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A REVIEW OF THE NUCLEAR SAFEGUARDS PROBLEM

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1 INTRODUCTION

Safeguarding special nuclear materials (SNM), such as plutonium, uranium-233, and uranium-235, because of their potential use in nuclear weapons has been of prime importance since the beginning of the atomic age. The developers of the atomic bomb, the U.S., United Kingdom, and Canada, recognized the link between military and civilian applications of nuclear energy and decided that information concerning "industrial application" of nuclear energy was not to be shared among nations until adequate and effective safeguards acceptable to all nations were developed. The U.S. tried to maintain its monopoly on fuel cycle activities with the passage of the Atomic Energy Act of 1946, which provided that there be no exchange of information on industrial uses of atomic energy until effective and enforceable international safeguards were established. Shortly thereafter, however, the Soviet Union and United Kingdom tested weapons, promoting the onset of the civilian nuclear programs that began in other countries. Recognizing that secrecy regarding a monopoly on fuel cycle activities could no longer be preserved, the U.S. revised its policy with the passage of the Atomic Energy Act of 1954. The Act provided for an exchange of information relating to commercial applications of nuclear power and for the expansion of nuclear exports. In order to promote nonproliferation of nuclear weapons, the U.S. decided that it must take an active role in shaping the commercial nuclear power programs of other countries. Since then, nuclear safeguards have evolved on both international and domestic levels. On the international level, safeguards are governed by the International Atomic Energy Agency (IAEA) and the Non-Proliferation Treaty (NPT), while on the domestic level the governments of individual countries oversee the physical security and safeguards of the commercial nuclear industry.

Today, safeguarding the civilian nuclear fuel cycle is of prime importance. Proliferation of nuclear weapons and nuclear terrorism are the two major reasons why the nuclear fuel cycle is safeguarded. However, such varying fuel cycles as the once-through light-water reactor (LWR) cycle, the plutonium breeding cycle, or the thorium breeding cycle, have different proliferation and terrorism risks, each requiring particularized safeguards. Currently, neither the U.S. nor several other industrialized nations have made firm future commitments to any of the above fuel cycle options, inasmuch as the implications of each cycle are still being studied. Consequently, the purpose of this report is to identify the risks associated with scenarios covering these three future nuclear fuel cycles: (1) exclusive use of the once-through LWR cycle; (2) introduction of fuel reprocessing into the LWR cycle followed by use of the plutonium breeding cycle; and (3) conversion to the thorium breeding cycle. The status of international and domestic safeguards is surveyed followed by a detailed discussion of nuclear weapons proliferation and nuclear terrorism. Then each of the above three nuclear power scenarios are examined to identify areas in which risks occur and the possible safeguards needed to alleviate or eliminate these risks.

2 CURRENT STATUS OF NUCLEAR SAFEGUARDS

2.1 INTRODUCTION

As noted above, nuclear safeguards are governed on the international level by the International Atomic Energy Agency (IAEA) and the Non-Proliferation Treaty (NPT). Since neither the IAEA nor the provisions of the NPT can enforce physical security practices and procedures of the commercial nuclear industry within a particular country, their main function is merely to inspect nuclear facilities to see that countries adhere to IAEA and NPT guidelines. The physical security of a nuclear site is the sole responsibility of the country in which the site is located. The purpose of this chapter, then, is to describe the safeguards that exist at both the international and domestic levels.

2.2 INTERNATIONAL SAFEGUARDS

Almost four years after President Eisenhower's presentation of the Atoms-for-Peace plan to the U.N. in December 1953, the U.N. formed the IAEA in July 1957. The IAEA was set up not only to promote peaceful uses of atomic energy but also to prevent the misuse of sensitive nuclear technology by implementing a system of international safeguards. The main nonproliferation function of the IAEA is to prevent nonnuclear weapon states from obtaining nuclear weapons ("horizontal" proliferation), not to prevent states already possessing weapons from acquiring more ("vertical" proliferation). The IAEA establishes and administers safeguards at commercial nuclear facilities for all NPT signatories in addition to those facilities specified in bilateral nuclear technology trade agreements between an NPT member supplier and a non-NPT member buyer.

Inspections of nuclear facilities are the backbone of IAEA safeguards. The IAEA has a staff of 72 full-time inspectors who are responsible for the safeguarding inspections of hundreds of nuclear facilities worldwide. Because the physical security of a facility is the responsibility of the state, IAEA safeguard inspections are limited to auditing a facility's SNM to see if the inventory has a substantial amount of material unaccounted for (MUF). If there is a large amount of MUF and diversion is suspected, a report is made to the Board of Governors of the IAEA. Cases in which the Board of Governors can prove diversion or which they are unable to resolve to the contrary are reported to all IAEA members and to the Security Council and General Assembly of the United Nations. The board then recommends an appropriate action to be taken such as return of materials and equipment made available to the offending state, suspension of assistance provided by the IAEA, or, as a final act, suspension of IAEA membership. Because the IAEA has no policing power it must rely upon the member states to carry out its recommended sanctions against a guilty state. Hence the effectiveness of the IAEA is totally dependent upon the participation of its members. Finally, because IAEA inspectors' reports are classified, it is not known how effective safeguard procedures actually are or what IAEA data on MUF look like.

The NPT is another action governing international safeguards and was entered into force in March 1970. Provisions of the treaty are that nonnuclear weapon states agree not to manufacture or acquire nuclear explosives for military or peaceful purposes and agree to accept IAEA safeguards on all commercial nuclear facilities. Although there are 98 parties and 13 signatories (i.e., countries that have signed the treaty but have not yet ratified it) of the NPT, international support is incomplete. Among countries with nuclear weapon capabilities, France and China have not signed the treaty but do not in practice encourage or aid proliferation. More importantly, however, are the nonnuclear weapon countries who still have not signed or ratified the treaty; noteworthy among them are Argentina, Brazil, India, Pakistan, Israel, South Africa, Spain, and North Korea. To these countries, the motivation not to sign the NPT may lie with the hope that the acquisition of nuclear weapons will bring them the global status they desire or tip the military balance in their favor in a local rivalry. Nonsignatories cite the discriminatory nature of the NPT as the reason for refusing to sign. They dislike the outlawing of peaceful nuclear explosives (PNE), the inequality between weapon and non-weapon states, and the sacrifice of national sovereignty through the acceptance of IAEA safeguards.

2.3 PHYSICAL SECURITY OF FACILITIES (U.S.)

Because the U.S. already has a nuclear weapons capability, national diversion is not a concern, but diversion by subnational or terrorists remains a constant threat. Therefore, the objectives of the U.S. domestic safeguards program are to prevent terrorism, to detect terrorism or theft, and to respond to threats. To carry out the objective of preventing terrorism, barriers, locks, alarms, etc., are used to guard areas that contain SNM or sensitive facilities that could initiate a serious accident if sabotaged. Furthermore, the operators of a nuclear facility carefully screen all potential employees in an attempt to hire only reliable and stable people. Finally, intelligence gathering by the government can help to identify groups that may be contemplating terrorist actions and their potential targets. The safeguarding of all facilities handling SNM is regulated by the NRC. Before the NRC issues a license to operate, the licensee must demonstrate its capability to protect the SNM in its possession against loss, theft, or acts of industrial sabotage. Periodic inspections also are made to determine whether or not licensees are in compliance with NRC rules and regulations.

Detection of theft or terrorism is accomplished by surveillance of strategic points of a nuclear facility. Surveillance equipment includes cameras to monitor personnel entering or exiting an area in addition to detectors to monitor material transfer throughout the facility. Material accountability procedures are conducted every few months to inventory the SNM and to determine the MUF. To improve material accountability, real-time computer systems could be installed. Such systems allow for more frequent material balance checks (e.g., at the end of each shift) and provide faster detection of diverted material.

Another detection strategy is the use of onsite armed guards as the initial response to a threat. Most facilities have agreements with local police to provide assistance if needed. However, onsite guards are, for the most part, merely watchmen who are powerless against a well-prepared paramilitary terrorist group. Furthermore, although local police may be called in to assist onsite guards, most police forces lack the training and knowledge of a facility needed to adequately respond to a nuclear emergency. Federal involvement in a threat at a nuclear facility is assured but the extent of the involvement and the responsibilities of various federal agencies are not well defined.

The need to increase physical security systems at nuclear facilities has brought up several important questions, the most important of which is civil liberties violations. Employee background searches and surveillance of potential terrorist groups bring up possible infringements of civil liberties. Guidelines must be developed so that security procedures can be strengthened without violating the civil liberties of nuclear facility employees or the general public. The effectiveness of onsite guards has also been questioned. One possible solution would be the creation of a special federal police force to protect nuclear facilities. Such a force would receive uniform training, access to and authority to use a wide range of weapons, and a clear conception of mission and responsibility. Yet, this special force could infringe upon the authority of the local police and expansion of federal police powers could increase the possibility of civil liberties violations. Nuclear safeguard contingency plans are another issue involved in the increase of physical security at nuclear facilities. Definition of the responsibilities of the nuclear facility licensee, the local law enforcement agency, and the federal government during a nuclear emergency is essential so that their responses will be timely, reliable, and effective.

2.4 PHYSICAL SECURITY OF FACILITIES ABROAD

The physical protection of nuclear facilities overseas is an important consideration for U.S. nonproliferation policy. Stepped-up terrorism in many countries calls for strong security measures to be taken at all nuclear installations. Studies by the NRC and the Office of Technology Assessment[1,2] found that foreign safeguards are fundamentally sound. However, as in the U.S., material accounting requirements need improvements. Although all countries claim that their capabilities at least meet IAEA requirements. Details concerning physical protection systems are generally unavailable because of security reasons. Even the IAEA inspectors are not allowed to test these systems because of encroachment upon national sovereignty.

3 ISSUES INVOLVED WITH NUCLEAR SAFEGUARDS

3.1 INTRODUCTION

Safeguarding the commercial nuclear fuel cycle was instituted to prevent proliferation of nuclear weapons among nonnuclear weapons states as well as protecting against theft of SNM or sabotage of nuclear facilities by subnational or terrorist groups. This chapter discusses these issues of proliferation and terrorism, explains possible motivations behind each action, and identifies possible targets in the fuel cycle that groups intent upon gaining weapons or sabotage may strike.

3.2 PROLIFERATION

A decision by a nonnuclear weapon state to acquire nuclear weapons is tempered by two considerations. The first is the effect that acquisition of nuclear weapons will have on its national security. Countries embroiled in regional conflicts may look at nuclear weapons as a way to achieve military advantage over a neighboring foe. The second is the state's desire for prestige in the world community. Many third-world nations see that the economically successful countries, such as the U.S., U.S.S.R., France, and the United Kingdom are all nuclear weapon countries and they feel that the acquisition of nuclear weapons can catapult them into prosperity. Even hinting at the possibility that a state has acquired nuclear weapons may achieve the same effect as actually having tested one. For such a claim to be credible, a state must be actively pursuing a nuclear power program, which has been the case with Israel, a non-NPT party, for a number of years. Israel takes the official position, though, that it will not be the first to introduce nuclear weapons into the Middle East.

There are also several disadvantages in acquiring nuclear weapons. One disadvantage is that nuclear weapons may not afford a country any military advantage whatsoever, for its rival then has the excuse to pursue its own nuclear program. Thus, this situation leads to no net advantage to either side. A second disadvantage of acquiring nuclear weapons is that nonweapon states that acquire nuclear weapons may be violating a defense treaty with a larger protectorate nation. Without such a defense pact, the new nuclear state would be isolated and vulnerable to attack from both outside and inside its borders. In the event of a military revolt or civil war, nuclear weapons or fissionable materials may be tempting targets for seizure and use by dissident or rival groups. Lastly, a country must consider the economic implications of "going nuclear." Should a nonweapon NPT state "go nuclear," any civilian nuclear program it had or was contemplating having would be seriously crippled, since it would be expelled from the IAEA. It would thereby lose any technical assistance provided by the IAEA, as well as the materials, facilities, and technical assistance provided by a NPT supplier nation. Non-NPT states that "went nuclear" would have similar economic sanctions imposed against them by NPT suppliers. Consequently, any military advantage gained through owning nuclear weapons could be more than offset by a contingent blow to the country's economy.

The manufacture of weapon-grade nuclear material can occur only at two points in the nuclear fuel cycle, either in the enrichment stage or in the reprocessing stage. The enrichment process practiced by the nuclear industry is accomplished by gaseous diffusion. This technique requires large capital investments and is highly energy intensive, both of which features make this method of enrichment extremely unattractive to poor third-world countries. On the other hand, advanced enrichment techniques such as gas centrifuge and laser separation may prove to be more economically and technically manageable and could relatively easily make enrichment an easy process for the manufacture of weapon-grade material. At present the reprocessing stage is more vulnerable to diversion because of the presence of Pu-239, which is better for nuclear weapons manufacture because the critical mass of Pu-239 is substantially less than for U-235. Another point is that chemical separation of plutonium from spent fuel is easier than enrichment of uranium. Commercial reprocessing of spent fuel has been accomplished through the use of the Purex process, but because this process produces pure Pu-239 and U-235 at various stages, it is very unattractive for widespread use. Hence, another process, called Civex, has been developed[3] that reprocesses spent fuel in such a way as to make it less susceptible to diversion. Unlike Purex, the Civex process leaves a small percentage of waste mixed with the uranium or plutonium in such dilute concentration that neither can be used to manufacture weapons directly. The quality of the uranium or plutonium as a reactor fuel is unaffected by the remaining waste. Because this waste maintains such a high level of radioactivity, the material must be handled remotely. Furthermore, Civex combines both spent fuel reprocessing and the refabrication of new fuel into one facility, eliminating the transportation of plutonium from reprocessing plant to refabrication plant.

The commercial nuclear fuel cycle, however, is not the only way to obtain weapon-grade plutonium and uranium. Research and plutonium production reactors provide far cheaper and less technically sophisticated methods of producing weapon-grade plutonium. Natural uranium-fueled research reactors are capable of producing 10 kg of plutonium per year and the design of these reactors is openly available.[4] Slightly more expensive than research reactors, the plutonium production reactors yield greater amounts of plutonium and can be optimized as to isotopic content of plutonium.[5] Hence, these types of reactors coupled with dedicated chemical separation facilities are much preferred routes to manufacture of nuclear weapons. Also, these research facilities are, for the most part, not subject to international safeguards. In fact, such special facilities have been the route of choice by the six states with known nuclear explosive capabilities (India's source of plutonium was a large natural uranium research reactor).[6]

3.3 TERRORISM

Protection against terrorists bent upon theft of SNM or sabotage of nuclear facilities is the second aspect of nuclear safeguards. As noted in the section on proliferation, the enrichment and reprocessing stages are the most attractive to secure SNM for weapons manufacture or for use as a poison. But because a terrorist group would certainly not have either the facilities or the funds to further enrich the low enriched uranium (LEU) that is manufactured by enrichment plants, these facilities would be an unlikely target for theft. Spent fuel recently removed from the reactor would also not be a likely target for theft because of its intense radioactivity; as the spent fuel ages, radioactivity declines and therefore "old" fuel elements are not altogether impossible to handle for the extraction of plutonium.

But the reprocessing stage is much more of a target for terrorists than the enrichment stage. Depending upon the reprocessing technique used and the degree of sensitivity of the detection devices in the plant, thefts of plutonium and other SNM may be difficult to detect. Thefts of large amounts of materials would most certainly be detected by the material monitoring instruments, but thefts of amounts below the threshold of these instruments may not be discovered for several weeks until a material balance occurs. Therefore, the use of real-time computers to continuously monitor the inventory could detect small thefts much earlier.

Transportation of SNM is probably the weakest link in the nuclear fuel cycle and the most likely target of terrorists. Recent revisions in transport regulations have reduced the likelihood of employee theft but have not eliminated the possibility of a small armed group successfully hijacking a truckload of SNM.

Sabotage of nuclear facilities is another terrorist activity that safeguards must protect against. Facilities that may be targets of such attacks are nuclear reactors and reprocessing facilities. One incident terrorists may try to initiate in a reactor is a meltdown. To cause a meltdown, the safety systems designed to guard against this occurrence would have to be disabled. To accomplish this aim, terrorists could force the plant employees to assist them in knocking out these safety systems with conventional explosives. A deterrent to such a plan, is the possibility that the terrorists themselves would be the victims of prompt radiation if a meltdown was successfully started or that they would most likely be captured if they tried to escape. Spent fuel cooling ponds inside the reactor are another possible terrorist target. Conventional explosives could be placed in the cooling ponds and upon explosion could disperse spent fuel throughout the plant causing serious damage to the plant itself and possible radiation release to the environment. Similarly, explosives at key points in a reprocessing plant could also cause serious damage to the plant as well as exposing the public to radiation. Consequently, there is virtually no aspect of the nuclear fuel cycle that does not require safeguarding.

4 FUTURE NUCLEAR CYCLE SCENARIOS AND SAFEGUARD IMPLICATIONS

4.1 INTRODUCTION

The extent to which safeguards are applied is dependent upon the nuclear fuel cycle chosen. Antinuclear activists contend that the only way to eliminate safeguards concerns is to shut down all nuclear power plants. Yet closing down nuclear power plants is very unlikely in the near future, considering the current oil shortage and the fact that certain areas of the U.S. depend upon nuclear energy for more than 40% of their electric energy requirements. But to ease safeguard requirements, some nuclear experts advocate the continued use of the "once-through" LWR fuel cycle because of the absence of weapon-grade plutonium from the fuel cycle. Others advocate the recycle of plutonium in LWRs, followed by the fast breeder reactor (FBR) using the plutonium cycle. This procedure, they hold, will eliminate the hazards associated with spent fuel disposal as well as control the overall amount of plutonium in the world. Still others hold that because of the hazards associated with plutonium, the current U^{238}-U^{235} fuel cycle should be dropped in favor of the breeding cycle utilizing thorium-U^{233}. Although no fuel cycle can totally eliminate the need for stringent nuclear safeguard measures, each of the aforementioned options has some favorable characteristics in that regard. This chapter discusses these three future nuclear power scenarios and considers the safeguard measures each one implies.

4.2 THE ONCE-THROUGH LWR OPTION

A schematic diagram of the once-through LWR cycle is shown in Fig. 4.1. Low enriched uranium (LEU)(about 3% U^{235}) is used as the fuel and the spent fuel is not reprocessed but disposed of as is. As can be seen, there is no place in this fuel cycle where weapon-grade material, i.e., high enriched uranium (HEU) or pure U^{235} or Pu^{239}, is present. The material used must either be further enriched or reprocessed to obtain material suitable for weapons; tasks that are not particularly easy. The lack of weapon-grade material, proponents say, is the distinct advantage of this fuel cycle. This scenario advocates the construction of once-through LWRs to replace those withdrawn from service or growth at a very slow rate. If the adoption of this energy plan becomes worldwide some experts believe time will be bought so that proliferation and diversion risks can be alleviated or solved through diplomacy. Once these problems are worked out, more advanced fuel cycles can be instituted if the need arises. Additionally, if the money that would have been spent upon R&D for advanced fuel cycles is used for R&D on "soft" technologies such as solar, wind, etc., advanced reactors may not be needed at all. Furthermore, by following this scenario, the demand for enriched uranium will be kept low enough so that the U.S. and several European concerns, who supply virtually all of today's non-Communist world demand, can continue to do so reliably in the future. Assured supplies of enriched uranium will prevent enrichment technology from spreading and, therefore, help to alleviate some proliferation problems. Although the once-through fuel cycle as practiced today is rather inefficient in its use of uranium, improvements of up to 15% are expected to be introduced in about ten years.[7] Realization of this expectation could help to reduce further the world demand for enriched uranium.

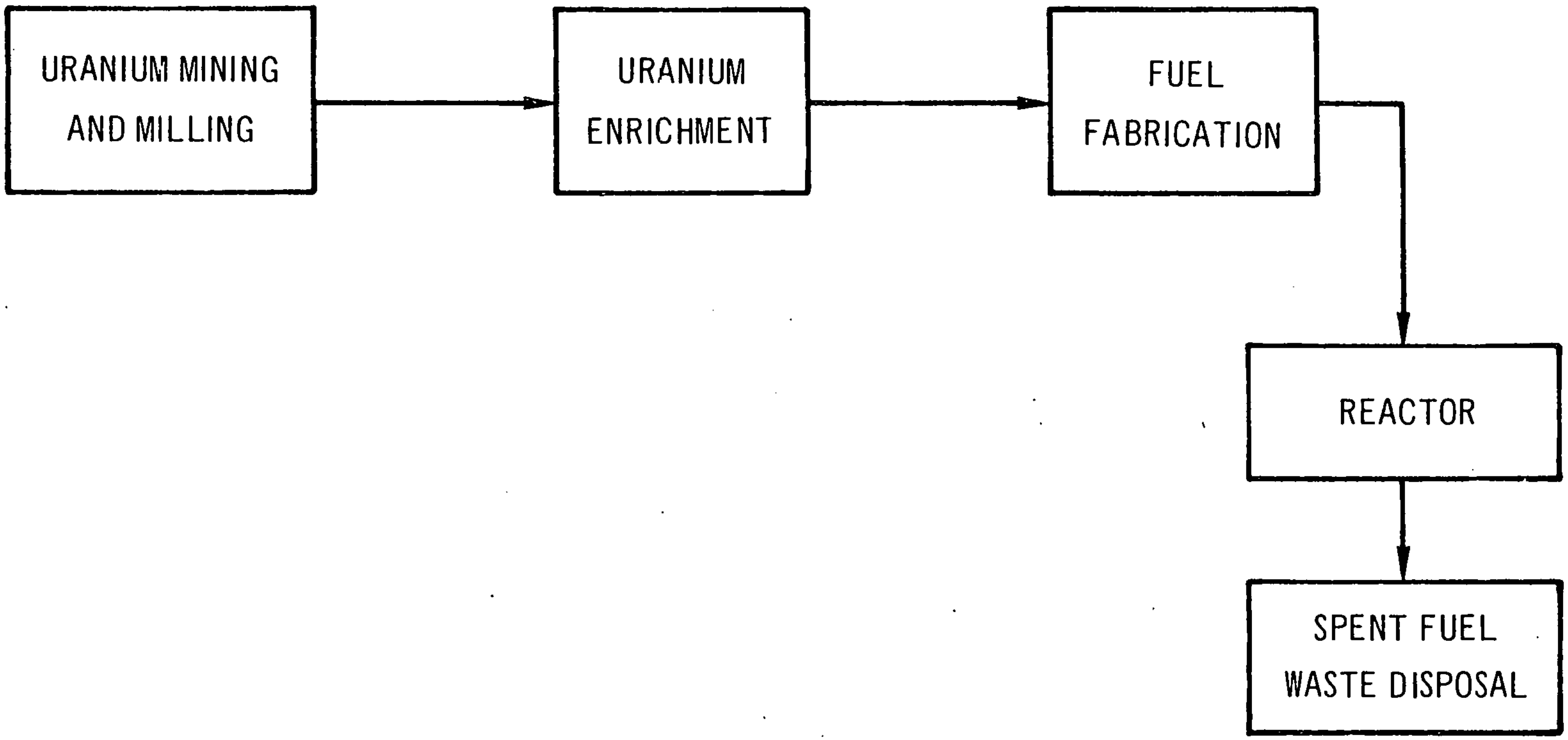

Fig. 4.1. Schematic Diagram of the Once-Through LWR Fuel Cycle

Opponents of this scenario are not as optimistic about the reduction in proliferation risks that the once-through LWR fuel cycle allegedly affords. They claim that plutonium is not eliminated from the fuel cycle, but that in fact, it is stockpiled in spent fuel rods.[8] Consequently, extensive safeguards will be required to guard the spent fuel that is piling up at reactor sites or at away-from-reactor (AFR) storage facilities, awaiting decisions as to final disposition. Furthermore, once these fuel elements have "cooled down" for about 30 years, the radiation will no longer prevent terrorists from stealing them and reprocessing the spent fuel into plutonium; a task made considerably easier by the decay of fission products initially present in spent fuel. Hence, proliferation can occur even without the presence of pure plutonium in the fuel cycle.

In addition to stockpiling plutonium in spent fuel rods, the LWR cycle also creates a large disposal burden to be dealt with by waste management methods. Without reprocessing, the volume of spent fuel waste is about 16 times greater than that of reprocessed waste[3] and must be isolated from the biosphere for at least 25,000 years compared to about 700 years for reprocessed wastes.[9] Moreover, there could be adverse international implications should the U.S. strongly advocate this scenario as a worldwide policy. If the U.S. tries to force other countries to follow a once-through LWR energy policy by refusing nuclear assistance to countries wanting to develop other fuel cycles, this refusal can be taken to mean the U.S. is reneging on its NPT obligations, they may not feel compelled to honor theirs, and a severe blow would have been dealt to the hope for nonproliferation. A U.S. refusal of nuclear aid will force countries seeking help in developing advanced reactors to look elsewhere. Already, free world countries such as France are pursuing a plutonium economy utilizing the fast breeder reactor (FBR) and will be in the commercial market probably before 2000. The Soviet Union is also researching plutonium use in FBRs and may begin to market their design to the free world. Hence, regardless of U.S. policy, many countries are looking to the plutonium cycle for their future energy needs.

4.3 THE PLUTONIUM BREEDER OPTION

A schematic diagram of a plutonium breeding cycle utilizing both thermal and fast reactors is shown in Fig. 4.2. Initially, plutonium and uranium would be recycled in LWRs followed by a plutonium FBR cycle. The core of the FBR contains plutonium and depleted uranium, while the surrounding blanket contains only depleted uranium. Plutonium is bred in the blanket as a result of neutron capture and subsequent decay of U^{238}. The introduction of FBRs would depend upon reprocessing economics and energy demand. Proponents argue that utilizing the plutonium and unburned uranium is one way to prevent the stockpiling of plutonium and uranium in spent fuel rods from the once-through LWR cycle. The FBR can also be operated so that it can either incinerate more plutonium than it produces or produce more plutonium than it incinerates, depending upon the demand. In this way, the amount of plutonium can be controlled so that the supply meets the demand, unlike the once-through cycle where the amount of plutonium in spent fuel rods grows without limit. Furthermore, in a mature FBR economy, there will be a great incentive for rapid turn around of the plutonium, so that very little time elapses from the time it comes out of the reactor core or blanket to the time it is put back in the reactor. Therefore, the amount of plutonium inventory outside of the

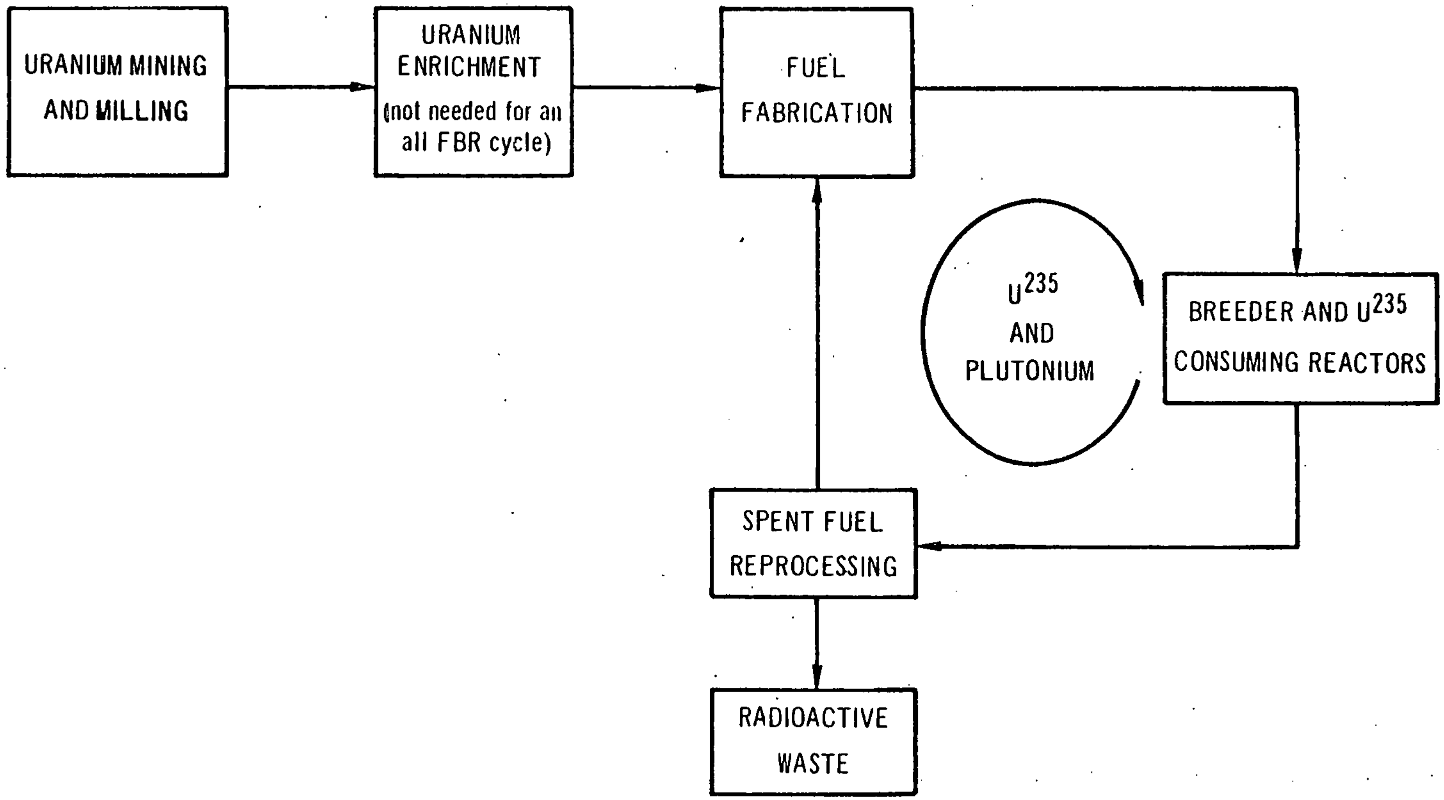

Fig. 4.2. Schematic Diagram of the Plutonium Breeder Fuel Cycle

reactor is kept to a minimum. The vulnerable reprocessing stage can be made more diversion-resistant through the use of the Civex rather than the Purex reprocessing technique.[3] The Civex process has no stage where plutonium or uranium is in a pure form. Certain amounts of fission products remain with the plutonium so that it must be handled remotely and can be easily detected in case of theft.

Physical security must be increased in a plutonium economy, but proponents claim it will involve no more security than will be needed for the once-through LWR cycle. Increased security guards, security checks, and improved detection devices and accountability procedures will be needed regardless of fuel cycle. The security of this fuel cycle can be increased by colocation of reprocessing and fuel fabrication plants into one well-guarded installation. This setup would eliminate transportation between reprocessing and fuel fabrication facilities, further strengthening the plutonium breeder option. Therefore, an increase in security measures will not violate civil liberties but will preserve them by alleviating the diversion problems associated with a plutonium economy.

On an international scale, proliferation can be checked in several ways. First, multinational fuel centers under IAEA supervision can be instituted. In this way, sensitive reprocessing technology, fuel fabrication, and plutonium supplies will be under international control and the diversion potential, greatly reduced. Second, nuclear weapon states should enter into strong defense treaties with nonnuclear weapon states. These treaties will help to increase the sense of security of a non-weapon state and will go a long way toward the foregoing of nuclear weapons by these states.

An FBR plutonium economy has other advantages as well. As noted earlier, reprocessed wastes are easier to dispose of because of a reduced volume and a lesser radioactivity hazard. Assuming 99.9% removal of uranium, neptunium, and plutonium and 99% removal of americium and curium from the spent fuel, the waste will remain a hazard for only 700 years rather than the 25,000 years required to reduce the radiation of spent fuel to sufficiently low levels.[9] The extracted actinides (i.e., neptunium, americium, and curium) can be recycled in the FBR at a small penalty, where they will be eventually turned into fission products and subsequently be removed. Furthermore waste disposal techniques that require liquid high level waste (HLW) which are a by-product of spent fuel reprocessing are ideally suited for use with the plutonium breeding cycle since the wastes can be disposed of as soon as they are generated. Colocation of reprocessing plants and waste repositories will eliminate the hazards associated with transportation of radioactive wastes, i.e., diversion and accidents. Another advantage to reprocessing is that the uranium supply will increase by a factor of 50.[10] Hence, many countries will have the opportunity to become energy self-sufficient.

Opponents of the plutonium breeder option find many faults with the arguments of breeder supporters. First, proliferation is not successfully thwarted even with multinational fuel centers under IAEA control. Sensitive reprocessing technology will be spread throughout the world and little can be done to prevent clandestine reprocessing operations carried out by countries intent upon getting nuclear weapons. Proliferation can be checked only by eliminating reprocessing from the fuel cycle. Second, even if security systems at reprocessing plants are increased, reprocessed fuel is one step closer to weapon fabrication than spent fuel. Because the time required to construct a weapon from stolen SNM is reduced, the ability of the security systems to detect a theft in time to prevent use of a weapon is questioned. Third, it is felt that the necessary increase in safeguarding measures such as employee background checks and domestic surveillance to identify possible terrorists will not insure safety as much as they will violate civil liberties. Furthermore, should a crisis arise, hundreds or thousands of citizens may be subject to searches, warrantless surveillance, or forced evacuations in order to find the terrorists and recover the stolen material. Once the crisis is past, there is the risk that some tactics employed in the crisis might be carried over into routine operations. The energy crisis is not severe enough that plutonium is the only way out and a police state the only way to insure safety.

Fourth, many feel that the consequences of even a slightly successful sabotage of an FBR are too severe to warrant the use of this type of reactor. The accident at an FBR near Detroit in 1966 that resulted in a partial core meltdown is often cited as the reason FBRs must not be used. Although this accident was successfully brought under control, sabotage of such a reactor by terrorists knowledgeable in FBR design or by forcing employees to assist them could result in hundreds of fatalities and hundreds of thousands of dollars in damage. And, finally, critics of FBRs cite adverse economics as the reasons not to turn to a plutonium economy. Soaring construction costs require greater capital expenditures for FBRs than LWRs. In addition, the cost of uranium is not high enough to warrant building FBRs until well into the next century.6 Therefore, critics feel that for all of these reasons, the plutonium breeder option is not the fuel cycle of the future.

4.4 THE THORIUM OPTION

Another fuel cycle option is the thorium-U^{233} breeding cycle. A schematic diagram is shown in Fig. 4.3. As can be seen, this fuel cycle is very similar to that of the plutonium breeder option, except that U^{233} is bred from thorium and recycled rather than breeding plutonium from U^{238}. The major difference lies in the interaction between the breeder-converter and the consuming reactors. In the plutonium breeder option, consuming LWRs would eventually be replaced by the FBR; in the thorium option both breeder-converter and consuming reactors play an integral role. As some envision the cycle, regional fuel cycle centers and national reactors would be instituted.[5] The regional fuel cycle center would be under international control subject to IAEA safeguards and would take care of reprocessing, fuel fabrication, plutonium to U^{233} converter-breeder reactors (whether a reactor is a converter or a breeder will depend upon fuel and energy demand), and waste management facilities. The national reactors would utilize the fuel fabricated at the regional fuel cycle center to produce power and send their spent fuel to the center for reprocessing. A diagram illustrating this reactor symbiosis is shown in Fig. 4.4. The ratio of national to regional power could be anywhere from very large to very small, depending upon a large number of key parameters such as reactor types and specific distribution of key isotopes in the reactor fuel. These parameters are not easy to estimate without the use of complex computer programs.[5]

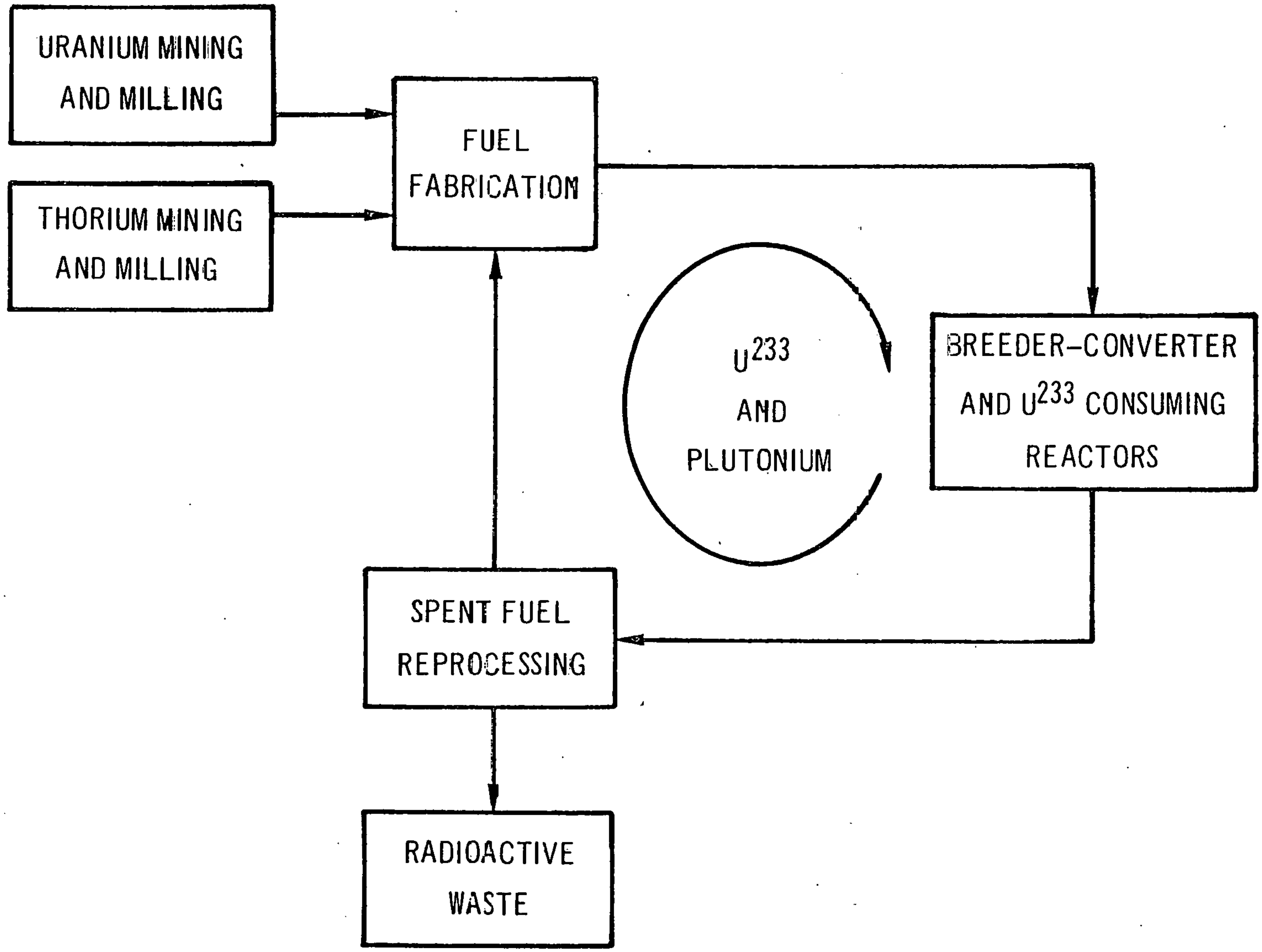

Fig. 4.3. Schematic Diagram of the Thorium Fuel Cycle

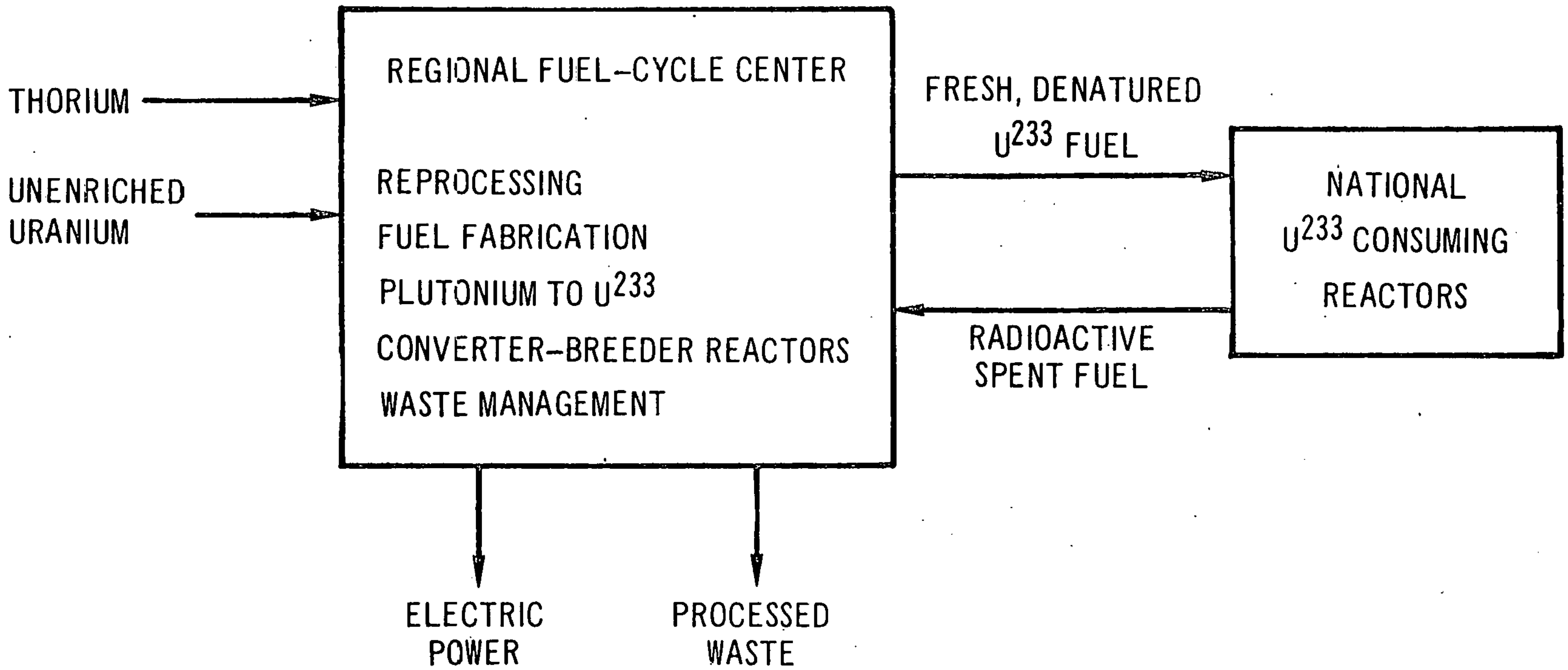

Fig. 4.4. The Mature Denatured Uranium Fuel Cycle
Source: Reference 5

Proponents of this fuel cycle option cite several characteristics that make the option favorable from a safeguards point of view. First, the fuel in the national reactors, which has a 4% concentration of U^{233} in a denatured mixture with U^{238}, is not suitable for nuclear weapons, even though U^{233} is highly fissionable. The Civex process can also be used to make the U^{233} inaccessible during reprocessing. Second, sensitive fuel cycle support technologies and the breeder-converter reactors, which utilize recycled plutonium as the core material, can be heavily safeguarded at international centers. This feature will help to reduce greatly possibilities of SNM diversion or sabotage of reactor facilities.

Another advantage of the thorium cycle is the extension of uranium resources. The uranium ore mined today is of relatively low quality and huge amounts must be mined in order to process a sufficient amount for fuel. Because of this, uranium costs keep rising. However, the concentration of thorium in the earth's crust is three times greater than the concentration of uranium.[11] Furthermore, an advanced converter reactor requires an inventory of 50 tons of thorium compared to 400 tons of U_3O_8 for a standard LWR.[12] Hence, the thorium mining and milling industry would grow to only a fraction of the size of the uranium industry, in addition to alleviating problems associated with dwindling uranium supplies.

On the other hand, critics find several faults with the thorium cycle. First, plutonium is again produced and reprocessed in this fuel cycle. Even though the plutonium is reprocessed and used at proposed heavily guarded international fuel cycle centers, reprocessing technology will still be distributed worldwide. Similar to the case of the plutonium fast breeder cycle, little can be done to prevent a determined country from clandestinely building and operating their own reprocessing facility dedicated to producing weapon-grade plutonium. Second, problems exist with U^{233} as a fuel because it is almost as potent an atomic weapons material as plutonium. Because both plutonium and U^{233} are recycled, there are now two reprocessing technologies and two weapons-potential materials to deal with. Furthermore, the isotope U^{232} is produced along with U^{233}. The isotope U^{232} is so gamma radioactive that even fresh, unirradiated fuel assemblies would have to be handled by remote control. It would be an ideal contaminant from the point of view of a terrorist weapons designer intent upon making the biggest mess.[13] Third, the thorium fuel cycle is largely unresearched and some insurmountable barriers may be encountered. For example, some converter reactors call for heavy water and there is presently no heavy-water industry in the U.S. Moreover, the heavy-water CANDU reactors cost 20% more to build than LWRs of the same capacity.[13] Also the disposal of uranium-thorium wastes would have to be demonstrated and licensed. Hence, a whole new technology must be developed for this industry. Development time for such a project could extend from several years to several decades.

5 CONCLUSIONS

To summarize, the issues surrounding nuclear safeguards are proliferation and terrorism. Protecting the nuclear fuel cycle against attempts by nonnuclear weapon states to divert nuclear materials for weapons manufacture has been the function of the NPT and the IAEA. However, because all nations have not signed the NPT and IAEA safeguarding inspections are not foolproof, the fuel cycle itself has been looked to as a possible way to alleviate concerns over proliferation. The three fuel cycles most advocated for future use are the once-through LWR cycle, the plutonium breeding cycle, and the thorium breeding option. As seen from the preceding discussions, neither of the above cycles will eliminate the possibility of clandestine diversion of nuclear material by countries bent upon obtaining a nuclear arsenal. Furthermore, a civilian nuclear industry is not needed to produce weapon material, since research reactors can provide the necessary weapon-grade uranium or plutonium much cheaper and easier than commercial power reactors. Thus, altering the nuclear fuel cycle does not necessarily reduce the possibility of proliferation of nuclear weapons. Only strict enforcement of the NPT and of the safeguard guidelines of the IAEA can achieve nonproliferation.

Terrorism is the second issue surrounding nuclear safeguards. Again, changing the fuel cycle does not prevent terrorists from either stealing highly radioactive material to be used for weapons or from sabotaging nuclear facilities. Policing a nuclear facility by using guards, alarms, barriers, and searching and screening of employees is the only way to protect against terrorism. But these actions then bring up questions regarding civil liberties violations of both the employees at a nuclear site and of the public in general. Hence, altering the nuclear fuel cycle will not eliminate the risks of nuclear terrorism.

In conclusion, before deciding upon the nuclear fuel cycle to be used in the future, the safeguarding risks and implications of a particular fuel cycle must be fully studied. Both nuclear proliferation and terrorism must be addressed and decisions made regarding what risks will be accepted and how these risks will be reduced through safeguard practices and procedures.

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