CHAPTER 3. TECHNICAL STATUS AND ASSESSMENT

Technologies analyzed in this section support alternatives judged to have a good chance of technical success. It is desirable to rely on technologies that have been proven for similar applications and have a high likelihood of success. The key factors relating to this section are:

- technical maturity
- technical risk
- research and engineering development needs
- condition, capacity, and reliability of infrastructure
- regulatory/licensing requirements

A particular difficulty is predicting how the regulatory process will proceed. This difficulty is exacerbated for some of the alternatives since no clear regulatory regime currently exists. Whereas the regulatory basis for reactors and fuel fabrication facilities is reasonably well documented, the basis for licensing an immobilization facility or a deep borehole, for example, has not been established. In all alternatives, the licensing arena represents a risk for experiencing protracted delays in the implementation actions which remains, at least in part, unpredictable.

3.1 COMMON TECHNOLOGIES

3.1.1 Safeguards and Security

A team of Safeguards and Security experts has been working with each Alternative Team to assure that proliferation risks and impacts have been considered consistently throughout the program. In addition, an independent technical evaluation team has been assembled to identify potential weaknesses in the proliferation resistance of disposition alternatives to theft, diversion, and/or retrieval and reuse of material. An unclassified summary report[1] of the team's conclusions was released in October, 1996.

3.1.2 Transportation and Packaging

In general, meeting the stored weapons standard requires transport of significant quantities of plutonium by safe, secure trailers (SSTs) in accordance with DOE Orders. It is likely that IAEA safeguards for these shipments can be accommodated without significant cost impact. Although there are no significant barriers to shipments by SST to Canada, agree-

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[1] *Proliferation Vulnerability Red Team Report,* SAND97-8203-UC700, October 1996

ments for security and transfer of custody will need to be negotiated. Similarly, agreements for shipping materials to Europe will have to be negotiated.

Since there has been no need for certified containers before, NRC-certified containers for shipping immobilized plutonium forms designated for the high-level waste repository do not currently exist. A container is being designed and developed by the Westinghouse Savannah River Company as a primary container for defense high-level waste which has only trace quantities of plutonium. As this container is developed, it could be certified and used for other plutonium immobilized forms.

Transportation and associated packaging technologies required to support facility operations have been evaluated. Identification of surrogate facility locations, specifications of material forms, types of containers required, total number of shipments, modes of transportation, and total life cycle costs associated with transportation and packaging have been developed as a part of each alternative/variant analysis. Significant conclusions are:

- Based upon a review of DOT, DOE, and NRC regulatory requirements, all surplus weapons-usable plutonium feed materials are transportable, although it is impractical to ship liquids because of the very small permissible quantities based on 10 CFR 71 and 49 CFR 100-189 (limit is 20 curies, which is 30 to 40 grams of plutonium).

- It is likely that IAEA safeguards will not significantly impact the cost of shipping surplus fissile materials.

3.1.3 Front-End Processing

The Department has initiated a two-year project to demonstrate a pit disassembly and conversion system called the Advanced Recovery and Integrated Extraction System (ARIES). The project will demonstrate a full-scale integrated ARIES prototype with a throughput capacity of 250 to 500 pits per year (1 to 2 per 8-hour day). Depending on specific application, the throughput can be increased by the addition of specific modules or by replication of the entire system. The ARIES prototype will demonstrate the ARIES process and support the design of a production scale pit disassembly facility. The oxide from the ARIES test and demonstration phase will feed downstream disposition operations, including possible supply of plutonium oxide to European MOX fuel fabricators for an accelerated start-up of the existing reactor variants.

Components of the ARIES system have been developed and demonstrated in small scale applications, and the hydride-dehydride process is now in use at Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) to remove plutonium from pits in support of other DOE programs. Plutonium oxide produced by the ARIES hydride-oxidation process was used to produce the first MOX fuel pellets made with plutonium from pits. This effort is part of the investigation of the suitability of weapons-grade MOX fuel for commercial reactors.

Most of the other chemical and physical processing steps to convert and stabilize plutonium materials to acceptable feed forms for any of the alternatives have been demonstrated within the DOE Complex, and no development efforts will be required that could be expected to delay implementation of any alternative.

3.1.4 Existing Facilities

A preliminary analysis was performed for front-end processing in Building 221F at the Savannah River Site (SRS). This building was selected as an illustrative example of potential cost savings and does not necessarily represent the optimum use of equipment and facility space nor serve to select Savannah River as the site for existing facilities for front-end processing. This analysis included both a system for pit conversion and processing for other types of plutonium feed for the disposition alternatives. This analysis indicated that both a cost savings and a shortening of the schedule for getting started could be realized over the greenfield approach through the use of Building 221F.

For the MOX fabrication facility, the Department briefly reviewed a number of existing facilities at Savannah River, INEL, Hanford, and the Nevada Test Site (NTS). All sites could accommodate MOX fuel fabrication though considerable facility modification and equipment procurement would be required. None of these facilities were originally intended for fuel fabrication except the Fuels and Materials Examination Facility (FMEF) at Hanford; however, this facility had installed systems and equipment for fabrication of specialized fuel for the Fast Flux Test Facility and for the Clinch River Breeder Reactor Plant. Extensive facility modifications would be required as the MOX fuel fabrication for LWRs or CANDU reactors involves work with a significantly different fuel form and throughput. A preliminary review of what could be eliminated from the greenfield approaches by using existing approaches indicated some potential cost and schedule savings could be realized over the greenfield approach through the use of an existing facility for MOX fuel fabrication. It was also learned that much of the cost and schedule advantage could be realized by utilizing the existing nuclear infrastructure at certain DOE sites for MOX fuel fabrication, even if a new facility were constructed.

An independent contractor reviewed a limited number of facilities within the DOE complex for potential licensability by the NRC as a MOX fuel fabrication facility. The review concluded that licensing the different facilities presented different degrees of difficulty. In some cases, the quality assurance records appear sufficient to demonstrate adequate design and construction while in at least one case, a post construction quality assurance program (e.g., analysis and tests) would be required.

3.1.5 Oversight and Licensing

A series of meetings were held in 1995 with the NRC staff to review oversight and licensing issues associated with the disposition alternatives and related common technologies. The results of these meetings were factored into the development of costs and schedules for each of these alternatives.

3.1.6 High-Level Waste Repository

Feasibility analyses were conducted to evaluate the potential for disposing plutonium waste forms in a high-level waste repository. The waste forms evaluated were: 1) spent fuels generated from existing LWRs, partially complete or evolutionary reactors operating with MOX fuel cores, 2) forms produced by immobilizing plutonium in glass or ceramic matrices, and 3) forms produced by the electrometallurgical treatment process. The analyses quantified impacts on an operating repository with a focus on logistics, thermal behavior of the waste forms in a repository environment, dose to the public at the accessible environment, and long-term criticality behavior of the wastes.

Repository analyses for the CANDU spent fuel have not been included in these discussions because the spent fuel from this option is expected to remain in Canada, where the reactor owners are responsible for disposal of their waste.

Logistics

For each alternative analyzed, the total number of additional waste packages that would be added to the approximately 12,000 packages currently envisioned for the first high-level waste repository is small enough that any changes in emplacement could be accommodated within the design ratings of such a repository. The number of additional waste packages ranges from as little as none for the existing LWR variants to as many as 488 waste packages for the spent fuel from the evolutionary reactors. This small change to the total handling of waste packages can be readily accommodated within the design ratings of the repository facilities. Assuming successful form qualification, it has been determined that the plutonium waste forms will be available to the repository for disposal within the time frame that the repository is currently planned to be operational.

Thermal Behavior

Thermal calculations for the waste package have shown that for the MOX spent fuels the peak cladding temperatures are well below the 350° C required to meet the repository thermal goals (e.g., fuel cladding integrity, drift wall temperature, etc.). For the vitrified waste forms (Greenfield glass, adjunct melter, can-in-canister options) and the glass bonded zeolite (produced by the ET process) it has been shown that the peak temperatures are below the 400° C glass transition temperature. Thermal analysis of the plutonium loaded ceramic waste packages (ceramic greenfield, and ceramic can-in-canister) shows a peak temperature around 200° C. Ceramic, unlike glass, does not have a transition temperature because it is a crystalline material. The lowest melting point temperature for the oxides of this ceramic material is around 1800° C. Therefore, the calculated peak temperatures are unlikely to affect the ceramic matrix.

Dose to the Public in the Accessible Environment

Total System Performance Assessments were conducted for each of the waste forms evaluated. Calculations at the accessible environment showed that the dose contribution from the plutonium wastes are a factor of about two orders of magnitude less than the dose calculated for a repository with commercial spent nuclear fuel and defense high-level waste, exclusive of the forms envisioned for plutonium disposition.

Long-Term Criticality

Long-term criticality considerations fall into three broad categories: waste packages that retain their initial configuration with time (intact mode); waste packages and waste forms as they degrade with time (degraded mode); and fissile material transported away from the degraded waste forms and waste packages (external mode). Criticality calculations conducted to date for the plutonium waste forms have been for the intact mode. Degraded mode analyses are underway based on data being developed in the on-going research and development efforts. External mode evaluations will be addressed in concert with the commercial spent fuel and defense high-level waste program as part of the repository safety analysis.

MOX Spent Fuels

Criticality calculations for the MOX spent fuels followed the same methodology as is currently being used for the commercial spent fuel. No credit is taken for the residual integral neutron absorbers (e.g., gadolinium), and full burn-up credit is taken for the principal isotopics resulting from the nuclear reaction (principal isotope burn-up credit). The analysis of as-fabricated criticality assumed a waste package fully loaded with assemblies, flooded with water, and no additional neutron absorbers. For the BWR spent nuclear fuel from existing reactors using MOX fuel with integral neutron absorbers, the calculations show that the effective neutron multiplication factor, k_{eff}, values are lower than those obtained for the corresponding low-enriched uranium fuels. On the other hand, the PWR spent fuels from the partially complete and evolutionary reactors using MOX fuels contain a higher fissile content and require the use of criticality control technologies or reducing the number of assemblies per waste package to bring the k_{eff} values in compliance with NRC regulations. Calculations for the PWR spent fuel from existing reactors using MOX fuel without integral neutron absorbers have not been completed, but an inspection of the fissile content shows values that are comparable to those in low-enriched uranium spent fuels.

Immobilized Forms

The defense high-level waste currently planned for disposal in a high-level waste repository is a borosilicate glass waste. Because the defense high-level waste glass has no significant quantity of fissile material, no direct comparison with immobilized forms containing plutonium can be made. Therefore, the results of the long-term criticality calculations of the immobilized disposition forms were evaluated solely against the NRC requirements. In all cases only the intact form criticality was calculated, with neutron absorbers, like gadolinium, added to the immobilized form. In all cases, it was shown that the k_{eff} for both the dry and flooded conditions was well below the 0.95 specified by NRC. The waste forms included in these calculations are the greenfield glass, adjunct melter, can-in-canister glass, the glass bonded zeolite, the ceramic greenfield, and the ceramic can-in-canister alternatives.

3.2 REACTOR ALTERNATIVES

Two components drive the degrees of technical risk for the reactor alternatives. The first component is fuel fabrication; the second is reactor operation. The technical risks associated with the alternatives are outlined below.

3.2.1 Existing Light Water Reactors

Although MOX fuel is not used in commercial reactors in the U.S., fabrication of MOX fuel for LWRs is an industrialized operation in Europe with at least three companies actively involved with the MOX fuel supply business. However, this experience involves the use of reactor-grade plutonium derived from previously irradiated fuel and is limited to partial MOX cores. As such, there are a number of technical uncertainties with the fabrication of MOX fuel from weapons-derived plutonium related to commercial MOX fuel usage:

1. Weapons-grade plutonium contains small amounts of gallium, a corrosive metal added as an alloying agent. The impact of gallium on the fuel fabrication process and the fabrication equipment is presently unknown. The potential impact will have to be determined or a process added to remove gallium from the MOX fuel feed. Aqueous processing is considered a backup process that could readily be used to remove the gallium, but this creates considerable radioactive aqueous waste and involves additional cost and complexity.

2. Reactor-grade plutonium used in Europe is generated through aqueous separation processes. Most of the weapons-derived plutonium is expected to be extracted via dry processes. The differences in the physical characteristics of the different sources of plutonium need to be assessed, since parameters such as particle size can be quite important in producing MOX fuel.

3. Some alternatives require MOX fuel with depletable integral neutron absorbers. There is no industrial experience with integral neutron absorbers in MOX fuel and a corresponding fuel fabrication process would have to be developed and qualified.

The use of MOX fuel in LWRs in the U.S. has its own risk, relative to operating experience with MOX fuel reactors in Europe. As with MOX fuel fabrication, there is extensive experience with the operation of reactors with MOX fuel. Existing reactors operating experience is based on partial MOX cores and would have to be reassessed for full MOX cores. Using full-core MOX fuel designs is innovative and is selected for the higher plutonium throughputs which can be achieved. The fuel fabrication of full-core MOX fuel designs is not significantly different from the fabrication of partial-core loads, assuming no integral depletable neutron absorbers are employed; however, reactor performance will need to be confirmed by additional analyses and will likely require lead test assemblies. The impact of gallium, the higher fissile content of weapons-grade plutonium versus reactor-grade plutonium, and, depending on the variant selected, the impact of depletable integral neutron absorbers on in-reactor fuel performance would have to be characterized through a fuel qualification program. If the fuel qualification program were not successful because of the presence of gallium, aqueous processing of the feed would be required. If the fuel qualification program were not successful because of the presence of integral neutron absorbers, the reactor variant that does not use the integral neutron absorbers would be required. This would involve using more reactors for the mission. Confirmatory design analysis and a likely LUA irradiation would also be required, though such a confirmatory effort would be much less demanding than the integral neutron absorber variant.

In addition to the risks relating to the maturity of the technology, there are risks related to the availability of the infrastructure for fuel fabrication. European capacity for making MOX fuel is limited, so it is likely that a domestic MOX fuel capability will need to be developed by either using a new facility or modifying an existing facility. Some risks are present with actions which require designing, building, and licensing a plutonium facility in the United States. However, the design basis and regulatory requirements for a MOX fuel facility are well established. The risks relating to a new facility are partially offset by modifying existing facilities; however, modifications to existing structures represent their own risks because of the need to demonstrate conformance with modern regulatory requirements.

With sufficient delay in the program, it is possible the alternative could become non-viable due to the loss of the reactors as their licenses expire. The issue also applies to BWRs and PWRs but is less critical for PWRs because there are more PWRs, and they tend to be newer than BWRs. Section 5.2.2 addresses the availability of reactors in more detail.

A great many of the 110 commercial nuclear reactors licensed to operate in the U.S. can utilize MOX with few, if any, changes to the reactor design. Excluding reactors which are small (less than 750 MWe) and those with limited remaining life (licenses set to expire by 2015), approximately 60 or more reactors may be suitable for the mission. As few as three reactors are needed to complete the mission. Clearly, the capacity of the existing reactor infrastructure is adequate as long as there is no protracted delay in the mission. The risks present with the use of commercial reactors relate to obtaining an amendment of reactor licenses to utilize MOX fuel and negotiations between reactor owners and the U.S. government over use of the reactors for plutonium disposition.

There also may be issues related to packaging and shipping weapons-grade plutonium to Europe which would need to be resolved if European MOX fuel fabrication were selected for implementation.

3.2.2 CANDU Reactors

CANDU reactors have a number of technical viability risks similar to existing LWRs with respect to this mission. The similarities include: acceptance of MOX fuel with little or no reactor modification; operation with MOX fuel within an existing approved safety envelope;

common isotopics and gallium issues; and the need for negotiation of an agreement between the reactor owners and the respective governments. A number of characteristics imply simpler fabrication processes compared to LWR fuel fabrication processes: the small size of CANDU bundles, the absence of any need for integral neutron absorbers with plutonium, a fissile fuel content lower than LWR fuels, and low burnups. On the other hand, industrialization of CANDU MOX fuel has never been attempted and a fuel development and qualification program is required. Therefore, CANDU reactor technology, for the use of MOX, fuel is not as mature as that for LWRs. There also may be issues related to packaging and shipping weapons-grade plutonium to a separate, sovereign state which would need to be resolved.

The CANFLEX fuel form, which is currently being developed independently for natural uranium fuel designs for CANDU reactors, features a higher concentration of plutonium in the fuel than the reference MOX CANDU fuel form and requires a fuel qualification and demonstration phase that goes well beyond that required for adaptation of the existing reference CANDU MOX fuel. The MOX CANFLEX fuel design, although it has significant cost, schedule, and environmental advantages over the reference CANDU fuel design, represents a departure from the existing CANDU technology base and is therefore more developmental than the reference CANDU fuel.

3.2.3 Partially Complete Light Water Reactors

Partially complete LWRs share the same risks as the existing LWR existing facilities variant with the following additions: 1) integral neutron absorber MOX core strategies would be required and 2) the risks associated with the completion of the design, construction, and licensing of the reactors are present in addition to the existing LWR risks, and 3) there are only an limited number of partially complete reactors. Partially complete reactors require integral neutron absorbers since the enhanced plutonium throughput is required to complete disposition within approximately 25 years with two reactors.

3.2.4 Evolutionary Light Water Reactors

Evolutionary reactors involve more risk than the partially complete reactor variant since there are greater risks associated with designing, building, and licensing entirely new reactor facilities. The evolutionary reactor designs are novel and involve their own technical risk for qualification and procurement of equipment and satisfying regulatory reviews. For the same reason as with the partially complete reactors alternative, integral neutron absorbers are necessary for the evolutionary reactor alternative.

3.2.5 Actions to Address Technical Risk

All of the reactor alternatives pose some degree of technical risk to implement and the degree of risk varies with each alternative. The range of technical risk varies from adapting existing LWRs to new MOX fuel cycles, which is substantially a confirmatory effort, to building new LWRs with new fuel forms, which involves an extensive fuel qualification program and extensive reactor construction. Activities are currently underway to mitigate the specific reactor alternative risks. These activities are as follows:

A. A series of fuel fabrication tests for LWR and CANDU fuels are being performed at LANL. These tests are being performed to address the fuel fabrication issues relating to morphology, powder particulate size, powder processing steps, processes to render plutonium powder from pits (dry versus wet processes), and gallium in the plutonium feed stream.

B. Irradiation tests of LWR fuel rods containing MOX fuel pellets are planned to confirm the adequacy of the fuel fabrication processes and to confirm the compatibility of LWR reactors with weapons-grade MOX fuel cycles.

C. Irradiation tests of CANDU fuel rods containing MOX fuel pellets are planned to confirm the adequacy of the fuel fabrication processes and the compatibility of the CANDU reactors with weapons-grade MOX fuel cycles. These irradiation tests will be performed in conjunction with tests of MOX fuel derived from Russian weapons-grade plutonium fabricated in Russia.

3.3 IMMOBILIZATION ALTERNATIVES

Despite an abundance of research and experience in immobilizing high-level waste, the plutonium immobilization alternatives still have a number of design questions to be resolved. Key technical uncertainties involve process equipment development and formulation of waste forms suitable for long-term performance in a high-level waste repository. Significant experience exists with some immobilized forms and a reliable body of experimental data is emerging. A summary of the technical risks relating to the immobilization alternatives is given below.

One important issue to be resolved for all immobilization alternatives is the need to establish a process for demonstrating acceptability of immobilized waste forms to a high-level waste repository. The immobilization alternatives differ from defense high-level waste with regard to the higher fissile loadings expected in the immobilized waste forms. A program will be required to demonstrate criticality prevention over long periods of emplacement. Preliminary results from consultations with the Office of Civilian Radioactive Waste Management indicate that all waste forms being analyzed are anticipated to be acceptable to a repository.

3.3.1 Vitrification Alternative

All of the vitrification variants will require research to understand and quantify a number of design considerations, including plutonium solubility and dissolution kinetics, selection of an optimum neutron absorber, solubility interactions of the neutron absorber and plutonium, impact of impurities on quality of waste form, and melter design for criticality control and compaction process. A development effort is in progress to design facilities and equipment for the mission. This effort can build upon the extensive data base of technologies for vitrification of high-level waste forms that exists both in the United States and overseas. Much of that experience is limited to applications where actinide concentrations were very low (generally less than 0.1% by weight). However, an experience base for vitrification with higher concentrations of plutonium is beginning to emerge.

Conceptual designs of systems and components have been identified for the vitrification variants, and technologies have been demonstrated at laboratory scale. Crucible melts with plutonium nitrate feeds have successfully been dissolved in glass. For example, plutonium loading has been demonstrated at the laboratory scale at 11 wt % for Löffler glass (the proposed high-temperature glass form for the can-in-canister glass variant) and at 5% for the lower temperature alkali-tin-silicate (ATS) glass (the proposed glass for incorporating the cesium radiation barrier in the greenfield and adjunct melter variants). Key processing parameters requiring further development and demonstration are plutonium oxide (high and low fired) solubility in glass, uniform mixing in the melter, and processing time and temperatures for production-reliable operation of the melter at the required glass physical properties.

The can-in-canister variant appears the more viable since the glass containing the plutonium does not have to simultaneously incorporate the ^{137}Cs because the radiation source is the vitrified high-level waste outside the can. In addition, this approach allows use of the Defense Waste Processing Facility (DWPF) at Savannah River, eliminating the need for a new hot cell. The can-in-canister variant has been successfully demonstrated cold (i.e., without radionuclides) at the DWPF.

3.3.2 Ceramic Alternative

The ceramic variants are expected to provide superior confinement of plutonium over geologic time scales. This argument is supported by the existence of mineral forms found in nature ("natural analogs") that have demonstrated the immobilization of actinides for periods exceeding 100 million years. Ceramic waste forms have been under development for high-level waste for many years; however, the application of ceramic technology for the immobilization of plutonium is currently developmental. Key technical issues for plutonium immobilization include achieving simultaneous high densities, reacting plutonium from oxides to an incorporated phase, and attaining compatibility with expected impurities. Success in each of these areas depends on the ceramic mineral formulation, as well as the methodology selected for fabrication (including the technology for densifying the ceramic and whether the plutonium feed is dry oxide or a nitrate solution).

The two fabrication methods for ceramic immobilization being considered for this mission are generally well known: hot pressing in bellows and cold pressing and sintering. Hot pressing generally achieves higher densities and can retain ^{137}Cs added as a radiation barrier but accommodates a relatively lower throughput. Cold pressing and sintering is generally more cost effective due to a higher throughput and is suitable only for the can-in-canister approach because it will likely not retain ^{137}Cs at the high temperatures in the sintering furnace.

The can-in-canister variant appears the more viable since the ceramic containing the plutonium does not have to simultaneously incorporate the ^{137}Cs. In addition, this approach allows use of the Defense Waste Processing Facility (DWPF) at Savannah River with minimal interference on the ongoing high-level waste operation and eliminates the need for a new hot cell.

Hot pressed ceramic samples containing 10 to 100 grams of plutonium at a loading of 12% have been prepared which indicate that full-scale production is viable. Cold pressing and sintering has produced ceramic pellets with oxide powder loading of 12%. Full characterization of these samples have not yet been completed. The technology for cold-press and sinter is similar to that used for production of MOX fuel and is a mature production advantage for this waste form.

The baseline feed approach for producing hot press ceramics is the use of plutonium nitrate solution. This “wet” feed approach generally results in a more fully reacted plutonium ceramic product; however, it requires an off-gas system (thus larger capital equipment) and could result in greater volumes of secondary waste. A more desirable approach would be to use a “dry” plutonium oxide feed, which results in significantly reduced secondary waste but is more difficult to obtain completely reacted plutonium in the ceramic matrix and is less well demonstrated at the present. Additional developmental work to reduce technical uncertainties would be required to select the dry feed approach.

3.3.3 Electrometallurgical Treatment Alternative

The electrometallurgical treatment alternative requires further development to confirm its applicability as an immobilization option for plutonium disposition. Although the technical viability of several components of this alternative is well established for spent nuclear fuels, questions regarding the technical viability of this alternative for the plutonium disposition mission remain. Most of the technical risk associated with this alternative is due to a small experience base of several unit processes with pure plutonium. The lithium reduction step of the process has been demonstrated with uranium oxide and with mixed uranium and plutonium oxides but not with pure plutonium oxide or plutonium containing large quantities of inert material. The zeolite waste form has been demonstrated at a few gram scale (total mass) using plutonium-loaded chloride salt. The electrorefining process is currently being operated with irradiated Experimental Breeder Reactor-II fuel and blanket assemblies on a limited demonstration basis at ANL-W using some of the same facilities, equipment and processes that would apply to fissile materials disposition.

Regarding the qualification of the zeolite waste form for the high-level waste repository, a NAS National Research Council Report noted several concerns with the long-term performance of this waste form, including radioactive decay effects and chemical and thermal stability.[2] The NAS recommended increased development program efforts to address these issues.

3.3.4 Actions to Address Technical Risk

The following activities are currently underway or will soon be initiated to mitigate specific implementation risks.

A. The glass can-in-canister approach was recently demonstrated at the DWPF. Small cans containing a high-temperature glass with a plutonium surrogate were loaded into two full-size DWPF canisters (one canister contained 8 cans and the other 20) which were subsequently filled with a surrogate high-level waste glass in DWPF as part of the cold startup qualification tests of that facility. Destructive and non-destructive analyses confirmed that the simulated high-level waste glass filled both canisters without creating significant void spaces, while preserving the integrity of the can and canister assembly. Additional information will be analyzed on the physical and chemical properties of both the simulated plutonium and high-level waste glasses. The results of these examinations will be used to quantify the operating parameters of the can-in-canister concept.

B. An effort is underway to develop and demonstrate prototypical systems for the production scale incorporation of plutonium in one of the glass and ceramic waste forms currently under investigation. The glass forms require the development of a suitable melter system which includes both suitable feeders and product load out systems. The ceramic forms require either (1) the development of a suitable feed preparation and cold pressing system coupled with an appropriate sintering heat cycle similar to that used to fabricate nuclear reactor fuel or (2) the development of a suitable feed preparation and hot pressing system. Each system must be operable within a glove box enclosure to provide for safe plutonium operations.

C. Current plans for electrometallurgical treatment alternative requires demonstration of the lithium reduction equipment to convert plutonium oxide to metal and for fabricating plutonium-spiked samples of glass-bonded zeolite for performance testing.

D. A continuing effort of research and development activities are being performed to address uncertainties associated with plutonium incorporation kinetics, plutonium and neutron absorber leach rates, neutron absorber selection, durability of waste forms, and other studies to identify potential show stoppers for implementation.

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[2] National Academy of Science, National Research Council, An Evaluation of the Electrometallurgical Approach for Treatment of Excess Weapons Plutonium, National Academy Press, Washington, DC, 1996.

3.4 DEEP BOREHOLE ALTERNATIVES

While no deep borehole disposal facilities for plutonium disposition have ever been developed, many of the technologies needed for this alternative are quite mature; and the basic concept has been considered previously for waste disposal. The overall concept of deep borehole disposition has been considered in recent decades for disposal of both hazardous and radioactive wastes. This concept received significant investigation in the 1970s for disposal of high-level radioactive waste and spent nuclear reactor fuel. Similar studies have been conducted in other countries including Russia, Sweden, and Belgium.

Technical unknowns for deep borehole disposition center around underground conditions and post-closure performance and a regulatory environment against which performance objectives can be measured. It is believed that suitable rock formations can be found in a variety of areas, that they can be adequately characterized, and that the long term evolution of processes can be predicted to assure long term isolation and safety.

One distinguishing feature of the deep borehole alternatives is that it effects geologic disposal whereas, for the reactor and immobilization alternatives, the plutonium is converted to a waste form which must be disposed of in a high-level waste repository. In all cases, however, the disposition cost summaries budget for geologic disposal.

The immobilized deep borehole disposition alternative differs somewhat from the direct deep borehole disposition alternative in terms of technical unknowns. The extra cost of immobilizing the plutonium may be accepted in part to give added assurance of long term isolation safety and a simplified licensing safety argument. These factors result in this alternative having less technical uncertainty than the direct deep borehole disposition alternative.

The reasons for this increased confidence in the immobilized deep borehole disposition alternative with respect to long-term performance are:

1. *Reduced Post-Closure Contaminant Mobilization:* The ceramic pellet disposal form used in the immobilization alternative is the highest performing, most geologically compatible and thermodynamically stable disposal form available. The solubility and plutonium release rate from this disposal form is at least three to four orders of magnitude lower than those of other competing disposal forms including the plutonium metal or plutonium oxidedisposal forms of the direct disposal alternative.
2. *Increased Confidence in Emplacement Zone Sealing:* The degree of isolation of the disposed plutonium from the biosphere will depend not only on the geologic barrier posed by the geosphere but also on the nature of the transport mechanisms and the resistance to transport up the deep borehole past the deep borehole seals. It is necessary to seal properly not only the isolation zone in the upper half the deep borehole but also the emplacement zone in the bottom half of the deep borehole. The immobilized emplacement alternative reduces uncertainty in emplacement zone sealing by eliminating long, vertical canisters which could degrade into potential flowpaths.

3. *Increased Post-Closure Criticality Safety:* The plutonium loading in the ceramic pellet option has been kept to a very low 0.5% effective loading (for a 1:1 mix of 1% loaded pellets and plutonium-free pellets) to drive the criticality coefficient down to a value of 0.67 under the worst possible brine saturated conditions without any addition of integral neutron absorbers. This is far below the value of 0.95 specified for the safe storage of plutonium metal.

Siting guidelines and procedures is the largest area of uncertainty. Site suitability guidelines consistent with the mission and safety concept of deep borehole disposition will require development. Separated fissile material in significant quantities has never been considered for direct disposition before and a regulatory framework to address this deep borehole disposal does not currently exist. Therefore, regulatory uncertainty was identified as a risk that affects the viability of deep borehole disposition. However, preliminary discussions with licensing experts indicate that a licensing regime can be developed, given sufficient time and a mandate.

The equipment required to implement the deep borehole alternatives are adaptations of equipment designed and used for nuclear weapons testing, geological studies, and the petroleum and gas drilling industries. The equipment requirements with respect to environmental safety and quality are within current capability or are viable extrapolations from existing mechanical engineering designs. An integration and demonstration of the equipment will be required, and the systems engineering must be performed. Notwithstanding, the mechanical design is not expected to be a controlling technical risk for these alternatives.

3.4.1 Actions to Address Technical Risk

The potential for very long-term geochemical processes in the deep borehole environment to mobilize and redistribute fissile isotopes into critical configurations is a subject of current research and development activity. Preliminary research and development results indicate that there exist a number of characteristics of the deep borehole environment that provide a very strong safety argument against both post-closure criticality and post-closure contamination of the biosphere. The high safety margin arises from the great depth of burial, the high resistance to mobilization of the selected disposal forms, the properties of the subsurface rock and brines, the low-permeabilities of fractured rock at great depths, and the lack of driving forces for fluid flow at sites selected according to the site selection criteria developed for deep borehole disposition.

3.5 HYBRID ALTERNATIVES

Hybrid approaches, wherein different feed materials (pits versus impure plutonium, for example) go different routes, opens the possibility of utilizing existing facilities in different ways to achieve program objectives. As an example, a newly completed chemical recovery facility at Savannah River could be used as designed to directly support the immobilization portion of a hybrid alternative with relative little modification and expense. Other possible uses of present facilities are also possible and these approaches need to be further evaluated.

Likely benefits of a hybrid approach include:

- Hybrid approaches may provide better utilization of existing facilities and operations with fewer modifications and reduced expense.

- Hybrids may enhance early start capabilities since the start-up of any portion of the hybrid is a start of the U.S. plutonium disposition mission .

- Since parallel processing paths are being utilized, proper utilization of the hybrid approach could also result in earlier completion of disposition. As an example, the hybrid approach reduces the quantity of plutonium going through reactors by about 33%. This reduction in throughput could require either fewer reactors (same mission duration), or would result in an earlier finish using the same number of reactors as in the existing LWR variant.

- Hybrids provide insurance against technical or institutional hurdles which could arise for a single technology approach for disposition. If any significant roadblock is encountered in any one area of a hybrid, it would be possible to simply divert the feed material to the more viable technology. In the case of a single technology, such roadblocks would be more problematic.

- Hybrids minimize the purification and processing of the existing plutonium feed materials for disposition. Since such operations tend to produce quantities of transuranic and low level nuclear waste, utilization of a hybrid approach will likely reduce such waste over the case of stand alone reactor variants.

The downsides to the hybrid approaches include having two sets of processes and facilities to be designed and operated and also having both sets of technical issues to resolve.

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