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# Multilateralization of the Nuclear Fuel Cycle:
## Assessing the Existing Proposals

*Yury Yudin*

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**About the cover**

Pellets of uranium dioxide are inserted into zirconium fuel rods and used in light water nuclear reactors to produce energy. United States Nuclear Regulatory Commission file photo.

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The United Nations Institute for Disarmament Research (UNIDIR)—an autonomous institute within the United Nations—conducts research on disarmament and security. UNIDIR is based in Geneva, Switzerland, the centre for bilateral and multilateral disarmament and non-proliferation negotiations, and home of the Conference on Disarmament. The Institute explores current issues pertaining to the variety of existing and future armaments, as well as global diplomacy and local tensions and conflicts. Working with researchers, diplomats, government officials, NGOs and other institutions since 1980, UNIDIR acts as a bridge between the research community and governments. UNIDIR's activities are funded by contributions from governments and donor foundations. The Institute's web site can be found at:

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## FOREWORD

In September 2008, the United Nations Institute for Disarmament Research (UNIDIR) began a research project entitled Multilateral Approaches to the Nuclear Fuel Cycle. Recognizing that multilateral fuel-cycle frameworks could benefit the whole of humankind, the project is concerned with assisting policy makers in discussing and ultimately negotiating such an approach to the nuclear fuel cycle.

The proliferation of nuclear weapons and nuclear terrorism are among the greatest threats to humanity. From the very outset of the nuclear age, the challenge has been to facilitate the civilian use of nuclear energy while prohibiting the spread of nuclear weapons. But the inherent link between military and civilian nuclear technology makes countering proliferation an especially difficult task. As Nobel laureate Hannes Alfvén said, "Atoms for peace and atoms for war are Siamese twins".

The peaceful and military uses of nuclear energy both depend essentially on the same key ingredient: fissile material. The revival of interest in nuclear power could result in the worldwide dissemination of uranium enrichment and spent fuel reprocessing technologies, which present obvious risks of proliferation as these technologies can produce fissile materials that are directly usable in nuclear weapons—high enriched uranium and separated plutonium.

Multilateral approaches to the fuel cycle, which would place the sensitive steps of the cycle under international control, could ensure that the benefits of nuclear energy are made available to all states that seek them, while strengthening the non-proliferation regime and ensuring safe and secure management of the fuel cycle.

There will be no easy solution found along this road, and numerous stumbling blocks lie ahead. Among these are the lack of trust, national self-interest, and various political, financial, and legal hurdles. Nonetheless, the world has no choice but to protect itself from the misuse of sensitive nuclear technologies. To be successful, multilateral nuclear fuel-cycle arrangements will inevitably require broad political consensus on how the international community can limit access to these technologies, while protecting states' rights to develop nuclear energy for peaceful purposes.

This book is the first published under the Multilateral Approaches to the Nuclear Fuel Cycle project, and is the most comprehensive analysis of existing proposals on fuel-cycle multilateralization available to date. We hope that those working in non-proliferation and security-related fields will find this publication stimulating and useful in helping to further develop and implement creative methods to address the challenges ahead.

Theresa Hitchens
Director
UNIDIR

## SUMMARY


The anticipated increase in global energy demand is driving a potential expansion in the use of nuclear energy worldwide. It is estimated that the global nuclear power capacity could double by 2030. To a large part the expected "revival" of nuclear energy is driven by the power plant construction programmes in countries that do not currently have established nuclear industries. This could result in worldwide dissemination of uranium enrichment and spent fuel reprocessing technologies. These sensitive nuclear technologies present obvious risks of proliferation as they are capable of providing states with materials that are directly usable in a nuclear weapon or a nuclear explosive device—high enriched uranium and separated plutonium.

Technical measures alone would not compensate for the limitations of the existing nuclear non-proliferation regime. Certain international institutional mechanisms, which are non-technical in nature and involve various political, economic or diplomatic strategies for controlling access to sensitive materials, facilities or technologies, are needed for dealing with this problem.

The focus of international efforts has recently been to try to develop a system of credible guarantees of supply of low enriched uranium (LEU) and nuclear fuel to assure customer countries that they will have a reliable fuel supply conditioned only on their meeting some predetermined qualifying non-proliferation criteria. Over the past few years, 12 proposals have been put forward by states, nuclear industry and international organizations, which aim at checking the spread of uranium enrichment and spent fuel reprocessing technologies, in particular by suggesting means of assuring nuclear fuel supplies and establishing international fuel cycle centres.

This book contains an overview and analysis of the 12 existing proposals on multilateralization of the nuclear fuel cycle, including an evaluation of the pros and cons of the various projected international mechanisms.

The proposals for a multilateral approach to the nuclear fuel cycle that are on the table differ considerably in their vision, scope, targets and time required for their implementation. The majority of the proposals are rather

limited in their goals, dealing primarily with the front end of the nuclear fuel cycle, that is, the supply of nuclear fuel and in particular LEU for power production.

In the category of short-term proposals can be counted the US national reserve of nuclear fuel, the Russian International Uranium Enrichment Centre (IUEC) at Angarsk, the Six-Country Concept combined with the World Nuclear Association proposal, and supplemented by the UK Enrichment Bonds and the Japanese Standby Arrangements. These projects would not require much work by the international community because they rely to a great extent on national policies. Many key elements of these projects are already in place and, what is more, two of these projects now proceed full steam.

The Nuclear Threat Initiative (NTI) Fuel Bank and the German Multilateral Enrichment Sanctuary Project (MESP) proposal are multilateral projects that would require new physical infrastructure and involve complex political, legal and financial issues that must be solved before making these projects a reality. Nevertheless, the NTI Fuel Bank can be counted as a simpler short-term project, while the German MESP proposal represents a more complex mid-term project.

The Russian Global Nuclear Power Infrastructure, the US Global Nuclear Energy Partnership and the Austrian proposal are in fact long-term conceptual visions.

It is evident that there would be no single, generic multilateral formula that would be satisfactory for all technologies and all countries and that successful implementation of multilateralization will depend on the flexibility of its application. The establishment of multilateral fuel cycle arrangements should be implemented step by step, with existing proposals pursued on their own merits.

While the current emphasis is on concepts for LEU and fuel supply assurances, this may only give modest incentives for customer states to participate, since the commercial market already provides reliable supplies of LEU and nuclear fuel. Proposals that respond to the “entitlement” motivation of the customer states, in terms of their participation in ownership, management, operation, decision-making, profit-sharing and so forth, perhaps would be more attractive for these states than just backup mechanisms for the existing market.

Proposals that would include removing spent nuclear fuel after it was used, as well as providing other back-end services, would create far stronger incentives to rely on international mechanisms for fuel supply.

Having guaranteed access to LEU will not help customer states immediately because they require a reliable supply of fabricated fuel assemblies to load into their power reactors. Creating a backup supply system for fuel fabrication would be more complicated because fuel design is specific to each reactor design. Fuel fabrication technology for uranium oxide fuel with LEU is not sensitive from a proliferation perspective. If countries choose to establish their own fabrication capabilities to produce fuel assemblies for their nuclear power reactors, without establishing uranium enrichment or spent fuel reprocessing capabilities, this should not pose significant international concern.

The existing ideas for multilateralization of the nuclear fuel cycle have all come from suppliers of front-end fuel cycle services, while the prospective customers have generally been lukewarm because they often, yet not always fairly, consider these ideas as technology denial approaches. The international mechanisms for multilateralization of the nuclear fuel cycle cannot credibly be tied to demands on the customer states to forgo some of their rights. Instead they should dissuade these states from developing indigenous sensitive fuel cycle technologies by offering palatable political and economic incentives as well as providing a certain “entitlement” motivation to participate. The issue of a multilateral approach to the nuclear fuel cycle needs to be addressed in terms of opportunity and advantage, not in terms of denial.

Although the success of implementation of multilateral approaches to the nuclear fuel cycle is by no means guaranteed, more progress in this direction has been made in the last five years than in the previous fifty. The Russian IUEC should start providing its uranium enrichment services in early 2009, and Russia decided to supply uranium for the first IAEA-controlled LEU reserve, which is to be located in Angarsk. Several other proposals are also being actively pursued, including the US-controlled reserve of LEU, the NTI Fuel Bank and the German MESP proposal.

Any real progress toward a multilateral approach to the nuclear fuel cycle can be achieved only in the context of broad agreement that, in the face of global problems such as nuclear proliferation and nuclear terrorism, an international non-discriminatory nuclear fuel cycle control regime has the potential to benefit the whole of humankind. Inhibiting the spread of sensitive nuclear technologies and nuclear-weapon-usable materials, while promoting better access to safe and clean energy, is undoubtedly in the interests of the world community.

## CHAPTER 1

# INTRODUCTION

For the last decade there has been talk of a coming nuclear revival or "renaissance". The anticipated increase in global energy demand is encouraging an expansion in the use of nuclear energy worldwide after the more than two decades of virtual stand-still as a consequence of the Three Mile Island accident of 1978 and the Chernobyl accident of 1986. The International Energy Agency (IEA) of the Organization for Economic Co-operation and Development (OECD) in its *World Energy Outlook* for 2007 estimated that "the world's primary energy needs are projected to grow by 55% between 2005 and 2030, at an average annual rate of 1.8% per year", while electricity use is projected to double, its share of final energy consumption rising from the current 17% to 22% by 2030.[1]

Several other factors have also contributed to the renewed interest in nuclear energy. First, limited and unevenly distributed supplies and the unpredictable cost of fossil fuels drive the search for alternative cost-competitive energy sources. Second, there is the increased awareness of the dangers and effects of global warming and climate change and the realization that nuclear power would have to be one of the major contributors in the global effort to reduce the emission of greenhouse gases. Now, nuclear power is the only readily available, proven technology that can serve as the large-scale alternative to fossil fuels for the continuous, reliable production of electricity. Third, an increasing shortage of fresh water calls for energy-intensive desalination plants, and nuclear reactors can be used to produce large amounts of potable water. Fourth, future hydrogen production for transport purposes would need large amounts of electricity or heat, which can potentially be provided by nuclear power plants.

As of September 2008, 439 nuclear power reactors were in operation in 30 countries with a total net installed electricity generating capacity of 372GW(e),[2] providing about 15% of the world's electricity production in 2007, a percentage that has been roughly stable since 1986. Thirty-seven nuclear power plants with a net electricity generating capacity of 31.6GW(e) are currently under construction in 13 countries.[3]

The International Atomic Energy Agency (IAEA) makes two annual projections (low and high) concerning the growth of nuclear power. The low projection assumes that all nuclear capacity that is currently under construction or far along in development is completed and brought on line, but that no other capacity is added. The high projection includes capacity resulting from likely or promising projects.

In its 2008 edition of *Energy, Electricity and Nuclear Power Estimates for the Period to 2030*, the IAEA expects global nuclear power capacity in 2030 to range from a low of 473GW(e)—some 27% higher than today's 372GW(e)—to a high of 748GW(e), that is, double today's capacity.[4] The latter would require an average growth rate of about 3.2% per year.

A World Nuclear Association (WNA) exercise *Nuclear Century Outlook* also projects possible expansion in world nuclear generating capacity. From a base of 372GW(e) today it projects at least 1,140GW(e) by 2060 and up to 3,500GW(e) by then. The upper projection for 2100 is 11,000GW(e).[5]

The highest percentage of existing nuclear reactors is in the industrialized countries of North America, Europe and Asia, while an anticipated revival of nuclear power would be driven to a large part by the power plant construction programmes in other parts of the world. In fact 19 of the 37 reactors now being built are located in China, India and Russia. Another 90 or more nuclear reactors are planned to come on line during the next 10 years. While countries with established nuclear power industries are seeking to replace old reactors as well as expand capacity, an additional 25 or so countries are either considering or have already decided to make nuclear energy part of their power generation capacity, among them Belarus, Egypt, Indonesia, Iran, Jordan, Morocco, Oman, Saudi Arabia, Turkey, Venezuela, Viet Nam and others. Besides constructing nuclear reactors for the production of electricity, these countries may consider developing their own fuel cycle facilities and nuclear know-how.

Even if some of these plans are to be realized, it could result in worldwide dissemination of uranium enrichment and spent fuel reprocessing technologies. These technologies present obvious risks of nuclear proliferation as they are capable of providing states with materials that are directly usable in a nuclear weapon or a nuclear explosive device—high enriched uranium (HEU) and separated plutonium.

It is in the light of these developments that the Director General of the IAEA, Dr Mohamed ElBaradei, in his introductory statement to the IAEA Board of Governors on 11 June 2007 argued that:

> The increase in global energy demand is driving an expected expansion in the use of nuclear energy. This means an increase in the demand for fuel cycle services. It also means an increase in the potential proliferation risks created by the spread of sensitive nuclear technology, such as that used in uranium enrichment and nuclear fuel reprocessing. The convergence of these trends points clearly to the need for the development of a new, multilateral framework for the nuclear fuel cycle. In my view, such a framework could best be achieved through establishing mechanisms that would assure the supply of fuel for nuclear power plants—and over time, by converting enrichment and reprocessing facilities from national to multilateral operations, and by limiting future enrichment and reprocessing to multilateral operations.
> …
>
> Controlling nuclear material and the use of nuclear energy is a complex process. And it is clear that an incremental approach, with multiple assurances in place, is the way to move forward.[6]

## HISTORICAL PERSPECTIVE

The idea, of course, is not new. For an in-depth overview of the multilateral fuel cycle issue see, for example, "The Nuclear Fuel Cycle: A Challenge for Nonproliferation" by Lawrence Scheinman, first published in 1981 and then reprinted in 2004.[7]

The fact that nuclear energy can be utilized both for military and for peaceful purposes has presented a dilemma that has not been satisfactorily resolved. Interest in institutional arrangements for the nuclear fuel cycle dates back to the start of the nuclear age. The *Report on the International Control of Atomic Energy*, generally known as the Acheson–Lilienthal Report, was written by a committee chaired by Dean Acheson and David Lilienthal in 1946. It was the first effort to define a policy on the international control of atomic energy. The report called for a United Nations authority to own and control all uranium deposits and all fissile material and ensure that atomic research was conducted for peaceful purposes only. The report called for "assignment of the intrinsically dangerous phases of the development of atomic energy to an international organization responsible to all peoples". The authors of the report defined the "dangerous activities"—those that, in their opinion, ought to be subject to an international monopoly:

- the provision of raw materials;
- the production in suitable quality and quantity of the fissionable materials plutonium and uranium-235; and
- the use of these materials for the making of atomic weapons.[8]

But conflicting national objectives at the time made impossible the task of establishing some form of international authority over the most dangerous aspects of the nuclear fuel cycle and further nuclear development has moved forward along national lines.

In 1953, US President Dwight Eisenhower unveiled his Atoms for Peace plan that laid the ground for widespread dissemination of civilian nuclear knowledge and technology. Since then, institutional arrangements have focused on political commitments and verification safeguards, rather than multilateral strategies designed to prevent the spread of fuel cycle technologies and facilities.

The dissemination of nuclear know-how heightened concerns that, with unlimited access to the technologies of nuclear fission and the fuel cycle, the number of countries possessing nuclear weapons would increase rapidly. US President John F. Kennedy said that he was "haunted by the feeling that by 1970 … there may be 10 nuclear powers instead of 4, and by 1975, 15 or 20".[9] Warnings like this helped to awaken the world to the dangers of unconstrained proliferation. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was intended to halt such proliferation by limiting the nuclear-weapon states to those states that had manufactured and detonated a nuclear explosive device prior to 1 January 1967 (France, the People's Republic of China, the Soviet Union (obligations and rights now assumed by Russia), the United Kingdom, and the United States). With regard to non-nuclear-weapon states, the NPT required that their nuclear activities be for peaceful purposes only and subject to the safeguards system of the IAEA.

The NPT's international legal obligations rest on three pillars:

- Pillar 1: **non-proliferation**. Each nuclear weapon state party undertakes not to transfer "nuclear weapons or other nuclear explosive devices" or control over them and "not in any way to assist, encourage, or induce" a non-nuclear weapon state to acquire nuclear weapons (Article I). Non-nuclear weapon states parties agree not to "receive", "manufacture" or "acquire" nuclear weapons or to "seek or receive any assistance in the manufacture of nuclear weapons or other nuclear explosive devices" (Article II). Non-nuclear weapon states parties also agree to accept safeguards by the IAEA to verify that they are not diverting "nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices" (Article III);
- Pillar 2: **peaceful use of nuclear energy**. All NPT states parties agree that each has the "inalienable right" to exploit "nuclear energy for peaceful purposes without discrimination" (Article IV.1). As a result, all NPT states parties are obliged "to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy" (Article IV.2); and
- Pillar 3: **disarmament**. "Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament" (Article VI).

The NPT has been successful in limiting, albeit not entirely preventing, the further spread of nuclear weapons. Nevertheless the world again turned to the multilateral management of the nuclear fuel cycle in the second half of 1970s. The impetus was India's "peaceful nuclear explosion" of 1974 and the 1970s oil crisis, which led to expectations of an exponential rise in the number of nuclear facilities in order to meet global energy demands. At the time the report of the International Nuclear Fuel Cycle Evaluation (INFCE) estimated that by 2000 about 1,000GW(e) of nuclear power would be produced by the world's nuclear reactors.[10] The world was staring at the prospect of large-scale equipment and nuclear material transfers, all bearing on the most sensitive aspects of the nuclear fuel cycle, combined with the dissemination of knowledge of nuclear fission and its various uses, as well as associated training—the "plutonium economy" as it was referred to in those days. In response, there was a number of proposals for regional, multinational and international arrangements. The proposals were intended, on the one hand, to reinforce the NPT objective of discouraging horizontal proliferation, that is, the spread of nuclear weapons to states that had not previously possessed them, and, on the other, not to undermine the right of all states to exploit nuclear energy for peaceful purposes.

Among the more visible efforts to promote a multilateral approach to the nuclear fuel cycle in the 1970s and 1980s were the IAEA study on Regional Nuclear Fuel Cycle Centres (1975–1977), the International Nuclear Fuel Cycle Evaluation exercise (1977–1980) then being actively promoted by the Carter administration; the Expert Group on International Plutonium Storage (1978–1982); and the IAEA Committee on Assurances of Supply (1980–1987). In a general sense, these studies concluded that most of the proposed arrangements were technically feasible and that, based on the projections of energy demand, economies of scale rendered them economically attractive. The focus of the proposed arrangements was on the back end of the fuel cycle, specifically spent fuel reprocessing and plutonium containment.

But none of these proposals and initiatives led anywhere partly because of Cold War tensions, but also because parties could not agree on the non-proliferation commitments and conditions that would entitle states to participate in the multilateral activities. Moreover, differences of views prevailed between those countries or regions that did not plan to reprocess or recycle plutonium and those that favoured doing so. In addition, much of the momentum was lost with the slowdown in new civil nuclear programmes after the accidents at Three Mile Island and Chernobyl, thereby limiting the spread of reprocessing facilities and temporarily laying to rest fears of a global plutonium economy.

Hopes for a multilaterally controlled fuel cycle have never entirely faded, and were addressed anew within the IAEA-sponsored International Symposium on Nuclear Fuel Cycle and Reactor Strategies in 1997, which, in retrospect, can be credited with expanding the focus on multilateral approaches from the back end of the nuclear cycle to include the front end. Then, through a series of IAEA-sponsored meetings in 2001 and 2002, the focus on multilateralization of the fuel cycle was broadened beyond reprocessing and enrichment to include international options for spent fuel and nuclear waste storage and disposal.

Responding to recent non-proliferation concerns, in 2003 the Director General of the IAEA proposed a fresh look at multilateral approaches that could serve to strengthen the nuclear non-proliferation regime while not impeding the development of nuclear energy for states wishing to choose that option. Among those concerns were:

- the significant changes in the international political and security environment since the end of the Cold War;
- the emergence of new sources of supply of sensitive nuclear technologies and their components, particularly dual-use items that can serve as a basis for indigenous development of weapons-relevant equipment and facilities, such as the A.Q. Khan nuclear supplier network;
- the erosion of technical barriers to designing nuclear weapons and to mastering the processing steps;
- the newly expected expansion in the use of nuclear energy and a revived interest in the closed fuel cycle, which could result in an increase in the potential proliferation risks created by the spread of sensitive nuclear technologies, in particular, uranium enrichment and nuclear fuel reprocessing;
- the revelations that some NPT states parties conducted clandestine weapons-relevant activities;
- the fear that some states may use their NPT status to openly and legally acquire fuel cycle capabilities that could allow them to attain nuclear weapon status if they invoked the withdrawal clause of the NPT (so-called "break-out"); and
- the possibility that organized transnational terrorist groups may obtain access to weapon-usable materials, which increases with the growing number of potential sources of such materials.

In his article "Towards a Safer World" in which he laid out his ideas, Mohamed ElBaradei proposed a three-pronged approach to limiting the processing of weapon-usable material (separated plutonium and HEU) in civilian nuclear fuel cycles. In particular, he proposed placing all enrichment and reprocessing facilities under multinational control and considering "multinational approaches to the management and disposal of spent fuel and radioactive waste". He did not place any non-proliferation requirements on participation, but instead suggested that the system "should be inclusive; nuclear-weapon states, non-nuclear-weapon states, and those outside the current non-proliferation regime should all have a seat at the table".[11]

In mid-2004, an International Expert Group on Multilateral Approaches to the Nuclear Fuel Cycle was established by the Director General of the IAEA. The group examined the nuclear fuel cycle and possible multilateral approaches, and issued its report in February 2005. The report outlined a set of multilateral nuclear approaches (MNA):

> 1. Reinforcing existing commercial market mechanisms on a case-by-case basis through long-term contracts and transparent suppliers' arrangements with government backing. Examples would be: fuel leasing and fuel take-back, commercial offers to store and dispose of spent fuel and commercial fuel banks.
> 2. Developing and implementing international supply guarantees with IAEA participation. Different models should be investigated, notably with the IAEA as guarantor of service supplies, e.g. as administrator of a fuel bank.
> 3. Promoting voluntary conversion of existing facilities to MNAs, and pursuing them as confidence-building measures, with the participation of NPT non-nuclear-weapon States and nuclear weapon States, and non-NPT states.
> 4. Creating, through voluntary agreements and contracts, multinational, and in particular regional, MNAs for new facilities based on joint ownership, drawing rights or co-management for front-end and back-end nuclear facilities, such as uranium enrichment; fuel reprocessing; disposal and storage of spent fuel (and combinations thereof). Integrated nuclear power parks would also serve this objective.
> 5. The scenario of a further expansion of nuclear energy around the world might call for the development of a nuclear fuel cycle with stronger multilateral arrangements—by region or by continent—and for broader cooperation, involving the IAEA and the international community.[12]

Since then the subjects of assurances of supply and international fuel cycle centres have received constant attention. A number of further proposals have been put forward by governments, nuclear industry or international organizations. These proposals cover a broad spectrum, from establishing an IAEA-controlled last-resort reserve of low enriched uranium (LEU) to providing backup assurances of supply and setting up international uranium enrichment centres. Various political and legal aspects of these proposals for multilateral approaches to the nuclear fuel cycle are to be discussed in this book.

Building on these ideas, the Director General of the IAEA recently proposed a three-stage process for developing a new multilateral mechanism:

> The *first* step would be to establish a system for assuring supply of fuel for nuclear power reactors—and, if necessary, supply of the actual reactors. The *second* step would be to have all new enrichment and reprocessing activities in future put exclusively under multilateral control. And the *third* step would be to convert all existing enrichment and reprocessing facilities from national to multilateral operations.[13]

The Director General then explicitly noted that first it would be necessary to conclude a global, verifiable Fissile Material Cut-off Treaty (FMCT).

## MULTILATERAL APPROACHES—RATIONALE

First, a few words about terminology. In their report, the International Expert Group noted that a distinction should be made between the words multilateral, multinational, regional and international.[14] In this book the terms multilateral and multinational can be used interchangeably as they refer to any approach to the management of the nuclear fuel cycle that goes beyond purely national control.

The rationale for multilateral approaches to the nuclear fuel cycle is relatively straightforward. These approaches are institutional mechanisms for dealing with the problem of sensitive materials and technologies. Institutional measures are non-technical in nature and involve various political, economic or diplomatic strategies for controlling access to sensitive materials, facilities or technologies. Different institutional approaches are currently used to cope with challenges to non-proliferation regime effectiveness, among them national nuclear export policies and the IAEA safeguards system. Multilateral arrangements are generally aimed at denationalizing sensitive fuel cycle activities by placing decisions on the operation of nuclear facilities, as well as on the disposition of their products, in the hands of a number of nations or international organizations rather than individual states. If appropriately arranged, these arrangements appear to meet energy security concerns by providing participants with a legal and economic stake in the supply system, and to meet non-proliferation concerns by limiting the spread and the number of sensitive facilities, thus reducing the likelihood of break-out, diversion or theft.

In the case of a multinational enrichment or reprocessing facility, in which ownership, control or operation are shared among a number of states that can watch each other, all of its participants are under a greater degree of peer scrutiny making it more difficult and risky to cheat. The possibility of seizure of the facility by the host country would always be present, but because of the ensuing confrontation between that country and the other participants and the international community, a considerable political barrier inhibits such action. The use of multinational facilities instead of a multiplicity of national facilities would reduce the number of plants to be placed under safeguards, increasing the feasibility of continuous inspection while possibly reducing costs of these inspections. Multinational facilities could also serve as confidence-building measures, helping to reduce suspicions among participating states about their nuclear weapon intentions. Moreover, large multinational fuel cycle facilities could provide the benefits of cost effectiveness and economies of scale as compared to smaller national facilities.

Despite all the prospective benefits, the case for the multilateral approaches is not self-evident because potential problems are also noticeable. First, multilateral options could stimulate the unwarranted transfer or leakage of sensitive nuclear technologies. Second, to guard against proliferation, multilateral arrangements must be part of an integrated regime that not only puts facilities and technologies under appropriate controls, but the produced materials as well. Third, a fully operational multilateral facility would require the development of new organizational arrangements of a complex political, economic and managerial nature that, even allowing economies of scale, could add measurably to the cost, detracting from the general viability of the enterprise.

The question of non-proliferation raises other issues that must be considered in relation to multinational institutional arrangements. According to Scheinman:

> There is no single, generic multilateral formula that would be satisfactory for all technologies and all partners. While all such ventures will have to meet certain basic requirements, successful implementation of the multilateralization will depend on the flexibility of its application. …
>
> An institutional arrangement can only be as strong as the foundation upon which it is built. … To be viable, institutions must be politically acceptable, thus requiring a wide consensus on the nature, purpose,

> and limits of the nuclear fuel cycle, and on how non-proliferation and energy security goals relate to one another.[15]

Any multilateral arrangement would hardly deter a state firmly determined to develop nuclear weapons or to obtain "threshold" capacity, or any state determined to acquire the full nuclear cycle. Such states would likely reject participation in a multilateral arrangement. However, with a multilateral alternative in place, it would be more difficult for a state to justify a national programme, "with the result that the international community becomes more alert to the possible nuclear intentions of the state in question".[16] As the Director General of the IAEA said: "by providing reliable access to reactors and fuel at competitive market prices, we remove the incentive or justification for countries to develop indigenous fuel cycle capabilities. In doing so, we could go a long way towards addressing current concerns about the dissemination of such capabilities".[17]

Multilateral approaches to the nuclear fuel cycle are by no means a "magic bullet" solution that would resolve all non-proliferation problems once and for all. But, if appropriately arranged, they have substantial potential to ensure that the benefits of nuclear energy are made available to all countries, while strengthening the nuclear non-proliferation regime, ensuring safe and secure management of the nuclear fuel cycle, and reducing incentives to build new nuclear fuel cycle facilities in countries that do not now have them.

# CHAPTER 2

## A NEW MECHANISM

Since the beginning of this century, international attention has been increasingly focused on multilateral approaches to the front end (uranium enrichment) of the nuclear fuel cycle (see Annex A for an explanation of the fuel cycle). A global "plutonium economy" is still out of sight and, in spite of some revival of interest in the closed nuclear cycle and recycling of plutonium, for the next few decades the once-through nuclear fuel cycle without the reprocessing of spent fuel seems to be the option of choice for the majority of countries for economic and technical reasons. Most countries have already decided to adopt interim storage instead of reprocessing their spent power-reactor fuel, at least as a medium-term alternative, and there are no immediate expectations for new reprocessing plants or a growing demand for reprocessing services in the world.

Nevertheless, the use of nuclear power for electricity production seems certain to grow significantly in the next decades. The anticipated increase in the number of nuclear power reactors as well as the increase in the number of states operating those reactors raises certain questions. Where will the nuclear fuel for these reactors come from? Will it come from existing suppliers or will additional states develop enrichment capabilities? Given the huge capital cost and long expected lifetimes of nuclear power plants, how best to insure against a lack of fuel? Here there can be various models put forward for a multilateral approach, including those that need not entail full-scale multinational facilities. By adding new institutional arrangements to the existing commercial uranium market, these models could be helpful in giving greater assurance of supply of nuclear materials to countries that seek the peaceful benefits of nuclear energy.

Currently, the commercial market satisfies the demand for fuel services subject to government approval of exports. There is a diversity of commercial enrichment suppliers; enrichment capacity exceeds demand; and, based on current plans for the substitution of diffusion by centrifugal technology, capacity is likely to be in excess of projected increases in demand in the medium term. But then, the dependency on only a few enrichment suppliers located in and controlled by a few states gives rise to concerns as to the continuity of supply, for example possible interruptions due to political considerations. Customer countries may feel more assured that they will always have reliable supply of front-end services for their reactors if there are multilateral mechanisms in place that provide a backup if a supply interruption occurs.

The focus of international efforts has recently been to develop a system of credible guarantees of supply of nuclear fuel to assure customer countries that they will have a reliable fuel supply conditioned only on their meeting predetermined qualifying non-proliferation criteria.

As the chairman of the IAEA Special Event of September 2006, Charles Curtis said:

> Proponents of the establishment of an international back-up mechanism for assured supply of nuclear power reactor fuel assert that it would have a dual-objective, i.e. to address: (a) the possible consequences of interruptions of supply of nuclear fuel due to political considerations that might dissuade countries from initiating or expanding nuclear power programmes; and (b) the vulnerabilities that create incentives for building new national enrichment and reprocessing capabilities. Thus, an assurance of supply mechanism would be envisaged solely as a back-up measure to the operation of the commercial market, for those States that want to make use of it, in order to assure supply in instances of interruption for political reasons. It would neither be a substitute for the existing commercial market in nuclear fuels, nor would it deal with disruption of supply due to commercial, technical or other non-political reasons. While an assurance of supply mechanism would be designed to give supply assurance to States that voluntarily choose to rely on international fuel supply, rather than build their own indigenous fuel cycle capabilities, a State availing itself of such a mechanism would not be required to forfeit, or in any way abridge, its rights under Article IV of the NPT, in connection with peaceful uses of nuclear energy.[18]

## A NEW FRAMEWORK FOR ASSURANCE OF SUPPLY AND A DOZEN PROPOSALS

The Director General of the IAEA called for the creation of "a new mechanism that will assure supplies of nuclear fuel and reactors to countries which want them, while strengthening non-proliferation through better controls over the sensitive parts of the nuclear fuel cycle—uranium enrichment and plutonium separation—by way of a multinational approach to the front and back ends of the cycle".[19]

Over the past few years a number of proposals have been put forward by individual states, groups of states, nuclear industry and international institutions, which aimed at thwarting the spread of uranium enrichment and nuclear fuel reprocessing technologies, in particular by suggesting means of assuring nuclear fuel supplies and establishing international fuel-cycle centres. These proposals are as follows and are listed in chronological order:[20]

1. **US Proposal on a Reserve of Nuclear Fuel**: United States of America, September 2005. The United States announced in Vienna in September 2005, at the forty-ninth regular session of the General Conference of the IAEA, that it would commit up to 17 metric tons of HEU to be down-blended to LEU "to support assurances of reliable fuel supplies for states that forego enrichment and reprocessing".[21]

2. **Russian Global Nuclear Power Infrastructure**: Russian Federation, January 2006. Vladimir Putin, President of the Russian Federation, outlined a proposal to create "a global infrastructure that will give all interested countries equal access to nuclear energy, while stressing reliable compliance with the requirements of the non-proliferation regime", including the "creation of a system of international centres providing nuclear fuel cycle services, including enrichment, on a non-discriminatory basis and under the control of the IAEA" as a key element in developing this new infrastructure.[22]

3. **US Global Nuclear Energy Partnership**: United States of America, February 2006. The United States announced the Global Nuclear Energy Partnership (GNEP) as "a comprehensive strategy to increase US and global energy security, encourage clean development around the world, reduce the risk of nuclear proliferation, and improve

the environment”. One of the elements of GNEP is a proposed “Fuel Services program to enable nations to acquire nuclear energy economically while limiting proliferation risks. Under GNEP, a consortium of nations with advanced nuclear technologies would ensure that countries who agree to forgo their own investments in enrichment and reprocessing technologies will have reliable access to nuclear fuel”.[23]

4. **World Nuclear Association Proposal**: World Nuclear Association, May 2006. A World Nuclear Association (WNA) Working Group on Security of the International Nuclear Fuel Cycle, including representatives of the four principal commercial enrichment companies, proposed a three-level mechanism to assure uranium enrichment services: (a) basic supply security provided by the existing world market, (b) collective guarantees by enrichment companies supported by governmental and IAEA commitments, and (c) government stocks of enriched uranium product.[24]

5. **Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel**: France, Germany, the Netherlands, the Russian Federation, the United Kingdom and the United States of America, June 2006. The six enrichment service supplier states proposed essentially two levels of enrichment assurance beyond the normally operating market. At the “basic assurances” level, suppliers of enriched uranium would agree to substitute for each other in the case of certain supply interruptions to customer states that have “chosen to obtain suppliers on the international market and not to pursue sensitive fuel cycle activities”. At the “reserves” level, participating governments could provide physical or virtual reserves of LEU that would be made available if the “basic assurances” were to fail.[25]

6. **IAEA Standby Arrangements System**: Japan, September 2006. Japan proposed an information system to help prevent interruptions in nuclear fuel supplies. The system, to be managed by the IAEA, would disseminate information contributed voluntarily by IAEA member states on their national capacities for uranium ore, uranium reserves, uranium conversion, uranium enrichment and fuel fabrication. The proposal is described by Japan as complementary to the concept for reliable access to nuclear fuel just described.[26]

7. **IAEA Nuclear Fuel Bank**: Nuclear Threat Initiative, September 2006. The Nuclear Threat Initiative (NTI) offered to contribute $50 million to the IAEA to help create an LEU stockpile controlled by the Agency that could be made accessible should other supply arrangements be disrupted. The offer was contingent on the following two conditions being met within two years from when the offer was made: that the IAEA takes the necessary actions to approve the establishment of the reserve, and that one or more IAEA member states contribute an additional $100 million in funding or an equivalent value of LEU. "Every other element of the arrangement—its structure, its location, the condition for access—would be up to the IAEA and its member states to decide".[27] In December 2007 the US Congress authorized a $50 million contribution, in February 2008 Norway pledged $5 million, in August 2008 the United Arab Emirates pledged $10 million, and in December 2008 the European Union pledged €25 million, and finally, in March 2009, Kuwait offered US$10 million. At the request of the IAEA, the deadline for the offer has been extended to September 2009.[28]

8. **Enrichment Bonds Proposal**: United Kingdom, September 2006. The United Kingdom proposed a "bonding" principle that would—in the event that the IAEA determines that specified conditions have been met—guarantee that national enrichment providers would not be prevented from supplying enrichment services, and provide prior consent for export assurances.[29] Germany and the Netherlands are cooperating with the United Kingdom in the development of the enrichment bonds concept. Recently the name of the proposal was changed to the Nuclear Fuel Assurance proposal.

9. **International Uranium Enrichment Centre**: Russian Federation, January and May 2007. As an element in the creation of a global nuclear power infrastructure, earlier propounded by President Vladimir Putin, the Russian Federation proposed the establishment of an International Uranium Enrichment Centre (IUEC) at the Angarsk Electrolysis Chemical Complex to provide participating countries guaranteed access to uranium enrichment capabilities. On 10 May 2007 the first agreement in the framework of the IUEC was signed by the Russian Federation and the Republic of Kazakhstan. A mechanism is being developed to set aside a stockpile of LEU that might contribute to a broader assurance of supply mechanism, and "a regulatory

basis will be developed in the sphere of export control such that the shipment of material out of the country at the request of the [IAEA] is guaranteed".[30] In June 2007, Russia offered to set up an LEU reserve of 120 metric tons under IAEA auspices, and stored under safeguards at Angarsk, for use by IAEA member states.

10. **Multilateral Enrichment Sanctuary Project**: Germany, May 2007. Germany proposed the creation of a multilateral uranium enrichment centre with extra-territorial status, operating under IAEA control on a commercial basis as a new supplier in the market. From there, potential users could then obtain nuclear fuel for civilian use under strict supervision.[31] Germany has further developed this proposal into a Multilateral Enrichment Sanctuary Project (MESP) for a multilateral enrichment facility established by a group of interested states on an extra-territorial basis in a host state, supervised by the IAEA, owned and operated by a multinational commercial consortium.[32]

11. **Multilateralization of the Nuclear Fuel Cycle**: Austria, May 2007. Austria proposed a two-track multilateral mechanism. The first track would "optimiz[e] international transparency going beyond current IAEA safeguards obligations". The second track would place all nuclear fuel transactions under the auspices of a "Nuclear Fuel Bank" to "enable equal access to and control of most sensitive nuclear technologies, particularly enrichment and reprocessing".[33]

12. **Nuclear Fuel Cycle non-paper**: European Union non-paper, June 2007. The EU non-paper noted that flexibility would be appropriate in considering an approach to fuel supply options and proposed criteria for assessment of a multilateral mechanism for reliability of fuel supply. These criteria included: proliferation resistance—minimization of the risk of unintended transfer of sensitive nuclear technology; assurance of supply—reliability of long-term supply arrangements; consistency with equal rights and obligations—obligations of private companies, supplier states, consumer states and the IAEA; and market neutrality—avoiding any unnecessary disturbance or interference in the functioning of the existing market.[34]

## THE ROLE OF THE IAEA

The IAEA Secretariat has in the meantime developed further its own ideas on assurances of supply. All of these proposals and ideas were catalogued in a report that was presented during the June 2007 session of the Agency's Board of Governors.[35] This report, which remains restricted, was designed to provide information to IAEA member states on the evolution of proposals put forward by states and international organizations concerning assurance of supply and international fuel cycle centres. The report also presented a range of options to guarantee supplies of LEU and nuclear fuel while minimizing proliferation risks. Presenting the report, IAEA Director General ElBaradei said, "Trends clearly point to the need for developing a new multilateral framework for the nuclear fuel cycle. And it's clear that an incremental approach, with multiple assurances in place, is the way to move forward".[36] The steps to achieving such a framework were identified as:

- assuring the supply of fuel for nuclear power plants;
- converting enrichment and reprocessing facilities from national to multilateral operations over time; and
- limiting future enrichment and reprocessing to multilateral operations.

The main ideas of this report have been summarized elsewhere, and are recapped briefly below.

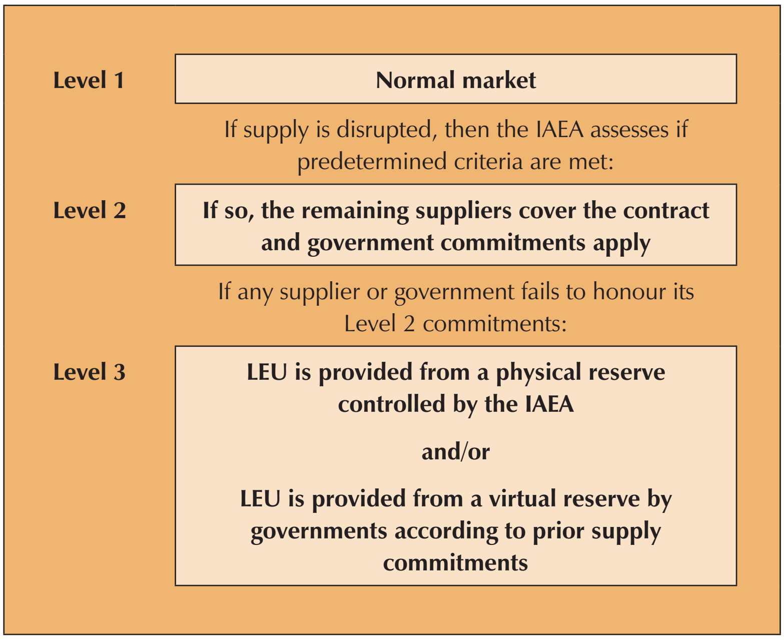
A proposed multilateral framework would be voluntary and states would be free to choose their fuel options—no rights of states would be compromised. It is important to retain flexibility, as diversity of proposals enables consumer states to choose options according to their needs. A possible framework would not be a substitute for the existing international uranium enrichment market, but rather a backup mechanism.

For assuring LEU supply a possible new framework could be established on three levels (see Diagram 1):

- Level 1: existing global market arrangements;
- Level 2: backup commitments, when predetermined criteria are met, provided by suppliers of enrichment services and their respective governments to assure supply in cases of political disruptions; and

- Level 3: a physical LEU reserve under IAEA control, or a virtual LEU reserve based on commitments by governments to make LEU available to the IAEA. Such a reserve, either physical or virtual, could be utilized when Level 2 commitments cannot be fulfilled and the same predetermined criteria are met.

**Diagram 1:** Three-level framework of assurance of LEU supply




In the context of developing a system of credible guarantees of supply of LEU, the most important seems to be Level 3 that would provide last resort reserves, which could be in the form of IAEA-controlled physical reserves, virtual reserves or a combination of the two.

The option likely to be least burdened by financial, legal, technical and institutional complications is that of a virtual LEU reserve with the IAEA acting as a guarantor of supply. In this case the IAEA would not have direct possession of LEU so that its assurance and guarantee would need to be backed up by agreements of governments of supplier countries to fulfil commitments made by the IAEA. Such guarantees, however, would not be entirely convincing to some consumer countries, especially those that do not have strong political ties with at least one supplier state.

The truly international status of a physical nuclear material reserve with the IAEA acting as an administrator of the reserve would increase the level of assurance provided. But in this case a number of financial and legal issues would need to be resolved. The establishment of an IAEA physical reserve would require covering the reserve start-up costs, initial LEU costs as well as operating costs. The customer countries certainly would not be happy to pay a premium for such guaranteed supply arrangements. Moreover, such a reserve would require resolving various legal issues with the state or states where the reserve was located, which would cover the international status of the reserve, safeguards, transit, security and liability for nuclear damage.

The IAEA report also considers a possible framework for fuel fabrication, though given the diversity and continuing evolution of fuel assembly designs, the creation of a physical bank of finished fuel assemblies is unrealistic.

Criteria would need to be applied for the release of material under any multilateral framework for the assured supply of LEU and nuclear fuel. In other words, who would qualify to benefit as a customer country? This would likely require that "the state is in good standing with the IAEA". This short sentence may imply different things to different people, so specific qualifying conditions would need to be agreed. Naturally, safeguards would be applied to the material supplied, and release criteria set forth in the IAEA statute (Article XI.E) should be fulfilled for an IAEA-controlled LEU reserve. But qualifying criteria should not be too restrictive because this is the easiest way to defeat the whole undertaking. States fulfilling all imaginable criteria could most likely buy uranium with no restrictions from the commercial market without the need for new complex arrangements. In order to attract less "virtuous" countries, the bar should be set lower.

These release criteria will have to be pre-established and be the same for all states wanting to avail themselves of this mechanism. As the IAEA Director General has stated, such criteria would have to be "non-political" and "applied in a consistent and objective manner".[37] The IAEA Board of Governors could evaluate these criteria each time a request for fuel is received or it could delegate this task to the Director General and the Secretariat. The clear benefit of the latter approach is that it allows for a more factual consideration of the criteria established by the IAEA statute and the Board, thereby avoiding the risk of bringing political considerations into play. As Bruno Pellaud, the former IAEA Deputy Director General, observed, the Board is:

> eminently political, not always free from external pressures. An influential Board member—after having denied a fuel delivery—will do its utmost in the Board to prevent the IAEA to step on the scene as a substitute supplier. To give the IAEA a maximum of credibility for any of the proposals put forward, a clear distinction must be made between the role of the Board and the role of the Secretariat. It is up to the Board to write the appropriate guidelines and up to the Secretariat to implement them free from external interferences.[38]

## LEGAL ASPECTS[39]

Almost all of the proposals put forward to assure the supply of fuel for nuclear power reactors call for the active participation of the IAEA, envisaging that the status of the Agency would give potential consumer states greater confidence in a multilateral approach. This raises the question of whether the IAEA's prospective role would have a sufficient basis in the IAEA's statute.

From the Agency's perspective, the provisions of the statute allow it:

- to establish its own stock of nuclear fuel purchased from, or donated by, member states for supply to another member state;
- to facilitate the supply of nuclear material from one member state to another; and
- to facilitate enrichment and fuel fabrication services by one member state to another or to the Agency.

Under **Article III** of the statute, the IAEA is authorized "to act as an intermediary for the purposes of securing the performance of services or the supplying of materials, equipment, or facilities by one member of the Agency for another; and to perform any operation or service useful in research on, or development or practical application of, atomic energy for peaceful purposes".

**Article III.C** states that "the Agency shall not make assistance to members subject to any political, economic, military, or other conditions incompatible with the provisions of this Statute".

**Articles IX.A** and **B** provide that "materials made available to the Agency may, at the discretion of the member state making them available, be stored either by the member concerned or, with the agreement of the Agency, in the Agency's depots".

If the Agency undertakes such storage, **Article IX.H** requires that "the Agency shall ensure the geographical distribution of these materials in such a way as not to allow concentration of large amounts of such materials in any one country or region of the world".

**Article IX.D** provides that "a member shall, from the materials which it has made available [to the Agency], without delay deliver to another member or group of members such quantities of such materials as the Agency may specify". **Article IX.E** provides that the quantities, form and composition of materials made available by any member state can only be changed with approval of the Board. **Article IX.J** determines that no member state has the right to require that the materials it makes available be kept separately or to designate the specific project in which they must be used.

Acknowledging the cost of supplying nuclear fuel, **Article XIII** provides for the reimbursement of member states providing materials. And **Articles XIV.E** and **F** state that "charges for nuclear fuel furnished to a Recipient State have to be levied on a scale that the revenues for the Agency are adequate to meet the expenses and costs incurred. These charges shall be placed in a general fund for use as determined by the Board and the General Conference".[40]

In regards to requirements for the release of fuel, **Article XI.A** states that "Any member or group of members of the Agency desiring to set up any project for research on, or development or practical application of, atomic energy for peaceful purposes may request the assistance of the Agency in securing special fissionable and other materials, services, equipment, and facilities necessary for this purpose", and **Article XI.C** provides that the IAEA "may arrange for the supplying of any materials, services, equipment, and facilities necessary for the project by one or more members or may itself undertake to provide any or all of these directly".

Certain legal arrangements would be needed to make any Level 3 assurance of supply mechanism to work in practice, and these arrangements would vary depending on the multilateral mechanism in question. These would include:

- an arrangement between the supplier state and the IAEA (Supply Agreement). In this context, elements of national law, such as consent rights, licensing, transport and immunities have to be considered;
- an arrangement between the consumer state and the IAEA (Project Agreement) to include inter alia the issues listed in Article XI.F of the statute;
- underlying commercial contracts between the actual supplier company (whether state or industry), the IAEA and the customer company (again whether state or industry);
- in case the IAEA establishes a physical bank of LEU or nuclear fuel, agreements covering safeguards, security and possibly liability for nuclear damage with the host state (Host Country Agreement) as well as transit agreements with neighbouring states need to be concluded. The host country agreement should also cover corresponding privileges and immunities; and
- in case a commercially run enrichment plant is established in a territory administered by the IAEA, an agreement between the IAEA and a commercial consortium (Management Agreement) needs to be concluded. An agreement on protection of technology between the Agency and the technology-supplying company and its home state needs to be considered either as a part of the management agreement or as a separate agreement.[41]

It can be seen that the IAEA already has the basic institutional mechanisms and relevant expertise to be able to function as a nuclear fuel bank, once member states or other interested institutions work out the details. Nevertheless, many complex legal issues must be solved before making international mechanisms for multilateralization of the nuclear fuel cycle into reality.

## CHAPTER 3

# THE CURRENT PROPOSALS FOR MULTILATERAL APPROACHES

The aforementioned proposals on limiting the spread of sensitive fuel cycle technologies, which have been tabled by states, nuclear industry and international organizations, aim at persuading countries not to develop indigenous nuclear fuel cycle capabilities by providing attractive alternatives and allaying concerns about politically motivated interruptions of supply. The majority of proposals focus on the front-end problem, dealing with LEU and nuclear fuel supply and production.

## US PROPOSAL ON A RESERVE OF NUCLEAR FUEL

The United States announced in Vienna in September 2005, at the forty-ninth regular session of the General Conference of the IAEA, that it would commit up to 17 metric tons of HEU "from materials previously declared excess to national security needs" to be down-blended to LEU "to support assurance of reliable nuclear fuel supplies for states that forego enrichment and reprocessing".[42] The US proposal urged the uranium supplier states and the IAEA to "establish a reliable mechanism to resolve problems should a disruption in supply arise. Materials made available by the United States under the initiative … would serve to back-up this proposed mechanism". Down-blending is currently underway, and is expected to be completed in 2010.[43]

At the IAEA Special Event on Assurances of Nuclear Supply and Non-proliferation in September 2006, US Assistant Secretary for Nuclear Energy Dennis Spurgeon said that this LEU stock could complement reserves established under control of the IAEA.[44] According to Gregory Schulte, the US ambassador to the IAEA, any such LEU reserve in the United States would be kept under national control because US law requires national control over such material. Stringent requirements on US-origin material, pursuant to the Atomic Energy Act, may limit the attractiveness of that material for some states. Schulte agreed that, "for some countries, that will provide reassurance, but for others, perhaps it won't".[45]

In the past, some consumer countries have experienced certain negative impacts from the necessity of US consent to transfer and use of US-origin nuclear materials. If the proposed reserve of nuclear fuel would be under the standard requirements on US-origin material, it would make a limited contribution, if any, into the creation of a new mechanism to ensure supplies of nuclear fuel.

## RUSSIAN GLOBAL NUCLEAR POWER INFRASTRUCTURE

In January 2006, during a meeting of the Council of the Eurasian Economic Union, Russian President Vladimir Putin outlined an initiative to create "a global infrastructure that will give all interested countries equal access to nuclear energy, while stressing reliable compliance with the requirements of the non-proliferation regime", including "the creation of a system of international centres providing nuclear fuel cycle services, including enrichment, on a non-discriminatory basis and under the control of the IAEA" as a key element in developing this new infrastructure.[46] The proposed global infrastructure would allow for increasing the role of nuclear power in assuring global energy sustainability and security.

President Putin also said that "Russia has already made just such a proposal and is prepared to establish an international centre of this kind on its territory". He also noted that "innovative new technologies will undoubtedly be required in this respect to create new generation reactors and their fuel cycles. These kinds of issues can be resolved only through broad-based international cooperation".

Earlier that month Sergei Kiriyenko, head of Russia's Federal Atomic Energy Agency (Rosatom), said that he envisaged Russia hosting four types of international nuclear fuel cycle service centres:

- the first is an International Uranium Enrichment Centre (IUEC). Kiriyenko said that it is sufficient to have one IUEC on the Russian territory, but that from three to five such centres should be present in major regions around the world;

- the second would be for reprocessing and storage of spent nuclear fuel. The head of Rosatom noted that new technologies minimizing the amount of produced radioactive waste would be needed for the creation of these centres;
- the third would deal with training and certification of personnel, especially for emerging nuclear states. Kiriyenko noted that this is "one of the most important issues as far as safety is concerned". In this context there is a need for harmonized international standards, uniform safeguards and joint international centres; and
- the fourth would be for research and development on new nuclear energy technologies and for integration of new scientific achievements.[47]

As a first step in the creation of the proposed global nuclear power infrastructure, the Russian Federation has established a model International Uranium Enrichment Centre at the Angarsk Electrolysis Chemical Complex (about 5,000km east from Moscow) "to provide guaranteed access to uranium enrichment capabilities to the Centre's participating organizations". Russia also offered to set up an LEU reserve of 120 metric tons under IAEA auspices, and stored under safeguards at Angarsk, for use by IAEA member states. Such a reserve would be sufficient to produce fuel assemblies for two core refuelings of a light water reactor (LWR) with an installed electricity generating capacity of about 1GW(e).

In September 2006 Sergei Kiriyenko said that the expansion of nuclear energy technologies was accompanied by the threat that nuclear energy could be used for military purposes. This problem, he said, could be solved by the Russian initiative to create a global nuclear power infrastructure (GNPI) that would provide equal access to nuclear power on market terms for all countries under regulation and standards of non-proliferation.[48]

The GNPI idea is very ambitious—to create a global supply mechanism featuring a limited number of international centres for the sensitive steps of the nuclear fuel cycle, which would give all countries the equal right to receive the services of these centres without spreading sensitive nuclear technologies—but its details have yet to be fully defined. The primary incentive offered by the GNPI to customer countries is "security of supply" of the front-end services, while no clear and specific proposals have been made on the back-end part of the arrangement. There is no current shortage of front-end services on the global nuclear market, while the provision of a comprehensive service, which would include fuel supply and spent fuel take-back (nuclear fuel leasing), spent fuel interim storage and/or reprocessing, and spent fuel and/or waste disposal services, would be a strong incentive for consumer countries to sign up to the initiative. Russia already has legislation in place to offer fuel leasing and has such a contract in place with Iran.

Two other points, which are relevant to all proposals on limiting the spread of sensitive fuel cycle technologies, are worth mention here. First, President Putin's initiative does not specify where these international centres would be located, thus not confining them, for instance, only to the nuclear-weapon states. As has been pointed out, "the overwhelming majority of consumer countries would probably be ready to renounce building purely national sensitive facilities, but not ready to give up the right to do so multilaterally with partners of their choice".[49] Second, as for the nuclear-weapon states, they could make a remarkable contribution to a multilateral approach, as well as to disarmament, by gradually converting their existing enrichment and reprocessing facilities from national to multilateral operations despite the anticipated difficulties (national interests; political, financial, and legal hurdles; security considerations; and so forth).

## US GLOBAL NUCLEAR ENERGY PARTNERSHIP

In February 2006, US Secretary of Energy Samuel Bodman announced the Global Nuclear Energy Partnership (GNEP), an initiative that included far-reaching proposals, such as the expansion of nuclear power in the United States, the development of advanced nuclear fuel cycles (including new spent fuel reprocessing/recycling technologies), reduction of the stockpiles of separated civilian plutonium, promotion of clean development around the world and reduction of the risk of nuclear proliferation. As initially proposed, it contained both domestic and international components, drawing together two of the Bush administration's policy goals: promotion of nuclear energy and non-proliferation.

The domestic component of the GNEP focused on the future of nuclear energy in the United States: what kind of future reactors would be licensed, and how spent nuclear power-reactor fuel would be handled.

Apparently, the GNEP idea has its roots in unresolved domestic problems with the management of spent nuclear fuel. Currently there are no near-term options for moving spent fuel off of US reactor sites. The commissioning of the planned Yucca Mountain repository in Nevada is delayed indefinitely and there is massive opposition to all proposed interim storage sites. US law limits the capacity of the Yucca Mountain repository. No more than 63,000t of spent fuel could be stored there before a second repository would have to be opened in another state, while 100,000 to 130,000t of spent fuel will be discharged by the current generation of US power reactors. The prospects of a second repository are highly uncertain. In this situation only spent fuel reprocessing, which would minimize the amount of disposed waste, could allow the expansion of nuclear power in the United States. It seems that the international component and well-meant non-proliferation objectives of the GNEP have been used, at least partially, to help sell a departure from the thirty-years-old US policy of not encouraging the use of plutonium in civil nuclear fuel cycles and not reprocessing spent fuel domestically.

The GNEP builds on the US Department of Energy's Advanced Fuel Cycle Initiative (AFCI), a programme that began in 2003 to develop and demonstrate spent fuel reprocessing/recycling technology. Reprocessing facilities would use new technologies developed by AFCI or industry to avoid separation of pure plutonium that could be used for weapons. Future high-level waste from reprocessing (mostly long-lived fission products) would go to the Yucca Mountain repository, and the recycled plutonium, uranium and other minor actinides would be fabricated into fuel for an Advanced Burner Reactor (ABR), a fast-neutron reactor to be developed by Department of Energy's Generation IV Nuclear Energy Systems Initiative. In the longer term, plutonium and other transuranics in spent fuel would be fabricated into new fuel for future fast-neutron reactors. Eventually, that fuel would be continually recycled until all the transuranics were consumed, leaving the fission products to be disposed of in a geologic repository.

Much of the AFCI's research is now focusing on a reprocessing technology called UREX+, in which uranium and some other elements are chemically removed from dissolved spent fuel, leaving a mixture of plutonium and other highly radioactive elements. UREX+ is considered by some to be proliferation-resistant, as further purification would be required to make the plutonium useable for weapons and because its high radioactivity would make it difficult to work with. In contrast, conventional reprocessing using the PUREX process (see Appendix A) can produce weapon-useable plutonium. Critics consider the non-proliferation benefits of UREX+ over PUREX to be minimal.

The international component of the GNEP envisioned a consortium of nations with advanced nuclear technology that would provide fuel services and reactors to countries that "refrain" from fuel cycle activities, such as enrichment and reprocessing.[50] Thus, it is the supplier that takes responsibility for the final disposition of the spent fuel. This could mean taking back the spent fuel, but might also mean, according to the Department of Energy, that the supplier "would retain the responsibility to ensure that the material is secured, safeguarded and disposed of in a manner that meets shared nonproliferation policies".[51] While this describes the responsibility of the supplier, the vagueness of the language suggests that any number of solutions, including on-site storage, could be the outcome.

A separate set of questions focuses on how effective the GNEP would be in achieving its goals. As the only current proposal that offers incentives for the back end of the fuel cycle, it may hold more promise of attracting states to participate in the fuel supply assurances part of the framework. However, back-end fuel cycle assurances will require significant changes in policies and laws, as well as political will, on the part of suppliers to allow take-back of spent nuclear fuel.

In addition to major changes in policies and laws, the GNEP non-proliferation element—a promise of instituting a US-based nuclear fuel take-back arrangement to provide reliable fuel services—has a key technical problem because it depends on the success of long-term technology development programmes included in the GNEP. Once advanced nuclear fuel reprocessing technology (the UREX+ process, a pyroprocessing technique, or something else) is developed, demonstrated and implemented on a commercial scale, and once an ABR is developed and commercialized, only then would the leased spent fuel returned to the United States be reprocessed, and the small amount of long-lived nuclear waste remaining would be sent to a US national waste repository. Commercial implementation of all these technologies will likely require several decades and massive financial investments, while success is by no means guaranteed. Until such a time, the GNEP take-back arrangement could not be fully implemented.

The GNEP proposal has attracted some international interest, at least among potential supplier states. Officials from China, France, Japan, Russia, and the United States met in Washington on 21 May 2007 to discuss the GNEP and its goals. According to a joint statement issued after the meeting, "the participants believe in order to implement the GNEP without prejudice to other corresponding initiatives, a number of near- and long-term technical challenges must be met. They include development of advanced, more proliferation resistant fuel cycle approaches and reactor technologies that will preserve existing international market regulations".[52]

The GNEP was formally presented on 16 September 2007 in Vienna, Austria, and participation was opened to all nations that would agree to internationally accepted standards for a secure nuclear fuel cycle. Sixteen countries joined the United States in signing the Statement of Principles in September 2007, and nine countries have joined the partnership since then.[53] The principles call for safe expansion of nuclear energy, enhanced nuclear safeguards, international supply frameworks, the development of fast-neutron reactors, "more proliferation resistant" nuclear power reactors and spent fuel recycling technologies in facilities that do not separate pure plutonium. They do not prohibit indigenous development of enrichment or reprocessing technologies but rather seek to create "a viable alternative to acquisition of sensitive fuel cycle technologies". It is further emphasized that participants do not give up any rights to benefit from peaceful nuclear energy.[54] This effectively means that:

> the United States shelved initial plans to require countries that joined the partnership to forswear enrichment and reprocessing. Instead, the United States has chosen to rely on a set of other bilateral incentives, such as help with financing, infrastructure, and workforce issues, as levers to convince countries to sign a bilateral memorandum of understanding … pledging to rely on the global nuclear fuel market instead of developing sensitive technology.[55]

As part of this effort, on 15 January 2009 the United States signed an agreement on peaceful uses of nuclear energy with the United Arab Emirates, which pledged to forgo any domestic uranium enrichment or fuel reprocessing.

Soon after the establishment of the GNEP, its participants created a steering group. Two working groups then were established by that steering group: a working group to address reliable fuel services and a working group to address infrastructure development. The first meeting of the working group on reliable fuel services took place in April 2008. The joint statement of the partnership's ministerial-level Executive Committee meeting in October 2008 mentions briefly that "the Reliable Nuclear Fuel Services Working

Group has analyzed the results of a survey on each partner country's legal and institutional frameworks to identify common practices and gaps needing to be addressed in moving towards comprehensive, reliable and safe, fuel service arrangements".[56]

The GNEP had been initially envisaged to be a consortium of supplier states with advanced nuclear technologies that would provide full fuel-cycle services, as well as reactors, to customer countries. But it may be a difficult task to define which states are suppliers and which are customers. Recognizing that the window of opportunity to become a supplier state may be closed soon, countries that do not currently enrich uranium or reprocess plutonium, such as Argentina, Australia, Canada, South Africa, South Korea and Ukraine, have shown their interest in developing sensitive nuclear technologies. South Korea has expressed interest in becoming a GNEP supplier state through development of a new pyroprocessing technique, while Argentina, Australia, Canada and South Africa have expressed interest in acquiring their own uranium enrichment capabilities.

Although GNEP is not the only factor that has contributed to the renewed interest in uranium enrichment and fuel reprocessing, it has had an impact in spurring countries to consider joining the club of suppliers of sensitive nuclear technologies.

In the context of a multilateral approach to the nuclear fuel cycle, GNEP is a far-reaching initiative having its focus on the back end of the nuclear fuel cycle and specifically on how to deal with the world's growing inventory of spent nuclear fuel. No other mechanism proposed by states, nuclear industry and international organizations has made specific proposals on the back end of the fuel cycle. It is hard to imagine how plans to significantly expand nuclear power could be realized without new ideas and approaches in this area. At the same time the GNEP has its drawbacks. First, its future heavily depends on the success or failure of long-term development of unproven technologies and, second, it has increased the risk of proliferation of sensitive nuclear technologies.

## WORLD NUCLEAR ASSOCIATION PROPOSAL

In May 2006, the private-sector World Nuclear Association (WNA) Working Group on Security of the International Nuclear Fuel Cycle outlined a proposal for ensuring security of supply in the international nuclear fuel cycle.[57] Representatives of the four leading commercial suppliers of uranium enrichment services—AREVA (France), Tekhsnabeksport (Russia), URENCO (Germany, the Netherlands and the United Kingdom), and USEC (the United States)—were members of that group. This proposal summarized the uranium suppliers' and uranium enrichment companies' ("enrichers") approaches to strengthening guarantee of supply. The WNA proposal argued that any approach to strengthening security of supply must be consistent with the operation of the existing world market and that guarantee arrangements should only be relied upon when market mechanisms have failed, not as substitutes for the market.

The WNA proposes a three-tier system of supply assurances. The first tier concerns normal market procedures to re-establish fuel supply after an interruption. In the second tier, "collective guarantees by enrichers supported by governmental and IAEA commitments" would be triggered in the event of a disruption of normal commercial supplies. Under this arrangement, to be agreed to by all providers of uranium enrichment services, if one enricher could not meet its obligations due to political pressure from its government, then all enrichers party to the agreement would fill the gap from their own resources under terms specified between the IAEA and the enrichers. This guarantee would be given to all consumer countries contracting to obtain enrichment services from any enricher party to the agreement. If that network then failed, the third tier of supply assurance, represented by stocks of enriched uranium product held by national governments, could be used as a last resort.

The proposal sets specific criteria to be met by customer states in order to be entitled to participate in the supply guarantee mechanism, among them: "To be eligible, a customer State must have made a commitment to forego the development of, or the building or operation of, enrichment facilities. The IAEA must certify that the customer (and the host nation) are, and are expected to remain, in full compliance with international safeguards".

The WNA proposal acknowledges that a similar backup supply system for fuel fabrication would be more complicated. "Because fuel design is specific to each reactor design, an effective mechanism would require stockpiling of different fuel types/designs. The cost of such a mechanism could thus be substantial". However, WNA noted that unlike uranium enrichment technology, "uranium fuel fabrication per se does not present a proliferation risk".

Appropriately, the WNA proposal also noted the need for back-end nuclear fuel cycle assurances, to prevent a scenario in which reprocessing technologies spread as nuclear power programmes expand. The WNA recommends that a clear option to reprocess spent fuel at affordable prices be offered to countries that do not have indigenous reprocessing programmes. But the report is vague on the details, saying only that "In light of the robust nuclear energy initiatives now under way in many countries, concepts of international reprocessing/recycling centres are worth pursuing and deserve further, more detailed review".

The distinctive element of this proposal is the concept of collective guarantees of supply on the part of enrichers, which oblige all participating providers of uranium enrichment services to fill the gaps, in equal measures, in the case of disrupted supply. "To ensure that no single enricher is unfairly burdened with the responsibility of providing backup supply, the other enrichers would supply the contracted enrichment in equal shares under terms agreed between the IAEA and the enrichers", according to the proposal.

The problem with this model is that it requires a complicated set of agreements among all suppliers to assure such an approach to guaranteed supply. This set of agreements would have to be signed not only among the uranium enrichment companies, but also between each enricher's government and all participating enrichers. The proposal is also vague on the role of governments, saying only that the collective guarantee of supply on the part of enrichers would be "supported by governmental commitments", but not specifically binding host governments to abide by the agreements signed by their enrichment companies. If supply is disrupted for political reasons, the collective guarantees by enrichers cannot provide protection against government embargoes imposed on their enrichment companies.[58]

There are two other drawbacks to this proposal that need to be noted. First, stocks of enriched uranium product held by national governments have to be used as a last resort in the event that enrichers were unable to meet their backup supply commitments. Such last resort guarantees, however, would not be entirely convincing to some countries, especially those that do not have strong political ties with at least one enricher. Second, the enrichment companies must be somehow "compensated for any cost of providing the

Level II [second tier] guarantee (e.g. dedication of inventory, construction of facilities, and actual supply necessary to fulfil this commitment)". Thus the proposed mechanism may require substantial funding to satisfy financially both enrichers and customers.

The WNA proposal provides a useful input to the Multilateral Mechanism for Reliable Access to Nuclear Fuel proposal discussed next and to the possible new framework for the utilization of nuclear energy proposed by the IAEA Secretariat, discussed briefly earlier.

## SIX-COUNTRY CONCEPT

In June 2006, six governments that operate commercial uranium enrichment plants providing services on the international market—France, Germany, the Netherlands, Russia, the United Kingdom and the United States—tabled a Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel (referred to hereafter as the Six-Country Concept but also known as the Reliable Access to Nuclear Fuel or RANF proposal) to offer "reliable access" to nuclear fuel for countries opting to rely on the international market for such.[59] This proposal would not require states to forgo enrichment and reprocessing, but participation would be limited to those states that do not currently have such capabilities.

The Six-Country Concept is essentially a modified version of the WNA proposal aiming to address some its limitations. It endorses the WNA assertion that "the existing commercial market for nuclear fuel is functioning well", particularly with respect to uranium enrichment, and agrees that a new "backup … mechanism would be established in a manner that would not disrupt the existing commercial market". The Six-Country Concept maintains the multi-tier structure of the WNA proposal while offering a simpler and more straightforward second tier to ensure the supply of LEU.

The consumer countries are encouraged to strengthen their first-tier enrichment supply contracts by available market mechanisms such as using multiple contracts with various suppliers, maintaining a mix of short-term and long-term contracts, and establishing in-country buffer stores of enriched uranium.

The second-tier backup mechanism would work as follows: (1) a commercial supply relationship is interrupted for reasons other than non-proliferation obligations and cannot be restored through normal commercial processes; (2) the customer state or the supplier state can trigger the mechanism by approaching the IAEA to request backup supply; (3) the IAEA would rule out commercial or technical reasons for interruption (to avoid a market disruption) and assess whether the customer state meets the following qualifications:

- it has a comprehensive safeguards agreement and an additional protocol in force and has no exceptional safeguards implementation issues outstanding with the IAEA;
- it adheres to accepted international nuclear safety standards and the Convention on the Physical Protection of Nuclear Materials and Nuclear Facilities; and
- it is not pursuing sensitive fuel cycle activities (which are left undefined); and

(4) the IAEA would seek to facilitate new arrangements with one or more alternative suppliers, with the cooperation of supplier states and companies.

The Six-Country Concept includes commitments by supplier states. According to the proposal:

> States hosting companies supplying enrichment services and enriched uranium would participate actively in the consultations conducted under the multilateral framework to help find a solution. In the implementation of this mechanism and consistent with their national legal and regulatory requirements, supplier States should endeavor to allow export from their territories of enriched uranium and commit, in principle, to avoid opposing such exports from other States.

As an addition to the second tier, the concept also welcomes mutual backup arrangements made by commercial companies, to substitute for each other in the event of problems. These arrangements should be entered into by the commercial suppliers and customers themselves.

If the above mechanism fails to find an alternative supplier, the backup mechanism could be supported by established third-tier reserves of LEU, envisioned as a last resort. These reserves would not necessarily by held by the IAEA, but "rights regarding their use could formally be transferred to the IAEA, if so desired by the State providing the reserve". The Six-Country Concept specifically referred to the abovementioned US initiative to allocate the 17 tons of HEU to be converted to LEU and held in reserve to support fuel supply assurances. It encouraged other supplier countries to create similar reserves. The proposal asserts that "the size, location, control, and conditions for release and transfer, as well as replenishment of the reserves are issues for further discussion and development".

The Six-Country Concept also addressed in general terms several future options, all of which are longer term in nature. They include providing reliable access to existing reprocessing capabilities for spent fuel management, multilateral cooperation in fuel fabrication and spent fuel management, international enrichment centres, and new fuel cycle technology development that could incorporate fuel supply assurances.

By removing the requirement that all suppliers contribute equal shares to fulfil a disrupted contract, the Six-Country Concept allows a greater degree of flexibility in terms of backup contracts among suppliers for meeting a remaining obligation.

On the downside, the conditions of admission to the proposed backup mechanism are set very high: countries meeting these criteria already have reliable access to the uranium enrichment market. And the proposal assigns only a limited role for the IAEA in controlling the use of the backup LEU reserves, which may not be entirely convincing to the customer countries.

## IAEA STANDBY ARRANGEMENTS SYSTEM

The Japanese Government presented a "complementary proposal" to the Six-Country Concept at the IAEA in September 2006.[60] Japan's concerns with the Six-Country Concept centred on the implication that it was limited to only six countries and would deny the right of states to use civil nuclear technology for commercial purposes. Japan was also concerned that the Six-Country Concept assured the supply only of LEU, rather than all front-end nuclear fuel cycle services from natural uranium supply to fuel fabrication.

Japan proposed instead to create an IAEA Standby Arrangements System that would act as an early warning system to prevent a break in supply to customers. Any state determined by the IAEA Board of Governors to be in good non-proliferation standing could participate in this mechanism. Participating governments would annually notify the IAEA, as a depository organization, about their supply capacities of front-end fuel cycle services (uranium supply, uranium conversion, uranium enrichment and fuel fabrication). The IAEA would administer this information in a database and would facilitate supply to customer states in order to avoid disruption.

Should disruption occur, the IAEA would then act as an intermediary between consumer countries and countries that could provide the required services or materials. The IAEA would not be involved in negotiating the supply contracts beyond helping the consumer country find the right supplier country or countries.[61]

The Standby Arrangements proposal is quite simple and allows flexibility in execution. At the same time, many practical details of this proposal are still to be defined. A distinctive feature of the proposal is that it embraces fuel fabrication. Unlike uranium enrichment technology, uranium fuel fabrication is not generally of proliferation concern.

The proposal says that "any [IAEA] member State is eligible to participate in the system, provided that the IAEA Board of Governors finds no non-compliance of the IAEA safeguard agreement by the State". This inclusiveness allows Japan's proposal to avoid charges that it is an approach advocated by an effective "cartel" of nuclear suppliers that want to perpetuate their positions in the global nuclear market. Japan now enriches uranium only for domestic purposes but plans to provide front-end services on the international market in the future. The Standby Arrangements proposal says that the Six-Country Concept "is based upon a dichotomy between supplier States and recipient States"; Japan's proposal is explicitly intended to bridge this gap, stating that "it is desirable to make it possible for as many States as practicable to participate in and contribute to the system on a voluntary basis".

On the negative side, the proposed system could potentially encourage proliferation of sensitive nuclear technologies, even inadvertently, by inviting all IAEA member states to contribute to the proposed mechanism.

## NTI NUCLEAR FUEL BANK

In September 2006, the Nuclear Threat Initiative (NTI), a US non-governmental organization, offered $50 million as seed money to create an LEU stockpile controlled by the IAEA.[62] NTI believes that the establishment of such an LEU reserve would assure an international supply of nuclear fuel to consumer states on a non-discriminatory, non-political basis. As former Senator Sam Nunn, Co-Chairman of NTI, said in his speech announcing the pledge, “We envision that this stockpile will be available as a last-resort fuel reserve for nations that have made the sovereign choice to develop their nuclear energy based on foreign sources of fuel supply services—and therefore have no indigenous enrichment facilities”.

This money was contingent on two conditions being met within two years of the announcement of the offer: (1) that the IAEA take the necessary actions to approve the establishment of the reserve; and (2) that one or more IAEA member states contribute an additional $100 million in funding or an equivalent value of LEU to start the reserve. No other conditions were set by NTI—policy questions are to be solved by the IAEA and its member states. Key issues still to be determined include the reserve’s content, location, criteria for determining access to the stocks, the LEU pricing, fabrication of fuel assemblies for the customer’s reactor, safety and export control standards, and so forth.

NTI proclaims that nothing in their proposal “would limit the rights of nations to pursue peaceful nuclear technology. Our proposal is designed to reinforce the sovereign choice of nations who decide to rely on foreign sources of nuclear fuel”.[63]

The US Congress allocated $50 million for a nuclear fuel reserve under the auspices of the IAEA. On 26 December 2007 President George W. Bush signed the funding allocation into law, which says “$50,000,000 of such funds shall be available until expended for the contribution of the United States to create a low-enriched uranium stockpile for an International Nuclear Fuel Bank supply of nuclear fuel for peaceful means under the International Atomic Energy Agency”. This move was welcomed by IAEA Director General Mohamed ElBaradei, who noted “I have long been advocating the establishment of assurance of supply mechanisms in view of increasing demand for nuclear power and to strengthen non-proliferation”, and recognized such a fuel bank as central to this.[64]

In addition to the US pledge, in February 2008 Norway has made a $5 million contribution,[65] and in August 2008 the United Arab Emirates pledged a further $10 million.[66] In December 2008 the European Union pledged to contribute up to €25 million, "once the conditions and modalities for the bank have been defined and approved by the Board of Governors of the IAEA".[67]

"The EU pledge, along with those by Norway, the United Arab Emirates and the USA shows growing momentum for a new more equitable framework for nuclear energy," said IAEA Director General Mohamed ElBaradei.[68] Sam Nunn, Co-Chairman of NTI, said that "This announcement represents major progress toward the goal of bringing an IAEA bank into reality … . This announcement by the European Union brings the total amount raised to approximately $97 million of the $100 million needed. I am delighted that more than 30 countries [including 27 EU members] have joined together in support of the fuel bank and our effort to reduce nuclear dangers".[69]

Before the whole amount was raised, the IAEA could not meet the second condition and take the steps necessary to establish the reserve. The IAEA Director General decided not to approach the Board of Governors for a decision until "the necessary funds to establish an IAEA fuel bank become available".[70] However, on 6 March 2009 Kuwait pledged US$ 10 million toward the fuel bank. Now that all funding is finally pledged, the fuel bank will become subject of a complicated discussion in the IAEA Board of Governors on terms and conditions for its use and release criteria for LEU.[71]

The NTI proposal is the only one containing a specified deadline, originally requiring that both conditions be met by the IAEA and its member states by the end of September 2008. At the request of the IAEA Director General and with the consent of NTI, the deadline has been extended by an additional year, and now stands at September 2009.

The fact that this last-resort LEU stockpile would be controlled by the IAEA could be more appealing to customer countries than would be commitments by supplier states.

## ENRICHMENT BONDS PROPOSAL

The United Kingdom proposed in September 2006 that enrichment bonds be created that would give advance assurance of export approvals for uranium enrichment services to customer states as a further enhancement to the Six-Country Concept.[72] The Enrichment Bonds proposal provides further assurance that governments would not stop existing supply contracts for reasons other than commercial or non-proliferation issues.

The bonds would be an agreement between the supplier state or states, the customer state and the IAEA. The supplier government guarantees that its enrichment service providers will be given the necessary export approvals to supply the customer state, subject to the customer being in good non-proliferation standing with the IAEA. This mechanism aims to give further assurance of supply with a "prior consent to export" arrangement. The IAEA would make the final decision on whether conditions had been met to allow the export of LEU.

The proposed mechanism would depend on certain conditions being met by both supplier countries and customer counties. On the supplier side, the proposal requires the governments of participating supplier states to surrender their right to withhold approval for exports of enriched uranium product in favour of the IAEA taking the final decision solely on the basis of non-proliferation issues. On the consumer side, the proposal requires customer states to satisfy a number of conditions, which might include:

- the customer state is not able to secure enrichment services through the normal operations of the world market for reasons other than commercial or non-proliferation issues;
- the customer state is in full compliance with its IAEA safeguards agreement and has an additional protocol for safeguards in force, and the IAEA has determined that all nuclear materials in the state are in peaceful use;
- the supplied material is for peaceful purposes and not for re-transfer; and
- the physical protection levels of the supplied material meet internationally agreed standards.

The proposal attributes a key role in providing confidence in the reliability of anticipated supply mechanism to the IAEA:

> The legal agreement underpinning the enrichment bond captures the role of IAEA as guarantor. The IAEA would take the final decision as to whether the conditions had been met to allow the export of LEU from enrichment plants. As a consequence, the transparency of decision-making involved in this agreement should serve to provide a credible guarantee of supply.

The proposal has been supported by Germany and the Netherlands. In a joint declaration the foreign ministers of Germany, the Netherlands and the United Kingdom stressed that this initiative is “designed to promote energy security by providing a robust back-up guarantee against politically motivated interruptions of uranium enrichment services”; the three countries agreed to “develop this initiative further”.[73]

Recently the name of the proposal has been changed to the Nuclear Fuel Assurance proposal.

## INTERNATIONAL URANIUM ENRICHMENT CENTRE

As a first practical step toward the creation of a “global nuclear power infrastructure”, earlier propounded by Russian President Vladimir Putin, the Russian Federation has established a model International Uranium Enrichment Centre (IUEC) at the Angarsk Electrolysis Chemical Complex “to provide guaranteed access to uranium enrichment capabilities to the Centre’s participating organizations”.

On repeated occasions representatives of Rosatom[74] have stated that the basic principles of the IUEC are:

- equal and non-discriminatory membership;
- guaranteed access to uranium enrichment services for IUEC participant states;
- the IUEC would operate as a commercial joint stock company;
- transparency of IUEC activities would be guaranteed by placement of its nuclear materials under IAEA safeguards;
- the IUEC would be a “black box”, as participant states would not have access to Russian enrichment technologies;

- political and economic advantages from membership in the IUEC would discourage its participant states from developing indigenous enrichment technologies; and
- step-by-step implementation of the IUEC concept.

The IUEC is envisioned as a mechanism for providing guaranteed supplies of uranium enrichment services while at the same time strengthening the non-proliferation regime.

In a September 2006 address to the WNA, Sergei Kiriyenko, head of Rosatom, explained that the IUEC would be governed by a management board, set to include representatives of IUEC shareholder governments, while the IAEA would carry out observer functions. The centre would be set up as a joint stock company to guarantee "financial independence from the State budgets of the participatory countries".[75]

Simultaneously Russia embarked on a broad reorganization of the Russian nuclear industry. President Putin authorized the law "On Special Terms of Management and Disposition of Assets and Shares of Organizations Operating in the Area of Atomic Energy Uses and Amendments to Certain Legislative Acts of the Russian Federation", which, among other changes, allows Russian legal entities to own nuclear materials and facilities. This legislation allowed the creation of the 100% state-owned holding company Atomenergoprom, which united the civil enterprises of Russia's nuclear power industry.

The IUEC concept has moved toward full implementation during 2007 and 2008. The IUEC was formally brought into existence with the signing of an agreement between Kazakhstan and Russian on 10 May 2007. This intergovernmental agreement defines, inter alia, the following issues:

- the main goals and terms for IUEC activities (Article 3);
- executive bodies and authorized organizations nominated by governments (Article 2);
- form of incorporation and location of the IUEC (Article 3);
- basic requirements for participant states and authorized organizations that seek to become shareholders of the IUEC, namely compliance with NPT obligations (Article 6);
- prohibition of access by foreign shareholders to Russian uranium enrichment technologies (Article 9); and

- application of IAEA safeguards to nuclear materials produced and owned by the IUEC (Article 10).[76]

The proposed organization of the IUEC seems similar in some respects to the EURODIF model that involves five participating countries (France, Italy, Spain, Belgium and Iran) but only one enrichment facility in France. The level of investment of each EURODIF member corresponds to its percentage share of the product. In this model, management, operations and technology remain under the national control of the host state. As has been said, the IUEC is structured ("black-boxed") in such a way that no access to enrichment technology or classified information will be granted to the foreign participants.

The IUEC does not have its own uranium enrichment capacity. Instead it will negotiate contracts for uranium enrichment services with the Angarsk Electrolysis Chemical Complex—a nuclear fuel cycle facility that has provided enrichment services to foreign partners since the 1980s. According to Alexey Grigoryev, general director of the IUEC, these contracts will be guaranteed by the Russian government.[77] In September 2008, in the context of the continuing reform of the Russian nuclear industry, the Angarsk Electrolysis Chemical Complex was reorganized into a state-owned joint stock company. Maybe later, if the IUEC develops into a stakeholder of the Angarsk enrichment complex, it would become an owner of some of its centrifuges. The IUEC project is essentially "market neutral" as it does not create new enrichment capacity but at the same time helps to diversify the roster of suppliers.

The registration of the IUEC as a Russian legal entity was completed in September 2007 and the first issue of shares took place that November. Since then, a board of directors for the joint venture has been put in place, and a director general was elected. Today Russia owns a 90% stake in the IUEC while the remaining 10% share is owned by Kazakhstan. In December 2007 the Russian Government included the IUEC on the list of Russian nuclear fuel cycle enterprises that can be put under the IAEA safeguards.

Any IAEA member state that meets "the established non-proliferation criteria" (which are not defined) is eligible to participate in the IUEC, although it has previously been indicated that members should also not be "envisaging the development of indigenous sensitive nuclear technology".[78] In his statement to the fifty-second Regular Session of the IAEA General

Conference in September 2008, Sergei Kiriyenko said that the IUEC is "open to third state parties without any political preconditions". He continued, "In January 2008 we officially informed IAEA that we had included the centre in the list of the Russian nuclear fuel cycle companies that can be subject to the IAEA safeguards. We expect that by the end of this year the centre will get all necessary permissions and licenses".[79]

Several countries have already shown their interest in participating in the IUEC. Armenia indicated its interest in joining the centre in February 2008, when the foreign ministries of Russian and Armenia exchanged relevant diplomatic notes. The Russian–Ukrainian Action Plan, which was signed by the presidents of both countries in February 2008, included an agreement that Moscow and Kiev would consider the participation of Ukraine in IUEC activities. Rosatom has promoted the idea to a few other countries, including Bulgaria, Finland, Japan, Mongolia, Slovakia, South Korea and Uzbekistan. With the joining of new participant states, the shares in the IUEC's chartered capital will be redistributed with the Russian portion diminishing in favour of new stakeholders. But, the Russian portion will never fall below 51%. The IUEC stockholders would either have guaranteed enriched uranium product, or a share in the profits.

In addition to uranium enrichment services, Russia will supply the uranium to create an independent IAEA-controlled LEU reserve at the Angarsk site, which would provide the Agency with means to assure supply to customer states in case of a politically motivated disruption of supply. The reserve will hold about 120 metric tons of LEU that will be safeguarded by the IAEA, and released from the bank (with guaranteed export permission) on request of the IAEA Director General. Such a reserve would be sufficient to produce fuel assemblies for two core refuelings of a typical light water power reactor (LWR) with the installed electricity generating capacity of about 1GW(e).

The IUEC is a first practical step to make the IAEA's Multilateral Nuclear Approaches concept a reality. IAEA officials have repeatedly stated that the Agency would put its support behind the IUEC as "the most advanced" of all of the MNA proposals.[80] However, agreements between the IAEA and Russia on the safeguards arrangements and on the LEU fuel bank, which were originally expected to be concluded in the first half of 2008, still have not been finalized. In December 2007 the Director General of the IUEC

Alexey Grigoryev announced that the centre will start rendering its services to participant states in 2008–2009.[81]

Russian authorities hope that the IUEC will serve as a model for similar international enrichment centres in other parts of the world. Also important is that the project can be considered as a practical, although tentative, step toward placing an existing national enrichment facility in a nuclear-weapon state under some form of multilateral control.

It still remains to be seen how the proposed scheme for the international enrichment centre and the IAEA-controlled LEU stockpile at Angarsk would actually work, how strong would be "entitlement" motivations offered by this mechanism to potential participant states, and how many states would be willing to join the IUEC to make this project truly multilateral.

See Annex C for more details on the IUEC.

## MULTILATERAL ENRICHMENT SANCTUARY PROJECT

Germany proposed in May 2007 that a new multilateral enrichment facility be built and placed under IAEA supervision in an extraterritorial area.[82] The plant would be financed and run on a commercial basis, but the IAEA would control the release of nuclear materials. Germany has argued that such an arrangement "is advantageous since it does not prohibit uranium enrichment, but does provide a commercially viable, politically neutral option for fuel supply and could create competition on the world market by creating a new fuel service provider".[83]

The proposal has been actively pursued, refined and amended during 2007 and 2008 and was renamed the Multilateral Enrichment Sanctuary Project (MESP). According to the proposal, "a host country would … cede the administration and certain sovereign rights over a certain area … to the IAEA". The host country would have to transfer functional immunities to the IAEA to such an extent that the operation of the enrichment plant would be protected from any potential interference by the host state or others.

The proposal, as developed thus far, has recommended that "the site [for the enrichment plant] be based in a State that does not currently have enrichment capability".[84]

The IAEA itself would not own the enrichment facility. A Group of Interested States (GIS) should agree with the IAEA to "build one (or more) enrichment plant(s)" in a special extraterritorial area called a Multilateral Enrichment Sanctuary (MES).[85] This group of states would invite their national industries to set up an international company "which finances, constructs and manages an enrichment plant on a commercial basis". The company would be "owned, governed and managed under rules set by the GIS and their national industries".

The MESP proposal particularly elaborates that "Arrangements would have to be made to ensure that no comparative advantages arise from the fact that the plant(s) were sited in an area not under national jurisdiction, thus acting as competitively neutral players in the world market for uranium-enrichment services".[86]

The IAEA would act as the nuclear regulator and supervisor for the operation of the enrichment facility, the role which is normally carried out by a state body. The MESP proposal does not intend to transfer enrichment technology to the IAEA. The plant "would have to be constructed as a 'black box' and would therefore only be accessed and maintained by the supplier".[87]

The IAEA Board of Governors is responsible for defining the criteria by which decisions would be made on the release of LEU from this plant, which would offer its services to all potential customer states fulfilling these criteria. Thus, "the supply of LEU would not be limited to the nuclear power plants of the GIS".

It was discussed that "the enrichment plant(s) could in addition provide a revolving buffer stock of LEU, which, released only by order of the Director General of the IAEA, would serve as a crisis mechanism to supply countries in need, in cases of political, i.e. not commercial, or technical interruptions of supply".

Two model agreements are being worked out, which could serve as legal basis for the MESP: an agreement between the IAEA and a host state (the so-called "Host State Agreement"), and a multilateral framework agreement between the IAEA and the GIS (the so-called "MESP Agreement").

In the MESP Agreement the participating states and the IAEA agree to the rules that they both will follow. This agreement would include such key provisions as separation of functions between the IAEA, the GIS and the enrichment company; release of nuclear material and enrichment services according to "a predetermined and fixed set of criteria"; some issues related to ownership and management of the enrichment company; and costs, liability and other provisions. The MESP Agreement may also include some obligations of its parties related to protection of the enrichment technology.

The Host State Agreement would resemble agreements in which "the Host State grants certain rights—including rights over a defined territory—to international organizations". The proposal states that a "Host State would have to comply with a certain criteria set in advance by the IAEA". The IAEA would ensure that activities in the MES comply with the applicable IAEA standards for safety, security and safeguards. The IAEA "would be responsible for licensing, inspection, enforcement, and import and export controls in the MES", although some of these tasks could be delegated to the host state or other state authorities.

The MESP proposal is explicitly welcoming to all interested parties, even including those who might wish to develop an indigenous enrichment technology, by noting that they would "remain free to develop their own enrichment technology, if they choose to do so and circumstances require".[88] This inclusiveness increases the attractiveness of the MESP idea, particularly to states that "have long been concerned that participation in multilateral ventures was dependent on not pursuing indigenous enrichment and reprocessing activities",[89] while still providing a cost-effective alternative to national programmes.

However, it may prove difficult to find a host country for the MESP proposal. In addition to requiring that the country does not currently have uranium enrichment capability, the MESP proposal lists the following criteria for the host country: reliable infrastructure and good accessibility, political stability, adherence to the IAEA safeguards agreement, and good standing with the NPT. Even if some country meeting all these criteria, as well as criteria to be set by the IAEA, would be willing to cede the requisite territory, there would be numerous practical issues that would need to be resolved.

See Annex D for more details on the MESP.

## MULTILATERALIZATION OF THE NUCLEAR FUEL CYCLE

Rather than establishing a bank as a reserve of LEU or nuclear fuel, Austria suggested in May 2007 a two-track mechanism aimed at the creation of a new multilateral framework for nuclear energy that over time would include converting enrichment and reprocessing facilities from national to multilateral operations. Austria called this new multilateral framework a Nuclear Fuel Bank.[90]

According to the proposal, "a first track could be devoted to optimizing international transparency going beyond current IAEA safeguards obligations". At this stage all states should declare their existing nuclear programmes, development plans, and activities, and all transfers of nuclear material, equipment and related technologies. The exchange of information would take place through the IAEA. The proposal states that "the increased transparency resulting from these procedures would provide greater clarity as to the nature of every country's nuclear programmes and thus enhance overall confidence".

The second track would place all nuclear fuel transactions under the auspices of the Nuclear Fuel Bank. Existing civilian enrichment and reprocessing facilities would eventually operate exclusively through it. "Once this stage has been reached, nuclear fuel would be supplied exclusively via multilateral facilities and institutions", according to the proposal.

This proposal is more conceptual in nature and represents a long-term vision. The Austrian Government believes that "there should not be a differentiation in 'haves' and 'have-nots', only in 'wants' and 'want-nots'. For those states that opt for nuclear energy, access to nuclear fuel should be a strictly regulated but impartial and fair undertaking". Austria plans to "continue to contribute to the multilateralization debate and intends to present a more detailed outline of its proposal in the IAEA's appropriate fora in the near future".[91]

## NUCLEAR FUEL CYCLE NON-PAPER

The European Union submitted a non-paper on the nuclear fuel cycle to the IAEA Secretariat and the 2007 NPT Preparatory Committee meeting.[92] However, this non-paper did not suggest a stand-alone mechanism like other proposals, but rather offered a list of criteria by which such mechanisms could be evaluated.

The EU non-paper noted that flexibility would be appropriate in considering an approach to fuel supply options, "As different states will have different motivations and interests, we should refrain from focusing on the idea of a uniform approach". It suggested that a mix of a limited number of multilateral mechanisms could be a step forward to institutionalizing control "over potentially dangerous substances and thereby contribute to mutual trust and confidence among the parties involved".

The non-paper pointed out that "The individual perspective, interests and concerns of potential participants in a multilateral mechanism must be analyzed and taken into consideration, as well as the interests and concerns of those states that may be affected by the establishment of a multilateral mechanism or supply scheme".

The European Union proposed criteria against which different proposals could be assessed. These criteria included:

- **proliferation resistance**: minimization of the risk of unintended transfer of sensitive nuclear technologies or a "break-out" (the use of a facility for military purposes);
- **assurance of supply**: factors relating to customer confidence, including "reliability of long-term supply arrangements; role and powers of the IAEA; applicability of national export controls and flag rights ("prior consent"); "back-end"-rules; production capacity and reserves; possibility of an intervention by the state in which a facility is located; functioning of the system in a situation of an acute shortage of supply";
- **consistency with equal rights and obligations paradigm**: obligations of private companies, supplier states, consumer states and the IAEA; consistency with Article IV of the NPT; and
- **market neutrality**: avoiding any unnecessary disturbance or interference in the functioning of the existing market.

The non-paper further noted that technical issues, in particular safety and security, would have to be considered as well. It noted that fuel supply mechanisms should not contribute to the development of nuclear programmes that depart from the highest safety and radiation protection standards.

# CHAPTER 4

# COMPARISON OF PROPOSALS

The proposals for the multilateralization of the nuclear fuel cycle that are currently on the table differ considerably in their vision, scope, targets and time required for implementation. Nevertheless, there are a few points on which these proposals seem to reach broad agreement:

- first, the proposals generally agree that any multilateral mechanism should not disturb the international market for nuclear fuel cycle services, especially for supply of front-end services, such as uranium enrichment and nuclear fuel. Many of the proposals seek to ensure the "market neutrality" of projected multilateral supply mechanisms by designing them as a "guarantee-in-depth" or a supplement instrument that would be triggered only in the event of a disruption of normal commercial supplies for political reasons;
- second, the proposals for the most part concur that the establishment of multilateral fuel cycle arrangements should be implemented step by step. Most proposals focus on the front-end problem, dealing with LEU and fuel supply. The back-end issues—reprocessing/recycling of spent fuel or waste disposal—are mainly left to be addressed later; and
- third, there seems to be a common understanding that there is no uniform approach that would be satisfactory for all technologies and countries, and that successful implementation of multilateralization would depend on the flexibility of application.

The Russian GNPI and the US GNEP have offered the most far-reaching visions for global supply mechanisms, addressing services ranging from enrichment and fuel supply to spent fuel take-back and reprocessing. Both seek to avoid the creation of national enrichment and reprocessing facilities by states that currently do not have any. Their success depends on the long-term development of new technologies and both would require considerable effort to establish the necessary infrastructure and overcome the political, legal and technical obstacles.

The Austrian proposal has offered a bold, although vague, conceptual vision of eventually placing all sensitive nuclear technologies and activities, including existing civilian enrichment and reprocessing facilities and fuel supply, under multilateral control.

All three proposals are very ambitious but can only be accomplished in the long term, with much more thought to be given to the details before these proposals will be mature enough to deal sufficiently with the stumbling blocks that lie ahead.

The remaining proposals are more limited in their targets, dealing primarily with the front end of the nuclear fuel cycle. The solutions thus far proposed can be categorized into three groups:

- providing backup assurances of supply in addition to the existing commercial uranium market (WNA proposal, Six-Country Concept, Japanese IAEA Standby Arrangements, UK Enrichment Bonds);
- establishing nationally controlled (US reserve of nuclear fuel, WNA proposal, Six-Country Concept) or IAEA-controlled LEU reserves (Russian IUEC, NTI Fuel Bank); and
- establishing/placing uranium enrichment facilities under some form of international control, including the establishment of an IAEA-controlled uranium enrichment facility (Russian IUEC, German MESP proposal).

One can also distinguish between those proposals that have a prospect for relatively short-term implementation and those that can be realized in the mid-term.

First, there are those proposals that, if the remaining problems can be solved, would not require much further work by the international community because they rely to a great extent on national policies. This group includes the US reserve of nuclear fuel, the Russian IUEC, the Six-Country Concept and the WNA proposal (the latter two proposals can be supplemented by the UK Enrichment Bonds proposal and perhaps by the Japanese IAEA Standby Arrangements). These proposals can be counted in the category of short-term projects.

The key elements of these projects are already in place and, what is more, two of these projects now proceed full steam. With down-blending of HEU to be completed in 2010,[93] the proposed US-controlled LEU stockpile will be capable of operation. The Russian IUEC should start providing its uranium enrichment services in early 2009, and Russia decided to provide uranium for the first IAEA-controlled LEU reserve, which should be located in Angarsk. Some combination of the Six-Country Concept and the WNA proposal, supplemented by the UK Enrichment Bonds and the Japanese IAEA Standby Arrangements, can build on the existing enrichment market, coordinated national policies and the good political will of nuclear-supplier governments and IAEA member states. Of course, successful implementation of these proposals will require active and productive involvement of the IAEA, but all remaining issues (agreements between the IAEA and Russia for the IUEC and LEU reserve would have to be finalized; the IAEA Board of Governors would have to agree that the Director General might act as a broker in fuel deals within the framework of the Six-Country Concept mechanism, and so forth) can be resolved rather expeditiously. On the negative side, these projects may not give sufficient incentive for potential customer countries to participate, as they may consider these projects as serving the self-interest of supplier states, aimed at perpetuating their position in the global nuclear supply market. Additional efforts might be required to persuade the customer countries that these projects would serve their best interests.

The other group of proposals comprises multilateral projects that would require considerable effort to create the necessary physical, political, legal and financial conditions. This category includes the NTI Fuel Bank and the German MESP proposal. These proposals have the advantage of being truly multilateral, which may provide additional "entitlement" motivation for customer countries to participate. On the negative side, they would require new physical infrastructure and the resolution of complex political, legal and financial issues before becoming a reality. Such issues include the siting, the legal status of an extraterritorial area for the international uranium enrichment plant, the questions of managing the site and providing protection as well as basic support services, the LEU reserve's content, start-up and operational costs, safety and export control standards, fuel pricing, and so forth.[94] Nevertheless, the establishment of an IAEA-controlled fuel bank does not seem to be as complex an endeavour as the creation of a new internationally controlled enrichment facility in an extraterritorial area. All this said, the NTI Fuel Bank proposal can be considered as a short-term project, while the German MESP proposal is a mid-term project.

Table 1 provides a comparison of the existing proposals by their timeframe and scope. For a point by point comparison of the proposals, see Annex B.

**Table 1.** Comparison of existing proposals by timeframe and scope

| Timeframe | Proposal | Scope |
|---|---|---|
| **Short term** | Russian IUEC | Establishment of an IUEC under the IAEA safeguards; establishment of an IAEA-controlled LEU reserve |
| | US Reserve of Nuclear Fuel | Establishment of a nationally controlled LEU reserve |
| | Combination of Six-Country Concept and WNA proposal, supplemented by Enrichment Bonds and IAEA Standby Arrangements | Backup assurances of LEU and nuclear fuel supply in addition to the existing commercial uranium market; establishment of nationally controlled LEU reserves |
| | NTI Fuel Bank | Establishment of an IAEA-controlled LEU reserve |
| **Mid-term** | German MESP Proposal | Establishment of an IAEA-controlled international uranium enrichment plant in an extraterritorial area |
| **Long term** | Russian Global Nuclear Power Infrastructure | Establishment of a global supply mechanism. A system of international centres providing fuel cycle services from uranium enrichment and fuel supply to spent fuel take-back and reprocessing |
| | US Global Nuclear Energy Partnership | Establishment of a global supply mechanism. Front-end and back-end services provided by a limited number of supplier states using new proliferation-resistant technologies |
| | Multilateralization of the Nuclear Fuel Cycle | Establishment of a mechanism directed on eventual placing of the existing civilian enrichment and reprocessing facilities and fuel supply activities under multilateral control |

## CHAPTER 5

## LUKEWARM RESPONSE

IAEA Director General Mohamed ElBaradei emphasized that multilateral mechanisms for assurance of supply were "not an attempt to divide the nuclear community into suppliers and recipients".[95] However, it is notable that almost all proposals for multilateral approaches for the nuclear fuel cycle have emerged from current or potential nuclear suppliers. Many potential customer states have remained either indifferent or have voiced fears that a suppliers "cartel" might be created. The Minister of Minerals and Energy of the Republic of South Africa, Buyelwa Sonjica, most expressively summed up the views of these states:

> there is a need to guard against actions, which would merely serve to exacerbate existing inequalities, including through the creation of another kind of cartel that would exclude full participation, particularly by States in full compliance with their safeguards obligations. … Although prevailing proliferation concerns may prompt us to consider alternative arrangements on supply mechanisms, these may under no circumstances impose unwarranted restrictions and controls over the legitimate peaceful use of nuclear energy. … If we agree to such conditions, we may well be contributing to undermining the very bargains on which the NPT was founded and further disturb the delicate balance of rights and obligations under this instrument.[96]

The question critical to continued success of the proposed multilateral schemes is how to make them attractive to non-nuclear-weapon states in good standing under the NPT and, no less importantly, to those that are not.

The 40-year history of the NTP provides enough evidence that a large majority of states, non-nuclear as well as nuclear, share an interest in containing the spread of nuclear weapons. Most countries with nuclear programmes or those who plan to have such programmes in the future are not proliferators. Rather, their concern is energy security, including access to nuclear power. They generally recognize the risks of proliferation of sensitive technologies, but many find it difficult to accept arrangements that perpetuate what they perceive as discrimination between nuclear and non-nuclear states in terms of the peaceful use of nuclear energy.

At the same time, many countries recognize that an international regime to control nuclear fuel-cycle technologies and materials is “an idea whose time has come”. In the scenario of a strong expansion of nuclear energy around the globe, the number of enrichment and reprocessing facilities simply cannot expand in proportion to the number of expected nuclear plants. As well, the spread of fuel cycle capabilities to additional states would increase the risk of proliferation and undermine confidence in the non-proliferation regime. But it is here a nuclear fuel cycle control regime has the potential to benefit the whole of humankind. Various existing restrictions on international nuclear trade were, first of all, motivated by non-proliferation reasons. In this sense they were, in fact, also in the interests of the customer states.

But to be successful, such a multilateral nuclear fuel cycle control regime must not be based on the self-interest of a limited number of nuclear supplier states or nuclear industry. A serious weakness of the suppliers’ initiatives is in their failure to consult with the customers. To succeed, proposals for a multilateral approach must take into account not only the interests of fuel suppliers but those of other nations.

And, of course, the issues related to the nuclear fuel cycle cannot be separated from the broader context of nuclear disarmament and non-proliferation. Both nuclear-weapon and non-nuclear-weapon states should respect their mutual obligations and responsibilities under the NPT and other international agreements while avoiding political selfishness that would most certainly lead to an impasse. The nuclear-weapon states have to fulfil their obligation under the NPT to undertake negotiations on effective measures leading to nuclear disarmament. All NPT parties should actively engage on this issue with the non-NPT states. A world divided into nuclear “haves” and “have-nots” does not create a favourable environment for the internationalization of the nuclear fuel cycle—for its reorganization in a way that transcends national sovereignty. In their turn, non-nuclear-weapon states have to fully accept their own responsibilities and not use the uneven progress on nuclear disarmament as an excuse for not addressing the dangers of nuclear proliferation. A greater focus on how to resolve the real problem—that too many states have the capacity and the right to access sensitive fuel cycle technologies—would benefit all states.

The functioning global market for nuclear fuel, the historically rare interruptions of nuclear fuel supply and the caution when dealing with complex multilateral arrangements of yet unproven value make countries that purchase nuclear fuel generally indifferent to such proposals. Customer countries still need to be convinced that proposed multilateral mechanisms have been devised to strengthen global security while at the same time helping them benefit from the use of nuclear power. The issue of a multilateral approach to the nuclear fuel cycle needs to be addressed in terms of opportunity and advantage, not in terms of denial. The proposed mechanisms should not seek to deprive customer states of any of their rights, including sovereign rights, rights under the NPT or rights under the IAEA statute. These mechanisms should be open to as wide a range of participants as possible, not setting unnecessarily restrictive qualifying criteria for entry. Economic and other benefits from participation in multilateral mechanisms—for example, receiving enriched uranium at an economically attractive price from an international enrichment facility, while also sharing in decision-making and profits, versus going to the trouble and massive expense of developing indigenous enrichment technology—should be noticeable and well understood by potential customers. Rules and principles of these mechanisms should be clearly defined and not subject to unilateral change by a host country.

Many countries would not willingly agree to a permanent system where some nations are entitled to nuclear fuel cycle services, and others are not. Assurances of supply of uranium enrichment services and nuclear fuel, while capable of reducing the need to establish national enrichment plants, do not respond to the "entitlement" motivation of some customer states. To address that, "a mechanism that gives any nation that wants it at least some form of vested interest in one or more major elements of fuel cycle services is required".[97] This interest would not, and should not, include access to sensitive technologies, but can be satisfied by genuine participation in ownership, management, decision-making, profit-sharing and so forth.

An essential issue to be investigated is whether these multilateral mechanisms should be available for non-NPT states and states not in good standing with the IAEA. In its report, the International Expert Group on Multilateral Approaches to the Nuclear Fuel Cycle considered possible participation of non-NPT states in multilateral approaches mainly in the context of conversion of existing fuel cycles facilities from national to multilateral operations. The involvement of non-NPT states and states not currently in good standing with the IAEA should be thoroughly studied.

Karl Marx once observed that an idea "becomes a material force as soon as it has gripped the masses". The idea of multilateralization of the nuclear fuel cycle as a response to the growing proliferation risks created by the spread of sensitive nuclear technologies certainly has not yet fully gripped the international community. What is needed now is a concerted effort on the part of nuclear supplier and customer states contemplating starting or growing nuclear power programmes, international organizations, non-governmental organizations and academics to cooperate on the crucial international issues of the nuclear fuel cycle and non-proliferation, fully appreciating the responsibilities incumbent on owners and users of these dangerous technologies. To be successful, multilateral nuclear fuel cycle arrangements would inevitably require a broad political consensus on how non-proliferation and energy security goals relate to one another and how the international community can limit access to sensitive nuclear technologies, all while protecting states' rights to develop the nuclear fuel cycle.

## CHAPTER 6

# CONCLUDING THOUGHTS

1. The anticipated increase in global energy demand is driving a potential expansion in the use of nuclear energy worldwide after the more than two decades of virtual stand-still. Global nuclear power capacity is projected to double by 2030. To a large part the expected "revival" of nuclear power will be driven by the nuclear power plant construction programmes in countries that do not currently have established nuclear power industries.

2. If the "nuclear renaissance" scenario is realized, it could result in the worldwide dissemination of uranium enrichment and spent fuel reprocessing technologies. These sensitive technologies present obvious risks of proliferation since they are capable of providing states with materials that are directly usable in a nuclear weapon or a nuclear explosive device. Wide dissemination of these technologies could be the Achilles' heel of the global nuclear non-proliferation regime.

3. Technical measures alone would not compensate for the limitations of the existing nuclear non-proliferation regime. Some international institutional mechanisms, which are non-technical in nature and involve various political, economic or diplomatic strategies for controlling access to sensitive materials, facilities or technologies, are needed for dealing with this problem.

4. The Director General of the IAEA recently proposed a three-stage process in developing a new multilateral mechanism for the nuclear fuel cycle:

   - the first step would be to establish a system for assuring supply of fuel for nuclear power reactors and, if necessary, supply of the reactors themselves;
   - the second step would be to have all new enrichment and reprocessing activities in the future put exclusively under multilateral control; and

- the third step would be to convert all existing enrichment and reprocessing facilities from national to multilateral operations.

5. The focus of international efforts has recently been to try to develop a system of credible guarantees of supply of LEU and nuclear fuel to assure customer countries that they will have a reliable fuel supply conditioned only on their meeting some predetermined qualifying non-proliferation criteria. Over the past few years, 12 proposals have been put forward by states, nuclear industry and international organizations, aimed at checking the spread of uranium enrichment and spent fuel reprocessing technologies, in particular by suggesting means of assuring nuclear fuel supplies and establishing international fuel cycle centres.

6. The proposals for a multilateral approach to the nuclear fuel cycle that are on the table differ considerably in their vision, scope, targets and time required for their implementation. The majority of the proposals are rather limited in their goals, dealing primarily with the front end of the nuclear fuel cycle, that is, the supply of nuclear fuel and in particular LEU for power production. The proposed solutions to this problem can be categorized into three groups:

    - providing backup assurances of supply in addition to the existing commercial uranium market (WNA proposal, Six-Country Concept, Japanese IAEA Standby Arrangements, UK Enrichment Bonds);
    - establishing nationally controlled (US reserve of nuclear fuel, WNA proposal, Six-Country Concept) or IAEA-controlled LEU reserves (Russian IUEC, NTI Fuel Bank) as a last resort in the event the existing market for nuclear fuel fails; and
    - establishing/placing uranium enrichment facilities under some form of international control, including the establishment of an IAEA-controlled uranium enrichment facility (Russian IUEC, German MESP proposal).

    Two proposals—the Russian GNPI and the US GNEP—offer the most far-reaching visions for global supply mechanisms. But these proposals are rather vague on details and, as the devil is always in the detail, more thought must be given to them.

    The Austrian proposal has offered a bold, although vague, conceptual vision of eventually placing all sensitive nuclear technologies and activities, including existing civilian enrichment and reprocessing facilities and fuel supply, under multilateral control.

7. The US national reserve of nuclear fuel, the Russian IUEC and the Six-Country Concept, combined with the WNA proposal and supplemented by the UK Enrichment Bonds and the Japanese IAEA Standby Arrangements, can be considered as short-term proposals. Realization of these projects would not require much further work by the international community because they rely to a great extent on national policies. Many key elements of these projects are already in place and two of these projects now proceed full steam.

   The NTI Fuel Bank and the German MESP proposal are multilateral projects that would require new physical infrastructure and the resolution of complex political, legal and financial issues before becoming a reality. Nevertheless, the NTI Fuel Bank can be counted as a simpler short-term project, while the German MESP proposal represents a more complex mid-term project.

   The GNPI, the GNEP and the Austrian proposal are long-term conceptual visions.

8. While the current emphasis is on concepts for LEU and fuel supply assurances, they may only give modest incentive for customer states to participate, since the commercial market already provides reliable supplies of LEU and nuclear fuel. Proposals that respond to the “entitlement” motivation of customer states in terms of their participation in ownership, management, operation, decision-making, profit-sharing and so forth would perhaps be more attractive than just backup mechanisms for the existing market.

   Proposals that include taking away spent nuclear fuel and providing other back-end services would create far stronger incentives for states to rely on international mechanisms for fuel supply.

9. Having guaranteed access to LEU will not help customer states immediately because they require a reliable supply of fabricated fuel assemblies to load into their power reactors. But creating an international backup supply system for fabricated fuel would be more complicated as fuel design is specific to each reactor design. However, fabrication technology for low enriched uranium oxide fuel

is not generally of proliferation concern. Therefore it would not result in an increase in the proliferation risks if some countries decide to establish domestic production of fuel assemblies for their own nuclear power reactors, without developing uranium enrichment or spent fuel reprocessing technologies.

10. Multilateral approaches to the nuclear fuel cycle are by no means a “magic bullet” solution that would resolve all non-proliferation problems once and for all. They cannot eliminate all motives for acquiring enrichment and reprocessing technologies, and any multilateral arrangement could hardly deter the committed proliferator or any state determined to acquire the full nuclear cycle. Nevertheless, they have a substantial potential to ensure that the benefits of nuclear energy are made available to all countries, while further strengthening the nuclear non-proliferation regime, ensuring safe and secure management of the nuclear fuel cycle and reducing incentives to build new nuclear fuel cycle facilities in countries that do not now have them.

11. It is understood that no generic multilateral formula would be satisfactory for all technologies and countries, and thus successful implementation of multilateralization would depend on the flexibility of its application. The establishment of multilateral fuel cycle arrangements should be implemented step by step, with existing proposals pursued on their own merits. The IAEA and its member states should support a broad menu of these proposals, ensuring that they do not contradict and undermine each other.

12. A new multilateral nuclear fuel cycle regime should not deprive customer states of any of their rights. Instead it should dissuade them from developing sensitive fuel cycle technologies by offering political and economic incentives as well as providing certain “entitlement” motivations to participate.

13. Although the success of multilateral approaches to the nuclear fuel cycle is by no means guaranteed, greater progress in this direction has been recently made than during the 1970s and 1980s. The Russian IUEC should start providing its uranium enrichment services in early 2009, and Russia decided to provide uranium for the first IAEA-controlled LEU reserve, which should be located in Angarsk. Several

other proposals are also being actively pursued, including the US-controlled reserve of LEU, the NTI Fuel Bank and the German MESP proposal.

14. More efforts are needed from the IAEA and its member states for these proposed mechanisms to be accomplished in practice. The IAEA Board of Governors has apparently not formally discussed any of the proposals. The international discussion on these issues has remained to a great extent locked in political arguments instead of having a greater focus on the real problem—how to reconcile the anticipated expansion of nuclear power and the dangers associated with further proliferation of sensitive nuclear technologies.

    To help unlock this situation, the nuclear-weapon states should take concrete steps toward meeting their disarmament obligations under the NPT, including ending the stalemate on a Fissile Material Cut-off Treaty (FMCT) and bringing into force the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Non-nuclear-weapon states have to fully accept their own responsibilities and not use uneven progress on disarmament as an excuse for not addressing the dangers of nuclear proliferation.

    Any real progress toward a multilateral approach to the nuclear fuel cycle can be achieved only in the context of broad agreement that an international non-discriminatory nuclear fuel cycle control regime has the potential to benefit the whole of humankind. Inhibiting the spread of sensitive nuclear technologies and materials directly usable in nuclear weapons, while promoting better access to safe and clean energy, is undoubtedly in the interests of the world community.

15. The issue of multilateral approaches to the nuclear fuel cycle should be addressed at the 2010 NPT Review Conference. But if again countries will bring to the conference their own narrow agendas, this will be a recipe for disaster. All state parties must come to the conference with a genuine desire to improve the non-proliferation regime and international security.

16. Governments of supplier and customer states, international and non-governmental organizations and academics should cooperate in a concerted effort to ensure a dependable multilateral nuclear fuel cycle

regime in order to strengthen the global non-proliferation regime and guarantee prosperity and energy security for all.

# APPENDIX A

# THE NUCLEAR FUEL CYCLE AND NON-PROLIFERATION

The most important question with regard to nuclear power is whether it is possible for it to be widely used for peaceful purposes without states using their nuclear knowledge, technology and assets to develop nuclear weapons. The major proliferation risks lie in the spread of technologies used in uranium enrichment and nuclear fuel reprocessing as these can provide states with materials directly usable in a nuclear weapon or a nuclear explosive device—high enriched uranium (HEU) and separated plutonium.

## NUCLEAR FUEL CYCLE

The nuclear fuel cycle refers collectively to industrial activities associated with the generation of power from nuclear reactions. The uranium nuclear fuel cycle employs uranium (chemical symbol U) in different chemical and physical forms, depending on the stage of the process. Typical stages of the uranium nuclear fuel cycle are:

- mining and milling of uranium ore;
- uranium conversion and processing;
- uranium enrichment;
- fuel fabrication;
- use of the fuel in nuclear power, research, or propulsion reactors;
- interim storage of spent fuel;
- reprocessing and recycling;
- long-term disposal of spent fuel; and
- management and disposal of radioactive wastes.

The “front end” of the nuclear fuel cycle comprises the stages from ore mining to the use of the fuel in nuclear reactors. The “back end” comprises the stages concerning the management, storage, and either reprocessing or long-term disposal of spent nuclear fuel. If spent fuel is not reprocessed, the fuel cycle is termed an “open” or “once-through” fuel cycle; if the spent fuel is reprocessed, the fuel cycle is termed “closed” fuel cycle.

Not all of these stages are necessarily utilized in the process of electricity generation by nuclear power reactors. For example, uranium enrichment is not needed for some types of reactors, such as the Canadian-designed heavy water CANDU reactor, which uses natural uranium fuel. Another example is the once-through nuclear fuel cycle, in which spent fuel reprocessing and plutonium recycling are omitted, and all the spent fuel is ultimately disposed of as waste in a geological repository.

It is also conceivable to use thorium (chemical symbol Th) instead of uranium to produce electricity in nuclear reactors and in this case the fuel cycle is referred to as the thorium fuel cycle.

## URANIUM ENRICHMENT

The term "enrichment" is used in relation to an isotope separation process by which the abundance of a specified isotope in an element is increased, such as the production of enriched uranium from natural uranium or heavy water from plain water.[98] Enriched uranium is a critical component for both civil nuclear power generation and military nuclear weapons.

The predominant isotope in uranium as found in nature is U-238 (the number indicates the atomic mass of the isotope). This isotope accounts for 99.28% of natural uranium, while about 0.71% is U-235. Although the isotopes of an element have very similar chemical properties, their nuclear properties may be very different, as is the case with U-238 and U-235. The latter is the only naturally occurring isotope of any element that is readily fissionable not only by fast neutrons but also by thermal, or slow, neutrons, and able to sustain a nuclear chain reaction. "Fission" refers to the splitting of atoms by neutrons, a process which releases energy in the form of heat. It is the generated heat from fission of the U-235 atoms by thermal neutrons that is used to produce electricity in commercial power reactors. The U-238 isotope does not contribute directly to the fission process in any significant amount, although it does so indirectly through the formation of fissile isotopes of plutonium (chemical symbol Pu).

The most prevalent commercial power reactors in the world are light water reactors, which constitute more than 80% of the world power reactor fleet. A light water reactor (LWR) is a thermal nuclear reactor that uses plain water ("light" water, as distinct from "heavy" water, in which the water molecule is comprised of oxygen and deuterium, an isotope of hydrogen) as its neutron moderator and coolant. For use in commercial LWRs uranium is enriched to 3–5% U-235. Research reactors and fast-neutron reactors require higher enrichment—typically higher than 15%.

According to the IAEA classification, low enriched uranium (LEU) is enriched uranium containing less than 20% of the isotope U-235, while HEU is uranium containing 20% or more of the isotope U-235.[99] The fissile uranium in nuclear weapons, known as weapon-grade uranium, usually contains 90% or more of U-235.[100] Little Boy, the bomb dropped on Hiroshima in 1945, was constructed using uranium enriched to about 80% U-235.[101] Theoretically, however, a nuclear explosive device could be constructed using enriched uranium with a U-235 fraction ranging from as low as 20% or even less, even if such a device would be more difficult to design and fabricate. The IAEA considers any HEU as direct-use material, which means that it "can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment".[102]

Isotope separation is primarily a physical process, although a chemical technique has been demonstrated on a laboratory scale by France and Japan. The enrichment processes that have been demonstrated industrially or in the laboratory are:

- gaseous diffusion;
- thermal diffusion;
- gas centrifuge separation;
- atomic vapour laser isotope separation;
- molecular laser isotope separation;
- separation of isotopes by laser excitation;
- aerodynamic isotope separation;
- electromagnetic isotope separation;
- plasma separation; and
- chemical separation.

Only two—the gaseous diffusion process and the gas centrifuge process—are currently operating on an industrial scale. In both of these, uranium hexafluoride ($UF_6$) gas is used as the feed material. Enriching uranium is difficult because U-238 and U-235 have virtually identical chemical properties, and are very similar in weight. But molecules of $UF_6$ with U-235 atoms are about 1% lighter than molecules with U-238, and this difference in mass is the basis of both processes.

The diffusion process involves forcing $UF_6$ gas through a series of porous membranes. Because gas molecules containing U-235 are lighter, they move faster and have a slightly better chance of passing through the membrane than those containing U-238. Thus, $UF_6$ gas that has passed through the membrane is slightly enriched, while the gas that has not pass through the membrane is slightly depleted in U-235.

To achieve a noticeable level of enrichment, the process has to be done repeatedly in a series of diffusion stages assembled into a "cascade". Each stage consists of a compressor, a diffuser and a heat exchanger. The enriched $UF_6$ gas, called the product material, is withdrawn from one end of the cascade, while the depleted $UF_6$ gas, called the waste material, is removed from the other end. The gas must be processed through more than a thousand diffusion stages to enrich it to 3% to 4% U-235. Generally, diffusion facilities are large and require great amounts of energy to operate.

In the centrifuge process, $UF_6$ gas is fed into an evacuated chamber containing a cylindrical rotor that spins at high speed. As the rotor spins, the heavier $UF_6$ molecules with U-238 concentrate more towards the periphery of the cylinder, while the concentration of U-235 molecules increases near the centre. Gas enriched in U-235 is removed at one end of the centrifuge rotor and gas depleted in U-235 is removed at the opposite end.

A single centrifuge has much greater capability to separate isotopes than a single diffusion stage, but it still cannot produce the desired level of enrichment. Usually a large number of centrifuges are connected in parallel to achieve the desired product flow because the capacity of an individual centrifuge is rather small. These stages are then arranged in cascades to attain the desired level of enrichment. In the centrifuge process, however, the number of stages is much smaller than in the gaseous diffusion process.[103] The energy consumption of a gas centrifuge facility is much less than that of a gaseous diffusion plant. Centrifuge enrichment technology is gradually replacing the outmoded and non-competitive gaseous diffusion process.

Uranium enrichment technologies are sophisticated and challenging, but earlier centrifuge technology became more widely accessible in recent years. A dozen states currently possess such technology. Apart from the five official nuclear weapons states (China, France, Russia, the United Kingdom and the United States) and two de facto nuclear weapons states (India and Pakistan), three non-nuclear-weapon states (Germany, Japan and the Netherlands) operate large-scale enrichment plants, while two (Brazil and Iran) are building smaller enrichment plants. Several other countries have expressed their interest in acquiring uranium enrichment technology in the future.

There is the obvious proliferation risk attendant to the production of LEU. There is no technological barrier between the production of LEU and HEU. Weapon-grade material can be produced using the same enrichment equipment that otherwise is used to produce LEU for civilian power generation. The task of producing weapon-grade uranium is easier if LEU is available: "at the enrichment level of typically used in light-water power reactors—3.5 per cent uranium-235—already six-tenths of the separative work has been done; at the 20 per cent U-235 level used in fuel for many research reactors, nine-tenths".[104] The risk is compounded by the fact that certain types of enrichment facilities are difficult to detect via satellite imagery, emissions or any other methods of observation.

Table 2 shows enrichment facilities that are currently operational or planned. The work of isotope separation is measured in "separative work units" (SWUs).[105] Likewise, the capacity of enrichment facilities is commonly described in SWU per year.

Two of the four leading commercial suppliers of uranium enrichment services—URENCO and EURODIF—are actually multinational consortia, representing two different models of multinational ownership and operation.

**Table 2.** Large enrichment facilities—operational, under construction and planned[106]

| Country | Name/Location | Type | Status | Process | Capacity (1,000 SWU/yr) |
|---|---|---|---|---|---|
| Brazil | Resende Enrichment | civilian | commissioning | centrifuge | 120 |
| China | Lanzhou 2 | civilian | in operation | centrifuge | 500 |
| | Shaanxi Enrichment Plant | civilian | in operation | centrifuge | 500 |
| France | Georges Besse | civilian | in operation | diffusion | 10,800 |
| | Georges Besse II | civilian | under construction | centrifuge | 7,500 |
| Germany | Gronau | civilian | in operation | centrifuge | 2,000 |
| India | Rattehallib | military | in operation | centrifuge | 4–10 |
| Iran | Natanz | civilian | under construction | centrifuge | 100-150 |
| Japan | Rokkasho Enrichment Plant | civilian | in operation | centrifuge | 1,050 |
| Netherlands | Almelo | civilian | in operation | centrifuge | 4,000 |
| Pakistan | Kahutab | military | in operation | centrifuge | 15–20 |
| Russia | Angarsk | civilian | in operation | centrifuge | 2,600 |
| | Novouralsk | civilian | in operation | centrifuge | 9,800 |
| | Zelenogorsk | civilian | in operation | centrifuge | 5,800 |
| | Seversk | civilian | in operation | centrifuge | 4,000 |
| UK | Capenhurst | civilian | in operation | centrifuge | 5,000 |
| USA | Paducah | civilian | in operation | diffusion | 11,300 |
| | Portsmouth | civilian | standby | diffusion | 7,400 |
| | National Enrichment Facility | civilian | under construction | centrifuge | 3,000 |
| | American Centrifuge Plant | civilian | planned | centrifuge | 3,500 |
| | Idaho Falls Enrichment Plant | civilian | planned | centrifuge | 3,000 |

URENCO represents one approach, where each of the partners (Germany, the Netherlands and the United Kingdom) owns and operates a gas centrifuge enrichment facility within its borders, and shares knowledge of the centrifuge technology with the other partners. URENCO supplies uranium enrichment services to third countries based on the unanimous agreement of the participants.

EURODIF involves five participating countries—France, Italy, Spain, Belgium and Iran—but there is only one gaseous diffusion enrichment facility in France. EURODIF is intended to serve the domestic fuel requirements of its members. Each member receives a percentage share of the product according to its percentage of investment. In the case of EURODIF, management, operations and sensitive enrichment technology remain under the national control of France. The consortium provides its participants with security of supply and an equity share in a production enterprise.

## SPENT FUEL REPROCESSING

Unlike uranium, plutonium does not occur in nature. However, as stated above, while U-238, comprising most of the fuel mass in a nuclear reactor, is not directly responsible for the fission process, it absorbs neutrons forming new heavier isotopes. U-238 absorbs a neutron creating U-239, which in a matter of days decays to Pu-239 via the short-lived isotope neptunium-239. Subsequent neutron captures result in accumulation of other isotopes of plutonium, including Pu-240, Pu-241 and Pu-242, as well as other transuranic or actinide isotopes. Like U-235, isotopes Pu-239 and Pu-241 are fissionable both by thermal and fast neutrons.

According to the US Department of Energy, weapon-grade plutonium—that is, the plutonium most suitable for the use in nuclear weapons—consists mainly of Pu-239, with less than 7% Pu-240[107] and very small quantities of other plutonium isotopes. Nevertheless, most isotopic mixtures of plutonium can be used in a nuclear weapon or a nuclear explosive device. According to the IAEA classification, plutonium containing less than 80% Pu-238 is direct-use material that "can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment".[108] This effectively defines any plutonium discharged from commercial nuclear reactors as direct-use material, because this plutonium contains much smaller quantities of the Pu-238 isotope, which is the other main isotope of plutonium produced in nuclear reactors.

Fuel discharged from a nuclear reactor after irradiation still contains most of the U-238 that was present in the fuel when charged, appreciable concentrations of fissile nuclides (U-235, isotopes of plutonium), other artificial elements (called "actinides") produced by nuclear reactions, and large amounts of radioactive fission products. Once irradiated fuel is discharged from the reactor, it can be reprocessed to extract plutonium and unspent uranium for further use or recycling.

Reprocessing is the chemical separation of plutonium and uranium from the fission products and transuranics contained in spent nuclear fuel. There can be different reasons for reprocessing spent fuel:

- producing plutonium as fuel for nuclear weapons;
- recycling plutonium, uranium and other actinides as fuel for a special type of nuclear reactor, the so-called fast-neutron breeder reactors, thus closing the nuclear fuel cycle;
- recycling plutonium once as MOX fuel[109] for light-water nuclear reactors; and
- managing nuclear waste radioactivity by separating actinides and fission products and converting the radioactive constituents of spent fuel into forms suitable for safe, long-term storage.

The composition of irradiated fuel to be fed to a reprocessing plant varies widely, depending on many factors, among them the composition of the fresh fuel, the duration of irradiation, and the length of time the fuel was "cooled" (the interval between end of irradiation and start of reprocessing). For uranium fuel, as a rule of thumb, the lower the fuel "burnup",[110] the higher the content of the Pu-239 isotope and the lower the content of other plutonium isotopes. Higher burnup, such as in a nuclear power reactor, generates more plutonium, but also causes the other plutonium isotopes to build up, thus lowering the proportion of Pu-239.

The most wide-spread method for spent fuel reprocessing is the PUREX (plutonium–uranium extraction) process, which was originally developed by the United States in the early 1950s to produce plutonium for nuclear weapons. During the reprocessing, fuel cladding is first removed from the fuel, either mechanically or chemically, and the fuel is dissolved in nitric acid. This solution is then put through a series of solvent extraction phases in which the fission products and actinides are first separated out, followed by the uranium and plutonium. The latter two are separated from each other and purified.

Spent fuel reprocessing is not a very sophisticated technology. But it involves serious environmental and safety risks as reprocessing facilities handle large amounts of highly radioactive and dangerous materials. Obvious proliferation risks are associated with reprocessing, because reprocessing plants are difficult to safeguard and they produce separated plutonium, which is weapon-usable material.

Reprocessing was initially undertaken to provide plutonium and other materials needed for nuclear weapons. Separated plutonium was also expected to be used by some countries in a new type of reactor, called fast-neutron plutonium breeder reactors. The term “breeder” relates to the ability of such reactors to produce more fissile materials than they consume. Hypothetically this would allow them to fuel themselves and other reactors with the plutonium they produce, making the breeders an inexhaustible source of energy. Such reactors, however, proved expensive and unreliable. In the absence of commercial fast-neutron reactors, economic viability of the reprocessing technology is questionable, as low prices for uranium ore help make the once-through nuclear fuel cycle more cost effective than the recycling of plutonium as MOX fuel for light-water reactors.

As a result, spent fuel reprocessing has been deployed by very few countries so far—mainly for military purposes. With the exception of Pakistan, all official, de facto and suspected nuclear-weapon states (China, France, Russia, the United Kingdom and the United States; India and North Korea; and Israel) used reprocessing technology to produce plutonium for their nuclear weapons.

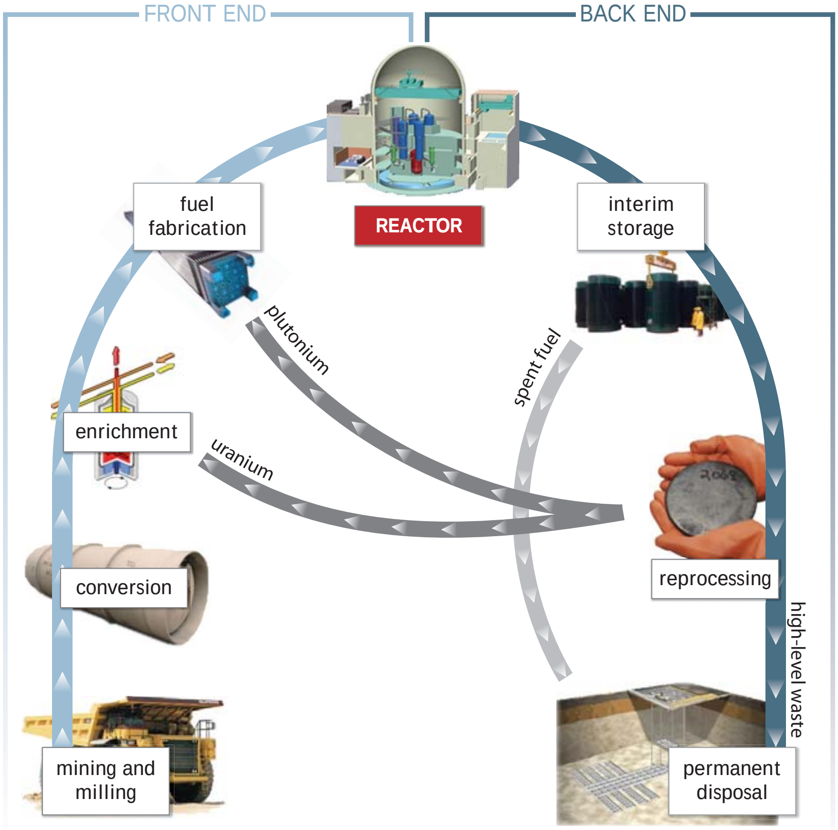
Only India, Pakistan and possibly Israel continue to produce fissile materials for nuclear weapons (either plutonium or HEU). France, Russia, the United Kingdom and the United States have officially announced an end to their production for weapons, while China has indicated this unofficially. North Korea has stopped its reprocessing activities as a result of the Six-Party Agreement announced in February 2007.

Today, five countries own and operate reprocessing facilities for commercial spent fuel from power reactors—France, India, Russia, the United Kingdom, and Japan, the only non-nuclear-weapon state to do so—while China is finishing the construction of a pilot reprocessing facility.

Over the last several years, international attention to reprocessing has been increasing as anticipation of a nuclear "renaissance" has revived the interest in the closed nuclear fuel cycle, fast-neutron reactors and the transmutation of radioactive waste.

Diagram 2 provides an overview of the nuclear fuel cycle.

**Diagram 2.** Schematic representation of the nuclear fuel cycle



## APPENDIX B

## COMPARISON OF CURRENT PROPOSALS

| | Goals | Target | Mechanism | Eligibility |
|---|---|---|---|---|
| **International Expert Group on Multilateral Approaches (INFCIRC/640)** | Identify multilateral approaches across the nuclear fuel cycle; strengthen non-proliferation without distributing market mechanisms | Front-end and back-end services including uranium enrichment, fuel reprocessing, and disposal and storage of spent fuel | Reinforced commercial contracts with government backing; international supply guarantees backed by fuel reserves; multilateral nuclear fuel-cycle centres | Voluntary participation. Customer states would renounce the construction and operation of sensitive fuel cycle facilities and accept safeguards of the highest current standards including comprehensive safeguards and the Additional Protocol |
| **US Reserve of Nuclear Fuel** | Support reliable fuel supply assurances | A reserve of LEU, produced from HEU declared excess to national security needs, as a backup to an international assurance supply mechanism | No particular mechanism specified. Presumably the same mechanism as for supply of any US-origin LEU | Customer states should comply with US requirements on US-origin material |
| **Russian Global Nuclear Power Infrastructure** | Increase the role of nuclear power in ensuring global energy security. Provide states equal access to front-end and back-end fuel cycle services while stressing the non-proliferation regime | A system of international centres providing fuel cycle services on a non-discriminatory basis and under IAEA control | Equal access on market terms for all countries under regulation and standards of non-proliferation | Participants should comply with regulation and standards of non-proliferation |

| Role of IAEA | Role of industry | Problems to solve | Potential concerns |
|---|---|---|---|
| Participates in administering supply guarantees, possibly as guarantor of service supplies with use of a fuel bank; fosters multilateral fuel-cycle centre agreements; safeguards | Managing and operating multilateral centres | Assuring front-end and back-end services supply; converting existing facilities to MNAs; creating multinational and, in particular, regional MNAs for new facilities | Unwillingness of states to give up control of their energy supplies to regional or international organizations |
| No particular role specified | Performing down-blending of HEU | Uranium enrichment contracts disrupted due to political considerations | The reserve would be kept under US control, which may limit its attractiveness to some customer states |
| Control over activities of created international fuel cycle centres; safeguards | Managing and operating international fuel cycle centres | Avoiding establishment of new fuel cycle facilities in states that do not have them | Details still have to be worked out. Emphasis is placed on the front end of the nuclear fuel cycle; no clear and specific proposals on the back end |

| | Goals | Target | Mechanism | Eligibility |
|---|---|---|---|---|
| **US Global Nuclear Energy Partnership** | Enable expansion of nuclear power in the United States; help resolve nuclear waste disposal issues; promote nuclear non-proliferation goals. Provide states with front-end and back-end fuel cycle services | Front-end and back-end services provided by a limited number of supplier states using new proliferation-resistant technologies | Use of existing and new enrichment capabilities. Development of more proliferation-resistant reprocessing technologies. Fuel suppliers will be responsible for spent fuel take-back | No specific requirements now versus initial requirements for customer states to forgo enrichment and reprocessing |
| **WNA Proposal** | Enhance security of existing market mechanisms in enrichment services | Primarily uranium enrichment services supply | Three-tiers: Level I: Market provides basic supply security. Level II: Collective guarantees by enrichers supported by governmental and IAEA commitments. Level III: Government stocks of LEU | IAEA-approved states that: (1) are in full compliance with international safeguards; and (2) made a commitment to forgo their own enrichment facilities |
| **Six-Country Concept** | Create measures for assurances of reliable supply of enrichment services or enriched uranium | Uranium enrichment services supply | Multi-tiered set of measures: Level I: Existing market. Level II: Fuel assurance mechanism through the IAEA and mutual commercial backup arrangements. Level III: LEU reserves | IAEA-approved states that: (1) have a comprehensive safeguards agreement and an additional protocol in force; (2) adhere to accepted international nuclear safety and security standards; and (3) are not pursuing sensitive fuel cycle activities |

| Role of IAEA | Role of industry | Problems to solve | Potential concerns |
|---|---|---|---|
| Application of safeguards | Performing front-end and back-end fuel cycle services | Avoiding establishment of new fuel cycle facilities in states that do not have them.<br>Resolving spent fuel and nuclear waste disposal issues | Dependence on the success or failure of long-term development of new technologies.<br>Risk of proliferation of sensitive nuclear technologies.<br>Lack of political will to take back spent fuel |
| Approves "triggering" mechanism for supply backup.<br>Ensures equal shares for enrichers in providing backup supply.<br>Assesses whether a customer state is eligible to participate | Performing enrichment contracts.<br>Providing backup supply under the Level II backup supply arrangements | Commercial uranium enrichment contracts disrupted due to political reasons | Requires a complicated set of agreements among all suppliers.<br>Does not bind host governments to abide by the agreements signed by their enrichment companies.<br>Incentives may not be sufficient |
| Acts as "broker" by facilitating new supply arrangements.<br>Assesses whether the customer state is eligible to participate.<br>Could own or manage LEU reserves | Performing enrichment contracts.<br>Providing backup supply under the Level II backup supply arrangements | Commercial uranium enrichment contracts disrupted due to political reasons | Admission criteria to the proposed backup mechanism are too restrictive.<br>A limited role for the IAEA in controlling backup LEU reserves.<br>Incentives may not be sufficient |

| | Goals | Target | Mechanism | Eligibility |
|---|---|---|---|---|
| **IAEA Standby Arrangements** | Inclusion of other front-end services in addition to uranium enrichment. Prevention of market failure for uranium fuel supply. Expansion of number of potential suppliers | Front-end services supply | IAEA Standby Arrangements System including (1) a list of supply capacities from each state updated annually; and (2) a virtual bank of front-end fuel cycle services | Any IAEA member state with no non-compliance problems with the IAEA safeguard agreement |
| **NTI Fuel Bank** | Assure an international supply of nuclear fuel | Access to LEU on a non-discriminatory and non-political basis | LEU stockpile owned and managed by the IAEA | States meeting non-proliferation obligations. Specific criteria are to be determined by the IAEA and its member states |
| **Enrichment Bonds Proposal** | Provide further assurance that governments would not stop existing supply contracts for political reasons | Uranium enrichment services | Enrichment bond: agreement between the supplier state, the customer state and the IAEA in which the supplier government would guarantee that national enrichers would be given the necessary export approvals to supply the customer state | IAEA-approved states that: (1) are in full compliance with the IAEA safeguards agreement and have an additional protocol in force; (2) adhere to accepted international nuclear safety and security standards; and (3) use supplied material for peaceful purposes and not for re-transfer |

| Role of IAEA | Role of industry | Problems to solve | Potential concerns |
|---|---|---|---|
| Acts as "match maker" between the consumer country and the supplier country that could provide the required service during the particular year | Performing front-end services supply contracts | Potential failure of the market to provide adequate front-end services supply | Risk of proliferation of sensitive nuclear technologies |
| Control, management of LEU stockpile, safeguards | Providing and hosting LEU stockpile | Commercial uranium enrichment contracts disrupted due to political reasons | Deadline would not be extended indefinitely.<br>Key issues still to be determined (the reserve's content, location, criteria for access, safety and export control standards, the fuel's pricing, etc.) |
| Acts as guarantor. Makes the final decision on whether conditions had been met to allow the export of LEU | Performing enrichment contracts | Insufficient confidence in reliability of supply mechanism | Conditions on customer states are too stringent |

| | Goals | Target | Mechanism | Eligibility |
|---|---|---|---|---|
| **IUEC** | Provide guaranteed and non-discriminatory access to uranium enrichment services | Uranium enrichment services | "Market neutral" IUEC under the IAEA safeguards with no access to technology by stakeholders. Independent IAEA-controlled LEU reserve | Any IAEA member state that meets the established non-proliferation criteria |
| **MESP** | Provide a commercially viable, politically neutral international option for fuel supply | Uranium enrichment services | "Politically neutral" IAEA-controlled international uranium enrichment plant in an extraterritorial area with no access to technology by stakeholders | All NTP member states in compliance with their obligations deriving from the NPT |
| **Multilateralization of the Nuclear Fuel Cycle** | Promote multilateralization of the nuclear fuel cycle | Placement of all enrichment and reprocessing facilities and nuclear fuel supply activities under multilateral control | Nuclear Fuel Bank: (1) all states declare to the IAEA and to each other all existing nuclear programmes and activities and all transfers of nuclear material, equipment, and related technologies; (2) all nuclear fuel transactions and, eventually, enrichment and reprocessing facilities and nuclear fuel supply are placed under multilateral control | All states participate. No restrictive criteria specified |

| Role of IAEA | Role of industry | Problems to solve | Potential concerns |
|---|---|---|---|
| Application of safeguards to nuclear materials owned by the IUEC. Control of LEU reserve, safeguards | Performing enrichment contracts. Providing LEU reserve | Spread of indigenous uranium enrichment technologies | Agreements between the IAEA and Russia have not yet been finalized. Incentives may not be sufficient |
| Administers the extraterritorial area. Supervises the uranium enrichment plant. Decides whether to supply LEU according to non-proliferation criteria | Owns and operates the enrichment plant | Spread of indigenous uranium enrichment technologies | Could be difficult to find a host country. Numerous political, legal and practical issues to be resolved |
| Creates and administers the Nuclear Fuel Bank | Participate in conversion of enrichment and reprocessing facilities from national to multilateral operations | Spread of indigenous sensitive nuclear cycle technologies Differentiation of states in “haves” and “have-nots” | Many details still have to be worked out. Difficulties of conversion of enrichment and reprocessing facilities from national to multilateral operations (national interests; political, financial, and legal hurdles; security considerations, etc.) |

## APPENDIX C

## IUEC DETAILS

The International Uranium Enrichment Centre (IUEC) was formally brought into existence with the signing of the "Agreement between the Government of the Republic of Kazakhstan and the Government of the Russian Federation on Foundation of the International Centre for Uranium Enrichment" on 10 May 2007. The two countries defined Tekhsnabeksport and Kazatomprom as the authorized organizations of the states parties.

The Russian state-owned nuclear holding corporation Rosatom unites all nuclear military, civil and research assets, including the 100% state-owned joint stock company Atomenergoprom, which unites the civil enterprises of Russia's nuclear power industry. Atomenergoprom owns 100% of the shares of Tekhsnabeksport, which is a major player in the global market of products and services of the nuclear fuel cycle.

Kazatomprom is a national operator of the Republic of Kazakhstan for import and export of uranium and other dual-use materials. All of the shares of this company are owned by the state.

Tekhsnabeksport and Kazatomprom own all the shares of the International Uranium Enrichment Centre.

Other countries can join in the centre. A new participant state will have to conclude intergovernmental agreements, or exchange diplomatic notes, with the governments of the Russian Federation and the Republic of Kazakhstan and define its authorized organization. The authorized organization of the participant state will buy shares of the IUEC. Currently Kazatomprom owns 10% of the shares and Tekhsnabeksport owns 90%. With the joining of new participant states, the shares will be redistributed with the Russian portion diminishing in favour of new stakeholders. But this portion will never fall below 51%.

The IUEC signs contracts with the Angarsk Electrolysis Chemical Complex, a Russian centrifugal enrichment facility owned by Atomenergoprom.

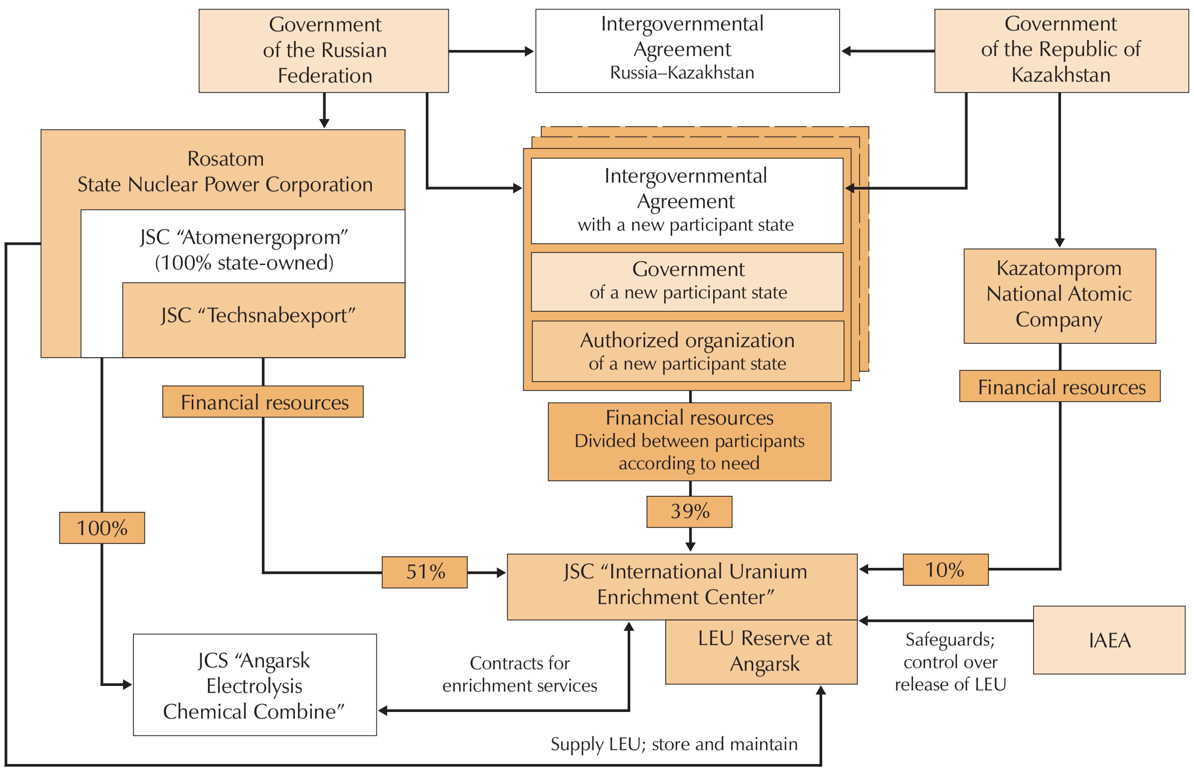
According to these contracts, the Angarsk Complex will supply uranium enrichment services to the IUEC.

Nuclear materials owned and processed by the IUEC are subject to IAEA safeguards.

The Russian Federation will also create an independent IAEA-controlled LEU reserve at the Angarsk site, which would provide the Agency with the means to assure supply to customer states in case of a politically motivated disruption of supply. The reserve will hold about 120 metric tons of LEU that will be provided, owned, stored and maintained by Russia and be safeguarded by the IAEA. This material will be released from the bank on the request of the IAEA Director General.

Diagram 3 provides an overview of the organization of the IUEC.

**Diagram 3.** IUEC organizational structure (JSC indicates a joint-stock company)



# APPENDIX D

# MESP DETAILS

A Group of Interested States (GIS) will agree with the IAEA to build an enrichment plant in a special extraterritorial area called Multilateral Enrichment Sanctuary (MES). This group of states will invite their national industries to set up a commercial MESP Enrichment Company, which will finance, construct, own and operate the enrichment plant. The MESP Enrichment Company itself will be owned, governed and managed under rules set by the GIS and their national industries.

The IAEA and the GIS will conclude a multilateral framework agreement, the so-called MESP Agreement. The MESP Agreement will include such key provisions as separation of functions between the IAEA, the GIS and the Enrichment Company; the rules governing the release of nuclear material and enrichment services to customers; costs, liability and other provisions.

A host country would cede the administration and certain sovereign rights to the IAEA in a part of its territory. The IAEA and the host state will conclude a separate agreement, the so-called Host State Agreement. It would resemble regular agreements in which a host state grants certain rights—including rights over a defined territory—to international organizations.

The IAEA will administer the Multilateral Enrichment Sanctuary. The Agency would also act as the nuclear regulator and supervisor for the operation of the enrichment facility, the role which is normally carried out by a state body.

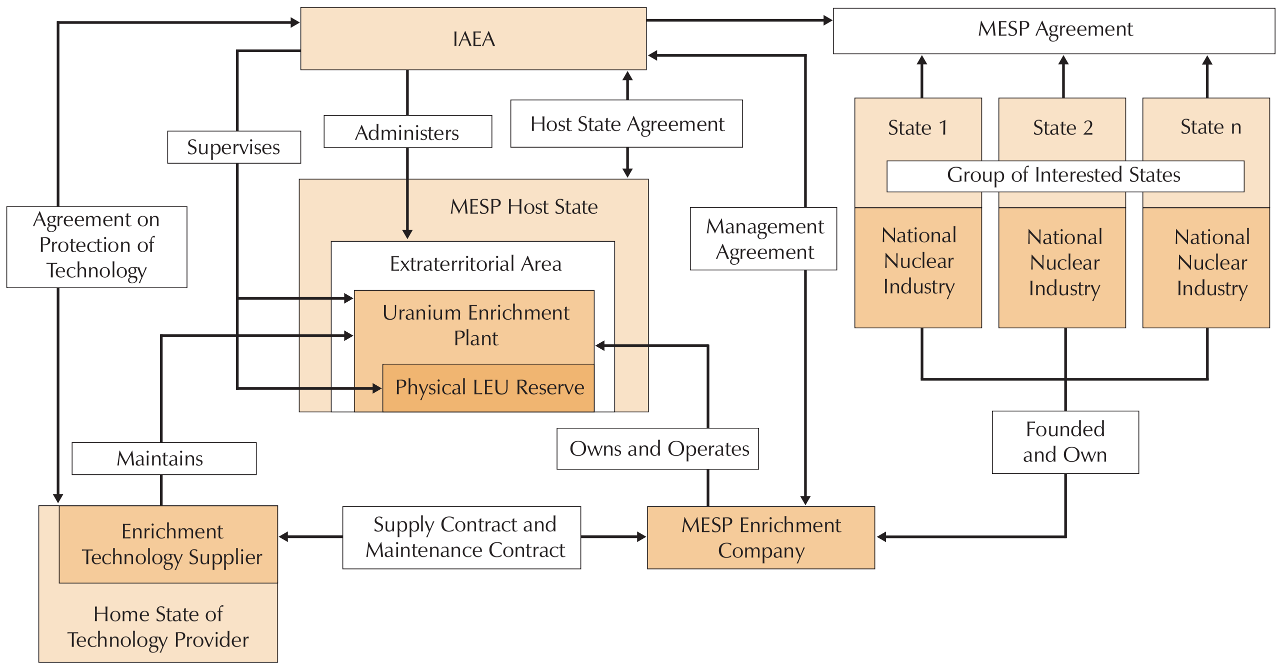
The IAEA will also conclude a separate agreement of protection of uranium enrichment technology with technology-supplying companies and their home governments. Instead of a separate agreement, obligations related to protection of the enrichment technology may be part of the MESP agreement.

One more agreement between the IAEA and the MESP Enrichment Company will cover issues pertaining to the day-to-day management of the enrichment plant.

The MESP enrichment plants could also have a physical stock of LEU, which would be released only by order of the Director General of the IAEA serving as a crisis mechanism to supply customers in cases of political interruptions of supply.

Diagram 4 provides an overview of the MESP structure.

**Diagram 4.** MESP organizational structure



## Notes

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States and/or international organisations, such as the IAEA)". IAEA, *Multilateral Approaches to the Nuclear Fuel Cycle, Expert Group Report submitted to the Director General of the International Atomic Energy Agency*, document INFCIRC/640, 22 February 2005, pp. 19–20.

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[32] IAEA, *Communication dated 30 May 2008 received from the Permanent Mission of the Federal Republic of Germany to the Agency with regard to the German proposal for a Multilateral Enrichment Sanctuary Project*, document INFCIRC/727, 30 May 2008; IAEA, *Communication dated 22 September 2008 received from the Permanent Mission of Germany to the Agency regarding the German proposal on a Multilateral Enrichment Sanctuary Project*, document INFCIRC/735, 25 September 2008.

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[109] Mixed-oxide fuel, or MOX fuel, is a mixture of the oxides of plutonium and natural or depleted uranium used as reactor fuel for the recycling of plutonium in thermal nuclear reactors ("thermal recycling") and for fast reactors.

[110] Burnup is a measure of the neutron irradiation of the fuel in a reactor. It is usually quoted in megawatt-days per metric ton of uranium metal (MWd/MT). This is the amount of heat liberated by the fuel through fission and other nuclear reactions. It gives a rough measure of the number of nuclear fission events that have taken place within the fuel.

## GLOSSARY

These definitions are taken primarily from the *IAEA Safeguards Glossary*, 2001 edition.

**Direct use material**
Nuclear material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment. It includes plutonium containing less than 80% $^{238}Pu$, high enriched uranium and $^{233}U$. Chemical compounds, mixtures of direct use materials (e.g. mixed oxide (MOX)), and plutonium in spent reactor fuel fall into this category. Unirradiated direct use material is direct use material which does not contain substantial amounts of fission products; it would require less time and effort to be converted to components of nuclear explosive devices than irradiated direct use material (e.g. plutonium in spent reactor fuel) that contains substantial amounts of fission products.

**Enriched uranium**
Uranium having a higher abundance of fissile isotopes than natural uranium. Enriched uranium is considered a special fissionable material.

**Enrichment plant** (or isotope separation plant)
An installation for the separation of isotopes of uranium to increase the abundance of $^{235}U$. The main isotope separation processes used in enrichment plants are gas centrifuge or gaseous diffusion processes operating with uranium hexafluoride ($UF_6$) (which is also the feed material for aerodynamic and molecular laser processes). Other isotope separation processes include electromagnetic, chemical exchange, ion exchange, and atomic vapour laser and plasma processes.

**Fast reactor** (fast neutron reactor)
A reactor that, unlike thermal reactors, operates mainly with fast neutrons (neutrons in the energy range above 0.1MeV) and does not need a moderator. Fast reactors are generally designed to use plutonium fuels and can produce, through transmutation of $^{238}U$, more plutonium than they consume, i.e. they can be operated as breeder reactors with a conversion ratio greater than unity.

**Fissionable material**
In general, an isotope or a mixture of isotopes capable of nuclear fission. Some fissionable materials are capable of fission only by sufficiently fast neutrons (e.g. neutrons of a kinetic energy above 1MeV). Isotopes that undergo fission by neutrons of all energies, including slow (thermal) neutrons, are usually referred to as **fissile materials** or fissile isotopes. For example, isotopes $^{233}U$, $^{235}U$, $^{239}Pu$ and $^{241}Pu$ are referred to as both fissionable and fissile, while $^{238}U$ and $^{240}Pu$ are fissionable but not fissile.

**Fuel element** (fuel assembly, fuel bundle)
A grouping of fuel rods, pins, plates or other fuel components held together by spacer grids and other structural components to form a complete fuel unit which is maintained intact during fuel transfer and irradiation operations in a reactor.

**Fuel fabrication plant**
An installation for manufacturing fuel elements or other reactor components containing nuclear material.

**Geological repository**
Underground installation for the disposal of nuclear material, such as spent fuel, usually located more than several hundred metres below ground level in a stable geological formation that ensures long term isolation of radionuclides from the biosphere. In the operating phase the repository will include a reception area which may be above or below ground, as well as container handling and emplacement areas underground. After the final closure, the backfilling of all emplacement areas in the repository will have been completed and all surface activities ceased.

**Heavy water reactor**
A reactor using heavy water as the moderator. A prominent example is the Canadian deuterium uranium (CANDU) type reactor, which is moderated and cooled by heavy water (deuterium oxide) and is fuelled with natural uranium.

**High enriched uranium** (HEU)
Uranium containing 20% or more of the isotope $^{235}U$. HEU is considered a special fissionable material and a direct use material.

**High-level radioactive waste**
Highly radioactive materials produced as a by-product of the reactions that occur inside nuclear reactors. High-level wastes take one of two forms: spent (used) reactor fuel when it is accepted for disposal; or, waste materials remaining after spent fuel is reprocessed.

**Isotope**
One of two or more atoms of the same element that have the same number of protons in their nucleus but different numbers of neutrons. Isotopes have the same atomic number but different mass numbers. Isotopes of an element are denoted by indicating their mass numbers as superscripts to the element symbol, e.g. $^{233}U$ or $^{239}Pu$, or as numbers following the name or symbol of the element, e.g. U-233 or Pu-239. Some isotopes are unstable to the extent that their decay needs to be considered for nuclear material accountancy purposes (e.g. $^{241}Pu$ has a half-life of 14.35 years).

**Light water reactor** (LWR)
An power reactor which is both moderated and cooled by ordinary (light) water. LWR fuel assemblies usually consist of clad fuel rods containing uranium oxide pellets of low enrichment, generally less than 5% $^{235}U$, or mixed oxide (MOX) having a low plutonium content, generally less than 5%. There are two types of LWR: boiling water reactors (BWRs) and pressurized water reactors (PWRs). In a BWR, the heat generated is extracted by allowing the water to boil as it passes through the reactor core, the steam raised being passed directly to the turbine. In a PWR, the reactor vessel is operated at a pressure sufficient to suppress the boiling of the water; the steam required for the turbine is produced in the secondary circuit by passing the primary coolant water through heat exchangers (steam generators).

**Low enriched uranium** (LEU)
Enriched uranium containing less than 20% of the isotope $^{235}U$. LEU is considered a special fissionable material and an indirect use material.

**Mixed oxide** (MOX)
A mixture of the oxides of uranium and plutonium used as reactor fuel for the recycling of plutonium in thermal nuclear reactors (“thermal recycling”) and for fast reactors. MOX is considered a special fissionable material and a direct use material.

**Natural uranium**

Uranium as it occurs in nature, having an atomic weight of approximately 238 and containing minute quantities of $^{234}U$, about 0.7% $^{235}U$ and 99.3% $^{238}U$. Natural uranium is usually supplied in raw form by uranium mines and concentration (ore processing) plants as uranium ore concentrate, most commonly the concentrated crude oxide $U_3O_8$, often called yellow cake.

**Nuclear fuel cycle**

A system of nuclear installations and activities interconnected by streams of nuclear material. The characteristics of the fuel cycle may vary widely from state to state, from a single reactor supplied from abroad with fuel, to a fully developed system. Such a system may consist of uranium mines and concentration (ore processing) plants, thorium concentration plants, conversion plants, enrichment (isotope separation) plants, fuel fabrication plants, reactors, spent fuel reprocessing plants and associated storage installations. The fuel cycle can be “closed” in various ways, for example by the recycling of enriched uranium and plutonium through thermal reactors (thermal recycle), by the re-enrichment of the uranium recovered as a result of spent fuel reprocessing or by the use of plutonium in a fast breeder reactor.

**Plutonium**

A radioactive element which occurs only in trace amounts in nature, with atomic number 94 and symbol Pu. As produced by irradiating uranium fuels, plutonium contains varying percentages of the isotopes 238, 239, 240, 241 and 242. Plutonium containing any $^{239}Pu$ is considered a special fissionable material and, except for plutonium containing 80% or more of $^{238}Pu$, a direct use material.

**Power reactor**

A reactor intended to produce electrical power, power for propulsion, or power for district heating, desalination or industrial purposes.

**Reactor**

Any device in which a controlled, self-sustaining fission chain reaction can be maintained. Depending on their power level and purpose, reactors are subdivided into power reactors, research reactors and critical assemblies.

**Reprocessing plant**
An installation for the chemical separation of nuclear material from fission products, following dissolution of spent fuel. The installation may also include the associated storage, head-end (cutting and dissolution) operations, conversion and analytical sections, a waste treatment facility, and liquid and solid waste storage. Reprocessing involves the following steps: fuel receipt and storage, fuel decladding and dissolution, separation of uranium and plutonium and possibly other actinides (e.g. americium and neptunium) from fission products, separation of uranium from plutonium, and purification of uranium and plutonium. Once purified, uranium nitrate and plutonium nitrate may be converted, respectively, to $UO_2$ and $PuO_2$ powder at the reprocessing plant.

**Research reactor**
A reactor used as a research tool for basic or applied research or for training. Some reactors are used for radioisotope production. The fission heat is generally removed by the coolant at low temperature and is usually not used.

**Special fissionable material**
Plutonium-239; uranium-233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing.

**Spent nuclear fuel**
Used fuel from a reactor that is no longer efficient in power production, because its fission process has slowed. However, it is still thermally hot, highly radioactive, and potentially harmful.

**Thorium**
A radioactive element with atomic number 90 and symbol Th. Naturally occurring thorium consists only of the fertile isotope $^{232}$Th, which through transmutation becomes the fissile $^{233}$U.

**Transmutation**
The conversion of one nuclide into another through one or more nuclear reactions, and more specifically, the conversion of an isotope of one element into an isotope of another element through one or more nuclear reactions. For example, $^{238}$U is converted into $^{239}$Pu by neutron capture followed by the emission of two beta particles.

**Transuranic elements**
The chemical elements with atomic numbers greater than 92 (the atomic number of uranium).

**Uranium**
A naturally occurring radioactive element with atomic number 92 and symbol U. Natural uranium contains isotopes 234, 235 and 238; uranium isotopes 232, 233 and 236 are produced by transmutation.

## ACRONYMS

| | |
|---|---|
| ABR | advanced burner reactor |
| AFCI | Advanced Fuel Cycle Initiative |
| FMCT | Fissile Material Cut-off Treaty |
| GNEP | Global Nuclear Energy Partnership |
| GNPI | Global Nuclear Power Infrastructure |
| HEU | high enriched uranium |
| IAEA | International Atomic Energy Agency |
| IEA | International Energy Agency |
| IUEC | International Uranium Enrichment Centre |
| LEU | low enriched uranium |
| LWR | light water reactor |
| MESP | Multilateral Enrichment Sanctuary Project |
| MNA | Multilateral Nuclear Approach |
| NPT | Treaty on the Non-Proliferation of Nuclear Weapons |
| OECD | Organization for Economic Co-operation and Development |
| WNA | World Nuclear Association |

Global energy demands are driving a potential expansion in the use of nuclear energy worldwide. It is estimated that the global nuclear power capacity could double by 2030. This could result in dissemination of sensitive nuclear technologies that present obvious risks of proliferation. Certain international institutional mechanisms for controlling access to sensitive materials, facilities and technologies are needed for dealing with this problem. Over the past few years, 12 proposals have been put forward by states, nuclear industry and international organizations, aimed at checking the spread of uranium enrichment and spent fuel reprocessing technologies. This book presents an overview and analysis of these proposals, including an evaluation of the projected international mechanisms.

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