SKI Report 2004:15

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

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Foreword and acknowledgements

This report is about what can and ought to be done regarding the large quantities of highly enriched uranium (HEU) that exist in the Russian Federation. It is our hope that the report will catch the attention of an audience in Europe regarding the persistent threat of HEU and also help deal with the associated dangers.

The motivation to write this report came out of the seminar in May 2002 in Sigtuna on promoting disarmament of tactical nuclear weapons. The seminar was organized by the Swedish Pugwash Group. In the discussions on how to proceed with further activities aiming at the reduction of the large stocks of HEU in Russia, it was suggested that the Swedish Nuclear Power Inspectorate (SKI) explore the possibilities of funding for the purpose of addressing the threats emerging from HEU. Based on initial discussions with the Swedish International Development Cooperation Agency, (SIDA) and the Swedish Ministry of Foreign Affairs, a project proposal was submitted to SIDA. The response was positive.

In the ensuing months, several meetings were held, documentation and data was collected and drafts written. The participants in the *HEU Elimination Study Group* - as we named ourselves - used their professional skills, expertise in the nuclear non-proliferation field and their personal involvement in the work of the Pugwash movement to complete this work.

On behalf of the Study Group we thank SIDA for funding our work and contribution to security-building. We would also like to express our gratitude to the Swedish Ministry for Foreign Affairs for sharing our interest for something that can be actively used to further practical steps in the field of nuclear disarmament and non-proliferation. Furthermore, our employers deserve our appreciation and acknowledgement for granting us the time and opportunity to commit ourselves to this work. Furthermore, it is fair to thank the International Working Group Secretariat of the European Nuclear Cities Initiative hosted by the Landau Network-Centro Volta for hosting our first meeting in Como in September 2002; and the Russian Pugwash Committee under the Presidium of the Russian Academy of Sciences as well as the Center for Political and International Studies, Moscow, for organizing our second meeting and conversations with Russian experts in February 2003.

Finally, the Pugwash Conferences on Science and World Affairs deserves mention because it brought us together and continues to contribute to the common resolve to deal with contemporary and future nuclear threats.

Stockholm and Rome, April 2004

Lars van Dassen and Paolo Cotta-Ramusino

Executive Summary

Background

This study aims at establishing options for a European contribution in the field of eliminating highly enriched uranium (HEU). Vast quantities of this material have been produced during the Cold War. The major portion of the material is located in nuclear weapon states; and thus outside the international control of the International Atomic Energy Agency, IAEA. The larger the stocks of nuclear material - and the longer it is stored under uncertain conditions the greater the risk is that the material can be diverted and find its way into the hands of states and terrorist groups harbouring nuclear weapons ambitions.

Many incidents involving illicit trafficking in nuclear material more than indicate that inadequate physical protection and control, particularly in the Newly Independent States, continue to be a major problem. Insufficient accountancy practices in the past make it difficult to have proper inventories of fissile materials. Today, with some noteworthy exceptions, there are no official figures of the existing stocks of HEU possessed by states. *Estimates* indicate a total of 1000-1500 metric tons in Russia alone. The *uncertainties* concerning Russian HEU holdings alone amount to hundreds of tons. Viewed against the fact that some tens of kilograms of HEU (depending on the degree of enrichment and the sophistication of the device) is sufficient to construct a workable nuclear explosive device with yields in the kiloton range, the figures are staggering.

HEU and/or plutonium are the essential ingredients of any nuclear explosive device. However, once the needed quantities of fissile materials have been obtained, it is much easier to construct a nuclear explosive device using HEU than plutonium. For a number of reasons, the theft of HEU is by far the most direct way for any actors seeking nuclear explosive capabilities:

- HEU is the only material that allows for the easy manufacture of crude nuclear explosives. No sophisticated implosion designs and technology is needed.
- Anybody with access to sufficient quantities of HEU of high enough quality will have a good chance to achieve a kiloton-range nuclear explosion – i. e. a yield approaching that of the Hiroshima bomb.
- HEU exists in abundant quantities throughout the world under varying levels of security and physical protection.
- HEU detection, e.g. at boarder-crossings and checkpoints, is rather difficult due to the low levels of radiation emitted.
- The radiation levels from fresh uranium are low and the handling of HEU involves minimal health hazards

As a consequence, highly enriched uranium represents the largest fissile material threat to international security and stability. As long as safe and secure storage cannot be assured, terrorist acquisition and use of HEU to inflict disastrous damage cannot be ruled out. A resourceful terrorist group is capable of manufacturing a crude nuclear explosive with a yield in the lower kiloton range. The proximity to areas of potential nuclear leakage could make Europe particularly exposed to nuclear terrorism. This threat can only be reduced by denying potential nuclear proliferators access to highly enriched uranium. The ultimate way of preventing proliferation is by eliminating as much of the HEU as possible – as quickly as possible.

Proposed HEU elimination scheme

In cooperation with the Russian Federation, European parties should urgently consider an agenda for eliminating stockpiles of highly enriched uranium by *de-concentrating* the HEU into low-enriched uranium (LEU) through *down-blending*. Technically, down-blending is a simple process and the existing Russian nuclear infrastructure can be used.

The HEU should be down-blended to a level where it is ”proliferation safe”; that is below 20% enrichment in uranium-235. Uranium enriched below this level is not suited to sustain chain reactions that result in a nuclear explosion. Hence, manufacturing nuclear explosive devices is not feasible unless the material is re-enriched. This is a process that only resourceful states can handle – terrorist groups can hardly accomplish this procedure.

Through financial incentives - possibly in the form of creating civilian job-opportunities in the oversized Russian nuclear weapons complex - it is likely that Russia could consider which stocks of HEU are exceeding to national needs. These stocks could be slated for elimination with European economic assistance. The G8 Global Partnership Against the Spread of Weapons and Materials of Mass Destruction could form a natural point of departure and a framework for the European HEU elimination support.

The goal of European parties should be to buy as much HEU as possible for elimination – by down-blending it. The resulting LEU should remain in Russia and under Russian ownership. Russia could explore future commercial potentials of the LEU on the world market.

In other words, European parties should provide financial incentives to Russia for the down-blending services at Russian facilities**.** However, for European parties security considerations must prevail over economic and commercial benefits. Russia would have to commit itself to refrain from producing any new HEU and not to re-enrich any of the down-blended LEU above a plus-20% level.

The elimination should come as a supplement – not as a substitute – for the ongoing US-Russian HEU elimination activities. The cooperation should therefore build upon, and not rest upon, the 1993 US-Russian HEU agreement to eliminate 500 tons of Russian HEU. After a decade of cooperation, well-functioning working schemes for the down-blending and needed transparency provisions have been put in place under the US-Russian cooperation. These experiences can constitute important lessons for further efforts to eliminate HEU.

Scope of the study and the prospects for Russian HEU elimination

This study is of an exploratory nature. It provides preliminary assessments of issues of relevance for HEU elimination in Russia including: (a) technical issues concerning the HEU down-blending; uranium transparency and verification requirements; description of current Russian HEU locations; the HEU down-blending capacities, and the HEU logistics, and (b) various political and financial requirements and considerations.

For future, practical project measures to be put in place, further investigations that deal with HEU logistics and handling are needed. Such studies – that obviously should include and engage key Russian actors – are possible, if they take legitimate Russian security and sensitivity concerns into consideration. Interestingly, there is a growing perception in Russia that large stocks of HEU are not required and that they could, in fact, constitute a source of danger.

Chapter 1: Introduction

The end of the Cold War has dramatically reduced the risk of a nuclear war. Yet, the legacy from this era continues to pose challenges to international security. There are more than 30 000 nuclear warheads either operational or in reserve stocks and stockpiles amounting to millions of kilograms of weapons-grade nuclear material (both HEU and plutonium). The prospects of both horizontal and vertical nuclear proliferation have not ceased to exist.[1] Moreover, this situation has greatly accentuated a new nuclear threat: The possibility of terrorist uses of crude nuclear explosive devices.

Renewed attention should be directed toward diminishing these threats through joint international efforts to secure, reduce and eliminate the core ingredients of any nuclear device: highly enriched uranium (HEU) and plutonium. Specifically, the objective of this study is to identify ways and means to reduce the HEU threats – through the active engagement of new actors, the European Union, or other singular European states, possibly in the context of the G8 Global Partnership Against the Spread of Weapons and Materials of Mass Destruction.

On a global scale, the arms race has led to the production of large quantities of HEU that far exceed the stocks of weapons-usable plutonium. Due to the fact that HEU has mainly been produced for military purposes in nuclear weapon states, only a minuscule amount (roughly 1%) of all HEU stocks come under international control of the International Atomic Energy Agency (IAEA). There have been several cases of theft of kilogram quantities of this weapons-useable material.[2]

The largest amount of "unirradiated HEU", (i.e. "fresh HEU, or HEU that has not been burned in a reactor) is found in Russia and hence the focus of this study. The exact figure is not known. Unofficial estimates vary between slightly above 1000 to 1500 tons – amounting to tens of thousands of nuclear warheads. Currently, less than 40 % of the material potentially vulnerable to theft has been covered by physical security upgrades funded by the US.[3] Less than one sixth of Russia's stockpile of highly enriched uranium has been eliminated under a US–Russian agreement.

According to this US-Russian HEU agreement, 500 tonnes of HEU will be transformed to low enriched uranium and marketed in the US and burned in commercial nuclear power plants. After initial difficulties, the HEU elimination scheme is now back on track.[4] However, even after being fully implemented by 2013, the deal will cover less than 40% of existing Russian HEU stocks. Additional HEU

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[1] Canberra Commission on the Elimination of Nuclear Weapons, 1996. http://www.dfat.gov.au/cc/cchome.html; Joseph Cirincione, "Nukes Endanger Asia's Future", Los Angeles Times, September 29, 2003; Sarah Diehl/James Clay Moltz, Nuclear Weapons and Nonproliferation, ABC-CLIO Inc., Santa Barbara, 2002.
Monday, September 29, 2003

[2] Bunn, Matthew, Anthony Wier, and John P. Holdren. Controlling Nuclear Warheads and Materials: A Report Card and Action Plan. Washington, D.C.: Nuclear Threat Initiative and the Project on Managing the Atom, Harvard University, March 2003; Lyudmila Zaitseva and Friederich Steinhausler, "Illicit Trafficking of Weapons-Usable Nuclear Material: Facts and Uncertainties", Physics and Society vol. 33, no. 1, pp. 5-8, January 2004; http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp

[3] General Accounting Office, "Weapons of Mass Destruction. Additional Russian Cooperation Needed to Facilitate U.S. Efforts to Improve Security at Russian Sites", GAO-03-482, submitted to Subcommittee on Financial Management, the Budget, and International Security, March 2003, www.gao.gov/cgi-bin/getrpt?GAO-03-482.

[4] Nigel Hunt, "Russian nuclear warheads help to power U.S.", Feature, 14 March 2004.

elimination efforts to speed up the destruction of this highly proliferation attractive material are thus highly desirable and urgently needed.

HEU elimination and the international security agenda

Recently, the elimination of HEU has become the object of multilateral agendas and declarations. Most international commitments are, however, still at a declaratory level. The practical implementation and realization of these pledges are nevertheless essential.

In April 2002, the Preparatory Committee meeting for the 2005 Review Conference of the Nuclear Non-Proliferation Treaty (NPT), under the chairmanship of Ambassador Salander of Sweden, stated that international commitment is needed to ascertain the security of fissile materials and thereby reduce the risk of terrorist use of these materials.

The G-8 summit in Kananaskis, Canada, June 2002, launched a new Global Partnership against the Spread of Weapons and Materials of Mass Destruction. 20 billion USD were pledged over the coming 10 years to support specific cooperation projects, primarily in Russia, to address non-proliferation, disarmament, counter-terrorism and nuclear safety issues. Among the priority concerns of the G8 are the safe and secure disposition of fissile materials.

The Multilateral Nuclear Environmental Programme in the Russian Federation, or MNEPR, was signed in Stockholm in May 2003. The agreement paves the way for projects in management of radioactive waste and spent nuclear fuel from the Northern Fleet nuclear submarines. As such, it is likely to be a major step forward for Russia and its European partners in tackling nuclear safety and security problems, including the safe and secure handling and storage of naval HEU.

In July 2003, the Swedish government made public its initiative for establishing an independent international commission on weapons of mass destruction for which the former Director General of the IAEA, Dr. Hans Blix, has been appointed as Chairman. The purpose of the “Blix Commission” is to provide new impetus to the international efforts involved in disarmament and non-proliferation of weapons of mass destruction and missiles.[5] Reduction of security risks associated with excessive stocks of HEU could thus form an integral part of the work of the Commission.

Objective and structure of the study

This study will investigate both *why* and *how* concerned states, most notably European states, should and could eliminate a major threat by means of the down-blending of HEU to low enriched uranium (LEU). In this study, special attention is given to Russia due to its vast HEU stocks which in many cases are under unsatisfactory levels of security.[6]

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[5] http://www.srp6.net/red/eng/redaktion/show.php3?type=1&rubrik=1&action=single&show=4826 (12 December 2003)

[6] However, HEU stocks persist throughout the world. Eventually, all HEU stocks need to be taken into consideration and dealt with in accordance with the security threat they pose.

To interested European parties, this assessment should serve as a pilot study and guideline into the field of HEU elimination. To the interested Russian parties, on the other hand, the study provides a possible framework for attracting more and new European sources of funding to improve domestic - and thus international - nuclear security. The outcome should be a contribution to a better understanding of the risks associated with excessive and poorly guarded stocks of highly enriched uranium. To both sides, the study could serve as a stepping-stone towards closer and focused cooperation in the field of future HEU elimination, and thus reducing the risk of nuclear terrorism dramatically.

This study is divided into two parts. The first part discusses *why* there is urgent need to focus on the elimination of HEU as a global security-building measure. The second part focuses on *how* to accomplish this through a set of technical, political and economic instruments. The rationale, background and the structure of the report are stated below:

The point of departure for the assessment (Chapter 2) will be a discussion of the European and Russian interests in and perspectives on additional HEU elimination. Here, the key questions are whether there are any nation-specific priorities and restrictions of importance, and, if so, how these could influence viable solutions and the identification of a common understanding. The study then moves on (Chapter 3) to an assessment of HEU in the contemporary threat picture: For instance a world where terrorists operate and are willing to carry out spectacular suicidal attacks. This chapter will be followed by a presentation of the experiences from existing HEU elimination efforts, together with a discussion of how further HEU elimination could be achieved (Chapter 4).

The second part of the study starting with Chapter 5 describes a possible European scheme for accelerated HEU elimination in Russia. Here, a number of relevant technical questions are discussed, including the Russian HEU infrastructure, logistics, verification and transparency issues. The chapter also deals with some legal, political and administrative HEU issues in Russia, followed by the concluding chapter (Chapter 6).

Biographies of the the members of the HEU Elimination Study Group is in Appendix I. Appendix II contains an overview of the internal and external meetings of the HEU Elimination Study Group.

Chapter 2: Different perspectives on HEU elimination

What are the specific interests in the elimination of HEU in Russia and Europe, respectively? It should not be taken for granted that Europe has the same incentives as Russia. Different security considerations may prevail. The primary incentive for European engagement in HEU elimination may stem from its long-standing promotion of non-proliferation and the recent concerns over nuclear terrorism.

Europeans are particularly interested in making the Russian nuclear disarmament and non-proliferation efforts irreversible, more effective and faster. If this is the case, then additional European funds will have to be made available. European parties must, moreover, make security considerations prevail over (short-term) economic incentives and commercial benefits possibly associated with the uses of the uranium (see Chapter 5).

Russian HEU considerations

There are those who maintain (like many Russians) that Russia would have no interest in undermining its strategic reserve of materials. Maintaining stocks of HEU could be essential for national security, both for assuring the availability of materials for nuclear warhead components and for naval nuclear propulsion. The HEU may be viewed as a state asset based on the weapons potentials, the mere production investments, and its possible applicability in (commercial) nuclear power plants. To some, eliminating the material may thus seem to be at odds with national security considerations and reasonable practices.

Moreover, even if the excessive stocks of HEU were to be viewed as a security risk, security and non-proliferation issues other than HEU elimination are currently perceived as more important by key Russian actors. The primary nuclear security priority for the Russian Ministry for Atomic Energy (Minatom) and the Russian government is the dismantlement of nuclear submarines, as well as the safe unloading, transporting and reprocessing of the spent fuel from these vessels.[7] The second priority is the disposal of excessive stocks of plutonium. Dealing with stocks of HEU only comes third on the priority list, along with the fulfilment of Russia's obligations under the Chemical Weapons Convention: the elimination of 40,000 chemical weapons.

Apart from the HEU elimination efforts, practical project implementation and progress in al other priorities remains painfully slow – despite the fact that overarching agreements have been put in place and donors stand ready to provide funding. The current HEU elimination work is, however, moving ahead in accordance with the mutually agreed (US and Russia) schemes. From the Russian point of view, there is thus a limited need to deal with the HEU stocks.

For the time being, there are no Russian stocks of HEU declared as excessive to national security needs that are not covered by the existing HEU elimination co-operation between Russia and the United States. However, in this regard two items are of vital importance. Firstly, it should be kept in mind that even after its successful completion by 2013, the existing US-Russian HEU elimination co-operation would

[7] Based on a meeting with the Russian Minister of Atomic Energy, Rumyantsev, February 21, 2003.

cover less than half of the estimated total Russian HEU stocks. Clearly, there may be room for additional and accelerated reductions.

Secondly, financial incentives – perhaps in the context of a broader economic cooperation with the European Union – may improve the practical progress in Russian practical nuclear disarmament and non-proliferation activities. Indeed, before the US in 1993 indicated its willingness to buy and eliminate Russian HEU surplus, no stocks were identified by Russia as excessive to national security needs. Fresh European funds may thus not only improve Russian interest in HEU stockpile accountability, it may actually facilitate the process of Russia identifying additional stocks that could be declared as excess and slated for elimination.

The prospects of additional HEU excess declarations

Elimination of HEU beyond the already negotiated 500 tons that have been declared as excess obviously requires some political bargaining. In order to help possible donors understand the size of the problem, Russia needs to declare its stocks of HEU and the material possibly in excess to national security needs. Russian Minatom[8] experts stress that though there are facilities available to accelerate down-blending beyond the existing and agreed quantity, any additional HEU stock for elimination should be officially admitted and announced by the Russian government as "excessive to military needs". To reach such a political decision several domestic actors need to be closely involved in the process, , e.g. the Russian Ministry of Defence, the Foreign Ministry, the Security Council, the Russian Academy of Science and the respective structures inside the President's Administration.

Analysis of the history of the first Russian HEU excess declaration in conjunction with the US-Russian HEU deal may, however, provide hope that external actors may indeed influence such vital Russian decisions, and that there actually is more HEU available for a coming HEU excess declaration.

[8] In the hour of finalization of this report, the reformation of the government of the Russian Federation has changed the position and weight of what used to be Minatom. Though the reform process is expected to go on for some time (Julie Corwin, "Reforming the Russian Bureaucracy: A Progress Report, RFE/RL, 15 April 2004), its seems clear at this stage that Minatom will no longer be a ministry with its own minister but a federal agency, the Federal Agency for Atomic Energy, FAAE under the Ministry of Industry and Energy, headed by Minister Viktor Khristenko; Matthew Bouldin, "Russian Government Restructuring and the Future of WMD Threat Reduction Cooperation: A Preliminary Analysis, RANSAC Policy Update, March 2004.
In the following, the reference to "Minatom" will be kept and not be changed to the new name. This is in order to avoid obfuscation where some issues are past statements, agreements etc. made in the name of Minatom and where other future assessment etc are related to the FAAE. If both names were to be used it would create confusion and give the impression that it is two different agents that are mentioned.

Chapter 3: HEU threat assessment

The main barrier – for states and sub-national groups – in acquiring nuclear explosive capabilities is the considerable difficulty of producing the fissile materials needed for nuclear weapons: Plutonium and/or highly enriched uranium are essential ingredients of any nuclear explosive device. Of these two materials, HEU is the most likely choice for potential nuclear terrorists.

Theft of unirradiated HEU is by far the most direct shortcut for actors seeking nuclear explosive capabilities. There are several reasons for this:

- HEU is the only material that makes it easy to easy to manufacture crude nuclear explosives
- Anybody with access to sufficient quantities of HEU of high enough quality will have a good chance of achieving a kiloton-range nuclear explosion.
- HEU exists in large quantities throughout the world, in many cases under unsatisfactory levels of security and physical protection.
- HEU detection, e.g. at boarder-crossings and checkpoints, is difficult due to the low levels of radiation emitted.
- The radiation levels from fresh uranium are low and the handling of HEU involves minimal health hazards (as long as criticality is avoided).

Important efforts have been made to improve the security of fissile material and to destroy and render HEU inaccessible to potential terrorists and proliferating states. Some of these programs have made remarkable progress. Yet, they are moving too slowly and without the needed comprehensiveness.[9] According to the findings of an independent review panel in January 2001, the most urgent unmet national security threat to the United States is the danger that weapons of mass destruction or weapons-useable materials in Russia could be stolen and sold to terrorists or hostile nations.[10]

The threat is probably a threat to all nations, not only the US. Some scholars maintain that Europe is as much at risk as America with regard to large-scale terrorism.[11] Insecure nuclear weapons-grade material anywhere is a threat to everyone, everywhere.[12] Its proximity to areas of potential nuclear leakage could make Europe particularly vulnerable and exposed. While conventional weaponry will

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[9] Bunn, Matthew, Anthony Wier, and John P. Holdren. Controlling Nuclear Warheads and Materials: A Report Card and Action Plan. Washington, D.C.: Nuclear Threat Initiative and the Project on Managing the Atom, Harvard University, March 2003. http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp

[10] Howard Baker and Lloyd Cutler, "A Report Card on the Department of Energy's Non-Proliferation Programs with Russia", the Secretary of Energy Advisory Board, United States Department of Energy, January 10, 2001, http://www.ceip.org/files/projects/npp/pdf/DOERussiaTaskForceReport011001.pdf . The swift and effective elimination of Russian excess HEU was among the key recommendations of the review panel.

[11] Therese Delpech, “International Terrorism and Europe”, Chaillot Papers, No. 56, December 2002; Harals Müller, “Terrorism, proliferation: a European treat assessment”, Chaillot Papers No. 58, Institute for Security Studies, European Union, March 2003; Alexander Kelle, Annette Schaper, Terrorism using biological and nuclear weapons: A critical analysis of risks after 11 September 2001, PRIF Report n. 64, 2003.

[12] Bunn, Matthew, Anthony Wier, and John P. Holdren. Controlling Nuclear Warheads and Materials: A Report Card and Action Plan. Washington, D.C.: Nuclear Threat Initiative and the Project on Managing the Atom, Harvard University, March 2003. http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp

remain the choice for the vast majority of terrorists, some high-profiled terrorist groups have actively been seeking nuclear material and nuclear explosive capabilities.[13]

> *The threats associated with unirradiated HEU – including nuclear terrorism – thus call for elimination of as much HEU as possible, as soon as possible.*

Acquiring fissile material for a nuclear explosive device is by far the hardest part for potential nuclear terrorists, yet it is also the easiest step to check.[14] Reducing the threats from HEU is pretty straightforward, from a technological point of view. As opposed to plutonium disposal, the elimination of HEU is achieved by simply blending it down, that is mixing it with natural or depleted uranium to low enriched uranium (LEU).

LEU cannot be used to manufacture nuclear explosive devices. This LEU would have to be (re)enriched, which is a difficult process beyond the capabilities of sub-national terrorist groups and most states. For example, Saddam Hussein's Iraq failed in its attempts, even after investing significant resources in this clandestine enrichment effort.

Production of crude nuclear explosive devices with HEU

It is considerably simpler to make a bomb using highly enriched uranium than to make one using plutonium, even though the critical mass is larger for HEU than for plutonium.[15] HEU allows for the use of the so-called "gun-type" nuclear weapon configuration, a reliable and fairly robust design that could be designed and built in a fairly crude manner.[16] A piece of HEU, preferably in metallic form, is propelled (using conventional high explosives or some other means) into another piece of HEU, creating a super-critical mass and thus a chain reaction. This simple design was first used in the weapon dropped on Hiroshima in 1945. The device was never tested before being used.

The South-African nuclear weapon programme demonstrated the convenience of manufacturing HEU explosive devices based on the gun-type configuration. South Africa indigenously produced nuclear devices based on the simple uranium gun-type weapon principle in spite of an international embargo. Relying solely on its own domestic resources, the apartheid regime produced six nuclear weapons. The weapons were later dismantled.

In contrast, any nuclear explosive device based on plutonium requires the use of an implosion configuration, where the fissile material is swiftly and simultaneously compressed into a super-critical mass. Construction of such implosion devices is

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[13] Morten Bremer Mærli, "Nuclear Terrorism: Threats, Challenges and Responses", Atlanterhavskomiteen, Security Policy Library, No. 8, http://www.atlanterhavskomiteen.no/publikasjoner/sp/2002/8.htm , September 2002.

[14] Former Senator Sam Nunn, quoted in Bunn, Matthew, Anthony Wier, and John P. Holdren. Controlling Nuclear Warheads and Materials: A Report Card and Action Plan. Washington, D.C.: Nuclear Threat Initiative and the Project on Managing the Atom, Harvard University, March 2003. http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp

[15] David Bodansky, Nuclear Energy: Principles, Practices and Prospects Woodbury, New York, 1996.

[16] A. Narath, "The Technical Opportunities for a Sub-national Group to Acquire Nuclear Weapons", in: Proceedings of the XIV Amaldi Conference on Problems of Global Security; Atti dei Convegni Lincei 190, Roma, Accademia Nazionale dei Lincei, 2003, p.19-32.

technically much more demanding than manufacturing the gun-type explosive devices.[17] The high spontaneous fission rate in plutonium requires a much more rapid assembling than a gun-type device can provide.[18]

HEU is defined as uranium containing more than 20% of the isotope U-235.[19] Any uranium with U-235 concentrations above approximately 20% could in principle be used in nuclear weapons. For all practical purposes, however, even higher enrichment levels are needed. For enrichment levels approaching the lower end of this boundary the critical mass becomes so large that both the handling of the material and the construction of any nuclear device becomes impractical. Sub-national groups or states with nuclear weapon ambitions would thus normally look for uranium with enrichment levels well above 20%, and preferably uranium enriched to 90% or more. Depending on the sophistication (design) of the device, a gun-type nuclear explosive device would require about 50 kilograms of HEU enriched to 90%. For a sophisticated implosion device less than 10 kilograms of HEU is probably needed.[20]

Terrorists do not have the same safety, security, and reliability requirements associated with their nuclear activities as states do.[21] Nor do terrorists have to rely on missiles to deliver their crude nuclear explosive devices. This could ease construction and delivery. The limited size and weight (down to some hundred kilograms) of a primitive device based on HEU would allow for transportation and detonation in a cargo container or an ordinary van.[22] Alternatively, the HEU-device could be assembled in a downtown garage or residency, and then set off by a timer, allowing perpetrators ample time to get away, if they are not suicidal. This approach would eliminate any difficulty of delivery and could facilitate the construction of the device.

Detection of the device or material during transportation is challenging, due to the low radiation levels associated with unirradiated uranium.[23] This would, moreover, allow terrorists to handle and carry on their person the HEU without significant health risks.[24] No advanced laboratory or shielding against the radiation is needed. The radiation hazards associated with plutonium are larger. Due to its high specific weight, 50 kilograms of HEU could fit inside half a dozen one-litre milk cartons.

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[17] Any nuclear explosive device based on plutonium requires to be set off fast by assembling a supercritical mass by implosion. This is a much more demanding task than what normally can be realised by a terrorist commando, requiring sophisticated conventional explosives and electronics. Fizzling plutonium weapons may, however, serve as radiological dispersal weapons.

[18] While HEU may be used in both implosion type and gun-type weapons, plutonium may only be used in implosion designs.

[19] The IAEA and others operate with a boundary of 20% U-235 for "highly enriched uranium".

[20] See e.g. Thomas B. Cochran and Christopher E. Paine, "The Amount of Plutonium and Highly-Enriched Uranium Needed for Pure Fission Nuclear Weapons", Nuclear Weapons Databook, Natural Resources Defense Council, 13 April, 1995, p. 9.

[21] For more on this point, see e.g. Morten Bremer Maerli, "Relearning the ABCs: Terrorists and "Weapons of Mass Destruction"", *Nonproliferation Review*, Summer 2000, http://www.cns.miis.edu/pubs/npr/vol07/72/72maerli.pdf

[22] The total length of such a device need not be more than 1 meter and its diameter about 25 centimetres. From Frank Barnaby, Crude Nuclear Weapons. Proliferation and the Terrorist Threat, IPPNW Global Health Watch, Report No. 1, 1996, p. 7.

[23] Gunnar Arbman and Anders Ringbom, "Is It Possible for Terrorists to Produce Highly Enriched Uranium? And Can It Be Traced and Detected in the Hands of Terrorists?", paper presented at Pugwash Workshop on Terrorism : Terrorism with WMD, Pugwash Meeting no. 276, Como, Italy, 26-28 September 2002

[24] Potential perpetrators must, however, take criticality risks into consideration. Heat emissions from uranium are likely to pose minor problems, and again, less of a problem than for plutonium handling.

Effects of crude nuclear explosive devices with HEU

A crude nuclear explosive device manufactured using HEU could yield an explosion effect equivalent to that of several hundreds to a few thousand tons of TNT. Any pre-detonation would cause the device to disintegrate prematurely with a lower yield.[25] Thus, while the exact yield would be unpredictable, it is almost certain that it would exceed the explosion size and impact of all previous terrorist attacks. It might, with a significant probability, be analogous to that of the Hiroshima bomb. A 13-kiloton explosive yield of TNT equivalent then resulted from the fissioning of 700 grams of HEU.[26]

Crude nuclear devices by terrorists are likely to be detonated on the ground (not in the air). The explosion would thus create a huge crater and the resulting dust and debris would be sucked up in air and into the characteristic mushroom cloud. Hence, while the effects of the shockwave may be less severe due to possible shielding (houses and building structures), the radioactive fallout and population doses are likely to be much more severe than for a nuclear atmospheric explosion. This will, moreover, complicate rescue efforts. Persons who survive the initial nuclear blast may face long-term suffering. A terrorist Hiroshima-yield explosion downtown in a large and densely populated city could thus result in hundred thousands of casualties and property damage that, to the extent they could be estimated, could amount to trillions of dollars.[27]

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[25] The supercritical state of the HEU must thus be maintained long enough for the neutron multiplication to proceed for a sufficiently large number of generations. A yield of 10 kilotons requires about 10^{24} neutron-induced fission events. This is equal to roughly 80 generations and could elapse within microseconds. From Albert Narath, "The Technical Opportunities for a Sub-National Group to Acquire Nuclear Weapons", XIV Amaldi Conference on Global Security", April 27, 2002.

[26] The energy yield due to complete fissioning of one kilogram of HEU is equivalent to that of approximately 17 kilotons of chemical explosives. The Hiroshima bomb contained some 65 kilograms of uranium enriched to 84%. The fission efficiency of the device was thus approximately 1%. Terrorists, however, would probably consider a conversion of even less than 1% quite acceptable. For more on this, see e.g. Albert Narath, "The Technical Opportunities for a Sub-National Group to Acquire Nuclear Weapons", XIV Amaldi Conference on Global Security", April 27, 2002 .

[27] A nuclear terrorist explosion stemming from a crude nuclear explosive device is not directly comparable to the Hiroshima-blast. Firstly, the uranium bomb dropped on Hiroshima was exploded above ground. Secondly, the housing in the city was highly combustible, thirdly, surroundings and possible shielding may influence the bomb yield. In Hiroshima, almost everything up to about one mile (1.6 kilometres) from below the point where the bomb exploded (ground zero) was destroyed. Two-thirds of the city's structure was ruined or severely damaged by the atomic bomb. Flash ignition of dry, combustible material was observed as far as approx. 6400 feet (approx. 2000 meters) from ground zero. Fires sprang up simultaneously all over the wide flat central area of the city, resulting in an immense firestorm. This firestorm burned out almost everything in a roughly circular area of 4.4 square miles (approx. 11 square kilometers) around the point directly under the explosion. Of the total Hiroshima population of 255,000 people, early - but contested for being too conservative - U.S. estimates suggest 66,000 immediate dead and 69,000 injured. See the Official U.S. Report on the Atomic Bomb's Effects in Hiroshima and Nagasaki: The Manhattan Engineer District, "The Atomic Bombings of Hiroshima and Nagasaki", June 29, 1946. The report is made available at The Avalon Project at Yale Law School, http://www.yale.edu/lawweb/avalon/abomb/mpmenu.htm . Other estimates indicate higher numbers.

The HEU stocks

HEU is used in nuclear weapons, for naval nuclear propulsion and in research reactors (see chapter 5). At least 1,750 tons of HEU have been produced since the dawn of the atomic era, most of this by the United States and Russia. These two countries, in their capacity as nuclear weapon states, are exempted from IAEA safeguards.[28].

Moreover, fissile material also exists in civilian facilities around the world. According to IAEA estimates, a total of more than 1,300 kilograms of highly enriched uranium exists in research reactors in 27 countries, sometimes in quantities large enough to make a bomb.[29] This material is safeguarded, but experience has shown that some of it is vulnerable to theft.[30]

Satisfactory nuclear materials accountancy is a prerequisite for controlling nuclear materials. Today, more information about military nuclear stocks is available than only a few years ago. But still – with some noteworthy exceptions – no official figures exist on the military inventories of HEU in the nuclear-weapon states. Inventories of all nuclear materials on hand have not been declared by any nuclear weapon state, except the United Kingdom. Hence, estimates still carry with them large uncertainties – in the case of Russia, in the range of several hundred tonnes (see table 1).[31]

Non-weapon nuclear material is scattered throughout Russia at more than 53 sites[32] and in more than 300 buildings. Most of them have 1000 kilograms or more of HEU stored or in use, while a few facilities are listed as having smaller quantities of tens or hundreds of kilograms. [33] Smaller amounts, ranging between grams and a few kilograms of HEU exist at several other research institutions in Russia.[34] At the upper limit of these estimates (see table 1), a possible 1.500 tons of Russian HEU may represent the equivalent of some 60.000 to 80.000 warheads.[35] By comparison, the United States' total production of highly enriched uranium from 1945 to 1992 was

[28] Albright, D. W. Walker and F. Berkhout, 1997. *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities, and Policies*. New York: Oxford University Press.

[29] IAEA, "Nuclear Research Reactors in the World," IAEA-RDS-3, September 2000, quoted in George Bunn and Fritz Steinhausler, Guarding Nuclear Reactors and Material From Terrorists and Thieves, Arms Control Today, October 2001, http://www.armscontrol.org/act/2001_10/bunnoct01.asp#notes

[30] Matthew Bunn and George Bunn, "Reducing the Threat of Nuclear Theft and Sabotage", paper delivered at and IAEA Symposium on nuclear terrorism, 30 October 2001, http://www.iaea.org/worldatom/Press/Focus/Nuclear_Terrorism/bunn02.pdf

[31] Part of the discrepancy can be explained due to different HEU-enrichment levels of the material used in the comparisons and the fact that some of the figures may not distinguish between the quantities in Russia and those present in the former Soviet Union.

[32] Joseph Cirincone, John Wolfstahl and Miriam Rajkumar, Deadly Arsenals.Tracking Weapons of Mass Destruction. Carnegie Endowment for International Peace, p. 116.

[33] John Wolfsthal, Cristina-Astrid Chuen, and Emily Ewell Daughtry (eds.) Nuclear Status Report 2002, pp. 75-175.

[34] The number of facilities where HEU is located will be much larger if the many locations for strategic and tactical weapons are included.

[35] This is a very rough estimate. The number depends on the kind of nuclear weapons in question. If one, for instance, assume that an HEU implosion device requires 10 kg, which is a very conservative estimate – the equivalent is 150 000 warheads. On the other hand, thermonuclear weapons may have 30-40 kg HEU or so in their secondaries, giving an equivalent of some 40.000 warheads. As mentioned above, some 50 kg HEU suffice for a crude nuclear explosive device, giving an equivalent of some 30.000 such devices.

approximately 1000 metric tons.[36] It remains unclear how much of this material has been consumed in nuclear tests or reactors.[37]

Source	**Quantity of HEU outside weapons**	**Total quantities of HEU, including in weapons**
Mikhailov (1993) [38]		1250 tons
Albright, D. Walker, W. and Berkhout, F. (1997)[39]	825 tons	1050 ± 300 tons
Bunn, M. & Holdren, J (1997)[40]	825 tons	
Bukharin, O (1998)[41]		1300 tons
DOE (1998)[42]	600 tons	
Albright, D. and O'Neil K. (1999)[43]		1050 tons
CSIS Task Force (2000)[44]		1050 tons
CEIP (2002)[45]		Up to 1500 tons

Table 1. Estimated quantities of highly enriched uranium in Russia according to different sources.[46]

The United States and Russia have now declared 174 tons and 500 tons, respectively, of HEU in excess to their national security needs. These quantities will be down-blended for use as commercial reactor fuel and some of it will be disposed of.[47] The ongoing HEU-deal (see Chapter 4) between the United States and the Russian Federation is covering the 500 tons of HEU currently declared as excess by

[36] U.S. Department of Energy, "Declassification of the United States Total Production of Highly Enriched Uranium", DoE Facts, Office of the Press Secretary, Washington, DC 20585. http://www.osti.gov/html/osti/opennet/document/press/pc13.html

[37] The average enrichment of the U.S. material is significantly less than the Russian, making the stockpile disparity even greater than the numbers indicate.

[38] David Albright, Frans Berkhout, William Walker, Plutonium and Highly Enriched Uranium 1996. World Inventories, Capabilities and Policies, SIPRI, Oxford University Press, 1997, p. 94.

[39] See pages 399-400 and 414. Based on 10.000 operational warheads. HEU figures given in weapon-grade equivalents

[40] Assuming a stockpile of 10.000 warheads.

[41] Bukharin, Oleg. "Analysis of the Size and Quality of Uranium Inventories in Russia". Science and Global Security, Vol. 6, 1998, p.70.

[42] MPC&A Program Strategic Plan, Office of Arms Control and Nonproliferation, U.S. Department of Energy, January 2, 1998.

[43] HEU figure given in weapon-grade equivalents.

[44] The Center for Strategic and International Studies. Managing the Global Nuclear Materials Threat. Policy Recommendations. Washington D.C.

[45] Joseph Cirincone, John Wolfstahl and Miriam Rajkumar, Deadly Arsenals.Tracking Weapons of Mass Destruction. Carnegie Endowment for International Peace, p. 115.

[46] Based on Morten Bremer Maerli "Managing Excess Material In Russia", in Andreas Wenger and Joachim Krause, eds., Nuclear Weapons and International Security in the 21st Century, Studies in Contemporary History and Security Studies, Center for Security Studies and Conflict Research, Swiss Federal Institute of Technology, Bern et al. loc.: Peter Lang, 2001. http://www.fsk.ethz.ch/documents/Studies/volume_8/content.htm

[47] Rose Gottemoeller, "Beyond Arms Control: How to Deal with Nuclear Weapons", Policy Brief, No. 23, Carnegie Endowment for International Peace, February 2003, http://www.ceip.org/files/pdf/Policybrief23.pdf. Material slated for disposition is scrap metal, not usable for reactor purposes.

Russia. These declarations of excess must be characterized as limited, compared with the total HEU stocks. No further declarations of excess HEU stocks are currently envisioned by either side. However, it should be observed that the initial Russian excess declaration of 500 tons happened only after the US offered economic incentives.

Past HEU diversion

In February 2002, representatives of the U.S. intelligence community stated to the U.S. Congress that "weapons-grade and weapons-usable nuclear materials have been stolen from some Russian institutes".[48] The law enforcement representatives acknowledged that undetected smuggling has occurred, although they were unable to know the extent or magnitude of such incidents.[49]

According to the IAEA, 20 cases involving plutonium and uranium have occurred over the last decade, many of which originated from the former Soviet Union. The vast majority of incidents confirmed by states involve plutonium or highly enriched uranium in far too limited quantities to produce a nuclear explosive device. However, accumulation by receivers cannot be excluded and some of the confiscations may be test samples for larger quantities available.[50]

A close call apparently took place in December 1998. The Russian Federal Security Services intercepted an attempt to divert 18.5 kg of "radioactive materials that might have been used in the production of nuclear weapons".[51] Russian officials, stating that the perpetrators "could have done serious damage to the Russian state", later confirmed this attempt, and made it the first confirmed case that apparently involved a conspiracy to steal enough materials for a bomb in a single act. The material involved was fresh HEU.[52]

While the number of confirmed seizures remains low (some five to six cases annually involving plutonium or HEU), the mere fact that there exists a viable black-

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[48] National Intelligence Council, Annual Report to Congress on the Safety and Security of Russian Nuclear Facilities and Military Forces, February 2002, p. 2., quoted in Tom Z. Collina and Jon B. Wolfsthal, **"**Nuclear Terrorism and Warhead Control in Russia", Arms Control Today, April 2002, http://www.armscontrol.org/act/2002_04/colwolfapril02.asp

[49] For an anecdotal overview of fissile material thefts from nuclear facilities, see appendix 1 in Bunn, Matthew, Anthony Wier, and John P. Holdren. Controlling Nuclear Warheads and Materials: A Report Card and Action Plan. Washington, D.C.: Nuclear Threat Initiative and the Project on Managing the Atom, Harvard University, March 2003. http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp

[50] In a recent article it was reported that IAEA inspectors had found traces of highly enriched uranium that presumably originated from Russia and with much likelyhood from a nuclear submarine. It was pointed out in the article that there could be an Iranian strategy behind this to illigally import HEU or spent HEU of a certain available kind and then accumulate the materials. One by one these smuggled amounts would maybe not be discovered but altogether they could amount to significant amounts in Iran and a possible Iranian nuclear weapons programme, Craig Smith, "Alarm Raised Over Quality Of Uranium Found in Iran", New York Times, 11 March 2004.

[51] Scott Parrish and Tamara Robinson, Efforts to Strengthen the Export Controls and Combat Illicit Trafficking and Brain Drain, Nonproliferation Review, Spring, 2000 and Matthew Bunn, The Next Wave: Urgently Needed Steps to Control Warheads and Fissile Materials. Carnegie Endowment for International Peace, 2000.

[52] Bunn, Matthew, Anthony Wier, and John P. Holdren. Controlling Nuclear Warheads and Materials: A Report Card and Action Plan. Washington, D.C.: Nuclear Threat Initiative and the Project on Managing the Atom, Harvard University, March 2003. http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp

market for fissionable material is worrisome. Law enforcement authorities only detect failed smuggling attempts. More sophisticated smugglers and new smuggling routes, cannot be excluded e.g. through the southern border of Russia. Scholars maintain that the current illicit trafficking picture is "just the tip of the iceberg".[53]
Specialists from the Russian law enforcement authorities have identified poor physical protection as the primary cause of nuclear thefts, along with the acute shortage of funds allocated for nuclear material protection, control and accounting (MPC&A).[54] Today, less than 40 % of the storage sites for nuclear materials in Russia have received security improvements through U.S. assistance.[55] Moreover, the practices for the establishment of physical protection upgrades focus on the immediate storages and sectors where the materials are. On the other hand, the general security measures such as access control systems for personnel and vehicles to the facility and the perimeter defence is given low priority. This means that in many cases there is not a layered defence with increasing screening closer to the HEU storage.[56] So far, most progress has been made at facilities outside the Russian nuclear weapon production complex. Some estimates indicate that if security control is not enhanced, Russia's nuclear material will not be "completely secure until 2029".[57]
Past deficient accounting practices make inventory control challenging, and the insider threat remains. For instance, according to the August 2000 report by the Russian nuclear regulatory agency, Gosatomnazdor, a Russian resident of Elektrostal (the fuel-fabrication facilities) near Moscow was detained in an attempt to try to sell 3.7 kilograms of HEU enriched to 21%.[58]

Stealing HEU could be particularly easy when it is stored in the oxide form, in which case its physical state as a powder makes it less susceptible to precise accounting. For use in nuclear explosive devices, the oxide should then *ideally* be converted to uranium metal. Conversion of the HEU is a fairly simple task.

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[53] BBC, "Fears over missing nuclear material", March 7, 2002, http://news.bbc.co.uk/1/hi/world/americas/1859560.stm

[54] V.A. Orlov, Exports Control and Nuclear Smuggling in Russia", in G.K. Bertsch and W.C. Potter, (eds.) Dangerous Weapons, Desperate States, New York: Routledge, 1999.

[55] United States General Accounting Office, "Weapons of Mass Destruction. Additional Russian Cooperation Needed to Facilitate U.S. Efforts to Improve Security at Russian Sites", Report to the Ranking Minority Member Subcommittee on Financial Management, the Budget, and International Security, Committee on Governmental Affairs, U.S. Senate, 2003. The facilities that have not been upgraded are weapons facilities with very large stocks. The problem has been disagreements over the level of U.S. access to these sensitive facilities to verify that the assistance provided is being used as intended.

[56] In essence, this means that it is possible to come close to the material and that it is possible for intruders to identify the core security provisions of the facility.

[57] Sen. Dick Lugar at the Nuclear Threat Initiative Conference: "Reducing the Threats from Weapons of Mass Destruction and Building a Global Coalition Against Catastrophic Terrorism", Moscow, May 27, 2002.

[58] Incident quoted in William C. Potter and Elena Sokova, "Illicit Trafficking in the NIS: What's New? What's True?", Nonproliferation Review, Summer 2002, p. 116.

Chapter 4: On-going and proposed HEU elimination work

U.S. and Russia have initiated HEU elimination activities through both official and unofficial channels. The most prominent effort is of an official character called the HEU-deal. The deal was launched in 1993, and recently followed up with related state-to-state initiatives. The Nuclear Threat Initiative (NTI) and the Federation of American Scientists (FAS) have respectively initiated their own "track two" effort and research.

The HEU-deal

In February 1993, the Agreement was signed between the Government of the United States and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted from Nuclear Weapons. Under the agreement, which is commonly referred to as the "HEU-deal",[59] the U.S. will purchase low enriched uranium derived from 500 metric tons of HEU from dismantled Russian weapons.

The HEU-deal may constitute the single most important non-proliferation measure introduced bilaterally, covering a significant part of Russia's weapon stockpile of HEU. For the first time, the HEU-deal allowed for the conversion of weapons-grade nuclear material from dismantled warheads to commercial reactor fuel for electricity generation. After a slow start and organisational difficulties, implementation of the agreement is accelerating and new transparency measures have been installed.[60]

As of late November 2003, the deal had resulted in the down-blending of 193 metric tons of Russian HEU.[61] The weapons-grade material – the equivalent of more than 7,700 eliminated nuclear warheads – has been converted into some 5,700 metric tons of LEU power plant fuel. The deal – which just passed its 10th anniversary – was initially planned for an overall period of 20 years. Technical improvements are under investigation to complete the down-blending of the remaining 313 tons significantly quicker.

The HEU-deal is implemented in Russia by the government-run Techsnabexport (Tenex) and in the United States by the privately owned USEC Inc. The agreement has been hampered with financial problems. Ending years of negotiation, the United States and Russia approved in June 2002 a new contract, under which USEC will pay Tenex a market price for the down-blended uranium.[62] Under the previous contract, Tenex received a fixed price that was well below the

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[59] Another appropriate and widely-used name of the agreement is the "Megatons to Megawatts-deal".
[60] Peter Scoblic, "United States, Russia Approve New 'HEU Deal' Contract", *Arms Control Today*, July/August 2002, http://www.armscontrol.org/act/2002_07-08/heujul_aug02.asp
[61] http://www.usec.com/v2001_02/HTML/Megatons_status.asp
[62] The actual amount paid will be an average of international market prices over the past three years minus a discount, allowing USEC to make a profit when it resells the material to U.S. and foreign power companies. According to a senior administration official, Russia will earn less revenue than it did under the previous contract, at least in the short-term. From J.Peter Scoblic, "United States, Russia Approve New 'HEU Deal' Contract", *Arms Control Today*, July/August 2002, http://www.armscontrol.org/act/2002_07-08/heujul_aug02.asp

market value for enriched uranium. But in the late 1990s, the market price dropped sharply, reducing USEC's profit margins.

In 1999, USEC opened negotiations on a new contract with Tenex that would account for market fluctuations. The terms of the new pricing contract went into effect on January 1, 2003, and remain valid through the completion of the HEU-deal in 2013. According to Alexander Rumyantsev, the Russian Minister of Atomic Energy, Russia expects an estimated additional 5.5 to 6 billion US dollar from the completion of the HEU-deal.[63]

Spin-offs from the HEU-deal

In their May 2002 Summit in Moscow, Presidents Bush and Putin agreed to establish a Joint Expert Group to work out proposals on near- and long-term bilateral and multilateral means to reduce inventories of HEU and plutonium. According to the group's proposal, further reductions in Russia's stocks would be made by US purchases for a strategic uranium reserve consisting of down-blended material from Russian sources.[64] In September 2002, the expert group presented their proposals identifying several areas where joint co-operation could lead to additional reduction of Russian HEU. These include:[65]

1. Creation of a reserve in the United States from Russian HEU down-blended into LEU and increase in the rate and quantity of HEU converted to LEU under the Nuclear Material Consolidation and Conversion Project;
2. Use of LEU down-blended from Russian HEU to fuel reactors in Russia;
3. Use of Russian HEU to fuel selected United States research reactors, until cores are converted to LEU, and
4. Parallel, work on accelerated development of LEU fuel for both Soviet-designed and United States-designed research reactors.

The work of the Joint Expert Group is in its initial phase. Its real impact on Russian HEU stockpile reductions remains to be seen.[66]

HEU elimination work by the Nuclear Threat Initiative (NTI)

As a "track two" approach, the NTI - a Washington-based NGO led by former senator Sam Nunn - initiated close co-operation with Minatom on additional and accelerated HEU elimination. In October 2002, a Memorandum of Understanding was signed by the NTI and the International Relation Department of Minatom. According to the NTI, the non-committing character of this co-operation could make it easier for Russia to join than what might have been the case with US government sponsored projects.

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[63] Based on a meeting with Minister Rumyantsev on 21 February 2003 in Moscow.
[64] Oleg Bukharin, "More transparency needed", the Bulletin of the Atomic Scientists, March/April 2003.
[65] Joint Statement Secretary Abraham and Minister Rumyantsev, September 16, 2002, http://www.ne.doe.gov/home/09-16-02.html
[66] So far, most progress has been on the use of Russian HEU to fuel reactors in Western reactors.

The co-operation will explore options for accelerated HEU elimination using Russian facilities that are currently outside the scope of the existing HEU-deal. A technical study carried out by Russian experts and sub-contractors has been launched. The goal is to present preliminary results by the summer of 2004. Due to the sensitivity of the issues, any information or results from the study can, however, only be released to third parties after a joint understanding and acceptance by both sides.

Down-blending of the uranium to 4%, 12% and 19% are all options likely to be investigated under the project. No specific recommendations on how to proceed will be produced. Rather, a comprehensive set of different options for action will be presented for further consideration.

Report by the Federation of American Scientists: Closing the Gaps

Robert L. Civiak published the report "Closing the Gaps. Securing High Enriched Uranium in the Former Soviet Union" in May 2002 under the auspices of the Federation of the American Scientists (FAS). The report presents three proposals to expanding existing programs for reducing foreign stockpiles of HEU.[67]

In the first proposal, the United States government would expand the current HEU-deal and pay Russia to double the current down-blending rate. The additional LEU produced would then be stored in Russia and eventually sold for use as nuclear power plant fuel under the existing agreement. In the second proposal, the United States would expand its efforts and incentives for nuclear institutes in Russia to reduce - or preferably eliminate - their use and stocks of HEU. The HEU would be consolidated with larger stockpiles at other facilities and possibly be blended to LEU. In the third proposal, the United States would provide more help to institutions in Russia and elsewhere that depend upon research reactors for their work to replace their HEU fuel with high-density LEU fuel.

The implementation of these three proposals would significantly reduce the risk of HEU being diverted. So far, however, none of these proposals have resulted in any practical project implementation – or any additional HEU elimination.

[67] The report can be down-loaded at http://www.fas.org/ssp/docs/020500-heu/

Chapter 5: Technical aspects of HEU elimination

The inherent proliferation risks of unirradiated HEU can be reduced in a number of ways. One approach could simply be to establish centralised and highly protected storage facilities for all the materials. This option, however, will be costly and only be effective for short-term or immediate purposes. It does not reduce the stocks, and therefore the long-term threats associated with HEU.

All facilities containing HEU continuously need upgrades, overhauls and well-trained guards. With the rapid societal transformations, there is no guarantee that it will be easy or even possible to maintain the needed security effectiveness of the nuclear weapons-usable materials.[68] While adequate physical protection systems are a minimum requirement for avoiding HEU falling into the hands of unauthorized users, physical protection as such is not a viable and final solution to the proliferation risks.

A second potential approach could be to grind and dissolve HEU in the oceans and thus ”give the materials back to nature”. Though HEU dumping would represent minuscule releases of radioactivity and no harm to health and environment, such efforts would clearly represent an up-hill political battle. Most likely, it would be very hard to convince the public opinion that any released amount would be minuscule compared to the existing 3 billion metric tons of uranium-235 in the oceans. Moreover, new security risks may emerge. The transportation logistics of land and sea transports could create situations where the HEU is vulnerable and prone to theft, sabotage and accidents. Proper accountability in conjunction with the discharges may also be a challenge.

A third approach is defined (and described in chapter 4) by the ongoing US-Russian HEU deal whereby the military HEU is down-blended, commercialised, and burned in civilian nuclear power reactors. This solution has merits, as the electricity (and thus the financial) potential of the HEU is utilized. However, given the diverging political views on nuclear power within Europe, a full-fledged commercialisation of the issue may be neither feasible nor desirable.[69] Strong commercial considerations may thus impede a swift and focused elimination process.

[68] In a recent study about the establishment of physical protection in the NIS, it was concluded that many of the best-trained and most efficient persons are not interested in working to secure nuclear power plants etc. It is much more attractive to work for ”tangible companies” that pay good salaries like banks etc. (see George Bunn, Fritz Steinhäusler, Lyudmila Zaitseva, ”Strengthening Nuclear Security Against Terrorists and Thieves Through Better Training”, The Nonproliferation Review, Fall-Winter, 2001) In this context, the nuclear sector can stand out as archaic and less interesting as a work place in a post-deterrence era. This development may become stronger in the coming decades.

[69] In Europe, attitudes regarding the present and future role of civilian nuclear power are diverse. Some states, e.g. France, the UK, Belgium, and Finland rely heavily on nuclear power, and intend to do so for the foreseeable future. Others, like Sweden and Germany, have put forward long-term policy options by which national nuclear energy sectors may be abolished. Under these circumstances, a common EU position towards uranium fuel originating from Russian HEU stocks may be hard to conceive – particularly if it is seen as an expansion of civilian nuclear energy in Europe. Euratom also limits in a certain way Russian quota on selling HEU reprocessed into LEU. Regulations of Euratom require as a a diversification of sources of supply: Every user (nuclear power plant) must have not less than four alternative sources of fuel supply.

Preferred HEU elimination approach

For the European actors, the ideal option is to put itself outside the shortcomings of political and commercial constraints of the three potential options mentioned above. A European approach for the elimination of unirradiated HEU should:

- Consider security – not economy – as the first objective for HEU elimination.
- Be permanent and irreversible in the sense that it converts HEU into a form where it can never again be used for nuclear weapons purposes.
- Make sure it is environmentally sensitive by accommodating sound environmental standards and practices.
- Limit unnecessary risks relating to HEU transport, handling, and management.
- Allow strict (Russian) ownership and custody of the HEU and the down-blended HEU at all times.
- Not to rule out any future (Russian) commercial exploitation of the down-blended HEU, for instance as a source of revenue by using LEU as a commercial and civilian fuel.

This means that Europeans could suggest a scheme for HEU elimination to appropriate Russian counterparts with a view of transforming HEU into LEU through rapid down-blending in Russia. Instead of establishing a commercial structure of Russian and European companies that market these products, the down-blended LEU should remain in the ownership of the Russian Federation. Ideally, the funds obtained by Russia in this manner should be used for securing remaining fissile material and restructuring of the Russian nuclear weapons complex for peaceful purposes. Clauses reflecting this may be contemplated by European parties.

In other words, European parties should make available adequate financial incentives to motivate Russia to eliminate HEU by down-blending it at Russian facilities.

The highly enriched uranium should be down-blended to a level where it is ”proliferation safe”; e.g. at least below 20% enrichment in uranium 235, outside any marke considerations.

Russia should retain the right to decide if, when, and to whom to sell the residual down-blended materials for possible future commercial purposes. Here, it has to be ascertained, however, that the LEU cannot be re-enriched to any plus 20% level. This could be ensured through international (possibly IAEA) verification and monitoring. In addition, it has to be inscribed as a precondition for any deal on additional HEU elimination that no new HEU is produced in Russia. To ensure this, the implementation of a comprehensive non-production transparency regime is desirable.[70]

The proposed approach will be a great achievement for security and non-proliferation, while also accomodating the nuclear energy opposition in some European states. Moreover, it will, supplement and not substitute ongoing US-Russian

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[70] Oleg Bukharin, “More transparency needed”, the Bulletin of the Atomic Scientists, March/April 2003.

HEU elimination practices. As such, it should neither interfere with this cooperation, or directly influence HEU markets or market prices.

The proposed scheme demands further in-depth consideration of several aspects including: (a) Technical issues concerning the HEU elimination, including transparency and verification requirements, down-blending capacities, and HEU logistics, as well as (b) various political, financial and legal requirements that will have to be taken into account in the process. These issues will be briefly considered below – after a presentation of the Russian nuclear (HEU) infrastructure.

Russian HEU infrastructure

All Russian facilities that produced HEU for nuclear weapons are located in Russia's closed nuclear cities. For an overview of HEU operations outside nuclear weapons production see table 2.

Facility:	*Activity:*
1: Plant Electrokhimpribor (Sverdlovsk-45)	HEU extraction from weapons, storage of weapons components
2: Electromechanical Plant “Avangard” (Arzamas-16)	HEU extraction from weapons, storage of weapons components
3: Institute of Techical Physics (Chelyabinsk-70)	nuclear weapons R&D, HEU research reactors
4: Industrial Association “Mayak” (Chelyabinsk-65)	storage of HEU components, metal-to-oxide conversion, reprocessing of HEU fuel, operation of tritium reactors, storage and use of HEU fuel
5: Siberian Chemical Combine (Tomsk-7)	storage of HEU components, metal-to-oxide conversion, HEU down-blending, operation of plutonium reactors, storage and use of HEU fuel,
6: Mining and Chemical Combine (Krasnoyarsk-26)	operation of plutonium reactors, HEU storage
7: Ural Electrochemistry Combine (Sverdlovsk-44)	HEU storage
8: Electrochemistry Plant (Krasnoyarsk-45)	HEU down-blending
9: Machine-Building Plant (Electrostal)	naval fuel fabrication

10: Chemical Concentrates (Novosibirsk)	fabrication of research reactor fuel
11: Inorganic Materials Institute (VNIINM Moscow)	HEU materials and fuel cycle research
12: Nuclear reactors Institute NIAR (Dmitrovgrad)	fuel cycle technologies, HEU research reactors
13: Physics and Power Institute (Obninsk)	fuel cycle technologies, HEU research reactors
14: NPO Khlopkin Radium (St. Petersburg)	fuel cycle research
15: Kurchatov Institute (Moscow)	nuclear technologies, HEU research reactors
16: Production Association "Luch" (Podolsk)	reactor fuel fabrication, HEU research reactor
17: Tomsk Polytechnical Institute (Tomsk)	HEU research reactor
18: Institute of Energy Technologies (Zarechny)	HEU research reactor
19: Karpov Institute of Physical Chemistry (Obninsk)	HEU research reactor
20: Institute of Device-Building (Lytkarino)	HEU research reactor
21: Moscow Institute of Physics and Engineering	HEU research reactor
22: Moscow Institute of Theoretical and Experimental Physics	HEU research reactor
23: Institute of Energy Technologies (Moscow)	HEU research reactor
24: Institute of Nuclear Physics (St. Petersburg)	HEU research reactor
25: Krylov Research Institute (St. Petersburg)	HEU research reactor
26: Naval facilities	Storage and use of HEU fuel

27: Atomflot icebreaker base (Murmansk)	Storage and use of HEU fuel

Table 2. HEU operations outside nuclear weapons production facilities[71]

Russian uranium is enriched to low levels at the Angarsk Electrochemical Combine in Irkutsk, at the Electrochemical Plant in Zelenogorsk (formerly Krasnoyarsk-45), the Ural Electrochemical Combine in Novouralsk (formerly Sverdlosk-44) and the Siberian Chemical Combine.[72] Historically, all of these with the exception of Angarsk produced HEU for weapons. Currently, the main product of all four uranium enrichment facilities is low-enriched uranium for nuclear fuel. In addition to enrichment activities, all but the Angarsk facility are engaged in down-blending of the HEU into LEU under the US-Russian HEU Agreement. In 1989, the Soviet government announced the cessation of production of HEU for nuclear weapons.

Russian HEU potentially available for elimination

Russian HEU can be categorised in accordance with its uses:[73]

1. Military material in operational nuclear weapons and their logistics pipeline.
2. Military material held in reserve for military purposes, in assembled weapons and in other forms.
3. Military material in weapons slated for dismantlement.
4. Military material recovered from dismantled weapons.
5. Military material declared for transfer to the civilian sector.
6. Material currently in reactors (including naval and research reactors, and power reactors) and their logistics pipelines and storages
7. Irradiated HEU in spent fuel from reactors, or in vitrified form for final disposal.

HEU belonging to the first two categories is by definition not available for the purpose of elimination of HEU, until it has been transferred to other categories 3, 4, or 5. To be sure, quantities of HEU belonging to category 1 or 2 are most likely better guarded than HEU of any other category, since they are subject to the same safety and security procedures as the nuclear warheads themselves. This leaves us with the HEU defined by categories 3 to 5 for the purposes of Russian HEU elimination.

[71] According to Oleg Bucharin, "Securing Russia's HEU Stocks", Science and Global Security, vol. 7, 1998, pp. 313-315.
[72] According to the database of the Center for Nonproliferation Studies, http://www.nti.org/db/nisprofs/russia/fissmat/enrichme/overview.htm
[73] Annette Schaper, "Proceedings from the Fissile Material Cut-off Seminar in Stockholm", June 1992, National Defence Research Establishment, 901 82, UMEÅ, Sweden, p. 83-84.

Russian de-enrichment capacities

Current HEU down-blending under the US-Russian co-operative deal takes place at the rate of approximately 30 tons per year. The remaining quantities covered by the HEU-deal could thus be down-blended within 10-11 years. With the existing technology and installations the blending down of HEU to a type of LEU which is no longer suitable for the manufacturing of nuclear explosive devices the elimination could be speeded up. An additional amount for down-blending equal to that encompassed by the present Russian-US HEU deal that currently proceeds at the rate of 30 tons pr year seems feasible. Hence, the Russian HEU elimination capacity could be doubled.

An increase by a factor of two might be achieved with minimal changes of existing installations and procedures and more substantial acceleration – possibly by a factor of five – could be achieved by marginal changes requiring small investments.[74] Estimates by the Russian Ministry of Atomic Energy confirm that from a technical point of view it is possible to expedite de-enriching. However, expedition of the HEU elimination is clearly an economic and a political issue for the Russians as well. As former Minister of Atomic Energy Mikhailov maintains, the process of completion of the current HEU deal may be compressed even into five years, but that contradicts Minatom's employment and development strategy.[75] The Ministry considers it inappropriate to create more advanced facilities and employ more people for a relatively short period, with a perspective to close facilities and lay off employees afterwards.

HEU elimination costs

The financial arrangements in conjunction with European funded HEU elimination in Russia, need to be negotiated thoroughly by the parties involved. But it is useful to specify what the terms of such an agreement could be. Overall costs relate to down-blending services, transportation, storage, verification, and administrative expenses.

A European-Russian agreement may encompass direct payments to Russia for every quantity of HEU that is de-enriched to 20%, or slightly below 20% (where any possibility of explosive uses can be excluded).[76] At a price of perhaps US $10 for each gram of high-grade HEU that is eliminated, $10 billion would be needed for the elimination of the approximately 1,000 tons of HEU remaining in Russia. For national security reasons, Russia would retain some HEU in its down-sized nuclear arsenal.

Only de-enrichment down to approximately 20% should be paid by donors. Payments to Minatom could be considered interest-free loans, to be repaid by Russia *if* (or when) the material gets further de-enriched and treated to qualify as marketable LEU for sale to facilities worldwide for the production of electricity.[77]

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[74] Personal communication with Richard Garwin and Matthew Bunn, Spring 2003.

[75] Asserted during a meeting 21 February 2002 with former Minister Viktor Mikhailov.

[76] Jeffrey Boutwell, Francesco Calogero, Jack Harris, "Nuclear Terrorism: The Danger of Highly Enriched Uranium (HEU) - Pugwash Issue Briefs Volume 2, Number 1, September 2002 http://www.pugwash.org/publication/pb/sept2002.pdf

[77] At current market prices, it is conceivable that Russia might earn twice as much money from the sale of LEU as it would have to repay for the interest-free loans obtained for the immediate de-enriching of HEU to below 20%, though such estimates must remain tentative given the uncertainty about future market prices for LEU.

Further de-enrichments to make commercial fuel out of the LEU will have to be paid for by Minatom. This would have the advantage of creating tight borders between what the donors and Russia do for security reasons and what Russia does for commercial reasons at a later stage. Furthermore, with this scheme it might be possible to reduce the costs for the Russian down-blending services.

Another flexibility could be added by negotiating paying for Russian HEU-originated fuel not by financial transfers from donor states, but by deducting existing Russian state debt to would-be donors**.** Possible "Debt for Nonproliferation Swaps" have been proposed at past G-8 Meetings. To Russian actors, such proposals may be attractive, but still have to be for further review.

For the scheme to work, enough transparency should be provided by Russia to enable the outside world to verify that the production of new HEU has definitely stopped, and secondly, that the de-enriched HEU is properly measured, accounted for and safeguarded (possibly by the International Atomic Energy Agency).

HEU elimination verification and transparency

To build trust and avoid cheating and diversion of the HEU slated for elimination under an extended HEU deal, verification and transparency measures are essential. However, HEU verification is generally quite challenging, partly due to the physical properties of highly enriched uranium, and partly because of the sensitivity issues involved. Nevertheless, transparency and verification measures have been successfully implemented under the ongoing HEU-deal (see chapter 4). Important lessons could be drawn from this and other bilateral co-operation.

Nuclear weapons components, shape, isotopic composition, and geometry is classified and/or sensitive information. This complicates measurements on HEU from nuclear weapons. Before any measurement technique can be accepted for use in an arms control agreement, all parties must agree upon its use. Experience has shown that the likelihood that an arms control technology will be accepted increases if the following is considered:[78]

- Measurements cannot reveal classified information
- Simple technology is preferable to complex technology
- Familiar technology is preferable to complex technology
- Passive measurements are generally preferable to active interrogation measurements.

All measures put in place should be as transparent as possible, thus the call for simplicity and familiarity. In the simplest cases, radiation emitted from the object of interest can be measured directly, through passive measures. Active measurements collect and analyse the resulting radiation after neutron-bombardment for example. However, such measures may be too intrusive, thus violating the number-one principle of arms-control verification, i.e. not to reveal any classified information.

[78] Gosnell, T. B. 2000. Uranium Measurements and Attributes. The 41st Annual Meeting of the Institute for Nuclear Material Management, and Preprint UCRL-JC-1394450, Lawrence Livermore National Laboratory, July 2000.

Technical communities are now examining a variety of non-intrusive measurements on items with sensitive or classified properties.[79] The underlying physics is well understood, but the need to protect and limit the data output while providing enough information to ensure sufficient confidence in the results of the measurements raises technical challenges. Current efforts to protect classified information include making radiation measurements behind information barriers.[80]

HEU measurements in practice

The experiences from ongoing transparency measurements under the existing U.S.-Russian HEU-agreement are of course of extreme interest to an expanded HEU elimination verification scheme.[81] Under this agreement there are three transparency objectives for the U.S. Department of Energy (DOE). Firstly, that the HEU is extracted from nuclear weapons. Secondly, that the same HEU is oxidised. Finally, that the HEU is blended into LEU. For Minatom, the transparency objective is that the LEU is fabricated into fuel for commercial nuclear power reactors in the United States.[82]

After the initial two years of operation, all measurements under the existing HEU-agreement have been consistent with the declared HEU enrichment levels.[83] The initial detector system using high-purity germanium detectors have been abandoned in favour of sodium iodine detectors for enrichment determination, because the former may reveal sensitive information. Portable instruments are used to confirm the presence of HEU in weapons-component containers.

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[79] For an overview, see e.g. U.S. Department of Energy. 2001. Technology R&D for Arms Control. Arms Control and Nonproliferation Technologies. Office of Nonproliferation Research and Engineering. Spring 2001.

[80] Generally, an information barrier must 1) prevent the release (accidental or intentional) of any classified information, and at the same time, 2) provide confidence that the measured systems are functioning correctly and that the unclassified display (output) reflects the true state of the measured item. This is often referred to as the “authentication problem”. See MacArthur, D. ”Attribute Measurement System with Information Barrier Technology”. Arms Control and Nonproliferation Technologies, Technology R&D for Arms Control, Spring 2001, p. 15, or Langner, D.G., D.W. Mac Arthur, N.J. Nicholas, R. Whiteson, T.B. Gosnell, and J. Wolford. 2000. Progress Towards Criteria for A Second-Generation Prototype Inspection System with Information Barrier for the Trilateral Initiative. Los Alamos Report LA-UR-00-3048, and Proceedings of the 41st Annual meeting of the Institute of Nuclear Material Management.

[81] Transparency provisions for the HEU deal is outlined and specified in a set of Annexes to the main agreement covering: Requirements for a bilateral US-Russian Transparency Review Committee, Requirements for notification of visits and related arrangements, Procedures of US monitoring activities at specified Russian down-blending facilities, Procedures of Russian monitoring activities at specified US recipient facilities, Procedures of Russian monitoring activities at specified US fuel fabrication facilities, Forms for accountability records, Procedure for blind sample analysis, Description of analytical methods for determining the uranium content and assays of enrichment of uranium-235, Procedures for the use of tags and seals, Technological process descriptions, Description of financial arrangement for transparency activities, Requirements for monitoring equipment, Description of radioactive standards, Procedures for exchange of HEU material reports between Russia and the US.

[82] Mastal, E.F., Benton, J. and Glaser, J.W. “Implementation of U.S. Transparency Monitoring under the U.S./Russian HEU Purchase Agreement.” INMM Annual Meeting. Phoenix, 1999.

[83] Decman, D.J., J. Glaser, J.M. Hernandez, and S.J. Luke. Portable NDA Equipment for Enrichment Measures for the HEU Transparency Program. The 40th Annual Meeting of the Institute of Nuclear Materials Management, 1999.

The addition of key transparency arrangements in 1995 was undoubtedly aided by the $100-million cash advances to the Russian Ministry of Atomic Energy.[84] However, while it is clearly the goal to verify that the HEU originates from Russian weapons, doubts have been raised whether the measurements really can determine if the HEU is derived from dismantled warheads, as required by the agreement.[85]

Other relevant examples of HEU verification include the HEU weapon component measurements performed at Oak Ridge National Laboratory in November 1996 and August 1997.[86] The first measurements aimed at demonstrating the receipt of a weapons component and to detect the presence of HEU in the sample. The measurement also confirmed that two sealed components were identical. Secondly, in 1997, the successful conversion of a HEU component into metal shavings behind a metal barrier was demonstrated.

In sum, it is possible to establish and have verification systems that politically fit into the requirements and sensitivities of the controlled and the controlling parties. Technically, it has also been proved that it is possible to apply such techniques and technologies which offer assurances and confidentiality at the same time.

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[84] Oleg Bukharin and Kenneth Luongo, "U.S.-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals", PU/CEES Report No. 314, April 1999, www.ransac.org/new-web-site/pub/reports/transparency.html#introduction

[85] Oleg Bukharin and Kenneth Luongo, "U.S.-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals", PU/CEES Report No. 314, April 1999, www.ransac.org/new-web-site/pub/reports/transparency.html#introduction

[86] Based on Andrew Bieniawski's "Historical Review", as presented in table 3 in Bukharin O. and J. Doyle. 2002. Transparency and Predictability Measures for U.S and Russian Strategic Arms Reductions. Nonproliferation Review, vol. 9, no. 2, Summer 2002, p. 89.

Chapter 6: Conclusions

The most effective approach to reduce the danger of nuclear terrorism and further state nuclear proliferation is to eliminate – as drastically and as quickly as possible – the existing stocks of unirradiated (fresh) highly enriched uranium (HEU) by converting them into low enriched uranium (LEU).

The largest obstacle to manufacturing and detonating crude nuclear explosive devices is the difficulty to acquire the basic “raw material” for such devices – weapon-grade highly enriched uranium. Technical barriers, in terms of what it takes to design a nuclear explosive device, are unlikely to suffice as an adequate measure to deny new actors (including terrorists), nuclear capabilities.

European parties should thus, as early as possible, provide Russian authorities with the financial incentives needed for the blending down of HEU stocks currently outside the scope of the ongoing US-Russian HEU elimination agreement. A scheme where additional highly enriched Russian uranium is down-blended to low enriched uranium, kept in Russian custody and ownership and then stored in Russia under international control, is feasible and likely to provide the quickest results.

The resulting LEU is thus decoupled from the market and market fluctuations that could have affected the pace of the HEU elimination. To European donors, security concerns should thus prevail over isolated economic benefits from uranium trade. European actors should focus on the single and clearly defined goal of non-proliferation and avoid possible gaps in the nuclear energy issues. To further other non-proliferation goals, requirements could be formulated to ensure that the revenues of the Russian Federation from the HEU elimination are used to improve Russian nuclear security.

If additional HEU elimination efforts are to be initiated, then it is likely to require an initial push from the European side. In this regard, the Russian willingness to address fissile material disposition under the auspices of the G-8 could provide the political openings needed for improved HEU elimination. Proposals of debt swaps for nuclear non-proliferation swaps are also of high interest in conjunction with additional HEU elimination.

Before any practical HEU elimination efforts in the future, however, further in-depth assessments are needed. They should be performed by key qualified Russian experts once the needed political interest has been generated. Ongoing HEU elimination work shows that satisfactory HEU verification schemes are feasible with the required intrusiveness to gain confidence in non-diversion, and at the same time taking into consideration legitimate Russian security concerns.

Irrespective of the different history, strategic considerations and priorities of different parities, common ground can probably be reached through innovative security thinking. Accelerated HEU elimination may be accomplished through the common denominator of mutual, regional, and global security benefits. Eventually, closer relations developing between Russia and the EU has the potential of doing more good to Russian-EU relations and perceptions of security than the old ways of viewing security and strategic reserves have done in the past.

Appendix I: The members of the HEU Elimination Study Group

Gunnar Arbman: Ph.D., has worked for the Swedish Defence Research Agency (Totalförsvarets forskningsinstitut, FOI) since 1965 and was appointed Director of Research in 1987. In 1980–90 his work was concerned mainly with protection against the effects of nuclear weapons, and in this context he designed protection systems for Swedish military and civilian systems. Since 1995 he has focused on nuclear weapon policy issues, including arms control and disarmament. He edited the *Proceedings of the Fissile Material Cut-off Seminar in Stockholm* (1998) and co-edited the *Proceedings of the Workshop on FMCT Verification: Detection of Clandestine Activities* (1999). He is the co-author of *Weapons of Mass Destruction and Security in the Middle East Region* (in Swedish, 1999) and *Arms Control and Tactical Nuclear Weapons* (2002). He is a board member of the Swedish Pugwash Group.

Francesco Calogero is professor of Theoretical Physics at the University of Rome I "La Sapienza". From 1989 to 1997 he served as Secretary General of the Pugwash Conferences on Science and World Affairs, and in that capacity he accepted in Oslo, on behalf of Pugwash, the 1995 Nobel Peace Prize jointly awarded to Pugwash and to Joseph Rotblat. He served from 1997 to 2002 as Chair of the Pugwash Council, of which he is now a member. From 1982 to 1992 he served as member of the Governing Board of the Stockholm International Peace Research Institute (SIPRI). He has published (in English) over 300 papers (about half co-authored) and 3 books (one co-authored) on scientific topics in theoretical and mathematical physics, and over 380 papers (about half of which in Italian and half in English, a few of which co-authored) and two books (coauthored) on science and society topics (mainly arms control and disarmament).

Paolo Cotta-Ramusino has been Secretary General of Pugwash Conferences on Science and World Affairs (Nobel Peace Prize 1995) since August 2002. He is also Professor of Mathematical Physics at the University of Milano (Italy), Senior Researcher at the Italian National Institute of Nuclear Physics, and Director of the Program on Science, Technology and International Security at the Landau Network - Centro Volta (Como). In 1983, he co-founded the Italian Union of Scientists for Disarmament (USPID), which organizes the Castiglioncello Conferences on problems related to Proliferation of Weapons of Mass Destruction.
In recent years, Prof. Cotta-Ramusino has carried out research on tactical nuclear weapons, ballistic missile defense, the Pakistani and Indian nuclear programs, and the control of nuclear materials in the former Soviet Union. As part of the activities of the Landau Network - Centro Volta, he promoted the development of a European Nuclear Cities Initiative aimed at involving European governments and private entities in supporting the conversion of Russian Nuclear Cities and the development of programs for cooperation on energy-related issues in the Korean peninsula.

Lars van Dassen, M.A. works for the Swedish Nuclear Power Inspectorate, SKI, as Director of the Swedish Nuclear Non-Proliferation Assistance Programme to the NIS. From 1996 till 2001, he was a Ph.D. candidate and Programme Director at the Department of Peace and Conflict Research, Uppsala University. From 1994 till 1996 he worked as research fellow at the Peace Research Institute Franfurt, Germany. He is in the process of completing a Ph.D. dissertation entitled: *Stepping-Stones and Stumbling-Blocks: A Theory-Based Comparison of the Evolution of the Nuclear Non-Proliferation Policies of the Nordic Countries, 1945-1991*, and has published numerous articles and newspaper articles on nuclear weapons issues and conflict resolution. He is a board member of the Swedish Pugwash Group.

Maurizio Martellini is an associated professor at the University of Insubria in Como, Italy and consultant of the Italian Ministry of Foreign Affairs on international security issues. He is Secretary General of the Landau Network-Centro Volta (LNCV), a high level, worldwide, non-profit international network dealing particularly with Institutions, NGOs and scientific communities in the field of international affairs, security and global issues. He is running the Executive Secretariat of the International Working Group (IWG) of the European Nuclear Cities Initiative (ENCI). In 2003 he was a Senior Fellow of the International Security Program at the Belfer Center for Science and International Affairs of the Harvard University, Cambridge, USA.

Morten Bremer Mærli, M.A. is a researcher at the Norwegian Institute of International Affairs, working on nuclear non-proliferation and prevention of nuclear terrorism. From 1995 till 2000 he served as senior excutive officer for the Norwegian Radiation Protection Authority with control and protection of nuclear materials as his main responsibility. During the academic year 1999/2000 Bremer Mærli was a Fullbright Science Fellow at the Center for International Security (CISAC), Stanford University. In 2000/2001, he was a Visiting Research Scholar at Sandia National Laboratories, California. He is the author of the monography Atomterrorisme (1999, in Norwegian) and has published widely in renowned journals and newspapers on nuclear non-proliferation and disarmament. He is in the process of completing a Ph. D. dissertation entitled: *Crude Nukes on the Loose? Preventing Nuclear Terrorism By Means of Optimum Nuclear Husbandry, Transparency, and Non-Intrusive Fissile Material Verification*.

Alexander Nikitin, Professor, Moscow State Institute of International Relations, Russia. Born in 1958, graduated from the Department of Philosophy of Moscow State University in 1979. Postgraduate studies and Ph.D. (History of International Relations) in 1983 from the USA and Canada Studies Institute of the Academy of Sciences. Research work for 10 years (1979-1989) in the USA and Canada Studies Institute (Senior Research Fellow, Sector Head). Diplomatic practice in the Soviet Permanent Mission to the United Nations (New York, USA, 1985). Since 1989 till now Dr. Nikitin teaches in the Moscow State Institute of International Relations (since 1998, as Professor of the Department of Political Sciences). Since 1989 till present time, he has been Director of the Center for Political and International Studies an independent non-governmental research institution involved in analytical work, consulting, publishing, organization of conferences in the spheres of international security and international relations.

International Research Fellowship in the NATO Defense College (NDC) in Rome (Italy) in 1996. He has given guest lecture courses in the University of Iowa (USA), NDC (Rome), Geneva Center for Security Policy (GCSP), and he is an elected Academy member of the Russian Academy of Military Sciences as well as serving as First Vice-President of the Russian Political Science Association and Executive Board member of the Russian Academy of Political Sciences. Dr. Nikitin is Vice-Chairman of the Russian Pugwash Committee of Scientists for International Security and Disarmament and an elected member of the International Pugwash Council. Dr.Nikitin is the author of 6 monographs and more than 50 articles and chapters in academic periodicals, journals and books published in Russian, English, French, Korean, Punjabi, Spanish, Portuguese, German languages.

Jan Prawitz, born in 1932, he is a senior research associate at the Swedish Institute of International Affairs (SIIA) in Stockholm since 1997, after he retired from government service. He was a research associate at the nuclear weapon department of the Swedish Defence Research Institute (FOA) 1956 –1970 and spent a sabbatical at SIPRI in 1969.1970-1992 he served in the Ministry of Defence as the Special Assistant for Arms Control. He then joined SIIA 1993-1995, and back in FOA 1995-1996. Prawitz also served as Scientific Advisor of the Swedish Disarmament Delegation 1962-1992. Over the years, he published numerous papers on arms control mainly related to nuclear weapons issues. He is a board member of the Swedish Pugwash Group.

Lars Wredberg MSc, is a consultant to the Swedish Nuclear Power Inspectorate, SKI. Between 1977 and 1997, he was a staff member of the International Atomic Energy Agency, IAEA, where he was a Safeguards Operation Section Head in the Department of Safeguards. Prior to that, he was employed in the field of nuclear reactor safety, as Section Head at ASEA-ATOM and as Senior Officer at Westinghouse Nuclear Europe. He has also been an employee of the Swedish State Power Board, the Studsvik R&D Centre in Sweden and the Eurochemic Reprocessing Project in Belgium.

Appendix II: The meetings and work of the HEU Elimination Study Group

The members of the HEU elimination Study Group have met at regular intervals from May 2002 till November 2003 and have shared various tasks from taking notes, arranging meeting, writing drafts, reviewing the draft texts and finalizing the report and participating in trips and meetings.

The work started in May 2002 during a Pugwash seminar in Sigtuna, Stockholm, where disarmament of tactical nuclear weapons was the main theme. During the seminar, a group of concerned participants discussed whether something could be done to address the issue of HEU elimination in Russia. It was agreed to explore whether Sweden via the Swedish Nuclear Power Inspectorate, SKI, and the Swedish International Development Cooperation Agency, SIDA, could provide funding for a study of the HEU problematique.

When it was approved by SIDA to cover the expenses for the work of the HEU Elimination Study Group, it had been decided to have a first working meeting after a Pugwash seminar in Como, Italy, late September 2002. At this meeting hosted by Maurizio Martinelli and the Landau Network, it was discussed what would have to be the topic and content of the report and how we were to proceed further. It was also agreed to establish contacts with other specialists from which we could either draw knowledge or whom we could ask to join the Study Group.

In November 2002, several members of the Study Group were in Washington to participate in the Carnegie Endowment Conference on nuclear non-proliferation. In connection with this conference, a meeting was held with Laura Holgate from Nuclear Threat Initiative, NTI, to get information about the work of NTI in the field of HEU elimination. Ever since there have been several exchanges of information with NTI and Laura Holgate on the HEU issue.

During the months before February 2003, Alexander Nikitin made heroic efforts to ensure that the members of the Study Group visited Moscow and met met various Russian officials and experts having knowledge and influence on the HEU issue. The meetings in Moscow turned out to be the main source of information and inspiration for the work. On 19 February, we had a day-long meeting with the Russian Academy of Sciences where, in three sessions, we went through various technical, financial and social issues pertaining to the HEU elimination. On the following day, we had a meeting at the Kurchatov Institute and discussed different views on HEU elimination and the dangers arising from HEU. In the afternoon, we had a meeting with the press in the offices of the International Federation for Peace and Conciliation. The last meeting on that day was with the Russian Ministry for Foreign Affairs where the main issue under discussion was HEU elimination in the broader international non-proliferation and disarmament agenda.

On 21 February, we met Mr. Alexander Rumyantsev, the Minister for Atomic Energy. The meeting presented us with the priorities for the nuclear security work within the framework of the G-8 declaration from the Russian point of view. Much to our dismay, we discovered that from an official point of view HEU elimination does not enjoy a high priority.

The Commander of the CIS Military Cooperation Staff and former Commander-in-Chief of the Strategic Missile Nuclear Forces Vladimir Yakovlev received us later that day. The exchanges addressed general nuclear security issues as they are perceived from the point of view of the Russian military.

Finally, a meeting was held with former Minister for Atomic Energy, Mr. Viktor Mikhailov, currently Director of the Institute for Strategic Stability, in order to assess the Russian view of the lessons from the existing US-Russian HEU deal and inquire to which extent more materials can be declared excess and thus suitable for down-blending.

In April and May 2003, a small caucus of the Study Group collected the various contributions written by the members and completed a first draft that could be circulated. The comments were circulated and various other experts were asked to review certain technical issues and political assessments. Based on this feedback the report was updated.

In July 2003, several of the members met in Halifax, Canada where they participated in the International Pugwash Conference. This served as an opportunity to sit down and go through the draft report in detail. In the course of August these comments were incorporated in the report text.

Toward the end of November 2003 the findings of this report were presented to the Swedish Ministry for Foreign Affairs and discussed with a view to finalise the work and submit a report to the Swedish Ministry for Foreign Affairs in early 2004.

The report has been written by persons who are dedicated to nuclear disarmament and non-proliferation. All co-authors have been very busy with their daily activities in various countries and context. Therefore, it has taken longer to finalize this report that was planned from the beginning. Nevertheless, the engagement in this work has brought much new knowledge and information to all who participated. Hopefully these pages will also constitute an in-put into the current non-proliferation and disarmament agendas.

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