Conf-941148--6

PNL-SA-24036

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CONSOLIDATION OF NUCLEAR MATERIALS AND HAZARDOUS
CHEMICALS

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November 1994

Presented at the
Environmental Aspects of Decommissioning,
Decontamination, etc.
November 13-17, 1994
Washington, D.C.

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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IMPACTS ON HEALTH AND SAFETY FROM TRANSFER/CONSOLIDATION OF NUCLEAR MATERIALS AND HAZARDOUS CHEMICALS

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ABSTRACT

Environmental restoration plans at the U.S. Department of Energy (USDOE) Hanford Site call for transfer/consolidation of "targets/threats," namely nuclear materials and hazardous chemicals. Reductions in the health and safety hazards will depend on the plans implemented. Pacific Northwest Laboratory (PNL) estimated these potential impacts, assuming implementation of the current reference plan and employing ongoing risk and safety analyses. The results indicated the potential for "significant" reductions in health and safety hazards in the long term (> 25 years) and a potentially "noteworthy" reduction in health hazard in the short term (≤ 25 years).

I. INTRODUCTION

As part of the Hanford Site transition from plutonium production to environmental restoration, PNL evaluated the potential health and safety impacts from transfer/consolidation (T/C) of nuclear materials and hazardous chemicals. This study was performed for the Hanford Security Transition Program Office. In early 1993, studies of various T/C alternatives had already been planned, and some initiated, by the Office. Due to their interrelationship, PNL assessed their impacts through the T/C plans of the "1992/1993 Planning Basis" (92/93PB), as defined in the 1992 *Hanford Mission Plan*,¹ 1992 *Hanford Strategic Analysis Study*,² and 1993 *Hanford Mission Plan, Volume 1*.³

A. Strategies and Options

The 1992 *Hanford Mission Plan* defined three end-states, representing ultimate environmental restoration. These ranged from a minimum (Exclusive Use) to a maximum (Unrestricted Use) degree of environmental restoration. The 200 Areas' Waste Disposal represented an intermediate end-state. The 1992 *Hanford Strategic Analysis Study* referred to these end-states as "strategies"

and identified three "options" for each, ranging from a minimum (Option 1) to a maximum (Option 3) amount of material processing and handling. Option 2 characterized an intermediate effort.

These strategies and options paired into nine scenarios, covering the spectrum from "minimal" to "maximal" environmental restoration. We selected the 92/93PB, equivalent to the 200 Areas' Waste Disposal Strategy with Option 2, for evaluation and the Exclusive Use Strategy with Option 1, the minimum scenario, as the baseline.

B. 1992/1993 Planning Basis

Under the 92/93PB, the following materials presumably will be transferred/consolidated:

- "Cold" uranium (unirradiated reactor fuel)
- "Hot" (spent) fuel (irradiated reactor fuel)
- Special Nuclear Material (SNM)
- Liquid high-level waste (HLW)
- Transuranic waste (TRUW) and TRU mixed waste (TRUMW)
- LLW and low-level mixed waste (LLMW)
- Cesium (Cs)/Strontium (Sr) capsules
- Non-radioactive hazardous waste (hazwaste)

We assumed this will occur in the "short" (up to 25 years) and "long terms" (beyond 25 years), leading to the following T/C plans:

Short Term

- S1. Cold uranium (fuel) at the Uranium Oxide Plant
- S2. Hot fuel (spent) and SNM at the Plutonium Finishing Plant
- S3. Liquid HLW and Cs/Sr Capsules at the Waste Receiving and Processing Facility
- S4. LLW/LLMW and TRUW/TRUMW at the Expanded Central Waste Complex

S5. Non-radioactive hazwaste at the Hazwaste Storage Facility

Long Term

- L1. Cold uranium fuel, hot fuel (spent), SNM, TRUW/TRUMW, Cs/Sr Capsules, and non-radioactive hazwaste offsite
- L2. Liquid HLW (vitrified) and LLW/LLMW at the Expanded Central Waste Complex.

II. HEALTH

Based on the 1992 *Hanford Strategic Analysis Study*, the *Site Safeguards and Security Plan Preparation Guide*,⁴ and the *Hanford Threat Statement*,⁵ we distinguished between "health" and "safety" as follows. "Health" referred to radiological and non-radiological physiological effects on onsite personnel and the offsite public. It was related to the standard concept of risk as employed in facility analyses and generally implied accidental occurrences. "Safety" referred to "saboteur risk," i.e., the product of intrusion frequency; system failure probability; and radiological, industrial, or national security consequence. Generally, it implied intentional occurrences.

A. Radiological Health Hazards

The *Hanford Strategic Analysis Study* developed a "health hazard index" for preliminary screening of "long-term" (i.e., beyond 300 years) radiological health hazards. Since the *Study* "short-term" (i.e., up to 300 years) fully encompassed our analytic time frame, we focused only on these *Study* health hazards. Subsequent use of the terms "short" and "long term" continues to refer to our analytic time frame (i.e., ≤ 25 years and > 25 years). The *Study* based its radiological health hazards on Cs and Sr onsite and tritium offsite. For the 92/93PB, the onsite health hazard index = 0.0551, while the offsite index = $2.91E-5$, ~2,000 times smaller. Thus, we examined only the onsite radiological health hazard.

In the short term, the radiological health hazard should be reduced by T/C plans S2 through S4. In the long term, the radiological health hazard should be further reduced by T/C plans L1 and L2. No contribution was assumed from unirradiated reactor fuel (containing negligible Cs and Sr) or non-radioactive hazwaste. The *Study* estimated a health hazard index of 0.398 for the baseline strategy, approximately seven times higher than that for the 92/93PB (0.0551). These indexes corresponded to the long-term radiological health hazards (i.e., > 25 years).

1. Long Term. Since the *Study* based its onsite health hazard index (HHI) on Cs and Sr, a reasonable estimate of the index for each radioactive material (RM) was:

$$RM\ HHI = (RM\ Cs + Sr) / (Total\ Cs + Sr) \quad (1)$$

Table 1 provides the results, after scaling to the baseline total index (0.398).

Under the long-term T/C plans, only the vitrified Tank Waste and LLW/LLMW will remain onsite. We assumed that the total health hazard index (0.0551, or 0.138 when scaled to 0.398) arose solely from these radioactive materials. Their indexes were 0.704 and 0.00463, respectively. However, we would expect these to be reduced due to enhanced protection (i.e., locating the radioactive materials within individual areas) and disposal form stabilization (i.e., converting the Tank Waste to a vitrified form). To estimate the magnitude of these effects, we assumed that enhanced protection reduces both the Tank Waste and LLW/LLMW indexes by a factor of "P," while disposal form stabilization reduces only the Tank Waste index by a factor of "S." We expressed the total index in the long term as follows:

$$0.138 = 0.704/PS + 0.00463/P \quad (2)$$

We assumed that the effects of disposal form stabilization should exceed those for enhanced protection, i.e., $S \geq P$, and that neither action can increase the radiological health hazard. We solved the equation for the two extremes:

- Reduction only from disposal form stabilization, implying that $P = 1$ and $S \approx 5$.
- Equal reduction from enhanced protection and disposal form stabilization, implying that $P = S \approx 2$.

Based on the *Study* index values, the T/C plans will reduce the long-term radiological health hazard by a factor of ~7 relative to the baseline, mostly from the T/C of the Tank Waste at the Expanded Central Waste Complex.

2. Short Term. To estimate the relative reduction from the short-term T/C plans S2 through S4, we assumed the following:

- All target/threat radioactive materials undergoing T/C from their present locations will receive enhanced protection.
- Those target/threat radioactive materials

undergoing T/C at the Waste Receiving and Processing Facility will have their disposal forms stabilized.

For the radioactive materials subject to enhanced protection only (Irradiated Fuel, LLW/LLMW, and TRUW/TRUMW), the combined health hazard index was 0.0816. For the radioactive materials subject to both effects (Tank Waste and Cs/Sr Capsules), the combined index was 0.918. For the radioactive materials that are not targets/threats (underground tank structures, environmental contamination, and retired facilities), the combined index was 0.000875. Applying the factors "P" and "S" in the short term as in the long, we estimated the health hazard index (HHI) as follows:

$$\text{Short-Term HHI} = \frac{0.0816}{P} + \frac{0.918}{PS} + \frac{0.000875}{PS} \quad (3)$$

With $S \geq P$, as before, P ranged from 1 to ~ 2 while S simultaneously ranged from ~ 5 to 2. Thus, the product PS ranged from ~ 5 to 4. We estimated a short-term health hazard index of ~ 0.27 , which varied little with the assumption extremes. This corresponded to a reduction by a factor of ~ 4 , mostly from T/C plan S3.

B. Chemical Health Hazards

Although the *Study* did not estimate the chemical health hazards, we attempted to estimate the relative reduction in both the short- and long-term. For the long term, the estimate appeared straightforward, since T/C plan L1 calls for all non-radioactive hazwaste (including chemicals) to be transferred offsite. Thus, we concluded that T/C plan L1 will essentially eliminate the long-term chemical health hazard.

The *Study* inventoried the hazardous chemicals associated with target/threat materials as shown in Table 2. In addition, there are $5.28\text{E}+6$ kg of hazardous chemicals associated with the non-target/threat materials. The nuclear material hazardous chemicals ($6.64\text{E}+3$ kg) are currently stored in the Hazwaste Storage Facility. The Tank ($9.24\text{E}+5$ kg) and Solid Waste hazardous chemicals ($3.65\text{E}+6$ kg) are stored at their current locations. Their combined inventory ($4.57\text{E}+6$ kg) comprises approximately half the total inventory ($9.85\text{E}+6$ kg), with the remaining $5.28\text{E}+6$ kg arising from nuclear and non-target/threat material hazardous chemicals.

Under T/C plan S5, the $4.57\text{E}+6$ kg of Tank and Solid Waste hazardous chemicals presumably will be consolidated with the current $6.64\text{E}+3$ kg from nuclear

material at the Hazwaste Storage Facility. As for the target/threat radioactive materials, we expected a reduction in the short-term chemical health hazard from the T/C of the Tank and Solid Waste hazardous chemicals due to enhanced protection from consolidation and separation of potentially volatile chemicals and/or disposal form stabilization.

Analogous to the radiological health hazard, we postulated a chemical health hazard index (the "health hazard equivalent [HHE]"). Assuming a baseline value of 1.00 for total HHE, we apportioned it between the Tank and Solid Waste hazardous chemicals and the remainder as follows:

$$\text{Tank/Solid Waste Short-Term HHE} = \frac{(4.57\text{E}+6 \text{ kg})}{(9.85\text{E}+6 \text{ kg})} = 0.464 \quad (4)$$

$$\text{Remainder Short-Term HHE} = \frac{(5.28\text{E}+6 \text{ kg})}{(9.85\text{E}+6 \text{ kg})} = 0.536 \quad (5)$$

We expressed total short-term HHE as:

$$\text{Short-Term HHE} = 0.464/PS + 0.536 \quad (6)$$

where, as before, we represented the two T/C effects by the factors "P" and "S," respectively.

Based on our previous estimates, we found the product PS , representing the combined effects, ranged from ~ 5 to 4. We estimated a short-term HHE of ~ 0.64 , which varied little with the assumption extremes. This corresponded to a reduction by a factor approaching two, noticeably less than that for short-term radiological health hazard and solely due to T/C of the hazardous chemicals from Tank and Solid Waste at the Hazwaste Storage Facility.

III. SAFETY

From the *Site Safeguards and Security Plan Preparation Guide*, the risk of attack on a target is:

$$\text{Risk} = \frac{\text{Frequency}_{\text{attack}} \cdot \text{Probability}_{\text{failure}}}{\text{Consequence}_{\text{event}}} \quad (7)$$

The *Guide* described each parameter and provided values for the Consequence, with 1.0 as a maximum. For our purposes, we assumed that the T/C plans of the 92/93PB did not affect the Probability (i.e., it remains constant) and estimated values for an "equivalent-risk" measure:

$$\text{Risk/Prob.} = \text{Frequency} \cdot \text{Consequence} \quad (8)$$

A. Adversary Types

The *Guide* identified four categories of attacker: "outsider; active, violent insider; active, non-violent insider; and passive insider." We were concerned with the effect of their possible differences on the Frequency. The *Hanford Threat Statement* identified three types of "adversaries" as potential threats: "insiders, terrorists, and psychotics." Associated with these were "threat levels" of medium, low, and medium, respectively, where the *Statement* defined threat levels as follow:

- Low - Not likely to threaten ...
- Medium - Target has characteristics of the generic threat statement which is a key element of national security.
- High - Likely to occur over some period of time, given that the opportunity frequently exists.

For estimating "conditional risk," the *Guide* sets the Frequency = 1.0, which we assumed to correspond to the *Statement* "high threat level." We assumed that lesser "threat levels" can be assigned Frequency values of 0.1 for "medium" and 0.01 for "low." Additionally, we equated the *Statement* "adversaries" to the *Guide* "attackers" as follow:

- "psychotic" = "active, violent insider"
- "insider" = "active, non-violent insider"
- "terrorist" = "outsider."

For calculation, we combined the first two categories into the "active insider," with an assumed Frequency value of 0.1. This and a Frequency value of 0.01 for the "outsider" were assumed applicable throughout the subsequent estimation.

B. Risk Reduction

As with health, we wished to estimate the relative reduction in risk (actually, equivalent-risk) associated with both the short- and long-term T/C plans. We assumed that non-radioactive hazwaste poses minimal risk from adversary attack relative to nuclear materials. Thus, plan S5 and the non-radioactive hazwaste in plan L1 were not considered. Only T/C plans S1 through S4 could contribute to the risk reduction in the short term. Only plan L2 and the nuclear waste in plan L1 could contribute in the long term.

The calculations to estimate the reduction in equivalent-risk for each T/C plan were similar. For each radioactive material, the Consequence was assigned

a value from the *Guide*. The equivalent-risk was calculated as the sum of the products of this Consequence value and both assumed Frequency values of 0.1 and 0.01. Both "before-T/C" and "after-T/C" risks were estimated, and the reduction calculated as the difference.

The results shown in Table 3 indicated that the short-term reduction (0.0165) was approximately 1/10 of the before-T/C equivalent-risk (0.1606), corresponding to a reduction factor of ~1.1. The long-term reduction (0.1386) corresponded to a decrease by a factor of ~7 relative to this same baseline.

IV. SUMMARY

We assessed the potential health and safety impacts from T/C of nuclear materials and hazardous chemicals, assuming environmental restoration at the Hanford Site under the "1992/1993 Planning Basis." "Health" referred to radiological and non-radiological physiological effects, generally implying accidental occurrences. "Safety" referred to "saboteur risk," generally implying intentional occurrences. These impacts were evaluated relative to a baseline strategy, the minimal environmental restoration.

The results displayed in Table 4 indicated that "significant" reductions could be expected in both health and safety hazards in the "long term" (> 25 years). "Noteworthy" reductions in both the radiological and chemical health hazards could be expected in the "short term" (≤ 25 years). Little reduction could be expected in the safety hazard over the short term.

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TABLE 1. Cesium Plus Strontium Inventory and Corresponding Scaled Health Hazard Index (HHI) for Radioactive Materials

RADIOACTIVE MATERIAL	Cs+Sr (Ci)	SCALED HHI
Hot Fuel (Spent)	3.06E+7	7.60E-2
Cs/Sr Capsules	8.60E+7	2.14E-1
Tank Waste	2.83E+8	7.04E-1
LLW/LLMW	1.86E+6	4.63E-3
TRUW/TRUMW	4.28E+5	1.06E-3
Underground Tank Structures	2.51E+5	6.24E-4
Contaminated Soil, Groundwater, etc.	8.71E+4	2.17E-4
Retired Facilities	1.35E+4	3.36E-5
TOTAL	4.02E+8	1.00E+0

TABLE 2. Hazardous Chemical Inventory for Target/Threat Materials

HAZARDOUS CHEMICALS (4.58E+6 kg)	Nuclear Material Hazardous Chemicals (6.64E+3 kg)	Hot Fuel (Spent) Hazardous Chemicals	1.94E+3 kg
		SNM Hazardous Chemicals	8.45E+2 kg
		Cold Uranium Hazardous Chemicals	3.74E+3 kg
		Cs/Sr Capsule Hazardous Chemicals	1.10E+2 kg
	Tank Waste Hazardous Chemicals (9.24E+5 kg)	Single-Shell Tank Waste Hazardous Chemicals	4.94E+5 kg
		Double-Shell Tank Waste Hazardous Chemicals	4.30E+5 kg
	Buried Solid Waste Hazardous Chemicals (3.64E+6 kg)	Waste-Disposal-Site-Buried (WDSB) Solid Waste Hazardous Chemicals	1.43E+6 kg
		Non-WDSB Solid Waste Hazardous Chemicals	2.21E+6 kg
	Not-Buried Solid Waste Hazardous Chemicals		8.53E+3 kg

TABLE 3. Reduction in Equivalent-Risk from Short- and Long-Term Transfer/Consolidation (T/C) Plans

TIME FRAME	T/C PLAN	RADIOACTIVE MATERIAL	CONSEQUENCE VALUE	EQUIVALENT-RISK		
				Before-T/C	After-T/C	Reduction
SHORT TERM	S1	Cold Uranium	0.5	0.055	0.055	0
	S2	SNM	0.5	0.055	0.055	0
		Hot Fuel (Spent)	0.05	0.0055	0	0.0055
		Total		0.0605	0.055	0.0055
	S3	Tank Waste	0.2	0.022	0.022	0
		Cs/Sr Capsules	0.1	0.011	0	0.011
		Total		0.033	0.022	0.011
	S4	TRUW/TRUMW	0.1	0.011	0.011	0
		LLW/LLMW	0.01	0.0011	0.0011	0
		Total		0.0121	0.0121	0
	ALL			0.1606	0.1441	0.0165
LONG TERM	L1	Cold Uranium	0.5	0.055	0	0.055
		Hot Fuel (Spent)	0.05	0.0055	0	0.0055
		SNM	0.5	0.055	0	0.055
		Cs/Sr Capsules	0.1	0.011	0	0.011
		TRUW/TRUMW	0.1	0.011	0	0.011
		Total		0.1375	0	0.1375
	L2	Tank Waste	0.2	0.022	0.022	0
		LLW/LLMW	0.01	0.0011	0	0.0011
		Total		0.0231	0.022	0.0011
	ALL			0.1606	0.022	0.1386

TABLE 4. Approximate Reduction Factors Following Implementation of Short- and Long-Term T/C Plans

HAZARD		REDUCTION FACTOR	
		Short Term	Long Term
HEALTH (Onsite Physiological Effects)	Radiological	4	7
	Chemical	2	∞
SAFETY (Saboteur Risk)		1.1	7