CHAPTER 7. SUMMARY AND CONCLUSIONS

7.1 TECHNICAL CONCLUSIONS

7.1.1 General

Though each of the alternatives appears to be technically viable, each is currently at a different level of technical maturity. All alternatives will require some research and development, but there is high confidence that the technologies can support program requirements.

7.1.2 Common Technologies

- Proliferation vulnerability issues were addressed in an unclassified report (SAND97-8203-UC-700) released in October, 1996.

- Transportation and packaging technical issues appear to be readily resolvable. Furthermore, transportation issues do not appear to be significant discriminators between alternatives except for those alternatives involving transport of materials to other nations. In these alternatives, the transportation issues are mostly institutional and represent a higher degree of risk.

- The non-pit front-end process technologies are generally well developed and do not represent a significant technical risk to accomplishing the plutonium disposition mission. The pit processing technologies are being demonstrated presently, and they are expected to be available to support programmatic needs.

- With varying degrees of difficulty, all alternatives are expected to be able to satisfy oversight and regulatory requirements.

- LWR MOX spent fuel is similar to commercial uranium-based spent fuel to be sent to the high-level waste repository. Some prospective PWR MOX spent fuel may require some waste package modification (e.g., fewer assemblies per waste package) to accommodate the higher fissile content relative to commercial low enriched uranium-based spent fuel. Ceramic and vitrified waste forms also appear to be potential candidates for disposal in the high-level waste repository, though research and development will be required to obtain the necessary information for repository acceptance. In addition, authorizing legislation, NRC rule-making, or other actions may be required before placing immobilized plutonium in a high-level waste repository. While the glass-bonded zeolite waste form is less mature than the other immobilized forms, repository analyses to date identify no disqualifiers.

7.1.3 Reactor Alternatives

Existing LWRs

- MOX fabrication is a well-developed industrial technology currently operating in three countries.
- Cores involving integral neutron absorbers will require a significantly greater developmental effort to qualify the fuel form than the cores that do not involve integral neutron absorbers.
- The acceptability of small quantities of gallium in the fuel will need to be demonstrated or the gallium will need to be removed from the plutonium before fuel is fabricated.
- The licensing bases for the reactors and a MOX fuel facility are established.
- Modified facilities for both plutonium processing and fuel fabrication are viable approaches for the LWR cases (as well as for the CANDU cases).
- Sufficient reactor capacity exists, unless significant and unexpected delays occur in the mission. If such significant delays do occur, the availability of reactors with sufficient lifetimes remaining in their licenses is in question, particularly for BWRs.
- Foreign fuel fabrication facilities could be used to make some fuel early in the campaign, especially for lead use (or test) assemblies and a few subsequent partial core reloads. However, it is unlikely that sufficient fuel fabrication capacity will be available in Europe for the entire 50 MT mission. For this reason, a need for a domestic fuel fabrication facility is envisioned.
- Pressurized water reactors (PWRs), other things being equal, offer higher plutonium throughput per reactor year than boiling water reactors (BWRs).

CANDU Reactors

- The CANDU alternatives are similar in many respects to the existing LWR cases that do not use integral neutron absorbers. However, a qualified MOX fuel form for CANDU reactors does not exist and no industrial experience using CANDU MOX fuel is available, making the CANDU reactors less mature than LWR reactors for the plutonium mission.
- The CANFLEX fuel form, which involves a higher plutonium concentration in the fuel, is more attractive for the plutonium disposition mission because of its enhanced

ability to achieve higher plutonium throughputs. This advantage is partly offset by the need for a more extensive fuel development effort.

- Transportation across the border represents an institutional challenge to the CANDU alternatives. However, the transportation and packaging technologies to support the CANDU mission are well demonstrated and are technically viable.

Partially Complete LWRs

In most technical aspects the partially complete alternatives resemble the existing LWR cases. The important differences are: (1) because only two reactors are assumed to be available, the cores for the partially complete reactor alternative would have integral neutron absorbers, increasing the technical risk, relative to the existing LWR variants, which do not require integral neutron absorbers; (2) the reactors would need to be completed and the license application approved, both technical risks, relative to operating LWRs; (3) the partially complete reactors would generate spent fuel that otherwise would not have been generated, unlike the operating LWR alternatives where MOX spent fuel merely substitutes for LEU spent fuel.

Evolutionary LWRs

The conclusions that pertain to partially complete reactors would also apply to the evolutionary reactor cases. In addition, the technical risks for the evolutionary reactors are greater than the risks for the partially complete reactors given the latter's relative progress in licensing and construction. Furthermore, the evolutionary reactors themselves involve new reactor technologies that have not yet been deployed in the U.S., increasing the technical risk relative to partially completed reactors.

7.1.4 Immobilization Alternatives

Vitrification

- Experiments have been conducted to confirm that glass can immobilize significant concentrations of plutonium (> 5% for adjunct melter and greenfield variants and >10% for the can-in-canister variant).

- A significant data base exists relating to the vitrification of high level waste. The existing technologies can be adapted to the plutonium disposition mission, though different equipment designs and glass formulations will generally be necessary.

- In the can-in-canister and adjunct melter variants, using Savannah River facilities for the front-end processes as well for the vitrification processes provides substantial benefits.

- In terms of technical viability, it is judged that the can-in-canister variant is the most viable, the greenfield glass variant the least, and the adjunct melter variant intermediate. The can-in-canister approach is favored because it allows the separation of loading the plutonium into the small cans (glove box operations) and the mixing of the glass with the ^{137}Cs or high-level waste (hot cell operation).

Ceramic Immobilization

- Ceramic technologies have comparable maturity to the vitrification alternatives. In the case of cold press and sinter, production would utilize mature MOX fuel fabrication technology.

- An experience data base exists for ceramic immobilization; in particular, confirmatory experiments have demonstrated ceramic immobilization with plutonium loadings greater than 12%.

- Ceramic forms are expected to provide superior plutonium retention and better resistance to radiation damage over long periods of time relative to other alternatives.

- The can-in-canister variant is judged to be more viable than the greenfield variant for the same reasons as the vitrification can-in-canister variant is more viable than the greenfield glass variant.

Electrometallurgical Treatment

- The technical maturity of this alternative for the plutonium disposition mission is less than the other immobilization alternatives. The experimental data base for the alternative is limited and critical questions pertaining to waste form performance remain unresolved.

- Less is known about the long-term performance of the glass bonded zeolite waste form than glass and ceramic waste forms.

- The electrometallurgical treatment alternative is sited at ANL-W where some of the necessary infrastructure exists; however, additional capabilities would need to be added for front-end treatment of pits.

7.1.5 Deep Borehole Alternatives

- The mechanical equipment and processes for the borehole alternative would be adaptations of existing hardware and processes, requiring only system integration of the various components for this application (and not a dedicated component development effort).

- The ceramic immobilized form offers enhanced nonproliferation benefits for isolation and other technical advantages relative to direct emplacement.

- The most significant uncertainties relate to selecting and qualifying a site. These uncertainties can be resolved but require a mandate.

- Borehole alternatives place the least demands on front-end processing of the suite of disposition alternatives.

- This approach exceeds the spent fuel standard and approximates the fissile content of natural uranium. The deep borehole alternatives are the only disposition approaches which attain geologic disposal in concert with meeting the spent fuel standard.

- The borehole alternatives offer the potential for enhanced safety performance as the plutonium can be isolated from the biosphere over geologic time scales.

7.1.6 Hybrid Alternatives

Two alternatives which combine technologies were considered as illustrative examples of hybrid alternatives, using existing LWR or CANDU reactors in conjunction with a can-in-canister approach. The important conclusions are as follows:

- The hybrid alternatives are viable alternatives, since the LWRs and CANDU reactors are both viable candidate approaches for the reactor component, and the vitrification and ceramic can-in-canister approaches are viable candidates for the immobilized component.

- 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.

7.2 COST CONCLUSIONS

7.2.1 Investment Costs

The following discussion is in constant dollars unless otherwise stated.

- A significant fraction of the investment cost for an alternative/variant is related to the front-end facilities for the extraction of the plutonium from pits and other plutonium-bearing materials and for other functions which are common to all alternatives.

- Alternatives which utilize existing facilities for plutonium processing, immobilization, or fuel fabrication are preferable to building new facilities for the same function to realize significant investment cost savings.

- The investment costs for existing reactor variants tends to be about $1 billion; completing or building new reactors increases the capital commitments by several billion dollars.

- The investment cost for the immobilization alternatives ranges from approximately $0.6 billion for the can-in-canister variants to approximately $2 billion for new greenfield variants.

- Hybrid alternatives require approximately $200 million additional investment over the reactor stand alone alternatives.

- Large uncertainties in the cost estimates exist, relating to both engineering and institutional factors.

7.2.2 Life Cycle Costs

The following discussion is in constant dollars unless otherwise indicated.

- Like investment costs, the ranges of life cycle costs overlap for the three categories of alternatives; and as with investment costs, utilization of existing facilities is more attractive than building new facilities for the same functions.

- The net operating costs for the partially complete and evolutionary LWR variants depend on specific financial negotiations and are difficult to estimate.

- In no case could MOX fuel compete favorably with LEU fuel (natural uranium fuel for CANDU reactors) on a total cost basis

- The life cycle costs for hybrid alternatives are similar to the stand-alone reactor alternatives. For the LWR hybrid alternative, the cost is $260 million higher that the stand-alone reactor alternative; for the CANDU hybrid alternative cost is only $70 million higher.

- The immobilized borehole alternative life cycle cost is $1 billion greater than that for the direct emplacement alternative

- The sensitivity to the assumed discount rate, while not trivial, is relatively modest. In particular, a change in the discount rate by as much as 1% from the base case value (5% per year) changes net present worth only about 10% to 15%.

- Large uncertainties in the cost estimates exist, relating to both engineering and institutional factors.

7.3 SCHEDULE

- Significant schedule uncertainties exist, relating to both engineering and institutional factors.
- Opportunities for compressing or expanding schedules exist as only limited schedule optimizations have been performed.

7.3.1 Reactor Alternatives

- Except for using European MOX fuel fabrication facilities, the rate limiting step for existing and partially complete reactor alternatives is providing fuel to the reactors. This step is paced by the ability to make fuel at a MOX fuel plant and the ability to provide a supply of plutonium oxide to the MOX fuel plant.
- The time to attain production scale operation in existing LWRs and CANDU reactors is about 8–10 years from authorization, using European MOX facilities and specific feed streams for plutonium oxide.
- The time to complete the disposition mission is a function of the number of reactors committed to the mission, among other factors. For the variants considered in this report, the time to complete varies from about 24 to 31 years.

7.3.2 Immobilization Alternatives

- The rate limiting steps for the immobilization alternatives involve completing process development and demonstration and qualifying the waste form.
- The time to start the disposition mission ranges from 7 to 13 years after authorization.
- The operating campaign for the immobilization alternatives at full-scale operation was selected to be 10 years; it is possible to compress or expand the operating schedule by several years, if desired, by resizing the immobilization facility designs selected for analysis in this study. The overall mission duration is expected to be about 18 to 24 years.

7.3.3 Deep Borehole Alternatives

- The two related functions that drive the schedule for the deep borehole alternatives are selecting and qualifying a site and obtaining the necessary licenses and permits.
- The time to start-up is expected to be 10 years.
- The operating duration of the mission was established as 10 years, although completing all burial operations at the borehole site in 3 years is possible.

Therefore, the overall mission duration is estimated to be 20 years with accelerated emplacement reducing the duration by about 7 years.

7.3.4 Hybrid Alternatives

In general, the schedule data that apply to the component technologies apply to the hybrid alternatives as well. Some particular points apply:

- No schedule penalty accrues to using hybrid approaches. In fact, confidence in an early start-up and an earlier completion can both be improved, relative to their nominal schedules.

- Hybrid alternatives provide an inherent back-up technology approach to enhance confidence in attaining schedule goals.