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DEFENSE NUCLEAR FACILITIES SAFETY BOARD

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June 8, 1999

Mr. James M. Owendoff
Acting Assistant Secretary of
Environmental Management
Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-0113

Dear Mr. Owendoff:

The Department of Energy (DOE) is preparing to select a processing alternative for disposal of aluminum spent nuclear fuel from research reactors, which is to take place at the Savannah River Site (SRS). DOE is proposing a melt and dilute process that does not appear to be based on a comprehensive consideration of safety, technical certainty, and cost.

The enclosed Board's staff report evaluates the spent fuel inventory at SRS and the processing alternatives for its disposal. The report is provided for further consideration of this matter as DOE proceeds in its selection of a disposition alternative. The report concludes that DOE should look for ways of accelerating the consolidation of aluminum spent fuel at SRS and maximize the use of its existing processing capabilities, at least until the year 2010, to dispose of this unique spent fuel. As more information is gained regarding the expected type and quantity of research reactor spent fuel that will be received after 2010, DOE can better evaluate alternatives for continued disposal of this spent fuel.

Although progress has been made, DOE still has a considerable amount of nuclear materials that require stabilization and either storage or disposal. SRS's processing canyons are serving as workhorses in accomplishing this important task. During the last few years, these facilities have stabilized an impressive amount of plutonium solutions, plutonium residues, plutonium production targets, and spent fuel. On the other hand, the development of new technologies for stabilization of nuclear materials has been plagued with technical problems, schedule delays, and cost overruns. Examples include the project to stabilize spent fuel at Hanford and to stabilize americium-curium solutions at SRS. Where appropriate, DOE should protect and capitalize on its existing capability where safety assurance has already been demonstrated rather than hastening to replace it. Safety of speculative technology is yet to be demonstrated.

Sincerely,

John T. Conway

John T. Conway
Chairman

c: Mr. Mark B. Whitaker, Jr.
Mr. Greg Rudy

Enclosure

DNFSB/TECH-22

Savannah River Site
Spent Nuclear Fuel

Defense Nuclear Facilities Safety Board

Technical Report

April 21, 1999

Savannah River Site
Spent Nuclear Fuel

J. Kent Fortenberry

EXECUTIVE SUMMARY

A large inventory of aluminum spent fuel from research reactors is being stored in water basins at the Savannah River Site. More research reactor spent fuel is to be added to this inventory. Most of this spent fuel is in better condition than the damaged aluminum defense-related spent fuel currently being stabilized at the Savannah River Site, and arguably does not require immediate stabilization. However, some of the research reactor fuel is damaged or is in a form that merits expedited stabilization. In addition, even undamaged aluminum spent fuel is not suited for long-term wet storage, both because of the unpredictability of aluminum corrosion and because of the continuous water conditioning required to protect the fuel. Furthermore, aluminum fuel, especially the high-enrichment fuel typical of research reactors, must be packaged in a manner that will be acceptable for ultimate disposal in a repository. For these reasons, the Department of Energy (DOE) must remove this fuel from wet storage and is proposing a process to prepare it for stable interim storage and final disposal.

The Defense Nuclear Facilities Safety Board (Board) provides technical safety oversight of defense nuclear facilities. The aluminum spent fuel from research reactors is not considered defense-related, but the storage and processing of this fuel will occur in defense nuclear facilities. Potential safety impacts on facility operations and decommissioning have prompted the Board to evaluate DOE's proposed actions regarding this fuel.

DOE has considered three processing alternatives for this fuel: conventional processing, melt and dilute, and direct codisposal. Conventional processing is an existing capability that involves aqueous chemical separation to produce enriched uranium for use as commercial reactor fuel and a high-level waste stream compatible with the current high-level waste processing strategy. The proposed melt and dilute process would melt the spent fuel together with depleted uranium to produce a low-enriched spent fuel melt and a waste stream from the volatilized fission products and melt crucibles. The proposed direct codisposal process would dry and package the spent fuel to produce canisters of dried spent fuel and a waste stream resulting from the cutting and cropping of the spent fuel elements. DOE's preferred alternative for most of the fuel is the melt and dilute process, to be installed in the existing L-Reactor facility at the Savannah River Site.

Melt and dilute is a new processing technology that requires significant development work. Implementation of this process depends on successful demonstration of the technology and completion of design, construction, and startup activities. DOE has had several disappointing experiences recently with the implementation of new technology. The In-Tank Precipitation and Americium-Curium Vitrification projects at the Savannah River Site are examples of new processing technologies that appeared very promising in the laboratory and even in the demonstration phase, but are proving very difficult to implement.

There are potential safety risks associated with operating the melt and dilute process in the existing L-Reactor facility. The process will involve molten spent nuclear fuel and volatilized fission products without the benefit of a canyon structure for confinement. Also, fuel-melting operations in the L-Reactor facility could result in significant facility contamination that would impact equipment operation and maintenance and introduce new challenges for decommissioning of the facility.

DOE's cost comparisons of processing alternatives are based on life-cycle costs from 1998 through 2035. For the conventional processing alternative, this life-cycle cost includes a new facility to process residual fuel receipts after 2010, when the existing canyon capability is assumed no longer to be viable. Even with this new facility added to the cost of conventional processing, DOE concludes there is no significant difference in life-cycle costs among the alternatives.

All of the existing aluminum spent fuel from research reactors will be available for processing prior to 2010. As more information is gained regarding the type and quantity of fuel that might be generated after the year 2010, DOE will be better able to evaluate future processing needs. From this perspective, conventional processing would provide additional flexibility to accommodate the potential changes in the size, type, or quantity of fuel that might be received after 2010.

After examining the aluminum spent fuel inventory and the processing alternatives, this report concludes that DOE ought to accelerate consolidation of aluminum spent fuel at the Savannah River Site and take advantage of its operating conventional processing facilities to place this fuel in stable interim storage and prepare it for final disposal. This course of action would eliminate the uncertainty of a major technology development, design, and construction effort and avoid new safety risks associated with operation and decommissioning activities in the L-Reactor facility. This course of action also would allow future flexibility by providing for stable storage and final disposal of these fuel inventories through 2010, while making it possible to defer decisions that are currently based on assumed fuel receipts 35 years into the future. When more information is available on the type and quantity of aluminum spent fuel from research reactors to be received between 2010 and 2035, DOE will be able to better evaluate its need for future processing of this fuel. More generally, this report concludes that DOE ought to concentrate its limited resources on utilizing its existing stabilization and processing capability, which is currently playing a vital role in the successful stabilization of nuclear materials.

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1. INTRODUCTION

A large inventory of aluminum spent nuclear fuel is stored in water basins at the Savannah River Site (SRS). This spent fuel was generated by the production of defense nuclear materials at the SRS reactors and by the return of spent fuel from both domestic and foreign research reactors. The generation of aluminum defense-related spent fuel at SRS has ended, but the return of aluminum spent fuel from domestic and foreign research reactors will continue. Historically, most of the aluminum spent fuel generated at SRS or received from off site was processed to recover the enriched uranium. The aluminum spent fuel received from off site was stored in the Receiving Basin for Offsite Fuel (RBOF) before being sent to canyon processing facilities. With the cessation of routine canyon processing of aluminum spent fuel from research reactors and with continued returns from off site, the aluminum spent fuel inventory has now exceeded the RBOF capacity, necessitating storage of the fuel in the L-Reactor defense nuclear facility storage basin.

The spent nuclear fuel at SRS can be categorized as either aluminum defense-related spent fuel, nonaluminum spent fuel, or aluminum spent fuel from research reactors. To date, DOE has made decisions regarding the stabilization and disposal of the aluminum defense-related spent fuel and the nonaluminum spent fuel: the defense-related spent fuel is currently being processed in the SRS H-Canyon facility, while the nonaluminum spent fuel is to be shipped to the Idaho National Engineering and Environmental Laboratory (INEEL) and consolidated with similar nonaluminum spent fuel at that site. DOE is now preparing to make a decision regarding the stabilization and disposal of the aluminum spent fuel from research reactors.

The aluminum spent fuel from research reactors differs from spent fuel from commercial reactors. The aluminum fuel is less robust and less resistant to corrosion; some is in powder form. Also, the uranium-235 enrichment of the research reactor fuel is considerably higher than that of commercial fuel. These differences pose unique challenges to the stabilization and disposal of this fuel.

DOE has prepared an SRS Spent Nuclear Fuel Management Environmental Impact Statement to assist in the selection of a processing alternative for achieving stable interim storage and disposal of aluminum spent fuel from research reactors. A Record of Decision is expected to be issued by April or May 1999. Of the eight processing alternatives considered in this environmental impact statement, three have merited extensive evaluation: melt and dilute, direct codisposal, and conventional processing. The purpose of this report is to examine the inventory of aluminum spent fuel from research reactors and the alternatives being considered for its processing.

Section 2 of this report reviews the spent fuel inventory at SRS, while Section 3 summarizes its storage. Section 4 provides a brief history of DOE's decision making on the stabilization, storage, and disposal of SRS spent fuel. Section 5 describes the melt and dilute, direct codisposal, and conventional processing alternatives. Section 6 provides a comparison of these processing alternatives, along with a cost comparison. Finally, Section 7 presents a summary and conclusions.

2. SPENT FUEL INVENTORY

As noted in Section 1, the SRS spent nuclear fuel inventory can be divided into three categories: aluminum defense-related spent fuel, nonaluminum spent fuel, and aluminum spent fuel from research reactors. The current inventory of these categories of spent fuel at SRS is shown in Table 1. Table 1 also presents the projected additions to this inventory from off site receipts through 2035.

2.1 Aluminum Defense-Related Spent Fuel

The aluminum defense-related spent fuel, consisting of Mark 16 and 22 spent fuel assemblies, is composed of a highly enriched uranium-aluminum alloy with aluminum cladding. Long-term wet storage of this spent fuel, aggravated by poor water chemistry control and galvanic coupling, has resulted in significant pitting corrosion damage. The Defense Nuclear Facilities Safety Board (Board) addressed the need to expedite stabilization of this fuel in Recommendation 94-1 (Defense Nuclear Facilities Safety

Table 1. Savannah River Site Spent Fuel (Current Inventory and Projected Additions)

Category	Current Inventory		Additions Through 2035	
	No. of Items*	Weight (MTHM)**	No. of Items*	Weight (MTHM)**
Aluminum Defense-Related Spent Fuel	1,800	7	0	0
Nonaluminum Spent Fuel	1,200	20	0	0
Aluminum Research Reactor Spent Fuel	5,600	20	23,000	24
Total	8,600	47	23,000	24

* "Item" generally refers to a fuel element. The unique configurations of the various types of defense-related and research reactor spent fuel prevent use of a consistent unit.

** MTHM = metric tons of heavy metal (meaning the amount of uranium, thorium, or plutonium).

Source: B. Clark and C. Brizes, DOE-Savannah River Operations (personal communication, June 29, 1998); Westinghouse Savannah River Company (January 1998).

Board, May 26, 1994). The Board advised DOE that the best alternative for accomplishing this stabilization was conventional processing using the SRS canyon facilities (Defense Nuclear Facilities Safety Board, November 1, 1995). Although dry storage followed by direct disposal in a repository was evaluated for this fuel, the time required to develop new processes and facilities, as well as the technical uncertainty of the acceptability of the resulting dry fuel for ultimate disposal, led DOE to conclude that the best course of action was to process the fuel in the SRS canyons (Defense Nuclear Facilities Safety Board, August 3, 1995; U.S. Department of Energy, October 20, 1995, and February 21, 1996).

Processing of the 1800 assemblies of aluminum defense-related spent fuel (i.e., the Mark 16 and 22 fuel assemblies) began in July 1997 and is scheduled to be completed in early 2002. The stabilization process chosen for this fuel was well defined and utilized proven processes in existing facilities. In addition, ultimate disposal is ensured by utilizing currently operating processes and facilities to produce a vitrified glass waste form that is qualified for disposal in a geologic repository. The progress made thus far in stabilizing the defense-related spent fuel can be attributed to the fact that significant technology development and subsequent facility design and construction were not required. The enriched uranium recovered from the processing of this fuel will be isotopically diluted to about 5 percent enrichment and used as feed for commercial fuel.

2.2 Nonaluminum Spent Fuel

The nonaluminum spent fuel consists of a large variety of stainless-steel and zirconium-clad fuel. The materials of construction are important because they are much more durable than aluminum and more resistant to corrosion. These materials are also resistant to the chemical processes currently used at the SRS canyons. In the past, stainless-steel spent fuel from research reactors was processed at SRS using an electrolytic dissolver in the H-Canyon. This equipment is still installed, but would require some upgrades to allow resumption of operations. Zirconium-clad fuel was never processed at SRS, but mechanical operations could be employed to expose dissolvable fuel meat to the dissolution chemicals used in the canyons. Without facility modification to provide either of these mechanical operations or an alternative dissolution process, these fuels cannot be processed through the SRS facilities.

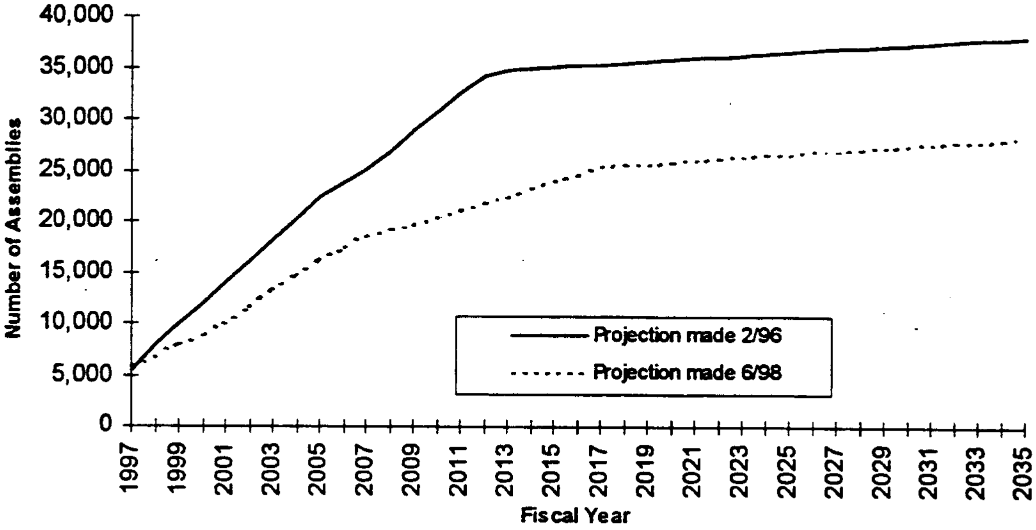
DOE has decided to consolidate similar fuel types for interim storage and preparation for ultimate disposal (U.S. Department of Energy, April 1995 and May 30, 1995). Nonaluminum fuel is to be consolidated at INEEL. All nonaluminum spent fuel stored at SRS is to be shipped to INEEL. Similarly, aluminum spent fuel is to be consolidated at SRS, and all aluminum spent fuel currently stored at INEEL is to be shipped to SRS. Interim safe storage and ultimate disposal of nonaluminum spent fuel are being pursued at INEEL. The alternatives being evaluated and their potential for success are not considered in this report.

2.3 Aluminum Spent Fuel from Research Reactors

The aluminum research reactor spent fuel comes from both foreign and domestic research and test reactors. A great variety of physical forms, sizes, and enrichments is associated with this spent fuel. Most of this fuel is of the Materials Test Reactor type and consists of uranium-aluminum, uranium oxide-aluminum, or uranium silicide-aluminum alloy with aluminum cladding. There is also some fuel that is of similar construction to the Materials Test Reactor type, but in differing shapes and sizes. A significant amount of fuel is in the form of loose uranium-oxide powder stored underwater in aluminum cans. There is also uranium and thorium metal fuel, either clad in aluminum or declad and packaged in aluminum canisters. A large portion of the aluminum spent fuel from research reactors is highly enriched, with a uranium-235 enrichment ranging from 20 percent to more than 90 percent.

The total SRS inventory of aluminum spent fuel from research reactors consists of the existing inventory at SRS, the projected inventory to be received from foreign and domestic research reactors, and the inventory of aluminum spent fuel to be received from INEEL. Figure 1 shows the projected total inventory through 2035. Examination of this figure reveals two significant points.

First, current projections of the total SRS inventory of this fuel are significantly lower than earlier estimates. The expected receipts from both foreign and domestic research reactors have been reduced. Foreign receipts have been reduced by about 40 percent because several foreign operators of research reactors (Belgium, France, Iran, Pakistan, South Africa, and Netherlands-HFR Petten Reactor) have opted not to return their spent fuel to DOE. Two other foreign reactor operators (Canada and Netherlands-Delft Reactor) have expressed uncertainty and are evaluating whether to return their fuel. Should these two additional reactor operators not participate, the amount of foreign research reactor fuel expected to be received at SRS would be reduced by almost 70 percent from that originally projected. Moreover, a significant number of the remaining foreign reactor operators expected to return spent fuel to the United States have requested to delay their participation until the end of the DOE program (i.e., to not return fuel until 2006 to 2009). It would not be improbable between now and 2009 for some of these remaining countries to elect not to return their research reactor fuel to DOE.



Source: B. Clark and C. Brizes, DOE-Savannah River Operations (personal communication, June 29, 1998); Westinghouse Savannah River Company (February 1996).

Figure 1. Inventory of Aluminum Spent Fuel from Research Reactors, Savannah River Site

The amount of domestic research reactor fuel expected to be received at SRS has also been reduced by about 40 percent from earlier estimates. Unlike the foreign research reactors, the domestic reactors have no alternative to returning their spent fuel to DOE. The 40 percent reduction in the amount of the domestic fuel is due instead to the permanent shutdown of several reactors. Given the age and use of many of the domestic research reactors, there are likely to be additional reductions in the fuel expected to be received at SRS from domestic sources.

The second point illustrated by Figure 1 is that most of the projected SRS inventory of aluminum spent fuel from research reactors is to be received during the first half of the planning period. Figure 2 illustrates the currently projected yearly receipts of this fuel at SRS. For the fuel from domestic reactors, the backlog is expected to be received at SRS by the year 2000. The remaining projected receipts from these reactors through 2035 are based on long-range projections from only a handful of reactors. All of the foreign inventory is to be received by 2009. Finally, the aluminum spent fuel stored at INEEL is currently scheduled to be received at SRS during 2010–2017.

Scheduling of the shipment of aluminum spent fuel from INEEL to occur after the foreign shipments have been completed in 2009 represents an attempt to level out the receipt of spent fuel at SRS. A reduction in the projected returns from foreign research reactors, as discussed above, or a more aggressive rate of receipt would allow the INEEL shipments to be made earlier. This in turn would cause the fuel receipt profile to be even more exaggerated toward the early years of the planning period. Figure 3 illustrates the result of accelerating the shipment of spent fuel from INEEL to SRS to occur during 2002–2009.

Both Figures 2 and 3 show a small but protracted 'tail' of fuel receipts projected out to the year 2035. This tail is based on the estimated future generation of spent fuel from the following domestic research reactors:

- University of Missouri Research Reactor
- University of Michigan Ford Nuclear Reactor
- Massachusetts Institute of Technology Research Reactor
- National Bureau of Standards Reactor
- Brookhaven Medical Research Reactor
- Brookhaven High Flux Beam Reactor
- Oak Ridge High Flux Isotope Reactor

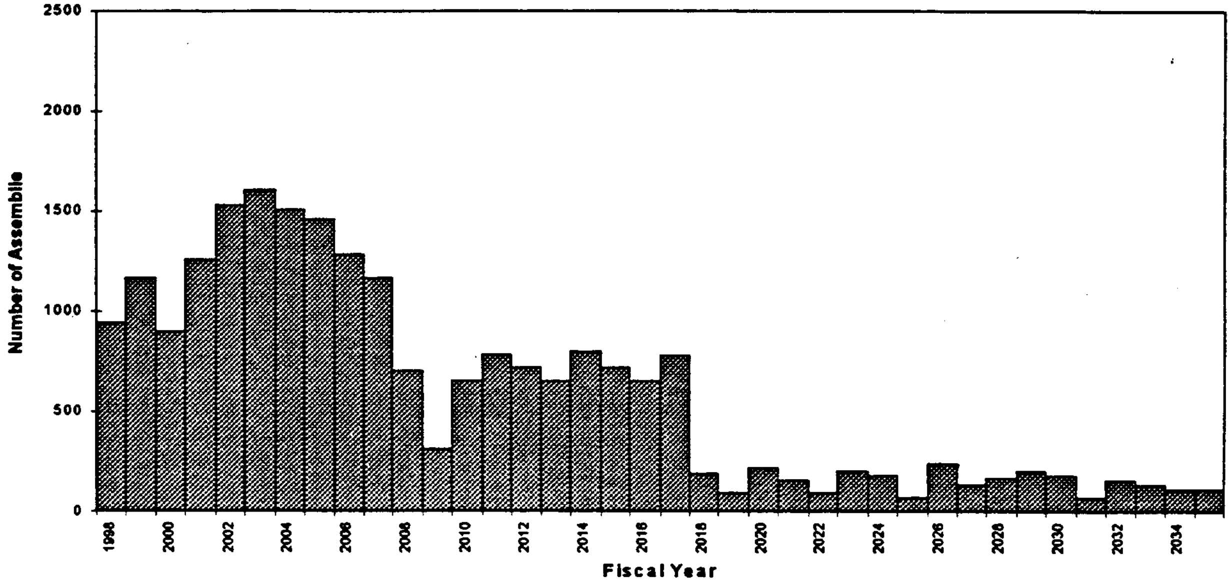


Figure 2. Receipt of Aluminum Spent Fuel at SRS

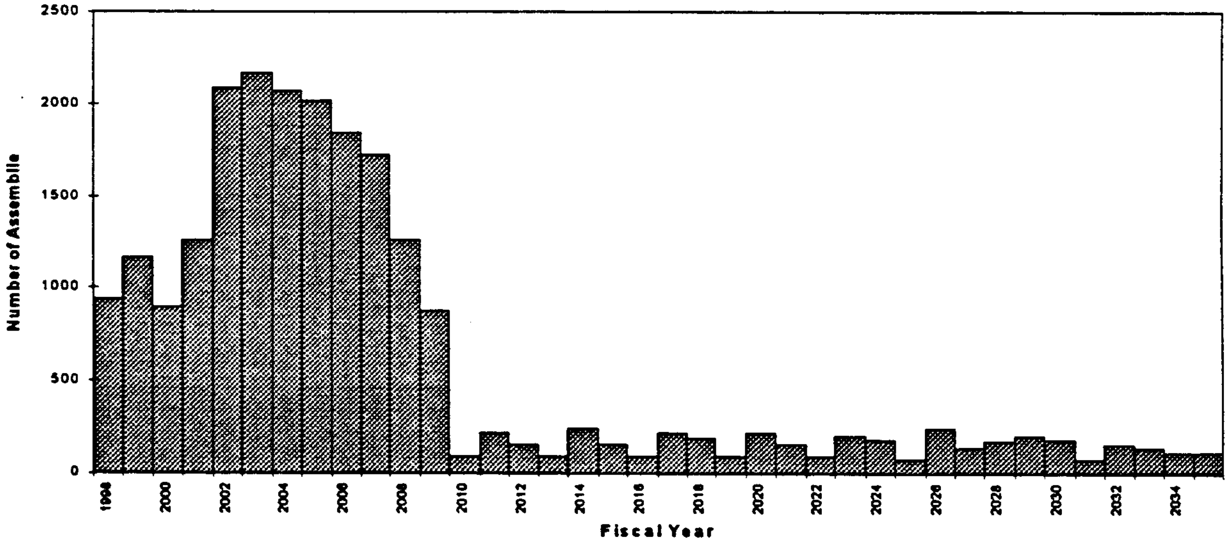


Figure 3. Receipt of Aluminum Spent Fuel (accelerated receipts from INEEL)

The above inventory projections assume constant production of spent fuel from these seven domestic research reactors through 2035. There is considerable uncertainty in this assumption. The age of these reactors currently ranges from about 30 to 40 years; by 2035, the age of these reactors will range from about 70 to 80 years. In addition, almost half of the spent fuel projection making up the tail in Figures 2 and 3 is from the Brookhaven High Flux Beam Reactor, which is currently shut down. The decision on whether to restart this reactor is pending.

The above projections of future fuel receipts affected the way DOE approached the evaluation of alternatives for its aluminum spent fuel. DOE assumed that the existing canyon processing capabilities at SRS would not be maintained beyond the year 2010. With this constraint, and with significant fuel receipts projected for 2010–2035, the conventional processing alternative would have to utilize canyon processing until 2010 and then implement a new replacement treatment capability. It is interesting to note that even under this scenario, the conventional processing alternative remains financially competitive with the melt and dilute and direct codisposal alternatives.

As discussed earlier, the amount of spent fuel projected toward the end of the planning period may be grossly overestimated. Also, 10–15 years from now, the fuel type used in a refurbished 50-year-old research reactor or in a new replacement research reactor may not be compatible with any of the processing alternatives currently being considered. DOE's decision process appears to have been too heavily influenced by these questionable projections of fuel inventories 15–40 years from now.

3. SPENT FUEL STORAGE

Interim management of spent nuclear fuel at SRS consists of storage in three water-filled storage basins: K-Reactor storage basin, L-Reactor storage basin, and RBOF.

The inventory in the K-Reactor storage basin consists of Mark 16 and 22 aluminum defense-related spent fuel. The K-Reactor storage basin is expected to be deinventoried of spent fuel by the end of 2000, when the last of its inventory is transferred to the H-Canyon for processing.

The inventory in the L-Reactor storage basin consists of Mark 16 defense-related spent fuel plus the research reactor spent fuel that has been placed in storage there since 1997. By the end of 2001, all of the Mark 16 spent fuel will have been transferred to the H-Canyon for processing. The L-Reactor storage basin will then continue to store aluminum spent fuel received from both foreign and domestic research reactors.

The RBOF inventory consists of a large variety of both aluminum and nonaluminum research reactor spent fuel. The nonaluminum fuel is scheduled to be transferred to INEEL. RBOF will then continue to store the aluminum fuel.

Several vulnerabilities have been identified with wet storage of spent fuel at SRS. Severe water chemistry problems and significant fuel corrosion have been experienced periodically in the K- and L-Reactor storage basins. The Board addressed the susceptibility of aluminum spent fuel to corrosion in DNFSB/TECH-7, *Stabilization of Deteriorating Mark 16 and Mark 22 Aluminum-Alloy Spent Nuclear Fuel at the Savannah River Site*, which led to expedited stabilization of corroded defense-related spent fuel in the H-Canyon. In addition, to improve storage conditions pending stabilization, the water quality and chemistry control capabilities at both the K- and L-Reactor storage basins were recently upgraded.

The RBOF facility has historically maintained very good water chemistry. Even so, some especially susceptible aluminum spent fuels stored at RBOF have experienced failure, prompting decisions to stabilize these fuels by processing them in the SRS canyons.

Successful long-term storage of aluminum spent nuclear fuel depends on maintaining high-purity water. However, corrosion behavior is difficult to predict. For example, some amount of corrosion at preexisting sites of pitting or other clad damage can continue even under excellent water chemistry conditions. Also, recent studies at RBOF have noted the presence of microorganisms and biofilms that could contribute to microbial-influenced corrosion of the aluminum spent fuel (Westinghouse Savannah River Company, June 1, 1998).

Most of the aluminum research reactor fuel being stored at SRS is in generally better condition than the defense-related fuel stored in the reactor disassembly basins. Water and fuel conditions in RBOF and the L-Reactor storage basin are being closely monitored for signs of water chemistry changes, fuel corrosion, or microbial activity. Even so, there is no fundamental disagreement on the vulnerability of aluminum fuel in wet basin storage.

Some of the aluminum spent fuel from research reactors has already been stored in water basins for up to 40 years. A small portion of this fuel has experienced significant cladding corrosion. Some the fuel being returned from foreign reactors is sufficiently corroded to require aluminum canister overpacks before being stored in the SRS water basins. Also, a portion of the research reactor spent fuel is in a form that is particularly susceptible to corrosion during wet storage. Examples of such forms include uranium metal fuels that have been declad, fuel that has been cut up for research purposes, and loose uranium oxide spent fuels, all of which have been packaged in aluminum canisters for storage in the SRS water basins.

DOE has stated its general commitment to avoiding long-term storage of spent nuclear fuel in wet storage basins (U.S. Department of Energy, February 1996 and December 1998a). When specific cases are considered, such as damaged or declad fuel, the need to remove the fuel from long-term wet storage is even more pressing.

4. HISTORY OF DOE'S DECISION MAKING ON SPENT FUEL

The history of DOE's decision making related to the stabilization, storage, and disposal of SRS spent nuclear fuel starts with the 1992 decision to stop reprocessing of spent fuel for the purpose of producing defense nuclear materials (U.S. Department of Energy, April 28, 1992). In announcing this decision, DOE stated that phaseout plans should "include processing of existing inventories of aluminum clad fuel at SRS as well as fuel receipts while stabilization is being conducted." DOE noted that processing of the aluminum spent fuel "will result in less than a two percent increase in high-level waste" and "will also relieve potential near-term fuel storage problems...." However, because canyon processing had been shut down, the existing inventory of aluminum fuel at SRS could not be processed. Instead, the spent fuel inventory remained in underwater storage. The DOE spent fuel and related facilities were designed for reprocessing, not for long-term storage underwater, and the shift in activities from reprocessing to longer-term storage soon began to evidence problems.

Starting in March 1993, the Board's staff began reviewing the storage of DOE-owned spent nuclear fuel. In November 1993, DOE issued the *Spent Fuel Working Group Report on Inventory and Storage of the Department's Spent Nuclear Fuel and Other Reactor Irradiated Nuclear Materials and Their Environmental, Safety and Health Vulnerabilities*. This report identified existing and developing problems associated with the long-term storage of spent fuel. DOE has expended considerable resources in addressing these vulnerabilities.

The Board's Recommendation 94-1, *Improved Schedule for Remediation in Defense Nuclear Facilities Complex*, was issued in May 1994. This recommendation, focused on DOE's defense-related nuclear materials, expressed special interest in the large amounts of deteriorating spent fuel stored in canyons and reactor storage basins, and recommended that DOE expedite the processing of this fuel into a form suitable for safe storage. DOE's Implementation Plan for this recommendation was issued in February 1995 and proposed the use of conventional processing to stabilize the aluminum defense-related spent fuel at SRS.

In May 1995, DOE decided to consolidate similar fuel types. This decision resulted in plans to send all aluminum spent fuel to SRS and nonaluminum spent fuel to INEEL. One exception to this consolidation plan is the small amount of aluminum fuel from production reactors at the Hanford K-Basin facility. This fuel was thought to be best managed together with the N-Reactor fuel at Hanford. A more recent evaluation has led to the recommendation that this aluminum fuel be considered for processing in the SRS canyons (U.S. Department of Energy, May 6, 1998).

In December 1995, February 1996, and April 1997, DOE issued decisions to use canyon processing to stabilize a significant amount of SRS aluminum fuel. These decisions resulted in successful processing of about 16,000 aluminum defense-related Mark 31 targets, successful processing of all of the aluminum spent fuel from the Taiwan Research Reactor stored at SRS, and successful processing of a leaking canister of Experimental Breeder Reactor-II spent fuel. In addition, these decisions led to the current processing of the aluminum defense-related Mark 16 and Mark 22 spent fuel.

In May 1996, DOE issued a Record of Decision (ROD) for the Foreign Research Reactor Environmental Impact Statement (FRR EIS), establishing a 10-year policy to accept and manage aluminum spent fuel from foreign research reactors. The return of this spent fuel would result in a substantial amount of spent fuel at SRS. To avoid continued long-term wet storage of this fuel, the FRR EIS attempted to select a process for establishing a stable long-term storage configuration and ultimately a path for the fuel's disposal. Conventional processing was an alternative for accomplishing this stabilization and disposal, but one premise of the FRR EIS was avoidance of conventional processing as a result of nonproliferation concerns.

Because ready alternatives to conventional processing were not available, the ROD proposed that the development of alternative technologies be initiated. The undesirability of continued wet basin storage of the aluminum spent fuel while these alternative technologies were being developed prompted DOE to limit the development time; if the new technology could not be implemented by 2000, conventional processing would be used. In addition, because some of the aluminum fuel was known to be damaged and especially vulnerable to wet basin storage, the ROD provided for conventional processing of any aluminum spent fuel from foreign research reactors that presented a health and safety concern. To help in the decision making on how to stabilize and dispose of the aluminum spent fuel, the ROD proposed the conduct of additional studies of the proliferation risks, costs, and timing associated with conventional processing.

DOE has prepared an SRS Spent Nuclear Fuel Management Environmental Impact Statement (SNF EIS) to assist in selection of a processing alternative for achieving stable interim storage and disposal of the aluminum spent fuel. A ROD is expected to be issued by April or May 1999. The SNF EIS represents an attempt to complete the decision-making process for determining the stabilization and disposal of the remaining aluminum spent fuel at SRS. As noted earlier, although DOE presents eight alternatives in the SNF EIS, only three of these have merited close examination: melt and dilute, direct codisposal, and conventional processing.

DOE has sponsored several studies and reviews whose results will be factored into its decision on a processing alternative. Some of these are discussed below.

Research Reactor Spent Nuclear Fuel Task Team Report (U.S. Department of Energy, May 1996 and June 1996). As proposed by the FRR EIS ROD, DOE sponsored a task team to evaluate eleven potential alternative technologies for processing of aluminum spent fuel. In the final draft of this report, conventional processing was used as a baseline and was scored significantly higher than the alternative technologies in terms of confidence in success, cost, technical suitability, and timeliness. However, in the final version of this report, conventional processing was removed, and only the relative scores of the alternative technologies were given. The report concluded that direct codisposal should be pursued as the primary processing alternative, with melt and dilute (or press and dilute) used as a backup.

The task team report also identified certain aluminum domestic spent fuels the team believed should be processed using the conventional processing capability at SRS, regardless of the alternative technology selected. These included metal fuel (especially susceptible to corrosion), particulate or powdered fuel (readily dispersible, requiring special handling, and difficult to qualify for direct disposal), and one-of-a-kind fuel (requiring special handling or canning). These fuels were listed in Table 5.2-1 of the final report, and so have become known as the Table 5.2-1 fuel. DOE is proposing to follow this recommendation and process the Table 5.2-1 fuel, which represents about 3 percent (by volume) of the total projected SRS inventory of aluminum research reactor fuel, in the SRS canyons. A similar category of fuel, identified as Table 5.2-2 fuel, consists of spent fuel from foreign research reactors expected to be received in powdered form. The Table 5.2-2 fuel, which represents a significant amount of powdered fuel, is still planned to undergo DOE's proposed melt and dilute process. The distinction between the Table 5.2-1 powdered spent fuel and the Table 5.2-2 powdered spent fuel appears to be arbitrary.

Spent Nuclear Fuel Alternative Technology Decision Analysis (Westinghouse Savannah River Company, June 26, 1998a). In this analysis, Westinghouse Savannah River Company (WSRC) weighed the relative merits of the direct codisposal and melt and dilute alternatives and recommended that DOE use the melt and dilute process to replace conventional processing. However, WSRC also suggested that uncertainty in repository requirements made it prudent to continue development of the direct codisposal alternative as a backup technology. The conventional processing alternative was not considered in this analysis.

National Research Council Review (National Research Council, 1998). This review evaluated the alternatives being considered to replace conventional processing. The report generally concluded that DOE was seeking a definitive solution to a problem that was not yet well defined, before the information needed to make sound choices was available. DOE was therefore encouraged to apply a phased strategy for selection and implementation of a processing alternative. The report pointed out the uncertainty in future fuel receipts; the poorly defined waste acceptance requirements; and the uncertainties of cost, performance, and safety of unproven technologies. The report also concluded that there appeared to be no technical basis for rejecting conventional processing and that "DOE should have given more careful consideration to the conventional reprocessing option for treating aluminum spent fuel" (p. 7). The report stated that conventional processing "has been demonstrated for aluminum spent fuel ..., the costs and risks are well known, the necessary facilities are currently in operation at Savannah River, and the waste form (borosilicate glass) will likely be acceptable for disposal at the repository" (p. 7).

DOE-Sponsored Multi-Attribute Utility Decision Analysis (Sandia National Laboratories, May 23, 1998). This decision analysis, conducted at Sandia National Laboratories, weighed the relative merits of two of the DOE alternatives: direct codisposal and melt and dilute. The conclusion reached was that the melt and dilute alternative is preferable to direct codisposal. Traditional canyon processing was not considered in this analysis.

Nuclear Regulatory Commission Review (Nuclear Regulatory Commission, June 5, 1998). DOE requested that the Nuclear Regulatory Commission conduct a topical review of the melt and dilute and direct codisposal alternatives. The report resulting from this review concluded that although additional development work was required, both melt and dilute and direct codisposal would be acceptable concepts for the processing of aluminum research reactor spent fuel. The issues identified as requiring additional work included the degradation of the fuel during interim storage in the road-ready canister; postclosure criticality; and the partitioning of radionuclides in melted fuel among slag, alloy, and offgas. Canyon processing was not considered in this review.

Westinghouse Savannah River Company Cost Study (Westinghouse Savannah River Company, December 1997 and May 1998; and U.S. Department of Energy, December 1998b). This study compared annual, 10-year, and life-cycle costs for variations on the direct codisposal, melt and dilute, and conventional processing alternatives. As described earlier, all of the variations on conventional processing call for canyon processing until 2010, followed by use of a new treatment capability. Even so, the conventional processing variations were found to be cost-effective, especially during the first decade. One exception was an alternative involving the construction of a new conventional processing facility.

Nonproliferation Assessment (U.S. Department of Energy, December 1998a). This assessment was performed to meet the commitment for an "independent study of the nonproliferation...implications of chemical separation of spent nuclear fuel from foreign research reactors" made in DOE's ROD for the FRR EIS. Rather than limit the scope to chemical separation, this study evaluated the nonproliferation implications of all technology alternatives being considered by DOE for stabilization and disposal of the aluminum spent fuel. This assessment reached several conclusions, including that "all of the options would be consistent with U.S. nonproliferation policy...." (p. ES-11), and "all of the options have the potential to support fully U.S. efforts to reduce the civil use of HEU...." (p. ES-11). However, this assessment generally concluded that the Office of Arms Control and Nonproliferation "views the melt and dilute recommendation as a favorable technology in light of nonproliferation concerns. A decision to reprocess a majority of the aluminum-based spent fuel at the Savannah River Site could negatively affect the credibility of U.S. policy not to encourage reprocessing. Such a decision would also extend the period of time that reprocessing operations must continue at the Savannah River Site - making it more difficult for U.S. efforts to convince other nations not to pursue fuel cycles that increase proliferation risks" (p. 4.2).

5. DESCRIPTION OF PROCESSING ALTERNATIVES

This section describes the three processing alternatives that have merited close examination: melt and dilute, direct codisposal, and conventional processing.

5.1 Melt and Dilute

The proposed melt and dilute alternative involves melting a mixture of spent fuel and depleted uranium to reduce both volume and enrichment. The current proposal for implementing this process locates the melt and dilute operation within the existing L-Reactor facility. Melt and dilute is a new technology, so the following description of the process is largely conceptual.

All of the spent fuel is assumed to be stored or staged in the L-Reactor storage basin. Spent fuel that is not already stored in the L-Reactor storage basin, such as that stored at RBOF or not yet received on site, is assumed to be transported, received, and unloaded into the L-Reactor storage basin.

Pretreatment characterization requirements are unknown at this time. Although extensive analysis may be required, the sampling and analysis of the melted fuel would be much more straightforward than characterizing the large variety of intact fuel elements.

The aluminum spent fuel is stored in various arrangements (e.g., shipping cans, bundles, tubes). This fuel is disassembled as required, and some portions of the nonfuel aluminum are cropped or removed by means of underwater cutting. Some fuel types, such as the High Flux Isotope Reactor cores, require special size reduction, accomplished by cutting the fuel area or by crushing. The cropped and sized fuel is transferred into the L-Reactor processing area using an existing transfer canal. Once in the processing area, the fuel is staged in drip-dry fuel storage racks to await the melting operation. From the staging racks, the fuel is transferred to a drying oven or rack, where an elevated air temperature (200°C) is maintained to preheat and further dry the fuel. All liquid water must be removed from the fuel to prevent a melt-water interaction or steam explosion that could expel molten fuel from the furnace. Additional puncturing and drying activities are necessary to accommodate aluminum canisters or overpacks that may be used to handle cut-up fuel pieces or loose oxide. These canisters require special care to prevent pressurization in the furnace and to ensure that all liquid water is eliminated.

The dried spent fuel is charged into a furnace crucible, melted, heated to above the alloy liquidus temperature, and stirred. A sample is drawn from the melt and transferred out of the process area for quick analysis of total uranium concentration and uranium isotopic concentration. Based on sample results, appropriate amounts of depleted uranium and aluminum are added to the crucible to achieve both the desired uranium-235 enrichment and the desired alloy composition. This 'recipe' is based on the sampling results, as well as on the type of fuel (i.e, uranium-aluminum alloy, uranium-silicide, or uranium-oxide). Preliminary criticality evaluations indicate that the addition of neutron poisons may also be required. The added materials are melted, and the mixture is maintained at a temperature of at least 850°C, and possibly 1000°C or higher. Induction currents are used to stir the mixture. At elevated temperatures, some of the fission products volatize. The furnace is maintained at negative pressure by an offgas system that captures the fission products (with the exception of noble gases, such as krypton) and exhausts to an existing ventilation stack.

A second sample is drawn from the melt and transferred out of the process area for composition analysis. This second sample confirms the final uranium concentration and alloy composition, as well as providing other necessary characterization data. The melted mixture is allowed to harden in the crucible.

When the fuel melt is solid and cooled, it is removed from the crucible, conveyed to a shielded transfer cell, and loaded into a shielded canister. The canister is about 17 inches in diameter and about 120 inches long and accommodates several fuel melts. Using a shielded transfer cask, the filled canister is conveyed to a canister preparation station where the canister is backfilled with helium, welded closed, and leak tested. Finally, the transfer cask is loaded onto a transporter and transferred to modular dry storage units outside the L-Reactor facility. The fuel is stored on site in these modular dry storage units pending transfer to the geologic repository.

5.2 Direct Codisposal

The proposed direct codisposal alternative involves packaging the spent fuel without changing the fissile material enrichment and without significantly altering the volume. As with the melt and dilute alternative, packaging operations are located within the existing L-Reactor facility. Also as with the melt and dilute process, the following description is largely conceptual.

All of the spent fuel is assumed to be in storage at the L-Reactor water storage basin. Spent fuel that is not already stored in the L-Reactor water storage basin, such as fuel stored at RBOF or fuel not yet received on site, is assumed to be transported, received, and unloaded into the L-Reactor water basin.

Pretreatment characterization requirements are currently unknown, but will be based on repository acceptance criteria, which are still being defined. Depending on the data determined necessary to meet repository requirements, characterization activities could be extensive. Data from fuel shipping papers do not always meet repository quality assurance requirements. Also, in contrast with commercial fuel, the property data and operation history for research reactor fuel range from good to nonexistent. Initial assessments indicate that the characterization requirements for direct codisposal will be significant, involving visual, thermal, neutron, gamma, and weight measurements.

As with the melt and dilute alternative, the fuel is disassembled as required, and some portions of the nonfuel aluminum are cropped or removed by means of underwater cutting. The cropping of the fuel assemblies to eliminate most of the nonfuel structural components reduces the volume of spent fuel.

Drying of the cropped fuel might be accomplished by removing the fuel from water storage and performing a drying operation similar to the drip-dry and preheat done for the melt and dilute process. In this case, the dried fuel would then be loaded into a dry storage canister. Alternatively, the fuel might be loaded underwater into a dry storage canister, and then undergo a water removal and drying process while in the canister. In either case, the assemblies would be vacuum-dried to remove free water.

Because of the enrichment of the research reactor spent fuel, neutron poison must be added to the canister, probably incorporated into baskets that serve to separate the fuel elements. The loaded canister will likely be vacuum sealed or backfilled with helium prior to weld sealing. Drying requirements must address maximum residual free water within the sealed canister to limit corrosion and hydrogen gas generation. Acceptance testing is required to verify various attributes of the package, such as residual water content and leak tightness.

The dry storage canister has a diameter of about 17 inches and a height of about 120 inches. Three to four baskets of fuel are stacked within each canister. After external decontamination, the dried, sealed fuel is generally considered road-ready because no further characterization, conditioning, or other handling is necessary before shipping. However, depending on the storage configuration, the canisters may require packaging into shipping casks and may need venting to relieve buildup of hydrogen pressure prior to shipping.

The canister temperature is limited to 200°C during interim storage to avoid excess creep and the potential for hydrogen blistering of the aluminum fuel and cladding materials during drying and storage. The heat transfer properties of the helium backfill result in lower temperatures and reduced degradation rates. The helium backfill also provides an inert atmosphere in the event that hydrogen generation should exceed 4 percent by volume.

Several requirements related to retrievability are likely to be imposed. Retrievability requirements define "the acceptable degradation or change in condition of the direct-stored [aluminum spent fuel] form that is allowable during the interim dry storage period. The requirement is based on engineering judgment to provide for ready removal of the fuel from a canister and handleability of the fuel" (Westinghouse Savannah River Company, October 1997, p. 3.4). Retrievability requirements address general corrosion or pitting corrosion (less than 0.003 inches in depth in spent fuel cladding or in exposed fuel material), plastic deformation of the fuel (less than 1 inch over a 3-foot length and deformation less than 75 percent of the clearance space between the fuel and the storage grid), and fuel rupture due to creep or severe embrittlement. There may also be a need for statistical sampling to ensure canister integrity and to verify compliance with waste acceptance criteria prior to transportation to a geologic repository.

One significant disadvantage of the direct codisposal alternative is that the scope of fuels to be processed is generally limited to the Materials Test Reactor design. The larger involute design (High Flux Isotope Reactor and Reacteur à Haut Flux) and longer pin design fuels cannot be accommodated, nor can the loose oxide fuel and metal fuels.

5.3 Conventional Processing

The conventional processing alternative described here is currently being used to stabilize aluminum defense-related spent fuel, as well as some of the foreign research reactor spent fuel. Because this alternative involves an operating facility and not a new technology, only a cursory description is provided.

Spent fuel, currently stored in RBOF or the L-Reactor water storage basin, is loaded in transportation casks and transferred to the H-Canyon via the site rail. At the H-Canyon, the spent fuel is unloaded and either placed into temporary staging storage or charged directly to the dissolver.

The fuel cladding and fuel meat are dissolved using hot nitric acid, which results in a solution of uranium, aluminum, fission products, and small amounts of transuranics (neptunium and plutonium). This solution is clarified by precipitation and centrifuge to remove certain impurities. It is then separated using a solvent extraction process into a waste stream, containing fission products and small amounts of transuranics, and a purified uranium stream.

The waste stream is neutralized and sent to the high-level waste storage tanks, adding to the current SRS inventory. The purified uranium stream (uranyl nitrate solution) is isotopically blended with depleted uranium solution to an enrichment of about 5 percent, and used as feed for commercial reactor fuel.

6. COMPARISON OF PROCESSING ALTERNATIVES

This report is concerned with risks to workers, the public, and the environment. The processing alternatives being proposed for the stabilization and disposal of the remaining aluminum spent fuel at SRS are examined here from the perspective of reducing the risks associated with operating the process, reducing the risk that the process might not be successful in providing for stable interim storage and ultimate disposal, and maximizing utilization of the limited resources available for risk reduction.

All of the processing alternatives considered involve risks to workers, the public, and the environment. The draft SNF EIS attempts to compare the risks associated with the various alternatives. However, the quantification of risks in the SNF EIS requires the comparison of numbers that are, because of the large uncertainties involved, generally below our ability to discriminate. For example, the estimated number of latent cancer fatalities in the SRS offsite population as a result of more than 35 years of fuel treatment is estimated to be 0.0034 for DOE's preferred alternative and 0.0044 for the maximum impact alternative. Likewise, the latent cancer probability for the maximally exposed member of the public is estimated to be 9.5×10^{-8} for DOE's preferred alternative and 3.3×10^{-7} for the maximum impact alternative. For site workers receiving no more than the allowed annual administrative radiation dose during the same period, the estimated latent cancer probability is reported as 2.8×10^{-3}.

These risk quantities are not very useful for discriminating among the alternatives. Furthermore, the risk estimates reported in the draft SNF EIS represent mitigated risk, and so include significant assumptions that may be inappropriate. For instance, the proposed melt and dilute processing alternative is to be located in the L-Reactor facility, but in estimating the release of radionuclides, the draft SNF EIS assumes that the process is implemented in a converted process cell of one of the SRS canyons (Westinghouse Savannah River Company, March 25, 1997). This assumption could result in a considerable underestimation of releases if the confinement afforded by the canyon structure and ventilation system is not achieved in the L-Reactor facility.

To compare the risk involved in operating the processing alternatives, this report emphasizes the new or unique risks that would be introduced. Although this approach results in a bias for the existing technology, it is a justified bias. Given a process with known and familiar hazards, it is possible to take advantage of previously developed experience and expertise to eliminate or mitigate these hazards. Unless a new technology offers significant risk reduction, risks that have been addressed and successfully mitigated during the course of several decades are more palatable than new risks that may not be well defined or understood and for which mitigation approaches have not yet been developed.

Besides the risks associated with operating the process, there is also risk associated with not implementing the process successfully, with experiencing substantial delay in the implementation of the process, or with failing to achieve ultimate disposal of the spent fuel. The longer the aluminum spent fuel is allowed to remain in interim storage in wet basins, the greater is the possibility of chemistry/corrosion problems, handling difficulties, criticality incidents, contaminations, and so on. Additionally, there is the risk of producing a material form that turns out to require further treatment, handling, or processing in order to meet repository acceptance requirements. Therefore, in comparing processing alternatives, this report also examines the risks and uncertainties associated with their successful implementation.

DOE faces a substantial task in stabilizing and cleaning up legacy nuclear material. The Board has focused on the stabilization of certain high-priority materials through various recommendations, especially Recommendation 94-1. However, DOE does not have unlimited resources. In general, large expenditures in one area challenge the resources available for other areas. It is prudent to compare the costs of the processing alternatives, since these costs represent resources that would be unavailable for addressing other conditions within the DOE complex. Such a cost comparison is provided at the end of this section.

6.1 Melt and Dilute

6.1.1 Risks Associated with Operating the Process

Melter Offgas. The melt and dilute process would require an offgas treatment system to remove volatile radioisotopes in the gases and vapors that would result from melting the fuel. In general, hot volatilized fission products would be condensed onto cooler surfaces. Cesium, for example, boils at 671°C and will condense on surfaces kept below this temperature. Baffles or other media maintained at below about 600°C could be positioned in the offgas stream to condense volatilized fission products. The condensing medium would also serve to cool the offgas in order to protect downstream high-efficiency particulate air (HEPA) filters. Radioactive particulates not collected onto the condensing medium would be captured downstream on these HEPA filters. Tritium, iodine, krypton, and other gaseous radionuclides would probably not be captured and would be released. Since the melting point for the uranium-aluminum alloy fuel is low (approximately 630°C), the mobility of fission products in the fuel above this temperature is quite high. Very little time is required for fission products to be released from the molten fuel once the boiling point of the fission products has been exceeded. Also, higher boiling point elements can sometimes associate with more volatile species and be released at temperatures lower than their boiling point. Studies have concluded that the ideal melting point for the diluted uranium-aluminum mixture would be near 850°C (Westinghouse Savannah River Company, October 1997). However, stirring requirements (i.e., the need for a lower viscosity), uranium sampling methods, and dilution techniques could drive this temperature up to 1000°C or higher. At higher temperatures, the volatilization and release of fission products would increase. Release rates would also increase with stirring. In addition to the confinement of volatilized fission products during normal operation, the offgas system could be required to provide treatment and confinement during or following abnormal conditions, such as loss of offgas cooling, melter overheating, energetic events inside the melter, facility fires, loss of power, and natural phenomena hazards (e.g., earthquake, high winds).

Building Ventilation and Confinement. The proposed melt and dilute furnace incorporates an offgas treatment and confinement system that would probably be tied into the existing process area ventilation system exhaust, discharging directly into the existing L-Reactor facility ventilation stack. Given the fuel handling, drying, and furnace operations in the L-Reactor facility process area, the existing ventilation that serves this area would need to provide a confinement function. This confinement function would become especially important during process upsets. It is not clear that the L-Reactor process area ventilation system could provide the reliable confinement function needed for melt and dilute operations. At a minimum, upgrades or modifications would be required.

Steam Explosions. The introduction of water in or around the melter would result in the potential for an energetic steam explosion event. Such an event could result in pressurization or mechanical damage to the furnace or auxiliary systems, such as the offgas system, the furnace room, or the process room, leading to expulsion of material from the melter and an unfiltered release of radioactive material. Water cooling of the furnace induction coils is one source of water that is part of the melter design. Another opportunity to introduce water into the melter is during the charging of spent fuel that has not been properly dried, damaged fuel, or fuel canisters or packages that might retain water from the storage pool.

Criticality. Storage of highly enriched spent fuel poses the potential for criticality. While the fuel is in wet storage, the consequences of an inadvertent criticality are substantially mitigated by the shielding and confinement provided by the water. However, the melt and dilute process involves handling the fuel out of the basin water. Fortunately, with the melt and dilute process located in the process area of the L-Reactor facility, substantial shielding would already be in place. In addition to the handling and storage of spent fuel, the amount of highly enriched fuel being added to the melter would need to be controlled to avoid a melter criticality.

Contamination. Drip-dry lag storage racks would be used in the process area before fuel was transferred to the furnace module. The air drying of fuel in this rack could contribute to airborne contamination levels in the process area. In addition, some fraction of the fuel to be processed would be damaged. Damaged fuel would further exacerbate the release of fission products and/or fissile material during the handling of dry fuel.

Another potential source of contamination is the melter operation. A negative pressure offgas system would be utilized to confine fission products volatilized in the melter. However, spent fuel would have to be charged to the melter, samples taken, dilution material added, and the resulting fuel melt removed. A significant amount of contamination could result from the flow of materials into and out of the melter during the course of several decades. Confinement of this contamination is discussed above as building ventilation and confinement. Although the proposed melt and dilute operation would be remotely operated, the melt and dilute process is not being designed as a remote canyon type of operation. Personnel access would be required to conduct equipment maintenance and repair. The reliability and maintainability of these remotely operated melt and dilute activities are unknown. Continually increasing contamination, poor equipment performance, and the need for personnel access to maintain the equipment could present significant operational challenges.

Waste Handling. The condensing medium in the melter offgas system would need to be removed periodically for disposal or washed with acid solution to remove the collected radionuclides. The acid solution would be neutralized and transported to the tank farms as high-level waste to await vitrification at the Defense Waste Processing Facility (DWPF). "Handling and disposing of substantial quantities of material of this type is a situation that would be...a first-of-a-kind process at SRS" (Westinghouse Safety Management Solutions, Inc., February 26, 1998, p. 4). In addition, downstream HEPA filters would collect material that did not condense onto the offgas system condensing medium. Given the nature of the offgas stream, and considering process upsets such as loss of offgas cooling, these HEPA filters could also pose a challenge for handling and disposal. Wastes from the melter offgas system have been estimated at one set of used HEPA filters every 3 months and 50 gallons of high-level waste solution per month.

Furnace Material Carryover. "A small fraction of the uranium and plutonium content of each melt batch may escape from the liquid surface and eventually adsorb on the filters (or elsewhere in the offgas system or ventilation system) as metallic and oxide dust particles or fines" (Westinghouse Safety Management Solutions, Inc., February 26, 1998, p. 4). This possibility must be addressed relative to criticality and material release. An aluminum-uranium casting furnace that was operated for years at SRS for the fabrication of new fuel deposited kilogram quantities of uranium-235 within the ventilation ductwork. Also, aluminum dusts can be combustible and can pose a detonation hazard under certain conditions. There is extensive experience at SRS with aluminum-uranium foundry operations. However, there is very limited experience with foundry operations involving highly radioactive fission products.

Unique Spent Fuel. Powdered spent fuel is included in the inventory of spent fuel that would be treated with the melt and dilute process. This material represents additional unique challenges. Also included in the inventory are various configurations of canisters and storage tubes, some of which are sealed. The powdered material would need to be repackaged, and would have to be handled and recanned to allow remote handling for charging to the melting furnace. Packages used for underwater storage would probably need to be punctured or opened to ensure that no water was introduced into the furnace and that sealed cans did not pressurize and rupture when heated in the melting furnace.

6.1.2 Risk of Not Being Successfully Implemented

Design, Construction, and Startup. Stabilization and disposal of the aluminum spent fuel depends on the ability to design, construct, and start up the facilities needed for the melt and dilute process within reasonable cost and schedule constraints. A challenge for the melt and dilute process is the need for significant technology development. Current plans are to locate the process in the L-Reactor facility. This facility was not designed for the kinds of activities required by the melt and dilute process. The shortcomings of the facility would have to be addressed in the design of a more elaborate, self-contained melter. In addition to providing its own confinement, the melter would require remote operation. The melter would have to be capable of providing at least two remotely obtained samples per charge. It would also require inductive stirring to ensure homogeneity of the fuel melt. If the melted fuel were not poured into a canister, the melter would have to remotely discharge its solidified fuel melt for subsequent packaging while maintaining confinement.

A suitable crucible furnace insert to contain the melted fuel would have to be identified. Metal crucibles tend to fail by interaction with the fuel melt at high temperatures, and graphite crucibles appear to have an affinity for some of the fission products. The ability to replace crucibles frequently would also be required.

To achieve the desired alloy composition and enrichment, each melt would have to be sampled and specific amounts of uranium and aluminum added. This process would require substantial engineering since the necessary additions would depend not only on enrichment and the amount of structural aluminum, but also on whether the fuel was a uranium-aluminum alloy, a uranium-silicide alloy, or a uranium-oxide alloy.

There is some concern that fuel pieces would have to be no longer than two-thirds the crucible diameter to prevent "bridging." If this were necessary, pretreatment for the melt and dilute process would involve substantial fuel handling and cutting operations that would in turn result in additional contamination and criticality concerns.

The above examples of technical challenges are not necessarily prohibitive. However, recent difficulties in the DOE complex with the development of unique processes for stabilizing highly radioactive materials—such as the vitrification of americium-curium at SRS, the removal of cesium from high-level waste in the In-Tank Precipitation Facility, and the stabilization of N-Reactor fuel at Hanford—illustrate the likely cost and schedule uncertainties of the melt and dilute process.

Repository Acceptance Requirements. Even if stable interim storage is achieved, the ability to produce a waste form that is acceptable for the repository is essential to achieving successful disposal of the spent fuel and preventing the need for additional processing. It is difficult to assess waste form acceptability for the melt and dilute process at this time because the acceptance criteria and requirements are still being defined. However, some aspects of the process would contribute to ensuring an acceptable waste form. For example, the melt and dilute process involves isotopic dilution of enriched uranium with depleted uranium. This reduces the criticality potential. Even so, preliminary criticality evaluations indicate that neutron poisons might have to be added to the spent fuel melt. Investigations are under way to explore the compatibility of neutron poison material with the fuel melt and with the canister.

Another possible advantage of the melt and dilute process is the relatively homogeneous waste form, which potentially eliminates the need for pretreatment characterization or a detailed fuel history. The ability to sample each fuel melt can provide a great deal of characterization information for ensuring that the waste form stays within the assumptions of the performance assessments. Unfortunately, specific characterization requirements are not clearly defined and could impose a significant post-treatment characterization burden on the process.

The melt and dilute process makes it possible to optimize the performance attributes (e.g., corrosion resistance, leachability) of the final waste form by controlling the relative amount of aluminum and uranium. This capability comes at the cost of having to adjust and confirm the alloy composition of each melter charge.

Several aspects of the melt and dilute process enhance its ability to produce a waste form acceptable for the repository. However, at present only borosilicate glass has been qualified for disposal in the federal repository. "One of the major challenges to the...disposition of DOE-owned Al-clad spent nuclear fuels is the lack of clear definition of the requirements for repository acceptance criteria of the fuels" (Westinghouse Savannah River Company, July 1998, p. 4.4).

6.2 Direct Codisposal

6.2.1 Risks Associated with Operating the Process

The direct codisposal process can be thought of simply in terms of dry handling of spent fuel. While this is an oversimplification, the process does not involve chemically altering the fuel or introducing energy sources. Thus, the process-related risks identified here are due primarily to handling.

Criticality. Storage of highly enriched spent fuel always poses the potential for criticality. As noted earlier, when the fuel is in wet storage, the consequences of an inadvertent criticality are substantially mitigated by the shielding and confinement provided by the water. Like the melt and dilute process, direct codisposal involves handling the fuel out of the basin water. Fortunately, the proposed location of the process in the process area of the L-Reactor facility would provide substantial shielding.

Contamination. Drying and the dry handling of spent fuel would contribute to contamination of the process areas. Handling and repackaging of damaged fuel would increase the contamination potential.

Direct Exposure. The direct codisposal process involves substantial handling of highly radioactive spent fuel out of the basin water. Current proposals to locate the process within the L-Reactor facility should result in adequate shielding for the remote operations. The transition to nonremote handling and packaging activities would provide an opportunity for direct radiation exposure.

6.2.2 Risk of Not Being Successfully Implemented

Design, Construction, and Startup. Of all three alternatives, direct codisposal appears to be the simplest technology. There are, of course, technical challenges associated with implementing a remotely operated spent fuel packaging process. Also, locating this process in the existing L-Reactor facility could pose additional challenges. However, the simplicity of drying and packaging suggests there is a reasonable probability of successfully designing, constructing, and operating this process.

Repository Acceptance Requirements. A large portion of the aluminum spent fuel is highly enriched and presents special criticality considerations. This criticality concern is aggravated by the more rapid corrosion and the lower burnup of research reactor fuel relative to commercial fuel, and hence a more rapid loss of subcritical geometry and potentially greater nuclear reactivity than is the case with commercial fuel. Studies to date indicate that without the addition of a neutron poison, there is a small but significant probability of postclosure criticality. The neutron poison would have to be chosen to provide the appropriate long-term dissolution rates as compared with the aluminum spent fuel. One form of neutron poison being considered is gadolinium phosphate.

The large amount of characterization anticipated for the direct codisposal process represents a significant disadvantage. The relatively simple process of drying and packaging the fuel could be overwhelmed by the extensive characterization measurements required to meet repository acceptance criteria.

Unique Spent Fuel. Some of the spent fuel inventory, such as the powdered spent fuel and the significantly damaged spent fuel, would require additional treatment prior to direct codisposal. The repackaging of these spent fuels would likely be restricted by the repository waste acceptance criteria. Powdered fuel, for example, would probably need to be solidified. These additional treatment operations might be relatively simple, but they have not yet been developed.

Overall, there is a relatively large uncertainty involved in the ability of the direct codisposal process to produce an acceptable repository waste form.

6.3 Conventional Processing

6.3.1 Risks Associated with Operating the Process

The facility most likely be used to process the aluminum research reactor fuel under the conventional processing alternative is the H-Canyon. The F-Canyon facility could also be used, with some modifications, since the two facilities are very similar. The source terms involved in H-Canyon processing can be significant. In addition, there is some potential for energetic events involving flammable solvent, reactive chemicals, and hydrogen gas. The Basis for Interim Operations (BIO) for the H-Canyon addresses the potential health and safety risks (Westinghouse Savannah River Company, April 1998). The BIO evaluates the risk of routine operations and potential accident conditions. It identifies dominant accident scenarios, including loss of containment, transfer errors, uncontrolled chemical reactions and explosions, fires, criticality, inadvertent personnel exposure, and natural phenomenon events. Equipment and process designs, in addition to the canyon structure, serve to mitigate the risk of these postulated accidents to an acceptable level. The BIO also concludes that routine releases from H-Canyon operations are negligible.

The H-Canyon design has allowed successful operations for many years. In addition, years of operating experience have resulted in corrections, upgrades, and additions to the facility to address lessons learned. Significant events during the H-Canyon operating history are described in the BIO, as are the corrective actions taken to prevent these and other events.

Because of the many years of H-Canyon operations at SRS, there is some certainty in the calculated risk assigned to that facility. The facility has undergone several upgrades in safety analysis and in the determination of operational readiness.

6.3.2 Risk of Not Being Successfully Implemented

There is minimal risk regarding the success of conventional processing in achieving stabilization and disposal of the aluminum spent fuel. As discussed earlier, conventional processing is currently being used to stabilize and dispose of the aluminum defense-related spent nuclear fuel. Also, the DWPF is currently vitrifying high-level waste and producing glass canisters that are qualified for acceptance in the repository. One aspect of high-level waste processing—the treatment of the high-level waste salt—requires additional development to support the vitrification of all of the SRS high-level waste.

6.4 Cost Comparison

Recent cost studies considered several variations of the three processing alternatives (Westinghouse Savannah River Company, December 1997 and May 1998). The melt and dilute alternative is evaluated as utilizing both a new facility and a modification to the L-Reactor facility. The direct codisposal alternative is also evaluated in both of these ways. The conventional processing alternative is evaluated as utilizing the SRS canyons through 2010, and then taking one of four actions to accommodate the tail of fuel receipts from 2011 to 2035 (see Section 2.3): (1) build a new conventional processing facility, (2) build a new melt and dilute facility, (3) build a new direct codisposal facility, or (4) send the tail of fuel receipts to INEEL to utilize the dry transfer facility expected to be operational there. Some of the results from the cost study are provided in Table 2.

Table 2. Cost Comparison for Processing Alternatives

Alternative	10-Year Cost (FY98 millions)	39-Year Life Cycle Cost (FY98 millions)
Melt and Dilute at the L-Reactor Facility	$916	$1960
Direct Codisposal at the L-Reactor	910	1920
Conventional Processing Followed by Melt and Dilute at SRS	698	2060
Conventional Processing Followed by Direct Codisposal at SRS	702	2010
Conventional Processing Followed by New Conventional Processing Facility	704	2380

Source: Westinghouse Savannah River Company, May 1998, and U.S. Department of Energy December 1998a.

Table 2 shows that there is very little difference in cost between the direct codisposal and melt and dilute alternatives. The table also indicates that there is a minimal difference in the life-cycle cost (about $100 million during 39 years) between the melt and dilute or direct codisposal alternative at the L-Reactor facility on the one hand and the conventional processing alternative through 2010 followed by a new treatment facility on the other hand. The one exception is the alternative that includes a new conventional processing facility, showing a difference of about $400 million.

Looking at the 10-year cost, there is a much larger difference between conventional processing and either the melt and dilute or direct codisposal alternative (about $210 million during a 10-year period). Thus if conventional processing were used to stabilize and dispose of the spent fuel, there would be an opportunity for significant future savings if the projected tail of fuel receipts did not occur or if the capability to treat and dispose of the fuel at INEEL became available. Furthermore, even if these opportunities do not develop, there is no cost penalty associated with the need to build a new treatment facility when conventional processing capability is no longer available.

The above cost estimates are based on an assumption that the SRS canyons will no longer be viable after 2010. Under the conventional processing alternative, the development of a new treatment facility to replace the canyon processing is assumed to begin in 2005 (i.e., a fiscal year 2005 line item project) so that the new facility will be operational in 2010. Thus the need for a new treatment facility to accommodate the tail of fuel receipts would have to be identified by 2005. Much more information about spent fuel receipts and the actual need for a new treatment facility would be available at that time.

7. SUMMARY AND CONCLUSIONS

Aluminum spent fuel from research reactors is unlike commercial spent nuclear fuel in that the aluminum fuel is less robust, more susceptible to corrosion, and of a much higher uranium-235 enrichment. This aluminum fuel is currently stored in wet storage basins at SRS. Improvements in water chemistry control and correction of other vulnerabilities associated with the wet storage of spent fuel at SRS have improved the storage conditions. However, corrosion behavior is difficult to predict, and some of the fuel has already undergone damage and corrosion at previous storage locations. There is no fundamental disagreement on the vulnerability of aluminum fuel in wet storage basins. This vulnerability prevents consideration of continued long-term wet storage as a viable alternative for managing this spent fuel.

DOE has committed to removing this aluminum research reactor fuel from wet storage and placing it in stable interim storage in a form suitable for ultimate disposal. DOE is preparing to select a processing alternative for this fuel. Three alternatives are being considered: melt and dilute, direct codisposal, and conventional processing.

The planning period for these processing alternatives is through the year 2035—about 40 years. The total amount of fuel to be processed during this period is uncertain. Estimates have been reduced by more than 25 percent during the last couple of years as a result of reactor shutdowns and the decision of some foreign countries not to return their research reactor fuel to SRS. More reductions are probable. Also, the tail of fuel receipts during at least one-half and as much as two-thirds of the planning period may be grossly overestimated, if it occurs at all.

DOE has sponsored several studies related to the selection of a processing alternative for stabilization and disposal of this spent fuel. In those studies that considered conventional processing, this alternative was assigned the highest rating. However, most of the DOE-sponsored studies excluded conventional processing from consideration.

Comparison of the estimated accident-induced latent cancer fatalities that could result from operation of each of the processing alternatives was found not to be very useful in discriminating among the processing alternatives. On the other hand, the two alternatives involving new technology or processes, especially the melt and dilute alternative, introduce new or unique hazards that must be understood and addressed. The melt and dilute process involves molten spent fuel, volatilized fission products, and the handling of high-level waste without the benefit of a canyon structure or underground waste facilities.

If one compares the risk or uncertainty involved in obtaining a waste form suitable for stable interim storage and acceptable for ultimate disposal, conventional processing is clearly favored. Conventional processing is a well-understood technology that is currently being conducted using the SRS canyon facilities. The direct codisposal and especially the melt and dilute alternatives would require significant process development. In addition, the waste form resulting from conventional processing has been qualified for disposal in the federal geologic repository. The melt and dilute and especially the direct codisposal processes produce a waste form with some uncertainties regarding its acceptability in the repository.

The life-cycle costs of the processing alternatives, allowing for the uncertainty in predicting a 39-year life-cycle cost, are generally comparable. The 10-year costs are generally most favorable for the conventional processing alternative. Cost comparisons of the alternatives are based on receipt and processing of spent fuel through 2035. The tail end of this inventory is highly uncertain. In addition, with accelerated receipts, the backlog of spent fuel could be eliminated as early as 2010. These uncertainties in the projected fuel inventories add to the uncertainty of the cost estimates for the alternatives.

Evaluation of the spent fuel inventory and the processing alternatives being considered leads to the conclusion that DOE ought to use conventional processing for aluminum research reactor spent fuel to the maximum extent practical. At a minimum, the SRS canyons ought to be used through 2010, allowing DOE to defer the decision on a replacement technology until at least 2005, when more information will be available on the type and number of future fuel receipts.

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ABBREVIATIONS AND ACRONYMS

Abbreviation	**Definition**
BIO	Basis for Interim Operations
Board	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
EIS	Environmental Impact Statement
FRR	Foreign Research Reactor
HEPA	high-efficiency particulate air
HEU	highly enriched uranium
INEEL	Idaho National Engineering and Environmental Laboratory
RBOF	Receiving Basin for Offsite Fuel
ROD	Record of Decision
SNF	Spent Nuclear Fuel
SRS	Savannah River Site
WSRC	Westinghouse Savannah River Company