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Management of high enriched uranium for peaceful purposes: Status and trends

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FOREWORD

High enriched uranium (HEU) was produced mainly for use in military programmes in the nuclear weapons States (NWS). Stockpiles of hundreds of tonnes of weapons-usable HEU from thousands of dismantled nuclear weapons were declared in excess by the United States of America and the former Soviet Union at the end of the Cold War. These stockpiles present a potential proliferation threat if the HEU materials are not properly managed and accounted for. In 1991 the USA and the Russian Federation signed an agreement under which the USA agreed to purchase 500 tonnes of HEU derived from Russian dismantled nuclear warheads. These HEU were to be down-blended to low enriched uranium (LEU) for use in civilian nuclear reactors. In addition, the USA declared 174 tonnes of its own HEU excess and available for down-blending to LEU.

HEU was also used as fuel for nuclear marine propulsion and research reactors. The widespread use of HEU fuels in research reactors poses a potential proliferation concern. To reduce the proliferation risks, the Reduced Enrichment in research and Test reactors (RERTR) Programme was implemented in 1978 to convert the HEU to LEU fuels. The concern for physical protection of the fresh and spent HEU fuels resided at many research reactor sites also led to the acceptance programmes for foreign research reactor fuels which are of US and Russian origin. These programmes aimed at returning the foreign spent research reactor fuels back to their sources of origin. In addition, the USA, the Russian Federation and the IAEA were cooperated in recent missions to remove fresh HEU fuels from several potentially unsecured research reactor sites.

The purpose of this publication, in general, is to gather data on the current status and to predict the future trends of global HEU inventory. It describes the potential proliferation risks of the widespread uses of HEU and reviews programmes to reduce and eventually eliminate those potential risks. It describes the management of HEU inventories, and the associated technical issues. The introduction of LEU down-blended from Russian and US HEU for use in civilian nuclear reactors had a significant impact on the uranium, conversion and enrichment markets. This report also reviews how the three markets have been impacted. The review of the report by J.S. Choi of Lawrence Livermore National Laboratory is appreciated.

The IAEA officer responsible for this publication was H.P. Nawada of the Division of Nuclear Fuel Cycle and Waste Management. His predecessor, L. Angers, initiated this task by organizing a Technical Committee Meeting on Current Status and Future Trends in Highly Enriched Uranium and Reprocessed Uranium in November 2001.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

Naturally occurring uranium consists of a combination of chemically identical isotopes, by weight about 99.3 % ^{238}U, 0.7 % ^{235}U and trace amounts of ^{234}U. Through complex physical processes that exploit the slightly different masses and/or other physical characteristics of the different isotopes, uranium can be 'enriched' in the ^{235}U isotope, which is the primary fissile isotope of uranium.

Of all the known uranium enrichment technologies, gaseous diffusion and gas centrifugation of uranium hexafluoride (UF_6) are the primary means that have been used to enrich uranium throughout the world. These enrichment techniques gradually increase the proportion of the ^{235}U relative to the ^{238}U in the 'product' stream (enriched uranium), and also produce a 'tails' stream that is lower than natural uranium in its ^{235}U content (depleted uranium, or DU). Uranium that has an assay of ^{235}U from the natural level to 20% is called low enriched uranium (LEU). Typical fresh power reactor fuel has ^{235}U assays below 5%. Uranium with an assay of ^{235}U equal to or more than 20% is called high enriched uranium (HEU).

Depending on the enrichment levels, enriched uranium can be fabricated into fresh fuels for power and research reactors, or into direct-use material for nuclear weapons. For depleted uranium, a joint expert group from the OECD-NEA and IAEA has recently published a report, which provides an overview of current inventories, potential new production, and management options [1].

Whereas enriching uranium is difficult, reversing the process to reduce its enrichment is a relatively simple matter of dilution if the only objective is to make weapons-grade HEU unusable in nuclear weapons. Blending HEU with LEU, with natural uranium (0.7% ^{235}U), or with DU by one of several available processes reduces the enrichment of the resulting mixture. By blending a HEU product to less than 20% enrichment, the material is made unusable in nuclear weapons. The resulting LEU cannot be made weapons-usable without going through the enrichment process again. However, in order to make the LEU resulting from impure HEU[1] conform to the ASTM specification and, therefore, fully marketable as reactor fuel, the enriched blendstock may have to be produced from depleted uranium.

The United States of America and the former Soviet Union, as well as other nuclear weapons States (NWS), produced HEU for their nuclear weapons programmes. HEU are also used to fuel nuclear submarines and aircraft carriers, as well as ice-breaking ships (naval nuclear propulsion). In addition, HEU has also been used as fuel in civilian research reactors and a small number of power reactors around the world. The end of the Cold War created a legacy of weapons-usable fissile[2] materials in the USA and the Russian Federation. Arms control agreements between these two countries have resulted in the removal of thousands of nuclear weapons from their respective active stockpiles, which in turn have produced stockpiles of excess weapons-grade plutonium and HEU from the dismantled weapons and other weapons production programmes. Excess stockpiles of weapons-usable fissile materials pose a danger to international security in the form of potential proliferation of nuclear weapons, and the

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1 Impure HEU refers to contaminants primarily in the form of minor uranium isotopes (^{236}U and ^{234}U).

2 Fissile materials are capable of undergoing nuclear fission, the splitting of an atom that results in the release of a large amount of energy. Weapon-grade plutonium and high enriched uranium are the primary fissile materials used as the explosive components of nuclear warheads.

potential for environmental, safety and health consequences if the materials are not properly safeguarded and managed.

It is widely recognized that the difficulty of acquiring fissile materials is the primary deterrent to nuclear weapons proliferation. Consequently, management, control and disposition of excess fissile materials have become a primary focus of nuclear non-proliferation efforts worldwide, but especially in the USA and Russian Federation. These two countries have discontinued their production of new HEU for military purposes though the Russian Federation may still produce HEU for civil uses, and both have major programmes underway to reduce their excess stockpiles of HEU. The Russian Federation is selling to the USA, the LEU derived from 500 tonnes of excess HEU, and the USA has a separate programme to eliminate 174 tonnes of its own HEU that has been declared excess. Together these programmes are currently supplying up to 15% of the LEU demand for power reactors worldwide.

Proliferation concerns about HEU have also resulted in a global effort, led by the USA, to eliminate the civil uses of HEU in research and test reactors. One programme, known as the Reduced Enrichment for research and Test reactors (RERTR) Programme, has already succeeded in converting a significant number (≈40%) of research reactors to the use of high-density LEU fuel. As reported in Reference [2], out of the 105 research reactors in the RERTR Programme, 39 are either fully or partially converted, 35 can be converted to use LEU fuel but still use HEU fuel and 31 requires new LEU fuel development. The excess HEU inventories are the primary source of supply for the RERTR Programme, where HEU is typically blended down to an enrichment of 19.75 % ^{235}U or lower.

2. HEU INVENTORIES: HISTORICAL BACKGROUND, TYPES, FORMS, ENRICHMENT AND OTHER SPECIFICATIONS

2.1. Definition of HEU

According to the American Society of Standards and Testing materials (ASTM) Designation C 1462-00 [3] HEU is any uranium with a ^{235}U assay of more than 20%. Typical fresh power reactor fuel has ^{235}U assays below 5%. Fresh research reactor fuel has ^{235}U assays ranging from below 20% to as high as 93% ^{235}U. Typical weapons-grade uranium has ^{235}U assays over 90%. Besides these assays, various other ^{235}U enrichments above 20% have been used in the past, mainly for research purposes (35% ^{235}U for zero-power experiments, 36 to 90% for some research reactors, and 40 to 60% for fuel for prototype breeders).

HEU production requires a large quantity of natural uranium and enrichment work (separative work units, SWU). Typical quantities of natural uranium and SWUs required for the production of 1 kg of enriched uranium (LEU and HEU at varying levels of enrichment) at a tails assay of 0.3% ^{235}U are given in Table I.

Table I. Natural uranium and SWU required to produce 1 kg LEU or HEU of varying assays

Assay (% U-235)	Required natural uranium (kg)	Required SWUs
4.5	10.2	6.23
20.0	47.9	38.30
50.0	121.0	103.00
90.0	218.0	193.00

2.2. HEU stockpiles

The amount of HEU produced and stockpiled is difficult to estimate because of lacking data in the open literature. Several estimates have been published, [4–9], including those listed in Table II which shows the estimates of global inventory of HEU and those declared or considered excess by the respective countries.

Table II. Estimates of global HEU inventories

Country	Estimated HEU inventory [a] (tonne)	Excess or declared HEU (tonne)
United States	~750	174
Russian Federation	~1050	500
United Kingdom	22	1.3 [b]
France	25	5.0 [b]
China	20	none
Total	~1870	~680

[a] Choi J.S. and Isaacs T.H., "Toward a New Nuclear Regime", UCRL-JC-151485 (2003); [b]INFCIRC/549, 2002

One of the International Atomic Energy Agency's mandates is to verify through its inspection system that Member States comply with their commitments under the Non-Proliferation Treaty and other non-proliferation agreements, to nuclear materials and facilities only for peaceful purposes. More detailed information on the Disarmament Treaties, Non-Proliferation Agreements, and the IAEA safeguards system is given in the Appendix. The HEU and other nuclear materials placed under IAEA safeguards from 2000 to 2002 are listed in Table III.

Table III. Nuclear material under IAEA safeguards by year (in tonnes) [10]

Nuclear material	2000	2001	2002
High enriched uranium (HEU)	21.8	20. 9	31.8
Plutonium contained in irradiated fuel (including recycled plutonium in fuel elements in reactor cores)	654	690	731.6
Separated plutonium outside the reactor core	72.2	77.5	82.0
Low enriched uranium (LEU)	48.974	50.097	51.226
Source material	91.686	94.940	96.410

The potential risk of fissile materials such as HEU for non-peaceful purposes emphasizes the need for special physical protection. There are substantial international cooperation efforts to upgrade the security of specific facilities around the world. Additional discussions on physical protection of nuclear materials are presented in the Appendix.

2.3. Chemical forms of HEU

Uranium is converted to uranium hexafluoride (UF_6) prior to enrichment. The chemical form of HEU after enrichment is UF_6, with a uranium content of approximately 67% by weight. The basic material properties of UF_6 and its production, handling, transportation, storage, disposal and economics have been discussed in detail in the IAEA publications [11–16]. UF_6 is generally converted by reduction into uranium metal as a starting material for production of nuclear weapons or as fuel elements for research reactors. In some cases uranium dioxide (UO_2) is also produced and used as fuel elements for special research reactors (prototype of fast breeders, Russian-designed fuel elements).

Depending on the sources of the feed materials to enrichment, HEU may contain, in addition to naturally occurring uranium isotopes, varying amounts of the artificial isotopes ^{232}U and ^{236}U, fission products, and transuranics. These contaminants can lead to acceptance problems at the fuel fabrication stage.

2.4. Replacement of HEU by LEU in research reactors

2.4.1. Historical background

From the 1960s to the mid-1980s, HEU was supplied by the USA for the production of fuel elements for US-origin research reactors within the USA and aboard. In the same time period, the Former Soviet Union supplied HEU with enrichments ranging from 36 to 90 % ^{235}U to fuel all the Soviet-designed research reactors.

In 1977, concerned about the widespread distribution of fissile uranium in research reactors worldwide and its potential risk, the USA launched a programme to reduce the fuel enrichment in research reactors in western countries. The International fuel Cycle Evaluation (INFCE) under Working Group 8 [17] recommended that the high enriched research reactor fuel should be converted to low enriched uranium (LEU), namely 19.75%.

A prerequisite for the conversion of research reactors from HEU to LEU fuel is the development of high-density fuels with the same fuel element geometry. The development of such fuel was initiated in 1978 by the Reduced Enrichment in research and Test reactors (RERTR) Programme of the US Department of Energy (USDOE) with international cooperation. The objective of the RERTR Programme at that time was to reduce the US annual export of HEU from 450 kg to 150 kg. The Russian Federation later began activities similar to RERTR Programme with the same objective to reduce the fuel enrichment in Russian-supplied research reactors.

The RERTR Programme determined earlier that a suitable chemical form for high density fuel would be uranium silicide (U_3Si_2) with uranium densities of up to 4.2 grams per cm^3. However, this fuel is difficult to reprocess, and it is not adequate for high-flux research reactors.

The search for an alternative to uranium silicide fuel led to the development of a uranium-molybdenum alloy (UMo) fuel with higher uranium densities (8 grams per cm^3). Such fuel can be reprocessed and it also allows for the conversion of high-flux reactors in the USA, Russian Federation, and the European Union (EU). The starting material for the production of UMo fuel elements is uranium metal.

Because of the existence of large stockpiles of HEU, it is no longer necessary to produce freshly enriched uranium to fuel research reactors. For US-supplied material, the LEU used to replace HEU in research reactors is obtained by blending metallic HEU with depleted or natural metallic uranium in induction furnaces. In some cases, the Russian fuel supply follows the same approach, but other processes can also be used to produce oxide-based fuels.

2.4.2. Estimated inventory of HEU for research reactor fuels

As of June 2003, expert assessment of HEU inventories available to the public (raw material and/or fabricated fuel) was as follows:

- USA: 10 tonnes of HEU destined for use as LEU research reactor fuel;
- South Africa: several hundred kg;
- European Union: several hundred kg;
- Canada: several tens of kg;
- Australia: several tens of kg; and
- Other countries: no confirmed information was available.

2.5. Predicting the trends of the HEU stockpile

General trends in HEU stockpiling are:

- The available HEU stockpiles are decreasing continuously due to the down-blending of HEU to LEU for power and research reactors and isotope production; and
- For research reactors, the need for HEU is diminishing as research reactors worldwide are converting to use LEU.

A similar evolution might take place in the targets that are used for the production of radio-pharmaceutical isotopes, such as ^{99}Mo and ^{99}Tc. Efforts are continuing to promote a shift to the use of LEU targets instead of HEU targets:

- The annual quantities of HEU needed to produce LEU for research reactors are relatively small. It is estimated that presently about 1 tonne of LEU produced from HEU is being used to fuel those reactors in the western countries that have been converted so far. This quantity could increase to 2-3 tonnes if high flux reactors in the USA and the EU are also converted to LEU. The production of 3 tonnes of LEU would mean the dilution of approximately 600 kg of HEU (90% ^{235}U) annually;
- The annual production of HEU fuel used in the Russian-supplied research reactors is approximately 850 kg with ^{235}U assays ranging from 20 to 90 %; and

- The total global demand for research reactor fuel (as both HEU and LEU) is approximately 3 tonnes ^{235}U per year.

Spent research reactor fuel is being stored pending disposal, or blended down through 'co-processing' with commercial power reactor fuel. Commercial reprocessing services for spent HEU and LEU research reactor fuel are currently offered by the Russian Federation and France.

3. RESEARCH REACTOR SPENT FUEL PROGRAMMES

3.1. US spent fuel take back programme

3.1.1. Foreign research reactor spent nuclear fuel acceptance programme

As discussed previously, both the USA and the Russian Federation recognized the potential threat from the presence of HEU in research reactors worldwide. They initiated similar RERTR programmes with a mutual objective to encourage eligible countries to convert their research reactors from HEU to LEU fuel and to eliminate stockpiles of HEU to prevent proliferation of nuclear weapons feasible material.

In addition to the RERTR programme, the USA accepted as of 1963 the spent fuel of US origin from foreign research reactors. New requirements for an Environmental Impact Statement (EIS) covering these operations resulted in suspension of the return of spent fuel with HEU and LEU in 1988 and 1992, respectively. Following the completion and approval of the EIS, the USA again accepted as of 13 May 1996 the US-origin spent HEU and LEU fuels from foreign research reactors under the following conditions:

Deadline for discharge of spent fuel: 12 May 2006

Latest receipt of spent fuel: 12 May 2009

Thereafter, the responsibility for the disposition of the spent fuel remains with the reactor operators. Various groups are attempting to persuade the USDOE to extend the May 2009 deadline. The rationale for the extension is that sufficient qualified UMo-LEU fuel elements will not be available in time to replace the HEU-based fuel.

With the foreign research reactor spent nuclear fuel acceptance programme (FRRSNFA) the USA is expecting to accept the return of 22 700 US-origin fuel assemblies containing about 5 tonnes of HEU (19 tonnes of HM) plus an additional 0.6 tonnes of HEU contained in target material from 41 countries [18]. Normal plate type fuels will be shipped to the USDOE Savannah River Site (SRS) and the TRIGA reactor fuels to the USDOE Idaho National Laboratory (INL).

Approximately 5 600 spent fuel assemblies containing in excess of 700 kg HEU from 27 countries had been received in the USA under this programme as of July 2003.

3.1.2. Breakdown of the supply of US HEU to research reactors outside the USA until 1993

According to a report dated January 1993 of the United States Nuclear Regulatory Commission (USNRC) to the US Congress on the disposition of HEU previously exported from the USA, the exports and returns of US-origin HEU until 1993 are summarized in Table IV.

Table IV. HEU previously exported from the USA until 1993, and US-Origin HEU retransferred to third parties or returned to the USA (in kg U)

	Direct US Exports	Indirect US Exports (via Third Countries)	Total US Exports	Retransfers to Third Countries	Returns to the US	Total Retransfers/ Returns	Total US Exports Minus Total Retransfers/ Returns
EURATOM	21 238	4 985	26 223	6 144	6 402	12 546	13 677
Non-EURATOM	4 637	1 717	6 354	550	1 992	2 542	3 812
Total	25 875	6 702	32 577	6 694	8 394	15 088	17 489

After 1993 the USA supplied HEU in small quantities only to Canada and the EU countries. The breakdown of the HEU exported by the USA until 1993 to non-EURATOM countries is given in Table V.

Table V. Breakdown of US HEU exports to Non-EURATOM countries until 1993, and US-Origin HEU retransferred to third parties or returned to the USA (kg U)

Region	Direct US Exports	Indirect US Exports (via third countries)	Total US Exports	Retransfers to Third Countries	Returns to the USA	Total Retransfers / Returns	Total US Exports Minus Total Retransfers / Returns
Asia & Pacific	2143	724	2867	242	399	641	2226
Latin America, Caribbean & Canada	2251	176	2427	52	1096	1147	1279
Europe & Africa	242	817	1059	256	497	754	306
Miscellaneous	1	0	1	0	0	0	1
Total	4 637	1 717	6 354	550	1 992	2 542	3 812

3.1.3. Breakdown of HEU used in the European Union

The bilateral agreement between the USA and the Euratom for the peaceful use of atomic energy does not require the reporting to the USA about transfers of HEU within the Euratom. It is estimated that after 1993 when USA supplies of HEU and LEU were not available, nearly all stocks of HEU of US origin within the EU were consumed in its research reactor [19].

3.2. Russian Federation spent fuel take back programme

3.2.1. Russian research reactor fuel return programme

At the end of the 1990s, the Russian Federation joined the US and IAEA efforts to return to Russia the Soviet- or Russian-supplied HEU fuels still resided at foreign research reactor sites. Based upon the success of the US FRRSNFA programme and assisted by the IAEA, the USA is supporting the Russian research reactor fuel return (RRRFR) programme for the return of spent and un-irradiated HEU to the Russian Federation. Twenty research reactors in 17 countries have been identified (Belarus, Bulgaria, China, Czech Republic, Republic of Korea, Egypt, Germany (the former German Democratic Republic, GDR), Hungary, Kazakhstan, Latvia, Libya, Poland, Romania, Ukraine, Uzbekistan, Vietnam, and former Yugoslavia).

The USA provided funding to the RRRFR programme based on the following criteria:

- The fuel return projects will include only existing former Soviet Union (FSU) - research/test reactors that possess nuclear fuel supplied by the FSU;

- Any country desiring to return fuel to the Russian Federation must agree to:

  (a) convert its operating research/test reactors using Soviet- or Russian-supplied nuclear fuel to LEU fuel as soon as (i) suitable LEU fuel licensed by the country's national regulatory authority is available and (ii) the reactor's existing inventory of HEU is exhausted; or

  (b) permanently shut down the reactor(s);

- Whenever possible, all available HEU must be made available for the return to the Russian Federation before any LEU fuel is supplied; and

- All nuclear fuel to be delivered to the Russian Federation under the programme must be handled in accordance with IAEA documents INFCIRC/225/R.4 and INFCIRC/153 (corrected) and subsequent revisions thereto.

Under the Russian research reactor fuel return programme some 2000 kg of HEU and some 2500 kg LEU as spent fuel will be shipped to the Mayak reprocessing complex near Chelyabinsk over the next ten years. Between 2005 and 2009, the programme envisages 38 shipments from 10 countries, comprising both fresh and spent fuels. In a second phase, eight or more shipments from six countries would remove all HEU fuel discharged before their reactors are converted to using LEU fuel.

The US and Russian Governments and the IAEA will seek financial support from other IAEA Member States, where required, for the fuel return projects to supplement the US financial contributions.

3.2.2. Russian legislation for the acceptance of spent Russian fuel

On 11 July 2003, the Russian Government adopted the new order for shipment of irradiated fuel assemblies from foreign nuclear reactors into the Russian Federation. This order is based on the set of Federal Laws signed by the President of the Russian Federation in 2001 [20]. The new order established the general rules for the Russian Federation to receive irradiated fuels from foreign research and power reactors for storage and (optional) reprocessing in the Russian Federation.

For Russian-origin fuel there is an option for the Russian Federation to retain all the recovered materials and radwastes after reprocessing. Reprocessing of fuel from **western**-design reactors in the Russian Federation requires that the radioactive wastes be shipped back to the country of origin.

According to the Russian legislation all contracts based on bilateral agreements with foreign governments must be agreed to by the Russian Ministry for Environment Protection, the Russian Gosatomnadzor (nuclear supervision authority) and regional authorities. Additionally, contracts for the shipment of irradiated fuel into the Russian Federation should support an environmental restoration project in the Russian Federation.

3.2.3. One-time repatriation projects for Russian-origin HEU fuel

Recognizing the urgent need to return HEU, which otherwise would constitute an unacceptable threat to international security, the USA and the Russian Federation cooperated in several one-time repatriation projects for Russian-origin HEU fuels. These repatriation projects are listed in Table VI.

Table VI. ‘Repatriation’ Projects for Russian-Origin HEU fuel

Receiving Country	Country of Dispatch	Year of Dispatch
Russia	Iraq	1993
USA	Kazakhstan	1994
UK	Georgia	1998
Russia	Romania	2003
Russia	Serbia (Vinca)	2002
Russia	Serbia (Vinca)	2005*
Russia	Uzbekistan	2004
Russia	Czech Rep.	2005*
Russia	Bulgaria	2003
Russia	Libya	2004

* to be determined.

3.3. Reprocessing of research reactor fuel and recovery of HEU

Reprocessing of spent research reactor fuel and recovery of HEU were no longer available at the Savannah River Site (SRS) in the USA, at Marcoule in France, and at Dounreay in the United Kingdom.

In the Russian Federation, reprocessing of UO_2-based research reactor fuels, primarily in Al matrix, is routinely conducted at the RT-1 reprocessing complex at the Mayak site. The recovered enriched uranium plus small quantities of other fissile materials are combined in a solution form with those from the RT-1 power reactor fuel reprocessing line and used for fresh LEU fuel fabrication by JSC TVEL. The Al- and fission product-containing wastes are solidified in alumina-phosphate glass matrix in the ceramic melter EP-500.

3.4. Co-processing of spent research reactor and light water reactor fuels

The French company COGEMA is offering to reprocess the spent research reactor fuels in uranium-aluminides and uranium-molybdenum alloys at the La Hague plant. The spent research reactor fuels will be co-processed with the spent LEU fuels from power reactors. In this process the HEU and LEU contained in the fuel elements are blended to make a LEU product with ^{235}U assay of approximately 1%. The research reactor operator is obliged to take back the generated waste in the form of vitrified glass. The process, however, cannot treat research reactor fuels in uranium silicides.

3.5. Direct disposal

Direct disposal of HEU is currently not available. Spent HEU fuels, if not reprocessed are stored in interim storage facilities.

3.6. Fast breeder spent fuel

Reprocessing of Russian fast breeder reactor, BN-600 fuel is conducted in the RT-1 plant at Mayak. The recovered uranium (with enrichment of about 20% ^{235}U) is used for fabrication of fresh fuel elements for RBMK reactors.

The BOR-60 fast reactor at RIAR site near Dimitrovgrad is fuelled with HEU and/or MOX fuels. The irradiated HEU fuel is reprocessed on site by dry reprocessing technology with re-use of the recovered uranium.

3.7. Naval reactor spent fuel

The Russian Federation implements a government-funded programme for shipment and reprocessing of its naval reactor fuels, of which most should be reprocessed by 2010. The recovered uranium (with enrichment below 20% ^{235}U) will be used as a blendstock to produce fresh fuel elements for power reactors. The limited amount of spent naval reactor fuels that cannot be reprocessed with current technology will be stored in special dry casks.

Information about isotopic composition and quantities of spent naval reactor fuels in the USA is not publicly available. Reprocessing of spent naval reactor fuel was discontinued in the USA in the 1980s. The current disposition of the naval reactor spent fuel is interim storage followed by final disposal in a geologic repository.

Information about isotopic composition and quantities of naval reactor spent fuel in France is not publicly available. It is believed that the French naval spent fuels are kept at interim storage facilities.

4. POTENTIAL UTILIZATION OF HEU INVENTORY

4.1. Options for the use of HEU as HEU

The present non-weapon use of HEU is limited to:

- manufacturing of targets for production of radio-pharmaceutical isotopes;
- production of fuel for naval reactors;
- production of fuel for Russian fast reactors; and
- production of fuel for research reactors which can not yet be converted to LEU.

A description of each of these options is given below:

(a) Manufacturing of targets for production of radio-pharmaceutical isotopes

^{99}Mo and ^{99}Tc are produced mainly in the Russian Federation, Canada and the EU using HEU targets. The annual consumption of HEU contained in the targets is estimated to be around 50 kg. research and development programmes are underway in Argentina, Australia, Indonesia, Republic of Korea, Russian Federation and the USA to replace HEU with LEU in the isotope production targets.

(b) Production of fuel for naval reactors

HEU is used for naval nuclear propulsion in the USA, the Russian Federation, France and the United Kingdom. The quantities and characteristics of the HEU used in these programmes are classified by these countries. Although technically conceivable, it remains an open question whether this HEU can be entirely replaced with high-density LEU fuels in the future.

(c) Production of fuel for Russian fast reactors

Annual consumption of the Russian fast breeder reactor BN-600 is 6 tonnes of uranium fuel with ^{235}U assays ranging between 17 and 26%, including 4 tonnes of HEU. The design lifetime of this reactor ends in 2010, but its operation may be extended until at least 2015. The annual consumption of uranium may decline in the future if the BN-600 reactor uses a hybrid core with 75% uranium and 25% mixed oxide (MOX) fuels, as part of the US-Russian plutonium disposition programme. The Russian programme does not envisage the use of HEU in new generations of fast breeder reactors.

(d) Production of fuel for research reactors, which can not yet be converted to LEU

HEU consumption has already been drastically reduced by the successful conversion of 31 western HEU research reactors with the assistance of the RERTR Programme (20 outside the USA and 11 in the USA). Five additional reactors in the USA and Europe are in the process of converting from HEU to LEU. There remain five civil HEU reactors in the USA and seven high flux reactors in the EU that are at present still fuelled by HEU. Development of new LEU fuel is needed to convert these high flux reactors.

The HEU-fuelled reactors that are yet to be converted in the USA and in the EU are shown in Tables VII and VIII, respectively.

Table VII. Remaining HEU-fuelled reactors in the USA

Name	MW(th)	State
MITR	5	Massachusetts
MURR	10	Missouri
NISTR	20	Maryland
HIFR	100	Tennessee
ATR	250	Idaho

The estimated annual HEU consumption for the five US HEU-fuelled reactors at present is in the range of 250 kg. For the seven research reactors in the EU the annual consumption is in the range of 170 kg HEU (including 40 kg for FRM-2).

The objective of the US RERTR Programme is to convert the five civil HEU-fuelled reactors in the USA to LEU by 2012, when new, high-density UMo fuels are expected to be available and qualified. According to the French Atomic Energy Commission (CEA) and the company CERCA, this type of fuel may also be available in France in the future.

Table VIII. Remaining HEU-fuelled reactors in the EU

Name	MW(th)	Country
RHF	57	France
Orphee	14	France
BR-2	100	Belgium
HFR	45	Netherlands
FRM-2*	20	Germany
MARIA	30	Poland
LWR-15 REZ	10	Czech Republic

*First criticality in March 2004.

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In the EU, the European Commission (EC), the owner/operator of the HFR reactor in the Netherlands, has committed to convert this reactor to use LEU. Also, the Technical University of Munich (TUM, Germany), the owner/operator of the FRM-2 reactor (which received its operating license in May 2003) has committed to convert to a ^{235}U assay of less than 50% (instead of 93%) after 2010.

The seven European research reactors are presently using HEU from both the Russian Federation and the USA.

Regarding present HEU supplies, the USA has made a decision and been in discussion with the Russian Federation to accelerate the disposition of Russian HEU by procuring the HEU from Russia for the fuelling of US research reactors. These discussions entail an inter-governmental agreement and related contract between the USDOE/National Nuclear Security Administration, the Y-12 Site Office and the Russian company TENEX for an estimated 1 500 kg of HEU.

Conclusion**:** The present annual demand of about 420 kg of HEU to fuel the five research reactors in the USA and the seven in the EU will be drastically reduced by the year 2012 and may decline further thereafter.

4.2. Options for the use of HEU after down-blended to LEU

4.2.1. Production of LEU (< 5 % ^{235}U) for power reactors

HEU contains a high quantity of natural uranium (NU) equivalent and SWUs that can be used for the production of power reactor fuel by diluting the HEU with uranium containing low ^{235}U assays. However, the blending down of HEU to LEU involves considerable SWU losses, which increase with the difference between the ^{235}U assays of the blendstock and the final product.

According to the World Nuclear Association's (WNA) Market Report of 2003 [21], worldwide uranium demand for commercial power reactors is estimated to be about 65 000 tonnes NU equivalent. Of this total, the demand from western world nuclear power plants accounts for about 58 000 tonnes NU equivalent assuming an average tails assay of 0.3% ^{235}U. The demand from power reactors in the CIS and Eastern Europe is 7 000 tonnes NU equivalent, assuming a tails assay of 0.1% ^{235}U.

Furthermore, in 2003, the worldwide enrichment demand for commercial power reactors is estimated to be about 40 million SWUs, based on the same tails assays as assumed in the preceding paragraph. Of this total, the demand from western world nuclear power plants accounts for about 31 million SWU, and the demand from power reactors in the CIS and Eastern Europe accounts for 9 million SWU.

The following calculation demonstrates how much power reactor fuel could be produced by blended-down HEU: For blending 30 tonnes of HEU (90% ^{235}U), a blendstock of about 886 tonnes LEU (1.5% ^{235}U) is needed to produce 916 tonnes of LEU with a product assay of 4.4% ^{235}U. Assuming a tails assay of 0.3% ^{235}U, this LEU would contain 9 130 tonnes of NU equivalent and 5.5 million SWUs.

Tables IX and X show the loss of SWU for the case of blending one kg of HEU with 1.5% enriched uranium and natural uranium, respectively:

Table IX. Blending of HEU with 1.50% Enriched uranium

	Quantity (kg U)	U-235 Content (%)	U-235 Content (kg)	NU Equivalent (kg)	SWU Content
HEU (to be blended)	1.000	90.00	0.900	218.248	192.938
Blendstock,1.5%LEU	29.517	1.50	0.443	86.181	27.231
Resulting LEU, 4.4%	30.517	4.40	1.343	304.427	-184.279
Loss of SWU					35.890

Table X. Blending of HEU with natural uranium

	Quantity (kg U)	U-235 Content (%)	U-235 Content (kg)	NU Equivalent (kg)	SWU Content
HEU (to be blended)	1.000	90.00	0.900	218.248	192.938
Blendstock, NU	23.201	0.711	0.165	23.201	0
Resulting LEU, 4.4%	24.201	4.40	1.065	241.421	-146.140
Loss of SWU					46.798

Conclusion: Blending of HEU with LEU (1.5% ^{235}U) results in a loss of 35.889 SWU per 1 kg of HEU, whereas the loss in SWU is higher if natural uranium is taken as blendstock (loss of 46.798 SWU per 1 kg of HEU).

4.2.2. Reuse of reprocessed uranium (RepU) with HEU to produce LEU

Only France and the Russian Federation reprocess the spent LEU and HEU fuels on a commercial basis. The Russian reprocessing complex RT-1 at the Production Association Mayak is reprocessing the spent LEU fuel from VVER-440 reactors as well as spent fuel from the BN-600 breeder reactor, and HEU fuels from naval and research reactors. In 2002, the Russian reprocessed uranium is partly blended to produce about 150 t U per year with enrichment equivalent up to 2.6% ^{235}U in the form of uranyl nitrate hexahydrate (UNH). This material is used to fabricate fuel for the Russian RBMK-1000 reactors. Additionally, the reprocessed HEU is used for blending in dry oxide form with the European reprocessed uranium (0.75 % assay) to produce 35 tonnes of LEU annually with an assay of 4.0% equivalent. The LEU is returned as fabricated fuel to western European power reactors.

In France, co-processing of spent HEU and LEU fuels will result in the production of reprocessed uranium with assays slightly higher than those of typical reprocessed LEU from power reactors. This is described in section 3.4 already.

4.2.3. Manufacturing high-assay fuel (>20%) for use in advanced high-temperature gas cooled reactors

Only two high temperature reactors (HTR) in the western world used HEU. These were the Fort Saint Vrain reactor in the USA and the THTR-300 reactor in Germany. Both reactors were shut down. Part of the non-irradiated fuel inventory has been fabricated into fuel for

European high-flux research reactors. Other high-temperature reactors (HTR in Japan, Pebble Bed reactor in China, and the proposed Pebble Bed Modular reactor (PBMR) project in South Africa) are using or will use fuel with an enrichment less than 20% ^{235}U.

4.3. Other options

4.3.1. Disposal as waste

For limited quantities of HEU inventories, the recovery of uranium is neither technically nor economically feasible. There is a need for research and development concerning the disposal of these materials, e.g., for suitable disposal containers and other barrier systems, and resolution of criticality issues associated with their disposal.

4.3.2. Interim storage

There is interim storage for spent HEU fuel in the USA, Germany, France, the Netherlands, and the Russian Federation as HEU as HEU pending down-blending or disposal as waste.

In the USA, the foreign research reactor spent nuclear fuel acceptance (FRRSNFA) programme has as of Fall 2003 safely and successfully received 25 shipments of spent research reactor fuel from foreign countries at the USDOE's Savannah River Site (SRS) and Idaho National Engineering and Environmental Laboratory (INEEL), pending final disposition in a geologic repository. Twenty-one of these 25 shipments, containing aluminum-based spent fuel from research reactors, went to SRS in South Carolina. The other four shipments, containing stainless steel-clad TRIGA spent nuclear fuel, were transported to INEEL in Idaho [22]. Twenty-seven countries have participated in the FRRSNFA Programme so far, returning a total of approximately 5600 spent fuel elements. The USA is expecting the return from 41 countries of a maximum of 22700 US-origin fuel assemblies containing about 5 tonnes of HEU plus an additional 0.6 tonnes of HEU contained in target material [18].

In Germany, spent HEU fuel from the THTR-300 reactor is currently stored at the Spent fuel Interim Storage Facility at Ahaus (BZA). When the US Foreign research reactor Spent Nuclear fuel Acceptance (FRRSNFA) Programme is expired in 2009, Germany will store the spent research reactor fuel, including spent fuel from the FRM-2 reactor, at Ahaus in specially designed containers (CASTOR-MTR).

France has a long-established policy to reprocess research reactor spent fuel. Consequently, there are only limited inventories of such spent fuel at interim storage sites in France. Since the closure of the Marcoule Reprocessing Plant in 1998, research reactor spent fuels are sent to La Hague for co-processing. The spent silicide fuels (Osiris Caramel fuel) are kept in the dry storage facility CASCAD in Cadarache, and some are in pool storage at reactor sites. Part of this fuel might be sent to SRS as part of the US FRRSNFA Programme.

In the Netherlands, spent HEU fuel from the High Flux reactor (HFR) in Petten is stored at the dry interim storage facility HABOG[3] (operated by state-owned company COVRA[4]) near the Borssele NPP site, together with spent fuel from the Dutch power reactors.

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[3] HABOG for **H**oogradioactief **A**fval **B**ehandeling- en **O**pslag **G**ebouw (High Radioactive treatment and storage building).

[4] COVRA for **C**entrale **O**rganisatie **V**oor **R**adioactief **A**fval (Central Organisation for Radioactive Waste).

In the Russian Federation, research reactor fuels are routinely reprocessed at the RT-1 plant at the Mayak site, and some research reactor fuel is reprocessed on a semi-industrial scale at RIAR (Dimitrovgrad). In addition, some experimental fuels are in interim storage at major research reactor sites, such as IPPE (Obninsk), Kurchatov Institute (Moscow), and RIAR (Dimitrovgrad). These fuels are mostly stored in water pools. Some of them cannot be reprocessed with the current technology.

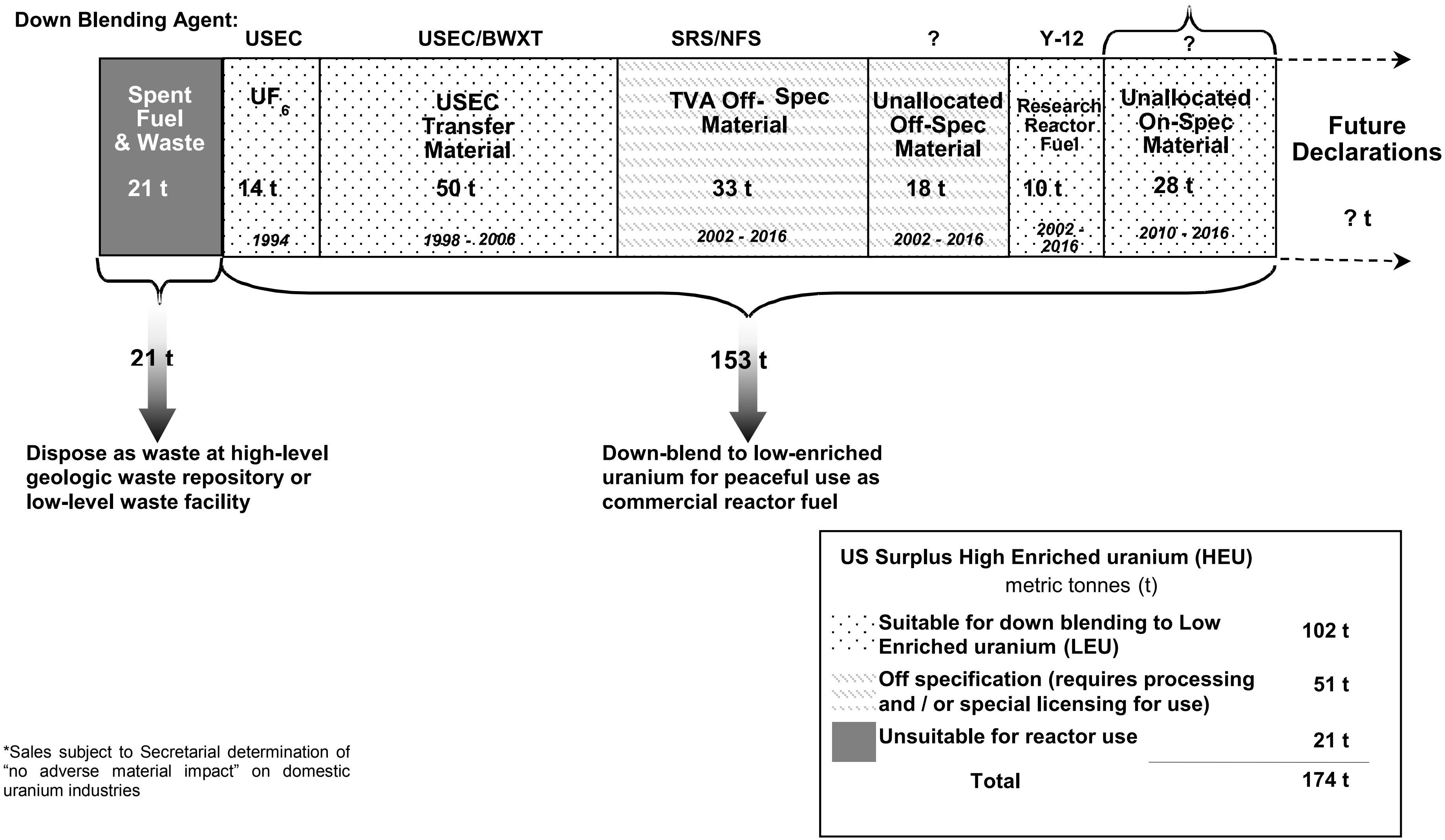
4.4. US HEU disposition programme

The sources of the 174 tonnes of HEU declared excess in the USA are quite varied. Although most of it is from weapons, significant fractions are from weapons material production reactor fuel cycles, nuclear energy research programmes, naval nuclear propulsion programmes, and various other historical USDOE programmes. Although certain information concerning the general locations, forms, and quantities of surplus HEU were released in February 1996 [9], specific details and changes since 1996 remain classified under the US Atomic Energy Act.

It is most useful to discuss the US inventory in terms of its existing or prospective disposition paths. Figure 1 is a graphic representation of those paths. About 21 tonnes out of the 174 tonnes are considered unsuitable for conversion to LEU reactor fuel. These are in the forms that can be disposed of as either high-level or low-level radioactive waste depending on the radioactivities of their associated contaminants. The remaining 153 tonnes can be blended down for use as reactor fuel. Of that amount, about 51 tonnes is deemed “off- specification”: If blended-down with natural uranium, the resulting LEU will not meet standard ASTM specifications for commercial reactor fuel. The off-spec material is nonetheless usable as reactor fuel under certain circumstances. Below are descriptions of the major categories of the US excess HEU and their current or prospective disposition paths.

4.4.1. USEC uranium hexafluoride

About 14 tonnes of HEU in the form of UF_6 were located at USDOE’s Portsmouth Gaseous Diffusion Plant in Ohio. That material was transferred to United States Enrichment Corporation (USEC) ownership pursuant to the Energy Policy Act of 1992. With the exception of small quantities of cylinder heels, it has all been down-blended to LEU as UF_6 at Portsmouth and sold by USEC. A significant fraction of the UF_6 material was down-blended under a “disposition verification experiment” by the IAEA.



*Sales subject to Secretarial determination of "no adverse material impact" on domestic uranium industries

Fig. 1. US surplus HEU disposition paths.

4.4.2. *Fifty tonnes of HEU transfer to USEC*

The USEC Privatization Act (1996) authorized the Secretary of Energy (USDOE) to transfer up to 50 tonnes of excess HEU and 7,000 tonnes of natural uranium to USEC. The purposes of this transfer were twofold: i) to further the HEU disposition programme by providing a mechanism for down-blending a portion of the excess HEU, and to enhance the assets of USEC prior to its sale from Government ownership to the private sector; and ii) to a 1998 Memorandum of Agreement between USDOE and USEC, HEU in oxide and metal forms is being delivered to USEC's down-blending contractor, BWX Technologies Nuclear Products Division (BWXT-NPD), in Lynchburg, Virginia, between 1999 and 2005. To date, about 38 tonnes have been delivered to BWXT from USDOE's Portsmouth and Y-12 National Security Complex (Oak Ridge, Tennessee) facilities, and BWXT is actively down-blending the material using uranyl nitrate solution blending.

HEU down-blending activities at BWXT are subject to an IAEA safeguards regime under the Voluntary Offer Agreement between the USA and the IAEA. The safeguards approach at BWXT is based on in-line IAEA monitoring equipment measuring the enrichments and quantities of inputs (HEU and NU solutions) and outputs (LEU solution) to the blending vessels, thus permitting the calculation of a mass balance.

4.4.3. *Off-specification HEU project*

Approximately 51 tonnes of the surplus HEU is considered off-spec. When it is blended with natural uranium to produce LEU with assay ranging from 3.5-4.95% ^{235}U, it will not meet ASTM commercial uranium fuel specifications, primarily due to the presence of minor uranium isotopes and plutonium contaminants.

The Tennessee Valley Authority (TVA) is a US Government agency, which operates five nuclear power plants and generates electricity used in the State of Tennessee and parts of the surrounding states. In April 2001, USDOE and TVA entered into an Interagency Agreement by which 33 tonnes of the off-spec HEU will be used by TVA as reactor fuel.

The material covered by the TVA agreement was mostly from the weapons material production reactor fuel cycle at USDOE's Savannah River Site (SRS). It was irradiated and reprocessed repeatedly, and thus, has very high levels of ^{236}U, as well as slightly elevated levels of ^{234}U and ^{232}U. To compensate for the neutron poisoning effect of ^{236}U, TVA and its contractors, Framatome Advanced Nuclear Power (Framatome ANP) and Nuclear Fuel Services (NFS), will produce fuel with ^{235}U enrichment that is about 0.6% higher than normal. TVA placed four Lead Test Assemblies made from the off-spec HEU in one of its Sequoyah reactors in 1999 to confirm the neutronics of the off-spec assemblies. Those assemblies have performed as expected.

Various parts of the off-spec material come from virtually every stage of the old SRS fuel cycle: irradiated fuel tubes, partially reprocessed uranyl nitrate solution, un-irradiated fuel tubes, uranium-aluminum alloy ingots and pure U metal buttons. Because of this variety of forms of the initial inventory, the details of the disposition paths are equally varied. The irradiated fuel, uranyl nitrate solutions, and un-irradiated fuel tubes will be processed through SRS's H-Canyon facility and down-blended to enrichment level 4.95% of ^{235}U in the uranyl nitrate solution chemical form between 2003 and 2007. The U-Al alloy ingots and U metal buttons will be delivered to Nuclear fuel Services, Inc., in Erwin, Tennessee, one of two commercial facilities in the USA licensed to process HEU, between 2003 and 2006. NFS will dissolve the material, perform solvent extraction on the alloy to remove the Al, and down-blend it as uranyl nitrate solution. New equipment is being installed at NFS to perform these operations. Framatome ANP is building an oxide conversion facility at the NFS site in Erwin, Tennessee to convert uranyl nitrate solution from both SRS and the NFS operations to UO_2. Framatome ANP is also building a uranyl nitrate solution storage building at NFS to hold LEU solution from both SRS and NFS down-blending activities. The oxide produced at NFS will be shipped to Framatome ANP's fuel fabrication facility in Richland, Washington for fabrication into pellets and fuel assemblies. The present plan is to use the blended LEU fuel in two of TVA's five reactors between 2005 and 2016.

4.4.4. Research and test reactor LEU fuel

The reduced enrichment for research and test reactor (RERTR) programme is managed by the National Nuclear Security Administration. Pursuant to this programme, the USA agrees to take back the spent HEU research reactor fuel that is of US-origin, assists in the development of new, high density LEU fuels, and supplies the LEU fuels, which are typically just below 20% enrichment. Up to 10 tonnes of the excess HEU inventory will be down-blended to 19.75% enrichment or less to produce research reactor fuel over the next 15 years.

4.4.5. Prospective US HEU disposition paths

The remaining of the US excess HEU is not yet allocated to a specific disposition path. The development of disposition paths has been delayed by a variety of factors, including inadequate availability of material, lack of detailed characterization data for some of the material, budgetary constraints, and concerns about impacts of additional material on uranium markets. Preliminary planning for additional disposition projects is, however, underway.

4.4.6. Unallocated off-spec HEU

In late 2001, USDOE published a new study that analyzes potential disposition paths for about 22 tonnes of off-spec HEU (in addition to the 33 tonnes currently allocated to the TVA project described in Section 4.4.3). This material is from a great variety of sources and programmes. The majority of it is off-spec due to the presence of plutonium contaminants, but a significant quantity is off-spec for other reasons, such as the presence of minor uranium isotopes. The study, entitled "Unallocated Off-Specification HEU: Recommendations for Disposition", establishes a baseline inventory of in-scope materials that are divided into 15 discrete groups, defines and analyzes disposition options for the materials, and recommends disposition pathways for each group. The predominant recommended disposition path in the study (for more than three-fourths of the material) is processing and down-blending to make reactor fuel. Some of this material may be added to the existing off-spec HEU agreement with TVA. Most of the remainder is recommended to be disposed of as waste.

4.4.7. Unallocated on-spec HEU

About 28 tonnes of additional surplus HEU are expected to be converted to on-spec reactor fuel when down-blended to LEU. This material includes about 10 tonnes of HEU that have been under IAEA safeguards inspections at USDOE's Y-12 National Security Complex, and material from future weapons dismantlement activities. There are two significant constraints on the timing of disposition of this material. First, the USEC Privatization Act provides that USDOE cannot sell natural or low-enriched uranium unless the Secretary of Energy determines that such sales will not have an adverse impact on the US uranium mining, conversion, or enrichment industries. (The transfers to USEC and TVA are exempt from this requirement). Second, under a 1999 agreement between the USA and the Russian Federation intended to avoid potential adverse impacts of too much non-traditional uranium on the uranium and enrichment markets, the USA agreed to withhold from the market for 10 years the equivalent of 10 770 tonnes of natural uranium from its own inventories. About half of that withheld inventory is from the US excess HEU inventories, including part of the unallocated on-spec HEU, as well as part of the unallocated off-spec HEU. Due to these legal constraints and current uranium market conditions, it is unlikely that the unallocated on-spec HEU will be commercialized until after 2009.

5. MARKET ISSUES IN THE CONTEXT OF THE US-RUSSIA HEU-LEU AGREEMENT

5.1. History of the agreement

On 18 February 1993, the USA and the Russian Federation signed a bilateral agreement for the USA to purchase 500 metric tonnes of HEU from Russia, the quantity contained in approximately 20 000 nuclear weapons. The USA and the Russian Federation were to appoint commercial executive agents to carry out the deal. The US Department of Energy (USDOE) and the privatized US Enrichment Corporation (USEC) were serving as the US executive agents. The Ministry for Atomic Energy of the Russian Federation (MINATOM: now called 'Federal Atomic Energy Agency' ROSATOM) was Russia's executive governmental authority and Techsnabexport (TENEX) was its executive commercial agent. By May 1993, the USDOE and TENEX officials had initiated a draft contract for the purchase of 500 tonnes of HEU to be blended down to reactor-grade fuel (low-enriched uranium, LEU) over 20 years.

The final contract was signed in January 1994. The contract initially specified that each year for the first five years of the agreement, the USA would take delivery of LEU derived from blended-down of 10 tonnes of HEU. Blending of this material would produce about 310 tonnes of LEU with an assay of 4.4% ^{235}U (containing the equivalent of 1.84 million SWU and 3 000 tonnes of natural uranium (NU) equivalent). For the following 15 years, the annual amount would increase to 30 tonnes of HEU, equivalent to about 930 tonnes of LEU. However, this delivery schedule has been altered by subsequent agreements.

The final contract turned out to be the beginning of a difficult process of implementation. For example, there were some initial technical difficulties with the delivery of the LEU, and the 'feed issue' became the central concern for the success of the HEU-LEU Agreement:

- It took some time to establish the blending process and necessary infrastructure for the performance of the US-Russia HEU deal (e.g., construction of filling stations, purchase of 30B UF_6 containers [23], etc.);

- The LEU product needed to meet the specifications of commercial grade enriched uranium, as set out in the relevant ASTM standard (C-996-96) [24] that defines the isotopic composition of enriched UF_6 acceptable for the fuel fabricators' re-conversion facilities;

- Natural uranium turned out to be an undesirable blendstock for the HEU, because of the excessive SWU loss (as described in Section 4.2.1). Furthermore, a considerable part of the Russian depleted uranium or tails materials turned out to be unsuitable for blending purposes, because during the 'Cold War' a substantial part of the material fed into the enrichment plants came from reprocessing, after slightly irradiation in plutonium production reactors. The tails materials from the enrichment process were contaminated with other undesirable isotopes, making this material unacceptable for HEU blending purposes;

- The arrangement between TENEX and the Russian enrichment enterprises concerning the production of the blendstock for the US-Russia HEU-LEU Agreement is based on the following simplified assumptions (disregarding that some LEU with an assay of 4.95% ^{235}U is also produced) (see also Section 4.2.1):

  - For the blending of 30 tonnes HEU (90% ^{235}U), a blendstock of about 886 tonnes LEU (1.5% ^{235}U) is needed to produce 916 tonnes LEU with a product assay of 4.4% ^{235}U;

  - The blending of the HEU with the LEU yields 916 tonnes LEU (4.4 ^{235}U). This material is physically delivered to USEC;

- The above-mentioned technical difficulties resulted in delaying the start of LEU deliveries to the US. Deliveries eventually began in 1995, and the entire delivery schedule was revised in 1996, resulting in expedited rates of down-blending and deliveries compared to the initial schedule; and

- In accordance with a December 1996 agreement, the USA has placed measuring devices at key points in the Russian weapons destruction facilities to verify the source of the HEU. The Russian Federation has a reciprocal right to monitor the use of LEU derived from HEU in the USA, to ensure it is not being used to produce new weapons material.

In addition, there have been trade-related problems:

- Seeking restrictions on the import of uranium to the USA, a trade action was brought in November 1991 by US uranium producers, with the concern that uranium was being sold in the US market at below production costs ('dumping'). A preliminary determination by the US Government trade officials in early 1992 supported the uranium producers' contention;

- In October 1992, the USA and the Russian Federation entered into a 'Suspension Agreement', suspending the anti-dumping action while setting price-related quotas on US imports of Russian uranium, which were to remain in effect through 2003. The HEU and the LEU derived from HEU blended down were included within the scope of the anti-dumping investigation and Suspension Agreement. However, a 1993 amendment to the Suspension Agreement specifically provided that it "in no way prevents the Russian Federation from selling directly or indirectly any or all of the HEU in existence", but simultaneously imposed certain restrictions on the sales of the HEU feed component in the USA, setting forth that any utility-owned uranium products delivered pursuant to enrichment contracts, affected by the purchase of HEU or HEU-derived products shall not be resold in the USA. These restrictions were one of the sources of problems with the disposition of and payment for the "HEU feed component" (NU in the form of UF_6); and

- The USEC Privatization Act of 1996 placed restrictions on the sale of the uranium component of the HEU. The Act sets annual quotas for the entry into the US market of the uranium component of LEU deliveries from 1998 onwards. Furthermore, the Act stipulates that ownership of the natural uranium and conversion components of deliveries of Russian LEU from 1997 onwards remains with the Russian Federation, clearly restricting USEC's interest in the enrichment component of the HEU deal.

Further milestones of the US-Russia HEU-LEU agreement's development were:

- On 21 October 1998, the US Congress passed a bill allowing the USA to spend US$ 325 million to buy about 11 000 tonnes U, equivalent to the HEU feed component contained in the 1997 and 1998 deliveries of blended-down HEU. This material will be kept off the market by the USDOE for an extended period of time – until March 2009. The goal of the purchase was to prevent natural uranium market prices from falling. The purchase was also meant to serve as an incentive to the Russian Federation to come to a purchase agreement with Cameco, COGEMA, and RWE NUKEM (collectively, the 'Western Companies') on the 'HEU Feed Deal', as the purchase of this feed material would not take place unless such an agreement was reached;

- On 24 March 1999, an agreement was signed between the USA and the Russian Federation regarding the disposition of the HEU feed component, resolving several long-standing disputes. The accord allocated about 9 000 tonnes U of natural uranium hexafluoride (UF_6) among the various parties on an annual basis. Among the resolved disputes was a commercial contract for the natural uranium feed component with the Western Companies. These companies, which signed the purchase contract with TENEX on 24 March 1999, were given the exclusive option to purchase about 72% of the annual feed component stocks;

- Under the Agreement, the Russian Federation may annually repatriate the unsold HEU feed component from the USA. This was made possible by a specific waiver by the US President. From these repatriated UF_6 quantities, the Russian Federation is allowed to use annually up to 2 580 tonnes of natural uranium for blending HEU down to LEU. Furthermore, provided that the Russian Federation maintains a minimum stockpile of 22 000 tonnes U, the Russian Federation may use additional quantities for sale as LEU under existing contracts to countries listed in the Annex to the Agreement. In addition, the Western Companies, pursuant to certain conditions, can purchase additional quantities through TENEX from the Russian stockpile;

- On 10 October 2000, USEC announced that 100 metric tonnes of HEU, the equivalent of 4 000 warheads, had been converted into LEU;

- In November 2001, Cameco, COGEMA, and RWE NUKEM signed an amendment to their 1999 agreement with TENEX, whereby the Western Companies undertook conversion of a major part of their options to a firm commitment to purchase the HEU feed component made available in the USA. The amendment commits the Western Companies to purchasing an annual amount of uranium not less than and in some years exceeding the US sales quota for Russian HEU feed component. Over the life of the agreement, which lasts until 2013, Cameco and COGEMA are committed to buying approximately 24 000 tonnes U (in UF_6) each, while RWE NUKEM will purchase about 8 200 tonnes U (as UF_6);

- More recently, in February 2002, USEC and TENEX reached a contract amendment and adopted market-based pricing terms for the SWU component of the LEU derived from

Russian HEU. In June 2002, the US and Russian governments approved implementation of the contract amendment for the remaining 11 years of the programme. The announcement that the contract amendment had been approved by both governments came shortly after the USDOE signed an agreement with USEC that confirmed USEC's role as sole executive agent and specified conditions for the renewal;

- The terms of the contract amendment include a commitment until 2013 to purchase at least 5.5 million SWU annually (which is derived from 30 tonnes of Russian HEU);

- The two components of revenue (payments for the natural uranium and the conversion component of the LEU (derived from HEU) on one side, and for the SWU component on the other side) are credited to the Federal Budget of the Russian Federation. The revenue received from the sales of the SWU component to USEC contribute to ROSATOM's budget fund. From this fund, ROSATOM:

  - Pays the plants and agencies for their services related to the production of LEU derived from HEU, such as the physical and chemical treatment of the LEU, for the production of the blendstock (LEU; 1.5% ^{235}U), for the blending operations at the enrichment facilities, and for services associated with the execution of the HEU deal;

  - Finances and implements numerous governmental programmes listed in the HEU-LEU Agreement, aimed at enhancement of the safety of Russian NPPs, conversion of defense-related enterprises, and ecological remediation of contaminated nuclear sites; and

- As of 1 May 2003, about 184 tonnes of HEU, the equivalent of more than 7000 warheads, have been converted into LEU.

HEU down-blending under the US-Russia HEU deal is conducted at four Russian nuclear sites:

- Mayak Production Association at Ozersk (until 1990 referred to as Chelyabinsk-40; after 1990 referred to as Chelyabinsk-65);
- Siberian Chemical Combine at Seversk (Tomsk-7);
- Urals Electrochemical Integrated Plant at Novouralsk (Sverdlovsk-44); and
- Electrochemical Plant at Zelenogorsk (Krasnoyarsk-45).

It has been estimated that down-blending of 500 tonnes of HEU from Russian nuclear weapons will produce about 15 000 tonnes of LEU, enough to generate 6 trillion kilowatts hours of electricity. LEU produced under the US-Russia HEU Agreement is approximately equivalent in energy to:

- 60 trillion cubic feet of natural gas;
- 10 billion barrels of oil, requiring 10 000 super-tankers for transportation; and
- 2.7 billion tonnes of coal, requiring 30 million coal cars for delivery.

These comparisons highlight the fact that the US-Russia HEU deal represents a very significant supply to and impact on western uranium, conversion and enrichment markets.

5.2. Accelerated HEU blend-down initiatives

The current annual rate of 30 tonnes at which Russian HEU is being blended down, was set primarily by what the market would bear, and not by US or Russian national security requirements. From a security perspective, it would be high desirable to blend down all the HEU in the world as rapidly as possible, to make the material unattractive and unusable for terrorists or criminal groups.

According to a recent report [25] the Russian Federation's uranium processing facilities are believed to be capable, with the addition of only a few pieces of equipment, of blending 60 tonnes of HEU, rather than 30 tonnes each year. However, the enrichment capacities in the Russian Federation might not be available to produce the blendstock (from depleted uranium) for such twofold quantities of HEU. This larger amount of material could not be sold to the nuclear fuel market without severely depressing the market prices and disrupting the existing 30 tonnes-per-year deal. But according to the Nuclear Threat Initiative (NTI), as a security investment, the USA and other G-8 Global Partnership participants could pay the Russian Federation to blend down an additional 30 tonnes each year and keep it off the market, in monitored storage, until the existing US-Russia HEU-LEU Agreement is complete.

At the May 2002 Summit, the Presidents of the USA and the Russian Federation instructed their experts to examine options for expanded disposition efforts for both ex-weapons Pu and HEU. The working group that resulted from the May 2002 'Bush-Putin Summit' prepared an initial report that examined a variety of options for modestly sized additions to the current HEU deal. The most important of these was the possibility of blending down a limited additional amount of material that could be stored as a 'buffer stock' in the USA, to be used in the event of a disruption in the supply of LEU from the current HEU Deal. The USA has requested US $30 million in fiscal year 2004 to finance the first year of a decade-long purchase of such a buffer stock, along with the other modest blending initiatives. A study has been sponsored by the NTI to examine options for large-scale accelerated HEU blend-down.

5.3. The market impact of the US-Russia HEU-LEU agreement

The US-Russia HEU-LEU Agreement is a major source of uranium, conversion and enrichment services made available from HEU disposition programmes. The impacts of this Agreement have been progressively assimilated by the uranium, conversion and enrichment markets and the related supply is now fully integrated amongst the other supply sources.

5.3.1. Weight of the US-Russia HEU-LEU agreement by comparison with other sources

The following are comparisons of the projected output from the HEU Agreement with conventional supply sources and services:

- Uranium: The yearly natural uranium content of the related LEU (delivered as UF_6 to the USA) is about 9 100 tonnes, based on a calculated tails assay of 0.3 % ^{235}U. According to the existing arrangements, this material will be available annually up to 2013. For comparison, the all-time maximum annual production recorded for a single uranium mine was from the Canadian McArthur River project, which was about 7 100 tonnes U produced in 2002. These figures show that the US-Russia HEU-LEU Agreement currently represents the largest single supply source of uranium;

- Conversion: Currently, six major commercial conversion plants are operating worldwide (one each in Canada, the USA, France and the United Kingdom, and two in the Russian

Federation). They have nameplate capacities to convert natural uranium concentrates to UF_6 ranging from 5 000 to 18 000 tonnes U/year. Thus, the US-Russia HEU-LEU Agreement, which provides conversion services with the equivalent of 9 100 tonnes U/year as UF_6 is similar in size to the average annual production of an existing commercial conversion facility; and

- Enrichment: Currently, nine large commercial enrichment plants (with capacities greater than 1 million SWU per year) are operating in France, the USA, the United Kingdom, Germany, the Netherlands and the Russian Federation. They have nameplate capacities ranging from 1.5 million SWU/year to 10.8 million SWU/year. The 5.5 million SWU/year brought to the market by the US-Russia HEU-LEU Agreement is almost equal to the total annual production of URENCO's centrifuge plants, and close to current US annual production.

5.3.2. Worldwide uranium supply and demand relationships

Figure 2 shows the projected worldwide uranium supply-demand relationships through 2025. The impacts of the US-Russia HEU-LEU Agreement on the western and Eastern nuclear fuel markets were addressed separately as the integration of, these two markets, although progressing has not yet been completed.

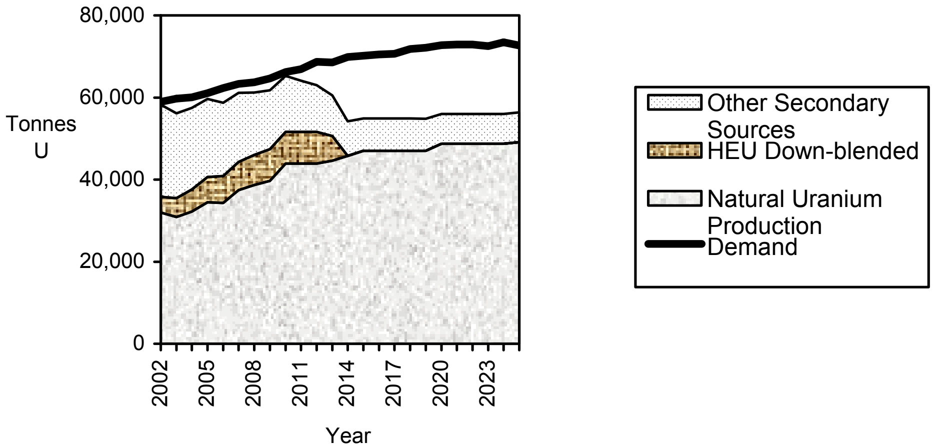


*Fig. 2. World uranium demand and supply projections. Data are based on the report of World Nuclear Association (WNA) [21] projections plus input from the experts.**

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* Normally, such contemporary data on uranium demand and supply would have been collected from the reference "Uranium 2003: Resources, Production and Demand" (called also as "Red Book") a joint report by the OECD/NEA and the IAEA published in the middle of 2004. The Red Book describes a statistical profile of the world uranium industry in the areas of exploration, resource estimates, production and reactor related requirements. However, the figures 2, 3 and 4 presents not only estimates on uranium production and world reactor requirements but also illustrates the contribution of the secondary sources in filling the gap between anticipated production and demand as well as account for the different fuel procurement strategies of Western-design reactors (supplied mainly by Western suppliers and producers in Central Asia) and of Russia-design reactors (supplied mainly by Russian companies). Particularly, the Red Book does not describe the contribution of HEU (down-blended to reactor-grade LEU) to filling this gap.

5.3.3. *Western market (western-design reactors)*

Uranium

Figure 3 shows uranium demand and supply relationships for western-design reactors until 2025. The demand side takes into account the uranium requirements of all reactors currently operating, under construction, firmly planned and anticipated. The supply side takes into account the production from all currently operating, firmly planned and potential mines as well as the perceived availability of currently known secondary supply sources, including LEU derived from Russian weapons-grade HEU. In Figure 3 the category "Other Secondary Sources" comprises inventories of processors in different stages of the nuclear fuel cycle, utility inventory drawdown, material gained from the re-enrichment of the tails (obtained from western sources) in Russian enrichment facilities, the natural uranium equivalent of mixed oxide (MOX) fuel and reprocessed uranium (RepU), as well as the natural uranium equivalent of fuel imports from the Russian Federation.

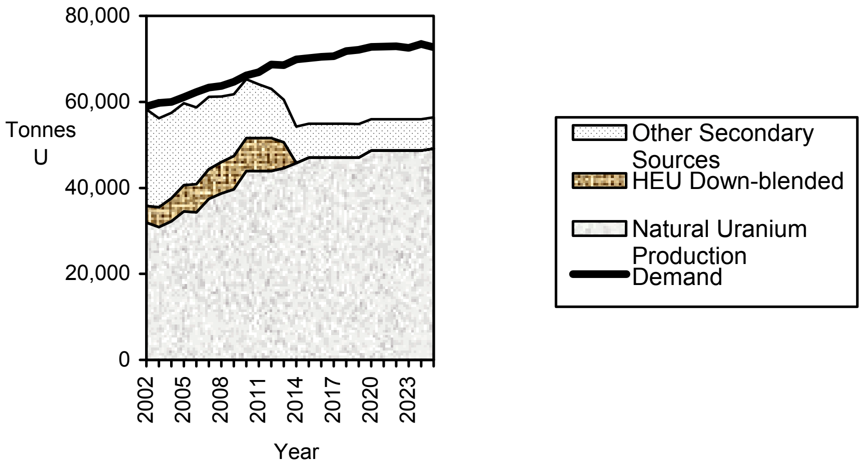

Fig. 3. Western reactors uranium demand and supply. Data are based on the report of World Nuclear Association (WNA) [21] projections plus input from the experts.[5]

During the period 2002 to 2025 shown in Figure 3, the feed component of the HEU-derived LEU provided to the western Market under the US-Russia HEU-LEU Agreements will be the total feed content of the LEU delivered in the USA, less the quantities returned to the Russian Federation. This supply will account for 10 to 15% of the aggregate uranium needs for western-design reactors through 2013.

According to Figure 3, throughout this decade the supply and demand will be approximately in balance. However, starting from the first few years of the next decade i.e. around the expiration date of the US-Russia HEU-LEU Agreement, a gap between supply and demand will likely occur, and it could widen to more than 10 000 tonnes of uranium in the year 2020. Such gap can be filled by the blending down of additional HEU (from both western and Russian sources) and other governmental strategic stockpiles**.** As the facilities for HEU blending already exist and can probably be expanded, this potential supply source of LEU is likely to be quicker to mobilize than almost all the other sources. However, only limited

[5] See footnote on p. 25.

information has been released about the potential availability of such governmental stockpiles. And this depends mostly on political will and much less on signals from the nuclear fuel market.

Other likely possibilities for bridging this gap are as follows:

- **Expanded production from existing mining and milling capacities** (with a potential of adding about 3 000 tonnes of uranium/year), requiring limited investments and a relatively short time lag;

- **Production from planned projects and prospective capacities**, provided regulatory approval and investment decision would be reached in time: This could represent a substantial supply (about 10 000 tonnes of uranium/year according to the World Nuclear Association (WNA)), but only with a five-year or longer lag to a clear signal from the market (time needed for licensing, construction and start-up phase);

- **Reactivation of small, stand-by mines,** especially in the USA: These mines can add limited supplies (about 1 000 tonnes of uranium/year), but with at least one-year lag;

- **Reduction of the tails assay** from the current level of 0.30-0.35% ^{235}U to ~0.25% ^{235}U: This would reduce uranium needs by roughly 10-15%, leading to savings in excess of 5 000 tonnes of uranium/year. However, only substantial uranium price increases (assuming stable SWU prices) could stimulate utilities and/or enrichers to select lower tails assays. This, in turn, would translate into higher SWU needs, which could require the commercial enrichers to expand their capacities;

- **Drawdown of utility and government excess inventories**, if still available;

- **Increased recycling of Pu and RepU**, after expansion of the existing and/or the construction of new MOX and RepU fuel fabrication capacities: These additional capacities could replace about 1 000 tonnes of uranium/year. However, the lead times to bring these additional capacities into operation could be substantial; and

- **Increased Russian LEU supplies to the West**: Since the Russian Federation is primarily an enrichment services provider, this option depends on the availability of natural uranium that the Russian Federation could combine with its SWU for delivery to western utilities. That means that the potential Russian LEU supplies could fill only part of the gap.

Conversion

The following companies supply conversion services ($U_3O_8 \rightarrow UF_6$) on a commercial basis: Comurhex in France, ConverDyn in the USA, Cameco in Canada, British Nuclear Fuels Plc. (BNFL) in the United Kingdom and TENEX in the Russian Federation. Conversion services are also provided by the companies, engaged in the marketing of the HEU Feed ('Western Companies', see Section 5.1). However, BNFL will cease conversion activities early in 2006.

According to the provisions of the US-Russia HEU-LEU Agreement, the UF_6 conversion component of the LEU provided to the western market will be the total feed content of the LEU delivered in the USA, less the quantities returned to Russian Federation. Up to 2013, this supply will account for 10 to 15% of the aggregate conversion needs.

Currently, the availability of the conversion component of the HEU Feed leads to a slight oversupply in the western market, which is compensated by both decreased conversion capacity load factors and the return of part of the HEU Feed back to the Russian Federation (with a potential future access to part of this material by the Western Companies participating in the US–Russia HEU–LEU Agreement).

However, with BNFL's withdrawal from the conversion market, reduced availability of other secondary sources (besides the HEU Feed) and increasing demand for conversion services, a supply gap is likely to occur in the second half of the current decade. Thus, despite the availability of the conversion component of the HEU Feed, additional conversion capacity will be needed. In the longer term, after the expiration of the existing HEU-LEU Agreement, the supply gap would widen significantly. This gap could be filled by blending-down of additional HEU and other Government-held stockpiles.

This additional capacity could be brought about by expanded production of existing facilities and by removal of any obstructions that hinder smooth flow of production of existing facilities. In the longer term, after the expiration of the existing HEU-LEU agreement, the supply gap would widen significantly. The following possible resources could fill this supply gap. Other sources could help fill the supply gap. These include:

- Construction of additional conversion capacities;
- Reduction of the tails assay;
- Increased conversion supplies in form of LEU, provided by the Russian Federation: This option is directly linked to the supply by Russian enrichment services, but would also depend on uranium availability in the Russian Federation;
- Supply by the Russian Federation of "pure" conversion services: This option could be exercised if the then prevailing conversion market conditions would make it economically feasible in the view of significant logistics-related costs; and
- Accelerated recycling of MOX and RepU.

Enrichment

There are only four large producers in the enrichment business, namely USEC, Eurodif/COGEMA, URENCO and ROSATOM/TENEX.

By 2005, two large operating enrichment plants will be more than 25 year old. Both USEC and Eurodif/COGEMA have started decision-making processes to replace their aging diffusion technologies.

Currently, more than 50% of USEC's SWU deliveries to its clients worldwide are based on the enrichment component of the HEU provided under the US-Russian HEU-LEU Agreement. But this Agreement will expire in 2013. Thus, in order to stay in the enrichment business beyond this date, USEC must select a replacement enrichment technology, demonstrate this technology's reliability and economic competitiveness, and establish industrial-sized plants in a timely manner.

Western market SWU needs can be covered by primary and secondary sources until the end of this decade. At that time, according to schedules published by USEC and

Eurodif/COGEMA, the industry will enter the period when new centrifuge plants are likely to replace and/or supplement the old gaseous diffusion plants.

SWU contained in down-blended Russian HEU, will account for about 16-18% of aggregate enrichment requirements over the period 2003-2013, making this source of supply a very important element of the western market's SWU supply pattern. Given URENCO's enrichment capacity expansion plans and capacity flexibilities of the still operating diffusion plants, currently no gap between SWU demand and supply is expected to occur before 2013.

After 2013, the 5.5 million SWU/year currently coming from the HEU-LEU deal could be replaced as follows:

- Capacity increases in the West; and
- Accelerated recycling of MOX and RepU; more SWU supply from the Russian Federation made possible by enrichment capacities freed due to the expiration of the HEU-LEU Agreement.

5.3.4. Eastern market (Russian-design reactors)

For the Russian uranium portfolio the calculated net gain of the US-Russia HEU-LEU Agreement (taking into account the terms of the USDOE-former MINATOM Agreement of 24 March 1999) is only about 500 tonnes of uranium as UF_6. Thus, this deal is of little importance for the uranium supply security in the Eastern market (see Figure 4). In Figure 4 the category 'Other Secondary Sources' comprises material gained from the enrichment of western tails in Russian enrichment facilities and retained by Russian Federation, the natural uranium equivalent of MOX fuel and RepU, as well as the natural uranium equivalent of the HEU Feed (in the form of UF_6) replaced by USEC under the US-Russia HEU-LEU Agreement.

The same applies to conversion supply security in the Eastern market. Furthermore, while the deal is of importance for the overall load of the Russian enrichment facilities, it is of no importance at all for the SWU supply security in the CIS and eastern Europe.

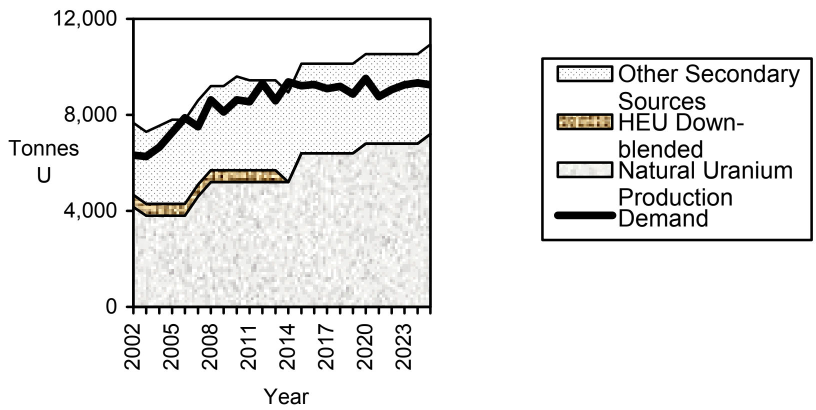

Fig. 4. Russian reactors uranium demand and supply. Data are based on the report of World Nuclear Association (WNA) [21] projections plus input from the experts.[5]

[5] See footnote on p. 25.

6. TECHNICAL ISSUES

6.1. Minor uranium isotopes (^{232}U, ^{234}U, ^{236}U)

Some of the US excess HEU comes from the weapons material production reactor fuel cycle, which has been irradiated and reprocessed repeatedly. Consequently, it contains significant levels of minor uranium isotopes such as ^{232}U, ^{234}U and ^{236}U. Since chemical processing does not alter the isotopic composition of the uranium, the LEU product may still be off-specification with respect to minor uranium isotopes. Special care must be taken in down-blending this material to ensure that the resulting LEU, though off-spec, is still usable in power reactors. In the case of LEU with ^{236}U impurity, it must be compensated by a slightly higher ^{235}U assay than normal due to the neutron poisoning effect of ^{236}U.

If ASTM specifications are met, the LEU down-blended from HEU is exchangeable with LEU enriched from natural U. This is the case for the LEU from both the US and Russian HEU being sold by USEC.

Portions of the US excess HEU that come from the production reactor fuel cycle are alloyed with substantial quantities of aluminum, or contain traces of fission products, tritium or transuranics. These are being processed through solvent extraction facilities at Savannah River Site's H-Canyon and at NFS to remove these contaminants prior to down-blending to LEU.

Additional quantities from the Russian Federation may have more issues with minor isotopes. Other contaminants include fission products, transuranics, alloyed metal, tritium, etc. Purification of the Russian HEU is being performed at the Siberian Chemical Combine at Tomsk and at the Mayak Production Association at Chelyabinsk.

6.2. Availability of processing facilities and transportation containers

- Special facilities are being constructed by Framatome ANP and NFS in the USA to handle off-spec HEU/LEU on behalf of TVA;

- Existing down-blending facilities in the USA are currently operating near their full capacity;

- Initially, the availability of facilities in the Russian Federation was a factor in the slow start of the implementation of the US-Russia HEU-LEU Agreement; Since then, new facilities in the Russian Federation have been added to a total capacity of processing up to 50 tonnes HEU/year (possibly increasing to 60 tonnes HEU/year); and

- Transport of LEU with ^{235}U assays of close to 20% ('20% LEU') requires dedicated shipping containers, which are currently available in limited quantities only. Accelerated down-blending of Russian HEU to 20% LEU may require significant numbers of additional shipping containers.

6.3. Radiological and fabrication issues

- To transport the off-specification materials of different chemical forms (solutions, oxides, and fuel assemblies), special Type B shipping containers are developed and licensed due to the presence of ^{232}U, ^{234}U and ^{236}U;

- To avoid contamination of their normal fuel fabrication facilities with these minor isotopes or other minor contaminants in the off-spec material, Framatome ANP, which is making the off-spec fuel for TVA, is building special facilities to convert the LEU solutions to oxide, and to sinter and pelletize the oxide; and

- Similarly, the elevated ^{232}U levels in some of the off-spec HEU require special shielding at the USDOE facilities that will package and ship it. Some of the decay products of ^{232}U, particularly ^{208}Tl, generate highly energetic gamma radiation that can pose a significant hazard to workers if not handled appropriately.

7. SUMMARY AND CONCLUSIONS

High enriched uranium (HEU) was the essential nuclear material used for both military and peaceful nuclear applications. Historically, HEU, with ^{235}U assays of 20 to 98%, has been used for manufacturing nuclear weapons, naval propulsion fuel and fuel for research reactors.

Large HEU inventories were built up in the USA and former USSR/Russia, largely for national defence purposes. The former USSR/Russia is estimated to have produced 1 050 tonnes of HEU between 1950 and 1988. The USA produced 750 tonnes of HEU between 1945 and 1992. Approximately a total of 67 tonnes of HEU were produced by other nuclear weapons States (NWS). While most of the HEU were produced for military purposes, smaller quantities have been used as fuel for civilian research and power reactors.

It is widely recognized that control of fissile materials is the primary deterrent to nuclear weapons proliferation, and that both military and civilian HEU pose potential proliferation threats. Therefore, it is incumbent on the world community to have a complete accounting of HEU and to ensure that it is properly stored, monitored and controlled to prevent it from falling into the wrong hands. The Nuclear Non-Proliferation Treaty (NPT) of 1968, which now has 188 signatory countries, remains the cornerstone of international efforts to prevent the spread of nuclear weapons. Arms control agreements between the Russia (former USSR) and the USA have dismantled thousands of nuclear weapons from their respective military stockpiles, which in turn have produced stockpiles of excess weapons-grade HEU from the dismantled weapons.

To lessen the proliferation threat of the weapons-grade HEU stockpiles, in accordance with the US-Russia HEU-LEU Agreement, the USA had agreed to purchase LEU down-blended from 500 tonnes of excess Russian HEU derived from dismantling of Russian nuclear weapons. In addition, 174 tonnes of US HEU had been declared excess. LEU derived from these excess inventories is converted to civilian nuclear fuel and now supplies about 15% of annual uranium requirements for global power reactors.

Proliferation concerns about HEU have also resulted in a global effort to eliminate use of HEU in civilian research and test reactors. High-density fuel has been developed that allows research reactors to lower their enrichment requirements to 19.75% ^{235}U, which is below requirements for manufacturing nuclear weapons. This programme has led to the conversion of 31 western research reactors from HEU to LEU fuel; five additional western research reactors are in the process of converting from HEU to LEU. The Russian Federation also has a programme to reduce research reactor fuel to ^{235}U assays of less than 20%.

In parallel with development of lower enrichment nuclear fuels, both the Russian Federation and the USA have implemented spent fuel 'take back' or repatriation programmes under which they accept research reactor spent fuel derived from US or Russian origin material. Approximately 5600 spent fuel assemblies containing in excess of 700 kg spent HEU have been received from 27 countries under the US programme. The Russian programme is expected to result in the return of 2 000 kg of HEU and 2 500 kg of LEU to the Russian Federation for reprocessing. The USA and the Russian Federation have made significant progress toward avoiding proliferation and misuse of HEU in research reactors through their reducing enrichment and spent fuel return programmes.

The international nuclear community has also made significant progress towards identifying and beginning to reduce stockpiles of military HEU. For example, as of May 2003, under the US-Russia HEU-LEU Agreement (popularly termed the 'megatons to megawatts' programme), about 184 tonnes of HEU, the equivalent of more than 7 000 warheads, have been converted to LEU. Much of the excess HEU will eventually be converted to LEU for use in civilian power reactors. The US-Russia HEU-LEU Agreement will ultimately result in production of about 15 000 tonnes of LEU, enough to generate 6 trillion kilowatts of electricity or enough to light the entire USA for about two years.

The overall non-proliferation benefits of the US-Russia HEU-LEU Agreement, which will reduce the weapons-grade HEU stockpile by 500 tonnes, are unquestioned. At the same time, the Agreement represents a significant supply of uranium and conversion and enrichment services, and as such significantly impacts the uranium, conversion and enrichment markets. For example, the yearly natural uranium content of the related LEU delivered under the Agreement is about 9 100 tonnes. By comparison, the all-time maximum annual production from a single mine was 7 100 tonnes of U from the McArthur River mine in Canada. Therefore, the US-Russia HEU-LEU Agreement represents the largest single source of uranium effectively replacing 9 100 tonnes of newly produced uranium annually. Similarly the HEU-LEU deal provides conversion services equivalent to 9 100 tonnes of uranium/year as UF_6, which is equal to the average annual production of the existing commercial plants. Likewise, the 5.5 million SWU/year brought to the market by the HEU-LEU Agreement nearly equals the total annual output of URENCO's centrifuge plants and is close to current US enrichment production.

The marketplace has gradually assimilated the impact of the US-Russia HEU Agreement. uranium production has been scaled back through closure of economically marginal operations and reduced output from other mines. Freshly produced uranium currently accounts for only about 53% of annual reactor uranium requirements worldwide, with the balance of supply coming from the HEU Agreement (approximately 15%), inventory drawdown, MOX and RepU (see Figure 2). Similarly, in response to the Agreement, western conversion plants have reduced annual output or in some cases have closed, bringing production and demand approximately into balance. SWU contained in Russian HEU will account for about 16% of aggregate enrichment requirements through 2013.

The current US-Russian HEU-LEU Agreement will expire in 2013. New arms control agreements will probably provide additional excess HEU. However, there is no assurance that either the Russian Federation or the USA will be willing to extend the Agreement beyond its primary term and if so under what conditions. While the short- and mid-term markets have adjusted to the current Agreement there remains uncertainty as to what will happen as far as long-term HEU availability is concerned. So far that uncertainty has led to depressed uranium prices, delayed development of new uranium production capacity and static conversion and enrichment markets. Certainty as to the disposition of future HEU surpluses is expected to contribute to more stability in these markets.

Additional factors such as possible demand for very large share of future electricity generation by nuclear and concomitant necessary preparations for future capacity building especially in the front-end of the fuel cycle as well as inevitable long-lead-times for obtaining environmental clearances, licenses and construction of such capacity should be considered. In this regard, multilateral discussions on the future availability of HEU might help in formulating strategies, which are completely complementary.

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APPENDIX I. DISARMAMENT TREATIES, NON-PROLIFERATION, IAEA SAFEGUARDS AND PHYSICAL PROTECTION

I-1. TREATIES

Several bilateral arms control treaties, as well as the multilateral Nuclear Non-Proliferation Treaty, have major impacts on the worldwide management of HEU inventories.

I1.1 SALT Treaties

The Treaty Between the United States of America (USA) and the Union of Soviet Socialist Republics (USSR) on the Limitation of Strategic Offensive Arms, (SALT I, 1972, and SALT II, 1979) placed limits on the numbers of launchers for strategic nuclear weapons permitted by the two nations. Although the SALT II Treaty never formally entered into force, both sides adhered to its limits. Since no limits were imposed on warheads, these treaties did not result in any HEU being declared excess.

I1.2 START Treaties

The Treaty Between the USA and the Russian Federation on Further Reduction and Limitation of Strategic Offensive Arms (START I), concluded in 1991 between the USA and the USSR/Russia, and since 1994 in force as a multilateral agreement among the USA, the Russian Federation, Belarus, Kazakhstan, and Ukraine, is the first arms control agreement that required reductions in the numbers of nuclear warheads by the superpowers. December 2001, marked the successful completion of the third phase of reductions in strategic offensive arms required by the Treaty. The USA and the Russian Federation each now maintain fewer than the Treaty's mandated limits of 1 600 deployed strategic delivery vehicles and 6 000 accountable warheads, a reduction of some 30 to 40 % of aggregate levels since 1994, when the Treaty entered into force. In addition, all nuclear warheads and strategic offensive arms have been removed from Belarus, Kazakhstan, and Ukraine. The START I Treaty is directly responsible for the identification of excess fissile materials, including HEU and weapons-grade plutonium, by the USA and the Russian Federation.

In 1991, US President George H.W. Bush and Russian President Boris N. Yeltsin signed the START II treaty. This treaty called for the elimination of almost two-thirds of the nuclear warheads and all the multiple-warhead land-based missiles controlled by the USA and the former Soviet republics. In January 1996, the US Senate ratified the START II treaty, but the Russian parliament never approved the accord. The START II treaty never went into effect, and in 2002 it was replaced by a new strategic arms reduction agreement known as the Treaty of Moscow.

I1.3 Treaty of Moscow

Under this 2002 agreement, negotiated by Presidents George W. Bush and Vladimir Putin, both nations are to reduce their active inventories of strategic nuclear warheads from about 6 000 each to about 2 200 warheads each by the year 2012. The agreement, known as the Treaty of Moscow, was ratified by both the US Senate and the Russian Parliament. The new Treaty replaces the previous START II Treaty. Either side can withdraw from the Treaty with only three months notice, and the reductions do not have to take effect until 2012, the same year the Treaty expires. The Treaty also enables both nations to place the deactivated warheads in storage or to set them aside as "operational spares" that could be quickly reactivated. At the time of this writing, neither nation has declared that it will actually dismantle additional weapons as a result of the new Treaty, so it is not clear whether it will result in additional excess fissile materials.

I1.4 Non-Proliferation Treaty

One of the most important agreements on arms control is the Nuclear Non-Proliferation Treaty of 1968 (NPT) [A1]. Signatories pledged to restrict the development, deployment, and testing of nuclear weapons to ensure that weapons, materials, or technology would not be transferred outside the five countries that had nuclear weapons (Great Britain, France, China, the USA, and the USSR/Russia). The NPT also strengthens the global nuclear safeguards regime of the International Atomic Energy Agency (see Section I3). In 1995 more than 170 countries agreed to permanently extend the Treaty. As noted by the US Department of State, “The NPT remains the cornerstone of international efforts to prevent the further spread of nuclear weapons. With nearly 190 states as parties, it is the most widely adhered to arms control agreement in history [A2].

This international instrument is augmented by a number of regional non-proliferation treaties [A3], providing for additional measures that reflect the political aspirations of states in the regions in question. The following treaties are in force or in the process of ratification:

(i) The Tlatelolco Treaty: The Treaty for the Prohibition of Nuclear Weapons in Latin America, which was opened for signature in 1967;

(ii) The Rarotonga Treaty: The South Pacific Nuclear Free Zone Treaty, which entered into force in 1986;

(iii) The Bangkok Treaty: The Southeast Asia Nuclear Weapon-Free Zone Treaty, which entered into force in 1997; and

(iv) The Pelindaba Treaty: The African Nuclear-Weapon-Free Zone Treaty, which was opened for signature in 1996.

In addition, the European states have created a system of safeguards administered by the European Atomic Energy Agency (EURATOM). In addition to the international and regional non-proliferation instruments, a large number of bilateral agreements on peaceful nuclear cooperation have been concluded between states to facilitate the transfer of nuclear material and technology. Most of these agreements provide for the application of IAEA safeguards to any transferred nuclear material. For example, Argentina and Brazil concluded in 1990 an arrangement (ABAAC) creating a bilateral inspectorate to apply full scope safeguards in both States.

In addition to providing a barrier against nuclear explosives development, guidelines for nuclear export and import controls determined by the IAEA also support a state’s fundamental regulatory task of preventing unauthorized persons in that state from acquiring nuclear material and technology [A4]. Establishing an adequate legislative framework for nuclear export and import controls is important for all states. Even states that are neither exporters nor importers of nuclear material or technology need a basis for controlling nuclear transfers through their territories. The purpose of transit jurisdictions is to ensure that states do not become unwitting accessories to improper nuclear transfer schemes.

I2. NATIONAL NON-PROLIFERATION PROGRAMMES

I2.1 United States non-proliferation legislation and programmes

US Atomic Energy Act of 1954 and Nuclear Non-Proliferation Act of 1978: The Atomic Energy Act of 1954 established rules for nuclear commerce, which have become the international norm. The Atomic Energy Act requires that a bilateral nuclear cooperation agreement be negotiated between the USA and any other country before major nuclear technology can be exported to that country. The Nuclear Non-Proliferation Act of 1978 strengthened those earlier rules and established the requirement of full scope safeguards as a condition of supply. This means that any country except the five NPT weapon-states that wants to import nuclear technology from the USA must accept the IAEA safeguards on all of its nuclear facilities.

US RERTR Programme and the "Schumer Amendment" to the energy policy act of 1992: To further reduce the danger of nuclear weapons proliferation, the USA in 1978 initiated the Reduced Enrichment for research and Test reactors (RERTR) programme, which was aimed at reducing the use of HEU in civilian programmes by promoting the conversion of US and foreign research reactors from HEU fuel to LEU fuel. research reactor fuel has become the major civilian use of HEU. But as part of the RERTR programme, the USDOE developed LEU fuel and worked with foreign research reactor operators to convert their reactors to run on such fuel.

The foreign research reactor operators who converted to LEU fuel did so in support of nuclear weapons non-proliferation objectives. The Schumer Amendment added a legislative requirement that the USA will discontinue supplying HEU for foreign research reactors unless rigorous requirements indicating progress toward conversion to LEU fuel are satisfied. The RERTR Programme has been remarkably successful at reducing civil use of HEU. A significant number of the western world's research and test reactors have already been converted to LEU fuel use, and many of those remaining may be converted in the future.

US 1993 Non-proliferation and export control policy and 1994 surplus declaration: In 1993, US President Clinton issued the Non-Proliferation and Export Control Policy statement, which, among other things, undertook "a comprehensive approach to the growing accumulation of fissile material from dismantled nuclear weapons and within civil nuclear programmes." The policy stated that the USA would:

- Seek to eliminate where possible the accumulation of stockpiles of HEU or plutonium, and to ensure that where these materials already exist they are subject to the highest standards of safety, security, and international accountability;

Propose a multilateral convention prohibiting the production of HEU or plutonium for nuclear explosives purposes or outside of IAEA international safeguards;

Encourage more restrictive regional arrangements to constrain fissile material production in regions of instability and high proliferation risk;

Submit US fissile material no longer needed for US defense purposes to inspection by the IAEA;

- Pursue the purchase of HEU from the former Soviet Union and other countries and its conversion to peaceful use as reactor fuel;

- Explore means to limit the stockpiling of plutonium from civil nuclear programmes, and seek to minimize the civil use of HEU; and

- Initiate a comprehensive review of long-term options for plutonium disposition, taking into account technical, non-proliferation, environmental, budgetary and economic considerations. The Russian Federation and other nations with relevant interests and experience would be invited to participate in this review.

In 1994, then-US President Clinton declared in a speech that, "To further demonstrate our commitment to the goals of the [Non-Proliferation] Treaty, today I have ordered that 200 tonnes of fissile material - enough for thousands of nuclear weapons - be permanently withdrawn from the US nuclear stockpile. It will never again be used to build a nuclear weapon." [A5] This constituted the beginning of the US excess fissile materials disposition programme. Subsequent announcements by the USDOE clarified that the excess material consisted of 174 tonnes of HEU, and 34 tonnes of plutonium. A September 2001 agreement between the USA and the Russian Federation addressed disposition of 34 tonnes of excess weapons-grade Pu in both countries.

I2.2 Russian Federation non-proliferation legislation and programmes

Starting from the first years of research reactor operation the uranium enrichment in fuel elements consecutively increased from 20 to 36% and eventually up to 90% ^{235}U. This option was used in the former USSR/Russia as well as in western countries. Nevertheless, the maximum enrichment in the fuel elements exported from the USSR/Russia was limited to 80% ^{235}U.

The USSR/Russia supported the reduction of uranium enrichment according to the recommendations of the International Nuclear fuel Cycle Evaluation (INFCE) study [A6].

Chapter 1.4 of the INFCE Report of Working Group 8 [A6], which discussed problems of the research reactor fuel cycle, emphasized that 'Proliferation resistance can be increased by:

- Enrichment reduction preferably to less than 20%, which is internationally recognized to be a fully adequate isotopic barrier to weapons usability of ^{235}U;

- Reduction of HEU stockpiles; and

- Reduction of the annual production of fissile materials in research reactors, although attainment of weapons-usable material would require spent fuel reprocessing.

USSR/Russia-manufactured fuel elements with HEU were used in 11 foreign research reactors with a total power of 99.5 MW(th).

In the late 1970s, the Government of the USSR/Russia, in accordance with INFCE recommendations decided to initiate activities aimed at reducing uranium enrichment in research reactors as a contribution toward international non-proliferation goals. In 1978, the USSR/Russia Minsredmash (predecessor of the Federal Atomic Energy Agency (ROSATOM)) passed a resolution, which prohibited uranium supply with enrichment over 21% for research reactors after modernization with USSR/Russia technical assistance. Special permission of the Ministry was required to supply fuel with 21% for some reactors. Therefore, even after the resolution had been put in force, fuel with uranium enrichment above 21% was exported on a case-by-case basis.

In the early 1980s, the Russian Programme of Reducing of Enrichment in research and Test reactors (RERTR) was started [A7]. This programme provided for development of new fuel elements and assemblies with higher uranium density in the fuel core. However, questions of repatriation of spent nuclear fuel from foreign research reactors to the Russian Federation have not been entirely resolved.

The main technical points of the Russian RERTR Programme were:

- Geometric sizes of fuel elements and assemblies shall be kept unchanged. Only the fuel core must be denser;
- Excess reactivity and fuel burnup in unloaded fuel assemblies shall remain essentially as originally designed;
- The reactor power shall be kept at the original level; and
- There should be only a minor increase in the fuel cost related to unit mass of ^{235}U.

In the early 1980s, the main type of fuel composition in Soviet research reactors was uranium dioxide dispersed in an aluminum matrix. At the first stage of the Russian RERTR Programme new fuel elements with uranium enrichment reduced to 36% were developed. The geometries of the new elements and fuel assemblies were identical to fuel with 80% enrichment and neutron-physical characteristics were practically the same, as were the characteristic initial assemblies with LEU.

The successful implementation of the first stage of the Russian RERTR Programme has resulted in the development of new fuel compositions with high uranium density in the fuel elements. Since 1986, the USSR and later the Russian Federation started supplying research reactors with fuel enrichment not over 36% ^{235}U.

The second phase of the Programme provided a further decrease in uranium enrichment to less than 20% based on new fuel compositions with higher density, for example uranium silicide. The second phase of the Russian RERTR Programme has not yet been finished due to insufficient funds.

The INFCE Working Group Report also addresses the final stage of irradiated fuel management. This issue, which is not part of the Russian RERTR Programme, has become more complicated due to lack of funds as well as the requirement for the conduct of so-called ‘environmental expertise’ for the repatriation of Russian-origin nuclear fuel (SNF) from research reactors.

In the early 1990s, new Russian legislation was put into force, which defined rules for export and import of nuclear materials. Chapter XIV of the Russian Federal Law on the use of atomic energy (1995) established principles for export and import of nuclear materials, nuclear equipment and facilities, etc. Nuclear exports and imports must be conducted in accordance with the international obligations of the Russian Federation on nuclear non-proliferation and the international agreements of the Russian Federation in the sphere of the use of atomic energy.

Russian nuclear export-import rules were established in Decree #574 of the Russian Federation (1996). This decree defines conditions of export and import of nuclear materials, equipment, special non-nuclear materials and technologies. According to this definition, critical nuclear exports include, for example, uranium with more than 20% enrichment, plutonium and fuel reprocessing facilities. The multilevel procedure for critical nuclear export licensing in the Russian Federation is quite strong.

I3. IAEA SAFEGUARDS

I3.1 Safeguards role — based on the NPT

Under the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the IAEA is the agency that verifies States' "peaceful use" commitments, made under the NPT or similar agreements. The Agency does this through its "safeguards" role.

Under the NPT and similar agreements, governments around the world have committed to three common objectives:

- preventing the proliferation of nuclear weapons;
- pursuing nuclear disarmament;
- promoting the peaceful uses of nuclear energy.

The NPT has made it obligatory for all its non-nuclear weapon State (NNWS) parties to submit all nuclear material in nuclear activities to IAEA safeguards, and to conclude a comprehensive safeguards agreement with the Agency. With all but a handful of the world community as State parties, the NPT is by far the most widely adhered-to legal agreement in the field of disarmament and non-proliferation.

There are five nuclear-weapon States party to the NPT, namely China, France, the Russian Federation, the United Kingdom and the United States; and there are more than 180 NNWS party to the NPT. These NNWS have pledged not to develop or otherwise acquire nuclear weapons.

I3.2 Safeguards purposes

'Safeguards' is a set of activities by which the IAEA seeks to verify that a State is living up to its international undertakings not to use nuclear materials, activities or programs for nuclear weapons purposes. The IAEA safeguards nuclear material and activities under agreements with more than 140 States. The IAEA's safeguards system functions as –

- a confidence-building measure;
- an early warning mechanism; and
- the trigger that sets in motion other responses by the international community if and when the need arises.

IAEA safeguards helps to provide assurance that nuclear material and activities are not diverted or misused in order to develop or produce nuclear weapons, and that no material or activities which are required to be declared under the NPT and/ or the safeguards agreements remain undeclared.

The safeguards system is based on assessment of the **correctness** and **completeness** of the State's declarations to the IAEA of their nuclear material and nuclear-related activities. To date, 145 States have entered into such agreements with the IAEA, submitting nuclear materials, facilities and activities to the scrutiny of IAEA's safeguards inspectors.

Over the past decade, IAEA safeguards have been strengthened in key areas. The measures aim to increase the likelihood of detecting a clandestine nuclear weapons programme, to build confidence that States are abiding by their international commitments, and thus to further allay security concerns among States regarding the development of nuclear weapons.

I3.3 Nuclear material and activities safeguarded by the IAEA

The IAEA takes account of all "source and special fissionable material" in countries under safeguards. Monitoring and verification activities focus on those types of nuclear material that are the most crucial and relevant to nuclear weapons manufacturing. This includes plutonium-239, uranium-233 and -235 and any material containing one or more of these. Safeguards activities are applied routinely at over 900 facilities in 71 countries. Each year, some 250 IAEA inspectors devote more than 21,000 days "in the field" to verifying hundreds of tons of special fissionable material.

When comprehensive safeguards agreements first became a requirement under the Treaty for the Prohibition of Nuclear Weapons in Latin America (1967) and subsequently under the NPT (1968), the IAEA established a safeguards standard which became INFCIRC/153 (Corrected) [A8], [A9]. This is suitable for application to both simple nuclear activities and to complex nuclear fuel cycles, i.e. a system applicable to reactors and to conversion, enrichment, fabrication and reprocessing plants which produce and process reactor fuel.

The State has an obligation to declare to the IAEA, when the agreement enters into force, all nuclear material and facilities subject to safeguards under the agreement. The State also has an obligation to update this information and to declare all new nuclear materials and facilities, which subsequently become subject to the terms of the agreement.

The IAEA uses nuclear material accountancy as its basic measure for safeguarding declared material. The system monitors the quantities of nuclear material present in a nuclear facility and the changes in these quantities that take place over time. In addition, the IAEA analyses all relevant information obtained through inspections and from other sources to ensure consistency with State declarations.

Under a safeguards system that is based on INFCIRC/153 (Corr.) alone, the capability of the IAEA to detect undeclared nuclear activities is limited. IAEA inspections have focused on declared nuclear material, and were centred on strategic points in declared facilities.

I3.4 Strengthened Safeguards: the Additional Protocol

The developments in the 1990s prompted the IAEA to develop and implement new measures in order to improve its ability to detect undeclared nuclear material and nuclear-related activities. The discovery of Iraq's clandestine nuclear weapons program demonstrated that limited information and access rights could seriously constrain the IAEA in fully exercising its verification and detection capabilities.

New and extended IAEA mechanisms for verification have been demonstrated to be an effective way to address the problem of detecting clandestine or undeclared nuclear activities. These measures require new legal authority through an Additional Protocol (based on INFCIRC/540 (Corr.)) to a State's safeguards agreement: this is the key to the strengthened safeguards system [A10]. The AP is a legal document granting the IAEA additional inspection authority to that provided in underlying safeguards agreements. A principal aim is to enable the IAEA inspectorate to provide assurance about both **declared** and **possible undeclared** material and activities. Under the AP, the IAEA is granted expanded rights of access to information and locations, as well as additional authority to use the most advanced technologies during the verification process. The State is required to provide the IAEA with broader information covering all aspects of its nuclear fuel cycle-related activities, including research and development and uranium mining. Specific measures provided for in an Additional Protocol include:

- information about, and access to, all aspects of States' nuclear fuel cycle, from uranium mines to nuclear waste and any other locations where nuclear material intended for non-nuclear uses is present;
- short-notice inspector access to all buildings on a nuclear site;
- information on the manufacture and export of sensitive nuclear-related technologies and inspection mechanisms for manufacturing and import locations;
- access to other nuclear-related locations;
- collection of environmental samples beyond declared locations when deemed necessary by the IAEA.

With wider access, broader information and better use of technology, the Agency's capability to detect and deter undeclared nuclear material or activities is significantly improved. To do this effectively requires broad information from States on nuclear and nuclear-related activities, and access for IAEA inspectors, as well as more simplified administrative procedures for inspections than those established under comprehensive safeguards agreements alone. Several new measures were implemented to strengthen safeguards' effectiveness under existing safeguards agreements:

- IAEA collection of environmental samples in facilities and at locations where inspectors have access during inspections and design information visits. Sample Analysis is at the IAEA Clean Laboratory and/or at certified laboratories in Member States.
- IAEA use of unattended and remote monitoring of movements of declared nuclear material in facilities and the transmission of authenticated and encrypted safeguards-relevant data to the Agency.
- IAEA expanded use of unannounced inspections within the scheduled routine inspection regime.
- IAEA enhanced evaluation of information from a State's declarations, IAEA verification activities and a wide range of open sources.
- State provision of design information on new facilities or on changes in existing facilities handling safeguarded nuclear material as soon as the State authorities decide to construct, authorize construction or modify a facility.
- IAEA right to verify the design information over the facility's lifecycle, including decommissioning.
- State voluntary reporting on imports and exports of nuclear material and exports of specified equipment and non-nuclear material.
- Closer co-operation between the IAEA and the State (and regional) systems for accounting for and control of nuclear material in Member States.
- Provision of enhanced training for IAEA inspectors and safeguards staff and for Member State personnel responsible for safeguards implementation.

Conclusion

Ultimately the strength of the IAEA safeguards system depends upon three related elements:

- the extent to which the IAEA is aware of the nature and locations of States' nuclear material and activities;
- the extent to which IAEA inspectors have physical access to these locations in order to provide independent verification of the exclusively peaceful intent of a State's nuclear program; and
- the will of the international community, through the United Nations Security Council, to take action against States that are not complying with their safeguards commitments to the IAEA.

By entrusting an impartial inspectorate with the task of verifying the peaceful use of nuclear energy, the international community has taken an important step in the direction of peace and international security. This is based upon States' readiness to submit to inspection of their nuclear activities, to demonstrate their transparency and, thus, to mutually assure their peaceful nature. By signing on to the strengthened safeguards system, by dealing promptly and responsibly with cases of safeguards violations, and by providing the Agency with the resources necessary to do the job, States demonstrate the political will to strengthen the safeguards system for the common good.

More information on IAEA safeguards can be found in the referenced documents [A11], [A12] and [A13].

I4. PHYSICAL PROTECTION

The events of 11 September 2001 in New York exemplified the growing dangers posed by terrorist groups, and highlighted the need to upgrade existing physical protection measures for nuclear material and facilities. The increasingly global nature of nuclear commerce and cascading developments in fields as diverse as transport, communications and information technology make it essential that states follow international best practice in trying to limit threats directed at nuclear material and/or facilities. Over the past three decades the IAEA has been developing a number of international instruments to help strengthen physical protection in individual IAEA Member States and to encourage greater consistency in requirements and procedures among states in this important area. The IAEA has established a physical protection advisory service, which offers international expert peer reviews, and coordinates donor state assistance for upgrading physical protection, at the request of IAEA Member States. Significant physical protection upgrades have been accomplished in several Member States. More in depth descriptions on the physical protection of nuclear materials and systems can be found in the referenced Agency publications [A14], [A15], [A16], [A17], [A18] and [A19].

Basic guidelines and recommendations for the physical protection of nuclear systems and materials were developed by the Agency in 1972. Subsequently, the guidelines have been revised several times. These guidelines cover physical protection for nuclear materials in use, storage and transport both domestically and internationally. In any international transport of nuclear materials, the implementation of effective physical protection systems is of direct concern to the shipping, receiving and transit states. The Convention on the Physical Protection of Nuclear material (CPPNM), which was signed in 1980, obligates Contracting States to ensure the protection of nuclear material within their territory or on board their ships or aircraft during international nuclear transport. The CPPNM, which entered into force in 1987, obligates Contracting States to implement specific protection measures for nuclear material in international transport. An important feature of the CPPNM is its categorization of nuclear material by type and quantity for the purposes of applying physical protection levels. In summary, the CPPNM requires Contracting States to:

- Make certain physical protection arrangements and ensure specific defined levels of physical protection for international shipments of nuclear material;

- Co-operate in the recovery and subsequent protection of stolen nuclear material; and

- Make specified acts (e.g. thefts of nuclear material and threats or attempts to use nuclear material to harm the public) punishable offences under national law; and

- Prosecute or extradite those accused of committing such acts.

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GLOSSARY

30B Container	Typical cylinders used for natural and enriched uranium hexafluoride (UF_6) are 48Y and 30B. Each standard type of cylinder is used within limits of quantity and ^{235}U assay, and is subject to shipping limits. 48Y cylinders are used for UF_6 storage and transport where the assay is below 1% ^{235}U and they hold about 8.4 tonnes of uranium (12 501 kg of pure UF_6 being the maximum net weight authorised for shipping). 30B cylinders are used when the assay is above 1% and they contain about 1.5 tonnes (2 277 kg of pure UF_6 being the maximum weight authorised for shipping). Cylinders must meet a series of rigorous testing and regulatory requirements before they are certified as containers for UF_6.
Assays	Analysis (as for uranium fuel components) to determine presence, absence or quantity of one or more components.
Blendstock	Material used to dilute the concentration of fissile materials (principally ^{235}U or ^{239}Pu) when blended with a feedstock containing relatively high concentrations of fissile materials.
Conversion	The process by which the product from a uranium processing plant is transformed into another chemical form suitable for subsequent processing. Conversion most frequently refers to natural uranium conversion, whereby uranium concentrates are purified and converted into uranium hexafluoride (UF_6), prior to enrichment. Conversion also sometimes refers to the transformation of natural uranium or enriched uranium hexafluoride to uranium dioxide (UO_2) or to uranium metal as a preliminary step in nuclear fuel fabrication.
Depleted uranium	Uranium with ^{235}U concentration lower than the 0.711% occurring in natural uranium. Depleted uranium is a residual product of the enrichment process.
Eastern market	Elements of the nuclear fuel cycle in the Commonwealth of Independent States (CIS) and Central and Eastern Europe, which have Russian-design reactors.
Enrichment tails (or tails)	The relatively depleted fissile uranium (^{235}U) remaining after the enrichment process. The natural uranium 'feed' contains 0.711% ^{235}U (by weight). The product stream contains enriched uranium (more than 0.711% ^{235}U) and the waste stream or tails contains depleted uranium (less than 0.711% ^{235}U).
High enriched uranium	Uranium enriched to at least 20% ^{235}U by weight.
Low enriched uranium	Uranium enriched in the ^{235}U isotope from 0.711% by weight in natural uranium up to 19.999%.

Natural uranium Uranium which has a ^{235}U isotope concentration of 0.711% by weight, the isotopic content found in nature.

Production from planned projects Projected annual output from production facilities for which development and construction plans have been announced.

Prospective capacities Estimated annual production capacities of prospective uranium production facilities for which no development or production plans have been announced.

Reprocessed uranium Uranium extracted from spent fuel, which may return to the fuel cycle to be fabricated as new fuel.

Reprocessing The chemical separation of uranium and plutonium from spent fuel. Reprocessing allows the recycling of fuel material and minimizes the volume of high level waste.

Separative work units The standard measure of enrichment services. The effort expended in separating a mass F of feed of assay x_p and tails of mass T and assay x_t is expressed in terms of the number of separative work units needed, given by the expression. SWU = TV(x_t) + PV (x_p) - FV (x_f), where V(x) is the "value function," defined as
V(x) = (1-2x) ln ((1-x)/x).

Tails Same as 'Enrichment Tails'.

Western companies Collectively Cameco, COGEMA and RWE NUKEM. The three companies that have entered into an agreement with TENEX, which gives them the exclusive right to purchase a portion of the natural uranium feed from the US-Russia HEU-LEU Agreement.

CONTRIBUTORS TO DRAFTING AND REVIEW

Aboimov, M.A.	TECHSNABEXPORT, TENEX, Russian Federation
Capus, G.	COGEMA, France
Max, A.	RWE-NUKEM GmbH, Germany
Hadfield, A.C.F.	International Atomic Energy Agency
Kudriavtsev, E.G.	Federal Atomic Energy Agency, ROSATOM, Russian Federation
McMurray, J.	McMurray Geologic Consulting Inc, United States of America
Nawada, H.P.	International Atomic Energy Agency
Müller, H.	RWE-NUKEM GmbH, Germany
Tousley, D.	Department of Energy, United States of America

Consultants Meetings

Vienna, Austria: 2–4 December 2002, 3–5 June 2003, 6–8 August 2003

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