Evaluation of the ALMR/IFR Technology 4

The advanced liquid metal reactor/integral fast reactor (ALMR/IFR) project within the Department of Energy (DOE) is currently a research project, and the key components necessary for proposed future applications which are reviewed in this chapter, require considerable development and testing. As described in chapter 3, many of these key components are still under development, at the concept stage, or still being tested. For example, studies are just beginning on the behavior of reprocessed ALMR/IFR nuclear fuel over its lifetime and may require as long as 5 years for completion.[1] In addition, the existing experimental breeder reactor (EBR-II), which is part of the test complex, is now scheduled to be shut down at the end of 1994. Fuel behavior studies are needed for each of the variety of fuel types proposed for the ALMR/IFR system, including those based on reprocessed spent light-water reactor (LWR) fuel, recycled ALMR/IFR fuel, and surplus weapons-grade plutonium. It is not clear how these studies will proceed without the EBR-II.

Many components of the ALMR/IFR fuel reprocessing and recycling system have been demonstrated on a bench scale. However, most have yet to be tested as prototypes or at a full production scale, or to be integrated into a complete operating system. In addition, the waste disposal technology for the system is still in an early research stage. Only after such research, development, and prototype work is complete could a commercial-scale ALMR/IFR system be deployed. Because of the nature of any research project in which both problems and opportunities have yet to be

[1] Unrecycled or reprocessed experimental fuels have been tested in the nuclear reactor for some years.

discovered, it is difficult to evaluate the suitability and potential of the proposed system for any specific goal. Such a research project will change and adapt in response to data gathered during its development. Thus, the Office of Technology Assessment (OTA) analysis therefore reflects that uncertainty. It also reflects the fact that all recent technical data available on this project have been developed by DOE contractors-Argonne National Laboratory and the General Electric Company (GE).

DISPOSING OF WEAPONS PLUTONIUM

ALMR/IFR technology has been proposed as an option for eliminating surplus military plutonium in both the United States and the former Soviet Union by converting and using it as nuclear fuel. Theoretically, with enough multiple fuel reprocessing cycles through an ALMR/IFR system, virtually all plutonium isotopes in the original weapons material and in reprocessed fuel could be converted into fission products. However, as discussed in chapter 3 and supported by previous studies, this technology would take more than a decade of research to build, require several hundred million dollars in research expenditures, and face uncertain outcomes (27, 37, 46, 48). To speed up the process, promoters of the technology have proposed that the surplus plutonium could initially be "deweaponized" by blending it with fission products (to make it too radioactive to handle outside a hot cell) and later returned to an ALMR (when one is developed) for complete fissioning (53). Such an approach may be feasible, but it is not unique to ALMR technology.

A consideration pointed out by the National Academy of Sciences (NAS) and others is that it may be inappropriate to wait for the possible development of the ALMR/IFR system before dealing with the problem of Russian plutonium now coming from warhead dismantlement. Many experts agree that the existence and status of that plutonium represent a "clear and present danger," and that advanced reactor concepts such as the ALMR/IFR are too far from realization to be considered useful disposition options for this material (27, 48). Given the status of development of the ALMR/IFR system, it will not be operational for decades. If current plans and budgets are followed, a prototype system scheduled by Argonne and GE researchers could begin operation about 2005. When the time necessary for technical, environmental, safety, and siting evaluations is considered, substantial ALMR/IFR capacity is unlikely to be available until about 2015 at the earliest.

If disposition of plutonium is urgent, other more immediately available and technically mature options, such as conversion into mixed-oxide (MOX) fuel and burning in existing nuclear reactors or vitrification, should be viewed as near-term preferred choices. Even if it were completed and performed as specified, the ALMR/IFR system requires substantial time for the elimination of large amounts of plutonium. In a maximized burner configuration (operating to burn the most plutonium possible), a full-sized commercial-scale 1 -gigawatt ALMR/IFR installation could destroy (by fissioning) only about 0.4 metric ton of plutonium per year (42, 45).

The use of ALMR technology for the complete destruction of surplus weapons plutonium would probably not be feasible as a stand-alone mission for this technology. It would have to be coupled with some other plutonium fuel source in addition to surplus weapons plutonium (e.g., material recovered from LWR spent fuel), because a minimum amount of plutonium must always be present in the ALMR for the reactor to function. For example, a hypothetical full-scale ALMR would require an initial plutonium fuel load on the order of 15 tons to begin operation. In the burner mode, after a fuel load was used up in approximately 2 years, it would be removed, and the remaining plutonium would be recovered during reprocessing to make new ALMR fuel. Only about 0.4 tons of new plutonium would have to be added per year to make up the reactor core load.

In other words, about 15 tons of weapons plutonium would be needed to initially load the reactor, but only about 0.4 tons would be transformed to fission products each year, and this would have to be replaced for continued reactor operation. When no more weapons plutonium was available as makeup fuel, slightly less than 15 tons of plutonium would remain in the reactor core. Thus, if the above-mentioned 1 -gigawatt reactor operated to consume plutonium for as many as 50 years it could destroy about 20 tons of plutonium, but would require about 35 tons to operate, leaving about 15 tons of plutonium in the system at the end of the 50 years. Under these conditions, only about 60 percent of the 35 tons of plutonium required for reactor operation would be destroyed. Further reactor operation to fission the remaining 15 tons would require a new source of plutonium other than dismantled weapons.

Another issue related to estimating the time to deployment is licensing and siting. If the ALMR were licensed in the manner of other civilian nuclear facilities, the process must be expected to require several years. Argonne and GE expect that licensing by the Nuclear Regulatory Commission (NRC) would be possible, and they have submitted a preapplication review to NRC that is now complete (44). The NRC review concluded that the concept is licensable, specifically including seismic isolation, fuel integrity, and emergency shutdown aspects (12, 44). This was a preapplication review, and further licensing could be subject to future questions and debate. If the ALMR were deployed by the private sector, licensing could elicit public concerns about plutonium reactors in general. An alternative licensing process would be to carry out operations at government sites in Russia and the United States to avoid the debate about proliferation issues that the use of multiple ALMR/IFRs would entail (53). Some believe that a very lengthy public debate about licensing and siting can be avoided if the only intention is to license several reactors at government sites operating with surplus weapons plutonium (27).

Plutonium storage could also bean issue if a decision is made to wait until the ALMR/IFR technology is developed before surplus weapons plutonium is processed. In that case, today's surplus plutonium may have to be stored for decades while ALMR technology is designed, tested, scaled up, deployed, and licensed. Some believe that the use of breeder reactors such as the ALMW IFR will make economic sense as a means of meeting future U.S. energy needs, and therefore the United States should store its military plutonium for this eventuality. Others point out that plutonium-fueled fast breeder reactors will not be economically competitive with current reactors for probably a century (37, 46). Plutonium could become an economic energy source only if uranium becomes much more expensive or the world's uranium resources become scarce. Most experts agree that, at present, the cost of fabricating and safeguarding plutonium fuels makes it uncompetitive with cheap and widely available low-enriched uranium fuels (27).

In a recent report, the National Academy of Sciences concludes that advanced reactor designs will not be available for plutonium disposition for many decades, and thus it makes little economic sense to store existing plutonium against this eventuality, especially when there are much more near-term disposition methods available (27). NAS also concludes that current decisions about disposition options for surplus weapons plutonium should not be used to drive decisions about future options for nuclear power in the United States. The amount of weapons plutonium likely to be surplus is small on the scale of global nuclear power use and is not a large factor in the future of civilian nuclear power (27). Another issue is that whatever economic value plutonium might have in the future must be considered in light of the security risks it may present. There is also a danger that long-term storage of military weapons plutonium awaiting a disposition technology may send the wrong political signal to the rest of the world about U.S. plutonium management goals.

Finally, the selection of any disposition option must await formulation of an overall national policy for managing plutonium and other nuclear materials from dismantled weapons that states the key, relevant criteria (48). Meanwhile, certain features of the ALMR/IFR concept-its potential capacity to protect plutonium from proliferation and its development status-can be used by policymakers to compare and evaluate it against other plutonium management options. A careful assess-

TABLE 4-1: Half-Lives of Some Fission Products and Actinides Contained in LWR Spent Fuel

Spent fuel nuclide	Half-life (years)
Technetium-99 (fission product)	210,000
Iodine-129 (fission product)	17,200,000
Cesium-135 (fission product)	2,000,000
Uranium-234 (actinide)	248,000
Plutonium-239 (actinide)	24,360
Americium-241 (actinide)	458

SOURCE *Handbook o/ Chemistry* and Physics, 48th Ed (Cleveland, OH The Chemical Rubber Company, 1967)

ment, independent of all reactor vendors and proponents of certain technologies, would be beneficial. Such an assessment might consider which criteria are most important in both the United States and the former Soviet Union, and evaluate the technology options against those criteria. Recent studies cited above could be used as a starting point for such an assessment.

NUCLEAR WASTE MANAGEMENT

Waste volume and characteristics are important factors in assessing potential applications of the ALMR/IFR concept. Because this concept is still in research and development stages, and has not been tested with actual spent ALMR/IFR fuel, its potential impact on waste reduction must be projected from available data. Nevertheless, developers of the ALMR/IFR cite some anticipated advantages of the system based on its minimization of waste.

I Processing Spent Reactor Fuel

Developers of the ALMR/IFR claim it may be possible to remove (by repeated reprocessing over time) the actinides from LWR spent fuel, including plutonium and uranium, leaving only the generally shorter-lived (but initially very radioactive) fission products, which would then be packaged for geologic repository disposal. However, the potential impact of ALMR processing on geologic repositories for spent nuclear fuel is far from clear. ALMR researchers claim that the removal of actinides from spent fuel (for recycling into ALMR fuel) would reduce the duration of radiological toxicity of such waste from millions of years to hundreds of years because a large portion of the long-lived radioactive isotopes would be removed (12).

Others have disputed some of these claims, based on calculations of the impact of actinide removal on key geologic repository parameters. Also, its developers claim that the ALMR/IFR might be able to eliminate a variety of problematic nuclear wastes, converting the actinides they contain into fission products. Others counter that actinide removal would offer few if any significant advantages for disposal in a geologic repository because some of the *fission product* nuclides of greatest concern in scenarios such as groundwater leaching actually have longer half-lives than the radioactive actinides. The concern about a waste cannot end after hundreds of years even if all the actinides are removed when the remaining waste contains radioactive fission products such as technetium-99, iodine-1 29, and cesium-135 with the half-lives between 213,000 and 15.7 million years (table 4-1) (5, 18, 19).

A final advantage of actinides removal (including plutonium) from spent fuel is to eliminate concerns about leaving plutonium in a repository that might be mined sometime in the future for the purpose of making weapons. This is a legitimate point that should be considered more broadly in the context of future proliferation potential.

In the proposed operation of the ALMR/IFR actinide recycle concept, the actinides separated from spent fuel would be converted into new fission products, that require disposal. Thus, this system does not eliminate the need for a nuclear waste repository, nor can it be considered a short-term solution to the U.S. spent fuel disposal problem. Also, unless the deployed ALMR/IFRs were permanently shut down and decommissioned at the end of this mission, they might continue to be used as breeder reactors for electricity production. In that case they would continue to produce radioactive fission products that would require disposal. Numerous other technical ques ions relating to proposals to eliminate plutonium n spent fuel by using various technologies are currently being evaluated by the National Academy of Sciences Panel on Separations Technology and Transmutation Systems (STATS panel).[2]

Processing all U.S. spent reactor fuel to remove actinides is likely to be very slow and require decades to significantly reduce the actinide content of existing LWR spent fuel (26, 27, 46). With a national deployment schedule. ALMR/IFR technology might permanently destroy a significant portion of U.S. spent fuel after 60 to 90 years (3). Another estimate is that it would take 20 ALMR/IFR facilities 100 years or more to destroy 90 percent of the LWR actinide waste inventory projected to exist in 2010 (26,). Each reprocessing cycle of LWR spent fuel in the ALMR/IFR system would transform and remove only a small proportion of the total actinides originally contained in LWR spent fuel, so that a great number of reprocessing steps would be required to transform all of the actinides. LWR spent fuel contains only about 1 percent plutonium, with the remainder being mostly uranium, much smaller amounts of other actinides, and fission products. Separating the plutonium would leave the vast majority of the LWR spent fuel material, mostly uranium-238, which would still require disposition. One proposal is to convert this surplus uranium-238 by breeding it into new plutonium fuel in the ALMR/IFR. During the course of this operation, much more plutonium would be generated than was present in the original LWR spent fuel.

In terms of the potential regulatory impact of an actinide recycling program. one study concluded that because of Environmental Protection Agency and NRC rules, acinide recycling would not make licensing of a repository significantly easier. A study on the potential of ALMR actinide recycling (and several other reprocessing/disposal technologies) for handling spent nuclear fuel concluded that the concept was flawed on both technical and poitical grounds. and that ALMR actinide recycling was neither an alternative to the current geologic disposal program nor essential to its success (36). In fact, the conclusion reached was that pursuit of such a program would require a major restructuring of the U.S. geologic repository effort because the waste forms generated would be so different (36). The study pointed out that even if the efficiency of spent fuel actinide recovery claimed by proponents were feasible on an industrial scale. it would solve the wrong problem. Many of the risks of a long-term geologic repository come not from the actinides contained in spent fuel but rather from long-lived soluble fission products that might leach from a repository into groundwater, which would not be eliminated by the ALMR/IFR system. In addition. the absolute radioactivity risk from a repository is already very low, and actinides do not contribute significantly to that risk.

Further, some argue that actinide recycling would aggravate rather than reduce public concerns by requiring the siting and operation of numerous reactors, as well as reprocessing and fuel fabrication facilities; by reviving the concerns over nuclear proliferation; by generating new and different waste streams: and by requiring centuries of reliable institutional control over power-producing, reprocessing, and storage facilities. Removing the actinides from radioactive waste is unlikely to have a significant impact on public antipathy to geologic disposal (23. 46).

It appears that actinide recycling is unlikely to reduce the difficulty of managing the overall waste stream from nuclear power reactor operations. In fact, the opposite is possible. New licensing. the operation of reprocessing facilities, transportation between the present locations of LWR spent fuel and reprocessing facilities, and management of ancillary waste streams would all be required. Finally. if the ALMR/IFR becomes a widely deployed technology for electricity generation, as envisioned by its developers, the net

[2] This report is scheduled for release in July 1994.

impact in the long term would be to *increase* the repository capacity required for the disposal of fission product wastes created by the technology.

I Processing Other Radioactive Wastes

According to Argonne researchers, the same technology that might convert LWR spent fuel into ALMR/IFR fuel would in principle be applicable to the processing of other types of nuclear waste materials. These would include DOE-owned spent fuel, surplus weapons plutonium, and scrap from plutonium processing operations (16). According to a recent DOE report, the problem of dealing with a large number of old and disintegrating fuel elements from its past operations is reaching critical proportions (52).

Since the ALMR/IFR technology will not be available soon, it may not be appropriate to consider its application for the most pressing and immediate waste disposal needs outlined by the DOE Spent Fuel Working Group. Nevertheless, some method for improved safe storage of this waste is urgently needed. And if parts of the ALMR technology could be developed for treating and packaging this material or similar waste further, investigation might be useful.

In summary, the ability of ALMR/IFR technology to reprocess LWR spent fuel into ALMR fuel has yet to be demonstrated, and significant technical problems remain, one possible application is for long-term management of radioactive wastes that do not require immediate attention. Because of the preliminary nature of research on the ALMR/IFR concept, characterizing its potential impact on a geologic repository for nuclear waste in terms of waste volume, longevity in a repository, or long-term risk factors, is difficult. Thus, it is also difficult to make comparisons with much more developed processes, such as direct disposal of spent fuel in geologic repositories or high-level waste vitrification.[3] Furthermore, any spent fuel reprocessing option must be evaluated in the larger context of establishing a U.S. plutonium reprocessing policy or of reviewing international policies regarding nonproliferation.

PROLIFERATION RISKS AND BENEFITS

I Concerns About Plutonium Breeding

Although some recent proposals for the future of the ALMR/IFR concept have focused more on its ability to transform and irreversibly use up plutonium, even its developers acknowledge that it is "uncontested that the IFR can be configured as a net producer of plutonium" (13). In principle, any nuclear reactor could be operated as a breeder (producing new plutonium). However, as mentioned earlier, the ALMR/IFR system originated as a reactor capable of reprocessing its own spent fuel and breeding more plutonium (42). In fact, liquid metal reactor (LMR) technology has always been associated with breeder reprocessing technology. The first reactor ever to produce electricity, which began operation in 1951, was a liquid metal cooled-breeder reactor design. In September 1993, ALMR/IFR developers emphasized the possible long-term energy advantages of the concept as a breeder reactor design (4). GE representatives described the flexibility of converting their full-scale reactor design from burner to breeder operation in a November 1993 status report to DOE (21, 34).

Thus, for the purpose of evaluating the potential impact of the ALMR/IFR on nuclear proliferation risks, it must be considered a breeder-capable reactor system. Even though this system might be capable of operating in a way that uses up plutonium from sources such as dismantled weapons, if properly modified it could also be used to breed more plutonium. Most proponents of the technology believe that its long-term mission will probably always be as part of an integrated system in which plutonium fuel and reprocessing make significant contribution to U.S. and world energy needs.

[3] Although vitrification is still under development in the United States, it has been demonstrated successfully in France and the former Soviet Union as a means of solidifying high-level radioactive waste. No vitrified waste has been placed in a repository, however.

If reactor design allowed sufficient room, a "breeder blanket" of fertile uranium-238 could be retrofitted around the reactor core that, when irradiated, could produce plutonium with a relatively low buildup of undesirable (from a weapons manufacturing standpoint) plutonium isotopes.[4] Breeder blankets have also been used to produce weapons-grtidc plutonium in LWRs. Some argue that the ALMR could be designed to allow no room for such a blanket of breeding material around the retie' t o r core. I n this case, however, although less efficient it would still be possible to breed plutonium by placing fertile material at either end of the fuel rods.

However, the designs recent] y described by GE do not require any extra room in the reactor core. They are designed to be flexibly convertible from breeding to consuming by simply altering the arrangement of a fixed number of reactor elements (for example, see figure 3-3). Thus, operatirrg an ALMR/IFR system to breed plutonium would probab]y not be difficult. It would, however, be difficult to design an ALMR reactor core that could not be converted to breeder operation given sufficient motivation and ability on the part of the reactor's owner. Any reactor could theoretically be converted to breeder operation. so the important proliferation concerns may be the access to a heavily shielded hot cell and fuel reprocessing equipment. along with access to a spent fuel source (e.g, the ALMR/IFR).

Although acknowledging that the ALMR/IFR is a breeder reactor system. its developers nevertheless claim that it has distinct proliferation advantages compared with curlier breeder/reprocessing systems such as the Clinch River Breeder Demonstration project that ended in 1983. The major difference between the two programs is the substitution of pyroprocessing for PUREX nuclear fuel reprocessing. The promoters of this concept believe that a switch to pyroprocessing by nations currently using PUREX reprocessing, including Japan, France, England. and North Korea, would represent a major step in nonproliferation. Others point out that it is difficult to justify the U.S. funding development of possible PUREX reprocessing substitutes for nations that clearly have not agreed to adopt them should they ever become available (27).

I Concerns About Weapons-Usable Plutonium

How does pyroprocessing differ from PUREX reprocessing in terms of inherent nuclear proliferation risks? One of the larger proliferation barriers claimed for ALMR/IFR reprocessed fuel is the presence of residual fission products and actinides that are highly radioactive. The irradiated fuel from an ALMR/IFR recycling facility could consist of up to 70 percent plutonium and 30 percent uranium and other actinides, along with small amounts of highly radioactive fission products. This radioactivity would make the material difficult to work with and require that all operations be carried out by using a heavily shielded remotely operated hot cell. Presumably it would be difficult to fabricate weapons components under such conditions with this material. Plutonium from PUREX reprocessing does not contain these fission products and thus can be used directly to fabricate weapons components. On the other hand, fuel from the ALMR/IFR cycle would be a preferable starting material for converting to weapons material compared with ordinary spent nuclear fuel from a conventional LWR because it contains a much higher concentration of plutonium (70 percent versus 1 percent) and significantly lower quantities of radioactive fission products. A large fraction (but not all) of the fission products would be removed by the pyroprocess. Thus, to obtain enough plutonium for a bomb it would be much

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[4]Plutonium that is high in the plutonium-239 and lower in plutonium-240 and plutonium-241 is preferable for use in nuclear weapons, because the greater radioactivity and neutron generation in the latter two isotopes complicate the design of such weapons. Nevertheless, even plutonium that is high in the 240 and 241 isotopes can be used to make a nuclear bomb.

easier to handle and process some tens of pounds of reprocessed ALMR fuel than almost a ton of spent LWR fuel.

The developers of this technology point to several factors as obstacles to the use of ALMR/IFR reprocessed material for fabricating weapons. These are the reduction of the plutonium concentration by the presence of uranium and other compounds, the presence of plutonium isotopes other than plutonium-239, and the high radioactivity of contaminating compounds that makes handling more difficult. None of these, however, is a particularly impenetrable proliferation barrier. Reducing the plutonium concentration, (e.g., because of the presence of 30 percent uranium in the reprocessed material) does not itself make the plutonium unusable in terms of weapons. For example, diluting plutonium-239 with 50 percent nonfissile uranium-238 would increase the amount of material required to make a weapon by only about a factor of four (40).

The isotopic composition of reprocessed ALMR/IFR is also not an insurmountable barrier to proliferation. Plutonium is produced by the same process in both military plutonium production reactors and civilian nuclear power reactors. However, military reactors were operated differently to produce a plutonium containing mostly the single plutonium-239 isotope, which is considered the most desirable isotope for bomb production. Nevertheless, plutonium obtained from *any spent nuclear fuel source* can be used to make a nuclear bomb; therefore, no distinction should be made between weapons and civilian reactor-grade plutonium from the standpoint of nuclear proliferation (27, 37, 40).

The plutonium from ALMR recycled fuel would have an isotopic composition similar to that obtained from other spent nuclear fuel sources. Whereas this might make it less than ideal for weapons production, it would still be adequate for unsophisticated nuclear bomb designs. In fact, the U.S. government detonated a nuclear device in 1962 using low-grade plutonium typical of that produced by civilian powerplants (10, 37). The bomb design used in the 1945 Trinity test could in principle contain civilian reactor-grade plutonium of any degree of burnup and isotope composition, and still provide nuclear yields in the multikiloton range (22). Using civilian power reactor-grade plutonium in the 1945 design would increase the probability that the yield would be reduced. However, it would not greatly change the value of the "fizzle" (lowest expected) yield, which although smaller than the nominal yield would nevertheless create quite damaging nuclear explosion (22, 40). Thus, although civilian power reactor-grade plutonium would be harder to work with for making bombs, the drawbacks are not serious and nuclear proliferators might not be deterred simply because the only accessible bomb material was less than perfect.

The plutonium recovered from spent ALMR fuel would also be contaminated by heat-generating plutonium-238, but this too would not present an insurmountable proliferation barrier.[5] In any case, the plutonium recovered from the ALMR by operating it as a breeder would be relatively free of plutonium-238.

On the other hand, some processing would probably be required to remove these residual fission products from ALMR/IFR reprocessed nuclear fuel. Currently available methods for removing the residual fission products in ALMR/IFR spent fuel could be performed in the hot cell (although they might interrupt normal operation and be detectable with any inspection regime); these

[5] The details of how heat output from plutonium used in warheads would affect its design and operation are not available publicly. The NAS report concluded that the heat generated by plutonium-238 and plutonium-240 would require careful management for weapons design, including the use of channels to conduct it from the plutonium through the surrounding explosive, or delaying assembly of the device until a few minutes before use (27). Similarly, [he radiation from americium-241 in ALMR/IFR reprocessed fuel would require that more shielding be used but is not an insurmountable obstacle (27). Only plutonium composed of more than 80 percent plutonium-238 is exempted from International Atomic Energy Agency safeguards; any other isotope composition must be considered usable for making a bomb (37).

would provide usable, if not optimal material. for weapons purposes. Thus, access to the hot cell associated with ALMR/IFR technology, and with its ability to handle highly radioactive materials safely (which is not a feature of conventional LWR systems), may be a key proliferation issue. Proponents claim that the purification of ALMR/IFR reprocessed material would require either construction of or access to a PUREX reprocessing facility. others point out that there are significantly simpler methods for removing fission products, such as a commonly used industrial process known as aqueous *ion exchange* (6, 56). Los Alamos National Laboratory has routinely used aqueous ion exchange to separate radioactive fission products from plutonium. The equipment and materials used in this process are commonly available for other types of industrial separation and purification (49). Such an operation would require the type of heavy shielding offered by the hot cell of an ALMR/IFR system.[6]

Other processes available *within* the ALMR/IFR system might also be modified to produce material suitable for making a nuclear weapon. ALMR/IFR designers expect to be able to remove the fission product wastes that would accumulate in the molten salt bath of an operating electrorefiner by using zeolite ion exchange, with the molten salt as a solvent. Analogous aqueous ion exchange processes have been used routinely to separate plutonium from other actinides and fission products, Since the same physical processes would be involved in molten salt-zeolite ion exchange, given sufficient motivation, one might be able to modify the process in order to remove fission products, and generate a material that could be converted into bomb components, with only a glove box for shielding. Similarly, although the conditions are substantially different, pyroprocessing (electrorefining)-type procedures have been developed by Lawrence Livermore National Laboratory for separating the actinide americium from recycled weapons plutonium (1). However, while the ALMR/IFR process and equipment might be modified to achieve such a separation with recycled fuel, any such modifications would probably be very difficult to conceal from a credible outside inspection regime.

Thus, in providing both the necessary starting material (ALMR/IFR recycled fuel) and the necessary facilities (hot cell and related reprocessing equipment), the ALMR/IFR system could be considered a source of weapons-usable nuclear material. Whereas it would probably be easier to generate weapons plutonium from a PUREX facility if one were available, but for a determined and capable proliferator, access to an ALMR/IFR facility is likely to serve such purposes.

An independent assessment of the proliferation potential and international implications of the integral fast breeder reactor, prepared by Martin Marietta for DOE and the Department of State in 1992 (the Wymer report), concluded that the diversion and further purification of plutonium by using the facilities available in the ALMR/IFR processing and recycle facility would be possible (56). The report also noted that the modifications required for these scenarios would be readily detectable with any reasonable inspection regime and that therefore proliferation scenarios involving *treaty* abrogation were the greater concern. In other words, any diversion of nuclear materials from the ALMR/IFR would be difficult to carry out clandestinely if an inspection regime were in place (24).

The Wymer report outlined several possible proliferation scenarios in which ALMR/IFR equipment could be modified to produce weapons material, including the following (56):

- The normal recycled ALNR/IFR fuel product could be reprocessed through multiple elcctro-

[6] If the hot cell were diverted for use with aqueous plutonium purification methods such as ion exchange or PUREX, either the process would have to be operated so as not to introduce water into the hot cell atmosphere, or the normal IFR fuel reprocessing, which is highly sensitive to water, would have to be interrupted.

refiner cycles to remove the rare earth fission products and reduce the radioativity of the material, thereby making it easier to manipulate.

- Multiple batches of fuel might be processed by using only the iron cathode electrode to remove uranium and allow the plutonium to accumulate in the molten salt phase (see figure *3-4).* This could generate a material with a plutonium-to-uranium ratio as high as nine, after electrochemical transport to the liquid cadmium cathode, although other actinides and rare earths would also be present.

- The reactor could be run in the breeder configuration with reprocessing of the irradiated fertile (breeding) material. For a more preferable grade (containing a higher proportion of the plutonium-239 isotope) of plutonium, it would be desirable to schedule blanket assemblies for reprocessing when the electrorefiner salt had just been replaced and was free of contaminants. Such plutonium would still be contaminated with fission products but, under certain conditions. could deposit a material having a plutonium-to-uranium ratio of one. Multiple batches of blanket fuel might have to be processed before the better grade of plutonium could be removed from the liquid cadmium (1 7).

According to this analysis, the proliferation resistance of ALMR/IFR technology is more a function of the adequacy of nuclear materials safeguards than of the technology itself. If a nation possessing an ALMR/IFR system chose to abandoned safeguards (e.g., by reneging on previous safeguards agreements), the technology alone would probably offer few proliferation barriers.

The Wymer study also considered the question: If it was willing to renounce international inspection, would a nation that had access to an ALMR/ IFR system have an advantage in proliferation. compared with a nation that did not have access to such a facility’? The study determined that having an ALMR/IFR facility would clearly provide a potential proliferating: nation several advantages. including a spent fuel receiving area and facilities for preparing the fuel for dissolution (56). Having an ALMR/IFR facility would be much more valuable to a potential proliferator that had no other existing reprocessing facilities. A nation that abandoned nonproliferation regimes and had existing PUREX facilities might see less proliferation advantage in having an ALMR/IFR facility.

If, instead of processing spent fuel, the ALMR system were used to reprocess *irradiated fertile (breeding) material* in the electrorefiner, the resulting plutonium would be a superior material, with an nearly ideal isotope composition for nuclear weapons manufacture (56). It would be superior even to plutonium obtained by PUREX reprocessing of conventional LWR spent fuel because of its higher plutonium-239 content. When it operates as a breeder, the plutonium available from the ALMR/IFR under normal operation will be weapons grade, whereas commercial LWRS always produce a much lower-grade plutonium unless they are shut down and refueled much more frequently than required for economical operation (49).

Developers of the ALMR/IFR technology indicate that it is an "uncontested fact that it would be technically possible to make nuclear explosives from material extracted in some (unspecified) fashion from an IFR process stream” (13). Other reports have come to similar conclusions. Even though the ALMR reduces certain proliferation risks when operated with proper safeguards, possess ion of such a facilitywould bring with it some of the technology needed to produce weapons plutonium as well (27).

ROLE OF NUCLEAR SAFEGUARDS

Part of the ALMR/IFR research program is a project to develop suitable nuclear material safeguards and monitoring and control systems. One study suggests that ALMR/IFR fuel recycling would have some features that require the development of unique safeguards and inspection systems (56). Others feel that the notion that plutonium in non-nuclear weapons countries can be made safe by the use of safeguards is misleading. That is, full-scale reprocessing and breeder development would involve such a large amount of separated plutonium that foolproof protection aga instns[version would be difficult or impossible (37).

According to the Wymer report, a safeguards regime for the ALMR/IFR system would have to be very different from that for a PUREX facility. (In fact, even safeguards for large-scale PUREX-type reprocessing plants remain to be proven in actual operation.) Conventional safeguards systems for PUREX rely heavily on materials control and accounting techniques in which representative samples of key, homogeneous solutions are taken during plant operation. Chemical analyses of these samples give an accurate and precise picture of the movement of materials through the PUREX reprocessing system. Such an approach may be less applicable to the ALMR/IFR system because of the lack of homogeneity of molten salt solutions used in pyroprocessing and at other key points during operation. In the clectrorefining process. for example, plutonium (along with other actinides) may actually precipitate from solution. leading to misleadingly low measurements (24). Safeguarding the ALMR/IFR system would therefore have to rely more on containment and surveillance methods. Similar methods have been developed as proliferation control techniques at sites such us Sandia National Laboratories (24). The development of adequate safeguards for the ALMR/IFR system may be an essential requirement to allow its future development and deployment (24). However, International Atomic Energy Agency (IAEA) inspection would always require actual hands-on monitoring of a facility.

According to one analysis, if nonnuclear countries obtain full-scale reprocessing plants and breeder reactors, even full safeguards may not provide timely warning if a country should decide to abrogate its safeguards agreements (37). Thus, no safeguards scheme. including any IAEA program, could be effective if such sensitive materials and facilities became widely available in nations that are current I y nonnuclear weapons states. This is because the possession of such facilities would allow a nation to build nuclear weapons too quickly for adequate international response. A year hasbeen estimateded as the time necessary for the United States and others to amass sufficient political and other pressures to prevent a proli ferating country from making a bomb. The only acceptable approach, therefore, may be for nonnuclear countries to completely forego nuclear reprocessing. Then, if a country seized spent fuel. it would still need 1 1/2 to 2 years to build the necessary reprocessing facility to extract the plutonium—time enough in them-y for the rest of the world to take heed and respond.

Supporters suggest that a key difference between ALMR/IFR technology and PUREX plutonium separation is that. in principle, the former would keep the entire cycle (fuel reactor burning, spent fuel reprocessing, fuel fabrication, and waste processing) at a single site. If adopted. this would elminate proliferation concerns stemming from the shipment of separated plutonium and spent fuel. Thus the configuration of the complete system. rather than the technology itself. may offer a proliferation resistance advantage compared with PUREX reprocessing. In countries currently de~cloping PUREX reprocessing for plutonium fuel recycling, such as France and Japan, spent fuel is transported to central facilities and reprocessed fuel must be transported back to the reactors. On the other hand. the United States prescnt-Iy curries out no reprocessing. If the United States begins reprocessing. there may be no technical reason why reprocessing facilities including PUREX could not be colocated with a nuclear reactor, if this were determined to be an important feature. In addition, GE acknowledges that it may be politicall y difficult to colocate reprocessing facilities at new nuclear reactors, and it is considering the possibility of a central reprocessing facility that could serve many reactors at different locutions (43). Therefore the collocation advantage may be an equally infeasible option for either IFR or PUREX reprocessing.

POLITICAL BARRIERS

Separate from the issue of whether the ALMR/IFR system could provide sufficient tcchni(w[*barriers* to proliferation is the question of the program's impact on political barriers to prlifera-tion. In particular. how much might a United

States decision to reprocess and bum plutonium influence the plutonium management policies of other countries? Since the late 1970s the United States has chosen not to carry out plutonium reprocessing for both economic and political reasons. In a September 27, 1993, policy statement the Clinton Administration reaffirmed this by announcing a nonproliferation initiative, which includes a proposal for a global convention banning production of fissile material (e.g., plutonium) for weapons, a voluntary offer to put U.S. excess fissile materials under IAEA safeguards, and a recognition that plutonium disposition is an important nonproliferation problem requiring international attention (55). Subsequently, President Bill Clinton and Russian President Boris Yeltsin, during their meeting in Moscow on January 14, 1994, agreed to cooperate with each other and other states in measures designed to prevent the accumulation of excessive stocks of fissile materials and to reduce such stocks overtime (3 3). They agreed to establish a joint working group to consider steps to ensure that these materials would not be used again for nuclear weapons.

Many are concerned that a U.S. emphasis on ALMR/IFR development, with its inherent reliance on nuclear fuel reprocessing, could undermine this policy and stimulate other nations to undertake plutonium reprocessing programs. In his September 1993 statement, President Clinton said that although the United States will not interfere with reprocessing in Japan or Europe, "the United States does not encourage the civil use of plutonium and, accordingly, does not itself engage in plutonium reprocessing for either nuclear power or nuclear explosive purposes" (55). If the United States breaks this long-standing norm by proceeding with the development of plutonium reprocessing technologies, other nations might be encouraged to consider LWR fuel without necessarily limiting the types of technologies used.

The example set by the United States in any decision about reprocessing for commercial reactors is likely to prove an important influence on the behavior of other countries and should be carefully considered. Setting an example for other nations has long been a primary argument for not supporting U.S. breeder reactor development. The NAS and others have warned that U.S. policy on plutonium disposition must take into account the signals sent by the choice of a particular disposition method (27). For example, if the United States treated its weapons plutonium as a waste to be disposed of, this could set an important example in its desire to discourage the use of plutonium reprocessing.

In summary, any nuclear technology carries with it some proliferation risks. These risks might be minimized by using inspection and safeguards regimes. However, the effectiveness of these measures is based more on political and international norms than on purely technical barriers. If the ALMR/IFR reprocessing technology were exported, the United States could not guarantee its ability to impose and enforce enduring and reliable technical barriers on other nations.

If the proliferation resistance of ALMR/IFR technology is judged from a purely technical viewpoint, its reprocessing facilities and nuclear reactor could clearly be adapted to breeder operation for producing plutonium. In addition, the technology carries with it several issues of general proliferation concern beyond whether it is designed as a breeder or a burner of plutonium. In itself, the use of reprocessing and its collocation with hot cell facilities provide some opportunity for plutonium concentration and the acquisition of plutonium for weapons. Although the ALMR/IFR system might prove more difficult to misuse for weapons production than a PUREX facilit y, its operation would produce a much more concentrated form of plutonium compared with spent LWR fuel, and would provide a facility (hot cell) and a technology for handling and reprocessing spent fuel into a weapons-usable form. Thus, from a purely technical viewpoint, if ALMR/IFR replaced or were developed as an alternative to PUREX-based reprocessing, it might be an incremental improvement nonproliferation. If it replaced the conventional LWR reactor with a once-through fuel cycle followed by direct disposal, then it could increase the risk of proliferation.

BEYOND THE SPENT FUEL STANDARD FOR PROLIFERATION RESISTANCE

ALMR/IFR promoters have focused attention on the fact that any plutonium contained in LWR spent fuel is a legitimate nuclear weapons proliferation concern. They and many others, including the recent NAS study on plutonium disposition, point out that there are large quantities of plutonium in low concentrations tied up in spent nuclear fuel in various nations around the world.[7] Although pure plutonium from dismantled nuclear weapons in the former Soviet Union is recognized as the immediate "clear and present danger" (27), the plutonium contained in spent fuel, as well as plutonium already separated from spent fuel, also represents a significant nuclear proliferation risk (30).[8] Since the plutonium obtainable from spent fuel can be used for making a nuclear bomb, the issue of the fate of this material must be addressed by all nations. The proposal to eliminate plutonium in spent nuclear fuel by using various technologies is currently being evaluated by the so-called STATS panel of the National Academy of Sciences, discussed earlier.[9]

In the past spent nuclear fuel was considered the benchmark for proliferation resistance because of its lethal "self-protecting" radioactivity. Although it contains weapons-usable plutonium, the spent fuel from a reactor is normally so highl y radioactive due to the presence of fission products that it cannot be handled or processed by a potential proliferator without complex specitil equipment and heavy shielding such as available in the nuclear weapons complexes of the United States or former Soviet Union.

Nevertheless, over the long term, mtiny experts agree that the unseparated plutonium in spent fuel must be considered a proliferation risk (27, 37, 46). The chemistry for separating plutonium from spent fuel is described in the open literature, and the essential technologies are available on the open market (49). Although commercial-scale separation is difficult and costly, a potential proliferator could use a much simpler and less costly facility to extract enough material for a few weapons. The plutonium contained in a truckload of spent fuel rods from a typical power reactor is enough for one or more bombs (27). Moreover, the intense radioactivity that initially makes nuclear spent fuel self-protecting declines after some decades. For example, after 100 years, spent nuclear fuel of typical burnup would decay to less than 100 rads per hour at 1 meter, which is the minimum radioactivity level considered sufficiently self-protecting by the NRC and IAEA to require less safeguarding (27). The unavoidable conclusion is that any plutonium, whether military or civilian, of any form and isotopic composition could be considered a proliferation risk over the long term.

Some solutions for plutonium safeguarding (including use of the ALMR/IFR) are directed at the idea of totally *eliminating all* the world's plutonium. Promoters of this solution argue that the best action for nuclear nonproliferation would be if all nations agreed to eliminate all plutonium and plutonium manufacture. However, this would require that all nations of the world agree to dispose of plutonium in all its forms, including surplus military as well as spent fuel and civilian sepa-

[7] U.S. commercial LWRs generate about 2,000 metric tons of spent fuel each year, of which about 1 percent (20 metric tons) is plutonium and other transuranics. The current inventory of spent fuel in the United States is about 28,000 metric tons, and DOE estimates that this will grow to about 61,000 metric tons (containing about 610 metric tons of plutonium) by the year 2010 when the Yucca Mountain repository is scheduled to open. That facility has a statutory capacity limit of 70,000 metric tons of spent fuel (46).

[8] The NAS committee ranked proliferation concerns as follows:

weapons plutonium = clear and present danger; civilian separated plutonium = nearly as bad as weapons plutonium; and plutonium in spent fuel = less immediate but long-term proliferation risk.

[9] Its report is scheduled for release in July 1994.

rated plutonium (30). Some countries such as the United Kingdom, Japan, and France have made ia substantial financial commitment to the commercial use of plutonium and might not be willing to accept this (37). The NAS concluded that this option could not be available for at least the next 50 years, although it may nevertheless be worthwhile to continue its development for future needs (30).

The NAS also made the point that it would be futile to develop a plutonium disposition process that made surplus *military* plutonium more proliferation-resistant than the much larger and growing quantity of *civilian* plutonium contained in spent fuel from commercial reactors. The spent fuel standard for proliferation resistance should be considered adequate for the nonproliferation benchmark unless methods are developed that also address the plutonium contained in LWR spent fuel (27). The corollary is that if a disposition method cannot achieve the spent fuel standard for military plutonium in a few decades, with low to moderate security risks along the way, it should not be considered (30).

The NAS also warned that it is far from clear that the best long-term nonproliferation solution for all the world's plutonium is total elimination by fissioning. Some type of geologic disposal method may be superior (27). The enormous costs of eliminating the entire global inventory of plutonium cannot be justified if options such as geologic disposal can provide acceptable nonproliferation risks.[10] Some elimination options involving repeated plutonium reprocessing and reuse may even have greater proliferation risks than to disposal in geologic repositories (27). Nevertheless, the major stumbling block will be that the elimination of plutonium would require a world consensus, which is clearly lacking today. It is important that this issue not be confused with the more clear and present danger of *surplus military plutonium.* A clear distinction must be made between the issue of dealing with the plutonium supply worldwide (by elimination or repository storage) and the issue of securing weapons plutonium. However, dealing with the current *weapons* plutonium disposition issue may serve to focus attention on long-term plutonium disposition and provide new options to that objective.

Finally, any international decision to eliminate the world's plutonium supply, including that in spent fuel, must be made against the background of international policy regarding the future of nuclear energy. In other words, it might be futile to adopt policies to eliminate all plutonium if the world continues to maintain or even increase the number of nuclear power facilities that produce more plutonium (in spent fuel). In this light, the deployment of a large number of ALMR systems for the purpose of eliminating plutonium in spent fuel might actually increase the total amount of plutonium in the form of recycling ALMR/IFR fuel inventories.

[10] The NAS report concluded that any spent fuel reprocessing option would cost in the tens to hundreds of billion dollars and require decades to centuries to develop fully.