Future Disposition of Nuclear Materials From Dismantled Weapons 4

After nuclear weapons are taken apart, the nuclear materials that contained such massive destructive power remain. Two principal materials-plutonium and highly enriched uranium (HEU)-are the most problematic. Together or separately they could be made into new weapons. Thus there are serious concerns about keeping these materials both safely contained and securely guarded. This chapter analyzes the management (disposition) of these materials; current plans for their storage, further use, processing, or disposal; studies that are addressing various technical approaches for disposition; and policies that affect these decisions. The discussion focuses on materials from U.S. warheads, although the technology for storage and disposition can have international application. Chapter 6 discusses possible application to Russian weapons materials.

Both plutonium and HEU can be used to make nuclear warheads, either in combination or alone. Although modern nuclear warheads commonly use both materials, the 'Fat Man" and "Little Boy" U.S. atomic bombs used in 1945 contained exclusively plutonium or HEU, respectively. Nevertheless, the ease of making a simple bomb from each material is quite different. A HEU bomb would be easier to design than one using plutonium, and would offer a higher confidence of working

Point

"We paid dearly for[weapons plutonium] in terms of dollars and the environment—let's get something back!"

DOE weapons design laboratory reviewer of OTA report

Counterpoint

"The DOE presumption of plutonium as an asset. . . is a significant policy issue that needs to be decided by Congress, not a group of career civil servants and cold warriors within DOE. "

Citizen group reviewer of OTA report

without being tested than a similar plutonium-based bomb (36).[1] With the frost U.S. nuclear bombs, only the plutonium-based design was tested before use.

This chapter discusses a variety of ideas for storing, utilizing, processing, and disposing of the plutonium and HEU recovered from dismantled warheads. Some consider HEU to pose a much simpler problem because there is an existing market for uranium fuel. Conversion of surplus HEU into conventional low-enriched uranium (LEU) fuel for use in existing nuclear reactors is technically straightforward. An existing U.S. reactor could use fuel from diluted weapons-grade material just as easily as fuel from conventional sources. On the other hand, it will take decades to convert large quantities of HEU in this manner; during that time the HEU will have to be stored, and will present a continuous risk of proliferation and diversion. In fact, if proliferation resistance were the *only* criterion by which to judge disposition options, one might actually consider options such as glassification of HEU with high-level waste-an option that is being considered seriously only for plutonium.

Plutonium may present a more difficult disposition problem. No civilian power reactors in the United States currently use plutonium for fuel, and although its use is technically feasible, the political and regulatory obstacles may be enormous. In addition, the United States chose to abandon the use of plutonium fuel in commercial reactors nearly two decades ago for political, security, and economic reasons, and it would be difficult to resurrect this effort. Therefore, it is likely that a greater number of possible options will have to be examined for plutonium than for HEU. In any event, considerably more literature is available about the disposition of plutonium than about HEU. The disparity is reflected in this report: the section analyzing plutonium options is considerably longer than that devoted to HEU.

Both plutonium and HEU have extremely long half-lives (24,000 years for plutonium-239 and orders of magnitude longer for the isotopes of uranium in HEU). They will, therefore, need to be contained or isolated for long periods to prevent environmental contamination or possible human intrusion and exposure. Both of these materials pose health risks, as described in chapter 3. Plutonium is especially toxic in minute quantities if inhaled or ingested.[2]

The amount of plutonium and HEU from retired weapons is growing, as is the need to do something with it. This chapter is about ‘disposition”[3] of this material, specifically the spectrum of possibilities about what to do with it beyond weaponry: destroy some portions if technically feasible and practical; dispose of some as waste if technology and national policies permit; or utilize some to produce civilian energy, if security is adequate and if technology and economics prove sound.

A few hundred tons of weapons-grade plutonium and more than a thousand tons of HEU (exact numbers are classified) exist in the world today—as either intact warheads; forms ready to be made into warheads, pits, and other components removed from retired weapons; or residues from the past manufacture of plutonium for weapons (75-77). The United States and Russia have by far the majority of these materials. Both plutonium and uranium are also found in various forms and quantities in the nuclear industry

1 However, HEU is much harder to make than plutonium. Plutonium-239 can be chemically separated from spent reactor fuel. Chemical separation could be done by solvent extraction or ion exchange. HEU production requires more work, equipment, and energy. The desire to build a nuclear bomb maybe more important than the requirement for a certain amount of fissionable material. Most nations that could build nuclear bombs havechosennotto, but rather to establish alternative security arrangements. Thus, it maybe more important to focus on a nation's security concerns than its technological capacity (36).

2 Plutonium-239 does not exist in nature but is extracted from spent uranium fuel that has been irradiated in a nuclear reactor.

3 “Disposition” means any of a number of steps from storage to disposal that may be followed after the nuclear material is removed from warheads.

U.S. DEPARTMENT OF ENERGY

Maintenance employees working in supplied protective oxygen suits tend to plutonium stored at the Rocky Flats Plant.

worldwide and in other industries that use nuclear materials but not in weapons grades. Most notably, large quantities of spent fuel from power reactors contain significant amounts of plutonium (in low concentrations). Taken as a whole, the worldwide tonnage of plutonium in commercial fuel is many times the amount in weapons grade.[4]

In countries other than the United States, some commercial plutonium is extracted routinely from spent fuel and used in commercial nuclear power plants or stored in anticipation of its use as fuel in existing reactors or new advanced reactor designs. In general, such commercial plutonium is kept as the oxide rather than the metal form used in weapons. These countries have been pursuing new generations of advanced plutonium-fueled reactors. Most of the programs in other countries, however, have experienced difficulties, and existing operating capacity is low (3).[5] In the United States, no plutonium reprocessing is done. The importance of these facts for weapons materials disposition is that the commercial needs and uses of plutonium worldwide could affect decisions about the future use of plutonium from dismantled weapons.

Nuclear warhead materials taken from dismantled U.S. weapons include, but are not limited to, plutonium pits placed in containers and stored in bunkers at the Pantex Plant, beryllium and "secondaries' returned from Pantex and housed at the Oak Ridge Y-12 Plant, and HEU also housed at Y-12. These are all considered to be in temporary or interim storage. Long-term or permanent solutions to the disposition of these materials await policy decisions by the President and Congress.

This chapter focuses on plutonium and HEU, although the disposition of many other materials from dismantled warheads is also of concern. Plutonium removed from warheads is generally given the most attention because it is a principal building block of nuclear weapons; it poses a great proliferation risk; and it represents a significant health, safety, and environmental problem. HEU poses similar problems and risks, but it is considered a simpler disposition problem because technology exists to modify and use it in many commercial nuclear reactors.

Preliminary planning efforts directed toward disposition decisions for these materials are under way within the Department of Energy (DOE), the Department of Defense (DOD), and some other agencies. Several task forces have been investigating plutonium and uranium inventory projections, and attempting to estimate what portion of these materials are to be held (stockpiled for possible future weapons) and what portion may be surplus (79). Task forces within these agencies are also investigating certain technical options for disposing of surplus materials. In addition, DOE has been preparing plans for reconfiguration of the Nuclear Weapons Complex and is in the

[4] The different isotopic content of plutonium from commercial spent fuel makes this material more difficult to convert for weapons use.

[5] Countries with advanced, plutonium-fueled reactor programs include Japan (Fugen, Joyo, and Monju reactors), France (Phenix), Britain (PFR reactor), Russia (BN-600), and Kazakhstan (BN-350). With the exception of the Monju, which is scheduled to startup soon, the continued operation of existing plutonium-fueled reactors is uncertain.

process of developing a programmatic Environmental Impact Statement for this reconfiguration that is to include consideration of both interim and long-term storage of plutonium pits from warheads (12). Assumptions about the future mission of a reconfigured Weapons Complex, however, have not yet been publicly presented by the Federal Government.

Several DOE-sponsored studies have focused on long-range options for plutonium disposition. High-tech approaches for "burning" plutonium in advanced reactors have been given attention in recent studies,[6] as has irradiation of plutonium as mixed-oxide (MOX) fuel in reactors that are more closely related to those currently in operation. Other work covers plutonium pit storage for moderate to long-range time frames and investigations of techniques for turning plutonium into a form suitable for disposal as waste. In addition, many experts continue to debate the question of whether plutonium is a valuable asset with beneficial uses or a major liability to be disposed of in the safest and most secure way (6,16,18,26,30).

It seems clear that in the future, the nuclear weapons enterprise must pay attention to materials management and the development of long-range disposition options. Consideration of all approaches to disposition must include a rigorous examination of potential impacts on human health and the environment. Disposition scenarios should include comprehensive plans for procedures and equipment required to protect worker and community health and safety, minimize **waste,** manage the waste produced, and prevent the release of toxic materials. The work is complex and requires both technical excellence and management expertise. The tasks will require many decades, and the consequences will last for centuries. Capable and enduring institutions are needed to ensure success. The following sections address the options for storage and ultimate disposition of plutonium, and approaches for the disposition of highly enriched uranium.

OVERALL DISPOSITION CONCERNS

Even though an official decision has not been made, some portion of the inventory of plutonium pits that will soon be in temporary storage is likely to be deemed excess or surplus (not needed for weapons). Current studies by the Department of Energy and others on disposition options make the assumption that about 50 tons of weapons plutonium could be available in the future for other uses or for disposal.[7]

In the same manner, DOE has not officially declared that any U.S. weapons-grade HEU is surplus to the needs of military programs. However, current plans indicate that between 25 and 100 tons may become available for other uses in the future.[8]

In early 1991 the Department of Energy established a task force on plutonium strategy[9] to plan for future needs and programs to manage plutonium under DOE custody. Since then, however, world events have forced a rethinking of DOE's plutonium strategy. The task force has had

6 The term "burning" refers to irradiation and partial or incomplete fissioning, rather than complete destruction of plutonium. Some concepts envision extensive recycling of plutonium in systems that could eventually result in near-complete destruction of most of the plutonium, but these require considerable research and testing and will generate fission products and other radioactive high-level waste.

7 DOE has recently issued the unclassified statement: "Up to approximately 50 metric tons of plutonium will (or may) become available by about 2005 from Defense Programs (DP) inventories for use in reactors and for other civil (unclassified) purposes. Part of that material will be provided from retired weapons and part from other DP inventories" (56),

8 DOE has recently issued the unclassified statement: ". . . under some planning scenarios substantial quantities of HEU (25 to 100 metric tons) may become available over the next 5 to 10 yea-s and such quantities maybe allocated to civil use" (56).

9 This internal DOE group was organized under the Office of Weapons and Materials Planning within Defense Programs and reports to the Deputy Assistant Secretary for Military Applications. The data used and the materials projections made by the task force are largely classified. None of the work is subject to outside review or public scrutiny. The product of the task force is still in internal draft form and unavailable for public distribution.

to take into account actual weapons retirements and plans for future retirements.

The task force has identified and categorized plutonium in the DOE inventory; it has made inventory projections based on an expanded weapons retirement program. Based on internal interpretations of stockpile plans, the task force has projected plutonium requirements for both future weapons programs and other uses and it has identified some options for future plutonium management. The plutonium material considered by the task force includes pits from dismantled warheads, pits in the process of being reworked for the stockpile, and materials such as metals, oxides, and residues that are left over from past production operations (80).

The task force completed its initial work early in 1993. Besides the plutonium in weapons still in DOD custody, the task force identified five categories of plutonium material, which it defined in terms of intended use or disposition:

1. plutonium in active use in the weapons production program;
2. a strategic reserve of plutonium for future weapons programs;
3. a reserve of plutonium for future, nonweapons programs;
4. a national asset reserve of excess plutonium for unspecified use; and
5. plutonium residues for treatment and disposal.

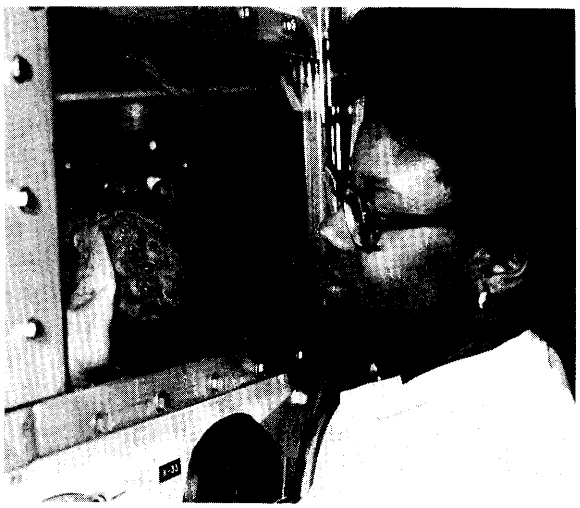
Disposition Approaches

Methods for plutonium disposition present a variety of difficult technical, regulatory, economic, environmental, political, and public policy questions. There is no consensus in the United States today about what to do with plutonium from weapons, and there is some question whether one or more sites can be identified at which the public will accept long-term plutonium storage.

The ultimate disposition of plutonium from dismantled nuclear weapons represents a problem without a ready technical solution. Ideally, options would be judged in light of how well they may accomplish relevant national goals and policies arrived at after public debate. Yet, to date, technical debate among experts about the merits and limitations of alternatives for managing surplus plutonium is taking place before important decisions about national goals and policies have been made by the Federal Government. Therefore, it is difficult to measure proposed options against goals and policies in an informed public debate. In addition, there is a wide diversity of opinion about how soon a decision regarding ultimate plutonium disposition (at least in the United States) needs to be made.

The Office of Technology Assessment (OTA) has gathered certain data and analyses about the plutonium disposition issue, and has held workshops to explore various approaches and their relative merits. The advantages and disadvantages of many options are being investigated by groups within or supported by the Department of Energy and through studies by the National Academy of Sciences. Conclusions and recommendations from these and other technical study efforts will probably be reached during the next year or two. At the same time, it will be important to make progress on defining national goals and developing a process to address the national security, political, environmental, and social impacts of various technologies that could be used.

Decisions in the United States about disposition of plutonium from warheads might also consider the disposition of plutonium residues and other special nuclear materials in various forms that were manufactured for either weapons or commercial use. Also, if certain technologies are pursued, it might be useful to consider whether they could have merit and application in other countries, particularly Russia and other members of the former Soviet Union. Another factor that might be considered is the future of the nuclear power industry. Civilian plutonium that has been separated from spent nuclear fuel in other countries might also be considered when



An inspector is reviewing a plutonium button at the Rocky Flats Plant. This is an example of the current practice employed for protecting workers during processing operations.

planning long-term disposition. Even though U.S. national security goals might be limited to controlling materials from other country's warheads in the short term, various commercial nuclear power activities could have along-term impact on uses and demands for the same or similar materials.

The Russian plutonium situation should be carefully considered. For example, the issue of whether Russia will extract plutonium through reprocessing of spent fuel in the future could be influenced by U.S. decisions to pursue certain technologies for plutonium disposition.[10] Some believe that commitments by Russia and the United States to reduce nuclear arsenals have created an opportunity to reach agreements to stop the production of more plutonium worldwide as part of a general effort to limit the proliferation of nuclear weapons (3,16).

Recent studies that address the issues surrounding plutonium disposition have generally focused on one or more of the following:

- retrievable plutonium *storage,* with or without a change in form, for periods up to 100 years or more (possibly as pits, metal ingots, or oxides);
- *processing* ("burning," "transmutation," "annihilation") of plutonium to destroy some portion or dilute and contaminate it, rendering it more proliferation resistant as spent fuel (this includes use as a fuel in existing or new civilian nuclear power reactors, or in special dedicated government facilities); and
- disposal of plutonium as *waste,* with or without some suitable change in form, with possible addition of high-level waste or specific fission products (e.g., cesium-137).

Each category has variations with unique implications, and the categories are not mutually exclusive. Most will be necessary to a greater or lesser degree at some time in the future. Some storage is required for all categories, but the time frame could vary significantly among them. Minimal processing is probably also necessary if only to maintain stability for long-term storage. The extent of processing could also vary greatly. In the end, some long-term disposal will be needed either for unconverted materials or for residuals and waste. Table 4-1 summarizes the categories covered in this chapter. Figure 4-1 illustrates the various paths that could be followed after dismantlement to dispose of plutonium from warheads.

It is virtually impossible to judge or compare most plutonium disposition technologies as reported in the literature unless one can be sure they are being evaluated using the same original assumptions. Some investigations of plutonium disposition options begin by assuming that the material no longer used for weapons is still a "national asset" and that research should be directed at extracting the greatest benefit from

10 Although the United States has publicly announced that it stopped plutonium production in 1988, some U.S. investigators and Russian officials state that Russia continues to operate plutonium production facilities (16, 47).

Table 4-l-Summary of Selected Plutonium Disposition Approaches

Category	Approaches discussed in OTA **report**	**Comments**
Storage	Existing storage of pits. New long-term storage facility.	Some storage will always be necessary.
Processing	Mixed-oxide fuel reactors. Advanced metal reactor. High-temperature gas-cooled reactors. Accelerator-based converter.	All processing options require development, and their feasibility and applicability depend on the results of such development.
Waste disposal[a]	Deep geologic disposal in containers after vitrification to form glass logs. Sub-seabed disposal. Disposal in space. Underground detonation.	Waste options require some technical development and may be difficult to support without convincing economic arguments.

a Waste disposal will eventually be necessary even if a processing option is chosen because no processing method can totally destroy all residuals of plutonium contamination from waste streams.

SOURCE: Office of Technology Assessment, 1993.

this asset. Such benefits could be either to produce energy or to provide the impetus for a future large-scale nuclear power economy. Other investigations make the assumption that plutonium is a liability and that systems should be sought that would most effectively destroy it or render it unusable.

Regardless of which long-term approach is pursued, storage for some period of time will be required for plutonium from dismantled nuclear warheads. Retrievable, monitored, and secure storage is inevitable while warheads are being disassembled and other long-term options such as processing or disposal as waste are being investigated. The period could last from one to many decades. There is sufficient existing technical knowledge about plutonium storage to have reasonable confidence in performance (technical, economic, safety, and environmental).

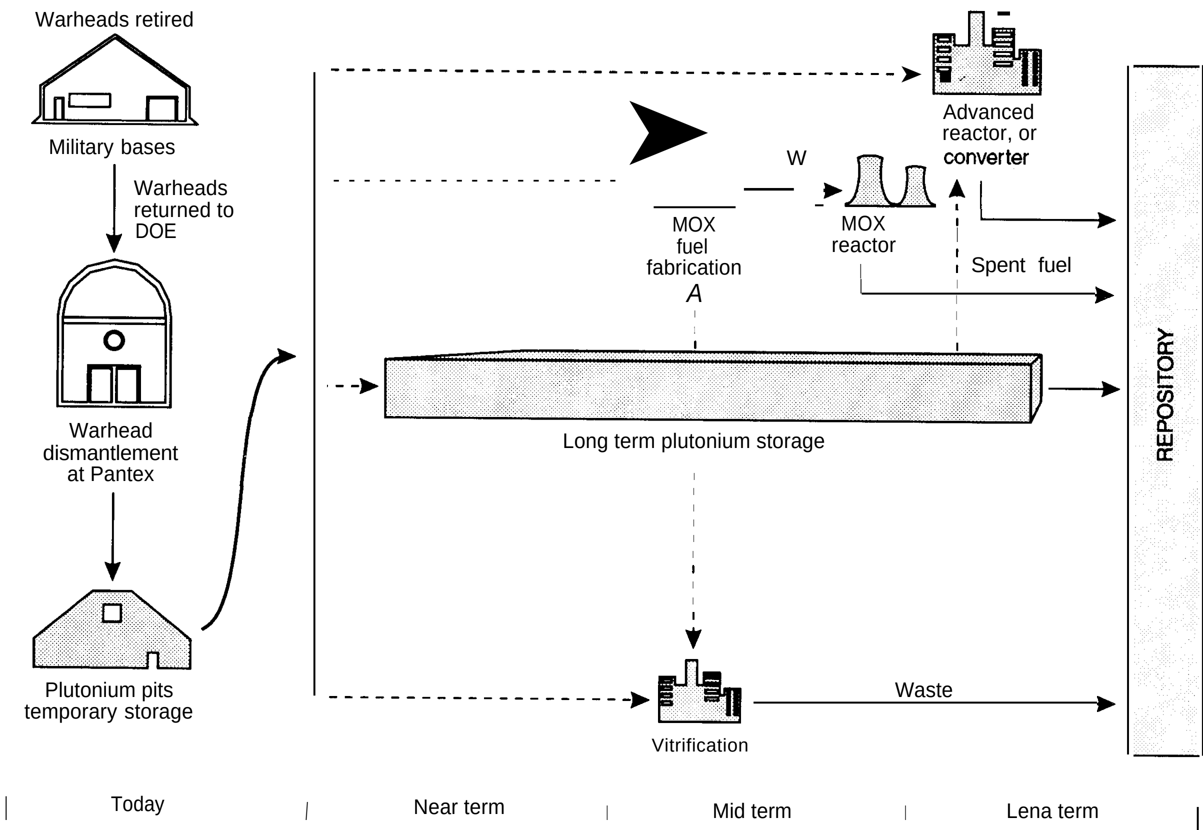
The conversion of plutonium to mixed-oxide (plutonium and uranium) fuel for use in light-water reactors is also considered by most experts to be technically feasible[11] in the near term. The basic technology to develop a facility for vitrification of plutonium, perhaps mixed with other radioactive products, to form a waste is also available.

Other technologies for plutonium disposition require various amounts of research and development. Some preliminary investigations are under way, but resources are limited. It will be very important to follow even these preliminary investigations, however, and understand their conclusions. Such conclusions will always involve compromise (among factors such as cost, time, and uncertainty); thus public debate about national benefits and costs will be important to their acceptability. Any decision about disposition must inevitably take into account the length of time that storage would be acceptable from both technical and security points of view, so that adequate research, development, and testing of other technologies (including environmental impact analyses) can be carried out.

To evaluate plutonium disposition options and select the most appropriate, it will be necessary to establish clear and measurable criteria. The criteria must specify objectives to be achieved and some means of measuring how well they are achieved. The criteria should be given relative

11 This technology has been demonstrated and used in other countries.

Figure 4-l—Warhead Dismantlement and Plutonium Disposition Scenarios



A **dotted line indicates alternative disposition** paths.

SOURCE: **Office of** Technology Assessment, 1993.

weights or listed in priority order. Establishing such criteria will be difficult, but important. To reflect a public consensus about national goals, they must also involve the public in the decision-making process.

Criteria for Judging Disposition Approaches

Individual researchers have developed their own notions about what criteria should be considered and which should be most important. A number of such criteria can be found in studies (3,4,20,23,48) whose principal results are discussed later in this chapter. OTA's analysis indicates that the criteria listed below are among **the** most important. This list is not necessarily complete, but it is a starting point. The items are not necessarily listed in order of priority. These criteria are based primarily on the oft-stated assumption that world peace and security will be enhanced if nations of the world reduce their nuclear weapons stockpile; prevent the materials from being released into the environment; render such materials as harmless as possible for future generations; and prevent proliferation of materials that might be reused for new weapons.

1. Security (including verifiability and proliferation resistance). Each approach must be judged on how well the material is controlled and protected from theft or other diversion. It

is necessary both to protect the material from possible terrorist actions and to prevent certain nations from receiving such material through either overt or covert means (69). If a future international agreement on storage, use, or disposal of plutonium is sought, acceptable means of verifying compliance will have to be established. Thus, an approach must also be judged on how well the amounts and forms of plutonium can be accounted for, measured, and controlled. An option could also be judged on how quickly the material could be converted to a more proliferation-resistant form.

2. Near-term health and safety risks. As discussed throughout this report, each approach must be judged on how well the health and safety of workers and the public are protected throughout the time the material is stored, moved, handled, and processed. Risks of human exposure to plutonium and other toxic materials are of primary importance. Risks of accidents, as well as exposures that may be associated with routine operations, must be considered. It is also important to consider in great detail the many complex steps usually involved in certain plutonium processing options.
3. Environmental and long-term health risks. All approaches must be measured by the degree to which environmental protection can be ensured and future exposures of humans to toxic materials can be prevented over long time frames. Because these materials have very long half-lives, the viability of a geological repository for long-term disposal is a prime consideration if plutonium is to be disposed of as waste.
4. Technical availability and feasibility. Most available work on disposition has included preliminary evaluations of technical feasibility. When options are compared, however, it will be necessary to realistically assess the status of development of some very complex systems; the nature of technical uncertainties associated with each; the possibility of technical failures; and the time needed to justify, fumd, design, build, test, license, and operate a full system.
5. Economics and cost. All options will be expensive, but to compare them it will be necessary to treat all costs on an equivalent and consistent basis. The options must be measured by a comprehensive evaluation of relative costs including the degree of uncertainty associated with each cost estimate. Potential benefits such as the value of electricity produced should be a factor, as should potential costs from accidents or environmental releases. Cost recovery should be measured in a consistent and comprehensive way. Researchers have presented some cost data in various studies to date, but none are of sufficient quality that comparisons among options would be fruitful.
6. Political and public acceptance. The consideration and debate of each option must include adequate involvement of the general public, experts, and various political interests. To satisfy this criterion, it will be necessary to consider public concerns—to understand how an option can be presented to the public, how public opinion will be formed, how public input can be incorporated into decisions, and how the public will measure benefits and costs.
7. International political impacts. Any choices made by the United States regarding the storage and disposition of plutonium and HEU recovered from dismantled nuclear warheads will have an impact on the way other nations approach this issue. Considerations could include the following: Will any option selected assist in ensuring that Russia will permanently destroy surplus weapons plutonium? Will it assist in securing a commitment from Russia to prevent the further separation of plutonium from reactor discharge materials? Will it assist and reinforce the U.S. position to discourage the separation and recycling of commercial plutonium worldwide, and to find an ultimate solution to the disposition of commercial plutonium. Finally, should any international reciprocity be considered for plutonium and HEU disposition options?

I Connections Between Civilian and Military Plutonium

Various analyses place different emphases on individual criteria. Almost all studies to date, however, regard proliferation resistance as a critical factor, and therefore the economic benefits or costs of different plutonium disposition options may not be overriding factors in the selection or elimination of any option (5).

The continuing production of new plutonium is also a factor used by some in evaluating schemes for disposing of existing weapons plutonium. Reports indicate that plutonium production and separation (reprocessing) continue in Russia. The rationale for running these reactors is that they are required to produce energy for the associated towns (67). Russian officials claim that reprocessing is continuing because it would be unsafe to store spent fuel from certain reactors or because it is part of a continuing effort to develop advanced plutonium-fueled reactors (16). Commercial plutonium reprocessing is also expanding (or planned to expand) in other countries (3). Although the United States has adopted a policy of not reprocessing any commercial fuel to recover plutonium, some other countries have pursued a nuclear policy that calls for reprocessing spent nuclear fuel to separate and recycle plutonium in reactors.

Worldwide, the civilian nuclear industry has already separated more than 100 tons of plutonium from spent fuel (67). Some of this has been "recycled" in various types of reactors, but the remainder is in storage. Most of the civilian international industry for plutonium separation is in Britain and France, but Russia has facilities and Japan is constructing some. These countries plan to separate another 200 tons over the next decade (67). The additional 200 tons to be separated is covered by contracts with reprocessing plants in Great Britain and France (3). Plans also call for this plutonium to be returned to the originating countries and thus entail a significant expansion in the handling, transportation, and circulation of plutonium, which will add to global proliferation, safety, and environmental risks (3).

Large amounts of separated civilian plutonium could be a factor in decisions about technologies that might be developed to convert plutonium from warheads. Since substantially more plutonium is available in spent fuel from civilian power reactors than is likely to become available from warhead dismantlement, some argue that it would be logical to consider the problem of weapons and civilian plutonium together, rather than separately (45). Others argue that the storage and production of separated civilian plutonium should be controlled in a manner similar to military material (16).

The control and management of plutonium from both weapons and civilian power reactors could be based on the same nonproliferation concerns (3). Some researchers believe that initially both must be stored under international safeguards and that there should be a verified ban on separation of any new commercial plutonium. Researchers also argue that the principal reason for current reprocessing and recycling activities in Western Europe and Japan is institutional inertia rather than economic benefit, and that this increased plutonium activity is unjustifiable on security, economic, or environmental grounds (3).

On the other hand, although recognizing that the large amount of civilian plutonium represents a serious proliferation problem, some think that there are both political and technical reasons for proceeding expeditiously with a permanent solution to the disposition of surplus military plutonium even if a solution to the civilian plutonium issue is not currently available. Weapons-grade plutonium comes in the best form for warhead construction. It is also in a form that can be modified more readily for certain disposition options such as conversion to oxide and glassilication with high-level waste. Finally, timely actions by the United States to permanently dispose of surplus weapons plutonium may strengthen its ability to influence Russian disposition actions, and will emphasize the U.S. position regarding the disposition of commercial plutonium and its world leadership role in nonproliferation (24,30).

PLUTONIUM STORAGE

OTA's analysis indicates that storage of most of the plutonium from weapons for a few decades at least is the most likely outcome of the plans and programs now under way in the United States. Other options for disposition will require considerable research, development, and testing before they can be implemented, and they must surmount significant technical and political hurdles to meet other criteria. In addition, the Federal agencies involved in making disposition decisions are generally reluctant to dispose of plutonium permanently because of the enormous cost and effort expended to create this material.

It is important to treat storage with great care and concern. Safe, secure storage requires attention to design requirements and to all factors that can affect protection of human health and the environment. It should be remembered that past inadequate practices in managing radioactive waste from weapons production have led to the vast environmental problems now existing in the Nuclear Weapons Complex (65). No one wishes to repeat those mistakes, but avoiding them will require that difficult decisions be made about providing adequate storage facilities and the best protection possible under future storage conditions.

It is important to begin soon to prepare plans for mid- to long-term storage of plutonium from dismantled weapons.[12] DOE is exploring storage options through its work on reconfiguration of the Weapons Complex and its plutonium task forces, but these efforts are not well coordinated. Among the factors to be considered initially are the size of a facility (number of pits or other forms to be stored); whether other plutonium forms and residues should be accommodated as well (there are now substantial quantities of plutonium in various forms throughout the Weapons Complex); the estimated life of a storage facility; and any additional capability required, such as the ability to handle and maintain some pits or classes of pits that need attention over time.

Current Efforts

DOE has the responsibility to evaluate all relevant issues pertinent to plutonium storage. Plutonium pits from dismantled warheads are currently considered by DOE to be in interim storage (6 to 10 years)[13] at Pantex. Because the capacity of the Pantex bunkers is restricted, DOE has prepared analyses of the safety and feasibility of expanding that capacity to a maximum of 20,000 pits. An Environmental Assessment (EA) has been prepared that incorporates the results of these analyses. In the EA, DOE discusses the potential of other Nuclear Weapons Complex sites as interim storage facilities (see table 4-2). Some of these alternatives maybe considered in connection with siting a long-term plutonium storage facility in a reconfigured Nuclear Weapons Complex.

The conclusion from DOE's initial efforts is that storage of plutonium pits at Rocky Flats or Hanford is neither reasonable nor cost-effective because current plans call for environmental restoration and no further use of these sites for any production purpose. Another alternative evaluated is to move the pits to one of the Weapons Complex sites not planned for closing, such as Savannah River. However, efforts to expand the

12 Any major new Federal facility t. be built will require a long time (more than a decade with current DOE procedures) from initial plans and concepts to actual completion and frost use (43). Some experts claim that an adequate storage-only facility similar to Pantex could be built in a much shorter time and at a cost of less than $100 million (58), but none of these estimates has been well developed or documented.

13 Many believe that DOE will not be able to provide a site and facility to replace the Pantex bunkers within 6 to 10 years. See appendix A for a discussion of the current proposal to expand plutonium pit storage capacity at Pantex and the reaction to tbis proposal by the local community, the State of Texas, and other citizen groups.

Table 4-2—Alternatives Considered by DOE for Interim Plutonium Pit Storage

Possible storage site	Storage capacity available for plutonium pits	Storage capacity available for other plutonium forms	Issues relevant to this activity
Pantex Plant (Texas) Single-layer configuration	Standard single-layer configuration is capable of providing interim storage for only 6,800.	Storage of other plutonium forms has not occurred and is not planned at the present time.	The concrete storage bunkers were built during World War II to protect conventional weapons and munitions from bomb blasts. Although some pits are already stored in these igloos, DOE is evaluating the potential impacts of extending this storage.
Multiple pit stacking	If approved, the proposed multiple pit stacking configuration will provide interim storage for up to 20,000 plutonium pits from disassembled weapons.	None	Environmental and safety documentation is being prepared and reviewed.
Hanford Site (Washington)	Facilities at this site are capable of providing storage capacity for more than 10,000 plutonium pits.	Existing facilities might enable the storage of nearly 20 tons of plutonium in forms other than pits.	Requests for funds to upgrade facilities for plutonium storage would appear to be in conflict with DOE's change in policy from defense missions to those of environmental restoration and waste management.
Los Alamos National Laboratory (New Mexico)	Existing facilities have limited capacity for storing plutonium pits. One facility currently under construction could provide storage for about 200 plutonium pits; however, larger capacities could be developed.	Storage for other plutonium forms is available but largely limited to certain forms such as plutonium oxide.	Cost of modifying facilities under construction or upgrading existing facilities is high.

Table 4-2—Alternatives Considered by DOE for Interim Plutonium Pit Storage (Cont.)

Possible storage site	Storage capacity available for plutonium pits	Storage capacity available for other plutonium forms	Issues relevant to this activity
Rocky Flats Plant (Colorado)	The capacity currently available for near- and long-term secure storage of plutonium pits is limited.	The space available for providing environmentally safe and secure storage is sufficient merely to accommodate the plutonium scrap, residues, and waste generated by the plant's past plutonium processing and current cleanup activities.	Storage of additional pits or other plutonium forms is a remote possibility because of the extensive costs and difficulty associated with facility and equipment upgrades. Addressing relevant environmental and safety problems would also be difficult.
Savannah River Site (South Carolina)	Use of existing facilities could provide storage space for up to 1,100 plutonium pits from nuclear weapons disassembled at Pantex.	Storing plutonium in forms other than pits is possible because current activities involve the storage of plutonium oxide and plutonium-rich residues originating at the site.	Without modifications to some facilities, storage capacity for plutonium pits may be further reduced by future shipment of plutonium materials and residues from other DOE sites.
Military bases	Although viewed by DOE as facilities with little potential for near-term plutonium pit storage, the possibility of using certain bases for long-term storage seems promising to DOE. The estimated capacity for pit storage has not been determined.	The possibility of using military bases to store other forms of plutonium has not been suggested or evaluated to date.	Many experts believe that most military facilities were designed for weapons storage only and are unsuitable for plutonium pits. Factors to be evaluated include institutional arrangements and costs associated with inspection, security, and surveillance requirements.

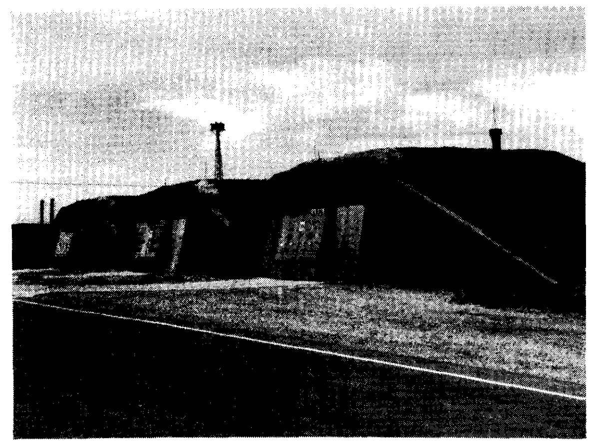
SOURCE: U.S. Department of Energy.

storage of plutonium pits at Pantex will also have to be continued since, according to DOE, alternatives such as the Savannah River Site would not independently provide the necessary capacity soon enough (73).

DOE also considered certain military bases as potential candidates for interim storage of plutonium pits. No detailed evaluation of converting facilities from weapons storage to pit storage was done, and the military services indicate that they do not have excess capacity at any of the candidate bases (73). Higher costs and additional logistical considerations could make storage at military bases difficult to implement[14] (34).

DOE is currently evaluating approaches that could lead to replacement of the current oversized Nuclear Weapons Complex by a new one in the year 2000 and beyond; this future complex is commonly referred to as Complex 21. The Los Alamos National Laboratory is preparing plutonium storage design guidance to be used in the design of a plutonium storage facility for Complex 21. In addition, private contractors are providing technical support for a conceptual design. and cost estimate for each alternative under consideration (72). DOE is using three major assumptions in regard to a plutonium storage facility:

1. It must be a modular design with remote handling capability to reduce worker radiation exposure;
2. It must consist of storage vaults and welded centainment vessels that minimize risk of intrusion; and
3. It must provide adequate capacity for safe, secure, long-term storage for projected amounts of plutonium pits, metals, oxides, and other stable forms (42).



Plutonium pits from dismantled warheads are temporarily stored at the Pantex Plant in bunkers like the ones shown here.

Other characteristics expected in the final design are that it must be self-contained, although it could share other support facilities located at the site, and it would be constructed at grade level rather than underground. The central advantage of adopting a modular approach is that modules can be added as required, thus eliminating potential capacity limitations for the plutonium form in question (12).

DOE is evaluating the storage of plutonium and highly enriched uranium at separate sites, along with the possibility of a single facility capable of storing both. The results of engineering and cost evaluations are expected to be published in early FY 1994 (9). The effect that the size of weapons stockpiles may have on future plutonium storage needs is also part of this continuing evaluation.

The storage facility design concept under consideration by DOE includes a Class I vault

14 Several researchers have also pointed to the Manzano Mountain facility at Kirkland Air Force Base as a possible alternative for plutonium pit storage. Pits were customarily stored at this facility, especially during the 1940s and 1950s when Manzano Mountain was considered the P-assembly area for nuclear weapons in the United States. Weapons assembly and plutonium pit storage are no longer conducted here. Before Manzano Mountain could be considered adequate for storing plutonium pits, however, several important issues (and their cost and time implications) need to be addressed: 1) the analyses and design modifications required to meet modem environmental and safety standards for plutonium pits; 2) the capacity available for pits; 3) programs to protect the health of workers; 4) programs to monitor and control radiation; and 5) maintenance associated with storage and security operations (50).

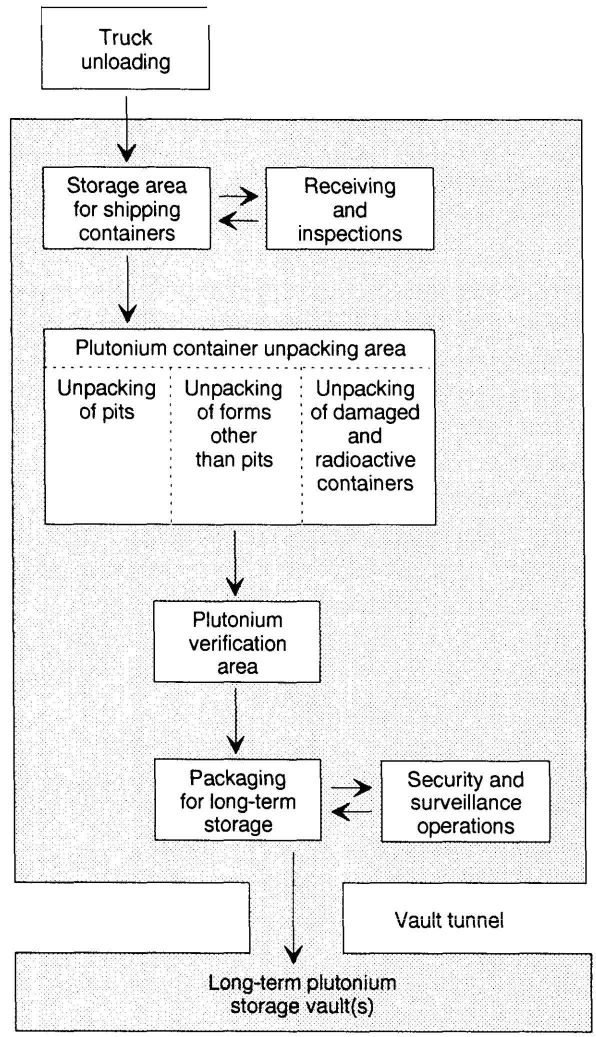
storage system to meet upgraded security and safety standards that are not found in current facilities such as the Pantex bunkers. One example of existing Class I facilities in the Nuclear Weapons Complex is the storage vaults recently built at the Savannah River Site.

Modifications to an early proposed design indicate that the final structural design for a long-term plutonium storage facility is still evolving. For instance, early designs assumed a 50-year life to address DOE's plutonium storage problem. This was found inadequate by some DOE reviewers, and a new structural design for a 100-year facility is now being proposed-with plans for replacing computer hardware and other special equipment every 25 years (34). Figure 4-2 illustrates the current design features being considered for this storage concept.

The recent reduction in the nuclear weapons stockpile, the closing of key processing facilities, and the downsizing of the Weapons Complex have also significantly changed DOE's approach to long-term plutonium storage. DOE is preparing a Programmatic Environmental Impact Statement (PEIS) for the Weapons Complex reconfiguration. One of the objectives of this study is to evaluate engineering and environmental approaches to replace the current Weapons Complex with one that is simpler, more environmentally safe, and less expensive to operate. The PEIS will also evaluate strategies for long-term plutonium storage.

As part of its efforts to reconfigure the Nuclear Weapons Complex, DOE created a Complex Reconfiguration Committee in 1991, with senior representatives from DOE, DOD, and the National Security Council. The committee considered such aspects as future stockpile needs, long-term production and maintenance requirements, environmental needs, and options for existing or new facilities (71). DOE had planned to issue the PEIS in August 1993, but changes in the weapons stockpile resulting from recently signed arms reductions agreements have led to revisions of their schedule (4,9,46). In July 1993 DOE issued a revised notice of intent to prepare a PEIS that explained the new conditions that caused this revision and provided a new list of options to be considered.[15] DOE stated that since February 1991 when DOE originally announced its intent to prepare a PEIS for reconfiguring the

Figure 4-2-Conceptual Design of a DOE Plutonium Storage Facility



SOURCE: U.S. Department of Energy.

15 *Federal* Register, vol. 58, No. 140, July 23, 1993, pp. 39528-39535.

Weapons Complex, conditions have changed in such a way that impact the requirements for the new complex. DOE's proposed changes in the PEIS reflect that the future nuclear weapons complex can be even smaller than originally envisioned, and also reflect the increased importance associated with stewardship of existing nuclear materials.

One major change in scope is that DOE considers it unreasonable to have plutonium component fabrication at a different site than storage facilities. Therefore, DOE proposes that all alternatives under consideration will have storage, processing, analysis, and fabrication operations co-located. For the function of nuclear materials storage, processing, and component fabrication, DOE now proposes three alternatives—constructing new facilities, me-g existing facilities, and no action. If new facilities are constructed, five alternative sites will be evaluated-Idaho National Engineering Laboratory, Savannah River Site, Oak Ridge Reservation, Pantex, and the Nevada Test Site.

Public scoping meetings on the revised PEIS will begin in the fall of 1993, and a plan and schedule will be announced later. If a decision is reached to build a long-term plutonium storage facility, some estimate that constructing such a facility will require at least 10 years (42). It now takes DOE more than a decade to obtain funds and build new budgeted projects, even if the technology is tested and proven (43).

Designing for plutonium storage beyond a few years is a relatively new concept within the Weapons Complex. For many years, plutonium pits recovered from warheads were stored only briefly at Pantex and then shipped to Rocky Flats where they were processed for recycling into new weapons. Scrap plutonium metal and other residues were stored at generating sites with the intention of recovering the plutonium when production ceased or when more effective recovery technologies become available. The current very costly and complex challenge to dispose of plutonium residues from past operations at the Rocky Flats Plant (see box 4-A) illustrates how past practices without attention to environmental protection have created massive waste management problems with no adequate, feasible, or practical solution. Future planners and designers should heed this lesson carefully.

Design Considerations for a Plutonium Storage Facility

OTA's analysis indicates that certain considerations will affect the design parameters for a plutonium storage facility. Box 4-B lists the types of technical and related analyses that would be required as part of any facility design. Additional considerations will also be important in designing a plutonium storage facility.

For example, it will be important to identify a time period within which pits can be stored safely without further processing. If intact pits are to ''sit on the shelf' for a defined period of time, the pit casing and sealed storage drum could obviate the need for immediate processing. However, once the design life of the container or casing is reached, adequate processing capability will have to be provided *(51).* There is also a need to assess the chemical and physical stability of the plutonium materials to be stored (e.g., pits, metals, oxides, glass, ceramics), and to define the sizes and concentrations of materials selected for storage so as to determine the space required for centainment and criticality control. Although it may be appropriate to store plutonium as pits for a defined temporary period, further study is required to determine any limiting factors for long-term pit storage.

Another design consideration is the need to evaluate opportunities for the use of remote handling technologies (e.g., robotics) in storage and maintenance areas (51). The selected containment system (e.g., drums, vessels, vaults) should be designed in a way that facilitates inventorying stored materials with minimum radiation exposure of workers. There is also a need to protect workers against plutonium particle exposure.

Box 4-A—Past Experience with Plutonium Processing at the Rocky Flats Plant

For nearly 40 years, the fabrication of weapons parts from plutonium metal took place at the Rocky Flats Plant (RFP) in Colorado. The limited efficiency and complex nature of the processes employed resulted in the generation of a large inventory of plutonium-contaminated scrap materials and residues ranging from processed plutonium materials that failed to meet weapons design specification, to scraps from shaping and machining, to contaminated items used during processing, to residues and waste. The high costs of plutonium production and the potential for future economic recoverability have, in the past, motivated DOE to store both scrap materials with high plutonium content and residues having lower plutonium levels. To date, plutonium can be found in more than 100 different types of residue at Rocky Flats. Other DOE sites where plutonium scrap and residues are found are Los Alamos National Laboratory, the Savannah River Site, and Hanford.

The handling of plutonium residues at Rocky Flats has traditionally been under the authority of DOE's Office of Defense Programs (DP). On January 15, 1993, however, a Memorandum of Agreement was signed between DP and the Environmental Restoration and Waste Management (EM) Program to share the responsibility for managing plutonium residues.

Under this agreement, DP continues to be responsible for managing RFP's plutonium-rich residues. Materials in this category include plutonium weapons parts, metal buttons, scrub alloy, and plutonium oxides. Limited processing is usually needed for these residues to meet transportation and long-term storage requirements. The plutonium present in these materials may be recoverable with existing processes or with technologies expected to be developed in the future.

With the signing of the January 15 agreement, EM is now responsible for the processing, storage, and safe disposition of more than 90 percent of the volume of plutonium residues at Rocky Flats. The average plutonium content is 2.6 percent by weight. In total, EM will manage nearly 7,300 containers of varying shapes and volumes containing from 6,000 to 7,000 pounds of plutonium. The presence of regulated hazardous constituents in the majority of these materials requires that their treatment and disposal be conducted according to the Resource Conservation and Recovery Act. The chemical instability associated with the majority of these materials makes their shipment to off-site storage or disposal sites without treatment or processing highly unlikely.

As part of a Programmatic Environmental Impact Statement for the reconfiguration of the Weapons Complex, Defense Programs is developing a long-term strategy of future needs, uses, and possible storage locations for plutonium. It is also reviewing several facility and technology designs and costs to provide storage for stable plutonium residues. EM is addressing problems associated with the low-concentration plutonium residues and evaluating technologies for stabilization, treatment, and storage.

SOURCES: General Accounting Office and U.S. Department of Energy.

During storage, plutonium metal (as found in pits) may oxidize and form particles small enough to be respired by humans. Even though the risk to workers of plutonium exposure during storage is low, accidents that could disperse fine particles are always a concern. In addition, if plutonium is processed (e.g., converted to oxide) or if pits are converted to small pieces, there is a risk of dispersion in forms susceptible to inhalation or ingestion. Plutonium, which emits alpha radiation, is dangerous when inhaled or ingested (see chapter 3). Also, over time, weapons-grade plutonium will form americium-241, which emits penetrating gamma radiation.[16] Since all military plutonium contains various amounts of americium, it must be handled with appropriate shielding precautions (18).

16 Weapons-grade plutonium contains mostly plutonium-239 and smaller amounts of plutonium-241, which naturally decays over time to americium-241 whose half-life is 13.2 years.

Box 443-Types of Analyses Required In Designing a New Long-Term Plutonium Storage Facility

- Safety Analysis Reports that address:
  General description of principal design criteria
  Nominal **capacity considered for the facility,**
  Type, form, quantities, and origins of the plutonium materials,
  Waste products generated during operations, and
  Materials handling and storage procedures, including control of decay heat, criticality safety, contamination control, and criteria for handling damaged containers.
- General operating procedures for **packaging, storage, and transportation.**
- **Design criteria for ventilation, filtration, and off-gas systems.**
- **Criteria for protection of equipment and selection of instrumentation.**
- **Radiation protection and control measures.**
- **Fire and explosion protection systems.**
- **Requirements for containers, container repair, and maintenance.**
- **Procedures to be used for monitoring.**
- **Classification of structures,** components, and systems.
- Criticality prevention and criticality factor analyses.
- Maximum radiation dose rates emitted by containment systems.
- Procedures for decontamination of personnel and equipment.
- Accident potential for normal and abnormal operations.
- Design criteria and general operating procedures relevant to security, verificatian inspection, and monitoring.
- Organizational structure, including functions, responsibilities, and authorities.

SOURCE: Office of Technology Assessment, 1993.

There are also broader policy issues to be considered. These include the need to evaluate security factors associated with storing plutonium at a consolidated facility as opposed to two or more locations. Preliminary analyses appear to suggest that placing plutonium in a centralized location may be more cost-effective. Each location will require significant security measures, including redundant barriers to slow down individuals who attempt to take possession of the stored materials (41). There are some advantages, however, to building two facilities, such as making international or bilateral verification easier.

It is important to consider whether a U.S. plutonium storage facility might become subject to international safeguards for verification some-time in the future. Some experts maintain that in order to minimize security, accountability, and proliferation problems, plutonium storage would best be carried out in collaboration with other nations that possess nuclear weapons (33). National security considerations also raise the question of whether verification by foreign governments or by any international organization, such as the International Atomic Energy Agency (IAEA), could be allowed in the future as the result of amendments to arms reduction treaties. Pending the development of an international plutonium and radioactive waste disposal strategy, some have suggested that the best interim solution is monitored, secure storage of surplus plutonium under bilateral safeguards *(25,53).* Although weapons plutonium could initially be placed under safeguards through bilateral agreements, some believe that in the long term, an international control entity such as the IAEA might better reflect a global interest in keeping these materials from weapons use *(3).*

In any event, some experts suggest that the facility design should enable verification inspections (46) and should accommodate possible modification of plutonium materials to meet verification requirements. These considerations would have an effect on the design, optimum number, and location of storage facilities.

Optional Form of Plutonium Storage

The ideal form in which to store plutonium depends on the goals set for storage. Different goals-such as greatest accessibility for possible weapons use in the future, highest proliferation resistance, or minimal impact on the environment and workers—may dictate different storage forms. Stability is also an issue. Some argue that plutonium metal is less desirable for storage than the more stable oxide form because fine metal pieces can ignite spontaneously if exposed to air. In addition, some claim that storage as plutonium oxide has proliferation resistance advantages compared with storage as metal (3), whereas others say that such advantages are minor (19).[17] However, the technology needed to convert plutonium oxide into its metallic form is easily accessible *(39).* Another point is that oxide powder may pose a greater health risk because it is more respirable.

If consideration is given to international verification and inspection of a storage facility, it would be necessary to protect weapons design information from disclosure. In this case, some changes to the pits that would modify their shape or convert them to small pieces may be desirable prior to storage. This process is commonly known as ‘‘sanitizing’ the component. Another approach, to minimize the risk of disclosure of sensitive design information, would be application of verification measures only to sealed containers holding the sensitive materials, etc. (55). Passive nondestructive neutron and gamma-ray spectral assay procedures are sufficient for the verification of plutonium, and a combination of active neutron interrogation methods and passive gamma-ray spectral analysis could be used for HEU (55).

DOE has stated that the new Special Recovery Facility at the Savannah River Site is an existing facility with the potential to process plutonium pits into plutonium oxide. Originally constructed to transform high-grade plutonium oxide into metal buttons for use at Roe@ Flats in making plutonium pits for nuclear warheads, the new Special Recovery Facility was never operated. Savannah River officials consider that reversing the intended function of the unused plant—processing pits into oxide rather than vice versa—may involve only minor design modifications. One additional function this facility could serve is to remove americium and other hazardous radioactive decay products from stored plutonium materials (34). DOE claims that the processing of plutonium pits into plutonium buttons is currently possible at the facility. One problem with the facility, however, is that it was not built to meet current environmental and safety standards, and if completely shut down, it would be very difficult to reopen under modern requirements (34).

On the other hand, storing plutonium pits in their original form may have some advantages in terms of ease of verification because each pit already represents a discrete unit and has a serial number (28). The cladding of plutonium pits was designed to have a 20-year lifetime but could probably last much longer (28).

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[17] Some researchers have suggested that pits could be made unusable in warheads by simple means such as crushing Or filling them with boron and epoxy. These approaches might deter a terrorist group but not a nation with weapons manufacturing capability, and are suggested mainly for nations other than the United States in which good security technology may not be in place.

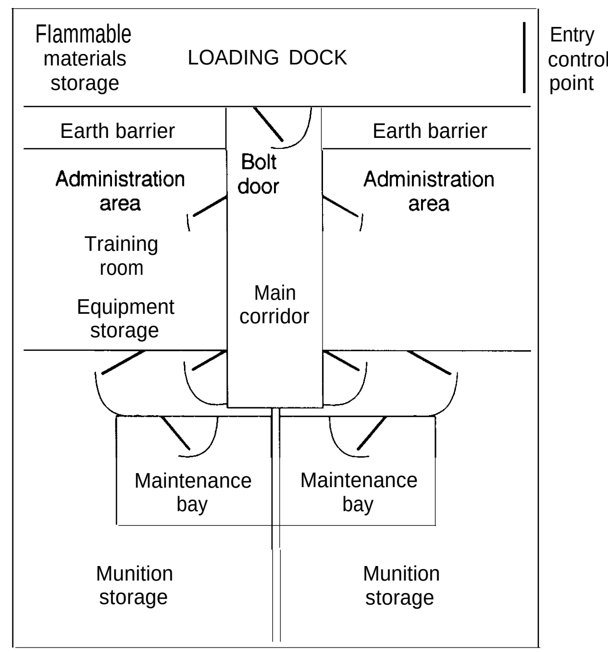
Plutonium Pit Maintenance During Storage

If plutonium is to be stored in pit form, it will be necessary to have the capability to inspect, modify, repair, or otherwise process any pits or materials that exhibit problems. Los Alamos National Laboratory and Lawrence Livermore National Laboratory already have some capability for pit handling and processing, which is used in connection with current Pantex operations. DOE has stated that it would locate a processing facility at the same site at which anew plutonium storage facility is built (12). Options based on storing plutonium in a form other than pits (such as plutonium oxide) would also require a plutonium processing capability. Either current facilities for processing could be upgraded or new areas could be developed. It should be noted, however, that most of the facilities processing plutonium in the past were built in the 1940s and early 1950s. They are obsolete and potentially dangerous, and have been closed because of safety and environmental concerns. Lessons learned from these past operations will be valuable to developers of any new facility. In addition, these facilities often used processes and technologies that were inefficient and costly, and created large amounts of waste (40).

The Kirtland Underground Munitions Complex

There are very few good examples of high-security weapons storage facilities built recently in the United States that might be used as an example of how a plutonium storage facility might be constructed. One such facility-the Kirtland Underground Munitions Storage Complex (KUMSC) at Kirtland Air Force Base in Albuquerque-was constructed in the late 1980s according to modern standards of safety and security at an Air Force munitions complex. Although not necessarily the ideal facility for storing weapons-grade plutonium, it illustrates how modern design standards and principles might be applied to a future storage facility.

Figure 4-3-Major Design Features of Underground Munition Storage Facility at Kirtland Air Force Base



SOURCE: U.S. Department of Defense.

KUMSC consists of an Underground Munitions Storage Facility, a Squadron Operations Building, and a Utility Building covering an area of approximately 7 acres (see figure 4-3). The Underground Munitions Storage Facility comprises eight areas specially designed to sustain accidental detonation of certain high explosives and to contain detonation products. In the event of an explosion, the particular area affected is automatically isolated by the closing of blast doors; after the explosion, pressurized gases are filtered out of the explosion area and the filtered air is released to the environment. Each storage vault at the facility contains multiple storage cells with approximate dimensions of 25 feet by 100 feet. Individual cells are bounded by doors and concrete walls able to withstand accidental explosions.

Several design features have been incorporated into the Underground Munitions Storage Facility to reduce accident and security risks. Examples include: 1) limiting the use of combustible materials during construction and operation; 2) confining the number of blast doors that can remain open at any given time to one, thus exposing only two containment areas to the risk of explosion; 3) providing fire protection systems and equipment; 4) demarcating boundary lines on floor areas near walls and doors to limit the quantities of munitions that can be stored; and 5) providing only one personnel entrance/exit to the facility (gravel-filled escape tunnels secured with heavy steel plates are provided to exit the facility if the main entrance is blocked) (70). Extensive security systems protect against unwanted entry and other threats to the integrity and control of the facility.

PLUTONIUM PROCESSING

A number of studies over the past few years have looked at various processing techniques that might be applied for disposition of significant quantities of plutonium from retired and dismantled nuclear warheads (see box 4-C). In practice, it is impossible to convert surplus weapons plutonium into a substance that is essentially nonradioactive or harmless to human health and the environment. It is also difficult to transform plutonium into a material that cannot be reformed into weapons material at a later date. No existing process is available that can completely eliminate surplus plutonium, and developing new processes will require substantial research efforts and resources. However, some technologies are available in the near term to create forms that would be less usable for weapons or to eliminate some portion of the plutonium.

The language used in discussions of plutonium processing options can be difficult to interpret. Some use the term "plutonium burning" to describe the use of plutonium as reactor fuel so that plutonium levels in spent fuel are reduced over time. The same options are sometimes called ''transmutation" or 'actinide burning" to reflect the fact that a significant portion of the plutonium (or various transuranic species) is changed by nuclear reaction into other, shorter-lived isotopes. In more recent studies on the use of accelerators to destroy actinides, the term plutonium 'annihilation" is used to depict approaches that reduce the plutonium to negligible amounts after the process is completed. Many proposals address plutonium disposition through processing. Although several current ideas have merit, it is too early in the development of most of them to compare their specific advantages and disadvantages accurately. In addition, many of the new approaches to the disposal of plutonium have been developed with different objectives (e.g., whereas one approach may be best at reducing the risk of environmental and human health impacts, another may be better for reducing the risk of proliferation, and yet another for extracting economic value from the plutonium). The tradeoffs among different approaches cannot be analyzed reliably until more research has been completed.

The more advanced technological approaches have significant uncertainties about when they might be available for full-scale development (30), how effective they might be, the development effort involved, what other impacts might result, what nontechnical barriers may arise, and what benefits they might offer (18). The costs to implement most of these technologies are not well known at present (30). Plutonium burning as U.S. mixed-oxide fue1[18] in conventional light-water reactors (LWRs), abandoned in the United States in the 1970s, is probably the best cost option (18,59). Costs of some of the fission options have been estimated by their proponents, although a detailed comparison of costs and assumptions has not been made (30).

Therefore, the following discussion of plutonium processing should be interpreted as a very early indication of how to approach the question

18 MOX is made by mixing the oxides of plutonium and **uranium,** and forming the product into conventional reactor fuel assemblies,

Box 4-C-Plutonium Processing

Plutonium processing is used in this report to define a myriad of manufacturing steps that maybe employed to change the form, configuration, content, and chemical or radiological state of the material. The purpose of these changes could be to make plutonium usable as reactor fuel, to make it more stable for storage, to prepare it for disposal, or to alter its radiological state so as to eliminate long-lived radionuclides. The steps may include chemical, thermal, mechanical, and radiological (neutronic) processes. One near-term proposal for processing Involves making mixed-oxide (plutonium and uranium) fuel and then using it in a nuclear reactor. Although this technology is available in some other countries, no facilities for carrying out these processes exist in the United States.

Many steps are required to make mixed-oxide (MOX) reactor fuel from plutonium pits. First, the plutonium metal must be removed from other associated materials--by chemical or mechanical techniques-then the metal can be purified, probably by a chemical solution process. Next, pure plutonium would be converted to plutonium oxide by calcination and finely pulverized to improve its reactivity. The plutonium oxide would t hen be blended wit h depleted uranium oxide or natural uranium. The uranium oxide would have been derived from enrichment plant residue by using a chemical step to convert uranium hexafluoride to uranium oxide and then finely pulverizing it. The mixture of uranium and plutonium oxides would be pelletized, sintered, and loaded into fuel tubes to be used in a reactor as MOX fuel. Each step in this process must be carefully controlled to prevent releases, protect workers, and ensure safety. Each step also produces some waste or scrap. Some of the waste maybe recycled, and some would be treated as transuranic waste because of its reduced plutonium content. Some waste maybe mixed with hazardous and toxic chemicals or other materials.

The waste generated by MOX fuel fabrication could contain about 1 percent of the plutonium input and 5 percent of the uranium input to the process, but the quantity of waste product would be significantly higher because it would be mixed with *other* materials, much of it hazardous waste itself, The experience with plutonium processing at the DOE Rocky flats Plant is a case in point, in which huge quantities of residue and waste still exist without a good disposal solution. Whatever waste is produced will require appropriate systems for storage, treatment, and disposal as well.

It should also be noted that after MOX fuel is made, the remainder of the fuel cycle, mainly within a nuclear power reactor system, also produces waste that must be properly controlled and handled. Finally, the disposal of spent fuel after irradiation in the reactor presents another waste disposal problem. As discussed elsewhere, all spent fuel from standard U.S. nuclear reactors is stored temporality at reactor *sites* awaiting an acceptable solution to its ultimate disposal. Spent MOX fuel would be subject to similar constraints.

The above is an example of just one plutonium processing option with its related waste generation and disposal issues. This report discusses many other processing approaches--making plutonium oxide forms to enhance storability; mixing plutonium with other wastes and vitrifying the mixture to enhance disposability; or transforming plutonium radioactively in advanced reactors or accelerators to change a large percentage of it into other, shorter-lived radionuclides. These processes would also include the generation of wastes and thus must be properly managed to protect human health and the environment.

SOURCE: Office of Technology Assessment, 1993.

of ultimate disposition of this material. Whatever path is pursued, it will be necessary to carefully investigate technical feasibility, impacts on health and the environment, ability to meet ultimate disposition goals, and possible economic benefits (18). Although varying amounts of technical information are already available for some options, such as vitrification or use as MOX fuel, these options generally have not been evaluated and compared on their merits *specifically* as options for processing surplus military plutonium in the United States (59). No best approach can be selected today with confidence. After some initial evaluation, however, a few approaches could be researched and their merits identified. If clear policy goals have been adopted, then the most technologically developed approaches could be compared more readily and an optimum one selected.

Use of Plutonium as Mixed-Oxide Fuel in Light-Water Reactors

Various options that call for plutonium to be used as a fuel in nuclear reactors have been proposed. These options are based on incremental changes in currently available, working technology. One option would involve incorporating plutonium in mixed-oxide fuel to substitute for some of the conventional low-enriched uranium fuel used in commercial LWRs. Proponents point to the electricity generation potential of this disposal option as uneconomic advantage, whereas opponents claim that MOX fuel cannot compete with ordinary LEU fuel economically (16). Another option would use the plutonium incorporated into MOX fuel in dedicated reactors that could be built on a Federal site, primarily to convert plutonium into more proliferation-resistant spent fuel elements and possibly to produce some electrical power as well, whose sale could offset some costs of the project. See box 4-C for a description of the facilities and steps required for a MOX-fueled reactor approach.

Some experts claim that the use of plutonium as MOX fuel in nuclear reactors is advantageous because after irradiation, the fuel would be poisoned with very toxic fission products that make plutonium recovery difficult for any group without reprocessing facilities (5). It is technically straightforward to substitute MOX fuel for about one-third of the LEU fuel used in conventional light-water reactors such as those in the United States. However, the use of MOX fuel in *existing* LWRS in the United States is viewed by many as detrimental to verification and proliferation resistance because the practice would distribute plutonium widely in the commercial sector (3). An alternative would be to have fewer specially designed reactors that could use 100 percent MOX fuel loadings in order to minimize physical distribution of the plutonium and thus enhance both verification (by on-site inspection) and proliferation resistance. However, utilities are uncomfortable with the prospect of using plutonium as fuel for civilian power reactors. They believe that public opposition may constrain such practices and that the regulatory process would be long and difficult (3,67).

Although the notion of recovering value from weapons plutonium by converting it to MOX fuel is attractive to some, there are drawbacks to this option. No MOX fuel fabrication facilities currently exist in the United States.[19] There are, however, MOX facilities in other countries. A large MOX facility, owned by Belgonucleaire, is located in Dessel, Belgium. Its startup and status are currently being debated in that country (15). The Siemens company built a facility in Germany that was designed to convert plutonium into MOX fuel, but operations have been delayed indefinitely. In Russia, the Ministry of Atomic Energy (MINATOM) plans to continue to reprocess spent power reactor fuel. MINATOM may also use separated civilian plutonium as fuel for its fast neutron or other reactors. Construction of an industrial-sized facility at Chelyabinsk-65, intended to manufacture fuel for three BN-800 nuclear reactors to be built at the site, was suspended. MINATOM would probably like to find outside financing to complete the MOX facility to manufacture MOX fuel for other existing reactors or even for future breeder reactors (17). However, there is also opposition to nuclear power expansion plans in Russia based on economic and environmental concerns.

If the United States built special dedicated LWRs, plutonium in MOX form might be used

19 Two MOX fuel fabrication facilities were constructed at Hanford to supply the now-canceled Clinch River Breeder Reactor. The facility was never operated, and it is unlikely that it could be reopened to comply with modern safety and environmental standards.

and converted to spent fuel. Plutonium would remain in the spent fuel but be mixed with highly radioactive fission products that would make it significantly less of a diversion risk (3). One analysis estimated that six l,000-megawatt reactors operating for a decade with full core loadings would convert about 50 tons of plutonium into spent fuel (3). If the same amount of plutonium were used as fuel in conventional reactors with one-third reactor core loadings, the number of reactors required would increase threefold. This could add to diversion risks (3). Dedicated reactors could be built as specially adapted, safeguarded, and secured for this purpose and probably located at a Weapons Complex site (3). However, a potential drawback, according to some observers, is that construction and operation of any plutonium fueled reactors might encourage the United States to adopt a permanent plutonium fuel cycle that could increase the risks of plutonium diversion and proliferation (15,16).

A few, very preliminary economic analyses have been done of the use of weapons plutonium as MOX fuel in civilian power reactors. Some of these, while emphasizing the proliferation, verification, security, and monitoring aspects of plutonium disposition, conclude that there are no economic benefits in the use of weapons plutonium as fuel in commercial reactors, even if the plutonium itself is “free.” At the current relatively low price of uranium, it would cost more to convert plutonium into MOX fuel and substitute it for LEU fuel in conventional LWRs (67). One estimate is that the fabrication cost of combining plutonium-which is more hazardous to work with than uranium-into MOX fuel is ‘‘at least” twice the cost of LEU[20] fabrication (3). However, others emphasize the inherent value contained in weapons plutonium and see it as an asset to be exploited. A related viewpoint is that economic cost-benefit arguments for any option are unlikely to be key criteria when measured against the importance of making plutonium less usable for weapons (5). Finally, according to another analysis, the cheapest and quickest way to get surplus plutonium into a more proliferation-resistant or long-term disposal form would be by some direct disposal option (17).

Other nuclear experts have noted that even if the primary goal is to convert surplus weapons plutonium into a proliferation-resistant waste, then a method such as burning in a MOX reactor (which would also generate some electricity) may be attractive. Studies of possible MOX fuel use have been performed by two utility industry groups (the Electric Power Research Institute and the Edison Electric Institute). These studies conclude that the once-through option[21] has merit (49,60). These studies also support the construction of a dedicated MOX-fueled reactor facility on a Federal site. Such an approach would avoid a major change in U.S. commercial regulatory policies and would enable the existing security and other infrastructure to be used.

Over the next 10 to 20 years, MOX-fueled LWRs may have the technical potential to dispose of large quantities of plutonium with partial core loadings of MOX fuel (5). This would require that facilities be built to convert plutonium to plutonium oxide, mix it with natural or depleted uranium oxide, and then manufacture MOX fuel.

A future problem in need of attention is that spent MOX fuel would eventually require disposal. Indeed, all schemes that call for use of plutonium in reactors produce spent fuel. There are no operable, long-term disposal facilities for spent fuel from commercial reactors. The outlook for geologic repositories for spent fuel is uncertain. Investigations of a possible repository site in Nevada have encountered serious delays and public opposition, and are unlikely to be completed soon.

20 The term ‘Clew-efiched uranium,’' or LEU, denotes fuel for conventional power reactors that contains 3 to 5 percent uranium-235.

21 ‘‘Once-through burn’' refers to the use of MOX in nuclear reactors as a means to convert the weapons-grade plutonium in MOX to the more proliferation-resistant reactor-grade plutonium. No recycling of the weapons plutonium embedded in spent nuclear elements is involved.

Developing the facilities and transportation for using plutonium as a fuel in civilian nuclear power reactors also poses special problems for nuclear proliferation and security. The environmental, safety, and health impacts of the processing of plutonium through MOX reactor fuel require updated investigations.

A final problem facing any proposed use of MOX fuel in commercial reactors is current U.S. practice of not recycling commercial plutonium. Such a policy was established in the 1970s after a long debate about commercial plutonium reprocessing and use in breeder reactors. A Generic Environmental Impact Statement on Mixed Oxide (GESMO) was the focus of this debate. The GESMO project was terminated in 1979 when the Carter administration announced the policy not to pursue plutonium recycling. Although this does not currently prohibit the use of MOX-fueled reactors, a new Environmental Impact Statement would be required, and many believe that the 1970s debate would be rekindled (32,60).

Other Plutonium Fission Options

Several other fission options have been proposed for plutonium processing. One approach envisions the use of ‘fast” reactors with a metal fuel cycle. Under some conditions, fast neutron reactors may be able to fission plutonium more quickly than light-water reactors. Several countries, including the United States, are developing fast neutron reactors—usually as ‘breeder’ reactors that produce, rather than consume, plutonium. None is available today as a proven means of plutonium disposition.

A recent study prepared for DOE’s Plutonium Disposition Task Force (48) appears to describe salient features of most of the known approaches with current data; this study concluded that use of excess weapons plutonium in fission reactors could address multiple goals. Certain options were compared on the basis of proliferation resistance, environmental protection, and power generation to offset operating costs (48). Fourteen different fission options were considered. The study estimated that the time required to deploy them ranged from 5 to 25 years, if the resources to support such development were available. The study estimated the remaining development costs of these options to range from $0.1 to $10.0 billion each and concluded that, when developed, most options would be able to produce sufficient power for sale to offset substantial portions of the operating costs.

It is clear that this study began with the notion that weapons plutonium is an asset. The options were selected and compared with the primary goal of obtaining a return on this asset while meeting an additional goal of making the material resistant to diversion for future weapons use. Recommendations made by this study are that some of the options appear quite promising and should be analyzed in greater detail. The advanced light-water reactor option with full MOX core appeared to be the best for relatively early deployment, and advanced concepts such as the accelerator-based converter had the best potential for achieving the greatest degree of plutonium transformations into more benign elements and shorter-lived radionuclides.

A number of concepts featuring advanced reactor or converter designs have been proposed with plutonium disposition as a primary objective. They all involve nuclear fission reactions in a device that focuses on long-lived radioisotopes such as plutonium and attempts to produce such reactions more efficiently than current reactor designs.

The descriptions in boxes 4-D, 4-E, and 4-F illustrate some of the technologies examined. Each represents an example of an advanced technological approach. The first is the advanced liquid metal reactor—a concept that, according to Omberg and Walter (48), would take about 10 to 15 years to deploy. This estimate is regarded by certain experts as highly optimistic. The second is the modular high-temperature gas reactor, a concept with a 10- to 20-year development time, and the third is the accelerator-based converter, a

Box 4-D--Plutonium Transformation Concept 1: Advanced Liquid Metal Reactor/Integral Fast Reactor System

The advanced liquid metal reactor/integral fast reactor (ALMR/IFR) has been proposed as a plutonium disposition option. It was originality designed as a fast breeder reactor for electricity generation (producing more plutonium than is consumed).

The ALMR design could be modified to consume plutonium and other transuranic actinides instead of producing them. This feature was promoted as a means to eliminate such actinides in spent fuel from conventional U.S. light-water reactors. It would still require plutonium reprocessing, and many burning/reprocessing cycles would be required to significantly reduce the actinide inventory in spent fuel. This proposal is currently being evaluated by the National Academy of Sciences Panel on Separations Technology and Transmutation Systems (STATS panel).

With a new interest in disposal of surplus military plutonium, ALMR designers have suggested the possible use of their design. However, the concept of plutonium transformation using fast reactors appears to have some limitations. To consume plutonium in a fast reactor requires significant design changes from the original LMR that was intended to produce plutonium. It could also be expensive: the required reprocessing could multiply the total volume of radioactive waste by 10, thereby driving up costs (7).

The concept also envisions reprocessing, to separate fission products in spent fuel, and subsequent recycling of the remaining plutonium. The licensing process would likely be difficult and contentious both for the ALMR facilities and their associated reprocessing facilities (45). Reprocessing would be either a standard chemical separation process or a pyrochemical process if one was sufficiently developed. Aqueous waste from the process would contain transplutonium actinides including neptunium and residual plutonium, although another process under development at Argonne National Laboratories can recover better t than 99.99 percent of all actinides, leaving only fission products in the waste solution (6), Fuel fabrication with recycled plutonium (after the first cycle with pure weapons-grade plutonium) would have to be done remotely in a hot cell because of gamma-emitting actinides (52).

If it operates according to present designs this option would eliminate most transuranic actinides, including plutonium, while generating high-level waste. That waste would require a repository, the future availability of which is unknown.

Deploying ALMRs solely for burning weapons plutonium would be difficult to implement because only a small amount of plutonium may be made available from weapons dismantlement Proponents usually tie this concept to a national decision to turn to a plutonium breeding/recycling energy program. Moreover, as a strategy to eliminate actinides including plutonium contained in spent fuel, this would be very slow compared to many other direct disposal strategies such as vitrification. To reach a tenfold reduction in the inventory of actinides accumulated in U.S. spent nuclear fuel (equivalent to burning 90 percent) was estimated to require more t han 100 years (45).

SOURCE: Office of Technology Assessment, 1993.

concept that would take 20 to 25 years to develop according to the study. Figure 4-4 illustrates the major steps involved in these three alternative reactor approaches.

In a general sense, all these concepts attempt to convert one atomic species or radionuclide to another. A significant percentage of a long-lived radioisotope (e.g., plutonium-239) is converted to either shorter-lived radioisotopes or stable isotopes by reaction with neutrons produced in a nuclear reactor or neutrons created by bombardment of a metal target in an accelerator.

The three concepts discussed in boxes 4-D through 4-F are merely illustrative of a larger

Box 4-E-Plutonium Transformation Concept 2: The High-Temperature Gas-Cooled Reactor

The high-temperature gas-cooled reactor (HTGR) concept has been under development for other purposes for along time. its predecessor was the gas-coded reactor designed by General Atomics and operated at Peach Bottom, Pennsylvania in the 1970s. More recently, the modular HTGR (MHTGR) concept was proposed as the basis of a new generation of reactors; it was also a possible choice for the new production reactor to produce tritium for weapons. Proponents of this concept claim that the reactor could act as a plutonium burner, converting a large percentage of weapons plutonium-239 to plutonium-241 and plutonium-242.

The MHTGR reactor uses fuel particles coated with ceramic materials that allow the long-term, high-temperature operation desirable for efficient energy production. The neutrons in the core are moderated by graphite, and the reactor is cooled with helium gas. Designers claim that reactor safety is based on inherent characteristics, physical principles, and passive design features, rather than on active engineered systems, operator actions, evacuation or sheltering, or even reactor vessel structural integrity. Core melting is not supposed to occur even with a loss of coolant accident because of the refractory nature of the fuel. The reactor is contained underground for added safety.

MHTGR designers have studied several options for “burning” weapons-grade plutonium. in one concept, more than 90 percent of plutonium-239 is consumed. The spent fuel discharged after 2 years contains roughly 40 percent plutonium-241. Although plutonium-241 is fissile, its half-life is only 14.7 years, much less than plutonium-239. in one reference design, 50 metric tons of weapons plutonium could be irradiated in six 450-megawatt (thermal) plutonium-fueled MHTGR modules over 40 years. The spent fuel packages would have some fissile materials in them but would also be contaminated with nonfissile actinides and long-lived fission products.

Developers of the MHTGR concept point out several weaknesses. This would be a “first of a kind” reactor with concomitant high costs, There would have to be a program to develop and verify performance of t he fuel and to develop fuel manufacturing capabilities. Also, the experiential base for this reactor concept is weak. The concept has also been proposed by the developers for application in Russia. A further claim by the developers is that it could be used for both tritium production and plutonium destruction.

SOURCE: Combustion Engineering/General Atomics.

number of possible approaches. One of these three, the accelerator-based converter (ABC), which involves the partitioning and recycling of long-lived fission products and actinides, is claimed to be capable of destroying essentially all the plutonium-a process termed ‘annihilation’ by Omberg and Walter (48). The other two are said to be somewhat less thorough than the ABC at completely fissioning plutonium and result in fission of some part of the original plutonium. All of these concepts involve considerable uncertainty, and much more work would be required to determine their feasibility. Each requires the development of various technologies and systems beyond the basic reactor or converter itself, such as systems for fuel fabrication and preparation and for waste treatment.

All technologies potentially capable of extensive conversion of plutonium will require substantial investments in development to move them closer to viability. The development time and effort required for most of these concepts have not been thoroughly investigated. Many claims have been made by proponents of certain systems, but they have not been compared on an impartial basis. A National Academy of Sciences panel is studying the transmutation of actinides in

Box 4-F—Plutonium Transformation Concept 3: An Accelerator-Based Converter, the Los Alamos Concept

Los Alamos National Laboratory (LANL) has been examining the potential for using accelerators to bombard targets in order to produce sources of neutrons to serve a variety of functions, including production of tritium, destruction of actinides and high-level radioactive wastes, and destruction of weapons-grade plutonium (94 percent plutonium-239 and 6 percent plutonium-240) by converting it to plutonium-242 and fission products. In this converter, a high-current proton accelerator would bombard a heavy-metal target, producing an intense source of thermal neutrons that interact with the weapons-grade plutonium. The plutonium would be fed continuously in a carrier medium, and the discharge would be separated and remaining plutonium recycled.

Advocates of this concept claim that advances in accelerator design stemming from the Strategic Defense Initiative, combined with experience in developing intense central neutron sources at Los Alamos, have brought this concept closer to reality. One virtue of the concept is that it does not involve use of a critical nuclear reactor. Although a subcritical reactor may be theoretically safer than a reactor that requires criticality to operate, the safety of a subcritical reactor with an intense neutron source has not been thoroughly evaluated. If the concept works, rapid destruction of plutonium-239 to very low concentrations may occur.

The LANL accelerator-based transmutation concept appears attractive for destruction of weapons plutonium. However, questions remain about its technical feasibility. The concept appears to be technically daunting, requiring the state-of-the-art development of three technologies—accelerator; subcritical reactor; and on-line, continuous reprocessing system. It will also produce radioactive activation products and wastes. Furthermore, the LANL concept involves on-line continuous processing and recycling of actinides and long-lived fission products, which would likely present significant health and safety hazards.

SOURCE: Office of Technology Assessment, 1993.

nuclear waste.[22] Its results, due in 1994, could have applicability to the disposition of surplus weapons plutonium.

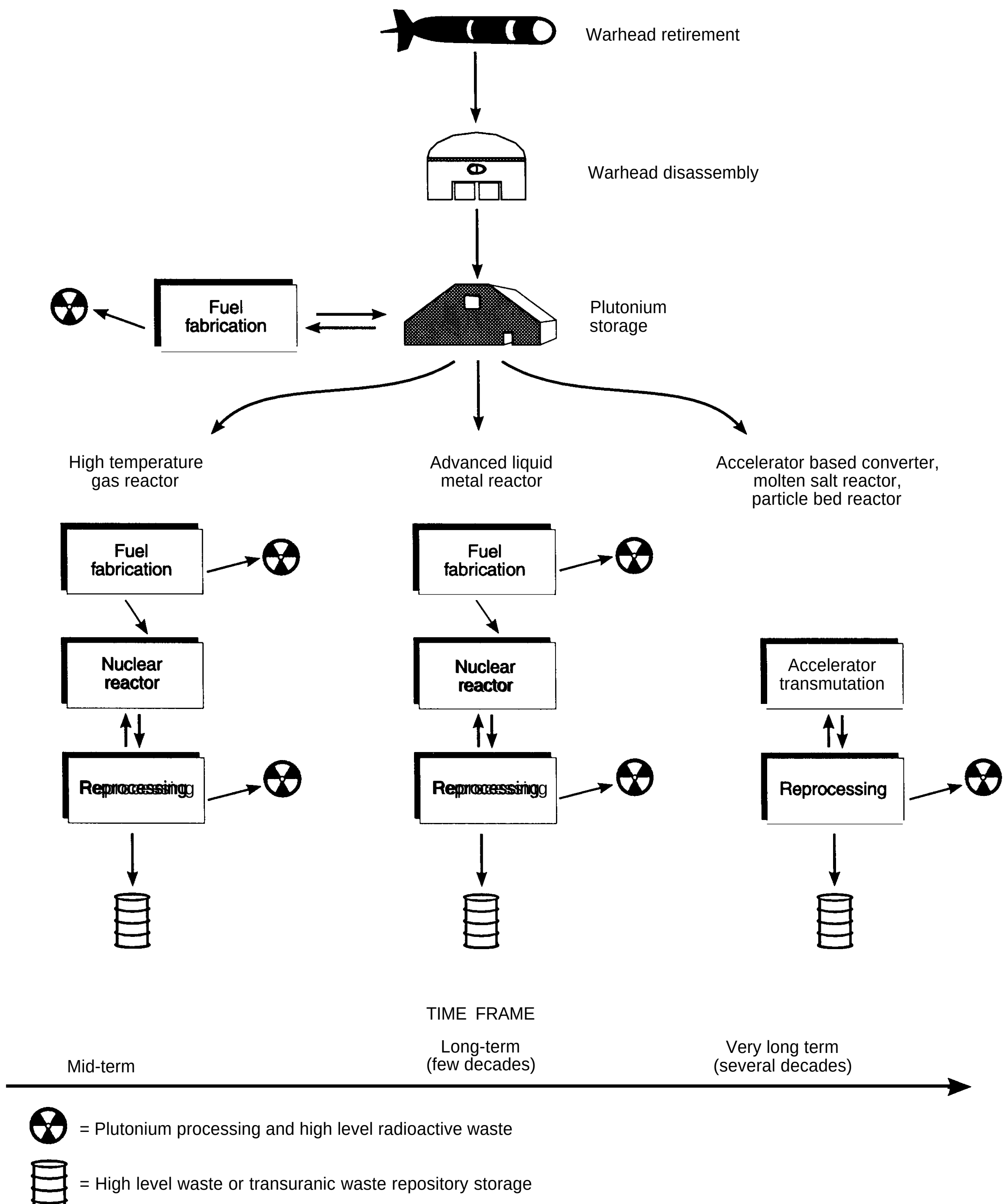
The Omberg and Walter study (48) reviews the time and effort for developing various plutonium fissioning concepts and indicates that if several approaches are pursued simultaneously, a multi-billion-dollar program spanning a few decades would be required before actual, full-scale systems could be tested and proven. A number of skeptics in the scientific and engineering community doubt promotional analyses claiming that certain options can both destroy plutonium and yield economic returns. Any program to develop these technologies should be based first on a clear overall national policy regarding the disposition of weapons material and second on an impartial, high-level, Federal Government evaluation of costs, benefits, and uncertainties.

It was not possible for OTA to conduct an independent analysis of the merits of various plutonium fission options. However, based on its general analyses, OTA concludes that it will probably be necessary to choose among options before they have been fully studied and developed. Unless a national policy is articulated in a timely reamer, large amounts of time and money could be spent on options that turn out to be contrary to future U.S. policy.

One key policy choice is whether or not plutonium should have a place in international commerce. If the answer is yes, the United States will have to develop the means to manage plutonium over the long term for possible useful economic purposes. If the answer is no, the

22 The panel on Separations Technology and Transmutation Systems (STATS) was organized in late 1991 and has investigated advanced reactor and converter technologies that could be applied to high-level radioactive waste management problems.

Figure 4-4-Selected Advanced Reactor/Converter Options for Plutonium Disposition



SOURCE: Office of Technology Assessment, 1993.

United States must find an acceptable means of processing plutonium via a reactor or directly disposing of it. Another key policy decision is whether plutonium should be put into a less weapons-usable form as quickly as possible. If this is an overriding goal, then technologies available in the near term would be favored over those requiring long and uncertain development.

Proponents of plutonium as waste and other experts conclude that the primary goal is to convert plutonium quickly to a form that is most difficult to extract and reuse in weapons. If this goal is accepted, then research could be directed to determine whether disposal of plutonium as waste is technically feasible and can be accomplished safely at reasonable cost. If conversion into waste is a goal, the best solution may be disposal with as little processing as possible. The option of plutonium disposal without conversion might be desirable because the infrastructure for plutonium utilization is not in place in the United States and there is significant public concern about its use (5). Moreover, a key reason for the U.S. abandoning the development of a plutonium infrastructure in the 1970s was concern that it would encourage worldwide plutonium proliferation.

Criteria for Treating Plutonium as Waste

The efficacy of treating plutonium as a waste may be gauged by the following criteria:

- Security. The treatment, storage, and disposal of plutonium must be such that the difficulty of plutonium reextraction from the waste is high.
- Accident. The risk of catastrophic accidents must be evaluated.
- Health and safety. Processing plutonium as a waste form involves consideration of, and protection against, health and safety risks to workers and the public.
- Long-term management. Because of its long half-life, plutonium must be isolated from the human environment for extremely long periods, and waste treatment must be compatible with long-term management.
- Cost. Some nuclear experts believe that the security benefits of converting plutonium into a waste form that is proliferation resistant far exceed any potential economic benefits from its use. The uncertainties associated with most proposed approaches make cost evaluations very difficult. However, nonproliferation benefits and the value of doing something quickly must also be weighed.

A number of waste disposal options for plutonium have received some attention, including:

- disposal in a geologic repository,
- sub-seabed disposal,
- detonation of warheads underground to fix plutonium in molten rock, and
- disposal in outer space.

DISPOSAL IN A GEOLOGIC REPOSITORY

Plutonium could be disposed of as a waste in a geologic repository. It could be disposed of directly after being packaged in special containers or immobilized in a vitrified form prior to disposal. Criticality requirements, however, must be developed and accepted.

Direct plutonium disposal in a repository also requires consideration of other factors. Plutonium would have to be packaged in small quantities and in special containers to prevent accidents. Increased criticality concerns and the potential for recovery of plutonium from the repository may open up new questions regarding repository licensing. A serious argument against such direct underground disposal is that the plutonium could be recovered easily in the future and, if not recovered, could pose a significant risk of contamination unless immobilized in a matrix.

If direct disposal of plutonium were unacceptable, the next approach might be to encapsulate it in a form that could potentially retard its dispersal into the environment. Encapsulation technology could also make it difficult and costly to recover the plutonium for reuse, compared with new plutonium production.[23] One option is to vitrify plutonium without adding any products except glass. Experts at DOE's Savannah River Site have been investigating methods to produce vitrified glass containing a small percentage of weapons plutonium. A second option is to mix plutonium with high-level waste or poisons prior to vitrification. Most experts agree that if appropriate "poisons' or other products are added to plutonium, it can, in theory, be made as proliferation resistant as spent fuel.

Encapsulation technology has been examined extensively for the high-level waste resulting from plutonium production (most of the waste is now in large tanks at Hanford and Savannah River). A number of different materials with a wide range of properties for encapsulation have been considered (including different forms of glass, ceramics, and cement-related materials, along with various metal coatings).

These materials possess varying properties in relation to the isolation of high-level radioactive waste. Most of them have not been thoroughly evaluated, manufacturing technologies are not fully developed, and knowledge of their applicability to weapons plutonium is limited. In 1982, DOE chose borosilicate glass as the waste format the Savannah River Site partly because the manufacturing technology for glass was far more advanced than that for other proposed waste forms.

Because glassification of radioactive waste is an available technology (at least in countries such as France and the United Kingdom, although not quite operational in the United States), encapsulation of plutonium in glass could, in theory, provide a relatively short route to disposition of plutonium as a waste. Two plants for the vitrification of high-level waste from reprocessing have been built in the United States. One is at West Valley, New York (the West Valley Demonstration Plant); the other, the Defense Waste Processing Facility, is at the Savannah River Site in South Carolina. Both are DOE facilities. Even though these facilities are nearing startup, they have suffered long development or implementation delays. Glassification is the most near term of any technology, but the remaining engineering and testing required should not be underestimated (66).

Although borosilicate glass has been investigated more extensively, other waste forms may possess better isolation properties for actinides—an important factor in light of the 24,000-year half-life of plutonium-239. The use of these other waste forms for plutonium has the disadvantage that much more research and development are required, and thus the relative costs and benefits are unknown. However, it may be useful to explore alternatives to borosilicate glass for plutonium vitrification, some of which could be more desirable for reducing long-term releases.

Plutonium pits from warheads would have to undergo some processing before being vitrified. Plutonium metal is too chemically reactive, pyrophoric, and insoluble in glass for vitrification. Suitable forms of plutonium for vitrification include plutonium dioxide (powder or particulate form) and plutonium nitrate. It maybe necessary to mix plutonium oxide or nitrate with other materials prior to or during vitrification. Calcined materials that could be mixed with plutonium for vitrification already exist at the Idaho National Engineering Laboratory and the Hanford Plant.

In May 1993, the Westinghouse Savannah River Corp. issued a draft report on vitrification of plutonium (79). The study provides technical

23 Plutonium production involves irradiation of uranium fuel in a nuclear reactor, followed by chemical separation of plutonium from the remaining uranium and fission products. Because the fission products are very radioactive and toxic, chemical separation requires elaborate facilities with extensive shielding, such as the canyon facilities at Hanford and the Savannah River Site. Recovering plutonium that has been encapsulated in glass along with high-level waste would be similar to the chemical separation used to produce new plutonium—and therefore would require access to elaborate and extensively shielded facilities. This is something a large nation might support but a terrorist group might not be able to.

information about several vitrification options—some using existing facilities with modification and some requiring new facilities. The report concludes that the most straightforward option with only slight modification of existing facilities would require almost 10 years before beginning operations. Some rough costs are also given in this study. The least costly option was seen as vitrification without addition of a radiation source, and vitrification in a modified reprocessing canyon with added radioactivity would be a high-cost option. Total costs for vitrifying 50 tons of plutonium range from $0.7 to $1.6 billion. Finally, the report notes that research and development for all options is still needed on criticality safety, defining physical and chemical properties of the glasses, and developing and demonstrating performance of processes and waste form.

More detailed, quantitative, environmental, safety, and cost analyses are required to fully assess all options for using either existing or planned high-level waste vitrification plants or, possibly, a new plant built exclusively to vitrify plutonium. Worker health and safety considerations would require particular attention to radiation protection measures, especially if fission products are combined with plutonium and vitrified. Different options would imply varying storage times for the plutonium from dismantled warheads because of different startup times for facilities. The composition of the glass is also important for its long-term isolation properties, which will be crucial in protecting the environment from eventual contamination after the disposal of vitrified plutonium. Also, depending on the product (plutonium and glass alone, or mixed with poisons and wastes), the difficulty of future recovery of plutonium may vary considerably. Although many countries do not have the technology to retrieve plutonium vitrified with high-level waste, certain nuclear countries such as the United States and Russia do. In terms of costs, one must evaluate the economics of plutonium recovery from glass relative to the production of new plutonium from reactors and reprocessing plants.

In summary, the direct disposal of plutonium as a waste-like the option of disposal as spent fuel after plutonium irradiation-would depend on the availability of a radioactive waste repository. No such repository is now available in the United States nor is one likely to become available in the near future. A minimum of a few decades will probably be required before a geologic repository for high-level commercial spent fuel can be opened, but so many technical and political setbacks have been encountered during the past decade that it is difficult to make realistic predictions.

Two approaches are most likely in considering the prospects for disposal of weapons plutonium in a repository-one is to plan for indefinite storage of whatever the short-term form is (from pits to glass logs); the second is to highlight the need to develop long-term solutions for this problem, as well as the problem of disposal of other defense and civilian radioactive wastes.

SUB-SEABED DISPOSAL

Another option that some have advocated is sub-seabed disposal of plutonium either directly or as glass logs with waste (57). Significant investigations have been done in the past on sub-seabed disposal of spent fuel from commercial reactors (64). These investigations were suspended several years ago, but some researchers have suggested that it may be appropriate to study this option for weapons plutonium disposal. Here again, more analysis is needed to determine the costs and benefits, and public and international acceptance may be a formidable obstacle.

UNDERGROUND DETONATION

The option of detonating a nuclear bomb underground as a means of fusing plutonium into the surrounding rock was suggested by a group of Russian scientists. Some believe the verifiability of this option to be good (5). Costs of this nuclear explosion classification process might also be low, but no good analysis is available. Irreversibility is problematic because of the possibility of

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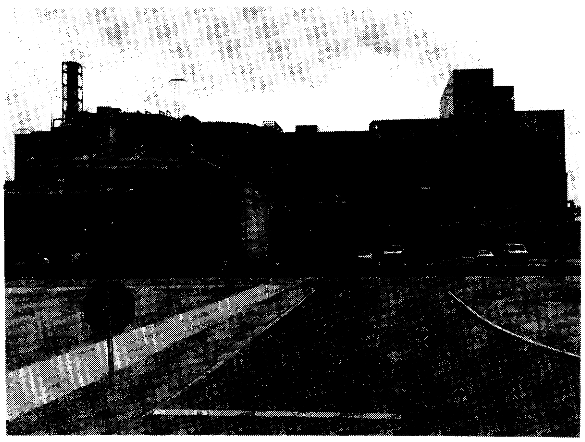


The Defense Waste Processing Facility (not yet operational) at the Savannah River Plant. Some have suggested using this facility for vitrification of plutonium mixed with high-level radioactive waste from past operations.

recovering the fused rock and leaching out plutonium (5). The safety and environmental impacts of this option have not been evaluated to any degree, and these concerns have blocked support for serious analysis.

Political and public acceptance would probably be extremely difficult to obtain in the United States, if not worldwide, and recent decisions about stopping nuclear testing in the United States and elsewhere could be affected by a serious consideration of this option. Thus some consider this an "option of last resort" (5).

DISPOSAL IN SPACE

The option of deep space disposal of plutonium could offer irreversibility, proliferation resistance, and verifiability. Concerns about the safety of such a project center on the possibility of accidents during launch, with the potential for plutonium dispersion over large areas (5). Costs, although currently difficult to estimate, may be *much* higher than for other options such as geologic disposal, although this could be subject to reevaluation. Very little analysis has been done on the space disposal option, and almost no attention has been given to it in the past 10 years. Most experts have relegated consideration of space disposal to the bottom of the list.

PLUTONIUM DISPOSITION–CONCLUSION

The discussion above has presented a variety of approaches for the disposition of plutonium in the United States from retired and dismantled nuclear weapons. The following concluding points summarize OTA's analyses of the available data, with reference to the technical and political factors in the United States. Some aspects may be applicable to other countries such as Russia, but different conditions can also result in very different conclusions. Plutonium disposition is considered by many to be one of the most difficult problems faced by those who will manage materials from retired nuclear weapons. Not only is it a difficult problem, but it also must be considered in the wider geopolitical context of security, human health and safety, and the environment.

- Storage is a necessary first step, regardless of which approach is selected for the ultimate disposition of plutonium. The questions regarding storage are, How long? In what form? What kind of facility? Where? Decisions about ultimate disposition are unlikely to be made soon, but even if they are, significant portions of the plutonium stockpile will be stored for decades. Thus, it makes sense to move toward a safe, secure, state-of-the art storage facility rather than rely on politically sensitive temporary facilities such as those at Pantex, with risky periodic lifetime extensions.
- The use of weapons surplus plutonium as fuel for U.S. commercial reactors is unlikely in the near term because of economic factors and the concerns of U.S. utilities about regulatory constraints and public opposition. Further, U.S. policies that discourage commercial plutonium use because of proliferation concerns would need to be reevaluated.

- The use of a modified light-water reactor system for disposition of plutonium as mixed-oxide fuel at a dedicated government facility is probably a viable near-term approach if proper attention is given to worker and public health and safety, environmental protection, and public involvement.
- It maybe possible to immobilize plutonium directly into some waste form such as vitrified glass, with or without high-level waste fission products. This approach could offer proliferation resistance. A rigorous analysis of the costs and benefits of this approach, compared with reactor approaches (e.g., dedicated reactors with 100 percent MOX fuel loading) that involve subsequent handling of the spent fuel, would be very useful. Here again, health, safety, and environmental protection would need adequate attention.
- Decisions about the fate of plutonium from U.S. weapons should be made with consideration of Russia and other nations that maybe planning to use plutonium in reactors. Policy goals should be stated clearly. If the United States wishes to reduce the world stockpile of plutonium that is easily available for weapons, it should take actions to discourage future production, control existing materials, and make them unusable for weapons.
- It is all but impossible to fission plutonium completely (and thus "destroy" it), but future technological developments may have the ability to convert it to different radionuclides more effectively than any existing system. Research into advanced reactors and accelerators would be costly and require long development times (decades), so any program should focus on specific goals. Research into space disposal or other unconventional options may merit limited support if they can be justified on the same basis.

DISPOSITION OF HIGHLY ENRICHED URANIUM

Substantial quantities of highly enriched uranium will result, by the end of this decade, from the dismantlement of retired weapons. The U.S. government has made no decisions regarding whether or when weapons-grade HEU will be available outside DOE programs. The technology required to use HEU in commercial or other reactors, after blending it down to LEU, is considered simple by many. The logic is that it will be easy to shunt weapons-grade uranium into the world's already established uranium-based nuclear power industry. Therefore, the interest in pursuing research into innovative HEU disposition options is sparse.

Significant attention, however, is focused on the purchase of surplus HEU from Russia and the consequent use of that material as fuel by the U.S. commercial nuclear power industry (see chapter 6). U.S. purchases of HEU would provide hard Western currencies that Russia desperately needs to bolster its economy and would guarantee that some Russian HEU will not be used for making new nuclear warheads.

However, OTA's analysis indicates that some problems must be addressed before a program to utilize warhead HEU can be implemented. More extensive investigation is needed of the following: the dilution and conversion of warhead HEU to the LEU used in commercial power reactors; the testing and operation of conversion facilities; interim storage prior to conversion; assurance of adequate safety, security, and verification in processing and transport; the impact of weapons surplus uranium on the already depressed U.S. and worldwide uranium industry; and the uranium dumping suit brought against the former Soviet Union by the U.S. Uranium Miners Union and others. It will also be important to develop clear national policies about what to do with U.S. military uranium in light of future security needs. These considerations will influence any decision on HEU disposition that may be made in the future and should be part of the present planning process even if no decision beyond storage is being considered at present.

DOE is reluctant to quickly convert U.S. weapons HEU for other purposes. Sometime will also be required to bring any HEU processing operation on-line and deal with possible disruptions in the uranium market. It appears likely that HEU (like plutonium) will have to be stored in a safe, secure manner for the immediate future.

The United States has stopped production of HEU and is not planning to make any additional HEU, at least in the near future. In 1992 the Bush administration stated that U.S. policy was not to make any more HEU for nuclear weapons and that DOE had actually ceased producing HEU specifically for weapons in 1964 (22). This announcement formalized what circumstances had already dictated. The production of nuclear weapons plutonium effectively ceased after 1988 because of safety and environmental problems at DOE reactors and weapons plants (62). However, DOE continued to produce HEU until 1992 for the nuclear Navy, research reactors, and defense production reactors. In addition, the U.S. decision to cease all HEU production was the recommendation of a high-level task force formed in 1991 to examine HEU options in light of the large amounts of HEU expected from dismantled warheads (62).

It is not certain what fraction (if any) of the HEU coming from retired U.S. warheads will be converted to civilian fuel,[24] as opposed to being kept for military purposes such as fuel for naval reactors (which presumably could be modified to use the slightly lower enrichments) or to make new nuclear weapons. The possibility of converting a portion of U.S. military HEU for sale in the commercial LEU industry is being considered seriously by some. In its report on the National Defense Authorization Act of FY 1993 (Public Law No. 102-484), the House Committee on Armed Services requested a cost-benefit analysis of blending surplus HEU with LEU and uranium scrap for use as commercial reactor fuel (14,21).

Some U.S. utilities would also like to see U.S. military HEU blended to LEU and made available on the market as fuel for civilian power reactors in a manner similar to current plans for Russian military HEU. The first U.S. military uranium that may be converted to civilian commercial reactor fuel would probably be HEU that is in DOE's inventory but not in warheads. Generating LEU fuel by blending down HEU, instead of mining more uranium ore and enriching it, is environmentally advantageous because it would avoid the land contamination associated with mining as well as the energy expenditure associated with uranium enrichment.

At present, there is no apparent effort in the United States to make available any HEU recovered from dismantling warheads (35). Nevertheless, the United States may come under some pressure to show reciprocity by converting its HEU to other uses, if it can be assured that the Russians are converting their military uranium to civilian purposes (as required by the pending Russian HEU agreement). However, the possible demand for reciprocity in nuclear warhead dismantlement has not received official attention (38,54). Most Russian officials have expressed more interest in the economic value of HEU than in its security value (38). The major pressure so far for reciprocity has been from other groups and other nations—particularly related to renewal discussions of the Non-Proliferation Treaty coming up in 1995. Some believe that resistance to reciprocity could become a major stumbling block for future dismantlement (38).

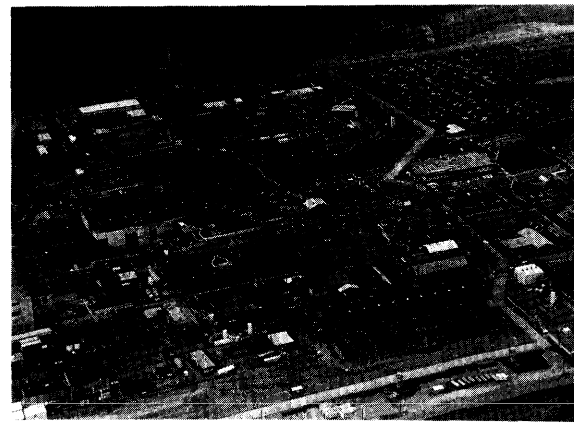
DOE has stated that enough HEU exists either in its nonweapons inventory or in warheads scheduled for retirement to meet all U.S. projected military needs for decades. DOE is currently developing plans to reconfigure the Nuclear Weapons Complex to meet these future needs (68,71). DOE's Uranium Task Force is

24 As noted earlier, DOE has stated that some quantities of HEU may be declared surplus sometime in the future.

charged with planning for the future of its uranium operations. The task force concluded that none of DOE's weapons HEU is in excess or should be considered surplus (26), and recommended that U.S. HEU be stored for now. This would represent a stockpile for future weapons or other programs and thus delay as long as possible the need to produce more HEU for defense purposes (62). Since this recommendation, additional unilateral U.S. and Russian warhead cutbacks and Russian initiatives to sell HEU may have increased the possibility that some U.S. HEU will eventually be declared surplus and converted, although no such decision has been made (62).

Clearly, storage of weapons-derived HEU must be anticipated. Presently DOE is planning to store all of its HEU indefinitely at the Y-12 Plant (26) and is not actively considering a decision beyond such storage. Because of the prospects for U.S. purchase of converted Russian HEU (see chapter 6), all HEU issues have been discussed in that context. Not much attention has been given by the Federal Government to possible commercial uses of U.S. HEU.

DOE has recently extended the work of the Uranium Task Force in the form of an internal management plan. DOE has stated that the goal of the plan is to manage the Department's uranium resources in a manner that extends the availability of uranium to meet user needs without new production and with minimal budget outlays, while meeting new environmental, health, and safety objectives. This plan is classified, and there are no plans to produce an unclassified version (26). The plan projects uranium needs through 2005 and sets requirements for facilities in a reconfigured Weapons Complex. The uranium needs considered include national defense; fuel for tritium production reactors, naval nuclear propulsion, and space nuclear programs; research and development programs; and unspecified 'commercial needs. ' The plan includes a model that takes into consideration these various needs and calculates the "crossover' date, the time when



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DOE's Y-12 Plant, Oak Ridge, Tennessee, where highly enriched uranium from warheads is now stored.

the need for building new production facilities could arise. The Uranium Task Force has also modeled the forms and amounts of uranium (accounting for all DOE's uranium) that will be present after reconfiguration (26).

Processing and Storage at Y-12

HEU taken from retired nuclear warheads is now stored at DOE's Y-12 facility at Oak Ridge, Tennessee. Y-12 is a large multipurpose facility with several different missions in both materials and weapons production, and a long history of working with uranium (44). In the past, the HEU components from warheads were removed and stored in special compartments at Y-12 (29).

Because Y-12 was built piecemeal, materials do not flow efficiently from place to place. The buildings are old, and there is a vast amount of waste on-site. The facility is also much larger than present or future levels of production require (40). Uranium operations at Y-12 involve many industrial processes, including casting, smelting, machining, and recycling, as well as different uranium forms (buttons, solutions, chips). Some HEU from weapons disassembled at the Pantex Plant is also processed at Y-12 (37).

DOE and the Y-12 contractors are currently reorganizing and redefining its mission-from weapons production to weapons dismantlement—

as DOE downsizes the Nuclear Weapons Complex. To improve the efficiency and cost-effectiveness of their operations, for example, Y-12 management recently reduced the number of operating uranium casting facilities from 12 to 6. Among the functions delineated in the new mission are: 1) disassembling nuclear weapons components; 2) storing and managing warhead materials such as lithium and highly enriched uranium; 3) transferring technology to the private sector (74); 4) evaluating and testing particular weapons system components; and 5) manufacturing components for other government organizations, such as the Navy's Seawolf submarine program (37).

CURRENT STORAGE ACTIVITIES

For security purposes, the area comprising the Y-12 Plant has been divided into three major zones: two low-security zones and a highly secured one. The high-security zone or "exclusion area' contains HEU processing and manufacturing facilities. This area also includes several facilities used for storing HEU and some radioactive waste generated by processing activities there (1,78).

The HEU stored at the exclusion area comes from a multitude of sources, including government and private institutions and universities. The largest volumes, however, originate from weapons disassembly operations. Upon arrival, the HEU-containing parts are inspected and temporarily stored (''staged' until the proper facilities and equipment become available to remove HEU from the containers or assemblies and prepare it for long-term storage.

When a decision is made to store HEU separated from weapons, the material is prepared for storage by recasting the metal in a specialized cylinder, placing it in a sealed container, and storing it in one of the seven operational concrete vault facilities in the high-security zone. If the HEU is part of the national strategic reserve, the container is stored in a location different from that used for nonstrategic HEU. HEU is generally stored in concrete vaults commonly known as tube vaults. Tube vaults consist of cylinders embedded in a concrete structure in a configuration that prevents any criticality accident. A typical tube vault can safely accommodate up to 40 metric tons of HEU, and its design life is estimated to be nearly 100 years (13).

In addition to HEU, Y-12 handles more than 80 other weapons materials and chemicals contained in weapons assemblies. Although HEU and certain other materials such as lithium and tungsten alloys are recycled and stored at the plant, most of the remaining inventory (e.g., aluminum, rubber, nylon, beryllium) is declassified and demilitarized before being made available to commercial facilities for recycling, treatment, or disposal. Considerable reduction in the amount of materials shipped for treatment and disposal has been achieved in the last 5 years (13).

Efforts to Address Weapons Dismantlement and Possible Impacts

Current plans call for storing HEU and other essential weapons materials returned from Pantex at Y-12's specialized storage facilities. Although the rate of "returns" has doubled since 1985, no HEU storage capacity limitations are anticipated by DOE for the foreseeable future. Since Y-12 receives only part of the total materials generated by weapons disassembly at Pantex, and since most weapons production facilities have considerably reduced their operations, plant officials claim that increases in weapons dismantlement activities will not constitute an operational or storage burden (13). Y-12 officials project current levels of personnel and expertise to be adequate for addressing future storage and processing needs for HEU from dismantled weapons.

To ensure proper management of dismantled materials, Y-12 officials have developed a computer model that estimates and projects work force needs, staging space requirements, processing and equipment demands, and long-term storage availability. Documentation detailing the handling and processing steps to be followed for each particular material returned from weapons disassembly has also been developed (13). In addition, safety analyses have been conducted at facilities where dismantlement activities take place, as well as where HEU is stored. Plant personnel are reviewing current processes and operations to determine whether additional adjustments must be made to successfully address any future dismantlement-related activities at Y-12 (8).

One possible result of expanding the storage of highly enriched uranium from dismantled weapons at Y-12 is an increase in radiation exposure during inventory assessment. Exposure levels are currently reported to be very low, particularly because of the limited ongoing processing and handling of HEU at the plant. With an increase in uranium processing and handling, exposures are expected to rise but—according to a Y-12 official—not to levels that will pose any risk to plant personnel or the general public (8).

No comprehensive analysis is available publicly that evaluates the capability of Y-12 to continue to accept and store HEU from dismantled weapons, particularly since the total quantity of U.S. HEU is classified. Plant officials do not expect Y-12 to run out of storage space for HEU. However, if such a situation developed, DOE claims that additional space could be obtained by using any of the recently closed buildings certified for HEU work. Storage space could also be made available at other facilities, but additional capital investments may be required.

Prior to a decision to use any additional existing Y-12 buildings as storage facilities for HEU, DOE will have to evaluate them in terms of safety, security, nuclear criticality, and environmental compliance. Because previous work at these facilities also involved uranium, the level of analysis required may not be extensive. Oversight by State agencies and the Defense Nuclear Facilities Safety Board may also be necessary (37). Public involvement should be incorporated in this process.

To avoid the costs associated with expanding the number of HEU storage facilities, officials at Y-12 have examined more efficient methods of storage. A new—as yet unnamed-storage system was reported to have been developed in December 1992 (13). Little public information exists, but according to Y-12 officials, the new system not only allows the storage of large amounts of HEU at subcritical conditions but is expected to triple the usable space in existing vaults.

Management and handling of HEU can lead to criticality concerns. The availability of criticality safety experts at Y-12 is limited. With the expected increase in uranium storage, efforts are being carried out to support training programs at the University of Tennessee for future staff. Several nonengineering personnel highly knowledgeable about Y-12 facilities have also been trained to become criticality safety experts. Another preventive measure being undertaken to minimize the potential for criticality safety accidents involves reducing the number of places in which HEU is handled (8).

Y-12 is one of the largest handlers of HEU in the world, and this experience could be a factor in considering a future de-enrichment and storage site should Russian weapons materials be purchased by the United States in the form of HEU.[25] Although HEU de-enrichment technologies have been employed at Y-12 for some time, its processing capacity is limited; consequently, scaling-up will be needed to handle adequately the much larger volumes of Russian HEU. The costs that may be incurred in expanding de-enrichment technologies have not been studied. In terms of storage, Y-12 officials claim to have sufficient storage space to accommodate Russian HEU, particularly in metallic form (13). If a

25 As discussed in chapter 6, the current agreement to purchase Russian HEU calls for its conversion to LEU in Russia but does not preclude the possibility of future HEU shipments.

decision is made to store or process Russian HEU at Y-12, a number of technical challenges (such as the possibility of accommodating Russian monitoring) will have to be considered. It does not appear that any serious analysis has been done on this issue to date (8).

If a new storage facility is developed for plutonium, as discussed earlier in this chapter, it would be beneficial to consider HEU storage needs and criteria at the same time. Separate HEU and plutonium storage facilities maybe warranted but only if the added cost and difficulty can be justified.

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