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Evaluation of Potential for MSRE Spent Fuel and Flush Salt Storage and Treatment at the INEL

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CONTENTS

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LIST OF TABLES

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LIST OF FIGURES

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ACRONYMS AND SYMBOLS

°C	degree centigrade
AMWTF	Advanced Mixed Waste Treatment Facility
Ba	Barium
CFR	Code of Federal Regulations
Ci	Curie (unit of activity)
CPP	Chemical Processing Plant
CSSF	Calcined Solids Storage Facility
DOE	Department of Energy
EIS	Environmental Impact Statement
F	Fluorine
FAST	Fluorinel and Storage (facility)
FEIS	Final Environmental Impact Statement
FPR	Fuel Processing Restoration (facility)
HF	Hydrofluoric acid
HLW	High-Level Waste
ICPP	Idaho Chemical Processing Plant
IDHW	Idaho Department of Health and Welfare
IFSF	Irradiated Fuel Storage Facility
ILTSF	Intermediate Level TRU Storage Facility
INEL	Idaho National Engineering Laboratory
LDR	Land Disposal Restrictions
LLW	Low-Level Waste
MSRE	Molten Salt Reactor Experiment
NRC	Nuclear Regulatory Commission
NUHOMS	Trade name for modular transport system
NWCF	New Waste Calcining Facility
ORNL	Oak Ridge National Laboratory
Pu	Plutonium
RCRA	Resource Conservation and Recovery Act
RH	Remote-Handled
RHIF	Remote-Handled Immobilization Facility
ROD	Record of Decision
RWMC	Radioactive Waste Management Complex
SNF	Spent Nuclear Fuel
Sr	Strontium
SREX	Strontium Extraction process
TRU	Transuranic (as referring to waste)
TRUEX	Transuranic Extraction process
U	Uranium
U.S.	United States
U.S. DOE	United States Department of Energy
UFSF	Unirradiated Fuel Storage Facility
WIPP	Waste Isolation Pilot Plant
Y	Yttrium
Z	Atomic number

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SUMMARY

The potential for interim storage as well as for treatment of the Molten Salt Reactor Experiment spent fuel at the Idaho National Engineering Laboratory (INEL) has been evaluated. Provided that some minimal packaging and chemical stabilization prerequisites are satisfied, safe interim storage of the spent fuel at the INEL can be achieved in a number of existing or planned facilities. Treatment by calcination in the New Waste Calcining Facility at the INEL can also be a safe, effective, and economical alternative to treatment that would require the construction of a dedicated facility. If storage at the INEL is chosen for the Molten Salt Reactor Experiment (MSRE) spent fuel salts, their transformation to the more stable calcine solid would still be desirable as it would result in a lowering of risks. Treatment in the proposed INEL Remote-Handled Immobilization Facility (RHIF) would result in a waste form that would probably be acceptable for disposal at one of the proposed national repositories. The cost increment imputable to the treatment of the MSRE salts would be a small fraction of the overall capital and operating costs of the facility or the cost of building and operating a dedicated facility.

Institutional and legal issues regarding shipments of fuel and waste to the INEL are summarized. The transfer of MSRE spent fuel for interim storage or treatment at the INEL is allowed under existing agreements between the State of Idaho and the Department of Energy and other agencies of the Federal Government. In contrast, current agreements preclude the transfer into Idaho of any radioactive wastes for storage or disposal within the State of Idaho. This implies that wastes and residues produced from treating the MSRE spent fuel at locations outside Idaho would not be acceptable for storage in Idaho. Present agreements require that all fuel and high-level wastes stored at the INEL, including MSRE spent fuel if received at the INEL, must be moved to a location outside Idaho by the year 2035.

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1. INTRODUCTION

The Oak Ridge National Laboratory (ORNL) is studying alternatives for the storage and disposal of the products of the Remediation Project for the Molten Salt Reactor Experiment (MSRE). The "Regionalization by Fuel Type" option adopted by the Department of Energy (DOE),[1] and shown in the Programmatic Spent Nuclear Fuel Environmental Impact Statement,[2] specifies that the spent fuel from the MSRE project will be shipped to the INEL for storage to await a final disposal solution. The shipping of this fuel, as all others, is conditional upon the availability of appropriate technology and facilities for stabilization, packaging, transportation, and storage.[2] Also, the "Settlement Agreement"[3] between the State of Idaho, the Department of Energy, and the U.S. Navy that allows the shipment of MSRE spent fuel to the INEL, requires that all spent fuel, including MSRE spent fuel, be removed to a location outside the State of Idaho by January 1, 2035.

A study was conducted by the INEL to evaluate the ability of the INEL to:

- Receive and store the spent fuel and flush salt from the ORNL MSRE experiment for interim storage
- Treat these materials to produce a more stable form, both for interim storage and for final disposition.

This report is based on information about the MSRE spent fuel and flush salt supplied to the INEL by ORNL.[4,5,6]

Sections 2 and 3 briefly describe the materials to be stored or treated and review their legal status. Section 4 discusses shielding requirements and summarizes a set of preliminary and approximate shielding calculations aimed at estimating the size and weight of the containers required for transportation and handling. Section 5 addresses chemical stabilization requirements. In Section 6, the INEL facilities that are likely candidates for storage of the materials are surveyed and their advantages and disadvantages enumerated. Section 7 discusses the storage options that are considered

[a] Useful discussions with W. A. Kyes, W. B. Palmer, B. H. O'Brien, E. D. Houck, and A. L. Olson of Lockheed Martin Idaho Technologies Company, and with D. F. Williams of Oak Ridge National Laboratory are gratefully acknowledged.

nonviable from the INEL perspective, because of either technical or legal reasons. In Section 8, present and future treatment options at the INEL are presented. Section 9 discusses the implication of the choice of treatment option on the best physical form for packaging and shipping the MSRE salts from ORNL to the INEL. Section 10 briefly enumerates treatment options that are considered nonviable from the INEL perspective. Issues associated with long-term and global considerations are briefly discussed in Section 11. Outstanding issues are discussed in Section 12. Conclusions for this study are presented in Section 13. The final section contains a list of the references cited in the text.

2. MSRE SPENT FUEL AND FLUSH SALTS

The Molten Salt Reactor Experiment spent fuel is currently slated for shipping to, and storage at, the INEL per the Record of Decision,[1] the Environmental Impact Statement (EIS),[2] and the Settlement Agreement.[3] The inventory of molten salt spent fuel is identified in the EIS (Volume 1, pp. 3.2-14 and 3.2-15). The total mass of spent fuel is given as 4,650 kg of salt mixture. This corresponds to the spent fuel salt inventories of the fuel drain tanks only[6] and does not include the secondary spent fuel inventories (totaling about 226.1 kg) or the flush salts. In contrast to the information contained in the EIS, the DOE Integrated Spent Nuclear Fuel Database[7] identifies both the spent fuel and the flush salts as MSRE spent fuel. In this section, therefore, both the spent fuel proper and the flush salt are discussed without presumption as to the ultimate fate and legal classification of the flush salt.

The compositions of the spent fuel salt and flush salt appear in a number of publications from ORNL.[4,5,6] The most important characteristics for the purpose of the present study are the volumes of the materials, their mass, the fissile nuclides content, the chemical nature of the materials (fluoride salts), and the overall gamma and neutron production rates and spectra. All of these data, with the exception of neutron production rates and spectra, are found in the literature.[6,7] The ORNL information most relevant for this study is repeated in Sections 2.1 and 2.2.

Knowledge of the mass, volume, radiation emissions, isotopic composition, and heat generation is important for planning and/or designing the packaging, transportation, and storage requirements (e.g., cooling). The relevant information on the spent fuel and flush salt, given in Sections 2.1 and 2.2, is adapted from Reference 6. Information concerning the masses of fuel and flush salts can be found in Tables 3 and 4 of Reference 6, and a summary is provided here in Table 1.

2.1 Spent Fuel Salt

The total amount of MSRE fuel salt present in Fuel Drain Tanks-1 and -2 at ORNL is estimated to be between 4,650 and 4,846 kg, with the lower figure deemed more consistent with the process history. Secondary stored fuel salts total 226.1 kg. These secondary fuel salts have a much lower uranium content. From these estimates, the upper limit for the quantity of fuel salt is 5,072.1 kg. Based on a density of 2.48 g/mL for the fuel salts (at 26°C), their volume is approximately 2,045.2 L or 2.0452 m^3.

The activity levels in the fuel salt and flush salt can be found in Reference 6. For the purpose of this study, only an upper limit of the radiation source need be known. The total gamma activity of the fuel salt, 25 years after discharge, is given in Reference 6 as 4.5×10^{14} decays per second, corresponding to 1.6×10^{14} MeV/s. The gamma spectrum is shown in Table 2, also adapted from Reference 6. Information on spontaneous neutron emission could not be found in the documentation received from ORNL, and hence was not used in estimating shielding requirements. These are, however, under most circumstances, dominated by the need for gamma shielding. The actual neutron field is, in any case, dependent on the geometric configuration and the effective multiplication. The actual configuration will have to be properly evaluated for both criticality and shielding requirements. In this limited study, neutron shielding requirements are assumed to be met by the gamma shields without further qualification. Heat generation per unit time in the spent fuel salt is given in the DOE spent fuel database as 200 watts.[7] As would be expected, major fission products include $^{90}Sr/^{90}Y$ (14,900 Ci)[8] and $^{137}Cs/^{137m}Ba$ (12,200 Ci).[8]

2.2 Flush Salt

The total amount of MSRE flush salt present in the Fuel Flush Tank at ORNL is estimated to be between 4,265 and 4,272 kg, with the lower figure deemed more consistent with the process history. Secondary flush salts total 20 kg, resulting in an upper limit for flush salt of 4,292 kg. Based on the density of 2.22 g/mL for the flush salts (at 26°C), their volume is approximately 1,934 L or 1.934 m^3.

The gamma production rate for the flush salt is much lower than that of the spent fuel salt, which can be used as an upper limit estimate, with a very wide margin. Heat generation per unit time in the spent flush salts is essentially zero.[7] Consequently, minimal cooling or heat dissipation will be required for the flush salts.

2.3 Composition of MSRE Salts

The detailed chemical composition of the MSRE salts is summarized in Table 5 of Reference 6. This information is reproduced in Table 1 of this report. Information on the inventory of radioactive isotopes and trace elements is found in Table 6 of Reference 6.

The composition of the MSRE flush salt is also summarized in Table 1.

3. LEGAL AND INSTITUTIONAL ISSUES

The legal framework applicable to the MSRE spent fuel has been briefly discussed previously in Section 1. The applicable laws, rules, regulations, and agreements originate within two groups: the Federal Government and its agencies and the State of Idaho and its agencies.

The principal conclusions to be drawn from the existing laws, agreements, and regulations are:

- The MSRE spent fuel is projected to be shipped to the INEL for storage.
- All spent nuclear fuel (SNF) stored at the INEL, including MSRE spent fuel if received at the INEL, must be removed to a location outside the State of Idaho by January 1, 2035.
- All INEL high-level wastes must be ready for shipment from the INEL by January 1, 2035. If the molten salts materials are treated at the INEL and become part of the HLW inventory, there is uncertainty as to whether they must have been shipped out by January 1, 2035, because they were received as spent fuel under the condition of being shipped out of Idaho by that date, or if they must merely be made ready to ship by January 1, 2035, because they would then be high-level waste.
- Acceptance at the INEL is contingent upon the availability or the prior construction and preparation of appropriate facilities for receiving the materials.

The first conclusion is based on Reference 2, the corresponding Record of Decision (as amended to reflect the agreement with the State of Idaho),[1] and the Settlement Agreement[3] between the Governor of Idaho, DOE, and the U.S. Navy. The MSRE spent fuel falls in the category of nonaluminum-clad fuels that must be sent from ORNL to the INEL. The second and third conclusions also stem from the Settlement Agreement.

Currently, the flush salt is defined as spent fuel in the DOE National Spent Fuel Database.[7] If this definition remains in effect after the State of Idaho permitting process, then the treatment of the flush salts would be no different than that of the spent fuel. However, a strict adherence to the definition of spent fuel may result in the flush salts being classified as either mixed TRU waste or mixed low level waste, based on the content of alpha-emitting transuranic elements with a half-life longer than 20 years. The issue of how the materials are classified is further discussed in Section 11. Ultimately, the matter may need to be referred to legal counsel for resolution.

If the flush salts are determined to be waste rather than spent fuel, then there would no legal mandate for the INEL to accept them other than for treatment. In this case, shipping the flush salts to Idaho raises questions regarding the legal acceptance of the salts within the borders of the State of Idaho and the impact of acceptance on the Settlement Agreement (schedules, number of available shipments, etc.). The same restriction would apply to the wastes resulting from the treatment of the MSRE salts at a location outside the State of Idaho. For example, if it were decided to treat the MSRE fuel to remove the fissile materials at a location outside Idaho, then the storage of the remaining wastes within the State of Idaho would be prohibited per the Settlement Agreement.[3] The separated fissile materials would also be excluded from shipping to Idaho.

If treatment of the MSRE salts takes place in Idaho, the resulting high-level wastes must at least be made ready for shipment by January 1, 2035, as required by the Settlement Agreement[3] for all HLW present at the INEL. An ambiguity arises, however, in this situation, as the materials, initially received as spent fuel, must be shipped out of Idaho by that date. The issue may have to be referred to legal counsel for resolution.

The fourth conclusion stems directly from Reference 2. The absence of a fully qualified system for managing the materials (i.e., handling, storage, and monitoring facilities) would preclude their immediate transfer to the INEL. Prior to initiation of transfer, the conclusions of the present exploratory study would, therefore, have to be confirmed by the firm identification of all the steps and required facilities in the transfer and storage process. This provision will also have implications to fuel and waste *leaving* Idaho.

The legal drivers and agreements governing the eventual treatment of the liquid radioactive wastes and calcines present at the Idaho Chemical Processing Plant (ICPP), and influencing the treatment schedule and the choice of technology to be selected for this purpose are discussed in Reference 8. Some of the conclusions are directly relevant to the scheduling of INEL actions regarding the management of MSRE salts.

If calcination (see Section 8) is chosen as the treatment option for the MSRE salts, then timing of the transfer of the MSRE salts to the INEL and of their preparation for treatment has to be made compatible with the schedule of the planned campaigns for operating the calciner. If the timing is not well devised, the cost of calcining the MSRE salts could become extremely high, and not commensurate with the size of the inventory. The currently accepted schedule for the calcining facility operations calls for the calcination of all nonsodium-bearing liquid wastes by January 1, 1998.[8] A legal requirement that could affect even the ability to process the MSRE salts into calcines is that action must be taken to "calcine or otherwise process as much sodium-bearing high-level liquid radioactive waste (sodium-bearing waste) as DOE and the Department [*Idaho Department of Health and Welfare*, IDHW] mutually agree is practicable by January 1, 1998." This requirement could result in an insufficient inventory of liquid wastes being available for dilution of the MSRE salts to levels sufficiently low to not adversely affect the calciner performance.

Further treatment of the MSRE salts, either as such or after calcination, would be affected by the legal drivers and agreements applicable to the storage and treatment of spent fuels and wastes at the INEL. In addition to the conclusions shown above, a technology for converting the calcine waste into a form appropriate for disposal had to be selected by June 1, 1995, and discussions between DOE and the IDHW had to start within 90 days of technology selection. The facility intended in these agreements is the RHIF.

Another legal aspect that cannot be neglected, but is beyond the scope of this report, is the status of the MSRE salts with respect to the Resource Conservation and Recovery Act (RCRA).

4. SHIELDING AND HANDLING ISSUES

The maximum amount of spent fuel that can be stored in one container depends on the internal volume of the container which, in turn, is a function of the external dimensions and of the thickness of structural and shielding materials. Smaller capacities will require using a larger number of containers and hence occupying a larger number of positions in the storage facility. The storage positions needs are inferred from (1) the spent fuel volume, (2) chemical stabilizer volume requirements (F_2 scavengers or "getters"), (3) structural requirements of the containers, (4) shielding requirements, and (5) criticality control requirements. In this section, the shielding requirements are estimated, and the chemical stabilization needs are discussed in Section 5. Structural design and criticality control requirements are beyond the preliminary scope of this report. The package shapes and sizes may also be dictated by the choice of receiving facility (rack dimensions, hole dimensions, weight restrictions, equipment availability, etc.). The conclusions about packaging are synthesized in Section 6 under the relevant facility subheading.

Preliminary evaluations (point kernel transport calculations) have been performed to estimate an upper limit for the shielding requirements of the MSRE spent fuel (and flush salt). In these calculations, only gammas were considered. It was assumed that all charged particles will be stopped either within the materials or within a short travel distance into the shield. The neutron field has also been neglected, as it is expected to pose a much smaller problem than the gammas. From these preliminary studies, it appears that sufficiently capable shields can be constructed that are fairly small and result in masses smaller than those of casks that can be handled with current cranes and transportation technology.

From these shielding calculations, an assessment of the size of the required containers has been made. The first calculation assumed an all-aluminum shield for the fuel in order to derive a limit for the potential shielding credit that should be associated with self-shielding and the getter materials surrounding the fuel. It was shown that low-atomic number (Z) getters (such as Al) will help the shielding, but would not replace an effective shield made from high-Z elements. The other two materials considered were lead and iron. It was shown that thicknesses of lead or iron that result in packages of size and weight reasonable for long-distance, interstate transportation are achievable. The entire MSRE spent fuel material (including flush salts) could conceivably be packaged into one very large container (NUHOMS-type,[9] see Section 6.3) or several smaller containers, including getter materials. The estimates presented here are extremely conservative, especially because no credit is taken for the significant self-shielding that can arise from the materials in the fuel. Calculations reported in Reference 6 show that, in the current storage configuration, more than 88% of all gammas are deposited within the fuel salt nearly uniformly.

The preliminary results that can be achieved are summarized in Table 3. The values presented there should not be construed as actual design values. Instead, they should merely be viewed as order-of-magnitude considerations. The calculations performed to produce the values in Table 3 entailed a large number of simplifying assumptions. The results show the shielding thickness and number of packages for the spent fuel to result in surface dose rates acceptable for contact handling. No optimization was attempted. Because of the nature of the approximations made, the results are very conservative. For example, if the effect of self-shielding in the fuel is approximately accounted for by assuming a radiation source reduced by 88%, then the lead shield case would result in a shield thickness of 16.16 cm, a reduction of 3.79 cm. Experience with other irradiated fuel shows that the shielding will actually need to be even thinner when all geometric effects are accounted for.

The most important conclusion of this preliminary shielding study is that the entire inventory of MSRE spent fuel salts and flush salts can be packaged into a reasonably small number of containers that are practical to handle. The entire inventory and an equal volume of getter materials would fit into two sufficiently shielded packages of internal dimensions 1 m by 1 m by 2 m, or one of dimensions 1 m by 1 m by 4 m. The maximum mass of each of these packages, including shielding, would be less than 48 metric tons for each of the two packages or slightly less than double this mass for the single package. The entire inventory of spent fuel salts and an equal volume of getter materials would fit into a single NUHOMS-type container, further engineered to prevent corrosion and criticality problems (i.e., by shielding from the effects of surrounding reflector materials *outside* the container). The total mass of the materials contained within the NUHOMS-type container would be less than 26 metric tons, including fuel salts, getters, and container mass. The mass of any structural, criticality control, and corrosion control liner materials would have to be added to this. The total mass is significantly below the maximum design mass of about 33 metric tons for the NUHOMS-type container. If a NUHOMS-type container is used, shielding would be provided by the shipping cask.

5. CHEMICAL STABILIZATION OF PACKAGE

5.1 F_2 and UF_6 Getters

The studies of the MSRE spent fuel conducted at ORNL recognized that fluorine and uranium hexafluoride can and do elute from the salt.[6,10] The process is slow in the solid state, but can be faster if the salt is melted. The gases pose a corrosivity problem. Another problem, if the salt is melted, is the possible production and subsequent precipitation of metallic uranium to the bottom of the storage container, with the consequent criticality risk.

The MSRE molten salts, although basically fluoride salts, are much different from the fluoride wastes handled at the INEL. Zirconium-clad fuel has been dissolved in hydrofluoric acid (HF) at the ICPP, giving rise to a liquid fluoride waste. This liquid waste has been stabilized by calcining to a solid following the addition of calcium nitrate to prevent fluoride volatility. Consequently, the solid materials currently in the calcine storage bins at the INEL contain calcium fluoride in a mix with other components. The ICPP calcium fluoride solids are inherently very stable, resulting in a much lower rate of radiolytic fluoride (or radicals) production.

The precipitation of fissile material to a configuration that could become critical can be avoided by precluding any possibility of melting the salts, i.e., by cooling them in the shipping or storage package at a rate sufficient to prevent the temperature from rising to (or near) the melting point of the salt, reported as 434°C by ORNL.[10] The corrosivity problem caused by eluting gases could be mitigated via two concurrent design artifacts: (1) the container should be constructed of a material resistant to corrosion by fluorine, such as a heavily nickel-plated or nickel-clad stainless steel or a Teflon-coated steel, or (2) the container should contain scavenger chemicals or materials that are capable of absorbing the eluted fluorine. Such materials may include powdered metallic aluminum, alumina, calcium, calcium sulfate, boron, zirconium, other powdered metals, or possibly other materials. Activated carbon could be considered if fire hazard and criticality issues can be resolved (for example, it could be used with the flush salts if these are stored as TRU waste). Other materials may be added to this list.

5.2 Fire Risk Control

The package or packages will have to be cooled sufficiently to dissipate the total of 200 Watts[7] of power production (plus the much lower power production in the flush salt). The cooling is aimed at preventing hot spots and the formation of metallic materials (that could pose fire and criticality hazards). Although activated carbon is good at scavenging UF_6, its use may have to be limited, as fluorine and carbon compounds may be explosive. Other materials used as scavengers ("getters") should also be screened for fire hazard. For example, aluminum powder could be a fire hazard at high temperatures.

5.3 Chemical Toxicity Mitigation

Beryllium powder is a RCRA-listed toxic material. Beryllium and its compounds, including beryllium fluoride, are toxic materials. Their possible effects on human health are potent and painful. This toxicity must be controlled during interim storage and in the final disposition option. The latter is discussed in Section 11.2. During interim storage, care must be taken to properly isolate the beryllium compounds from the environment and possibly from other waste streams that are only radioactive and not hazardous (in the RCRA sense) as well. If the beryllium is removed prior to interim storage, it should be sufficiently immobilized to allow for an application for disposal as low-level waste.

5.4 Preparation for Medium-term Interim Storage

5.4.1 Design of Storage Containers

Storage containers will have to be designed to serve several functions. The foremost of these are containing the materials during normal and accident situations, and allowing transportation, manipulation, and monitoring of performance. These functions imply a number of requirements, including:

1. Resisting corrosion
2. Providing facilities for handling (such as hooks or handles)
3. Providing interfacing facilities (such as docking features)
4. Being structurally strong
5. Being weight-, size-, and shape-compatible with the storage location
6. Being sufficiently conductive for heat dissipation (fins may or may not be needed)
7. Being fitted with appropriate monitoring taps and facilities (pressure, temperature, etc.)
8. Satisfying drop test requirements.
9. Being sized to ensure criticality control.

For storage in facilities not requiring shielding, the choice will have to be made as to whether the containers will include shielding or not (in which case an existing or a new cask system will have to be part of the design). For storage in facilities requiring shielded containers, the containers will have to incorporate the proper level of shielding. The above considerations constitute a minimum list of requirements to be considered. A full design of the containers will have to be performed.

5.4.2 Maintenance and Monitoring Plans

Periodic checks of the effectiveness of the scavengers ("getters") to absorb eluted gases should be performed to avoid buildup of pressure and of potentially corrosive products. Methods for verifying the integrity of the containers should also be sought and installed with the containers. Other regular monitoring and routine maintenance schedules of the accepting facility or facilities should still apply. Monitoring neutron poisons, if used, will be necessary.

6. AVAILABLE STORAGE FACILITIES

The discussion in this section assumes that the MSRE spent nuclear fuel does not include the flush salts. If the flush salts were to be included, the maximum possible impact would be a simple doubling of the space requirements presented here. This doubling would be an upper limit because shielding and cooling requirements for the flush salts would be lower than those of the fuel salts. The volume of getter materials required would also be smaller than a full doubling because the radiation level in the flush salts is much lower than in the fuel salts, resulting in lower releases of radiolytic fluorine.

Because of the chemical nature of the fuel salt and its potential for criticality in presence of a moderator, this survey a priori excludes all storage facilities that are either under water or are prone to flooding or to moisture collection. The main facilities that received consideration are three at ICPP, one at the Radioactive Waste Management Complex (RWMC), and a future facility at ICPP (plans for which are firm).

In addition to surveying the various facilities, this section presents a description of the packages that are expected and summarizes any special requirements for each facility. The package sizes resulting from the shielding requirements described in Section 3 that can be accommodated in the options available (or to be available) at the INEL are stated.

6.1 Storage Facilities at ICPP

6.1.1 CPP-749: Underground Fuel Storage (DRY VAULT)

6.1.1.1 Acceptable Materials. This facility (CPP-749) was built specifically for indefinite storage of spent fuel, including chemically reactive fuel, while providing for eventual retrieval.[11] This is an outdoor facility consisting of underground, engineered storage wells or vaults. Some of the vaults include engineered moisture collection and mitigation systems. In this study, the effectiveness of the moisture reduction and control measures implemented in this facility have not been evaluated. Placement of the molten salt fuel in this facility will require detailed studies of the handling requirements and needed equipment.

6.1.1.2 Space and Storage Locations Availability. There are currently 85 empty dry vaults in this facility. Between about 20 and 30 of these empty dry vaults have not been committed to any specific project. The amount of space available is therefore sufficient for accommodating the MSRE spent fuel and, if required, the flush salts as well. The useful space within each vault is 13 ft 2 in. high, with an inner diameter of 29.276 in.[12] Below this space is a 9-in.-thick crush pad, and above it is room for a 3.5-ft-thick concrete shield plug. The crush pad would need to be redesigned as necessary for the MSRE containers drop scenario.

6.1.1.3 Container Exposure Limit. The containers used in this facility are handled via a cask; therefore, the containers are normally not shielded, and it will be necessary, if this facility is chosen, to verify that the concrete shielding plug is sufficient to reduce the dose rate to the design value of 0.125 mrem/hr just above the sealed vault. If this condition is not satisfied, then either the containers would have to be partially shielded or the currently provided concrete shield would have to be replaced with a new plug that provides the necessary shielding. The availability of appropriate casks for the transfer of the fuel to the facility, and locations for fuel transfers, if required, must be verified.

6.1.1.4 Container Shape and Size and Maximum Mass. The useful depth of each vault is approximately 13 ft 2 in. (158 in.). The packages must be designed to be accommodated, with some clearance, by these dimensions or the dimensions of the carrying casks, whichever is more constraining. The estimates presented here assume the use of a cask similar to existing ones previously used in conjunction with this facility. These existing casks, used in handling packages that were placed into vaults at this facility, have an internal diameter of 26 in. and a total internal length of 159 in.[13] The dimensions to be used are, therefore, 26 in. inner diameter and 158 in. height. The containers are required to fit within the cask with a 1-in. total radial clearance and are assumed to have 1-in.-thick walls. With these constraints, the container inner diameter is 23 in. The container inner height is obtained by subtracting lengths for twice the wall thickness (2 in.), top and bottom shields (twice 5.75 in.), and an impact limiter (19.25 in.). The useful inner length of the container is therefore about 125.25 in. With these dimensions, the inner useful volume of the container is equivalent to about four drums (55 gal per drum). The spent fuel salt volume is approximately 9.82 drums, and the flush salt is about 9.29 drums. It follows that between three and five containers are needed for packaging the spent fuel salts, and between three and five containers are needed for the flush salts. The larger estimates correspond to the use of a volume of getters equal to that of the salts, while the smaller estimates correspond to the use of a small amount only (that does not result in the need for any additional container). If the spent fuel salts and flush salts can be packaged together (either mixed or stratified), then the estimate for the total number of containers ranges from a minimum of five to a maximum of 10 packages, depending on the amount of getters used.

The bottom of the storage vaults are known to be able to support up to about 10,000 lb. There may, therefore, be a weight limit for the total loading per dry vault. With the assumptions used above to estimate the capacity of each container, it is found that the total mass of the loaded container is about 4,508.37 kg, including the mass of the 1-in.-thick iron wall of the container, two lead shields (top and bottom, 5.75 in. thick each), and a mixture of spent fuel and getter totaling 2,114.83 kg. These estimates assume densities of 7.87 and 11.34 g/cm^3 for iron and lead, respectively, and of 2.48 g/cm^3 for the spent fuel. It is also assumed that two shields are used, one at the top and one at the bottom of the container. From previous practice in this facility, it appears that containers with only a bottom shield are needed. If this practice is adopted, then the total mass of the loaded and bottom-shielded container is 524.51 kg less than the previous estimate. This would allow the inclusion of an engineered impact limiter while respecting the 10,000-lb weight limit with some margin, since the numbers used in this estimate are all upper limits.

6.1.2 CPP-651: Unirradiated Fuel Storage Facility (UFSF)

6.1.2.1 Acceptable Materials. This facility is designed for the storage of unirradiated fuels.[14] The materials stored therein are unirradiated or low-activity. From this perspective, this facility is incompatible with the MSRE spent fuel and flush salts in their present state. If the requirements of the facility were expanded to allow for the MSRE spent fuel, the packaging would have to be sufficiently shielded to allow direct manual contact handling. This facility may, however, be a viable storage location for the fissile materials if they are separated from the rest of the fuel during treatment.

6.1.2.2 Space and Storage Locations Availability. Items stored in the UFSF are stored in racks, cabinets, boxes, and drums, located within vaults. The actual location and storage method can be decided only after a full criticality analysis.

6.1.2.3 Container Exposure Limit. All items to be stored in this facility must be manually handled. The containers must therefore be small, fully shielded, and satisfy all the criticality prevention criteria of the facility.

6.1.2.4 Container Shape and Size and Maximum Mass. The size, shape, and maximum fissile content of each package can only be determined with a complete criticality analysis.

6.1.3 IFSF (Irradiated Fuel Storage Facility) in CPP-603

6.1.3.1 Acceptable Materials. This is a large, remote-handled facility, similar to a hot cell containing fuel storage racks.[15] The facility was designed to receive spent fuels that, because of potential chemical reactions, corrosivity, or toxicity, could not be stored under water. This is, technologically, the second best option for the storage of the MSRE spent fuel, after the aboveground modular vaults discussed in Section 6.3.

6.1.3.2 Space and Storage Locations Availability. The facility contains racks for the storage of 636 storage canisters. A sufficient number of these are available to accommodate the MSRE spent fuel and flush salts.

6.1.3.3 Container Exposure Limit. There is no shielding requirement for the containers because they would be handled remotely in this facility.

6.1.3.4 Container Shape and Size and Maximum Mass. The containers are constrained to be cylindrical in shape, with an outer diameter of 18 in. and a length of 11 ft. The cooling capability of the facility is sufficient to accommodate the heat generation in the MSRE spent fuel. There is a total mass limit of 2,000 lb on any loaded canister. Consequently, the entire inventory of MSRE spent fuel, flush salt, and getter materials will have to be distributed over a number of canisters to satisfy this limit. If it is assumed that canisters with walls that are 0.25 in. thick, made primarily of iron (stainless steel with a nickel lining) are used, and that they are filled to half capacity with the spent fuel (or a mixture of spent fuel and getters of density 2.44), then the loaded containers would have a mass of 1,970.2 lb. A total of eight to 16 such containers would be needed to accommodate the spent fuel and getters. The lower value assumes a small amount of getters, whereas the higher value (16 containers) assumes an equal mass of getters and fuel. The flush salts, under similar assumptions, would require between seven and 14 canisters and the same number of storage locations in the IFSF.

6.2 Remote-Handled Transuranic Waste Facility at RWMC

This Radioactive Waste Management Complex (RWMC) facility, the Intermediate Level TRU Storage Facility (ILTSF), is used for the storage of intermediate-level remote-handled TRU wastes. It is not intended for storage of spent fuel, and therefore may not be acceptable. The use of this facility may present significant legal and permitting problems. It would also require a great deal of re-engineering to mitigate moisture collection, as well as the unpalatable requirement to dilute the fuel to bring the fissile material content down to less than 200 g per 55-gal drum. In order to achieve this acceptance criterion, the fuel inventory would have to be diluted into 250 drums. In view of these facts, this facility should be considered only as a last resort for the spent fuel if the other options (above and below, and at other sites) turn out to be impractical. At this point, it seems that this facility should not be considered as a likely candidate storage location for the spent fuel. It could be a technologically acceptable option for the flush salts if these are deemed to be TRU wastes and if they are packaged in water-tight containers. If this were the case, the flush salts will have to be stored in 10 or more containers to satisfy the 200-g-per-drum fissile materials limit. No determination was made as to whether the flush salts meet the legal definition of TRU wastes (100 nCi/g of alpha-emitting transuranic nuclides of half-life greater than 20 years) or if the ^{233}U present in them qualifies them as TRU wastes.

6.3 Dry Storage Vaults (Aboveground)

This is a proposed facility based on the concept of modular (i.e., independent) aboveground vaults. The system would use commercially available casks similar to the NUHOMS commercial system.[9] It consists of a thick concrete pad and superstructure where large casks can be stored. Fuel can be inserted into the casks for interim storage and then sent to a final disposal location in the same cask. This option seems to be appropriate for acceptance of the MSRE spent fuel. Precise dimensions for the internal canister (the "container" from the storage perspective) are not presently available; however, estimates from the known commercial fuel capacities of the containers (24 PWR fuel assemblies) implies a useful volume of about 4.5 m^3. Consequently, a single container of the type considered for this facility should be sufficient for containing the entire MSRE spent fuel and flush salts inventory. If an equal volume is required by an engineered chemical getter system, then two such containers would be required and would suffice. Radiation shielding would be provided during transportation and handling by the transfer cask and during storage by the vault. The only shielding needed as an integral part of the container would be for its axial ends. Special provisions will have to be made in the design and construction of the container to ensure corrosion resistance. In addition, off-gas, pressure, and temperature monitoring equipment will have to be installed on the container. Storage of MSRE spent fuel and flush salts would probably be most technologically and economically sound in this system. Furthermore, the use, for storage, of a separate container that is acceptable and ready for shipping, and the use of a separate modular vault, are likely to simplify the compliance with applicable State of Idaho requirements.[3]

7. NONVIABLE STORAGE OPTIONS

There currently exists an agreement between DOE and the State of Idaho for the INEL to accept certain spent nuclear fuels for storage and possible treatment. No similar agreement exists to accept radioactive wastes, byproduct materials, or source or special nuclear materials. Therefore, any treatment or reprocessing of the spent fuel, other than treatment for stabilization *as a spent fuel*, would create an impediment to acceptance at the INEL. Some of the cases in which acceptability would be difficult or impossible are discussed below. Also, moving the spent fuel to the INEL for storage should represent an improvement over the continued storage at ORNL or there would be no reason for transferring it. This criterion results in the exclusion of potential INEL storage facilities that are similar to those at ORNL such as various shielded areas that could possibly be used for storage but which are not designed for that purpose. These facilities, such as the Fluorinel and Storage (FAST), Fuel Processing Restoration (FPR), or other Chemical Processing Plant (CPP) facilities, would require extensive modifications to prepare them for this use.

7.1 Receiving Materials as Waste Without Further Treatment at INEL

The INEL cannot accept waste for storage. If no treatment is to be performed at the INEL, the waste would not be acceptable. If treatment is to be performed, followed at some future date by shipping out of Idaho, a radioactive waste might be acceptable.

7.2 Receiving the Fissile Materials Only as Waste Separated From the Fuel

If the fissile materials are separated from the spent fuel, they could be classified as special nuclear materials, so they may not be received at the INEL as there is no mandate to do so. There could also be legal and institutional (State of Idaho) impediments to their shipment to, and acceptance at, the INEL.

7.3 Receiving the Flush Salt Only as LLW or TRU Waste

The flush salt is classified as spent fuel in the DOE database. As spent fuel, it is acceptable, as discussed above. If it is reclassified as waste (Low-Level Waste -- LLW, or Transuranic Waste -- TRU), it would become unacceptable,[3] as per Section 7.1 above. If the wastes would require further treatment in facilities available *only* in Idaho, the case may be made for their acceptance. They would, however, have to be shipped to a destination outside the State of Idaho within six months following treatment.

7.4 Receiving the HLW From Which the Fissile Materials Have Been Removed If No Further Treatment Is Planned at INEL

The INEL cannot accept HLW generated at facilities in other states. If the MSRE salts are treated outside the State of Idaho to remove their fissile materials contents, then the remaining waste may not be brought into the INEL or the State of Idaho.[3] If the wastes generated would require additional treatment available *only* at the INEL, the case might be made to accept them. There is, however, no automatic mandate for such acceptance at this time, and wastes treated at the INEL must be removed from the State of Idaho within six months following their treatment.

7.5 Storage of MSRE Salts in the Calcine Bins

The storage of the MSRE salts in the INEL calcined solids storage facility (CSSF) bins without prior calcination is not acceptable as discussed in Section 10.1.

8. VIABLE TREATMENT OPTIONS

At the INEL, there exists at present no operating treatment facility that is fully capable of treating and further stabilizing the MSRE spent fuel or flush salt. With some additions and modifications, an existing facility, the New Waste Calcining Facility (NWCF), could be used to process the MSRE fuel and flush salts into calcine, provided sufficient volumes of other liquid waste streams remain available to appropriately dilute the MSRE salts.

Two new facilities have been proposed for the treatment of stored INEL wastes and spent fuels. Each of these facilities, when operational, could contribute to the treatment of the MSRE materials. The first of these, for which plans are firm (at present, the bidding process is under way), is the Advanced Mixed Waste Treatment Facility (AMWTF) that could be able to handle and stabilize the flush salts, provided a pre-processing cell or special additives are added to mitigate the likely detrimental effect of the fluorine and lithium chemistry on the overall process. Under this scenario, the flush salts would be considered a mixed TRU waste that would have to be shipped out of Idaho within 6 months of completion of treatment. The second facility is only at the planning stage, but its eventual construction is mandated by existing agreements between the State of Idaho and the Department of Energy.[16,17] This facility, the ICPP Remote Handled Immobilization Facility (RHIF), would be capable of handling a wide variety of wastes, and should, with the addition of one or more pre-processing cells and the incorporation of suitable chemical additives, be able to treat the MSRE materials either as salts directly or following their calcination and interim storage. This chapter discusses each of these facilities in turn.

8.1 Calcination in the New Waste Calcining Facility

The New Waste Calcining Facility (NWCF) is a calcination facility located in ICPP at the INEL. This facility could be used to calcine the MSRE salts after they have been dissolved and mixed with other waste streams. In the following, a brief description of NWCF, and its capabilities and limitations with respect to MSRE salts treatment, are presented.

8.1.1 Facility and Process Description

High-level liquid waste from the reprocessing of nuclear fuel has been converted into calcine at the Idaho Chemical Processing Plant since 1963. This process, illustrated in Figure 1, involves spraying the liquid waste into a heated vessel containing a fluidized bed of particles. As water and other substances in the waste vaporize, the remaining solids collect on the fluidized particles inside the vessel. Originally, waste generated from reprocessing aluminum-clad fuel dissolved in nitric acid was calcined. Later, waste from zirconium-clad fuel, dissolved in hydrofluoric acid, also was processed as well as other miscellaneous types of waste. A generalized flowsheet for the calciner operation as performed in the NWCF is shown in Figure 2. This is for illustrative purposes only, as flowsheets vary depending on the type of waste being processed.

Liquid wastes are calcined by introducing them as an atomized, blended feed solution into a bed of heated oxide particles, which are fluidized with air inside the calciner vessel. The aqueous waste feed solutions are sprayed into the fluidized bed through pneumatic atomizing nozzles. Evaporation occurs primarily on the surfaces of the bed particles. The chemical species in the waste are converted to oxides, which coat the surfaces of the heated bed granules. The fluidized oxide particles grow from the deposition of the solids in the waste on the fluidized granules. The granules are removed from the bed as product and from the off-gas as entrained solids.

Heat is supplied to the bed by the in-bed combustion of kerosene. The kerosene is atomized with oxygen and sprayed directly into the bed where spontaneous ignition and continuous combustion provide the process heat required for calcination.

When fluoride-containing waste is being processed, calcium nitrate is added to the feed to reduce the volatility of the fluoride and to stabilize the waste. An extensive off-gas cleaning system removes particulate material from the off-gas before it is released to the environment.

The highly radioactive calcine from the calcination process is pneumatically conveyed to stainless steel solids storage bins. The bins are housed in air-cooled underground concrete vaults at the Calcined Solids Storage Facility (CSSF).

The NWCF operates as required during campaigns of varying lengths. At present (September 1996), the NWCF is not operating but is being readied for the next 18-month campaign, to begin early in 1997.

8.1.2 Conceptual Applicability of Calcination Process to the MSRE Salts

The calcination process produces an interim waste form that must be further stabilized to make it acceptable at a waste repository. Calcination is likely to be applicable to both the MSRE fuel and flush salts. It may, however, not be the most economical option for the flush salts if either or both of the AMWTF and the RHIF are built and become operational. Conceptually, the calcining process is applicable because the MSRE salts could be dissolved and added to the calciner feed. The dissolved salts would be mixed with other existing waste streams and with additives to mitigate the potentially detrimental effects of the large lithium contents. It is expected that much of the lithium chemistry would be similar to that of sodium and that problems that would have to be solved prior to treatment of the MSRE salts would be similar to those encountered in the treatment of sodium-bearing wastes that are currently under investigation. For example, lithium nitrate decomposition temperature is about 600°C, nearly the same as that of sodium nitrate hence, the MSRE salts are likely to cause similar "stickiness" problems for the calcine that could be mitigated by the addition of aluminum (as aluminum nitrate) and by other treatment methods.[b] Some of the problems that need to be solved and questions that would need to be resolved prior to calcination of the MSRE salts in NWCF are enumerated in Section 8.1.4. Laboratory and pilot plant tests will be necessary to demonstrate an operable flowsheet before it can be definitely stated that the MSRE salts can be calcined in the NWCF.

8.1.3 Advantages and Disadvantages of the Calcination Option

Calcining the MSRE salts in the NWCF is probably a feasible option, and at present it appears to be the most economical one. It does not depend on the availability of large new facilities that would be capital intensive to build. The next two paragraphs discuss pros and cons of this option, both technical and institutional.

Among the factors that may impede the implementation of this option are: (1) the loss of identity of the materials (as they are mixed with wastes, possibly causing difficulties regarding compliance with the Settlement Agreement, in particular with the stipulation that waste brought to Idaho for treatment must be shipped out of Idaho within 6 months of completing the treatment); (2) the salts are highly toxic and very corrosive; (3) the fissile material content of the MSRE spent fuel is much higher than that of previously calcined materials and possibly incompatible with storage in the

[b] Personal communication from B. H. O'Brien, LMITCO, August 1, 1996.

CSSF. Dilution into existing INEL waste streams and incorporating necessary additives may mitigate these objections.

Considerations in favor of this option include: (1) The spent fuel is subject to the requirement that it be shipped out of Idaho by the year 2035. The calcine (HLW) must also be ready for shipping to a HLW repository by 2035. Although these two requirements are different, their intended impact is essentially the same, and the issue may be considered for negotiations. (2) The corrosivity and toxicity in the MSRE spent fuel and flush salts do not appear to be significantly different from that of other streams that can be handled (and have been handled) by the NWCF. In particular, the beryllium content is no more troublesome than the cadmium content of other wastes calcined previously. (3) In order to alleviate the effect of the high fissile content, the MSRE salts would be fed into the input stream of the calciner gradually, with full regard for criticality issues. This will of course require both sufficient volumes of other input liquid wastes for proper dilution as well as a significant dissolved solids content in these liquids to ensure proper dilution and dispersion of the fissile materials in the calcine phase. (4) The resulting calcine would be stored in an existing facility instead of a new one yet to be built. Calcination converts the fluorine contents to a more stable compound than those present in the MSRE salts, resulting in much reduced needs for special monitoring requirements and the elimination of the need for the addition of "getters" as well as the elimination of concerns about corrosion of the containers. (5) This option is technically feasible and would require the lowest additional capital investment. The only requirement is the adaptation and restart of existing facilities for the salt dissolution and provision of adequate piping from these to the calciner feed. Although this seems expensive, this option would make use of existing facilities, which is much cheaper than constructing new facilities elsewhere.

Calcination does not meet the Land Disposal Restrictions (LDR) treatment standard for high-level wastes. The calcination process produces a calcine, a stable solid interim waste form, suitable for storage until a final repository option is chosen and the waste is processed to a final waste form that meets the LDR treatment standards. It is projected that this final treatment will take place in the proposed Remote-Handled Immobilization Facility (RHIF).

8.1.4 Feasibility of Process

The use of calcination for interim stabilization of the MSRE salts and their subsequent storage in the calcine bins of the CSSF appears feasible and, in all likelihood, is the most cost-effective option at this point. The actual implementation of this option must, however, be preceded by studies of a number of significant issues that could not be addressed in full in the course of this study. In this section, some of these issues are identified. Other items, such as costs of additional developments, to be incurred prior to deployment are not addressed.

8.1.4.1 Determination of Input Point and Flow Sheets Modification. The point in the process at which the MSRE salts will be incorporated needs to be determined. This will require the development of flowsheets and the identification of the equipment where the incorporation step is conducted (mixing tank, holdup tank, etc.).

8.1.4.2 Dissolution. The ORNL reports available for this study do not describe the dissolution chemistry of the MSRE sufficiently to draw a conclusion on the final volume of the resulting solutions and on their dissolved solids density. The dissolution chemistry must be fully addressed prior to implementation of the calcination option. The dissolution chemistry and its compatibility with the other constituents of the feed must be studied and demonstrated. The dissolution should be complete and permanent until intentionally reversed. No precipitates should form (especially of fissile materials). The physical and chemical properties of the tank in which the dissolution is to take place must be determined, and an available tank meeting those conditions must either be identified at the INEL or acquired. In addition, the necessary piping and connections to the NWCF facilities must be built, equipped for pumping, and instrumented. Other instrumentation for monitoring the process will have to be defined and acquired. A materials compatibility constraint is that the solution of MSRE salts with additives should not be corrosive to 300 series stainless steel, a major constituent of the components of the calcination facility.

8.1.4.3 Feed Preparation Facility. Following dissolution, the MSRE salt would have to be incorporated into the feed to the calciner. The specific location where this is to occur must be identified, and the chemistry and the flow sheets for this step must be developed and demonstrated. If additives are to be incorporated that are not normally part of the feed preparation process when tank farm liquid wastes are calcined, the location and facility in which this is to be performed must be identified. This and other additions may have to be constructed if deemed necessary.

8.1.4.4 Dilution Requirements. Without knowing the dissolution properties of the MSRE salts, it is not possible to determine how much additional dilution will be required as a prerequisite to feeding the salts into the calcination process. The two main criteria that define proper dilution pertain to the material and chemical properties of the calcine granules (as relevant to operation of the calciner, operation of the pneumatic transport system, and to storage) and to the criticality control requirements in storage (as the calcine concentrates the fissile material initially in solution). The first condition implies that a sufficient volume of liquid wastes must be available in the tank farms to dilute the MSRE salts to a level where, with incorporation of the proper additives, the calcine granules would not stick, agglomerate, or cake. This criterion may be relaxed if new chemistry flowsheets are developed that do not require dilution. The second criterion requires the presence of amounts of dissolved solids in the liquid waste that are sufficient to "neutronically" dilute the calcine in storage. This can be achieved by the presence of strong neutron absorbers or by actual volumetric dilution of the fissile materials in the solid phase. The availability of tank farm liquid wastes will be affected by the agreed-to schedules for termination of the use of tanks, as discussed in Section 8.1.5. An assessment of the actual dilution requirements is beyond the scope of this study. This will probably entail both a theoretical and experimental demonstration of the chemical properties of the calcine granules and their properties in the fluidized bed and a full criticality analysis for the formed calcine in the bins. However, the starting point for any estimate is the current inventory of suitable liquid wastes. The volumes of high-level wastes currently in storage in the tank farms at the INEL are summarized in Table 4. The detailed dissolved and undissolved solids contents for the liquid wastes stored in Tanks WM-180, WM-181, WM-184, and WM-186 are shown in Table 5. The contents of these tanks are shown because following the next calciner campaign, they would be the only ones left in use,[c] as discussed in section 8.1.5. It remains to be determined, in a full study (process chemistry, criticality), whether the liquid volumes of these tanks and their solid contents are sufficient to result in proper (safe) dilution of the MSRE salts in both the liquid and calcine phases. Composition changes as wastes are added or removed from the tanks and processed, consequently, the data in Table 5 vary over time. For example a significant change involved the addition of 15 kg U-235 to tank WM-184 since the last sampling. The current total uranium content in that tank is about 78 mg/L.[c]

[c] Personal communication from B. H. O'Brien, LMITCO, August 1, 1996.

8.1.5 Calcination Scheduling Considerations

The NWCF option for treatment of the MSRE salts is essentially operational except for an additional head end. It should be possible to resolve the remaining issues with a small amount of lead time. The timetable for the treatment must, however, conform to existing campaign plans for processing existing liquid wastes at ICPP. The timetable for discontinuing the use of the tanks storing liquid wastes is mandated by agreements between the State of Idaho and the Department of Energy and can be found in a number of sources, including the recent Draft INEL Environmental Management Plan.[20] A salient feature of current planning is that all use of pillar and panel tanks shall cease by the year 2009, all HLW tanks must be empty by the year 2012, and all use of tanks shall cease by the year 2015 (this particular date is still the object of negotiations between the State of Idaho and the Department of Energy). Of more immediate importance is the current schedule for operation of the calciner. The next calciner campaign is scheduled to begin between January and March 1997 and will last 18 months. At the end of the campaign, only tanks WM-180, WM-181, WM-184, and WM-186 will still contain liquid wastes. Prior to accepting the calcination option as being truly available for the MSRE salts, a study of schedules compatibility should be completed.

8.1.6 Recommendations for the Calcination Option

The calcination option is the closest to possible deployment for treatment of MSRE salts at the INEL. Steps to implementation should include a demonstration of the chemistry and processes in a pilot facility and the construction of front end facilities. The first actions, however, should entail the verification of the compatibility of the MSRE remediation schedule with the operations schedule of the NWCF.

8.2 Treatment in the Advanced Mixed Waste Treatment Facility

The Advanced Mixed Waste Treatment Facility (AMWTF) is a proposed facility that will have the mission of treating and stabilizing remote-handled mixed TRU wastes. The wastes slated for this facility, although remote-handled, are expected to be of lower activity than those slated for the ICPP Remote-Handled Immobilization Facility (RHIF), as the shielding may be less than in that facility. The AMWTF should be able to handle toxic metals as well as organic compounds. In many respects, the flush salts are similar to existing mixed transuranic wastes. They could, therefore, be a potentially acceptable candidate for treatment in the proposed Advanced Mixed Waste Treatment Facility (AMWTF).

8.2.1 Description of Processes and Facilities

The AMWTF does not exist yet. It is only at the bidding stage. Consequently, a description of the processes and facilities is not available. The Site Treatment Plan[16] and the documents describing the requirements in the bidding process[21,22] describe the wastes to be treated and the performance criteria for the facility.

8.2.2 Applicability of Process

The processes that will be available in the AMWTF are not identified at present. They can, however, be partially inferred based on the requirements mentioned above. From the list of wastes to be treated in the AMWTF,[21] it can be concluded that a large variety of processes will be present. Some of the wastes to be treated in the AMWTF display problems that are similar to those of the MSRE flush salts. Consequently the facility will have a high probability of being able to treat the

MSRE flush salts. Some of the wastes to be treated in the AMWTF include molten salts, metal wastes, TRU pyrochemical wastes, TRU heavy metal sludge, and beryllium.

A discussion of the feasibility of using the facility for the MSRE salts and of the advantages and disadvantages of the processes is premature, as the available information is insufficient. In particular, it is not possible to determine at this time if the AMWTF will incorporate sufficient facilities to treat the MSRE flush salts without additional preliminary or subsequent steps. Cost considerations are also premature.

8.2.3 Schedule for AMWTF Option

This facility has been approved by DOE and is currently in the bidding stage. Bids from potential contractors interested in building the facility are expected by October 1996. Per the Settlement Agreement,[3] this facility should commence operation by March 31, 2003.

8.2.4 Recommendations on the Use of the AMWTF

A potential difficulty of institutional nature may arise regarding the treatment of the flush salts in this facility (or at any other in Idaho) if the flush salts are considered to be other than spent fuel. Per the Settlement Agreement,[3] TRU wastes received in Idaho must be treated within 6 months of receipt and must be shipped out of Idaho within 6 months following treatment. Low-level waste can be received in Idaho only if it is determined that Idaho is the best location for treatment and/or storage. This determination must be arrived at using the Federal Facility Compliance Act, as facilitated by the National Governors' Association. These difficulties could be avoided with proper timing (coinciding with acceptance at a repository for final disposition). At present, it is premature to presume that the AMWTF will be able to treat the MSRE flush salts. This facility should be considered an uncertain choice, and planning should not emphasize its use.

8.3 Treatment in the Remote-Handled Immobilization Facility

8.3.1 Description of Processes and Facilities

The Remote-Handled Immobilization Facility (RHIF) is a facility proposed for the processing of liquid wastes (mostly sodium-bearing) and calcines from the Calcined Solids Storage Facility (CSSF) at the ICPP into forms suitable for permanent disposal. The RH vitrification portion of the facility will be initially utilized to treat RH transuranic-contaminated waste as discussed in Section 8.3.5.

The facility and its components are described briefly in Reference 8. The complete facility encompasses several processes and is shown schematically in Figure 3. Figures 4, 5, and 6 show additional details of the dissolution and separation processes. The remainder, immobilization by vitrification or grouting, is not shown. The first step in the calcine treatment process, although not actually part of the RHIF, is calcine retrieval. This operation is performed by inserting a vacuum nozzle into each bin of the CSSF. After retrieval, the calcine is pneumatically transported to the RHIF where the first actual treatment step is dissolution. If the MSRE salts are to be treated in the RHIF without having been initially calcined, their first treatment step would also be dissolution. Testing has shown that the calcine can be almost totally dissolved using nitric acid. Dissolution studies and experiments will have to be performed on the MSRE salts to identify and develop an effective dissolution process. Following dissolution, the next step is the separation of the actinide contents via the TRUEX process as shown in Figure 5. To ensure that the low activity waste can meet Nuclear

Regulatory Commission (NRC) Class A low-level waste criteria, the following process step carefully separates the undissolved solids from the liquid. The liquid is then sent to a set of centrifugal contactors where the strontium is separated from the nonradioactive components using the Strontium Extraction (SREX) process. The next process step (not shown in the figures) separates cesium using ion exchange. Once this bed is saturated with cesium, the resins are removed and blended with other high-activity wastes; then immobilized.

Two waste streams result from the operation of the RHIF separation stages. The high-activity stream is vitrified by combining it with glass-forming frit and heating to temperatures greater than 1500°C to produce a glass. The melt is then poured into canisters, sealed, and transported to an interim storage facility prior to final disposal. The glass thus produced is a high-level waste form suitable for disposal at a geological repository. The low-activity stream is immobilized in barrels using grouting technology. The barrels are transported to an interim storage facility prior to final disposal. When hazardous materials are treated, it is expected that if the grout can be delisted to remove it from RCRA regulation, it would be disposed at a LLW site such as RWMC. If delisting is unsuccessful, the grout will need to be disposed at a mixed LLW site. The proposed RHIF includes interim storage for immobilized wastes (both HLW and LLW) with the capability for expansion as required.

8.3.2 Applicability of Process

The processes comprising the treatment and immobilization portions of the RHIF would be directly applicable to the MSRE salts either as received or following calcination provided the dissolution step is shown to be practically achievable. The actual chemical flow sheets for this process are beyond the scope of this work, but must be developed and demonstrated prior to concluding that the use of this proposed facility is indeed feasible for immobilization of the MSRE salts.

8.3.3 Advantages and Disadvantages

This facility is referred to in the INEL Site Treatment Plan as a proposed facility for the treatment of a variety of wastes. In particular, it should be capable of treating high-level wastes as well as spent nuclear fuel. Some of the perceived advantages of this option are enumerated below, followed by a presentation of perceived disadvantages.

An obvious advantage of the RHIF is that the processes it will involve have been well thought out and the relevant technologies have already been developed, with some already partially or fully deployed elsewhere. The end products are stable, and the waste forms suitable for ultimate disposal.

The primary drawback of this option is that, at the INEL, these facilities are still non-existent. Their construction is likely to be costly, although the incremental portion imputable to the treatment needs of the MSRE materials is comparatively small. A second drawback is that the option and its timing are uncertain. Alternate plans are under consideration that include construction of only the items labeled Phase I in Figure 3. Under those plans, the high-activity waste would have to be shipped to another site for vitrification.

8.3.4 Feasibility of Process

The only technical uncertainties perceived at present pertain to the dissolution chemistry of the MSRE salts (or the calcine that they would produce). The issues are twofold. First, the salts or the calcine must be effectively soluble, and the solutions must be compatible with the various extraction processes encompassed in the RHIF. Cost considerations are premature as of this writing, as they would depend heavily on the solution compatibility with the extraction and vitrification processes, or the lack thereof.

8.3.5 Schedule for RHIF Option

The processes and facilities for the RHIF are proposed but not DOE-approved. According to the INEL Site Treatment Plan,[16] this facility is scheduled to be operated for 3 years between 2017 and 2020 to treat waste that are remote-handled and contain transuranic contaminants, but are not acceptable for treatment in the AMWTF. Following processing of all the RH transuranic-contaminated wastes, the RHIF will be utilized to process high-level waste.[16] The transuranic-contaminated waste treated in this facility would be made into a form suitable for placement in WIPP. Under these conditions, the MSRE salts would have to be stored until at least 2017 for the flush salts and until after 2020 for the spent fuel salts if treatment is to be performed in the RHIF.

8.3.6 Recommendations

If treatment in the RHIF is selected as the preferred alternative, the dissolution chemistry of the MSRE salts and the resulting solutions compatibility with the extraction processes become the crucial determining factors for success and should be addressed early. This option should be pursued as vigorously as the schedule for the facility allows, as it offers a complete engineering solution up to final disposal. The use of this facility following initial treatment by calcination (Section 8.1) offers the same advantages, with the added benefit of a form more stable than the salts in the interim period.

9. INEL TREATMENT OPTION IMPLICATIONS FOR SHIPPING PHYSICAL FORM OF MSRE SALTS

The treatment options discussed in Section 8 can be made easier or more economical by a consequent choice of the form in which the MSRE salts are to be shipped to the INEL. This section briefly examines this issue and makes recommendations on the best physical form for shipping and storage of the MSRE salts, based on maximum compatibility with the most likely choice for a treatment alternative, and on ease and economy of the treatment alternative. In addition to the recommendations presented in this chapter, criticality control should be made an inherent part of the packages via appropriate design.

9.1 Shipping MSRE Salts as a Solid Block

Shipping the MSRE fuel salts or flush salts as one or two solid blocks is the least desirable alternative. A solid block of MSRE fuel or flush salts would require the development of special handling technology and equipment at the INEL to ultimately produce small lumps or granules suitable for measuring (mass) and incorporating gradually into the dissolution process with due regard to chemical compatibility and criticality control requirements. A solid block would be the most difficult form to deal with in further processing. This potential choice should be rejected.

9.2 Shipping MSRE Salts as Multiple Small Solid Blocks

Shipping the MSRE salts as small solid blocks (e.g., gallon size) is the second least desirable choice, as it may still require further breaking into smaller portions. The same objections as in the above section apply.

9.3 Shipping MSRE Salts as Granules in a Single Container

A single large container containing the MSRE salts in granular form presents the advantage of ease of handling during transportation and storage, and could be overall the most desirable alternative if the container can be fitted with an effective remote retrieval system such as valves and piping for pneumatic retrieval.

9.4 Shipping MSRE Salts as Granules in Multiple Small Containers

Granules in multiple small containers inside a larger container are probably the easiest packaging system both for transportation and for subsequent treatment, as the smaller containers may constitute either a single batch or fractions of a batch and could be handled remotely via pneumatic as well as mechanical means.

The extensive experience with pneumatic transport of granulate solids at the INEL makes this solution and the previous one the two most attractive for further handling.

9.5 Location of Getters in Shipping Package

Depending on their chemical nature and of the quantities required, it may be advantageous to mix the getter chemicals directly into the MSRE salts (if in granular form). If the getter materials are compatible with the calcination and/or the RHIF treatment processes, incorporating them fully mixed with the MSRE salts may present an advantage with regard to future treatment steps. If the getters are not compatible with the subsequent treatment steps, or if only a small quantity of the getter materials is needed in subsequent treatment (e.g., as an additive in the calcination process), then the getters should be packages adjacent to the MSRE salt, but separate and in such a way that the salts could be retrieved without inadvertently carrying the getters.

If the chemicals in the getters are not necessary additives of subsequent treatment steps, using them in an easy-to-separate configuration may improve the prospect of their subsequent disposal as LLW.

9.6 Recommendations

In light of the extensive experience of the INEL with pneumatic transport of granulated materials, and of the uncertainty about the chemistry of future treatment options for the MSRE salts, it is recommended to package the salts as granules in separate small containers, compatible with criticality limited batch sizes, and equipped with remote-handling handles. The getter materials should be retrievably separate from the salts (e.g., separated from the salts by a permeable mesh).

10. NONVIABLE TREATMENT OPTIONS

Besides the viable treatment options discussed in Section 8, a number of nonviable methods could be considered. This section justifies the rejection of three such options.

10.1 Store in Calcine Bins Without Treatment

The incorporation of the MSRE salts "as-is" into the calcine storage bins is not acceptable. The two main reasons for this are criticality control requirements and corrosivity of the MSRE salts. A third impediment, of institutional nature, may also arise.

The fissile material content of the MSRE spent fuel is higher than those of calcined solids currently stored in the calcined solids storage facilities (CSSF). A full criticality analysis was not conducted, but past practice precludes the storage of large quantities of materials with fissile nuclides contents similar to those of the MSRE spent fuel. This restriction may be relaxed for a calcine formed from the salts if deemed acceptable by a full analysis of criticality.

In their present chemical state, the MSRE salts elute fluorine compounds and gas that are incompatible with the construction of the storage bins primarily because of corrosivity. For these reasons, this option is not recommended.

The incorporation of the MSRE salts into the calcine storage bins is tantamount to declaring them to be a high level waste, making them subject to exclusion from acceptance within the State of Idaho per the Settlement Agreement.[3]

10.2 Calcine Separately Without Dilution

The MSRE salts are incompatible with the calcination processes as they currently exist. In order to be incorporated into a calcination process, they must be blended with other streams and diluted to mitigate the potentially detrimental effects of their lithium and beryllium content and prevent inadvertent criticality. Calcining the MSRE salts without blending and dilution is not acceptable.

10.3 Treat MSRE Spent Fuel Salts in the Advance Mixed Waste Treatment Facility (AMWTF)

The Advanced Mixed Waste Treatment Facility (AMWTF) is designed for the treatment of mixed TRU wastes, and will not accept spent fuels or high-level wastes. Dissolution of the spent fuels and subsequent addition to other streams prior to sending to AMWTF is not desirable.

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11. GLOBAL AND LONG-TERM CONSIDERATIONS

11.1 System Optimization

Economics have not been addressed in this study. It is obvious, however, that an analysis of trade-offs based on the number of packages, their transportation costs, and the cost of storage space and handling must be performed. This analysis should then be factored into a global decision-making framework encompassing a consideration of institutional issues, future disposition issues (after the interim storage period), and global risks. The basis for a final decision should include the answer to the question, "Does the transfer of the materials to the INEL result in an overall reduction of environmental and economic risk to the nation?" These considerations are beyond the scope of this report.

11.2 Final Disposition Options

Significant questions exist concerning the ultimate disposal of the molten salt fuel. This issue is not addressed in the DOE Spent Nuclear Fuel Management and INEL Environmental Restoration and Waste Management Programs Final Environmental Impact Statement (FEIS).[2] This FEIS states that, per the Nuclear Waste Policy Act of 1982, as amended, all DOE-owned spent fuel will be disposed of in the First Repository, namely at Yucca Mountain. The FEIS does not, however, address the acceptability criteria for any of the spent fuels, specifically stating that disposal of SNF was too speculative to include at that time. The INEL will, however, have to face the issue certainly by January 1, 2035, because of the stipulation in the Settlement Agreement[3] between the State of Idaho, the DOE, and the U.S. Navy authorizing the shipments into the INEL.

The movement of any fuel into Idaho and from Idaho to a final disposal destination is conditional upon the availability of proper technologies for stabilization (if necessary), packaging, transportation, storage space, and disposal space. A global systems approach should therefore keep in perspective the ultimate disposal alternatives and take them into account during all interim actions. As the molten salt remediation project proceeds, certain questions that are crucial to INEL interests will need to be addressed, including:

- Will the materials be acceptable for disposal at WIPP or Yucca Mountain? (e.g., Do they meet disposal sites waste acceptance criteria?)
- Are the interim packages suitable for final disposal?
- If treatment is to take place at the INEL (e.g., calcination, separation, grouting, vitrification), will the resulting materials be acceptable at one of the repositories?

Although final answers to these questions are beyond the scope of this study, preliminary considerations are presented below.

11.2.1 WIPP Acceptance Criteria

The Waste Isolation Pilot Plant is the planned facility for disposal of TRU wastes. The WIPP acceptance criteria[23] stipulate that "transuranic wastes shall contain no hazardous wastes unless they exist as co-contaminants with transuranics." It is also required that "all TRU-contaminated corrosive, reactive, and ignitable materials shall be treated to remove the hazardous characteristic." These criteria will have to be complied with prior to sending the MSRE salts, or materials resulting from their treatment, to WIPP for disposal.

11.2.2 Yucca Mountain Acceptance Criteria

Criteria for acceptance and disposal of various spent fuels and materials at the Yucca Mountain repository have not been finalized. A draft EIS will be developed in the future to address this issue. Currently, it is believed that the facility will comply with 10CFR60 and 10CFR960, and will not accept any mixed or hazardous wastes. It follows that the intent to have all DOE-owned fuels disposed of in the Yucca Mountain repository, as expressed in Reference 2, and as authorized in the Nuclear Waste Policy Act, may be difficult to achieve without significant treatment and reconditioning of certain spent fuel streams, such as the MSRE spent fuel. The future applicable criteria, as they are currently understood or expected to take shape (see for example 10CFR60, 10CFR960, and Reference 24), could explicitly exclude materials such as MSRE spent fuel. If properly treated, the MSRE spent fuel could be split into two streams, one acceptable at WIPP, and the other acceptable at Yucca Mountain.

11.3 On Treatment and Storage at the INEL

The receipt of MSRE spent fuel and flush salts merely for the purpose of interim storage may not result in a significant improvement of the global situation across the DOE complex. A real justification for the shipping of these materials to the INEL can be found in three possible deciding factors: (1) a net reduction of the risk complex-wide by storing the materials at the INEL, (2) a net reduction of risk complex-wide by treating the materials to an interim form at the INEL, and (3) the *necessity* to conduct *at the INEL* the next step in the preparation for their ultimate disposal at an appropriate repository.

All of the storage options discussed in Section 6 would result in a net decrease of risk from the current status of the MSRE spent fuel, though not necessarily from alternate storage options that may be considered by ORNL. The INEL site is far from large concentrations of population and has a very deep water table. These factors alone would result in risk reduction.

In Section 8, a discussion of the possibilities for treatment that may be considered at the INEL was presented. The ultimate selection process for treatment technology options and treatment locations should incorporate DOE complex-wide information and data in order to result in an optimum choice. It is clear, however, that the calcination option would result in significant risk reduction because it would produce an interim waste form that is much more stable than the salts (effectively removing the volatility problem of the fluorine) and would imply storage in a facility specifically designed for the storage of solid high-level wastes and already storing large quantities of calcines. An added benefit is a reduction of the financial commitment, as the operation and monitoring of the CSSF are on-going activities. The addition of the calcines from the MSRE salts would not result in a commensurately large increment of the financial burden.

11.4 Short-, Medium-, and Long-term Cost Issues

Costs and funding issues are important matters that should be addressed prior to any movement of the spent fuel and flush salts. In particular, funding sufficient for the completion of any operation to a state of safe storage must be appropriated prior to the beginning of the operation. Before any such operation is undertaken, preliminary studies and design work must be conducted. It is probably most logical for funding in the early stages to be managed primarily from ORNL, with the portion of the funding (storage design, safety analyses, etc.) assigned to the INEL. Examples of operational funds best managed from ORNL include funds for initial stabilization, packaging, and transportation. Examples of funds best administered by the INEL include safety analyses for the transportation container (with respect to its interaction and compatibility with receiving INEL facilities); design, safety analyses, and physical modifications for receiving operations; design, safety analyses, and construction or procurement of storage containers and storage facility (including any necessary modifications); long-term monitoring of stored packages; and any needed additional treatment. The long-term storage and monitoring budget, as well as funds for preparation for ultimate disposal, should be assigned to the INEL.

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12. OUTSTANDING ISSUES

The work presented in this report did not encompass an extensive array of engineering and design calculations. The conclusions were reached through a variety of means, including interviews of facility experts and reliance on previous experience with the facilities. Many issues were not addressed, and many quantitative verifications need to be carried out prior to any action being taken that would result in the MSRE salts being transported to the INEL for storage or prior to their treatment in any of the existing of planned INEL facilities. Some of these outstanding issues are discussed in this chapter.

12.1 Issues on Interim Storage of MSRE Salts

The first part of this report presented a preliminary study regarding storage of MSRE salts at the INEL. Since this is only a preliminary study, a number of questions have not been answered yet. Three significant items, pertaining to storage, that require further study are summarized below:

1. Potential Resource Conservation and Recovery Act (RCRA) implications have not been addressed. Permitting requirements, both for RCRA and the State of Idaho, have also not been addressed. These requirements will become important, especially if treatment is performed that separates the fissile materials from other components.

2. The subsequent acceptability of these materials for ultimate disposal by another facility, such as the Waste Isolation Pilot Plant (WIPP) or Yucca Mountain, following interim storage at the INEL has not been addressed. This issue remains extremely important and must be addressed in due time, as the acceptance of spent fuel in Idaho is subject to the laws of the State of Idaho and to agreements between Idaho and entities of the Federal Government. These laws and agreements may mandate the eventual transfer of the spent fuel to disposal facilities and final destinations outside Idaho.

3. The chemistry and chemical stability of the molten salt materials are not addressed. In particular, "getter" materials are not fully identified or characterized. Those that appear to be workable have not been assessed from the viewpoints of fire safety and of chemical kinetics at room temperature. Stability will have to be demonstrated before storage at the INEL is possible.

Other important issues will require further study. The storage portion of this report presented a scoping survey of storage facilities at the INEL and the likelihood of their ability to accept the MSRE spent fuel. A statement identifying a facility as able to accept the MSRE spent fuel should not, however, be construed to be a final determination. It is to be understood as merely a recognition that the facility meets the minimum criteria of (1) availability of space and (2) the usual acceptance of spent fuel or similar materials. Other issues may have to be considered and conditions met before the determination is complete and sufficient for reliable decision making. These issues range from the institutional and political to the technical. For example, technical issues not fully addressed in this report are the chemical stability of the packaged materials (including "getter" chemistry and chemical kinetics, as mentioned above), packaging requirements, the compatibility of the package with the accepting facility, the mechanical design of containers to fit the facilities, availability of shipping casks or containers, and availability of equipment to place the material in the chosen storage location. The institutional and political issues pertain essentially to permitting by the State of Idaho.

It is assumed in this study that the materials will be packaged for transportation into systems (e.g., containers and shipping casks) that are compatible with storage conditions and operations procedures at the potential storage facility. It is also assumed that the materials will be stabilized so as not to need any special treatment or increased monitoring during the storage period. Other requirements will include proper radiological shielding as part of the package and proper containment of volatile radioactive components (such as ^{220}Rn) during transfer operations and during storage. In this study, only rudimentary shielding calculations have been performed for the purpose of estimating the size and number of shipments or packages that will have to be stored. The calculations in this study are conservative and do not take into account precise geometric effects nor do they account for self-shielding by the fuel material.

12.2 Issues on Treatment of MSRE Salts

The second part of this report listed and described existing and projected facilities at the INEL that could treat the MSRE spent fuel and flush salt, provided that adequate modifications are implemented and that there exists a sufficient amount of other materials slated for treatment in a given facility when dilution of the MSRE salts is a prerequisite.

Again, the determinations in this report that a particular facility could treat the MSRE spent fuel and flush salts is not definitive. It is to be taken as merely the recognition that the facility has treated, or is intended to treat, similarly complex materials (radioactive and/or hazardous), and that with limited but sufficient modifications, it could handle the MSRE salts.

Three significant treatment issues are not addressed within this study. They are listed below.

1. Chemical compatibility of MSRE salts with the existing or proposed processes has not been demonstrated by actual tests. For example, sodium wastes intended for treatment at the NWCF are known to cause the fluidized particles to agglomerate ("stickiness") and the calcine to cake in storage, thus deteriorating the retrievability of the calcine. The high lithium content of the MSRE salts is expected to cause similar problems. These potential problems, and their solutions, cannot be fully anticipated by theoretical analyses. It will, therefore, be necessary to conduct laboratory and pilot tests of the flow sheets that must be developed for the treatment of the MSRE salts to determine the choice of necessary additives, compatibility with the process, and viability of the final product.

2. The ability of the INEL to produce a final product that is suitable for acceptance at WIPP or Yucca Mountain has not been demonstrated. This study did not address the ability of the INEL present and future facilities to produce, from the MSRE salts, a waste form that meets the Waste Acceptance Criteria of either WIPP or Yucca Mountain. It is assumed that in due time, and prior to treatment, a full study will be conducted to demonstrate that the products will be acceptable. Some of the relevant considerations were briefly discussed in Section 11.

3. Uncertainty remains regarding the acquisition schedules of the planned facilities (especially for RHIF). This report does not claim that the facilities will be available in a timely manner to meet the needs of the MSRE decommissioning effort. Conversely, it is uncertain that the MSRE remediation effort would proceed fast enough to take advantage of the planned calcination campaigns for existing liquid wastes at the INEL. This issue was explained further in Section 3, on legal and institutional considerations, and in Sections 8.1.4.2 and 8.1.4.4, on dissolution and dilution needs.

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13. CONCLUSIONS

13.1 Storage at the INEL

Conclusions regarding the storage of MSRE salts, presented in the body of the report, are summarized below:

- The Molten Salt Reactor fuel has been specified for shipment to the INEL as a spent fuel. Flush salts need further clarification.
- The volume to be shipped is small, consisting of about 4 m^3, which will fit into one to 16 containers, depending on the choice of storage location and the amount of getters to be included.
- Interim storage at the INEL appears feasible in existing or planned facilities.
- Storage in NUHOMS-type container(s) at a new facility at the ICPP is the preferred option. Storage at the IFSF or CPP-749 also may be possible with proper packaging and other changes.
- Stabilization of the fuel by use of a "getter" or processing will be required to ensure that the fuel is stable enough for interim storage.
- Further detailed studies to determine shielding, criticality requirements, safety requirements, handling needs, getter composition, and processing possibilities will be required.
- Adequate funding should be identified for interim storage as well as for final disposition options.
- A systems engineering approach should be used to evaluate the long-term implications of moving the fuel to the ICPP.

13.2 Treatment at the INEL

Conclusions regarding the treatment of MSRE salts at the INEL, presented in the body of the report, are summarized below.

The technology needed to treat the MSRE spent fuel and flush salt either exists (almost entirely in the case of calcination) or could be developed in a timely way, in the case of the ICPP RHIF, if current plans are approved by DOE. The most economical option appears to be incorporation into the calcination processes at ICPP-NWCF (requiring a minimum of modifications). This most desirable option is legally justifiable for the spent fuel. For the flush salt, the loss of identity of the material, and its incorporation into a waste stream might conflict with the Settlement Agreement stipulation that waste received from outside the State of Idaho, for the purpose of treatment in Idaho, must be shipped out of the State of Idaho within 6 months of completion of treatment. Treatment in the RHIF would result in a waste form suitable for disposal at a geological repository. All treatment options will require additional facility construction or technology development. The most immediately viable option is that of calcining the MSRE salts in the NWCF. The most desirable option is treatment in the RHIF including vitrification and grouting of the two resulting waste streams. These options can be combined to provide a technically feasible and environmentally acceptable interim solution followed by a permanent solution. The need to study the dissolution and chemistry of the MSRE salts remains the most important next step. The chemical compatibility of the MSRE salts with the calcination process or with the separation processes of the RHIF must be studied and demonstrated.

14. REFERENCES

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Table 1. Detailed inventory of MSRE spent fuel and flush salt (Adapted from Table 5 in Reference 6).

Component	Fuel Salt	Flush Salt	Total Mass (kg)
	Bulk composition mol % (*wt%*)		
LiF	64.5 (*42.6*)	65.9 (*51.3*)	
BeF_2	30.4 (*35.8*)	33.9 (*47.8*)	
ZrF_4	4.9 (*20.5*)	0.18 (*0.89*)	
	Major elements		
U, kg	37.1	0.5	37.6
Pu, kg	0.724	0.013	0.737
Fission products, kg	2.664	0.046	2.71
Rare earths			1.47
IA, IIA			0.275
Zr			0.626
Other metals			0.334
	Fissile element isotopes (wt%)		
^{232}U	160 ppm	75 ppm	
^{233}U	83.92	39.4	
^{234}U	7.48	3.6	
^{235}U	2.56	17.4	
^{236}U	0.104	0.245	
^{238}U	5.94	39.4	
^{239}Pu	90.1	94.7	
^{240}Pu	9.52	4.8	
other Pu	0.35	0.50	

Table 2. Gamma source spectrum in MSRE spent fuel salt (adapted from Table 11 in Reference 6)

Energy Group	Upper bound (MeV)	Average Energy	% gamma in group	% energy in group
1	0.050	0.030	33.94	2.86
2	0.100	0.075	10.69	2.25
3	0.200	0.150	6.89	2.90
4	0.300	0.250	2.80	1.96
5	0.400	0.350	1.60	1.58
6	0.600	0.500	1.57	2.20
7	0.800	0.700	41.60	81.72
8	1.000	0.900	0.28	0.70
9	1.330	1.165	0.15	0.50
10	1.660	1.495	0.07	0.28
11	2.000	1.830	0.01	0.04
12	2.500	2.250	0.00	0.00
13	3.000	2.750	0.39	3.00
14	4.000	3.500	0.00	0.00
15	5.000	4.500	0.00	0.00
16	6.500	5.750	0.00	0.00
17	8.000	7.250	0.00	0.00
18	10.000	9.000	0.00	0.00

Total source: $4.5 \times 10^{14}\ s^{-1}$, $1.6\ 10^{14}$ MeV/s

Table 3. Upper estimates for shield thicknesses and number of packages for MSRE spent fuel

Shield Material	Number of Packages	Shield Thickness (cm)
Al	118	50
Fe	2	32.21
Pb	2	19.95

Table 4. Volume of liquid high-level wastes in tanks (June 1996)

Tank Number	Waste Type	Volume (x 1000 gallons)
WM-100	High-Level Nonfluoride	1.0
WM-101	High-Level Nonfluoride	8.4
WM-102	High-Level Nonfluoride	3.3
WM-182	High-Level Nonfluoride	3.6
WL-101	High-Level Sodium	9.7
WM-180	High-Level Sodium	282.6
WM-181	High-Level Sodium	277.5
WM-183	High-Level Sodium	230.0
WM-184	High-Level Sodium	246.5
WM-185	High-Level Sodium	189.3
WM-186	High-Level Sodium	281.0
WM-187	High-Level Fluoride	84.2
WM-188	High-Level Fluoride	53.4
WM-189	High-Level Fluoride	233.6
WM-190	High-Level Fluoride	0.5

Table 5. Inventory of chemical compositions for tanks WM-180, WM-181, WM-184, and WM-186, June 1994 (adapted from Table I in Reference 18)

Waste Tank	Units	WM-180	WM-181	WM-184	WM-186
Waste type	-	Sodium	Sodium	Sodium	Sodium
Sample date	mth/yr	2/93	2/93	11/88	6/89
Volume at Sample	gallons	278,900	280,000	276,400	217,600
Volume as of 06/96	gallons	282,000	278,700	209,100	278,500
Specific gravity	-	1.262	1.156	1.256	1.173
Acid (H^+)	M	1.14	1.80	0.43	1.49
Nitrate (NO_3)	M	4.56	3.68	4.63	2.93
Aluminum (Al)	M	0.63	0.22	0.81	0.35
Boron (B)	M	0.010	0.015	0.0070	0.020
Cadmium (Cd)	M	0.00080	0.0052	0.00020	0.0017
Calcium (Ca)	M	0.034	0.044	0.011	0.063*
Chloride (Cl)	M	0.031	0.012	0.043	0.020
Chromium (Cr)	M	0.0038	0.0029	0.0021	-
Fluoride (F)	M	0.042	0.089	0.040	0.040
Iron (Fe)	M	0.018	0.012	0.020	0.018
Lead (Pb)	M	0.0014	0.0010	0.0011	-
Manganese (Mn)	M	-	0.013*	0.0084	-
Mercury (Hg)	M	0.00097	0.00045	0.0015	-
Molybdenum (Mo)	M	-	0.00052*	0.00050	-
Nickel (Ni)	M	0.0016	0.0012	0.0012	-
Phosphate (PO_4)	M	-	0.0061*	0.024	-
Potassium (K)	M	0.18	0.14	0.13	0.16
Sodium (Na)	M	2.0	0.90	2.0	0.96
Sulfate (SO_4)	M	0.032	0.024	0.071	0.033
Zirconium (Zr)	M	<0.0011	0.0046	0.00	0.00
Uranium (U)	mg/l	78	76	58	-
Undissolved Solids	g/l	0.63	0.17	1.61	5.05

* These items are shown in Reference 18 as having been taken from Reference 19.

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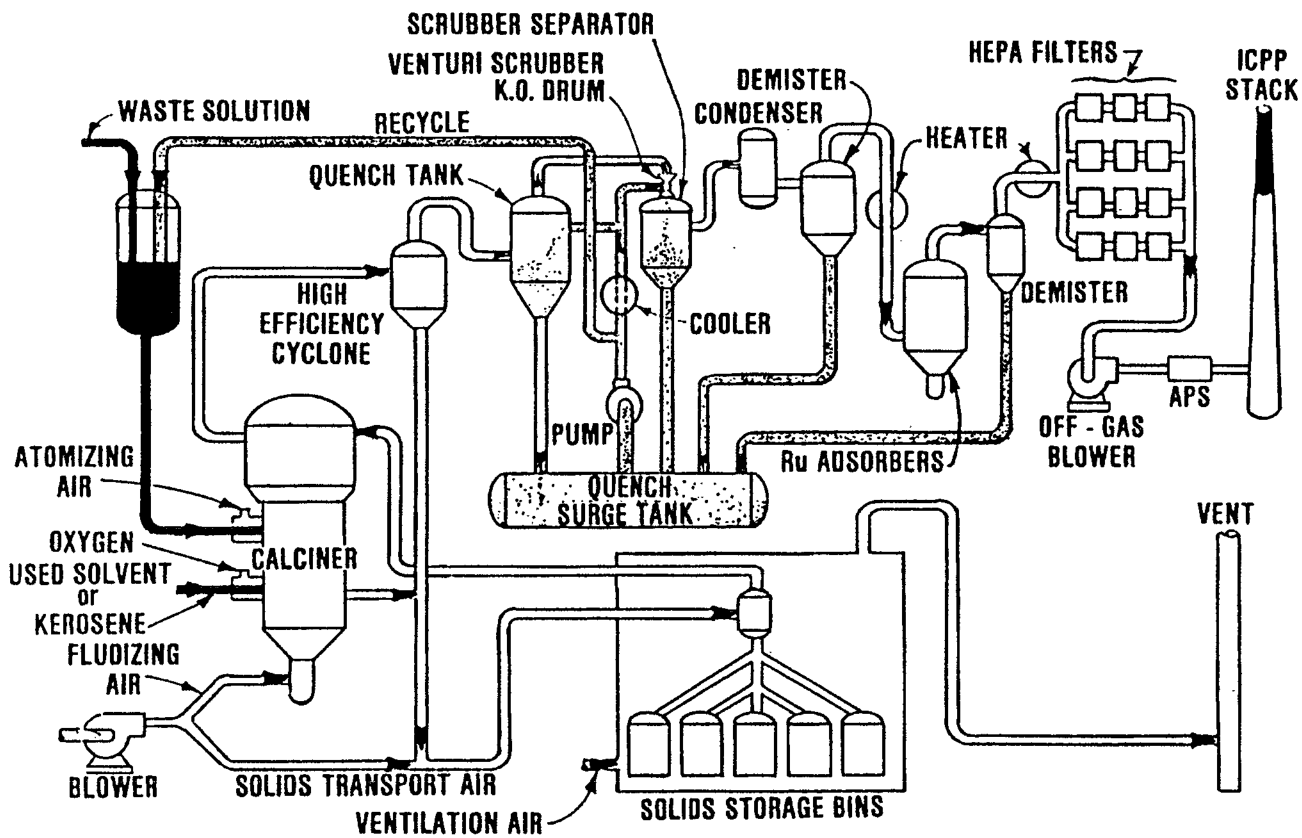
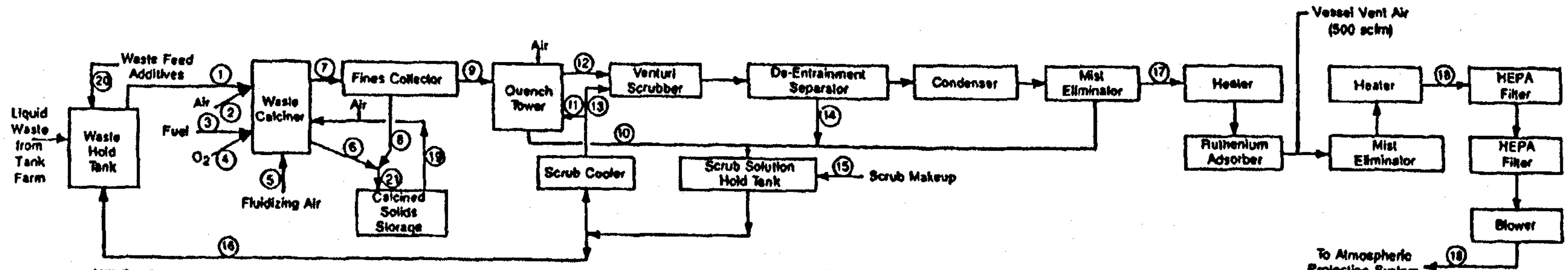


ICPP-S-1533

Figure 1. New Waste Calcining Facility Processes.



NOTE: Standard Conditions - 60 °F and 14.7 psia

Stream / Description	1 Waste Calciner Feed	2 Waste Atomizing Air	3 Fuel	4 Fuel Atomizing	5 Fluidizing Air	6 Calciner Solids	7 Calciner Off-Gas	8 Fines Collector Solids	9 Fines Collector Off-Gas	10 Quench Recycle	11 Scrub to Quench	12 Quench Off-Gas	13 Scrub To Venturi	14 Separator Recycle	15 Scrub Makeup	16 Recycle Scrub	17 Venturi Separator Demister Off-Gas	18 Off-Gas	19 Transport Gas Return	20 Waste Feed Additives	21 Average Solids Production
Total Solids, lb/hr						220	55-150	55-150	20-50												275
Waste Feed Solution, gph	214																			57	
Recycle Solution, gph																32					
Scrub/Quench Solution, gph										(3800)	3800		1200-2400	1200-2400	8						
Kerosene, gph			29.4																		
Air, scfm		130			325		795		795			825					885	1386	180		
O_2, scfm				120																	
Water Vapor, scfm							613		613			613					540	540			
CO_2 + CO, scfm							89		89			89					89	89			
							1497		1497			1527					1515	2015			

ICPP-E-0677
(11-86)

Figure 2. Illustrative New Waste Calcining Facility Flowsheet.

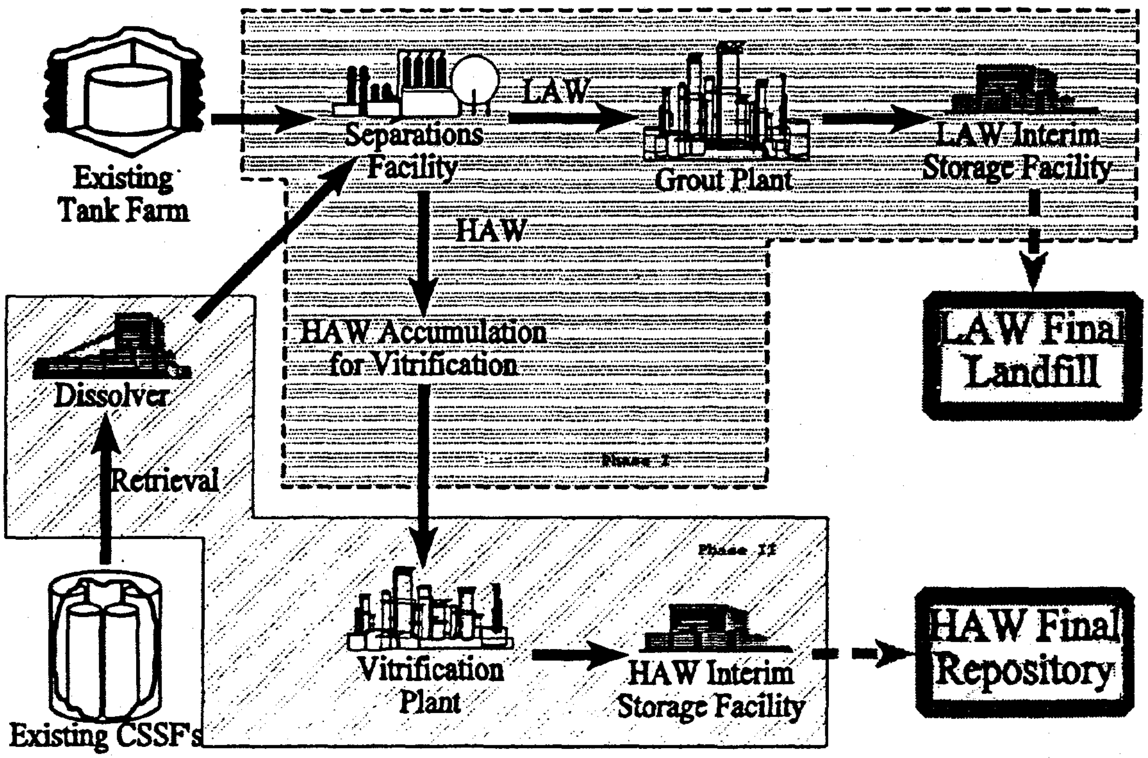


Figure 3. Overview of Remote-Handled Immobilization Facility Processes.

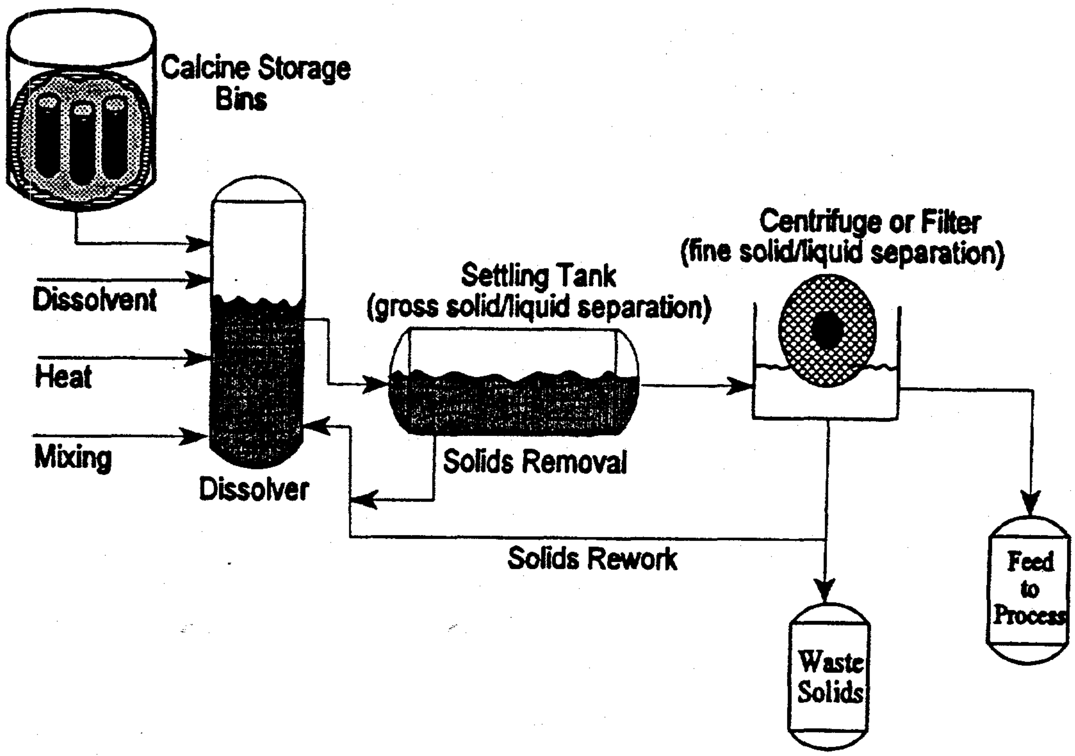


Figure 4. Dissolution Process in the RHIF.

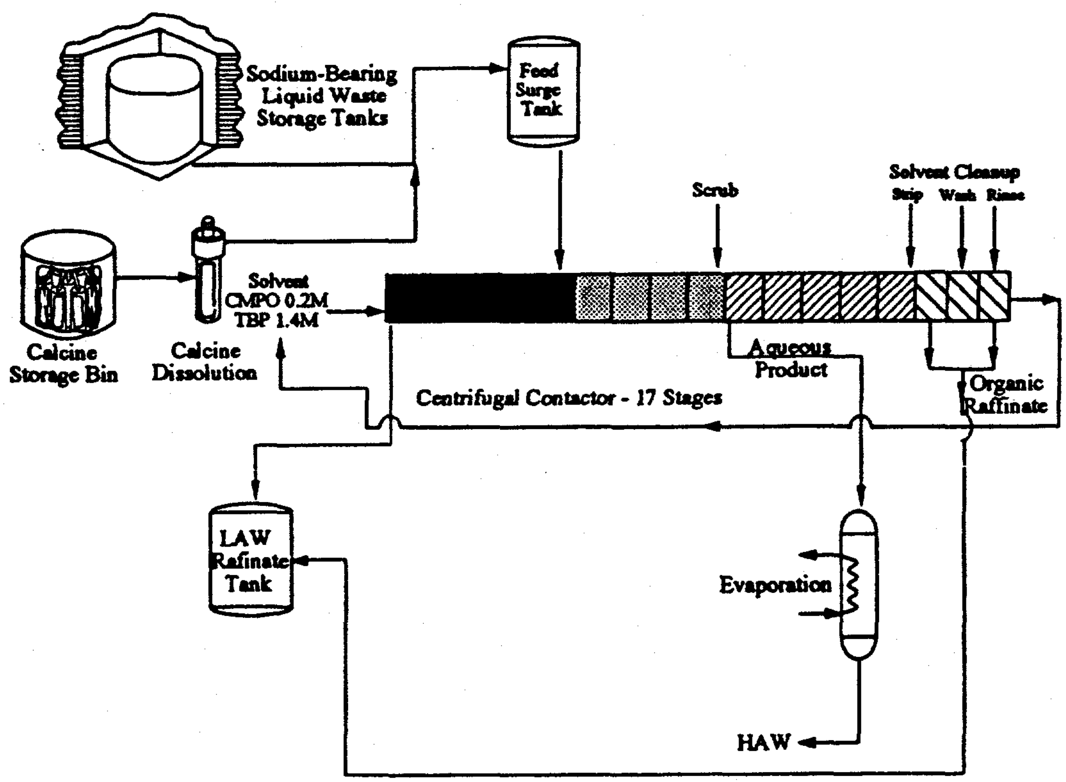


Figure 5. TRUEX Process in the RHIF.

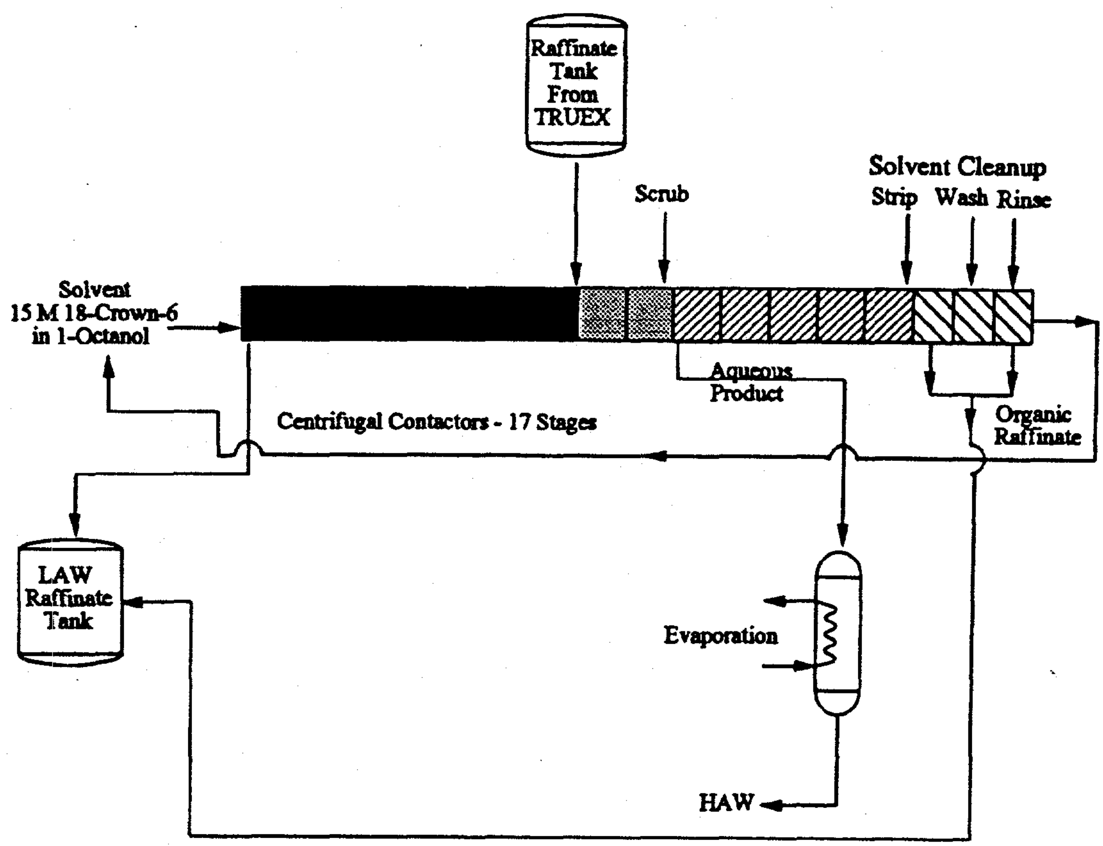


Figure 6. SREX Process in the RHIF.