UCRL-CONF-211009

Changing Perspectives on Nonproliferation and Nuclear Fuel Cycles

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April 1, 2005

2005 International Congress on Advances in Nuclear Power Plants (ICAPP 2005)
Seoul, South Korea
May 15, 2005 through May 19, 2005

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This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Abstract – *The concepts of international control over technologies and materials in the proliferation sensitive parts of the nuclear fuel cycle, specifically those related to enrichment and reprocessing, have been the subject of many studies and initiatives over the years. For examples: the International Fissionable Material Storage proposal in President Eisenhower's Speech on Atoms for Peace, and in the Charter of the International Atomic Energy Agency (IAEA) when the organization was formed in 1957; the regional nuclear fuel cycle centers proposed by INFCE in the 80's; and most recently and notably, proposals by Dr. ElBaradei, the Director General of IAEA to limit production and processing of nuclear weapons usable materials to facilities under multinational control; and by U.S. President George W. Bush, to limit enrichment and reprocessing to States that have already full scale, functioning plants. There are other recent proposals on this subject as well. In this paper, the similarities and differences, as well as the effectiveness and challenges in proliferation prevention of these proposals and concepts will be discussed. The intent is to articulate a "new nuclear regime" and to develop concrete steps to implement such regime for future nuclear energy and deployment.*

1. Introduction

The entry into force of the Kyoto Protocol[1] on 16 February 2005 signified the need for a consorted effect to combat the long-term impact on global environment due to the excessive CO_2 emissions from using fossil fuel. Key to the success of the Protocol is the balance between environmental preservation and sustainable economic development. Due mainly to the perceived adverse impacts to their respective economies, major coal-using countries including China, India and the United States (US) have not yet joined the Kyoto Protocol. To eventually achieve the goals of the Protocol, nuclear energy must play an important role in the world's energy mix.

About 35 years ago, the Non-proliferation Treaty[2] (NPT) entered into force aiming at balancing the prevention of the spread of nuclear weapons technology and the promotion of the peaceful use of nuclear energy. Many concepts of international control over nuclear technologies and materials and restricting them only to peaceful uses have been proposed and studied over the years. In this paper, we discuss these concepts from a historical perspective including those recently proposed by M. ElBaradei[3], Director General (DG) of the International Atomic Energy Agency (IAEA), US President Bush[4], the IAEA commissioned Expert Group on multilateral approaches to the nuclear fuel cycle[5], and others[6,7,8]. We examine the global network of nuclear fuel cycle facilities, a concept proposed by the authors in ICAPP 2003, and argue how such a network with reliable fuel supply and spent-fuel take back could be useful in dealing with the nonproliferation and environmental challenges. And finally, a small, secure, transportable and autonomous reactor (SSTAR)[9] concept with no on-site refueling is given as an example to support the global network concept.

2. Historical Perspective

The concepts of international control over technologies and materials in the proliferation sensitive parts of the nuclear fuel cycle, specifically those related to enrichment and reprocessing, have been the subject of many studies and initiatives over the years. The earliest concept for international arrangement regarding sensitive fuel cycle facilities was the Baruch Plan proposed by President Truman in 1946. The plan failed because the idea of international ownership of a US technology was ahead of its time and not compatible with the US free enterprise system[10].

President Eisenhower's Atoms for Peace Speech at the UN Assembly in 1953[11] introduced a new era of international cooperation in peaceful uses of nuclear energy. He also proposed a "uranium bank" intended for international control of fissionable material. The speech led to the formation of the International Atomic Energy Agency (IAEA) in 1957. But the uranium bank concept was abandoned because the supply of uranium in the world was not as limited as first envisioned, and also because of the keen competition to supply civilian nuclear technologies and materials among major supplier countries following the Atoms for Peace.

The centerpiece of the Euratom Treaty in 1957 was the assurance of supply of nuclear materials among the Euratom countries. The Treaty provided a safeguards system to ensure that nuclear materials within the Euratom community would not be diverted for non-peaceful applications. To this date, it remains an effective regional safeguards regime for verification and control of nuclear materials.

Following the establishment of the International Atomic Energy Agency (IAEA) in 1957, a safeguards regime (INFCIRC/66[12]) was implemented allowing the IAEA to inspect the activities in nuclear facilities declared by member states. However, provisions of this safeguards regime was not stringent enough to cover all nuclear material, and it soon led to the development of the Non-proliferation Treaty (NPT) in 1970.

This landmark international treaty was established to prevent the further spread of nuclear weapons beyond the five recognized nuclear weapons states. (For the purposes of NPT, a nuclear weapons state is one which has manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January 1967[2]. These include the United States (in 1945), Russia (in 1949), the United Kingdom (in 1952), France (in 1960), and China (in 1964)). The treaty also sought to foster peaceful uses of nuclear energy.

By signing the NPT, countries have a right to develop research, production and use of nuclear energy for peaceful purposes. Non-nuclear weapons states under the NPT commit to comprehensive safeguards agreements (INFCIR/153[13]) for all nuclear materials. Because of this requirement, India, Israel, and Pakistan did not join the NPT or reveal their materials to the IAEA. Nevertheless, with nearly 190 states as parties, the NPT remains the cornerstone of international efforts to prevent the further spread of nuclear weapons.

The Zangger Committee was formed in 1971 after the NPT entry into force to implement the export control obligations of the NPT. The Committee established a "Trigger List" (INFCIRC/209[14]) to govern the export of sensitive nuclear materials and equipment. The Nuclear Supplier's Group (NSG), formerly the "London Group," was formed in 1974 shortly after the Indian nuclear explosion. The Group set the "London Guidelines" in 1977 (INFCIRC/254[15]) to include an Annex 1 "Trigger List" and Annex 2 "Dual Use" equipment to govern nuclear trade among its member states.

In 1977, concerned about the widespread and potential misuse of higly enriched uranium (HEU) in research reactors worldwide, the US launched a Reduced Enrichment in Research and

Test Reactors (RERTR) program to reduce the fuel enrichment in research reactors in Western countries. The International Fuel Cycle Evaluation (INFCE) sponsored by the IAEA recommended that the HEU fuel in research reactors should be converted to low enriched uranium (LEU), namely <20% of ^{235}U. The Russian Federation also initiated activities similar to RERTR Program for Russian-supplied research reactors.

To late 2004, 31 Western HEU research reactors were converted to use low enriched uranium silicide (U_2Si_3) fuel with the assistance of the RERTR Program (20 outside the US and 11 in the US). Of the remaining 60^+ HEU research reactors, about half can be but are not yet converted with existing LEU fuel. The other half, mostly Russian designs, still await development of higher density LEU fuel (e.g. monolithic U-Mo) to satisfy their high flux requirement.

The IAEA study on regional nuclear fuel cycle centers and the INFCE projects in the late 70's resulted in a general conclusion that, while worth pursuing, technical measures alone would not compensate for weakness of the institutional regime designed to safeguard sensitive nuclear materials and facilities.

In response to the discovery of a clandestine nuclear weapons program in Iraq in 1991, the IAEA pursued strengthened safeguards to improve its capability of detecting undeclared nuclear activities. This led to the Additional Protocol (INFCIRC/540[16]) of 1997. It requires the states to provide an expanded declaration covering the rest of the fuel cycle not covered under INFCIRC/153 agreements and to provide complementary access beyond declared locations for IAEA inspection.

In 1993, US President Clinton issued the Non-Proliferation and Export Control Policy statement stating that the US would seek to eliminate where possible the accumulation of stockpiles of HEU and plutonium; proposed a multilateral convention prohibiting the production of HEU or plutonium for nuclear explosives purposes outside of international safeguards; and encouraged more restrictive regional arrangements to limit fissile material production in regions of instability and high proliferation risk.

In 1994, the US agreed to purchase 500 tonne of HEU over 10 years from Russia for conversion to peaceful use as reactor fuel. The US and Russia each declared 50 tonne of separated plutonium excess for defense purposes. They signed a bilateral agreement in 2000 to disposition 34 tonne of plutonium to MOX for use as reactor fuel. The US also declared 174 tonnes of HEU excess.

For purposes of non-proliferation, the US implemented Foreign Research Reactor Spent Nuclear Fuel Acceptance (FRRSNFA) Program and accepted as of 13 May 1996 the US-origin spent HEU and LEU fuels from foreign research reactors under the following conditions:

Deadline for discharge: 12 May 2006
Latest receipt: 12 May 2009

At the end of the 1990s, the US supported the Russian Federation in the IAEA sponsored tripartite efforts to return to Russia the Soviet- or Russian-supplied HEU fuels still residing at foreign research reactor sites. Under the Russian Research Reactor Fuel Return (RRRFR) Program some 2 tonne of HEU and some 2.5 tonne of LEU spent fuel will be shipped to the Mayak reprocessing complex near Chelyabinsk.

Recognizing the urgent need to return HEU that would otherwise constitute an unacceptable threat to non-proliferation and international security, the US and the Russian Federation cooperated in several one-time repatriation projects for Russian-origin HEU fuels. These repatriation projects are listed in Table 1.

Table 1. 'Repatriation' Projects for Russian-Origin HEU Fuel

Receiving Country	Country of Dispatch	Year of Dispatch
Russia	Iraq	1993

USA	Kazakhstan	1994
UK	Georgia	1998
Russia	Romania	2003
Russia	Serbia (Vinca)	2002
Russia	Serbia (Vinca)	2005*
Russia	Uzbekistan	2004
Russia	Czech Rep.	2005*
Russia	Bulgaria	2003
Russia	Libya	2004

Note: * to be determined

3. Recent Proposals

Following the nuclear explosions by India and Pakistan in May 1998 and the terrorist attack in the US on 11 September 2001, there was a high level of concern for state-based nuclear proliferation and terrorists acquiring nuclear explosives. The discovery of covert nuclear programs in North Korea, Libya, and Iran and the exposure of the A. Q. Khan Pakistan-centered black-market weapons network also alerted the world that something must be done to curb the spread of the sensitive technologies associated with the nuclear fuel cycle, namely isotope separation and spent fuel reprocessing.

The 3-part proposal by ElBaradei, the DG of IAEA, included (1) limiting the reprocessing and enrichment operations exclusively to those under multinational control; (2) deploying proliferation-resistant nuclear energy systems; and (3) considering multinational approaches to management and disposal of spent fuel and radioactive wastes. However, the multinational system for control of sensitive nuclear technologies and radioactive materials envisioned in his proposal requires a long time to formulate and even if established, its function would rely on a slow consensus process to resolve issues.

US President Bush in his speech at the National Defense University strongly urged the world's leading nuclear exporters to limit the sale of enrichment and reprocessing technologies only to states that already have full scale functioning plants and adhere to the IAEA Additional Protocol. However, his proposal could create an international cartel on enrichment and reprocessing, further separating "have" from "have-not" countries. His plan also relies on the NSG with export policies most sympathetic to the US policy.

Proposals by others include the nuclear fuel leasing scheme suggested by V. Reis, et. al., and the Assured Nuclear Fuel Services Initiative by E. Moniz, et. al. These proposals suggested that institutionalization of "fuel cycle states" and "user states" would improve non-proliferation. But they would also pose some obvious challenges such as security of fuel supply to user states and the notion that fuel cycle states are the "have" states and the "user states" are the "have-nots".

The expert group on Multinational Approaches (MNA) to the nuclear fuel cycle, commissioned by the DG of IAEA was mandated to (1) identify and analyze issues and options relevant to MNA on the front and back ends nuclear fuel cycle; (2) provide an overview of policy, legal, security, economic, institutional and technical incentives/dis-incentives for cooperation in MNA; and (3) provide historical and present experiences relating to multilateral fuel cycle arrangements. The group did not explicitly analyze how likely or how long for such a MNA to be formed. It also avoided addressing the concern of slow consensus processes such MNA would take to resolve issues. Nevertheless the group suggested (for nonproliferation assurances):

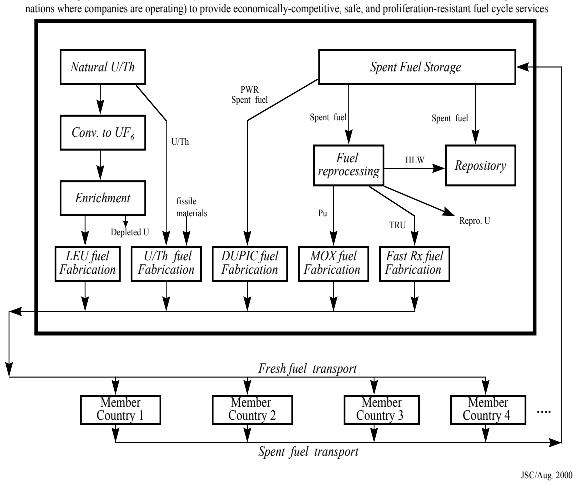
- Reinforcing existing commercial market mechanisms on a case-by-case basis through long-term and transparent arrangements with government backing,
- Developing and implementing international supply guarantees with IAEA as guarantor of service supplies, e.g., a fuel bank,
- Promoting voluntary conversion of existing national facilities to MNA, including regional MNA based on joint ownership, co-management, etc.

4. The Hard Parts

History reveals that it is challenging to pursue multilateral approaches to prevent the spread of the sensitive technologies of the nuclear fuel cycle while promoting the peaceful use of nuclear energy for sustainable economic development and a lessened environmental burden. Recent events also indicate the urgency for a global threat reduction effort to prevent state-based proliferation and terrorists acquiring nuclear explosives. "Business as usual" is no longer an acceptable option. We need a new nuclear regime to deal with the non-proliferation and environmental risks. The new regime would consist of a global network of nuclear fuel cycle facilities. Such a concept, shown in Figure 1, was presented at ICAPP 2003[6].

Figure 1 A Global Network of Nuclear Fuel Cycle Facilities

This is not a physical or national boundary, it is merely formed by contractual or (framework) agreements among companies (and nations where companies are operating) to provide economically-competitive, safe, and proliferation-resistant fuel cycle services



There are many contentious and challenging issues ("the hard parts") associated with the new regime and we discuss 3 aspects here:

(1) ***The front-end issue, i.e., market mechanism vs. international supply guarantee***

The fuel cycle facilities in this global network are not necessarily owned by a country, nor need to be co-located in a "regional fuel cycle center". In fact, such a network could best be formed by commercial market mechanisms or contractual agreements between two and among a few parties. The aim is to ensure a reliable supply of fresh nuclear fuel with an assurance that the spent fuel will be taken back by the supplier countries. If fresh nuclear fuel can be reliably supplied and the spent fuel removed, the "user countries" have less incentive to acquire their own enrichment or reprocessing technologies, hence, a "win-win" for the supplier and user countries in terms of non-proliferation.

In such network, reliable front-end fuel supply services, including conversion, enrichment, and fabrication for various fuel types are provided transparently and cost-competitively. Best behaviors can be enforced and bad actors can be penalized by the contractual obligations under international laws in a timely manner. This would avoid the slow and time-consuming processing in cases of violations or disputes if the supply is administered under an international guarantee system. However, international organizations, such as IAEA and NSG, can play an important role in a global network based on commercial mechanisms. They can assure that operations of the network's fuel cycle facilities are conforming to international safety standards and subject to safeguards.

Detailed analyses are needed here to assure a reliable fuel supply. For example, one could take current mining, conversion, and enrichment capabilities and analyze who produces what, how much is being shipped, who is enriching fuel, how responsive would the system be to supply disruptions, economics, and free of political constraints, etc. The analysis would also look at how such a system would respond to various growth scenarios.

(2) ***The central issue, i.e., the "Have" vs. "Have-Not"***

A "user country" joining the global network would have the assurance of reliable fuel supply and spent fuel removal. It can concentrate on operating the reactors safely and cost-competitively (to generate electricity and provide fresh water by sea-water desalination, and in the future produce hydrogen for transportation). The country can achieve the benefits of nuclear energy for its citizen without the burdens of non-proliferation concerns and management of nuclear wastes, much like a country can provide air transportation to its citizen by operating airlines without the large investment in aircraft manufacturing.

The "fuel cycle country" (or the "Have") operating fuel cycle facilities and providing fuel cycle services must follow international rules and regulations for safe operation. Its fuel cycle facilities must be subject to the most stringent international safeguards and export control requirements. If this country is a nuclear weapons state (NWS), it may have an advantage over a non-nuclear weapons state (NNWS) as most of its fuel cycle operations are exempt from international safeguards.

Japan deserves a special mention here as it is the only NNWS which possesses and operates both enrichment and reprocessing facilities. Japan has set a high standard of promoting the transparency of its fuel cycle operations and paid a substantial cost to maintain stringent international safeguards.

(3) ***The back-end issue, i.e., the national vs. multi-national approaches***

Even with reliable fresh fuel supply, if spent fuel is not removed from the "user countries" and instead accumulates at reactor or away-from-reactor sites (as in the present situation), there are no improvements to the non-proliferation and environmental risks. Also, there are countries with small nuclear power programs and small amounts of spent fuel. These countries may have limited potential and resources to develop their own spent fuel storage and repository disposal systems. A regional, or multi-national approach to long-term spent fuel management and waste disposal could be an attractive option.

However, for a country pursuing its own national repository program, there is a perceived fear that just the mention of the regional or multi-national approaches could jeopardize its national repository program. To allay such fear, the NWS as a group should lead in promoting and developing a regional or multi-national repository program[17].

The NWS group operates close to 90% of the world's nuclear electricity generation capacity, and holds more than half of the global spent fuel and radioactive waste inventories. They have to develop their own repositories and should be capable of providing spent-fuel storage and waste disposal services to "user states" within their region. In addition, there is less of a non-proliferation concern for managing other's spent fuel in the NWSs. And the host NWS may be able to gain favorable support to its waste management and repository program if such program can help lessen non-proliferation and global security concerns.

The former Soviet Union took spent fuel back from the soviet-designed reactors located in Eastern Europe and Finland. Currently, the Russian Federation (RF) accepts spent VVER (440 or 1000) fuel from Commonwealth Independent States (CISs) for a fee and on a case-by case basis. Also, the RF has changed its law to allow for import of other countries' spent fuel for storage and processing.

The US initiated the research reactor spent fuel take-back program (FRRSNFA) and supported a similar Russian program (RRRFR) on grounds of non-proliferation. Although it is a different and a more complex issue for public-acceptance, the take-back of power reactor spent fuel from "user states" to storage and processing facilities and repositories in or operated by the NWS is a viable solution on grounds of global security and non-proliferation.

Not all the NWSs can accept other user-countries' spent fuel. Notably, France and UK may have more geographic constraints in repository siting than the other 3 NWSs. A viable solution would be the cooperation among the NWSs, e.g., HLW canisters from France and UK may be shipped and disposed of in a Russian repository. Such cooperation may also help in the disposition of separated fissionable materials, e.g., the disposition of UK's plutonium in French reactors. Also, China may be interested in storing and disposing the spent fuel from Taiwan.

Major uranium-producing countries such as Canada, Australia and others can help in disposing spent fuel from other NNWSs. The return of spent fuel to these countries for disposal could benefit their uranium-supply business, in addition to enhancing global security and non-proliferation.

5. An Example: Small, Secure, Transportable & Autonomous Reactor (SSTAR)

The SSTAR is a concept researched by Lawrence Livermore National Laboratory (LLNL). It is a 10 to 50 MWe lead-cooled fast reactor targeted for use in developing countries and remote locations in developed countries. The unique features include a long core life and no on-site refueling. The reactor core is a single cartridge and is not composed of individual removable fuel assembly. The whole reactor unit is removed at the end of its operating life and returned to the supplier country for fuel reprocessing and recycling. A schematic of a variation of SSTAR, called the Encapsulated Nuclear Heat Source (ENHS) is shown in Figure 2, and the characteristics of a 20 MWe SSTAR are listed in Table 2.

Fig.2 Illustration of a SSTAR/LFR

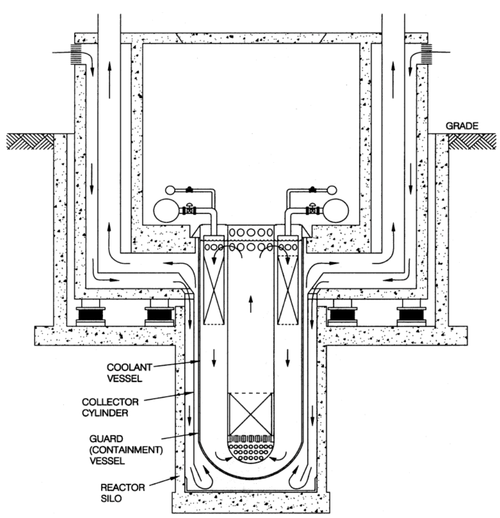


Table 2. Characteristics of a SSTAR

Power, MWe (MWt)	20 (45)
Outlet Temperature, ^{o}C	566
Power Density, W/cc	69
Ave. Discharge Burn Up, GWd/t	72
Fuel	Nitride
Cladding	HT9
Fuel/Coolant Volume Fractions	0.55/0.18
Core Lifetime, Years	30

The SSTAR would fit into the concept of a global network consisting of "fuel-cycle states" and "user states" for the improvement of non-proliferation and nuclear material and waste management.

6. Conclusion

The concepts of international control over technologies and materials in the proliferation sensitive parts of the nuclear fuel cycle, specifically those related to enrichment and reprocessing, have been the subject of many studies and initiatives over the years. It is clearly challenging to pursue multilateral approaches to prevent the spread of the sensitive technologies of the nuclear fuel cycle while at the same time, promoting the peaceful use of nuclear energy for sustainable economic development and a lessened environmental burden.

We suggested in this study a global network of fuel cycle facilities, formed by a framework of contractual agreements among companies (and countries where companies are operating). The formation of the network is intended to provide full-scope fuel cycle services which are economically competitive, meeting all applicable international safety standards, and complying with international safeguards and security requirements. Such a network does not need to be within a national boundary, and facilities in the network are not necessarily to be co-located in a nuclear fuel cycle center.

Such a network could eliminate a "user state's" incentive in developing its own fuel cycle technologies and relieve its "waste and non-proliferation" burdens. If the nuclear weapons states could provide spent fuel storage and waste repository services to the “user states”, a “cradle-to-grave” fuel-cycle service assuring a reliable fresh fuel supply and spent fuel take-back can be realized.

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