked as a reason to reject nuclear disarmament. But it focuses on a problem that is of rapidly declining importance.

Cross-border aggression is now the exception rather than the rule. Interstate wars are now extraordinarily rare—the wars of the of the twenty-first century are overwhelmingly civil wars in which nuclear weapons can have no conceivable role.

The declining incidence of major interstate war is not accidental; it arises partly from changes in the structure of nation states and the international system, and partly from a change in international norms regarding the appropriateness of war as a means of dealing with conflict. The salient factors include:

- The increasing interdependence and enmeshment of today’s industrial economies makes even conventional war hugely costly for the aggressor, as well as the victim.[21]
- War has, in general, ceased to be an efficacious way for states to increase their wealth. When land and raw materials were keys to wealth creation, conquest made economic sense. Today states get rich by increasing domestic productivity and foreign trade, not by seizing land and/or raw materials. Thus, much of the traditional economic rationale for aggression has disappeared.
- One of the strongest findings in international relations research is that democracies do not go to war against each other. Though the thesis is not uncontroversial, it suggests that as the number of democracies continues to spread, the risk of

21 Note it is not being argued here that interdependence is a necessary or sufficient condition for peace. There have been numerous examples of interdependent states being involved in war. What is being argued is that *on balance* interdependence generates more powerful incentives to avoid war than to wage it.

interstate war may decline still further. Today a large majority of states in the international system have democratic forms of governance—and the number is steadily increasing.

- The phenomena of hyper-nationalism and of state ideologies which glorify war and martial virtues have, at least in the industrialised economies, disappeared almost completely.
- In the international community the resort to war is no longer seen as an appropriate form of state behaviour except in the most extraordinary circumstances. War *per se* is proscribed; only when resort to arms is in self-defence is it perceived to be legitimate. The contrast with previous eras is marked.

Two further points need to be made. First, it may well be the case that the conditions noted above interact synergistically—that is, the whole is greater than the sum of the parts. Second, none of the above observations means that interstate war is impossible, simply that its costs have increased and its benefits have decreased. As the incentives to wage war decline, lower levels of deterrence will suffice and the case for the 'ultimate deterrent' will become ever less compelling.

Is the worst case really so bad?

A central concern of opponents of nuclear abolition is that they would be defenceless in the face of a successful 'breakout from global disarmament regime and at an extreme strategic disadvantage vis a vis their nuclear-armed adversary. Yet the idea that nuclear monopoly is of great military utility, while superficially plausible, needs careful critical scrutiny.

The United States was the sole nuclear power from 1945 until the first Soviet nuclear test in 1949, but derived little if any strategic benefit from this fact. Indeed, sole US possession of the 'ultimate deterrent' in this period did nothing to prevent the greatest expansion of Soviet control over neighbouring states in the entire Cold War period.

Moreover, since the global norm against nuclear use is stronger today than it was in the immediate pre-World War II period, and since it would be stronger still with a global ban on nuclear weapons in place, the constraints on the 'breakout' state actually using its weapons would be very considerable. The fact that a regime has the physical capability to commit nuclear mass murder does not mean that it has political capability to do so.[22]

A second point to note is that the nuclear monopoly gained by 'breakout' would almost certainly be short-lived. Threatened states would likely either reconstitute previously dismantled nuclear weapons programs, or start new programs from scratch.

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22 On the growing prohibitionary norm against nuclear use see Richard Price and Nina Tannenwald, 'Norms and Deterrence: the Nuclear and Chemical Weapons Taboo', in ed. Peter J. Katzenstein, *The Culture of National Security*, Columbia University Press, New York, 1996.

Reversion to a partially re-armed nuclear world, though highly undesirable, would be no more dangerous than the current situation. Indeed, in some ways it would be less so, not least because the relatively small numbers of weapons would mean that the costs of a nuclear exchange would be far less than would be the case with today's huge arsenals.[23]

Finally, some will argue that moves towards a nuclear-weapon-free strengthen the case for missile defences to deal with a missile-launched nuclear attack from a breakout state. The difficulty with this argument is that missiles are only one of many means of delivering nuclear weapons. Truck- or ship-mounted devices are impervious to missile defences.

Conclusion

Concern about 'breakout' has been a major reason why states have refused to countenance complete nuclear disarmament. Yet examination of a range of possible scenarios has demonstrated first, that the incentives for states to 'breakout' of a global abolition regime are less than is often assumed:

- Attempting 'breakout' would involve real risks of being caught.
- Being caught would likely incur severe penalties.
- In the worst-case scenario where a 'breakout' state actually achieved a nuclear monopoly, it would have less strategic value than the conventional wisdom assumes.
- The dubious strategic advantage of nuclear monopoly would likely be short-lived since other states would institute crash programs to reconstitute their nuclear weapons arsenals.
- Retention of nuclear weapons is irrelevant to dealing with the problem of terrorist nuclear 'breakout'.
- Nuclear weapons are wholly irrelevant in intra-state wars, which constitute the overwhelming majority of 'major armed conflicts' in today's world.
- The changing nature of the international system has reduced the incentives for war between the industrialised states (the only ones capable of going nuclear) and has increased the prohibitionary norm against using nuclear weapons—the so-called 'nuclear taboo'. The net consequence is that the need for an 'ultimate' deterrent and the risks of nuclear abolition have both declined.
- The major incentives for states like North Korea to acquire nuclear weapons is to deter attacks by the US and its allies and to acquire diplomatic leverage. These incentives can only be addressed through political and diplomatic means.

What all of this suggests is that, while the possibility of 'breakout' cannot and should not be ignored, neither its risks nor its potential costs constitute compelling reasons to reject global nuclear disarmament.

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23 There would, however, be strategic stability risks with small numbers since disarming first strikes might be thought to be possible—and might therefore be attempted.

Discussion of Andrew Mack's Lecture

Carsten Rauch *(Germany): I would like to ask for a clarification: is your assessment of a Nuclear Weapons Convention purely hypothetical and you are constructing it only to discuss the breakout matter, or do you believe that an NWC could actually be achieved in a foreseeable timeframe? Because listening to Harald Müller before allows you to believe that everything, including a total collapse of the non-proliferation regime, could be more likely than the abolition of nuclear weapons where the nuclear weapon states have to disarm decisively. Thank you.*

Andrew Mack: I think the problem with respect to proliferation is that over time more and more states have the technological capacity to become nuclear weapon states. Even if only a small percent of them do, that is a major threat to the non-proliferation regime. So I think there are real threats there. And at the same time I think there is an increasing realization amongst many states that interstate war – and really nuclear weapons only have any importance in the context of deterring interstate war – that the reality is going down and down and down. Less than 5 % of all wars today are interstate wars. There has been a seen change. I think most people in the arms control and disarmament community do not think about those sort of things. And that is why I have a degree of optimism. Do I think it is going to be a quick process? No way. In fact, the discussion we had yesterday – which indicates that the technical demands of a verification regime are just huge – means that this is a very, very long process in which we are going down and down and down. Perhaps for the time when we get to a few hundred nuclear weapons on all sides there will be a verification process at work. You know, in the past we have had arms control treaties that have been designed where there has been no effective verification system at all. It has not mattered. If the politics are right, verification does not matter all that much.

Giorgio Franceschin*i (Germany): I have just a remark. I could think about another disincentive why a nuclear breakout could be rather unlikely, and that is what is quite popular these days: internet shaming and blaming campaigns. If I just think of the 1996 French nuclear tests that caused an international outrage at a time where the global internet community was still quite small, and nowadays with billions of people using the internet, I could imagine if in the breakout state there is a civil society susceptible to some kind of nuclear norms, that very civil society would give a very hard time to their government to pursue or continue that breakout path. Thank you.*

Andrew Mack: I think that it is an incredibly important point. I think that in the technically oriented disarmament community the issue of normative change, the issue of taboos has not been thought about nearly enough. I was in Australia when the French did those tests. Australians were refusing – they were not refusing French fries as the Americans did, but there was a real, an extraordinary feeling against France and it was throughout the region. I think the French took note of that. So I agree totally.

Erwin Häckel *(Germany): Although I agree with the strength of your argument, I still wonder what would be the kinds of incentives for the nuclear powers to agree on nuclear disarmament.*

Andrew Mack: It is a good question, but then ask the question what is the real agenda of Henry Kissinger, George Shultz, William Perry and Sam Nunn? I think that they look ahead, they see a world that has some of the concerns, some of the threats that Harald (Müller) outlined so articulately. And they are asking themselves: what are the alternatives? From the point of view of all the major powers, they are going to be the ones that retain the large conventional military capabilities so they are going to have a large measure of conventional deterrence. I think the other thing is, if you actually think about it in the United States, deterrence is a very strange thing. If you ask whether the Americans would want to go back into another situation like Iraq, my guess would be no. This is not because they are off against the state which has massive conventional weapons and caused a lot of damage there; it is because it is incredibly difficult to know how to fight people who put IEDs on the side of the road. And you destroy civilians. It is very, very tough indeed. I think that if you are sitting in some of the major powers and nuclear weapon states and you are looking ahead – and there are two ways of looking at it: you can say we are going to need nuclear weapons even more because the system is getting more and more unstable, or you can say these nuclear weapons are actually making things worse because they are one of the things that encourage proliferation elsewhere. It has always struck me and it has been said time and time again: for the United States to say nuclear weapons in our hands contributed to global stability, but nuclear weapons in brown people's hands contributed to global instability, is if not racist at least fully inconsistent.

John Simpson *(UK): I find your presentation very thought-provoking. What you appear to be implying from your analysis is that effectively nuclear weapons have become increasingly irrelevant to the majority of the populations of the world because interstate war has become irrelevant. I just wonder how you feel this plays into Harald's analysis, because arguably one of the reasons why people are worried about the non-proliferation regime is that states no longer see that regime as really relevant to them. You only have to look at the issue of the Treaty of Pelindaba to see this, where the African states cannot actually get around to ratifying it and therefore bringing it into force.*

Andrew Mack: It is a good point and I think that if you actually look around the world, there are some states which quite clearly see that nuclear weapons really are in their interest. And I think it is actually an argument which is much more powerful for small states who perceive themselves to be threatened by larger collections of states, or in the case of North Korea, who see themselves to be threatened by the United States. North Koreans have witnessed over 20 years of Operation Team Spirit, which is a rehearsal – it was rehearsed every year essentially to fight a war against North Korea. It simulated the nuclear attacks against North Korea. If you were sitting there and you have a paranoid mind, to set off the North Koreans' nuclear weapons makes sense. So I think we are going down this path; perhaps the majority of states are going down the path, whereas there would be one or two states that are not that way. How you get around that is going to be a matter of some of the ingenious combinations of negative security guarantees and, in the long-term, just political change. That regime in North Korea is not going to be there forever.

Tenth Session - Reports

Chair: Götz Neuneck

Report on the Second Session - The Relationship between Scientists and Policy- Makers in the field of arms control[1]

Elvira Rosert (Germany)

Götz Neuneck: Ladies and Gentlemen, let us start with the tenth session which sees reports by young scientist *rapporteurs* on the salient results of the individual sessions. As all of you know, we invited to this conference about twelve younger scientists to come into discussion here in this conference; to speak with you, to exchange views, but they had not only the privilege to listen and to discuss, but also to write a report – which I think for younger people are always very good exercises. We have had around eight sessions; we will have 120 minutes to present these reports, that means we have 15 minutes for a session. I think first we would like to hear the reports, then we might have additionally five or ten minutes to discuss the different views. We asked the *rapporteurs* after a short introduction to give a summary of the discussion and at the end also to inject some of their views, things which are missing, or some ideas for a future discussion consideration. The first session was the lecture of the eminent Richard Garwin and I would ironically say this was the most perfect report you could have over the life of Pief Panofsky. We will certainly not hear a report on that, because we already had a very excellent, a very moving lecture by Dick Garwin. The second session was on the relationship between scientists in Spurgeon Keeny's talk and John Boright's talk. Elvira Rosert will give us her view and her report. She is a political scientist from the Peace Research Institute Frankfurt and her research topics are nuclear arms control and the nuclear taboo.

Elvira Rosert: Two papers were presented during the session on the relationship between science and policy: Spurgeon M. Keeny Jr. (USA) focused on some arms control cases where scientists, including himself, were directly involved. The second presentation was given by John Boright (USA) who explored the possible contribution of scientists to the yearly meetings of the Group of Eight.

At the beginning of his presentation, Mr Keeny emphasized that the scientists' involvement into political decisions is not itself a goal. Rather, he suggested two criteria for evaluating their advice: First, it needs to be considered, whether their advice relies on sound science. Second, the consequences of the involvement must be taken into account – will it promote arms control or inhibit it? Mr Keeny presented several examples for negative impacts of flawed and misleading scientific advice, including the early negotiations of a nuclear test ban treaty and its recent rejection by the US Senate, as well as Reagan's Strategic Defense Initiative. He concluded with an appeal to both the policy and the science sides – while the former is obliged to ask for the best advice, the latter should provide this advice voluntarily and sound the alarm bells in scenarios in which the policy makers pursue a course based on false scientific advice.

Mr Boright drew our attention to the G8 Summits, which in recent years have broadened their agenda and their participants. While these summits have traditionally

[1] The report was revised by the author after the conference. The information may differ from the audio content.

focused on economic issues, arms control questions such as non-proliferation are now discussed as well. Currently, the involvement of the scientific community, in particular of the science academies of the participating countries, is somewhat limited and includes only joint statements on the agenda topics. So far, arms control has not been included. Concerning the academies' involvement in the future and the addressing of security questions, Mr Boright stated that one possibility might be to intervene in the process earlier. That is, not only should the scientific community comment on the set agenda, but it should also to try to intercede in the agenda setting process itself. This might lead to a prioritisation of arms control issues. In the discussion of this topic, monitoring of the implementation of existing commitments was identified as another possible field of activity for the scientific community.

One aspect, which in my opinion deserves further consideration: What are the reasons for the flawed and misleading advice described by Mr Keeny? Is neutral and independent scientific advice even possible? Is scientific objectivity not an ideal which, strictly speaking, is impossible to reach? To what extent do scientists depend on personal convictions and beliefs which probably have an impact on their choice of a research subject and might influence their interpretation of the scientific results or their willingness to communicate those results? Apart from this rather normative point, there is also a rational aspect which is especially relevant for the nuclear issue. Here I am pointing to the US National Laboratories after the end of the Cold War – the importance of nuclear weapons seemed to decline, so there were a number of nuclear scientists who were about to loose their task, possibly their job and their prestige as well. In such a situation, the incentives to give misleading advice are quite high, just to assure your own position. I then wonder, to what extent can the objection to the CTBT and the promotion of new nuclear projects such as the bunker-buster, mini-nukes or the reliable replacement warhead be explained by scientists competing for public funding and fighting to protect their own jobs?

Giorgio Franceschini *(Germany): Just a remark. It is true that especially if one has to give scientific advice on a sensitive issue, like nuclear weapons, the very question is: where do you get the experts from? The real experts are in the labs and, as you say, they have got vested interests. You might be able to recruit Jasons, like in the U.S., which is a panel of independent scientists that are partly in the labs, did work or do some general scientific work, and maybe that is still the best thing one can do. I am just speaking out of personal interest, because I often see that the situation is that I deal with nuclear arms control, but there are many issues which I sincerely cannot answer since I do not have the proper insights of classified science, and only those people who have the insight have some interest even in keeping their science alive. I think the Jasons – and Dr. Garwin was part of them – is really the best one could have: a panel of independent scientists, as independent as possible.*

Götz Neuneck: This was an additional comment. Maybe Dick [Richard Garwin] would like to comment a bit on the Jasons' work?

Richard Garwin *(USA): Panofsky used to say there is a matter of independence and a matter of expertise: you could have people who are experts and not independent, and you could have people who are independent and not experts. It is preferable, according to him and to me also, to start with people who have independence because they can acquire expertise – or at least sufficient expertise. That was the problem that was* *identified in the 1950ies by the scientists who had served during World War II in the United States on the radar programs and underwater sound and in the weapon program, that they were aging – of course, they were very young at that time, but would not last forever, and by 1960 having tried several things, including bringing young people on to the technical panels of the president science of icebreakers committee – that was found to be inadequate because they did not have sufficiently long and deep exposure, so the Jasons group was created in the United States in 1960, which provided a longer emerge. And that has worked fairly well in adequate numbers, only about 50 Jasons altogether. Not all of them are involved in nuclear weapons work or intelligence. If one could have a larger number of people, that would be useful. We have tried to have that replicated in other countries, but the sociology of the military and of the military industrial complex is typically different in other countries, so that people do not have the easy access, as consultants, who are going in an out the defense industry to academy and back. That has not been very successful. The United States – I do not claim that we do much right, but probably has done a useful thing with the creation of the Jason group and that should be emulated, I think, in other countries.*

Francesco Calogero *(Italy): I would say that the experience of Pugwash has also been important in this respect, in the sense that Pugwash certainly is a declared pacifist movement, but nevertheless it has been traditional to involve in the Pugwash discussions and deliberations also quite a lot of people coming from the weapons labs, who had the experience in weapons, but also who, to some extent, were influenced by the ideology of the weapons lab. That was very useful to have this interaction from both sides of the Iron Curtain or the Cold War. It was also very important and interesting to have an interaction among scientists who have this background with scientists from the same country who did not come from the weapons lab, who maybe knew less of the details of the weapons, but nevertheless there was an interaction. Of course there were some people with whom it would be difficult to discuss because of a basic intellectual dishonesty. The famous argument was to end a discussion saying: "if you knew as much as I know, you would agree with me", which of course is a ground on which further discussion is difficult, unless in the room there is somebody else who stands up and says: "I know as much as you do and I do not agree", which is what sometimes happened in this context with some people who are maybe even in this room.*

Götz Neuneck: Thank you Elvira, you deserve certainly some applause for your work. I should add that these reports are also very important for the proceedings because then we have also additional views, protocols, minutes of the discussion.

Report on the Third Session - Regional Conflicts and the Nuclear Question[1]

Andreas Henneka (Germany), Miloš Jovanović (Germany)

Götz Neuneck: Let me come to the next session, which was Regional Conflicts and the Nuclear Question, which started with some kind of mathematics. The two *rapporteurs* are Milos Jovanovic and Andreas Henneka. Milos Jovanovic studied Information Science and is working at the Fraunhofer Institute – this is a network of institutions working on applied science, and he comes from the INT, the Institut für Naturwissenschaftliche Trendanalysen (Institute for Scientific Trend Analysis), from Euskirchen. The floor is yours. The second, the co-author is Andreas Henneka, who is working on the North Korea question and he is a political scientist.

Miloš Jovanović: The third session of this year's Amaldi Conference was chaired by Constanze Eisenbart and emphasized regional conflicts in different parts of the world. The nuclear question and its effect on these conflicts were given special attention. The conflicts discussed were the Indian-Pakistani-Conflict, the nuclear crisis in which the Democratic People's Republic of Korea (DPRK) was involved, and the conflict in the middle-east with Iran and Israel as major players. The presentations were given by Rudolf Avenhaus, Yari Evron, Saideh Lotfian, Aharon Zohar and Mark Suh.

The main result of the analysis of the Indian-Pakistani-Conflict was that, even though both countries had become nuclear powers, their potential for conventional warfare was not deterred, though somewhat limited in its intensity. The reason why this conflict did not escalate to the nuclear level was substantial diplomatic intervention from the U. S. A. which led to an unsteady peace. In this sense, the conflict on the Indian subcontinent was very different from the Cold War, with which it was compared. Also, among the lessons learned from this conflict was the fact that democracy as the ruling system in a state does not guarantee a careful and responsible handling of nuclear weapons.

The presentation of the regional conflict involving the DPRK described current contents of the Six-Party-Talks, in which the U. S. and the DPRK are in a deadlock. While Pyongyang has delivered a list with details to its nuclear facilities as agreed on during the negotiations, Washington is not willing to accept the list and to fulfil further parts of its announcements until the DPRK is willing to address questions reflecting their supposedly secret Highly-Enriched-Uranium-Programme (HEU) and the total amount of plutonium in its possession. Both the U.S. and the DPRK seem to use delay tactics in these talks, which hinders the whole process of solving the nuclear issue peacefully.

The regional conflict attracting the greatest attention, both during the presentations and the ensuing discussions, was the conflict in the Middle East. It is quite clear that expert opinion differs strongly on the question of why Iran is developing a nuclear programme, be it civil or military. Economic reasons, the balance of power and the Israeli-Palestinian dispute are mentioned as reasons for Iran's push into nuclear technology. With regard to the decision-making process in Iran, it is worth mentioning that the religious leader Chamenei publicly stated his opinion that the possession of a nuclear bomb is against Islamic law. Prof. Rudolf Avenhaus´ presentation used game theory

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analysis to depict possible solutions to the conflict by considering a certain number of variables. The best result for both players (Iran and the international community) would be a robust diplomatic offensive, including the visible option to eliminate Iran's nuclear programme through military intervention. However, the international community does not have sufficient capabilities of this kind. In the following discussion, concerns were raised about the multitude of unknown variables that cannot be sufficiently considered in such an analysis. Thus, this method should rather be used as an analytical tool to consider possible outcomes of international negotiations.

Götz Neuneck: Miloš, thank you. Andreas has nothing to add.

Constanze Eisenbart *(Germany): Just one addition. I thank you for your excellent summary, but I think there was one reflection that was quite important and was not so widely spread. That is what Prof. Evron said about the ambiguity of the Israeli's position concerning nuclear weapons. I think that is just out of the ordinary to reflect on that, and I would like to have a little bit more discussion on that point. Thank you.*

Miloš Jovanović: I agree with you.

Götz Neuneck: Thank you very much for the two excellent reports.

Report on the Fourth Session - Safe Fuel Supply for Civilian Nuclear Power Stations and the Risk of Nuclear Proliferation I[1]

Christoph Pistner (Germany), Matthias Englert (Germany)

Götz Neuneck: We have now as next Christoph Pistner and Matthias Englert. Matthias Englert is from IANUS at the Technical University Darmstadt, he is a physicist dealing with neutron physics but also with nuclear non-proliferation and the conversion of reactors. The speaker will be Christoph Pistner, who is formally from IANUS and he is also a physicist now with the Öko-Institut in Darmstadt and his specialty is reactor safety, fissile materials and plutonium disposition.

Christoph Pistner: The session started with a presentation by John Simpson describing "a clear and present danger" in the form of the still growing stockpile of currently of over 100 tonnes of separated plutonium stored in the U.K. Up until now, there is neither official policy on how to proceed in reducing these stockpiles nor clearly superior option to solve this problem. Solutions to the problem envisaged range from "doing nothing" up to "burning the plutonium" in a number of new, to-be-built power reactors as mixed oxide fuel (MOX). An alternative to burning would be to mix the plutonium with high level wastes and dispose it in a final geologic repository. Unfortunately, not much information on this option was available in the presentation and the underlying report. Long term storage of Plutonium in the form of oxide powder does not seem to be an acceptable long term solution from a security point of view because the plutonium must eventually be disposed at some point time.

Obviously, most of the currently discussed U.K. options rest on the fact that there is an existing facility to deal with the plutonium (as MOX or even "low spec" MOX), the Sellafield MOX plant. But, the potential of this facility as a relevant part of the solution remains to be shown because the facility has so far failed to produce relevant amounts of MOX. The most important steps to be taken are, in the first place, to stop further growth of the plutonium stockpile by ending reprocessing as soon as possible. It remains to be answered, whether the problem could and should be solved nationally in the U.K., or whether international cooperation (for MOX-production, MOX burning in reactors or other aspects) has an important role to play. Finally, the U.S. as well as the Russian program to dispose of their formerly military stockpiles of weapons-grade plutonium is far behind the original schedule. It would be interesting to see, whether there are lessons to be learned from these programs, especially why the timescale was not met.

Within the next talk by Tatsujiro Suzuki, the prospects of a possible nuclear renaissance and their related problems have been discussed. Two simultaneous scenarios were described: on the one hand in the western countries may need to construct new facilities to replace power plants taken out of service; in Asia, on the other hand, new plants may be needed to satisfy growing energy needs. It is to be expected, that several small countries that do not yet have nuclear energy programs may also begin to enter the field. Problems related to the management of spent fuel still pose a relevant obstacle to

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countries considering the nuclear option. Convincing answers to this problem are still found to be lacking. The approach currently followed in a few states of reprocessing spent fuel leads to the already discussed problem of ever growing stockpiles of separated plutonium. This poses a proliferation problem yet to be overcome. To enhance the chances of coming to a moratorium on plutonium reprocessing, at least as long as there is no clear need for the separated plutonium, it would be vital to provide sufficient means of interim dry storage in the countries where it is needed (like in Japan).

With respect to the front end of the fuel cycle, enrichment technologies also pose the danger of being used for the production of highly enriched uranium for military purposes. Thus, although a couple of countries are currently seeking to nationally achieve this technology, an alternative long term solution is proposed today in the form of a multilateralization of enrichment (and possibly reprocessing) facilities. However, there have been other historical efforts to establish multilateral fuel cycle facilities without success. Thus, it was discussed what the minimum requirements of such proposals are to be acceptable for the international community. Essential criteria are Universality, Transparency and Economic Viability. From our point of view, the discussed problems have obviously existed since the beginning of the nuclear age. Centrifuge technologies, but also current reprocessing technologies, pose inherent proliferation risks. As of today it is unclear which kind of new – technological or political – measures have the potential to overcome these problems.

In the last talk of the fourth session, Rudolf Avenhaus and Thomas Krieger investigated how an effective and efficient verification system may allocate its limited resources by way of mathematical modelling techniques. On the basis of the "technical parameter" of a designated detection probability, the necessary effort to be allocated for an effective system can be determined in the case of a single country under inspections.

Next, "political parameters" were introduced reflecting the expected gain of a country in the case of successful non-compliance to the treaty and the perceived loss of the country in case of timely detection of the non-compliance. Relating these parameters to the technical parameter of detection probability leads to a mathematical condition for legal behaviour. In theory, if the parameters would be known by the inspection system, an efficient strategy for verification would then be possible.

When changing to a case in which two (or more) countries are to be considered, while there are still limited resources available for the inspection system, a different situation evolves. Depending on the assumed values of the political parameters for the specific country, in an efficient system the inspection efforts would have to be divided between the two countries according to the differences in the perceived possible gains and losses the countries are facing.

This of course means that the different countries are no longer treated universally (as it is currently the case for the non-nuclear weapons states within the verification regime and which was one of the fundamental principles demanded in the last talk). To come to a more efficient system of verification, one would have to treat the countries individually. To establish a politically acceptable solution to this problem, a transparent and universal procedure to determine the political parameters would have to be negotiated, for example based on criteria like regional stability or the historical record of compliance of a country. But it seems unclear to us, whether such a procedure is feasible or could be developed at all.

Götz Neuneck: Thank you, I think you deserve some applause. Thank you again for this very comprehensive report.

Richard Garwin *(USA): I noticed in the presentations themselves as the rapporteurs commented that there were facts that turned out not to be facts; that we have the enormous program risks and costs in the nuclear field simply because the things that we think to be true are not true. I noticed this in the work of National Academy CISAC in the 1994 and 1995 volumes on management and disposal of excess weapon plutonium where this spent fuel standard was set forward and the two programs of burning as MOX or sequestering plutonium with high-level waste in vitrified form was seen to be reasonable for options. And then our Livermore laboratory decided that they did not want to dissolve plutonium oxide to make oxide out of the plutonium metal and dissolve the oxide in the glass, but wanted to use a can in canister approach, then that ran into problems. So it is very difficult to preempt. I noticed that John Simpson's excellent talk did not reflect the latest revelations of the Energy Minister in the U.K. that the Sellafield MOX plant has never produced more than 2.5 tons per year of a 120 tons annual plant capability. I think that there should be a future effort and I am suggesting it for the eyes of our committee in China this fall on reducing program risk and cost in the nuclear energy field so that we could look at some of these problems of the past and see what is necessary in the future in order to do a better job. The problem in nuclear energy is that the programs are all big programs. You cannot have as many competitors as you do in conventional energy generation with a considerable number of firms and a lot of experience, which is gathered gradually and accumulated. There ought to be a way fitted to this kind of monopoly approach, where better information can be made available.*

Götz Neuneck: Thank you Dick, I think this was a very useful comment.

Christopher Watson *(UK): I was interested in your summary of the talks. You dismissed in one sentence the idea of retaining the plutonium downside as plutonium downside in the store. I would like to challenge you on that just out of the devil's advocate position. The great advantage of plutonium oxide in that form is that the entire stockpile occupies a very small volume. We are talking about like 5 cubic meters for the entire British stockpile. We can afford to spend an enormous sum on defending such a small quantity of material. By the time you have diluted it down with all the waste to make it to a spent fuel standard, you got larger volumes and you got more disposal problems. It is not absolutely obvious to me that that first option is not an acceptable option.*

Christoph Pistner: I totally agree with you. The problem is not such that we have to do something within the next five years. Definitely, as long as the material is being stored through the very high standard of security, it is acceptable as a mid-term or near-term solution, but I did not see that we can just go on doing this for another 300 years. You know probably the numbers that the NBA evaluated on that. On an absolute term even if the relative amount of money I have to spend continuously is low, the absolute sums are really getting big. And secondly we do not really know what the future of nuclear energy is worldwide and in the U.K. I mean. The current options strongly rest on the possibility of using the SMP at least to produce some MOX fuel and old spec MOX fuel, and then possibly there might be some new reactors to burn plutonium in there, but taken to be 30, 40, 50 years from now on there might even be no SMP available and no reactor available in the U.K. and only a plutonium store, and if you start then to think about options to dispose of the plutonium it will be even more difficult than today. Therefore I think it is definitely not as urgent as to say we have something to do within the next five years, but it is definitely not an option to say we just wait for another 60 or 100 years to take action then.

Götz Neuneck: No further questions? So I thank again both *rapporteurs*.

Report on the Fifth Session - Safe Fuel Supply for Civilian Nuclear Power Stations and the Risk of Nuclear Proliferation II[1]

Giorgio Franceschini (Germany), Simon Hebel (Germany)

Götz Neuneck: The next *rapporteurs* will be Giorgio Franceschini from Germany – certainly with Italian origin. He is a physicist from PRIF, the Peace Research Institute Frankfurt, and he is dealing with nuclear arms control. The second *rapporteur* is Simon Hebel, he is a physicist at the Carl-Friedrich-Weizsäcker Center for Natural Science and Peace Research and he is also a physicist doing experiments and research on radio nuclides and noble gas measurements.

Giorgio Franceschini: The Fifth Session of the conference addressed various aspects of the nuclear fuel cycle and discussed diverse approaches of securing, distributing and safeguarding civilian nuclear technology in the twenty-first century. A keynote of the session was the awaited nuclear renaissance, an expected global rise of interest in the utilisation of nuclear power.

A Russian proposal for dealing with the increasing demand of low-enriched uranium, the International Uranium Enrichment Center (IUEC), was introduced by Professor Boris F. Myasoedov. The Russian package offers non-discriminatory membership to all countries interested in leasing nuclear fuel and even contains whole transferable nuclear power plants. “Leasing” implies the return of spent fuel elements to Russia for reprocessing or final storage. Further proposals include the introduction of a closed fuel cycle and development of new plant designs based on fast neutron reactors. IUEC would be operated like a privately owned company allowing for financial participation of partner states, in contrast to the Global Nuclear Energy Partnership (GNEP) proposed by the US Department of Energy, which does not foresee such an involvement.

Dr. Adele Buckley directed attention to matters often overlooked when debating the nuclear renaissance, namely nuclear safety and the need for a universal control system regulating all types of nuclear facilities indiscriminately for all countries. Current application of safety standards is largely voluntary and shows strong regional variations. The ideal institution for setting up such a regulatory regime would be the IAEA due to its immense expertise, although the budget would have to be raised considerably to comply with such an immense task. An advantage of such a system could be the presumably high acceptance by those countries outside the NPT, which deem the current proliferation control system unjust and biased due to its discrimination of nuclear weapon states and non nuclear weapon states. Thus, a truly universal safety culture could be envisioned which might alleviate some concerns associated with the expansion of nuclear technology in the decades to come.

The often mentioned notion of a nuclear renaissance was then outlined more clearly by Dr. John F. Ahearne. It is mainly founded on the booming economies of major developing countries and the great number of plants under construction. Although the public acceptance of nuclear power has been low especially in the west, global warming has incited new interest. A Nuclear Renaissance raises the question of whether nuclear power programmes and nuclear weapon proliferation are inextricably linked, as reactor

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operation is instructive regarding the handling of nuclear materials required for weapon construction. The dual use capabilities of enrichment plants and reprocessing facilities for generating weapon grade uranium and plutonium are well documented. Such concerns have led the United States and Russia to offer fuel supply programmes located in their own territory.

In addition to providing insight into current models of future nuclear fuel supply, the talks have managed to raise a multitude of interesting questions. Although the US and Russian approaches would indeed limit the possibilities of nuclear material proliferation, they have yet to answer for questions most pressing for developing countries, such as the ability to guarantee all participants a continuous fuel supply, even in case of political tensions between the receiver and the supplier state. Russia's policy to cut gas supplies to neighbor countries during minor political crises in recent years was not a very encouraging factor in the assessment a future supply guarantees. Even legally binding commitments might not give ultimate supply security as major powers showed no hesitation to overwrite international obligations when they collided with their national interests in recent years.

Another open issue is the exact form of participation, as participants will eventually demand the inclusion of their own qualified personnel and an exchange of know-how and technology. The notion of an IAEA managed fuel bank appears also worthy of further discussion and comparison.

Another aspect to be covered in more detail is the technology. The Russian proposal promotes fast neutron reactors, a technology of questionable reputation, and does not introduce a convincing strategy of waste disposal. Although unmentioned in this session, an aspect worth considering might be the upcoming generation IV of reactors, which inherently solve many safety and proliferation issues addressed. It seems sensible to envision the fuel cycle of tomorrow using the reactor designs of tomorrow.

Götz Neuneck: Thank you Giorgio for this comment, including these two fundamental questions at the end which give us a lot of opportunities for further Amaldi Conferences. I understood that Simon Hebel's report would be available in the next few days in written form, so you can add your view on these issues in the written report. Hopefully they will be distributed today or in the next few days via e-mail. We will see.

John Ahearne *(USA): My only comment is I think the rapporteur missed both Boris Myasoedov's point and my point. The issue we were addressing was fuel assurance, how can you assure that a country that was trying to get into nuclear power would have the ability to get fuel. That was really the issue we were trying to raise, not breeder reactors and such.*

Götz Neuneck: You should know that the *rapporteurs* have the responsibility for their own report and they can certainly add this point also in their report if they wish. Would you like to answer?

Giorgio Franceschini: I do agree, there are two separate issues. As far as I understand the GNEP concept includes some form of breeder reactors.

***John Ahearne**: But I was not talking about the GNEP proposal and Boris was not talking about the GNEP proposal.*

Giorgio Franceshini: Ok, the GNEP proposal was in your paper and I understand that Boris did talk about a future Russian breeder reactor. But as for supply assurance, again, I said that what we thought that the idea to design assurance of supply regimes is something we of course appreciated, but the question is really on whether these supplies can be guaranteed. That just was food for thought in the case of major crises. If you have an answer…

***John Ahearne**: The point that you raise explicitly is addressed both in the Russian program and in ElBaradei's proposal, and that is that fuel would be assured; the only restriction would be that in case a country would be in violation of the IAEA safeguard regime, it could not get fuel. But otherwise a political crisis would not prevent the fuel from either the Russian approach or the IAEA's fuel bank approach; that is explicitly addressed in those concepts.*

***Richard Garwin** (USA): On my website there is a full discussion of the GNEP program, especially in regard to the fast reactor that is proposed there: the lack of economic viability, the technical immaturity and the dishonesty of such proposals. When that is wrapped in a GNEP proposal and is a fundamental part of it, together with the initiation of reprocessing of all of the currently emerging spent fuel from the 103 U.S. operating reactors, one has a right to be skeptical of the rest of the proposal, which is the assured fuel cycle, especially since no preparation has been made for the take back of spent fuel. Same thing with the Russian program, which depends heavily on breeder reactors in the future for the burning up of the plutonium, but that program is far behind schedule. We heard nothing of the technical aspects of this program either. On the U.S. program to burn up plutonium, rather than to breed more, requires an advanced burner reactor with a small conversion ratio. Conversion ratio is the amount of new plutonium produced per plutonium burned. In the 1996 National Academy study supported by the Department of Energy, the General Electric company stated that it could not make a safe fast reactor within conversion ratio below 65 %. You would need three times as many burner reactors as if they had stereo fuel conversion ratio of zero. Yes, you would expect that the proposals of GNEP would in fact make statements. John Ahearn was not talking about GNEP, he was talking only about assured fuel supply, but the assurance requires more than the statement from a country that fuel supply will be assured, especially since the word of those countries has not proven to be very durable in regard to the Non-Proliferation Treaty. My own proposal is that countries that worry about the availability in the future of low enriched uranium should buy ten years supply of LEU for their nuclear industry, which is not very expensive in view of the fact that fuel is a very small proportion of nuclear electric power costs.*

Giorgio Franceschini: Just in terms of assurance of supply: I think the problem, which even arose in this very brief discussion, was the issue of who can enforce insurance of supply in the case of major crises. And the problem so far I saw is that – again, if we do not want to talk about GNEP, we can talk about the Russian proposal – the international uranium enrichment plant is on Russian sovereign territory, and since Russia is a sovereign state, and they decide not to supply from its sovereign state fuel to a given country, it would not. And we know from historical experiences that sometimes big powers simply override international law; even if they have a commitment to supply, they might not do it in a case of a major crisis. I just wanted to point out that there is therefore even a German proposal, which was submitted to the IAEA, for multilateral fuel bank, which should be erected on a soil controlled by the IAEA, which then has sovereign rights. That would change the situation for the better, I think.

Report on the Sixth Session - Detection of Clandestine Nuclear Activities[1]

Ole Ross (Germany)

Ole Ross: The sixth session, chaired by A. Keynan, dealt with research and development on technical means for collecting telltale traces of nuclear activities in environmental air samples and for radiological detection of tramping nuclear materials. Three presentations dealt with this topic: the monitoring and detection of plutonium levels in the air by J. Mietelski (Poland), the detection of clandestine nuclear weapons production and testing also through analysing air samples by Martin Kalinowski (Germany), and the detection of nuclear and radiological materials by Christopher Watson (UK). Christopher Watson also summarized a recent report on this subject by the Royal Society.

Monitoring of plutonium in the air

There is only little experience in determining environmental plutonium aerosol concentrations because spectroscopy of emerging alpha-particles is required. Known plutonium sources such as remaining fallout of historic atmospheric nuclear tests, a satellite demolition, and the Chernobyl accident each have a characteristic signature represented by activity and mass ratios of certain combinations of relevant plutonium isotopes. Nevertheless, there are occurrences of small Pu concentrations in the air which can't be directly attributed to those origins. The search for an explanation is ongoing, operational releases of nuclear power plants may be possible. For further investigations of deposition and re-suspension processes, particle filters carried by airplanes are evaluated as well. Broader application of environmental alpha spectroscopy was recommended for monitoring future radiological hazards.

Detection of clandestine nuclear weapons production and testing by analyzing air samples

Three independent measurements of elevated xenon-133 concentrations after the North Korean event in October 2006 combined with atmospheric transport simulations have already given strong evidence of a nuclear explosion. Analysing a certain isotope ratio in the data taken by Swedish scientists in South Korea in the week after the test could now prove that the source actually had to be a nuclear explosion and not a civilian facility.

The task of uncovering unreported reprocessing facilities through measurements of krypton-85 is equally both promising and challenging. Case studies have shown the feasibility of detection. Wide Area Environmental Sampling as foreseen in the IAEA additional protocol to the NPT for advanced safeguards was disfavoured for cost reasons in the early 1990s. But, developing more flexible technology, as well as new measurement techniques based on a magneto optical trap for krypton isotopes for operating with meteorological plume forecasts and bottled air samples, will put Wide Area Environmental Sampling back onto the agenda. Advanced technical verification methods have to be established, not only for improved NPT Safeguards, but also to improve the prospects for negotiations on a Fissile Material Cut-off Treaty,.

[1] The report was revised by the author after the conference. The information may differ from the audio content.

Radiological detection of nuclear material

For the detection of illicit trafficking of nuclear materials there are three layers of technical detection applied:
- Widely used detectors at logistically relevant points with coarse resolution for first detection
- Advanced detectors for spectroscopic determination of radionuclides
- Sophisticated analysis ("nuclear forensics") to get to know the origin of sampled material.

As the fundamental physics of radiation and detection is well known, there is no technological revolution expected to happen in the next few years. Nevertheless improvements in detector materials and cost effectiveness can be achieved. Especially the capability and reliability of nuclear forensics needs further research and development.

Prevention of uncontrolled travelling of nuclear materials or even nuclear explosive devices is a major challenge for Intelligence and Security institutions, as discussed in the following session.

Note: There was no further discussion on the report.

Report on the Seventh Session - The Risk of Nuclear Terrorism[1]

Markus Kohler (Germany)

Markus Kohler: This session was dedicated to discussing the risk of a terrorist attack by using nuclear materials. Jun Wu (China) presented an "Analysis of the Risk of Nuclear Terrorism," a report which outlined possibilities for a devastating attack against civilian population and evaluated their respective risk potential. Francesco Calogero (Italy) analysed the options and risks of nuclear terrorism, especially the likely scenario of a simple, reverse-engineered nuclear device with enriched uranium. Special knowledge of physics is no longer a barrier; the possession of significant weapon-grade uranium is enough. Therefore the speedy reduction of the HEU stockpiles demand the highest urgency.

In principle, the current possibilities could be separated into two major categories: An active and a passive option.

The active option represents the deployment of a nuclear bomb within a city. For technical reasons, the use of highly enriched uranium in a simple nuclear bomb seems to be more likely, but the use of plutonium can not be totally discounted. The simplest method for a terrorist group to furnish a nuclear explosive device would be to use enough highly enriched uranium in "gun type" trigger mechanism to achieve criticality. The use of a stolen "operational nuclear weapon" might also in the mind of some, but it is hoped that the nuclear weapon states do everything to protect their arsenal.

The passive option includes the use of nuclear materials as dirty bombs or the attack or sabotage of a nuclear facility. Normally these facilities are under security; the power plants are even constructed to withstand an attack. Consequently, the use of a dirty bomb appears more plausible. For such a device, which does not trigger a chain reaction and therefore induces very limited casualties (compared with a nuclear explosion), a strong radiation source is needed. These sources are available in large quantities even in the civilian sector.

The speakers agreed that the following countermeasures should be implemented to prevent nuclear terror:

- Blending down of the total highly enriched uranium stockpile as soon as possible
- Protect all nuclear materials (including bombs, HEU, Pu, …) efficiently
- Check key points like harbours to prevent smuggling by using radioactive detectors

Additionally, it was suggested that even some nuclear weapon states or some circles in these states might be willing to cooperate with terrorists. Thus direct access to weapon-grade material for terrorists cannot be excluded.

The discussion pointed out several interpretations of the keyword "terrorism."
The 9/11 attacks lend sympathy to the habit of equating terrorism with "mass murder." But is this the most likely scenario? In my opinion, it is not.

[1] The report was revised by the author after the conference. The information may differ from the audio content.

Two examples shall point out, that “small” attacks with dangerous substances can do much harm and might be therefore an option of terrorists. The first example is the “anthrax letters” which were delivered in the United States in 2001. Truly, the whole country was still under the 9/11 shock, but many people have been interpreting this action as a danger for their own lives. Everybody could be the next.
Another example is the sad destiny of Mr. Litvinenko. He was killed from the use of and exposure to radioactive polonium, a nuclear isotope which is produced in reactors. The trace of this radioactive material was found spread over Europe, even here in Hamburg. People were starting to feel insecure and this effect was pushed by the media. And that is one of the main goals, terrorists want to achieve: They want to bring confusion and uncertainty. These two examples show that even a small attack using e.g. nuclear material can paralyse modern life temporarily. In this light, further analysis including small-scale terrorist attacks in combination with nuclear materials is warranted.

Note: There was no further discussion on the report.

Report on the Ninth Session - Thoughts on the Nuclear Future[1]

Carsten Rauch (Germany)

Carsten Rauch: Session Nine dealt with the Nuclear Future. Using an institutionalist framework Harald Müller divided the Non-Proliferation-Regime in *Principles, Norms, Rules* and *Procedures* and showed that in each of these categories there is reason to be concerned or even alarmed. He concluded that, from the perspective of utility as well as from the perspective of perceived regime justice, the NPT has come under extreme pressure. The only remedy would be to reinstate the utility as well as the perceived justice of the regime. Andrew Mack on the other hand, went a step beyond the NPT and imagines a Nuclear Weapons Convention (NWC) that bans all nuclear weapons. He went on to explain that the risk of deception and exploitation from an NWC framework is not as high as conventional wisdom would have it. He discussed several risks of regime failure and concluded that they are either implausible or at least manageable. And even *if* a successful breakout should occur, this wouldn't be the nightmare scenario some would imagine, because the *breakout state* couldn't achieve much with its nuclear monopoly.

Among possible "open questions", I would like to bring up three topics which were partly touched in the discussion following the presentations:

1. A link between the situations described by Müller and Mack was conspicuous in its absence. If, as Müller argues, the NWS are evading their limited duties under the NPT already today, how can we even imagine a situation were they are ready to give up their nuclear weapons altogether? If on the other hand, as Mack argues, nuclear weapons are becoming increasingly useless and especially the great powers would profit from a nuclear free world, why are the NWS behaving as they are, in the existing Non-Proliferation Regime?
2. Mack's presentation was not entirely convincing in his arguments how to deal with the case of a successful breakout. I would question his notion that a new nuclear balance would re-establish itself relatively easy. Wouldn't such a new nuclear race be - in fact – quite hazardous? In my opinion the incentives for pre-emptive or disarming strikes could be quite high and lead to wars that would otherwise not be fought.
3. Müller was certainly right in criticizing the actions of the NWS and giving them much "credit" for the increasing regime instability. But I wonder if the curing of the regimes' flaws would really dissuade the nuclear ambitions of the states which he highlights and those actions leading to possible proliferation chains. Or, would this merely reduce the risk of proliferation by countries that don't really *desire* nuclear weapons in the first place? My own feeling is that, of all the defectors from the non-proliferation regime, only in the Indian case did dissatisfaction with the regime itself play a decisive role in motivating the aspiration for nuclear weapons.

Note: There was no further discussion on the report.

[1] The report was revised by the author after the conference. The information may differ from the audio content.

Open Meeting of the International Organizing Committee

Report by Richard L. Garwin

After a coffee break, there was the scheduled Open Meeting of the International Organizing Committee of the Amaldi Conferences, which was approximately constituted by Götz Neuneck, Richard Garwin, Boris Myasoedov, Alex Keynan, Klaus Gottstein, Carlo Schaerf, Ben Koppelman, Constanze Eisenbart, Vladimir Nekvasil, and Francesco Calogero. By default I chaired that session and set the agenda as follows:

1. Identify the international organizing committee for the XVIII Amaldi Conference and gain the acquiescence of the participants.

2. Define the main theme and "window" of the XVIII Amaldi Conference.

3. Set the potential dates (if it was to be in 2009 it would need to be late Fall of 2009 to allow planning and programming).

4. Request submitted papers early and post them on the closed website. Not all of the papers would be presented at the Conference, and in fact a selection would be made among some of them as to which would be presented. A major effort should be made by the authors to provide web references-- URLs and links to the references for the papers.

5. Funding, which turned out to have been about 35,000 EUR for the XVII Conference ($52,000, for about 60 people, about 50 of whom were put up in the guest houses at DESY at a price of 35 EUR fee plus 13 EUR/day).

6. The output and proceedings from the Conference.

7. Attendance and invitations.

Now I provide an indication of the discussion of each of these items.

1. Identify the international organizing committee for the XVIII Amaldi Conference and gain the acquiescence of the participants.

There was considerable discussion as to whether there should be a permanent international organizing committee of individuals identified by the principal participating academies (Italy, France, Germany, UK, US, Russia) or whether there should be a more ad-hoc committee. Constanze Eisenbart, for instance, indicated that she had been asked personally by G. Salvini to be a member of the International Organizing Committee; and Klaus Gottstein has been requested by the Union of German Academies of Sciences to be their representative to the Amaldi Conference. In the past it was the perpetual secretary of the French Academy of Sciences who was on the IOC. Apparently Israel had not had a representative on the IOC.

Boris Myasoedov indicated that he had been requested by N. Laverov to represent the Russian Academy of Sciences (RAS) at this XVII Amaldi Conference and that the Amaldi Conferences were well known and much esteemed by the Russian Academy of Sciences. Vladimir Nekvasil indicated that things are changing rapidly in the Czech

Republic and that there had been no security research and that it had been explicitly rejected several years ago.

Garwin indicated that since the Amaldi Conference was "of Academies of Sciences and of National Scientific Societies on Scientific Questions of Global Security," it was really a matter of the Academies of Sciences to identify or endorse their representatives on the IOC. For instance, if Garwin wished to be a member of the IOC, he would have to propose that to the U.S. National Academy of Sciences and be formally identified by them for this role.

After this discussion, it was concluded that Prof. Vesentini should identify the academies or scientific societies whose representation they desired on the IOC and that this should be not a committee of permanent membership but one that would be a rolling committee for the next two Amaldi Conferences. In identifying these academies and requesting their suggestion of a member or of a representative to serve on the International Organizing Committee, Vesentini might indicate the person from that Academy who had participated in these discussions and suggest that the Academy president might discuss with that person for further information and interpretation.

2. Define the main theme and "window" of the XVIII Amaldi Conference.

There was acquiescence that the main theme should be associated with nonproliferation and arms control. Since START-I expires the end of 2009, and since remedial measures will be needed for the Nonproliferation Treaty and regime, 2009 seems a crucial time for nonproliferation and arms control. Added to this is the substantial momentum of the Reykjavik-2 group personified by Kissinger, Nunn, Perry, and Shultz in their Op-Ed pieces of January 2007 and 2008, together with their recent meeting in Oslo. Further progress is to be expected from such a powerful group.

2009 seems auspicious also because of NATO's 60th birthday; and the G-8 session in Italy.

John Simpson noted that by end-2009 START-I dies and there are no remaining rules for verification. It is essential that something be done. He noted that the Conference on Disarmament is the international body that should be negotiating arms control agreements and it was not even mentioned at this meeting.

The "window" might have several papers and a presentation or two on the biological threat and what can be done about it, which might be a lesser prospect for a future Amaldi Conference.

Henri Korn noted that CISAC had a very good report in the bio-threat area, "Biotechnology in an Age of Terror,"-- the Fink report.

3. Set the potential dates (if it was to be in 2009 it would need to be late Fall of 2009 to allow planning and programming).

Foreign academy participation (including the German academies) in the Amaldi Conference is usually a matter that must be decided by an Academy board, and Gottstein indicated that one of these met in April 2007 and the other in November 2007.

Putting off any decision on the XVIII Amaldi Conference until October 2009 would preclude having such a meeting before Fall of 2009, but that would be feasible, if difficult.

4. Request submitted papers early and post them on the closed website. Not all of the papers would be presented at the Conference, and in fact a selection would be made among some of them as to which would be presented. A major effort should be made by the authors to provide web references-- URLs and links to the references for the papers.

Schaerf indicated that this would be the ideal approach, but it was difficult to have people provide their papers in advance and so one might hardly be able to utilize this mechanism. Garwin replied that it is a lot easier to prepare or customize a paper for a particular conference now than had been the case (with Cut and Paste) and that it seemed to be worth a try. In any case, there was wide acceptance of the need for hotlinks or their equivalent to enable potential participants and readers of the paper to take advantage of the information present on the web.

5. Funding, which turned out to have been about 35,000 EUR for the XVII Conference ($52,000, for about 60 people, about 50 of whom were put up in the guest houses at DESY at a price of 35 EUR fee plus 13 EUR/day).

The remarkably low cost of the XVII Amaldi Conference was a matter for discussion. In part it was because of the low cost of housing and similarly the low cost of meals provided by the DESY Cantine. Participants paid their way for the most part, except for several who came from a long distance. In fact, the cost was so low that one participant indicated that if the major academies participating in the meeting had an annual subscription to the Amaldi Conference, about $10,000 each should cover it, and that was a small amount compared with the amount paid for membership in, say, EMBO-- the European Molecular Biology Organization.

6. The output and proceedings from the Conference.

It is traditional in the Amaldi Conferences for individual participants (or those from a particular academy if there is more than one) to report to their academy on their views of the significant aspects of the Amaldi Conference. It was proposed that the routine descriptive part of this reporting could be eased if there were available from the host in English (or in German that could readily be translated into English) a one-two page summary of the conference.[1]

Each of the participants reporting to his or her academy could then use this summary as the basis for further particularized comments that might be in fact more contentious than could be agreed in the brief summary.

It was agreed that the proceedings should include this brief summary, the agenda, and list of participants, as well as the papers submitted to the conference, where the authors give their permission. Klaus Gottstein indicated that some authors had specifically requested that their papers not be published without their permission, because they

[1] The summary for the present conference may be found at the beginning of these proceedings.

wanted to have the opportunity to correct errors or make small modifications. In fact, Garwin had already done this before presentation in replacing an early draft with one that had had more input from various of his colleagues mentioned in the first Panofsky Lecture.

Gottstein was urged to write the authors of the papers to urge them to make any needed changes so that the papers could be published in the proceedings and on-line.

In some cases the papers are simply the slides that were used in the presentation, without expansion in prose. It is not obvious that we would be successful in getting full papers from these busy individuals, and in many cases the slides themselves (or computer equivalent) are extremely valuable, as in the case of Harald Müller's analysis of the state of health of the NPT.

Naturally, slides prepared for visibility at the back of an auditorium should not be printed one to a page in the proceedings, but could perfectly well be printed four to a page so as to save paper and bulk, and to be more readily legible by the eye at normal reading distance.

In the case of Francesco Calogero and perhaps others, it would be valuable if references were provided, and of course, if the paper were converted to "landscape" mode from its current "portrait" mode.

There was discussion over the cost and benefit of transcribing the questions and comments following the presentations, but no agreement was reached. That would certainly take time and while it would give participants other than the presenters an opportunity for their input, Constanze Eisenbart volunteered that the world would not come to an end if her comments went unrecorded.

Ben Koppelman reported that at the Royal Society Radiation Detection Symposium in December there were four RS staff taking notes and three CISAC staff, so that there was no need for recording and transcribing. It was suggested that each session at an Amaldi Conference have two participants assigned to take notes with their laptops and for one of them to produce a finished version.

Aharon Zohar noted that the subject should be the one that's most important at the time of the conference. He suggested a plenary at the beginning and at the end, with multiple group discussions in between.

The original concept for the Amaldi Conferences was to have as output the influence of knowledgeable, independent scientists on their governments' programs in national and international security. This goal is advanced even if academies that have had no such influence participate in the Conference and are educated as a result and at some time in the future are able to play this role. Furthermore, the corpus of work prepared for the Conference and provided in the proceedings, and especially on an on-line Amaldi Conferences website furthers that goal as well.

Pief often stated that neither the Amaldi Conferences nor governments should have to rely on government scientists and programs of limited independence when highly capable and independent scientists could acquire such knowledge by reading and talking with individuals involved in government programs. Alex Keynan indicated that connection between scientists whose countries are in conflict is very valuable and the participation of academies is of some worth even if their scientists don't happen to attend.

7. Attendance and invitations.

Some individuals will be identified by their academies for participation, as will be probably the case of Boris Myasoedov. Other individuals might be invited by Prof. Vesentini himself, if they are known to him as particularly valuable participants. So there should be a mixture of direct invitees and representatives of national academies or scientific societies.

The session terminated at 5:30 p.m. in a spirit of mutual respect and warm collaboration.

R.L. Garwin

Photo Selection

A. Wagner

J. Boright, E. Vesentini, S. Keeny

Y. Evron, S. Lotfian, C. Eisenbart

R. Avenhaus

R. Garwin

E. Vesentini

C. Jakobeit, A. Wimmer, A. Wagner, R. Garwin

A. Buckley, A. Zohar, H. Spitzer, A.Wagner

B. Myasoedov

C. Jakobeit

C. Watson

M. Brzoska

M. B. Kalinowski

A. Mack

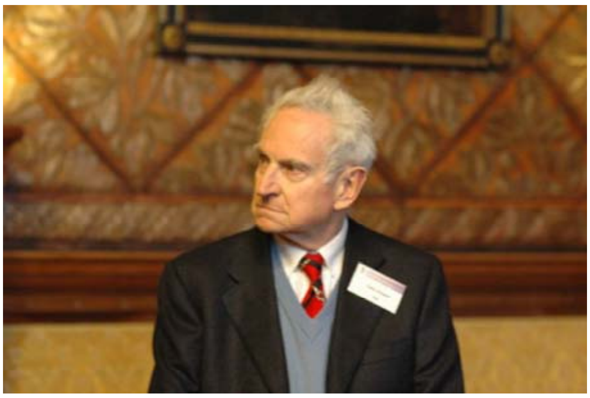
J. Simpson

F. Calogero

H. Müller

H. Korn, A. Buckley, J. F. Ahearne

T. Suzuki



C. Schaerf

J. Wu

J. Mietelski

G. Neuneck, A. Keynan, J. F. Ahearne, M. Jovanović, C. Pistner

C. Rauch, G. Franceschini, R. Garwin, M. Suh

Y. Evron

K. Gottstein

F. Lehner, K. Gottstein, K. Lehner

By courtesy of Marcel Dickow and Markus Kohler, see http://amaldi2008.desy.de/e103/