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ENGINEERING STUDY OF THE POTENTIAL USES OF SALTS
FROM SELECTIVE CRYSTALLIZATION OF HANFORD TANK
WASTES

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Engineering Study of the Potential Uses of Salts from Selective Crystallization of Hanford Tank Wastes

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**ENGINEERING STUDY OF THE POTENTIAL USES OF
SALTS FROM SELECTIVE CRYSTALLIZATION OF
HANFORD TANK WASTES**

EXECUTIVE SUMMARY

The Clean Salt Process (CSP) is the fractional crystallization of nitrate salts from tank waste stored on the Hanford Site. This study reviews disposition options for a CSP product made from Hanford Site tank waste. These options range from public release to onsite low-level waste disposal to no action. Process, production, safety, environment, cost, schedule, and the amount of CSP material which may be used are factors considered in each option.

The preferred alternative is offsite release of clean salt. Savings will be generated by excluding the material from low-level waste stabilization. Income would be received from sales of salt products. Savings and income from this alternative amount to \$1,027 million, excluding the cost of CSP operations.

Unless public sale of CSP products is approved, the material should be calcined. The carbonate form of the CSP could then be used as ballast in tank closure and stabilization efforts. Not including the cost of CSP operations, savings of \$632 million would be realized. These savings would result from excluding the material from low-level waste stabilization and reducing purchases of chemicals for caustic recycle and tank stabilization and closure.

Dose considerations for either alternative are favorable. No other cost-effective alternatives that were considered had the capacity to handle significant quantities of the CSP products.

If CSP occurs, full-scale tank-waste stabilization could be done without building additional treatment facilities after Phase I (DOE 1996). Savings in capital and operating cost from this reduction in waste stabilization would be in addition to the other gains described.

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TERMS

ALARA	As Low As Reasonably Achievable
$\text{Al}(\text{NO}_3)_3$	Aluminum Nitrate
CSP	Clean Salt Process
DCG	Derived Concentration Guidelines
DOE	U. S. Department of Energy
Ecology	Washington State Department of Ecology
ESP	Efficient Separations and Processing Crosscutting Program
HLW	High Level Waste
KNO_3	Potassium Nitrate
LLW	Low Level Waste
NaNO_3	Sodium Nitrate
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
TTP	Technical Task Plan
WAC	<i>Washington Administrative Code</i>

UNITS

Bq	Becquerel (disintegration/second)
Ci	Curie (3.7×10^{10} Bq)
kg	kilogram
m	meter
M	gram-mole per liter
mr	milli rad (1×10^{-3} rad [=] 1×10^{-5} Gray)
L	Liter (0.001 m^3)

ENGINEERING STUDY OF THE POTENTIAL USES OF SALTS FROM SELECTIVE CRYSTALLIZATION OF HANFORD TANK WASTES

1.0 OBJECTIVE

This engineering study evaluates the soundness of handling Clean Salt Process (CSP) products from the selective crystallization of Hanford Site tank waste as other than low-level waste (LLW). It evaluates alternative methods to determine the best disposition method. When considered possible, the cost benefits to be accrued from such a disposition are estimated.

This work, and that of other current selective crystallization tasks at the Hanford Site, are supported through the U.S. Department of Energy (DOE), Office of Technology Development (EM-50), Efficient Separations and Processing Crosscutting Program (ESP), under Fiscal Year (FY) 1996 Technical Task Plan (TTP) RL46C341. This report satisfies Milestone C2 "Issue Report on Cost/Benefit Analysis" of the TTP.

1.1 Background and Scope

The ability to provide a reasoned cost and benefit analysis of a waste treatment process depends on the following factors:

- Technical adequacy of chemical processing knowledge of the treatment
- Knowledge and scale of the waste stream
- Cost of treatment
- Disposition and worth of products and byproducts of the treatment.

This section provides background information on the history and development of the CSP at the Hanford Site, current work, and the scope of this study.

1.1.1 Background

The CSP is a selective crystallization process by which it is proposed to reduce the liquor masses in the tank waste. The process separates soluble nitrate salts from the waste. The salts to which this is potentially applicable include sodium nitrate (NaNO_3), aluminum nitrate ($\text{Al}(\text{NO}_3)_3$), and potassium nitrate (KNO_3), listed in order of their respective masses in the tank wastes (Orme 1995). The success of the CSP requires that the benefits accrued from separating these metals from the low-level waste disposal form (e.g., low-activity waste, DOE 1996) not be outweighed by the cost of handling the separated salt stream through ultimate disposition.

1.1.1.1 Salt Crystallization Chemistry

The salt crystallization chemistry involved in the CSP is fractional crystallization by supersaturation. This phenomenon has been applied at the Hanford Site through decades of waste management by evaporating the liquid from the waste and crystallizing the salts that remained in the tanks. However, such management has not been selective in the salts to be crystallized.

Early studies in salt solubility of Hanford Site tank waste were most rigorously detailed in *Vapor-Liquid-Solid Phase Equilibria of Radioactive Sodium Salt Wastes at Hanford* (Barney 1976). In this work, he developed solubility diagrams for the major waste salts at varying temperatures.

More recent work on the CSP has been led by Dr. Daniel L. Herting, of Westinghouse Hanford Company, with publications on the study of solubility (1992), crystal growth (1994a), and process application to Hanford Site tank wastes (1993 and 1994b). Current work in this field by Dr. Herting includes additional laboratory separations of radiologically contaminated tank waste.

1.1.1.2 Flow Sheet Development

FY 1994 CSP study included the development of a flow sheet for conducting the CSP in the context of the Tank Waste Remediation System (TWRS) treatment (Lunsford 1994). The flow sheet modeled CSP treatment of an overall Hanford Site tank waste inventory and composition, both before and after cesium ion exchange. Assuming that cesium exchange is done before the CSP, a three-stage evaporative crystallization model predicted the separation of 94 percent of the sodium (7.38×10^7 kg) and 78 percent of the aluminum (3.2×10^6 kg) for a total yield of 1.188×10^8 mole of $\text{Al}(\text{NO}_3)_3$, and 3.21×10^9 mole of NaNO_3 . [Calculation 2, Appendix A]

FY 1996 efforts in flow sheet development have been detailed in Slaathaug (1996), which evaluated the process benefits of using the CSP to treat the specific tank waste composition of Double-Shell Tank 241-AW-101. To a great extent, this analysis agreed with Lunsford (1994). However, it differed in the precipitation of potassium (the target waste stream has a concentration of approximately one molar potassium) and the use of an updated TWRS Process Flow Sheet (Orme 1995). Because the tank contains a limited amount of the low-activity waste product fluoride, this analysis modeled the post-cesium removal of 90 percent of the sodium, 74 percent of the aluminum, and 71 percent of the potassium. For this tank, it was further determined that compliance with proposed limits for the low-activity waste technetium (DOE 1996) would limit the reduction in low-activity waste product volume to only 40 percent of that achievable with a 90 percent sodium removal (Slaathaug 1996).

In each case of flow sheet development, the product stream is a concentrated brine of the nitrate salts of sodium and aluminum (and potassium, in Slaathaug 1996) with overall solids loadings of 69 wt% or higher following three evaporative crystallization stages. Because cesium ion exchange is expected to occur before the crystallization, the products from these efforts were modeled to contain 1.85 Bq/g (50×10^{-12} Ci/g) and 0.6 Bq/g (16×10^{-12} Ci/g) of $^{137}\text{Cesium}$

contamination for Lunsford (1994) and Slaathaug (1996), respectively. Lunsford and Slaathaug also analyzed CSP before cesium exchange. These analyses resulted in greater residual contamination for similar alkali separations.

Both Boldt (1995) and Jansen *et al.* (1995) considered evaluating CSP in TWRS documentation supporting the environmental impact statement. However, Boldt (1995) dismissed CSP from consideration by stating that the technology was not sufficiently mature; Jansen *et al.* followed that lead and considered CSP only as an optional process.

1.1.1.3 Cost of Treatment

At this time no formal analysis of waste treatment costs using the CSP has been completed. Such an analysis is proposed to be completed during September 1996 as Milestone C3 to TTP RL46C341. In the absence of such a cost analysis, the treatment cost is assumed (§ 5.2) to be approximately the same for all scenarios. The difference in product values should allow selection of a preferred treatment and disposition.

1.1.1.4 Disposition Options

Several material disposition options were considered both in Herting (1995) and again here (§ denotes section of alternative consideration). The options considered by Herting (1995) included the following:

- Recycle for use in acid/caustic production process (§ 5.3.3)
- Recycle for use as a fertilizer (§ 5.3.2)
- Recycle for use in ion exchange column backwash (§ 5.3.4)
- Onsite disposal in an inert waste disposal facility (§ 5.3.5)
- Onsite disposal in a LLW disposal facility (§ 5.3.5)
- Offsite disposal in an inert waste disposal facility
- Offsite disposal in a *Resource Conservation and Recovery Act of 1976* (RCRA) waste disposal facility.

Herting (1995) did not attempt to weigh the costs or significant benefits of any particular disposition, but provided general regulatory definitions, interpretations, and recommendations.

This analysis, by default (§ 5.2), does not consider offsite disposal for reasons of expected costs and concern of material releasability (§ 4.1). Within this analysis, the inert and low-level onsite disposal alternatives considered in Herting (1995) are treated as the same option.

The direct release of the sodium nitrate (§ 5.3.1), and use of the sodium nitrate following additional processing (§ 5.3.6), are derived from previously described alternatives with, respectively, less and more specificity than previously considered. Both are treated as new options.

1.1.2 Scope

This study estimates the benefits from the selective crystallization of Hanford Site tank waste when the disposition path can be fully defined. The primary material being evaluated is sodium nitrate, although other salts may be considered if they become available.

1.2 Purpose and Need

This analysis provides an economic basis for considering appropriate disposition of CSP products if the process is implemented at the Hanford Site. This economic basis of material disposition is required to support full economic analysis in conjunction with facility construction and operation estimates to be provided in the parallel work described in § 1.1.

2.0 SUMMARY

This study reviews disposition options for a CSP product from Hanford Site tank waste. These options range from public release to onsite LLW disposal of the salt to no action. Each option is weighed using these factors: process, production, safety, environment, cost, and schedule. The benefits to be accrued from each disposition option and/or the liabilities associated with the option are considered, as is the ability of any alternative to receive a significant fraction of the potential CSP production.

Estimates of benefits assembled here provide clear guidance for a recommendation that the public release of the clean salt product be sought. The savings from this disposition are estimated to be approximately \$1,027 million, less the cost of CSP operation. If DOE is not willing to consider this option, it is recommended that the CSP product be partially reused with caustic recycle and be calcined with the carbonate forms of the waste used as grout additives in tank stabilization and closure.

This document is written from the perspective of construction and operation of CSP by the DOE. A private vendor may conduct this type of salt separation after receiving the waste stream from DOE.

3.0 RECOMMENDATIONS AND CONCLUSIONS

This section provides recommendations and conclusions of the study based on details provided in the following sections.

3.1 Recommendations

The study of CSP should continue with the primary goal being the study of crystal growth and phase separations that could be applied in a process facility. Also, the Assistant Secretary (EM-1) should be petitioned to consider public use of these materials contaminated in-depth.

3.2 Conclusions

The benefits study of selective crystallization of Hanford Site tank waste led to the following conclusions:

- Offsite release and reuse of CSP products can be justified
- Onsite recycling and reuse would use only 19.3 percent of available CSP products [Calculations 7 and 8, Appendix A]
- Onsite recycling and reuse reduces some increment of material purchases and eventual disposal costs, but does not resolve the long-term issue of waste disposal cost
- If retained on site, optimal disposal for CSP products is as tank closure ballast
- If CSP occurs, full-scale tank-waste stabilization could be done without building additional treatment facilities after Phase I (DOE 1996)

4.0 UNCERTAINTIES

Uncertainties in this analysis include administrative and legal interpretations of material characteristics and disposition capability, facility costs and operability, and contractual expectations by DOE in waste treatment.

4.1 Offsite Release Criteria

Offsite release of a CSP product is potentially guided by release criteria established for any property of DOE. In particular, DOE (1993) has established criteria for release of soils and for materials and equipment with surface contamination. Soils contaminated with ^{226}Ra , ^{228}Ra , ^{230}Th and ^{232}Th , may be released when the top 0.15 m exhibits less than 0.18 Bq/g (5×10^{-12} Ci/g) and each 15-cm layer below exhibits less than 0.55 Bq/g. However, DOE (1993) specifically excludes materials except soils contaminated with radium and thorium from established release criteria as materials contaminated 'in-depth' (Citation 1).

Citation 1: 'In-Depth Contamination'

DOE Order 5400.5, Chapter II, Paragraph 5.c.

- (6) *Volume Contamination. No guidance is currently available for release of material that has been contaminated in depth, such as activated material or smelted contaminated metals (e.g., radioactivity per unit volume or per unit mass). Such materials may be released if criteria and survey techniques are approved by EH-1 (Assistant Secretary for Environment, Safety and Health).*
-

The application of the CSP product and final activity and type (alpha, beta, and gamma) may lead to releasability as described in DOE (1993). Given the dose consequence quality factor of 20 assigned to alpha-emitting materials (DOE 1988b) (compared to 1 for gamma-emitting materials) material with comparable activities may be reasonably considered for release pending petition to the DOE Assistant Secretary for Environment, Safety and Health (EH-1).

Two scoping analyses for dose consequence are provided in Appendix B. In the first analysis, the salt material is assumed to be converted to carbonates (without loss of cesium or strontium) and added to a cement at 10 wt% metal carbonate for injection into a Hanford Site waste tank; the dose consequence is estimated to be 4.2×10^{-3} mr/hour. In the second analysis, the salt material is assumed to be dispersed as a fertilizer at 124 kg/hectare; the dose consequence from the dispersal is estimated to be 5.1×10^{-6} mr/hour. Consequences of these minor orders may clearly provide a basis for acceptance of release of these materials.

4.2 Waste Designation

As described by Herting (1995), the reuse of the separated salts is recommended. If the material is not to be reused in a product, it will continue to be “inherently waste-like” and must remain designated as a waste. Because of application to the soil, it remains credible that the Washington State Department of Ecology (Ecology) will interpret use of the separated salts as fertilizers to be a form of waste disposal [*Washington Administrative Code* (WAC) 173-303-016(5)(a)(I)(A)]. However, according to the definition of a solid waste, a material is not a solid waste when it is placed on the soil when that is its usual use. This provides a clear path for separating the CSP products from hazardous waste management.

The current waste designation of the tank contents includes corrosivity, toxicity, and ignitability characteristics as well as listed waste constituents. In accordance with WAC 173-303-016 and DOE (1988a), the waste is considered mixed waste (radioactively contaminated dangerous waste).

Although the radioactivity would be significantly reduced, the separated salts would remain radioactive, toxic, and potentially ignitable as well as listed wastes unless they were chemically and administratively altered. Chemical alteration will be described in § 5.3, with details in § 5.3.6. Administrative alteration affects all dispositions because delisting may be required for such material to no longer be a considered dangerous (hazardous) waste. Delisting should be considered attainable, but would require proactive petition. Additional administrative action regarding the radioactive nature of the material is described in §§ 4.1 and 5.3.1.

4.3 Costs

The product stream under discussion for the CSP is a concentrated brine with a significant (~70 wt% or higher) solid salt loading. For storage or use as a solid, additional drying and handling is required. No costs for such handling are considered, but are assumed in § 5.2 to be part of the cost for a full-scale process plant. Costs for additional treatment (§§ 5.3.3, 5.3.4 and

5.3.6) instead of direct disposal are not fully estimated here, but are not anticipated to be greater than 30 percent of the cost of producing the separated salt.

The costs described here are those associated with the handling and disposition of the clean salt products. The savings to be accrued by not disposing of the salts as LLW are constant per unit mass separated for all cases. For this analysis, savings in LLW disposal can be termed in the manner of Boomer *et al.* (1994). Boomer *et al.* (1994) assumed that the LLW form would be a glass in sulfur polymer cement (70:30). The annual operating cost was estimated in 1995 dollars as \$75 million to produce 2×10^5 kg/day of glass at 25 percent Na_2O for a total sodium loading of 7.738×10^7 kg Na. Sodium removal with CSP is estimated to be 7.38×10^7 kg (Lunsford 1994). Such removal would constitute more than 95 percent of the sodium over a 10-year CSP operating period. These removals could reduce the operating cost by 50 percent. (Operating costs are not considered linear with changes in production rate at these levels.) The removal would reduce disposal costs for disposal bays and containers by \$26 million/year. Thus the net savings for removal of the salt from the disposal stream is estimated to be \$64 million/year. [Calculation 3, Appendix A]

In addition, reducing the waste-stream sodium mass by a factor of 10 to about 7×10^6 kg would decrease the sodium loading destined for a final stabilization (e.g., vitrification) facility. Based on the smaller feed mass DOE may decide to continue operating a small-scale stabilization unit (1996) built for proof of concept instead of building a large-capacity unit. Boomer *et al.* (1994) recommended a configuration of combined separations and LLW vitrification facilities to minimize costs. The total cost for the recommended configuration was \$8.4 billion (discounted to \$4.4 billion 1994 dollars). That estimate included process facilities, support facilities, operations, startup, spares and equipment replacement, low level waste vaults, high level waste (HLW) canisters, HLW interim storage casks, repository costs, and decontamination and decommissioning. The savings in construction, decontamination, and decommissioning of Phase II treatment facilities by the use of CSP may exceed \$3 billion. Because this facility savings estimate is not trivial, the savings have not been accumulated here, but should be considered for further analysis.

4.4 Operability

In Lunsford (1994), the model of CSP following cesium ion exchange required 3 evaporators and 10 centrifuges; running the CSP before cesium ion exchange would require 3 evaporators and 14 centrifuges. Because of the many evaporation and centrifugation cycles and extensive mechanical contacts, concerns may exist that the equipment will have significant operability problems and down time. However, based on experiences of the sugar production industry, these concerns are not well founded. The sugar industry refines beets and cane into sugar using a system similar to the CSP with as many or more evaporation and crystallization stages. Experience and equipment from the sugar industry could be used to improve the operability of the CSP.

4.5 Minimum Waste Guarantees to Private Treatment Entities

In an effort to reduce costs of treatment leading to disposal of waste in Hanford Site tanks, DOE has requested that private entities bid to treat and stabilize the tank waste (DOE 1996). Section H of the request for proposals (DOE 1996) provides minimum and maximum orders for waste categories described in the Phase I treatment effort. For low-level waste fractions, the request specified a minimum of 2.8×10^6 kg of sodium for treatment and a maximum of 5.1×10^6 kg of sodium. These contractual process guarantees affect the design and potential profit of a treatment vendor.

The time line for the work proposed in this first phase is such that the work may occur before any reasonable possibility of using the CSP. However, on successful conduct of this privatization effort, the precedent of a large minimum sodium order may restrict CSP by making it uneconomical to reduce the waste volume beyond the minimum sodium order to the vendor. For the purposes of this analysis, the waste sodium order specifications for long-term treatment are considered to reflect the actual material (potentially following CSP) rather than the precedent set in Phase I treatment demonstration.

Considering the maximum sodium order of 5.1×10^6 kg for the Phase I privatization and the modeled post-CSP sodium waste load of 7.1×10^6 kg, Phase I processing facilities could continue to operate without building larger scale facilities for Phase II stabilization. Not building a Phase II facility may be expected to save in excess of \$3 billion (§ 4.3).

This document is written from the perspective that DOE will build and operate the CSP. However, a private vendor may elect to conduct this type of salt separation after receiving the waste stream from DOE.

5.0 DESCRIPTION OF ALTERNATIVES/SOLUTIONS

The alternative solutions provide potential applications for the CSP product stream, which provides a basis for cost and benefit analysis. For an alternative to be fully considered, it must meet the criteria and be within the scope of assumptions described.

5.1 Criteria

Criteria that must be applied during this analysis are that facility operations and effluent streams meet current regulatory, permit, and DOE Order limitations and that the alternative address a significant fraction of the CSP products.

5.2 Assumptions

The following assumptions are applied in this analysis:

- The cost for offsite disposal is significantly higher than onsite disposal and will not be considered.
- The cost for all CSP processes is the same; cost differences depend on product disposition.
- The costs for drying and storing CSP product will be added in full economic analysis.
- The operational period for the CSP would be 10 years.
- Separated salts are valued at bulk market or 10 percent of reagent prices.

5.3 Alternatives

This section explains how each alternative is evaluated for a cost and benefit analysis.

5.3.1 Offsite Release of Clean Salt

5.3.1.1 Description

This alternative, in part considered in Herting (1995) as the basis for recycling as fertilizer, is considered without defining its use beyond being a product material.

The material, as described by Herting (1995) and depending on the metal, may reasonably be used as an oxidizing agent, propellant, fertilizer, glass additive, dye component, or in other applications.

5.3.1.2 Advantages and Disadvantages

Each application of the separated salt described could be considered an appropriate recycling activity following reclamation resulting in the designation of the material to not be a solid waste (WAC 173-303). However, DOE does not yet have release criteria for such materials. The product would have a low-level waste designation that would be acquired from DOE (1988a). DOE (1988a) does not consider reclassification of a waste as other than a waste except through §9 exemption. The petition requirements for property release (DOE 1993) must allow the release and designation of the material as a product rather than a waste.

5.3.1.3 Production and Programmatic Impacts

This alternative does not consider further processing except preparing the nitrate salts in a heavy slurry or dried form, so it causes no new production or programmatic impacts.

5.3.1.4 Safety Considerations and Impacts

This alternative does not consider further processing except preparing the nitrate salts in a heavy slurry or dried form, so it causes no new safety impacts. In approval for release, DOE must consider all applications of the material for acceptable dose consequences (DOE 1993). Such an acceptance must be considered a baseline for all offsite applications.

5.3.1.5 Environmental Impacts and Permitting Requirements

The conduct of the CSP has been modeled to release to the evaporator condensates 0.084% of inlet ^{137}Cs activity to the process, amounting to entrainment of 2.19×10^{13} Bq (591 Ci) (Lunsford 1994). Water mass in these condensates was estimated to be 2.05×10^9 kg. In accordance with DOE (1993) derived concentration guidelines (DCGs, Citation 2) for liquid effluent concentrations (1.1 Bq/mL), this condensate stream would leave the evaporator at 97 ^{137}Cs DCGs, necessitating additional cesium extraction before release to the environment. Similarly, calculated ^{90}Sr concentrations in the condensate would be at 5 DCGs. These environmental considerations remain for all applications of CSP. [Calculation 4, Appendix A]

DOE 5400.5, Definitions:

Derived Concentration Guide (DCG) is the concentration of a radionuclide in air or water that, under conditions of continuous exposure for one year by one exposure mode (i.e., ingestion of water, submersion in air, or inhalation), would result in an effective dose equivalent of 100 mrem 0.1 rem (1 mSv).

Citation 2: Derived Concentration Guide

The feed streams modeled by Lunsford (1994) and Slaathaug (1996) did not contain all applicable radioisotopes. These must be considered for any direct application. However, the only isotope of environmental dose significance not included in the effluent stream calculations is tritium. Because of process additions and separations, essentially all (>95%) of the tritium (as HTO) must be considered to exit in the evaporator condensates. Only a trace of the tritium will be in the salt product stream, with the balance in the waste stream.

Dose consequences from CSP processing should also be viewed from the perspective that the releases are a small fraction of what might be expected from direct vitrification or another high-temperature waste stabilization process.

The evaporation of waste materials has historically occurred on this site and continues today. Based on this precedent, Ecology would probably readily approve an evaporation system to reduce waste volumes.

If the materials produced remain classified as waste, they must be delisted for ready application off site. The chemical processing and separations of the CSP should readily support a delisting petition to the U.S. Environmental Protection Agency and Ecology.

5.3.1.6 Cost and Schedule Estimates

For a feed stream mass of 1.07×10^9 kg (Lunsford 1994), on a production basis of 10 years, the process would feed approximately $85,600 \text{ m}^3/\text{yr}$ (2.26×10^7 gallon/yr) and produce 2.73×10^7 kg/yr of NaNO_3 . If executed with aluminum and potassium removal, additional products may include up to 2.53×10^6 kg/yr of $\text{Al}(\text{NO}_3)_3$ and 2.57×10^5 kg/yr of KNO_3 . Masses of aluminum nitrate described in this analysis are as $\text{Al}(\text{NO}_3)_3$, although material recoveries would be in the form of aluminum nitrate nonahydrate ($\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$). [Calculation 5, Appendix A]

Waste feed flows to support these production rates will depend on tank waste retrieval activities. These rates would be more supportable when retrieving waste from Hanford Site single-shell tanks. World, if not national, markets could absorb these production rates. The potassium nitrate, as the smallest stream, would be expected to be used regionally in fertilizers.

According to recent market valuations of these salts, these materials are valued at \$0.759/kg, and \$0.357/kg for NaNO_3 and KNO_3 , respectively, as bulk fertilizer grade products (*Chemical Marketing Reporter 1996*). Aluminum nitrate nonahydrate, $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ as $\text{Al}(\text{NO}_3)_3$, is not reported in bulk chemical price indices; however, a reagent price of \$72/kg may be considered (JT Baker 1993). Assuming 10 percent net market value on reagent price and 100% on fertilizer grade bulk materials, offsite sales of these salts would yield \$39 million/year. [Calculation 6, Appendix A]

5.3.1.7 Other Decision Data

Because this is the only alternative considered for off site release, public perception must be considered. Public perception of radioactivity and dose consequence, and trust in the DOE are considered economically by assuming product at bulk market values and at only 10 percent of net market reagent value. They also must be considered the greatest potential lever of sales of the salt off site. Proactive measures must be taken to acquire a sufficient market for these materials.

5.3.2 Onsite Clean Salt Use as Fertilizer

5.3.2.1 Description

This alternative was considered in Herting (1995), and is a variation of that described in § 5.3.1. Applying the CSP streams as fertilizer on the Hanford Site is considered here. Primary application would be in environmental restoration activities such as those recently conducted with the 200-BP-1 surface barrier construction (Buckmaster 1994). Within the surface barrier, fertilizers are used to aid regrowth of vegetation.

5.3.2.2 Advantages and Disadvantages

The only distinct advantage seen in the use of these materials on site is that problems with public acceptance and perception that must be solved for offsite marketing of these salts would be avoided. However, disadvantages include programmatic delay in application and material limitations in considered application. In essence the material may only be able to be used too little, too late.

5.3.2.3 Production and Programmatic Impacts

Production time lines would be expected to yield significant inventories of nitrate salts when LLW solidification is starting. Thus, it is reasonable to believe that these inventories will grow rapidly beginning in about 2005. Current estimates, guided by negotiated activities under Ecology *et al.* (1994), yield expectations that completion dates for surface-barrier revegetation in the Hanford Site 100 Areas would not be established until December 2001. Revegetation may then be reasonably anticipated to occur in about 2005. Interim storage may be required.

An additional impact would be the near-complete restriction to using only potassium nitrates as fertilizers on site. In general, the sodium salts damage the soil and inhibit plant growth. For this reason, barrier designs have used only potassium nitrate (Buckmaster 1994). The rate of CSP production of KNO_3 , if applied at 124 kg/hectare, would provide fertilization for 20.8 km^2/yr . Only 0.85 wt% of the producible nitrate salts from the CSP would be projected to be KNO_3 , the remaining 99% would require other disposition. [Calculation 7, Appendix A]

5.3.2.4 Safety Considerations and Impacts

No particular safety considerations exist except the long-term storage of nitrates. These materials are combustible. Potassium nitrate, commonly called saltpeter, is an ingredient in the explosive black powder. Adequate safety measures can be taken without undue cost.

5.3.2.5 Environmental Impacts and Permitting Requirements

As described in §§ 4.2 and 5.3.1, using the material as a fertilizer may be considered to remove the material from consideration as a solid waste. Delisting for the KNO_3 used as fertilizer would

not be required; however, overall CSP product delisting may be deemed advisable or required by Ecology to remove these materials from waste management standards.

5.3.2.6 Cost and Schedule Estimates

For scheduling, these materials would not be expected to be applied in significant quantities in environmental remediation surface barriers until about 2005 in the establishment of Hanford Site 100 Area surface barriers. Storage costs, from production to application, should not be expected to exceed new fertilizer procurement costs from offsite vendors; cost savings versus liabilities may be considered to trade off evenly.

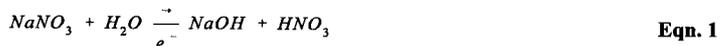
5.3.2.7 Other Decision Data

No other decision data are considered of significant merit at this time.

5.3.3 On-Site Clean Salt Use in Caustic Recycle

5.3.3.1 Description

This alternative considers the electrochemical separation of the nitrate salts to caustic solutions and nitric acid (**Eqn. 1**) as described by Herting (1995). Following such separation, the separated caustic and nitric streams may be used for processing tank wastes by alternately conducting caustic and acidic treatments.



Jansen *et al.* (1995) considered recycling caustic materials in Extensive Separations plans, but they proposed using direct calcination (line 3 of **Eqn. 2**), bypassing application of CSP.

5.3.3.2 Advantages and Disadvantages

One advantage of this alternative is that it reduces sodium hydroxide and nitric acid purchases expected in the baseline flow sheet (Orme 1995). The flow sheet anticipates purchases of 1.95×10^7 kg of NaOH and 4.26×10^7 kg of HNO₃, accounting for potential application of 4.14×10^7 kg of NaNO₃ (sodium basis). Also, the CSP flow sheet requires 4.29×10^6 kg of NaOH and 1.2×10^8 kg of HNO₃, accounting for 9.12×10^6 kg of NaNO₃. Together, these account for 18.5 percent of the sodium nitrate anticipated to be separable through the CSP. [Calculation 8, Appendix A]

The reduction of material purchases with the implementation of CSP and caustic recycle reduces some disposal costs, as described below, but does not eliminate the final disposal of the sodium, aluminum, and potassium separated from the waste. This alternative can only relieve waste disposal costs temporarily unless it is tied with another viable product or disposal alternative.

5.3.3.3 Production and Programmatic Impacts

The electrochemical separation process may require feed streams of low-molarity salts. Additional evaporation may be required following such dilution. In addition, the relatively large mass of material involved in recycling caustics may require additions to Site infrastructure (e.g., piping) instead of tank trucks or other types of product transportation.

5.3.3.4 Safety Considerations and Impacts

The electrochemical separation process will have high-tension hazards as well as corrosivity hazards for the product stream.

5.3.3.5 Environmental Impacts and Permitting Requirements

The separation and reuse of the material should pose no significant environmental impact or require extraordinary permitting activity. The separation would be a new treatment code for operations under current Site permits.

5.3.3.6 Cost and Schedule Estimates

The main cost of the electrolytic separation is the facility to house the cells and the electrical power. To coordinate schedules, the separation may be readily chained to the CSP during tank waste retrieval. Cash savings by reuse rather than procurement of additional NaOH and HNO₃, are estimated to be \$48 million. [Calculation 9, Appendix A]

5.3.3.7 Other Decision Data

Because this alternative does not remove the material from waste inventory streams, it must be linked with some other alternative that removes the material from the LLW stream for solidification (DOE 1996).

5.3.4 Onsite Clean Salt Use in Ion Exchange

5.3.4.1 Description

This alternative, also described in Herting (1995), would require the electrolytic separation of the salts and use the resulting sodium hydroxide for waste water effluent pH adjustment and ion exchange backwash. The proposed application site is the 200 Area Effluent Treatment Facility (Burke 1995). Additional waste water treatment facilities are available on the Hanford Site. This study is considering application only in the waste water facility expected to be closest to a CSP facility.

5.3.4.2 Advantages and Disadvantages

An advantage of the use of the sodium hydroxide in this alternative is that this method constitutes final disposition; the hydroxide would be sent with other waste water to the Columbia River. The disadvantages of this alternative are the small masses of hydroxide required and that no use is identified for the nitric acid or other caustic compounds.

5.3.4.3 Production and Programmatic Impacts

The application of sodium hydroxide is currently limited to adjusting pH and ion exchange backwash. Under the current flow sheet (Burke 1995), approximately 9,100 L/year of 50-percent NaOH is in use. This equates to 1.47×10^4 kg/yr of NaNO_3 , or about 0.05 percent of the CSP NaNO_3 production capacity estimate. [Calculation 10, Appendix A] The other hydroxides (aluminum and potassium) would be used to adjust pH, but would not be desirable in the cationic exchange resins used at the Effluent Treatment Facility.

The nitric acid would not be useful at the Effluent Treatment Facility. The facility currently uses sulfuric acid to regenerate their exchange resin because ultraviolet light is used down stream to oxidize the waste water and destroy organic components. The nitrate ion readily absorbs ultraviolet light; high concentrations of nitrate would effectively stop organic destruction in the process system.

5.3.4.4 Safety Considerations and Impacts

Electrochemical separation poses high-tension and corrosivity safety concerns as described in §5.3.3.4. However, no significant additional safety concerns arise in the application of these separated salts to ion exchange backwashing and adjustment of the waste stream pH that are not currently addressed at the Effluent Treatment Facility.

5.3.4.5 Environmental Impacts and Permitting Requirements

Compliance with waste water discharge limits requires that cesium discharges from the Effluent Treatment Facility not exceed 0.185 Bq/m^3 ($5 \times 10^{-12} \text{ Ci/m}^3$). As sodium hydroxide addition, the use at 1.85 Bq/g would limit hydroxide addition to 0.1 g/m^3 ($1.2 \times 10^{-6} \text{ M}$) in the aggregate effluent stream of $0.57 \text{ m}^3/\text{min}$. This limit would constrain total sodium hydroxide use from the separated salt to an equivalent of 30 kg/yr of NaNO_3 . Because this value is only 0.2 percent of that given in the flow sheet (Burke 1995), effluent limitations are not expected to be met with larger CSP salt loadings. [Calculation 11, Appendix A]

Because this alternative cannot comply with effluent limits, it must be dismissed as not viable.

No additional permitting requirements are seen in this application of the material.

5.3.4.6 Cost and Schedule Estimates

Primary cost of the electrolytic separation is the facility to house the cells and the electrical power. For scheduling, the separation may be readily chained to the CSP during tank waste retrieval.

Because most of the sodium hydroxide is used for pH control, waste feed changes from evaporator condensates to ground waters are anticipated to reduce hydroxide demand by approximately 75 percent. Scheduled use of this material should not depend on a constant demand expectation.

5.3.4.7 Other Decision Data

No other decision data are considered significant at this time.

5.3.5 Onsite Disposal of Clean Salt Product

5.3.5.1 Description

This alternative was considered in Herting (1995) as the cases of onsite inert waste disposal and onsite LLW disposal. This alternative is not defined in particular form, but is intended to be in the nature of a disposal action without significant additional treatment of the salt. For example, such a disposal action would be similar to the recently discontinued Grout Disposal Program at the Hanford Site. That program proposed, and conducted limited demonstrations of, cementitious disposal of tank wastes in near-surface disposal vaults.

This alternative is considered to address both the inert and low-level onsite disposal options described by Herting (1995) because no non-radioactive disposal facilities will be operating at the Hanford Site following recent assignment of contracts to local municipalities for waste disposal and the closure of the Site's central landfill. The material will retain some residual radioactive material that DOE (1988a) currently requires to be managed as LLW.

5.3.5.2 Advantages and Disadvantages

The existent Grout Treatment Facility and grout disposal vaults can be considered to be available for processing the salt to a cement-based waste form. The facility was designed for significantly greater radioactivity than would be present in the CSP product. The disadvantage is that the waste form would generate the same significant long-term disposal concern seen for the Grout Disposal program. The high-nitrate grout would have the potential to contaminate the groundwater through leaching, resulting in a significant nitrate plume. (Kincaid *et al.* 1995)

5.3.5.3 Production and Programmatic Impacts

Production of grouted wastes could begin almost immediately. Programmatically, the construction of vaults for the waste would slow implementation.

5.3.5.4 Safety Considerations and Impacts

No significant safety considerations arise for grout disposal of the CSP product other than those caused by construction. One hundred seventy-seven vaults filled with wastes at 5M nitrate species would need to be built. [Calculation 12, Appendix A]

5.3.5.5 Environmental Impacts and Permitting Requirements

The environmental impacts are within the scope of those of the Grout Disposal program. Dose consequences would be lower than those for the Grout Disposal program. The operations would require permitting as a mixed waste treatment, storage, and disposal facility. The only significant impact would be the potential for groundwater nitrate contamination and apportionment of nitrate limits to all Site activities.

5.3.5.6 Cost and Schedule Estimates

Vault construction and cementitious material procurement would be a significant driver. Disposal costs, based on those of the Grout Disposal program, would be expected to be approximately \$6.5/L or \$4.36 billion. [Calculation 12, Appendix A] These costs are fully burdened life-cycle costs for facility construction, operations, essential materials, disposal, decontamination and decommissioning, and long term monitoring. It is anticipated that large scale vitrification facilities would yield similar or larger life-cycle cost estimates (see also §§ 4.3 and 4.5).

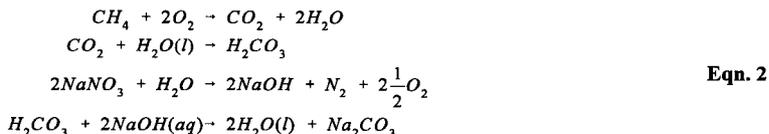
5.3.5.7 Other Decision Data

Land use has been a significant consideration in long-term Hanford Site disposition. The public will object to allocating enough land for disposal. The high cost is likely to eliminate this alternative.

5.3.6 On-Site Clean Salt Use as Tank Closure Ballast

5.3.6.1 Description

This alternative considers using separated salts as a ballast material for Hanford Site waste tank closure. The chemical pathway for this is carbonaceous oxidation (burning the nitrate salts using a carbon-bearing fuel) to form the metal carbonates in aqueous media (Eqn. 2). These materials would be amendments at high concentrations (~10 wt%) to cementitious mixtures that would be



injected into the tanks to set and provide stabilization and subsidence control. Cementitious fill materials for the tanks have been, and continue to be, considered a viable stabilization alternative (Kline 1995).

5.3.6.2 Advantages and Disadvantages

Among the prime advantages is that this alternative can be considered regardless of the success of all other alternatives. If the Hanford Site tanks are not destructively closed, they must be adequately stabilized; backfilling or jet-grouting the tanks would meet this need. Amending cements with high levels of sodium carbonates would not prevent the cement from setting properly. Also, dense Portland cement concrete reimmersed in sodium carbonate solutions displays little or no chemical action. (Lea 1971)

A second advantage of this alternative is that the destruction of the nitrate ion to acquire the carbonate form of the material eliminates the toxicity and ignitability hazards of the material, resulting in a waste form that is not a dangerous waste following delisting. This is a significant advantage over nitrate-bearing waste forms in groundwater contamination and transport.

The primary disadvantage in this alternative is that large-scale thermal processing is required to convert the CSP products to carbonates. A similar process was modeled in Hendrickson (1994) with the plasma calcination of tank waste liquors. Assuming the same conditions described in Hendrickson (1994) with methane supplement to stoichiometric requirements and plasma heating, the system would require 2.881×10^7 kg of CH_4 , 8.156×10^7 kg NH_3 (for stack NO_x removal), and a 6.9×10^6 -watt torch over the 10-year operation. Costs for these materials and services are anticipated to be \$3.8 million for methane (Waas 1996), \$18.8 million for ammonia, and \$30 million for electricity, for a total non-capital cost of \$52.7 million. The stack NO_x treatment constitutes 36 percent of this cost, so improving the efficiency or reducing the cost of this treatment may significantly improve the non-capital cost of this calcination. Modification of the off gas treatment to form ammonium nitrate may provide an additional product stream to offset the cost of materials. [Calculation 13, Appendix A]

5.3.6.3 Production and Programmatic Impacts

Operations to apply the carbonate forms of the CSP products would require 2.88×10^6 kg/year of CH_4 , 8.16×10^6 kg/year of NH_3 , and a power supply of 6.9×10^6 watt. This operation would provide carbonates sufficient (at 10 wt%) for $79,050 \text{ m}^3$ (2.09×10^8 gallon) of grout, approximately the volume considered for aggregate or grout filling by Kline (1995). The calcination of the salt product can be easily chained to the CSP process for continuous or batch salt conversion. [Calculation 14, Appendix A]

5.3.6.4 Safety Considerations and Impacts

Safety considerations are those of a high-tension, high-temperature facility, similar to those found at a vitrification facility if it were used in LLW solidification.

An acquired safety advantage is that public and worker exposure would be reduced. The exposure estimated in Appendix B for an individual standing on a tank filled with this grout would be less than 4.2×10^{-3} mr/hr.

5.3.6.5 Environmental Impacts and Permitting Requirements

An expected side effect would be the loss of much of the cesium to the off gas system in the carbonate conversion process. A loss also would be expected in a vitrification facility. In this application, however, the losses would be from the decontaminated salts rather than directly from the tank waste and would be much smaller.

In alkaline scrubber applications, most to all of the cesium will be able to be captured. For an estimated overall capture efficiency of 99 percent of the ^{137}Cs , the off gas might expect to pass 3.7×10^8 Bq/year (0.01 Ci/year) for an estimated dose consequence (from a 200 Area short stack) of 2.4×10^{-4} mrem/year (WHC 1991). These dose consequences are actually minor and would be considered reasonable in permitting and As Low As Reasonably Achievable (ALARA) program evaluations. [Calculation 15, Appendix A]

5.3.6.6 Cost and Schedule Estimates

Costs amount to \$52.7 million for materials and electricity over 10 years of operation. Significant cost reductions are possible in gaseous nitrogen oxides treatment, a major cost factor of this alternative. Facility construction and operating costs are estimated to be 30 percent of the cost of the CSP construction and operation. Adding a calcination unit to the CSP does not affect any schedules.

5.3.6.7 Other Decision Data

The closure methods for Hanford Site tanks has not been determined although it is under study. As a result, no decision has been made that the single- and double-shell tanks will be stabilized and closed or removed. I believe that ALARA considerations and the DOE (1988a) performance assessment requirements will lead to tank stabilization rather than destructive removal. If the tanks are stabilized in closure, several methods might be available; however, in any case of solid placement into the tanks, cementitious materials may still be needed to fill interstitial spaces and headspace.

6.0 DISCUSSION OF PREFERRED ALTERNATIVE/SOLUTION

The preferred alternative is offsite release of clean salt (§ 5.3.1). With the baseline potential savings in LLW form production of \$63 million/year for 10 years, and the potential income of \$39 million/year from sales of salt, this alternative could result in a savings and earnings of nearly \$1,027 million. [Calculation 16, Appendix A]

As described in §§ 4.1 and 5.3.1, the material must be able to be released from DOE management and it must be acceptable for commercial use in the eyes of the public. Dose perspectives described in § 4.1 and Appendix B should provide an adequate basis for Secretary approval (DOE 1993) for release of the Clean Salt products for public use.

Without approval for public release of CSP products, it is recommended that the material be calcined and the carbonate form of the product be used as tank closure ballast (§ 5.3.6). Again, dose considerations are favorable and the material will replace material that would otherwise be purchased as bulk fill. Although preparation through calcination can be expected to be costly, it is far less costly than direct disposal (§ 5.3.5). These efforts are estimated to save approximately \$632 million while in operation. [Calculation 17, Appendix A]

7.0 NO ACTION ALTERNATIVE

The no action alternative is simply that the CSP not be executed. If CSP is not executed, flow streams to low-level and high-level waste solidification processes will remain as described in Orme (1995). With the salts remaining in the LLW form, the volume of that stream could be as much as 20 times more than with CSP.

Because the CSP has remained an option in the consideration of treatment of tank wastes, no programmatic changes or cost and schedule impacts are envisioned to occur with a decision to not implement the process.

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APPENDIX A: CALCULATIONS

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1. Chemical data and Molecular Weights

$$MW_{Al} := 26.9815 \frac{\text{gm}}{\text{mole}} \quad MW_C := 12.0115 \frac{\text{gm}}{\text{mole}} \quad MW_O := 15.9994 \frac{\text{gm}}{\text{mole}}$$

$$MW_K := 39.102 \frac{\text{gm}}{\text{mole}} \quad MW_N := 14.0067 \frac{\text{gm}}{\text{mole}} \quad MW_{Na} := 22.9898 \frac{\text{gm}}{\text{mole}}$$

$$MW_H := 1.0079 \frac{\text{gm}}{\text{mole}} \quad MW_{CH_4} := MW_C + 4 \cdot MW_H$$

$$MW_{NH_3} := MW_N + 3 \cdot MW_H \quad MW_{NaOH} := MW_{Na} + MW_H + MW_O$$

$$MW_{CO_3} := MW_C + 3 \cdot MW_O \quad MW_{NO_3} := MW_N + 3 \cdot MW_O$$

$$MW_{AlNO_3} := MW_{Al} + 3 \cdot MW_{NO_3} \quad MW_{Al_2CO_3} := 2 \cdot MW_{Al} + 3 \cdot MW_{CO_3}$$

$$MW_{KNO_3} := MW_K + MW_{NO_3} \quad MW_{K_2CO_3} := 2 \cdot MW_K + MW_{CO_3}$$

$$MW_{NaNO_3} := MW_{Na} + MW_{NO_3} \quad MW_{Na_2CO_3} := 2 \cdot MW_{Na} + MW_{CO_3}$$

$$MW_{HNO_3} := MW_H + MW_{NO_3}$$

$$MW_{NO_3} = 62.005 \frac{\text{gm}}{\text{mole}} \quad MW_{CO_3} = 60.01 \frac{\text{gm}}{\text{mole}}$$

$$MW_{AlNO_3} = 212.996 \frac{\text{gm}}{\text{mole}} \quad MW_{Al_2CO_3} = 233.992 \frac{\text{gm}}{\text{mole}}$$

$$MW_{KNO_3} = 101.107 \frac{\text{gm}}{\text{mole}} \quad MW_{K_2CO_3} = 138.214 \frac{\text{gm}}{\text{mole}}$$

$$MW_{NaNO_3} = 84.995 \frac{\text{gm}}{\text{mole}} \quad MW_{Na_2CO_3} = 105.989 \frac{\text{gm}}{\text{mole}}$$

$$MW_{NaOH} = 39.997 \frac{\text{gm}}{\text{mole}} \quad MW_{HNO_3} = 63.013 \frac{\text{gm}}{\text{mole}}$$

2. Flow Sheet Yields (post Cs-IX models)

Lunsford (1994) input sodium, aluminum and potassium, Stream 1 Liquid and Solid

Let $M_{gm} = 10^6 \cdot gm$

$$M_{Na_in} := (7.84 \cdot 10^4 + 4.67 \cdot 10^2) \cdot M_{gm} \quad M_{Na_in} = 7.84 \cdot 10^4 \cdot M_{gm}$$

$$M_{Al_in} := (4.11 \cdot 10^3 + 1.78 \cdot 10^2) \cdot M_{gm} \quad M_{Al_in} = 4.11 \cdot 10^3 \cdot M_{gm}$$

$$M_{K_in} := (1.42 \cdot 10^3 + 1.11 \cdot 10^3) \cdot M_{gm} \quad M_{K_in} = 1.42 \cdot 10^3 \cdot M_{gm}$$

Lunsford (1994) output sodium and aluminum (Stream 58) and Slaathaug (1996) fraction potassium removed at 70%.

$$M_{Na_out} := (1.05 \cdot 10^4 + 6.33 \cdot 10^4) \cdot M_{gm} \quad M_{Na_out} = 7.38 \cdot 10^4 \cdot M_{gm}$$

$$M_{Al_out} := (5.56 \cdot 10^2 + 2.65 \cdot 10^3) \cdot M_{gm} \quad M_{Al_out} = 3.206 \cdot 10^3 \cdot M_{gm}$$

$$M_{K_out} := 0.7 \cdot M_{K_in} \quad M_{K_out} = 994.001 \cdot M_{gm}$$

Yield in %

$$Yield_{Na} := \frac{M_{Na_out}}{M_{Na_in}} \cdot 100 \quad Yield_{Al} := \frac{M_{Al_out}}{M_{Al_in}} \cdot 100 \quad Yield_K := \frac{M_{K_out}}{M_{K_in}} \cdot 100$$

$$Yield_{Na} = 94.133$$

$$Yield_{Al} = 78.005$$

$$Yield_K = 70$$

Molar Yields

Let: $Mmole = 10^6 \cdot mole$

$$MYield_{Na} := \frac{M_{Na_out}}{MW_{Na}} \quad MYield_{Al} := \frac{M_{Al_out}}{MW_{Al}} \quad MYield_K := \frac{M_{K_out}}{MW_K}$$

$$MYield_{Na} = 3.21 \cdot 10^3 \cdot Mmole \quad MYield_{Al} = 118.822 \cdot Mmole \quad MYield_K = 25.421 \cdot Mmole$$

$$MYield_{total} := MYield_{Na} + MYield_{Al} + MYield_K \quad MYield_{total} = 3.354 \cdot 10^3 \cdot Mmole$$

3. Glass Production Savings Estimate

Boomer et al. 1994: Annual Operating cost = \$75E6. 800 Containers/year at 29.8 cubic meters per container. Containers 70:30 Glass:sulfur polymer cement. Disposal \$19E3/container plus \$3e6/bay. Each bay holds 197 containers. Na is 74.2% of Na2O mass.

Assume glass SPG = 2.5, and a sodium target loading of 25% Na2O.

Glass product mass of sodium:

$$\text{Glass Na} = \frac{800}{\text{yr}} \cdot (29.8 \text{ m}^3) \cdot \left(\frac{0.7 \text{ m}^3}{\text{m}^3} \right) \cdot \left(\frac{2500 \text{ kg}}{\text{m}^3} \right) \cdot \left(\frac{0.25 \text{ kg}}{\text{kg}} \right) \cdot \left(\frac{0.742 \text{ kg}}{\text{kg}} \right) \quad \text{Glass Na} = 7.739 \cdot 10^3 \frac{\text{Mgm}}{\text{yr}}$$

Containers and bays saved (10 year CSP life):

$$\text{Less cont} = \frac{\left(\frac{M_{\text{Na out}}}{10 \cdot \text{yr}} \right) \cdot 800}{\text{Glass Na}} \frac{1}{\text{yr}} \quad \text{Less cont} = 762.88 \frac{1}{\text{yr}}$$

$$\text{Less Bays} = \frac{\text{Less cont}}{197} \quad \text{Less Bays} = 3.873 \frac{1}{\text{yr}}$$

$$\text{Less contcash} = 19000 \text{ Less cont} \quad \text{Less contcash} = 1.449 \cdot 10^7 \cdot \frac{1}{\text{yr}} \quad \text{Dollars}$$

$$\text{Less Baycash} = 3 \cdot 10^6 \cdot \text{Less Bays} \quad \text{Less Baycash} = 1.162 \cdot 10^7 \cdot \frac{1}{\text{yr}} \quad \text{Dollars}$$

Operation savings estimated at 50%:

$$\text{Less Opcash} = 0.5 \cdot \left(75 \cdot \frac{10^6}{\text{yr}} \right) \quad \text{Less Opcash} = 3.75 \cdot 10^7 \cdot \frac{1}{\text{yr}} \quad \text{Dollars}$$

Total Glass Exclusion Savings:

$$\text{Less total} = \text{Less contcash} + \text{Less Baycash} + \text{Less Opcash}$$

$$\text{Less total} = 6.36 \cdot 10^7 \cdot \frac{1}{\text{yr}} \quad \text{Dollars}$$

4. DCG Calculations in Evaporator Condensates

(Lunsford 1994, Stream 6+26+45) Cs and Ba = 1158 Ci and Sr and Y = 210.6 Ci

Water mass = 2.051E6Mg, at SPG of 1

DCG's from DOE 5400.5

$$\text{Condensate vol} := 2.051 \cdot 10^6 \cdot \text{Mgm} \cdot \frac{\text{mL}}{1 \cdot \text{gm}}$$

$$\text{DCG}_{137\text{Cs}} := \frac{3 \cdot 10^{-12}}{\text{mL}} \cdot (3.7 \cdot 10^{10}) \quad \text{DCG}_{137\text{Cs}} = 0.111 \cdot \frac{1}{\text{mL}} \quad \text{Becquerel}$$

$$\text{DCG}_{90\text{Sr}} := \frac{1 \cdot 10^{-11}}{\text{mL}} \cdot (3.7 \cdot 10^{10}) \quad \text{DCG}_{90\text{Sr}} = 0.37 \cdot \frac{1}{\text{mL}} \quad \text{Becquerel}$$

$$\text{Condensate}_{137\text{Cs}} := \frac{1158}{1.946} \cdot (3.7 \cdot 10^{10}) \quad \text{Becquerel} \quad \text{Condensate}_{137\text{Cs}} = 2.202 \cdot 10^{13} \quad \text{Becquerel}$$

$$\text{Condensate}_{90\text{Sr}} := \frac{210.6}{2} \cdot (3.7 \cdot 10^{10}) \quad \text{Becquerel} \quad \text{Condensate}_{90\text{Sr}} = 3.896 \cdot 10^{12} \quad \text{Becquerel}$$

Concentrations of 137Cs and 90Sr relative to the DCG limits:

$$\text{NumDCG}_{137\text{Cs}} := \frac{\frac{\text{Condensate}_{137\text{Cs}}}{\text{Condensate vol}}}{\text{DCG}_{137\text{Cs}}} \quad \text{NumDCG}_{90\text{Sr}} := \frac{\frac{\text{Condensate}_{90\text{Sr}}}{\text{Condensate vol}}}{\text{DCG}_{90\text{Sr}}}$$

NumDCG_{137Cs} = 96.712 NumDCG_{90Sr} = 5.134

5. Production Rate

(Lunsford 1994, Stream 58) Assume Spg of feed = 1.25

$$\text{Feed vol} := \frac{1.07 \cdot 10^{12} \cdot \text{g} \cdot \text{m}^3}{10 \cdot \text{yr} \cdot 1.25 \cdot 10^6 \cdot \text{g}} \quad \text{Feed vol} = 8.56 \cdot 10^4 \cdot \frac{\text{m}^3}{\text{yr}} \quad \text{Feed vol} = 2.26 \cdot 10^7 \cdot \frac{\text{gal}}{\text{yr}}$$

Mass of Nitrate Products:

$$M_{\text{NaNO}_3 \text{ _out}} := \frac{M_{\text{Na}_\text{out}} \cdot \text{MW}_{\text{NaNO}_3}}{10 \cdot \text{yr} \cdot \text{MW}_{\text{Na}}} \quad M_{\text{NaNO}_3 \text{ _out}} = 2.72 \cdot 10^4 \cdot \frac{\text{Mgm}}{\text{yr}}$$

$$M_{\text{AlNO}_3 \text{ _out}} := \frac{M_{\text{Al}_\text{out}} \cdot \text{MW}_{\text{AlNO}_3}}{10 \cdot \text{yr} \cdot \text{MW}_{\text{Al}}} \quad M_{\text{AlNO}_3 \text{ _out}} = 2.53 \cdot 10^3 \cdot \frac{\text{Mgm}}{\text{yr}}$$

$$M_{\text{KNO}_3 \text{ _out}} := \frac{M_{\text{K}_\text{out}} \cdot \text{MW}_{\text{KNO}_3}}{10 \cdot \text{yr} \cdot \text{MW}_{\text{K}}} \quad M_{\text{KNO}_3 \text{ _out}} = 257.02 \cdot \frac{\text{Mgm}}{\text{yr}}$$

6. Value of Nitrate Products

(JT Baker Catalog 1993-1994 for Al, Chemical Marketing Reporter for Na, K)

$$\text{Value}_{\text{NaNO}_3} = \frac{34.5}{100 \text{ lb}} \quad \text{Value}_{\text{AlNO}_3} = \frac{72}{\text{kg}} \quad \text{Value}_{\text{KNO}_3} = \frac{325}{\text{ton}} \quad \text{Dollars}$$

Assuming only 10% of value:

$$\text{Sales} := M_{\text{NaNO}_3_out} \cdot \text{Value}_{\text{NaNO}_3} + \frac{M_{\text{AlNO}_3_out} \cdot \text{Value}_{\text{AlNO}_3}}{10} + M_{\text{KNO}_3_out} \cdot \text{Value}_{\text{KNO}_3}$$

$$\text{Sales} = 3.907 \cdot 10^7 \cdot \frac{1}{\text{yr}} \quad \text{Dollars}$$

7. Fertilizer Demand Potential

KNO₃ as a fraction of total potential nitrate salt production

$$\text{Fert}_{\text{KNO}_3} := \frac{M_{\text{KNO}_3_out}}{M_{\text{NaNO}_3_out} + M_{\text{AlNO}_3_out} + M_{\text{KNO}_3_out}}$$

$$\text{Fert}_{\text{KNO}_3} = 0.0085$$

8. Caustic Recycle Demand

Orme 1995: 19500 Mgm NaOH and 42,600Mgm HNO₃

Lunsford, 1994, Stream 2 = 119,900 Mgm HNO₃, Stream 62 = 4,209 Mgm NaOH

$$\text{Nitric acid basis: Demand}_{\text{NaNO}_3} := (4.26 \cdot 10^4 + 1.119 \cdot 10^5) \cdot \text{Mgm} \cdot \frac{\text{MW}_{\text{NaNO}_3}}{\text{MW}_{\text{HNO}_3}}$$

$$\text{Demand}_{\text{NaNO}_3} = 2.084 \cdot 10^5 \cdot \text{Mgm}$$

$$\text{Sodium basis: Demand}_{\text{NaNO}_3} := (1.95 \cdot 10^4 + 4.209 \cdot 10^3) \cdot \text{Mgm} \cdot \frac{\text{MW}_{\text{NaNO}_3}}{\text{MW}_{\text{NaOH}}}$$

$$\text{Demand}_{\text{NaNO}_3} = 5.038 \cdot 10^4 \cdot \text{Mgm}$$

Therefore use sodium basis.

$$\text{Fraction of production} = \text{Demand}_{\text{prod}} := \frac{\text{Demand}_{\text{NaNO}_3}}{M_{\text{NaNO}_3_out} \cdot 10\text{-yr}} \quad \text{Demand}_{\text{prod}} = 0.185$$

9. Glass Savings in Caustic Recycle

By not adding the additional sodium hydroxide for caustic leaching

No credit taken for operations cost reduction.

$$\text{Less}_{\text{CRtotal}} := \text{Demand}_{\text{prod}} \cdot (\text{Less}_{\text{contcash}} + \text{Less}_{\text{Baycash}}) \cdot 10\text{-yr}$$

$$\text{Less}_{\text{CRtotal}} = 4.822 \cdot 10^7 \quad \text{Dollars}$$

10. Ion Exchange Nitrate Equivalent of Sodium Hydroxide

(Burke, 1995: 2,400 gal/yr NaOH at 50wt%)

Perry's Chemical Engineer's Handbook, 6th, Table 3-90: SPG (50%NaOH)=1.5253 @ 20

$$IX_{NaNO3eq} = \frac{2400 \text{ gal}}{\text{yr}} \cdot \left(\frac{1.5253 \text{ gm}}{\text{mL}} \right) \cdot \left(\frac{0.5 \text{ gm}}{\text{gm}} \right) \cdot \frac{MW_{NaNO3}}{MW_{NaOH}} \quad IX_{NaNO3eq} = 14.724 \frac{\text{Mgm}}{\text{yr}}$$

$$IX_{Demand} = \frac{IX_{NaNO3eq}}{M_{NaNO3_out}} \quad IX_{Demand} = 5.396 \cdot 10^{-4}$$

11. Radionuclide Effluent Limitations in Effluent Treatment Facility

$$Rel_{limit_137Cs} = \frac{0.185}{\text{m}^3} \text{ Becquerel} \quad Flow_{ETF} = 150 \frac{\text{gal}}{\text{min}} \quad Flow_{ETF} = 0.568 \frac{\text{m}^3}{\text{min}}$$

$$Salt_{137Cs} = \frac{50 \cdot 10^{12}}{\text{gm}} \cdot 3.7 \cdot 10^{10} \quad Salt_{137Cs} = 1.85 \cdot \text{gm}^{-1} \text{ Becquerel}$$

$$M_{Salt_limit} = \frac{Rel_{limit_137Cs}}{Salt_{137Cs}} \quad M_{Salt_limit} = 0.1 \frac{\text{gm}}{\text{m}^3} \quad L = 1000 \text{ mL} \quad \mu\text{M} = 10^{-6} \frac{\text{mole}}{\text{L}}$$

$$\frac{M_{Salt_limit}}{MW_{NaNO3}} = 1.177 \cdot \mu\text{M}$$

$$ETF_{NaNO3_out} := Flow_{ETF} M_{Salt_limit} \quad ETF_{NaNO3_out} = 29.864 \frac{\text{kg}}{\text{yr}} \quad \text{NaNO3 equiv. of NaOH}$$

Fraction of Sodium demand available through CSP addition

$$Frac_{ETF} := \frac{ETF_{NaNO3_out}}{IX_{NaNO3eq}} \quad Frac_{ETF} = 0.002$$

12. Grouted Waste Disposal

Assume waste feed at 5M total nitrate salts. See Kincaid, 1995, inventory

Vault feed 1 million gallons of liquor

Assume, from prior program, Grout cost = \$6.5/L

$$Grout_{vaults} = \frac{MYield_{total}}{\left(5 \frac{\text{mole}}{\text{L}} \right) \cdot 10^6 \text{ gal}} \quad Grout_{vaults} = 177.226$$

$$Grout_{Cost} := Grout_{vaults} \cdot \frac{6.5}{\text{L}} \cdot 10^6 \text{ gal} \quad Grout_{Cost} = 4.36 \cdot 10^9 \text{ Dollars}$$

13. Plasma Calcination Demands
(Hendrickson 1994)

For stoichiometric carbonate formation:

$$\text{Demand}_{\text{CH}_4} = \frac{\text{MYield}_{\text{Na}} + 3 \cdot \text{MYield}_{\text{Al}} + \text{MYield}_{\text{K}}}{2} \cdot \text{MW}_{\text{CH}_4} \quad \text{Demand}_{\text{CH}_4} = 2.88 \cdot 10^4 \cdot \text{Mgm}$$

Ammonia Demand for NOx treatment: $6\text{NO}_2 + 8\text{NH}_3 \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O}$

$$\text{Demand}_{\text{NH}_3} = \frac{4}{3} (\text{MYield}_{\text{Na}} + 3 \cdot \text{MYield}_{\text{Al}} + \text{MYield}_{\text{K}}) \cdot \text{MW}_{\text{NH}_3} \quad \text{Demand}_{\text{NH}_3} = 8.15 \cdot 10^4 \cdot \text{Mg}$$

Electrical Power required at 9 MJ/L (Hendrickson 1994) (Lunsford product 58 at 1.8SPG, 1994)

$$\text{Prod}_{\text{CSP}} = (8.52 \cdot 10^4 + 3.48 \cdot 10^5) \cdot \text{Mgm} \quad \text{SPG}_{\text{CSP}} = 1.8 \frac{\text{gm}}{\text{mL}}$$

$$\text{Demand}_{\text{PWR}} = \frac{\frac{\text{Prod}_{\text{CSP}} \cdot 9 \cdot 10^6 \cdot \text{joule}}{\text{SPG}_{\text{CSP}} \cdot \text{L}}}{10\text{-yr}} \quad \text{Demand}_{\text{PWR}} = 6.86 \cdot 10^3 \cdot \text{kW}$$

Methane Cost at \$2.50/MMBtu:

$$\text{CH}_4_{\text{Cost}} = \frac{2.5}{10^6 \cdot \text{BTU}} \cdot \frac{212.8 \text{kcal}}{\text{mole}} \cdot \frac{\text{Demand}_{\text{CH}_4}}{\text{MW}_{\text{CH}_4}} \quad \text{CH}_4_{\text{Cost}} = 3.792 \cdot 10^6 \quad \text{Dollars}$$

Ammonia cost (Chemical Marketing Reporter @ \$209/ton)

$$\text{NH}_3_{\text{Cost}} = \text{Demand}_{\text{NH}_3} \cdot \frac{209}{\text{ton}} \quad \text{NH}_3_{\text{Cost}} = 1.879 \cdot 10^7 \quad \text{Dollars}$$

Assume cost of power is \$0.05/kW-hr

$$\text{Power}_{\text{Cost}} = \frac{0.05}{\text{kW} \cdot \text{hr}} \cdot \text{Demand}_{\text{PWR}} \cdot 10\text{-yr} \quad \text{Power}_{\text{Cost}} = 3.008 \cdot 10^7 \quad \text{Dollars}$$

$$\text{Calcine}_{\text{Cost}} = \text{CH}_4_{\text{Cost}} + \text{NH}_3_{\text{Cost}} + \text{Power}_{\text{Cost}} \quad \text{Calcine}_{\text{Cost}} = 5.267 \cdot 10^7 \quad \text{Dollars}$$

$$\text{Fraction of cost due to Ammonia de-NOx} = \frac{\text{NH}_3_{\text{Cost}}}{\text{Calcine}_{\text{Cost}}} = 0.357$$

14. Grouted Carbonates from Calcination

$$\text{Yield}_{\text{Carb}} = \left(\frac{\text{MYield}_{\text{Na}}}{2} \cdot \text{MW}_{\text{Na}_2\text{CO}_3} \right) + \left(\frac{\text{MYield}_{\text{Al}}}{2} \cdot \text{MW}_{\text{Al}_2\text{CO}_3} \right) + \left(\frac{\text{MYield}_{\text{K}}}{2} \cdot \text{MW}_{\text{K}_2\text{CO}_3} \right)$$

$$\text{Yield}_{\text{Carb}} = 1.85 \times 10^5 \cdot \text{Mgm}$$

For Grouts at SPG 2.35:

$$\text{Ballast}_{\text{vol}} = \frac{\text{Yield}_{\text{Carb}} \cdot \text{mL}}{0.1 \frac{\text{gm}}{\text{gm}} \cdot 2.35 \text{ gm}} \quad \text{Ballast}_{\text{vol}} = 7.905 \times 10^5 \cdot \text{m}^3 \quad \text{Ballast}_{\text{vol}} = 2.08 \times 10^8 \cdot \text{gal}$$

15. Dose Consequence of Calcination

(WHC 1991, Table C-8: 2.39E-2mrem/yr/Ci emission 10m stack)
(Lunsford 1994, Stream 58, Cs-137 = 10Ci)

Assume 99% 137Cs recovery in stack gas systems

Note: Sievert=10⁵ mrem

$$\text{Rel}_{137\text{Cs}} = \frac{10}{10\text{-yr}} \cdot 0.1 \cdot 3.7 \cdot 10^{10} \quad \text{Rel}_{137\text{Cs}} = 3.7 \cdot 10^8 \cdot \frac{1}{\text{yr}} \quad \text{Becquerel}$$

$$\text{Dose}_{137\text{Cs}} = \frac{\text{Rel}_{137\text{Cs}}}{3.7 \cdot 10^{10}} \cdot 2.39 \cdot 10^{-2} \quad \text{Dose}_{137\text{Cs}} = 2.39 \cdot 10^{-4} \cdot \frac{1}{\text{yr}} \quad \text{mrem}$$

16. Preferred Alternative Savings and Gains

Preferred alternative = Do CSP, reducing glass and sell material off-site

$$\text{Pref}_{\text{Benefit}} = \text{Less}_{\text{total}} + \text{Sales} \quad \text{Pref}_{\text{Benefit}} = 1.027 \cdot 10^8 \cdot \frac{1}{\text{yr}} \quad \text{Dollars}$$

$$\text{Pref}_{\text{Benefit}} \cdot 10\text{-yr} = 1.027 \cdot 10^9 \quad \text{Dollars} \quad \text{Note: Current Hanford Budget } \sim \$1.6 \text{ Billion/yr}$$

$$\text{Fraction of estimated annual Budget:} \quad \frac{\text{Pref}_{\text{Benefit}} \cdot 1\text{-yr}}{1.6 \cdot 10^9} = 0.064$$

17. Second Preference Savings and Liabilities

Second Preference = Do CSP, do Caustic recycle, calcine and use as ballast in tank closure

$$\text{Pref2}_{\text{Benefit}} = \text{Less}_{\text{total}} + \frac{\text{Less}_{\text{CRtotal}} - \text{Calcine Cost}}{10\text{-yr}} \quad \text{Pref2}_{\text{Benefit}} = 6.317 \cdot 10^7 \cdot \frac{1}{\text{yr}} \quad \text{Dollars}$$

$$\text{Pref2}_{\text{Benefit}} \cdot 10\text{-yr} = 6.317 \cdot 10^8 \quad \text{Dollars}$$

$$\text{Fraction of estimated annual Budget:} \quad \frac{\text{Pref2}_{\text{Benefit}} \cdot 1\text{-yr}}{1.6 \cdot 10^9} = 0.039$$

APPENDIX B: SELECTED DOSE ANALYSES

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Source Terms for Selected Exposure Forms

In order to estimate anticipated doses acquired through two scenarios of agricultural application (fertilizer) and grout filling of Hanford waste tanks, production estimates and source terms are derived and tabulated below. Source terms are based upon Lunsford (1994) with the salt product stream containing 3.7×10^{11} Bq of ^{137}Cs (10 Ci) and 7.3×10^{11} Bq of ^{90}Sr (19.7 Ci) and their daughters. In exposure, the agricultural model is at man height (1.5 m) standing in a field with dose from an infinite plane while the grout model is at man height on ten meters of grout in an infinite slab. Microshield¹ analyses follow.

Salt production estimates are based upon Lunsford (1994) and Slaathaug (1996) [70% of K recovered].

	Molecular Weight			Product Form (Mg)		
	Metal	Nitrate	Carbonate	Metal	Nitrate	Carbonate
Al	26.98	213.00	233.99	3,206	25,309	13,902
K	39.10	101.10	138.21	994	2,570	1,757
Na	22.99	84.99	105.99	73,800	272,843	170,118
Total				78,000	300,722	185,777
^{137}Cs ($\mu\text{Ci}/\text{Mg}$)				128.2	33.3	53.8
^{90}Sr ($\mu\text{Ci}/\text{Mg}$)				252.6	65.5	106.0

Source terms are estimated based upon 50 kg of nitrate distributed per acre while Grout application is estimated based upon a 10% carbonate cement mixture at $2.35 \text{ g}/\text{cm}^3$.

Source Term			
Agriculture	50	kg/Acre =	0.012 kg/m ²
^{137}Cs	33.3	($\mu\text{Ci}/\text{Mg}$) =	4.11 E-08 $\mu\text{Ci}/\text{cm}^2$
^{90}Sr	65.5	($\mu\text{Ci}/\text{Mg}$) =	8.09 E-08 $\mu\text{Ci}/\text{cm}^2$
Grout	2.35	g/cm ³	10% Carbonate
^{137}Cs	53.8	($\mu\text{Ci}/\text{Mg}$) =	1.26 E-05 $\mu\text{Ci}/\text{cm}^3$
^{90}Sr	106.0	($\mu\text{Ci}/\text{Mg}$) =	2.49 E-05 $\mu\text{Ci}/\text{cm}^3$

¹ Microshield is a trademark of Grove Engineering, Inc., Rockville, Md.

Microshield 3.12

(Westinghouse Hanford Company - #197)

Page : 1
 File : CSPGRT1.MSH
 Run date: April 11, 1996
 Run time: 1:46 p.m.

File Ref: CSPAN11.OUT
 Date: 04/11/95
 By: DWH
 Checked: _____

CASE: Clean Salt - Grout Application

GEOMETRY 14: Infinite slab source - slab shields

Distance to detector.....	X	1150.	cm.
Source slab thickness.....	T1	1000.	"
Thickness of second shield.....	T2	150.	"

MATERIAL DENSITIES (g/cc):

Material	Source	Shield 2
-----	-----	-----
Air		.001220
Aluminum		
Carbon		
Concrete	2.350	
Hydrogen		
Iron		
Lead		
Lithium		
Nickel		
Tin		
Titanium		
Tungsten		
Urania		
Uranium		
Water		
Zirconium		

CASE: Clean Salt - Grout Application

BUILDUP FACTOR: based on TAYLOR method.
Using the characteristics of the materials in shield 1.

INTEGRATION PARAMETERS:

None - analytically integrated.

SOURCE NUCLIDES:

Nuclide	Curies	Nuclide	Curies	Nuclide	Curies
Ba-137m	1.1909e-11	Cs-137	1.2589e-11	Sr-90	2.4877e-11
Y-90	2.4880e-11				

RESULTS:

Group #	Energy (MeV)	Activity (photons/sec)	Dose point flux MeV/(sq cm)/sec	Dose rate (mr/hr)
1	.6641	3.965e-01	2.024e+00	4.196e-03
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
TOTALS:		3.965e-01	2.024e+00	4.196e-03

Microshield 3.12
 =====

(Westinghouse Hanford Company - #197)

Page : 1	File Ref: <u>CSPAN11.OUT</u>
File : CSPAGR2.MSH	Date: <u>04/11/95</u>
Run date: April 11, 1996	By: <u>DWH</u>
Run time: 1:46 p.m.	Checked: _____

CASE: Clean Salt - Agricultural Application

GEOMETRY 13: Infinite plane source - slab shields

Distance to detector..... X	150.	cm.
Thickness of first shield..... T1	150.	"

MATERIAL DENSITIES (g/cc):

Material	Shield 1
-----	-----
Air	.001220
Aluminum	
Carbon	
Concrete	
Hydrogen	
Iron	
Lead	
Lithium	
Nickel	
Tin	
Titanium	
Tungsten	
Urania	
Uranium	
Water	
Zirconium	

CASE: Clean Salt - Agricultural Application

BUILDUP FACTOR: based on TAYLOR method.
Using the characteristics of the materials in shield 1.

INTEGRATION PARAMETERS:

None - analytically integrated.

SOURCE NUCLIDES:

Nuclide	Curies	Nuclide	Curies	Nuclide	Curies
Ba-137m	3.8807e-14	Cs-137	4.1023e-14	Sr-90	8.0739e-14
Y-90	8.0726e-14				

RESULTS:

Group #	Energy (MeV)	Activity (photons/sec)	Dose point flux MeV/(sq cm)/sec	Dose rate (mr/hr)
1	.6641	1.292e-03	2.470e-03	5.121e-06
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
TOTALS:		1.292e-03	2.470e-03	5.121e-06

MICROSHIELD BATCH RUN LOG

Batch run started on Thursday, April 11, 1996 at 1:46 p.m.

Two files initially in the queue.

<u>CASE</u>	<u>FILE</u>	<u>START TIME</u>	<u>ELAPSED</u>	<u>GEOM</u>	<u>DOSE (mr/hr)</u>	<u>SENS. CYCLE</u>
1	CSPGRT1	1:46 p.m.	0:00:01	14	4.1964e-03	(n/a)
2	CSPAGR2	1:46 p.m.	0:00:00	13	5.1215e-06	(n/a)

Batch run completed on Thursday, April 11, 1996 at 1:46 p.m.

TOTAL EXECUTION TIME: 0:00:07

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