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ANALYSIS OF ENVIRONMENTAL EFFECTS FROM DISPOSAL OF SOLIDIFIED ICPP HIGH-LEVEL WASTES

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INTRODUCTION

The reprocessing of nuclear fuel from national defense programs has been ongoing for more than thirty years. The Idaho Chemical Processing Plant (ICPP) was constructed in 1949 to reprocess fuels clad in aluminum. Since that time modifications have been made to handle zirconium fuels, stainless steel fuels, and, by 1980 graphite fuels. A new fuel dissolution facility is now being constructed to process a zirconium-alloy high-burnup fuel. These dissolution processes generate highly radioactive, acidic liquid wastes that are stored in underground stainless steel tanks for an interim period before solidification by fluidized bed calcination. The solids produced from this process, called calcine, are placed in stainless steel bins within underground reinforced concrete vaults, called the Calcine Solids Storage Facilities (CSSF). The CSSF have an estimated life of greater than 500 years. This method of handling nuclear waste has proven to be both safe and cost effective. To date, 1700 m^3 (59,000 ft^3) of calcine have been stored in this manner. By 2020 (the end of the environmental analysis period), 16,000 m^3 (560,000 ft^3) of calcine will have been produced.

We agree with statements in the Report to the President by the Interagency Review Group on Nuclear Waste Management[1] recognizing that members of the public and industry feel a sense of urgency to achieve progress in the management of nuclear waste but that this urgency cannot be ascribed to any imminent public danger. However, as required by the National Environmental Policy Act (NEPA), environmental factors must be considered along with economic and technical factors in federal agency planning and decision making. Agencies must prepare environmental impact statements (EIS) as input for decisions on all federal actions that may significantly affect the environment. The Department of Energy (DOE) proposed guidelines for implementation of the Council on Environmental Quality (CEQ) regulations require that an EIS be prepared for each major nuclear waste management decision.

The work described here is an abbreviated version of a much more comprehensive study done by a DOE contractor to assess possible environmental impacts from different techniques for high-level defense wastes generated at the ICPP. Only radiological consequences are reported here. This and other work will be used in the preparation of an EIS. This evaluation represents effort by a DOE contractor and is not intended nor designed to establish a DOE position for waste management. However, some potential alternatives and their calculated impacts are presented and may be compared.

Many scenarios for nuclear waste management can be advanced; however, the preferred options for the ICPP waste fall into these general categories:

(1) Continue current operations

(2) Modify the waste form and dispose at the Idaho National Engineering Laboratory (INEL)

(3) Modify the waste form and dispose at an off-site federal repository

(4) Remove actinides from the waste, dispose of the actinide-depleted waste at the INEL, and dispose of the actinide waste at an off-site federal repository.

Based on the availability of technology in the required time frame (by 1982), certain waste forms were selected for analyses. The specific waste forms are calcine, stabilized calcine, pelletized calcine, vitrified calcine, and actinide-depleted calcine coupled with actinide glass.

Six candidate options were selected by evaluating 13 alternatives studied earlier and presented in ERDA 77-43.[2] Other alternatives not reported in ERDA 77-43 were examined and were considered less desirable or judged to be unavailable in the necessary time frame. The candidate long-range waste management options developed are:

Option 1: Continue current operations, which is disposal of calcine in the CSSF at the INEL.

Option 2: Convert the calcine to pellets and dispose of the pellets at the INEL.

Option 3: Convert the calcine to glass and dispose of glass at the INEL.

Option 4: Remove actinides from the wastes, convert the actinides to glass, dispose of glass at an off-site federal repository and dispose of actinide-depleted waste at the INEL.

Option 5: Stabilize the calcine by removing remaining nitrates and water, and dispose of calcine at an off-site federal repository.

Option 6: Convert the calcine to a glass and dispose of the glass at an off-site federal repository.

One variation to the above options could greatly enhance long-term characteristics of disposed waste. In Option 4, instead of converting the actinides into a glass, the actinides could be fissioned in a high neutron energy reactor. The fission process would produce power and at the same time fission the long-half-life actinides. Recent calcinations[3] on actinide burnup made at the University of Arizona indicate that the neutronics are quite favorable.

These six options were analyzed to estimate possible individual and population exposures if any one of them were implemented. The exposures were calculated for incremental time periods extending to 100 million years after processing.

METHODOLOGY

The options were examined for potential scenarios that might result in pathways to man. The basic scenarios were:

(1) Operational releases, either routine or accidental.

(2) Migration, such as leaching of isotopes from the disposed waste to a water source and subsequent use of the water.

(3) Intrusion into the waste, such as by an archaeologist or other person(s).

The scenarios of the pathways to man are illustrated in Figure 1.

For the computed doses to individuals, the methodology and parameters contained in Regulatory Guide 1.109 were used.[4] The estimates were made for adults only because refinement among age groups was not warranted primarily due to the comparative nature of the study. The doses calculated were 50-year dose commitments from exposures received during one year. To account for pathways where radioactivity may build up during interim storage, the doses were estimated for the last year of ICPP operation. Doses were calculated for each option, for each pathway, and for time periods extending out to 100 million years. Decay schemes and chronologically ambient isotopic inventories were used in all computations.

As part of this evaluation, estimates were made on population doses to those within 80 km (50 mi) of the ICPP. For some scenarios, the appropriate calculated values apply to doses for only a limited number of people and will not apply to widespread population exposures. Further, some of the scenarios could result in smaller doses to a large number of people. In the calculations of population doses by these modes, population distribution was taken into account. Where the maximum individual receptor is close to the point of discharge of an airborne release, the average dose to individuals within 80 km (50 mi) can be reasonably approximated by using a value of one percent of the maximum individual dose. A more rigorous treatment (not justified in these computations) requires the matching of site meteorology and population distribution. Table 1 shows the modes of population exposure that were considered for each pathway. For those exposure modes that result only in doses to individuals, assumptions were made as to the number of individuals involved to estimate the size of the population for the pathway and time period. Additional assumptions needed to carry out these calculations are shown in Table 2.

TABLE 1

MODES OF POPULATION EXPOSURE

Pathway	Individuals	Population Groups	Workers
	Results in Exposure to		
Operational Releases:			
Routine operations		X	
Spillage of calcine		X	
Decontamination spills		X	
Fire		X	
Transport to repository	X	X	X
Occupational exposure			X
Migrational Losses:			
Leaching into groundwater		X	
Radon emanation from bin	X		
Intrusions:			
Airplane accident		X	
Individual intruder			
Inhalation	X		
Direct Exposure	X		
Contaminated ground			
Food	X		
External exposure	X		
Radon	X		

TABLE 2

ASSUMPTIONS USED TO CALCULATE POPULATION DOSES DUE TO EXPOSURE OF INDIVIDUALS

Pathway	No. of Individuals Involved	Events Per Year
Groundwater	5	0.01
Intrusion	10	0.01
Food	5	0.0001
External radiation	5	0.0001
Radon - Bin	5	0.01
Radon - Soil	5	0.00001

The extrapolation of population and utilization of area-wide meteorology presented some difficulty for application to the scenarios. The population was scaled up linearly by a factor of five over the next 150 years and was assumed to be constant thereafter. Since the source terms were particulates, depleted dispersion factors were used. A deposition velocity of 0.01 m/s (0.03 ft/sec) was utilized to determine deposition of particulates. No releases from a geologic repository were considered for those options (4, 5, 6) that dispose all or part of the waste in such a repository. Therefore, the population doses from these options are unrealistically low. Calculations for repository release pathways are not being done based on the release scenarios contained in the Draft EIS, "Management of Commercially Generated Radioactive Waste".[5]

SOURCE TERMS

Worst-Case source terms for the calculations were determined by considering the inventories of all important isotopes in the wastes and allowing decay and in-growth of daughter products. These included solid and liquid wastes to be calcined through the year 2020. At the base year of 2020 the total quantity of wastes is 2 x 10^7 kg (4 x 10^{716}) calcine (or equivalent if in another waste farm). The concentrations of radionuclides used in all these calculations are shown in Table 3.

TABLE 3

INITIAL RADIONUCLIDE CONCENTRATIONS OF INPUT SOLIDS WASTES,[3] ALL OPTIONS

Nuclide	Activity (Ci/kg)	Nuclide	Activity (Ci/kg)	Nuclide	Activity (Ci/kg)
^{79}Se	6.4E-05*	^{87}Rb	3.6E-09	^{90}Sr	1.3E+01
^{90}Y	1.3E+01	^{93}Zr	3.1E-04	^{93m}Nb	7.5E-05
^{99}Tc	2.1E-03	^{106}Ru	9.7E-01	^{106}Rh	9.7E-01
^{107}Pd	2.0E-06	^{126}Sn	3.2E-05	^{126m}Sb	3.2E-05
^{126}Sb	3.2E-05	^{134}Cs	3.3	^{135}Cs	7.5E-05
^{137}Cs	1.3E+01	^{137m}Ba	1.2E+01	^{144}Ce	8.2
^{144}Pr	8.2	^{144}Nd	0.0	^{147}Pm	1.2E+01
^{147}Sm	0.0	^{151}Sm	1.7E-01	^{154}Eu	1.8E-01
^{226}Ra	0.0	^{230}Th	0.0	^{233}Pa	0.0
^{233}U	1.2E-12	^{234}U	4.3E-10	^{235}U	1.8E-09
^{236}U	1.0E-08	^{237}U	4.8E-12	^{238}U	1.0E-14
^{237}Np	4.8E-08	^{239}Np	0.0	^{238}Pu	7.0E-02
^{239}Pu	7.0E-04	^{240}Pu	6.5E-04	^{241}Pu	1.6E-01
^{242}Pu	1.8E-06	^{241}Am	9.8E-04	^{243}Am	8.3E-06
^{242}Cm	6.5E-04	^{244}Cm	5.2E-04		
Total	8.5E+01				

*6.4E-05 = 6.4×10^{-5} = 0.000064

A computer code was utilized to calculate concentrations as a function of time. The WALTS[6] code accumulates and decays all of the parent radionuclides, allows for the in-growth of daughter products, and for each time period of interest gives the total quantity (curies) and concentration (μCi/kg of calcine) or equivalent for each nuclide. The code also gives the average quantity and concentration integrated over that time period. It is the latter set of values that is used in making calculations for any particular time period.

As a matter of practical interest, when an existing radioactive nuclide (parent) decays, it frequently produces one or more subsequent nuclides (daughters) that are themselves radioactive. Some of these radioactive daughters are more toxic than their parents. Thus, in determining the inventories of radionuclides as a function of time, it is necessary to consider the buildup (and decay) of the daughter products.

PATHWAYS

Evaluations were made for the most conceivable types of releases from the facility. Operational releases, migrational losses, and intrusional modes were considered. The parameters used were based on actual operational experience, Regulatory Guide 1.109, reported soild data, and other applicable references. These references and the details of the calculations can be found in Appendices B and C of the Environmental Impact Analysis (base document) ACI-375.[7]

For operational releases, the following pathways were examined:

(1)	Routine releases	(4)	Fire in cell
(2)	Spillage of calcine	(5)	Occupational exposure
(3)	Decontamination spills	(6)	Transportation to repository

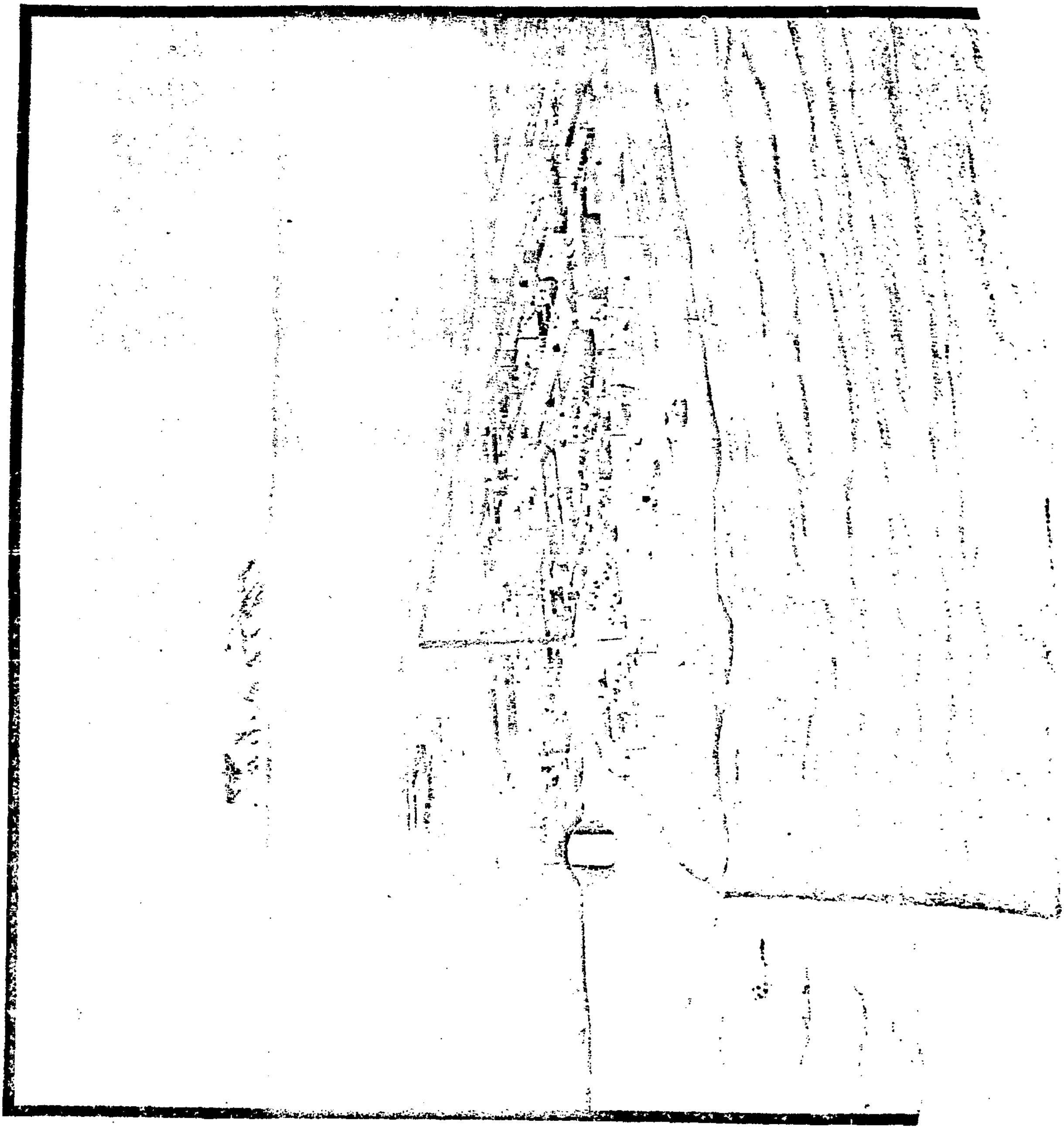
It should be remembered that in all cases evaluated, the starting point was calcined in the CSSF.

Migrational losses considered were:

(1) Goundwater migration
(2) Radon Emanation

In examining potential effects of losses due to groundwater migration, it was assumed that the CSSF will have deteriorated to the extent that incident rainwater could enter the bins and come in contact with the stored waste. The vertical distance to the aquifer at the ICPP is about 140 m (450 ft). From logs of well drilling near the ICPP, there are several layers of lava, totaling approximately 105 to 120 m (300 to 400 ft) and about 15 m (50 ft) of soil. For calculational puposes, a depth of 15 m (50 ft) of soil was considered for ion exchange capability. A cutaway of the site location is shown in Figure 2. More details of the assumptions and calculations are in the base document noted previously.

In the evaluation of radon emanation, it was assumed that sometime in the future, homes are built directly over the buried CSSF



without knowledge of the CSSFs presence. An additional assumption was that if a home were built on soil that has elevated concentrations of radon coming from it, the gas would be kept inside the dwelling long enough to allow daughter products of radon to build up, resulting in increased lung doses.

Intrusional modes included:

(1) Airplane accident
(2) Physical intrusion

The airplane accident was postulated to occur prior to the year 2100. The rationale behind this assumption was that prior to 2100 A.D., decay heat from the stored waste precluded entombment of the bins in concrete. Further, no additional precautions were made to protect the bins by placing a berm around the shielding housing the distribution system of the bins. Penetration of the bins due to impact was assumed to perpetrate the calcine release. The discussed event is only of significant consequence while the waste is calcine prior to encasement or conversion to other, less dispersible solid forms.

For evaluation of wastes residing for a long period of time near the surface, it must be assumed that intrusion would occur. This could be a well driller, an archeologist, a prospector, or simply someone who is curious. Once the intruder violates the storage complex, he would be exposed to radiation in two ways: receipt of direct penetrating radiation and inhalation of dust that would contain radioactivity. Both potential exposure pathways were evaluated.

After a physical intrusion has occurred, it is likely that some of the waste will have been brought to the surface as a result of that intrusion. Subsequent residents might then be exposed to this surface contamination in at least three ways: growing food in the contaminated soil and consumption of that food by the resident, direct exposure to pentrating radiation from the ground-plane contamination, and exposure to radon daughters in a home built on the contaminated land.

TIME PERIODS

For those cases where occupational exposures were calculated, the time period was from inception of the activity until it was completed, i.e., for most cases, up to 2020 A.D. The airplane accident scenario was assumed to be operating until 2100 A.D., at which time the entombment of the bins was completed.

The time periods examined for all other scenarios ended at 1,000, 2,000, 5,000, 10,000, 20,000, 50,000, 100,000, 200,000, 500,000, 1 million, 2 million, 5 million, 10 million, 20 million, 50 million and 100 million years after 2100.

There has been considerable discussion about the length of time institutional control could be assumed. Since the mode of storage is near surface an arbitrary time of 500 years was used as a combination of institutional control and memory of recorded history. The stainless steel bins and the encasement concrete were assumed to break down and potentially allow migrational effects to commence in 500 years.

Note that in these evaluations there were no particular attempts to ameliorate consequences. With relatively little effort, it is conceivable to be able to reduce the calculated doses.

RESULTS

In this report, possible environmental impacts are evaluated and compared to Option 1, the "no action" or "continue current operations" alternative.

The current high-level waste (HLW) management procedure at the ICPP is to convert high-level liquid wastes (HLLW) to calcine in a fludized-bed calciner. The calcine is stored in the CSSF at the ICPP.

If this option is implemented and the CSSF become the disposal site, improved in-place isolation will be provided by filling the interstitial voids between the CSSF bins and vaults with concrete. This action will be taken after the decay heat of the calcine diminishes (50 to 75 years after production).

The radiological impact of producing calcine has already been analyzed and presented in other environmental statements.[8,9] However, these statements did not cover the radiological impact of disposal in the CSSF.

Two migrational pathways, radon emanation from the vaults and groundwater migration, apply to Option 1. Maximum individual doses of 2300 and 1900 mrem would result from these pathways, repectively. The intrusional scenarios that apply to Option 1 include airplane crash, physical intrusion (inhalation and direct exposure), and exposure to activity removed from the bins by an intruder (direct radiation, food, and radon). The airplane crash results in a maximum individual dose of 100,000 mrem; other pathways result in 2000 to 4200 mrem doses to an individual (see Table 4). For the long term (1 million years), the largest population dose comes from the groundwater pathway; for shorter time periods, the intrusional pathway contributes most to the population dose. In no case does the population dose approach the dose from natural background radiation. Over any time period, the largest total impact is only 0.0046 percent of the total dose to the population due to background radiation.

Table 4

MAJOR RADIOLOGICAL CONSEQUENCES OF OPTION 1

Significant Release Pathways	Maximum Event Consequence (mrem/event)	Population Dose (manrem) 1000 yr	Population Dose (manrem) 1 million yr
Migrational Releases	1900 to 2300	2.2	290,000
Intrusional Releases			
Airplane Accident	100,000	2.3	2.3
Inhalation-Direct Radiation ~~meteorite~~[a]	3700 to 4200	400	79,000
[illegible]	[illegible]	[illegible]	[illegible]

~~[a] The probability of this event, 6×10^{-13}/y, is so low that this event is considered to be incredible. It is included for illustrative pruposes only.~~

Population doses are not significant when compared to nature background over the same time frames. High exposures conceivably could occur to a few individuals if the low probability airplane accident were to occur.

In the second option, calcine is mixed with a binder and heated to form pellets about 3 - 6 mm (1/8 - 1/4 in.) in diameter. These pellets are less despersible and more leach-resistant than the calcine, and will be disposed of at the ICPP in the CSSF or a similar facility.

The impact of converting calcine to ceramic pellets is a beneficial increase in the long-term margin of safety against release of radioactivity. This is caused by the greater leach resistance, lower dispersibility, and lower radionuclide concentration of the pellets. This benefit is partially offset by near-term operational exposures.

Possible pathways for radioactivity to reach the environment are: operational releases, migrational losses, and instrusional releases. Maximum doses to individuals and the population have been calculated and are summarized in Table 5. Occupational exposures (3000 mrem) and an airplane accident (100,000 mrem) cause the highest individual exposures.

Table 5

MAJOR RADIOLOGICAL CONSEQUENCES OF OPTION 2

Significant Release Pathways	Maximum Event Consequence (mrem/event)	Population Dose (manrem)	
		1000 yr	1 million yr
Operational Releases			
Occupational Exposures	3000	800	800
Migrational Releases			
Groundwater	180	.015	27,000
Radon	1600	.015	470
Intrusional Releases			
Airplane	100,000	0.24	0.24
Direct Radiation	2900	150	53,000
Contaminated Soil	4500	0.7	1600
Meteorite impact[a]			

[a] The probability of this event, 6×10^{-13}/yr, is so low that this event is considered to be incredible. It is included for illustrative purposes only.

Occupational exposure accounts for the largest part of the population dose in the short term. However, after 10,000 years, intrusion into the disposal facility becomes the primary mode of exposure. Pelletization, when compared with calcination, decreases the long-term exposure due to groundwater contamination by a factor of 10. The population dose during the first 1,000 years after Option 2 is initiated is only 0.00099 percent of the dose due to natural background radiation. Implementation of this option will not result in significant exposures to the public. A small number of individuals would receive high radiation doses if the low-probability airplane accident were to occur.

In the third option, calcine is vitrified and disposed of at the INEL in an engineered facility. The glass is less dispersible and more leach resistant than either calcine or pellets.

The impact of vitrifying calcine is a beneficial increase in the long-term margin of safety against release of radioactivity, resulting from the greater leach and dispersion resistance of the glass waste form. This benefit is partially offset by the near-term operational exposures.

Possible pathways for radioactivity to reach the environment are: operational releases, migrational losses, and intrusional releases. Maximum doses to individuals and the population have been calculated and are presented in Table 6. Individual doses result primarily from occupational exposures (3,000 mrem) and an airplane accident (100,000 mrem).

Occupational exposures account for virtually all of the radiological impacts to the population for the first ten thousand years. After one million years the glass is assumed to revert to calcine. At that time, releases due to migration and intrusion increase, but the increases are insignificant. The total exposure during the first one thousand years is only 0.0013 percent of the dose from natural background radiation during the same time frame.

The population doses from implementation of this option are low. Significant individual exposures occur only to a small number of people if the low-probability airplane accident should occur.

In Option 4, actinides are removed from the HLW and shipped to a federal repository for disposal. This requires that the existing calcine be dissolved, processed, from actinide removal, and recalcined. Newly generated HLLW would be processed for actinide removal before calcination. The removed actinides would be vitrified and disposed of at an off-site federal repository. The actinide-depleted waste would be calcined and disposed of in the CSSF at the ICPP.

Table 6

MAJOR RADIOLOGICAL CONSEQUENCES OF OPTION 3

Significant Release Pathways	Maximum Event Consequence (mrem/event)	Population Dose (manrem)	
		1000 yr	1 million yr
Operational Releases			
Occupational Exposure	3000	1300	1300
Migrational Releases	100	.13	8600
Intrusional Releases			
Airplane Accident	100,000	0.046	0.046
Contaminated Soil	4500	0.72	~~1060~~ 1100
~~Meteorite~~[a]			

[a] The probability of this event, 6×10^{-13}/yr, is so low that this event is considered to be incredible. It is included for illustrative purposes only.

The effect of removing actinides from calcine is a beneficial increase in the long-term margin of safety against release of radioactivity. However, this long-term gain is offset by short-term occupational exposure. The largest individual dose (180,000 mrem) occurs as a result of an accident during transportation of actinides to the federal repository.

Occupational exposures account for most of the radiological impact to the general population over the first one thousand years. However, after long time periods, the proportion of the population dose due to intrusion into the disposal facility increases. For one thousand years, the population dose associated with this option 0.0022 percent of the dose from natural background radiation for that time period. Individual and population doses are summarized in Table 7. As shown in the table, no significant population exposures will occur from this option. Individual doses will be to only a limited number of people and are significant only for certain low-probability accidents, such as the airplane and transportation accidents.

In Option 5, calcine stabilization, small quantities of nitrates and moisture normally present in calcine are removed by heat treatment. Removing these materials from the calcine prevents pressure buildup in the sealed disposal canisters due to water and nitrates

Table 7

MAJOR RADIOLOGICAL CONSEQUENCES OF OPTION 4

Significant Release Pathways	Maximum Event Consequence (mrem/event)	Population Dose (manrem)	
		1000 yr	1 million yr
Operational Releases			
Transport	180,000	300	300
Occupational Exposure	3000	1700	1700
Migrational Releases	50	2.2	200
Intrusional Releases			
Airplane Accident	100,000	2.1	2.1
Direct Radiation	3200	160	69,000
Contaminated Soil	4500	1.1	440
Repository			
~~Meteorite[a]~~			

~~[a] The probability of this event, 6×10^{-13}/yr, is so low that this event is considered incredible. It is included for illustrative purposes only.~~

decomposing in high-temperature and radiation fields. The stabilized calcine retains all other charcteristics of the original calcine.

The impact of stabilizing calcine is a beneficial increase in the long-term margin of safety against release of radioactivity resulting from disposal in a geologic repository. This is partially offset by the increased occupational exposure incurred during waste processing. Occupational exposures account for most of the population dose during the first one thousand years. Transporting the stabilized calcine in an off-site repository accounts for the remainder of the population dose 230 mrem). For 1000 years, the population dose associated with this option is only 0.0012% of the dose from natural background radiation for the same time period. Individual and population doses are summarized in Table 8. No significant exposures to the population will occur from implementing this option. High individual exposures are limited to a small number of people and occur from implementing this option. High individual exposures are limited to a small number of people and occur only for a few low-probability accidents such as airplane and transportation accidents.

In Option 6, calcine is vitrified and transported to an off-site federal repository for disposal. The vitrified calcine is identical to that glass described in Option 3, but the disposal location is now an off-site federal repository.

Significant Release Pathways	Maximum Event Consequence (mrem/event)	Population Dose (manrem)	
		1000 yr	1 million yr
Operational Releases			
Transport	21,000	230	230
Occupational Exposure	3000	1000	1000
Intrusional Releases			
Airplane Accident	100,000	0.046	0.046
Repository Releases			
~~Meteorite~~[a]			

~~[a] The probability of this event, 6×10^{-13}/yr, is so low that this event is considered incredible. It is included for illustrative purposes only.~~

The impact of vitrifying calcine and shipping it to a federal repository is a beneficial increase in the long-term margin of safety against the release of radioactivity. This is caused by the greater leach resistance, lower dispersibility, lower radionuclide concentration in the glass, and disposal in a geologic repository. This benefit is partially offset by near-term operational and transportation risk arising during processing and shipping the waste to the repository.

Major pathways to the individual include doses from an airplane or transportation accident (100,000 and 1200 mrem, respectively). Workers at the facility also will receive a maximum of 3000 mrem/yr during the length of the project as an occupational exposure.

Population doses are domianted by occupaional exposure (1200 man-rem) and an accident during transport (300 man-rem). Population doses are 0.0015 percent of the dose received from background radiation during the first one thousand years. Population exposures from implementing this option are minor; any major indivdual exposures will occur only for a few individuals if a low-probability accidents such as airplane crash or transport accident occurs. Individual and population doses are summarized in Table 9.

The scenarios leading to the largest and second largest individual doses, their numerical values, and time periods when they could

Table 9

MAJOR RADIOLOGICAL CONSEQUENCES
OF OPTION 6

Significant Release Pathways	Maximum Event Consequence (mrem/event)	Population Dose (manrem)	
		1000 yr	1 million yr
Operational Releases			
Transport	1200	300	300
Occupational Exposure	3000	1200	1200
Intrusional Releases			
Airplane Accident	100,000	0.046	0.046
~~Repository Releases~~			

occur are summarized in Table 10. For all options except Option 4, the maximum individual dose is 100,000 mrem from the airplane crash. The maximum individual dose for Option 4, 180,000 mrem from an accident during transportation of actinides to an off-site repository. The probabilities of these accidents actually occurring are very low: from 50×10^{-9} to 100×10^{-9} per year for the airplane accident and 27×10^{12} per rail-car km for the transportation accident.

Total population doses over the four time periods are summarized in Table 11 for each option. Natural background radiation to the population during the four time periods is also presented. The total population doses result in incremental additions to the background radiation of only 100×10^{-9} to 0.002 percent over the entire period of analysis. The population doses from each option are compared with the dose from Option 1 in Table 12 and Figure 3 over the four time periods. For the 1,000-year periods, all five options result in population doses higher than those from Option 1 by factors ranging from 2.5 for option 2 to 5.5 for Option 4. For the 10,000-year period, doses from Option 4 are still 1.1 times higher than those from Option 1, while other options result in doses lower than for Option 1. Over longer time periods, all options result in population doses lower than for Option 1 by factors ranging from 3 to 330. Again, however, no possible releases were assumed once the waste is placed in a geologic repository (Options 4, 5, 6).

Table 10

Summary of Highest Maximum Individual Doses

Option	Highest Event Consequence			Second Highest Event Consequence		
	Dose (mrem)	Pathway	Time Period	Dose (mrem)	Pathway	Time Period
Calcine	100,000	Airplane Accident	1980 – 2100	4200	Inhalation by Intruder	2100 – 3100
Pellets	100,000	Airplane Accident	1980 – 2100	2900	Radiation from Contaminated Soil	2100 – 3100
Glass	100,000	Airplane Accident	1980 – 2000	2800	Radiation from Contaminated Soil	2100 – 3100
Actinide Removal	180,000	Transportation Accident	1990 – 2000	100,000	Airplane Accident	1980 – 1990
Stabilized Calcine	100,000	Airplane Accident	1980 – 2000	91,000	Transportation Accident	1990 – 2000
Glass Off-Site	100,000	Airplane Accident	1980 – 2000	1200	Transportation Accident	1990 – 2000

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Table 11

~~TABLE 3-22~~

SUMMARY OF TOTAL POPULATION DOSES[a] RISKS (MANREM)

Time Period (Years from 2100 A.D.)	Option 1	Option 2	Option 3	Option 4[a]	Option 5[a]	Option 6[a]	Natural Background[b]
1,000 yr	400	980	1300	2200	1200	1600	100×10^6
10,000 yr	4600	3100	1500	4900	1200	1600	1.0×10^9
1 million yr	370,000	86,000	15,000	72,000	1200	1600	100×10^9
100 million yr	410,000	120,000	20,000	110,000	1200	1600	1.0×10^{12}

~~a) Does not include any potential release form disposal at an offsite Federal repository.~~

a. b) 700,00 persons at a dose of 0.15 rem/yr calculated for the appropriate time period. (10-million-yr period) was used for the longest period, because very little of the above doses occur after 10 million yr).

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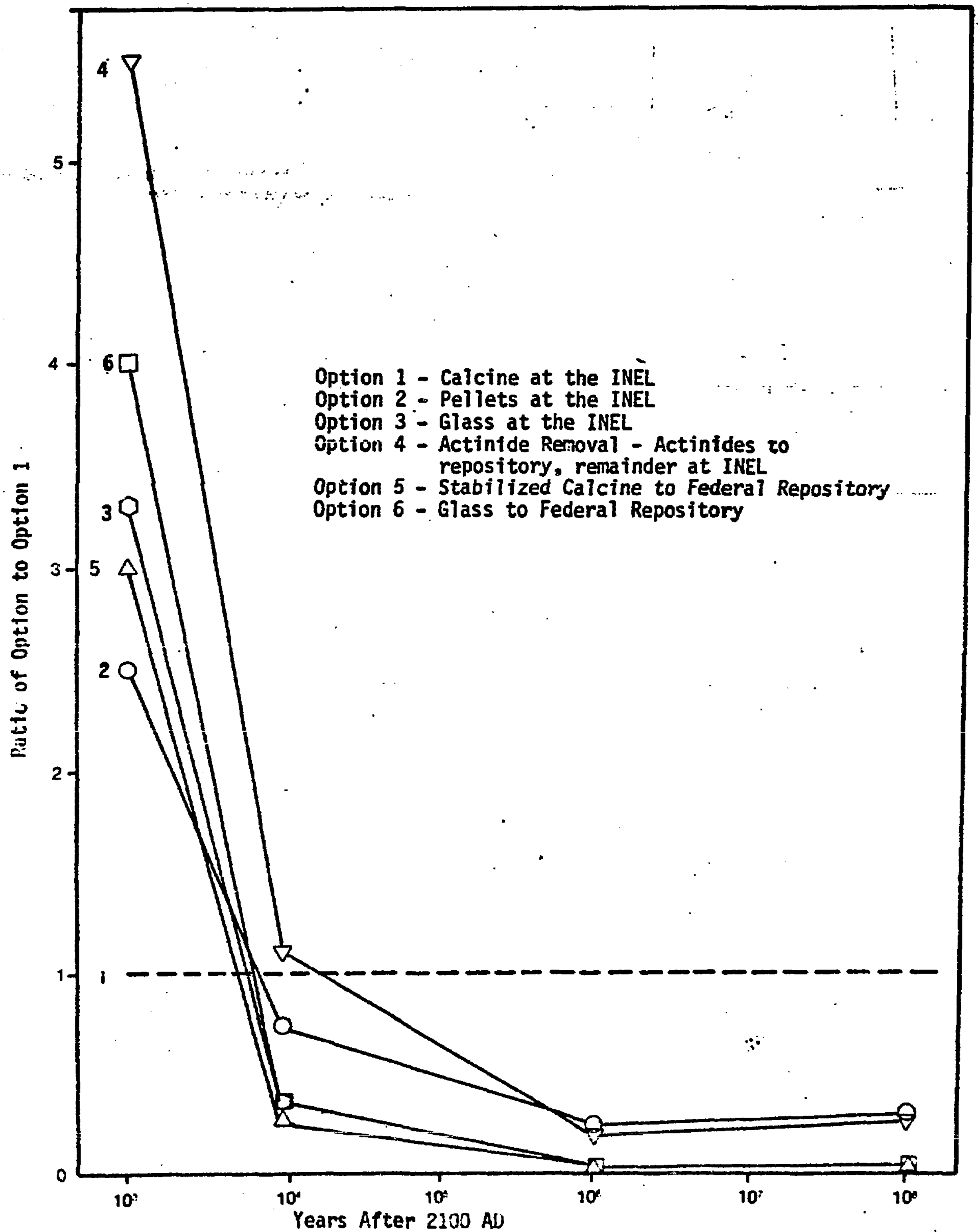
~~TABLE 3-10~~ 9 Table 12

COMPARISON OF POPULATION DOSES

Ratio of Population Doses for each Option to Option 1 for the Total Time Periods of:

Option	*1,000 Yr*	*10,000 Yr*	*1 Million Yr*	*10 Million Yr*
2	2.5	0.74	0.23	0.29
3	3.3	0.33	0.04	0.05
4	5.5	1.1	0.19	0.27
5	3.0	0.26	0.003	0.003
6	4.0	0.35	0.004	0.004

Revise Numbers



Option 1 - Calcine at the INEL
Option 2 - Pellets at the INEL
Option 3 - Glass at the INEL
Option 4 - Actinide Removal - Actinides to repository, remainder at INEL
Option 5 - Stabilized Calcine to Federal Repository
Option 6 - Glass to Federal Repository
Ratio of Option to Option 1
Years After 2100 AD

Figure 3 shows that the population dose received if any of Options 2 - 6 are implemented exceeds the population does currently being received in Option 1 until a relatively long period of time elapses. As the time period lengthens, the implentation of any of Options 2 - 6 would result in a net reduction of exposure because the long-term isolation of the waste is enhanced by altering its form or disposal location. Implementation of an option other than Option 1 requires an "expenditure" of population dose now to achieve probables lower than long-term population doses.

Risks and quantifiable environmental impacts are shown in Table 13 through 16. The tables are divided into three sections to show:

(a) The potential dose to future generations; this dose occurs because of exposure to the general population caused by intrusion into the disposal area or migration of radio- activity from the disposal area.

(b) The occupational radiation doses, potential population doses, potential occupational (non-nuclear-related) lost-time accidents and fatalities that are incurred during construction and the near-term processing period. These radiation doses are caused by such things as routine or accidental releases during process operation or waste shipment.

(c) A summary of the dollar investment required for each man-rem reduction in dose for future generations; this shows

TABLE ~~[illegible]~~ 13

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER [illegible]000 YEARS[a]

	Disposal at INEL			Disposal at Federal Offsite Repository			
	Option 1 Calcine in [illegible]	Option 2 Pellets in [illegible]	Option 3 Glass in [illegible] storage	Option 4 Calcine in [illegible]	Option 4 Actinide Glass in Canisters	Option 5 Stabilized Calcine in Canisters	Option 6 Glass in Canisters
Potential Impacts to Future Generations[a]:							
Population Dose, risk Manrem	400	170	12	160		0.046	0.046
Change from Option 1 Reference Case, Manrem	Reference	-230	-388	-240		-400	-400
Population Dose from Natural Radiation, Manrem[b]	$100x10^6$	$100x10^6$	$100x10^6$	$100x10^6$		—	—
Potential Impacts During Processing Activities[c]:							
Occupational Exposures at INEL, Manrem	Reference	800	1300	1700		950	1100
Occupational Exposure during Transportation, Manrem	—	—	—	1		50	75
Total Occupational Exposure, Manrem	—	800	1300	1700		1000	1200
Offsite Population Dose, risk Manrem	Reference	10	10	310		240	310
Total Exposure Dose, risk Manrem	—	810	1310	2000		1200	1500
Population Dose from Natural Radiation, Manrem[d]	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$		$1.4x10^6$	$1.4x10^6$

3-27

TABLE 13 (CONT)

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER 1000 YEARS[a]

	Disposal at INEL			Disposal at Federal Offsite Repository			
	Option 1 Calcine in [illegible]	Option 2 Pellets in the CCSF	Option 3 Glass in Engineered Storage	Option 4 Calcine in [illegible]	Option 4 Actinide Glass in Canisters	Option 5 Stabilized Calcine in Canisters	Option 6 Glass in Canisters
Non-nuclear (Occupational) Lost Time accidents	18	64	41	110		30	34
Non-nuclear (Occupational) Fatalities	0	<1	<1	<1		<1	<1
Cost to Reduce Dose to Future Generations, $/Manrem:							
Estimated Costs (1977	$\$35 \times 10^6$	$\$138 \times 10^6$	$\$360 \times 10^6$	$\$256 \times 10^6$		$\$460 \times 10^6$	$\$770 \times 10^6$
Reference Case, Manrem Population Dose from Nat-	Reference	$600,000	$920,000	$\$1.1 \times 10^6$		$\$1.2 \times 10^6$	$\$1.9 \times 10^6$

a Period 1000 yr after 2100.
b 700,000 population x 0.15 manrem/yr x 1000 yr
c Period 1990 to 2020.
d 310,000 average population x 0.15 rem/yr x 1000 yr.
e Cost to get waste on a current basis, assumed 12 yr after implementation of waste management option (exception Option 1).

See p 3-30

TABLE ~~2~~ 14

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER 10,000 YEARS[a]

	Disposal at INEL			Disposal at Federal Offsite Repository			
	Option 1 Calcine in CSSF	Option 2 Pellets in CSSF	Option 3 Glass in Expanded Storage	Option 4 Calcine in CSSF	Option 4 Actinide Glass in Canisters	Option 5 Stabilized Calcine in Canisters	Option 6 Glass in Canisters
Potential Impacts to Future Generations[a]:							
Population Dose (Risk) Within 50 mi of plant, Manrem	4,600	2,600	200	3,000		0.046	0.046
Change from Option 1, Reference Case, Manrem	Reference	-2,000	-4,400	-1,600		-4,600	-4,600
Population Dose from Natural Radiation, Manrem[b]	$1x10^9$	$1x10^9$	$1x10^9$	$1x10^9$		—	—
Potential Impacts During Processing Activities[c]:							
Occupational Exposures at INEL, Manrem	Reference	800	1,300	1,700		950	1,100
Occupational Exposure during Transportation, Manrem	—	—	—	1		50	75
Total Occupational Exposure, Manrem	—	800	1,300	1,700		1,000	1,200
Offsite Population Dose (Risk), Manrem	Reference	10	10	310		240	310
Total Dose (Risk) Manrem	—	810	1,310	2,000		1,200	1,500
Population Dose from Natural Radiation, Manrem[d]	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$		$1.4x10^6$	$1.4x10^6$

TABLE [illegible] (CONT)

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER 10,000 YEARS[a]

	Disposal at INEL			Disposal at Federal Offsite Repository			
	Option 1 Calcine in CSSF	Option 2 Pellets in [illegible]	Option 3 Glass in [illegible]	Option 4 Calcine in [illegible]	Actinide Glass in Canisters	Option 5 Stabilized Calcine in Canisters	Option 6 Glass in Canisters
Non-nuclear (Occupational) Lost Time accidents	18	64	41	110		30	34
Non-nuclear (Occupational) Fatalities	0	<1	<1	<1		<1	<1
Cost to Reduce Dose to Future Generations, $/Manrem:							
Estimated Costs (1977 dollars)[e]	$35x10^6	$130x10^6	$360x10^6	$256x10^6		$460x10^6	$770x10^6
Cost per Manrem Saved, for Future Generations	Reference	$69,000	$82,000	$160,000		>$100,000	>$152,000

a Period of 10,000 yr after 2100 AD.
b 700,000 population x 0.15 manrem/yr x 10,000 yr.
c Period 1990 to 2020.
d 310,000 average population x 0.15 rem/yr x 30 yr.
e Cost to get waste on a current basis, assumed 12 yr after implementation of waste management option (except Option 1).

Revise

TABLE 15

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER 1 MILLION YEARS[a]

	Disposal at INEL			Disposal at Federal Offsite Repository			
	Option 1 Calcine in CSSF	Option 2 Pellets in CSSF	Option 3 Glass in Sealed Storage	Option 4 Calcine in CSSF	Option 4 Actinide Glass in Canisters	Option 5 Stabilized Calcine in Canisters	Option 6 Glass in Canisters
Potential Impacts to Future Generations[a]:							
Population Dose Risk Within 50 mi of plant, Manrem	370,000	85,000	14,000	70,000		0.046	0.046
Change from Option 1, Reference Case, Manrem	Reference	-285,000	-356,000	-300,000		-370,000	-370,000
Population Dose from Natural Radiation, Manrem[b]	$100x10^9$	$100x10^9$	$100x10^9$	$100x10^9$		—	—
Potential Impacts During Processing Activities[c]:							
Occupational Exposures at INEL, Manrem	Reference	800	1,300	1,700		950	1,100
Occupational Exposure During Transportation, Manrem	—	—	—	1		50	75
Total Occupational Exposure, Manrem	—	800	1,300	1,700		1,000	1,200
Offsite Population Dose, Risk Manrem Risk	Reference	10	10	310		240	310
Total Dose Manrem	—	810	1,310	2,000		1,200	1,500
Population Dose from Natural Radiation, Manrem[d]	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$	$1.4x10^6$		$1.4x10^6$	$1.4x10^6$

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER 1 MILLION YEARS[a]

	Disposal at INEL			*Disposal at Federal Offsite Repository*			
	Option 1 Calcine in [illegible]	*Option 2 Pellets in [illegible]*	*Option 3 Glass in [illegible] Storage*	*Option 4 Calcine in [illegible]*	*Option 4 Actinide Glass in Canisters*	*Option 5 Stabilized Calcine in Canisters*	*Option 6 Glass in Canisters*
Non-nuclear (Occupational) Lost Time accidents	18	64	41	110		30	34
Non-nuclear (Occupational) Fatalities	0	<1	<1	<1		<1	<1
Cost to Reduce ~~Dose~~ Risk to Future Generations, $/Manrem:							
Estimated Costs (1977 dollars)[c]	$35x10^6	$138x10^6	$36[illegible]10^6	$256x10^6		$460x10^6	$770x10^6
Cost per Manrem Saved, for Future Generations	Reference	>$400	>$1,010	>$850		>$1,240	>$2,080

a Period of 1 x 10^6 yr after 2100 AD.
b 700,000 population x 0.15 manrem/yr x 1x10^6 yr.
c Period 1990 to 2020.
d 310,000 average population x 0.15 rem/yr x 30 yr.
e Cost to get waste on a current basis, assumed 12 yr after implementation of waste management option (except Option 1).

16

TABLE ~~7-4~~

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER 100 MILLION YEARS[a]

	Disposal at INEL			Disposal at Federal Offsite Repository			
	Option 1 Calcine in CSSF	Option 2 Pellets in CSSF	Option 3 Glass in Engineered Storage	Option 4 Calcine in CSSF	Option 4 Actinide Glass in Canisters	Option 5 Stabilized Calcine in Canisters	Option 6 Glass in Canisters
Potential Impacts to Future Generations[a]:							
Population Dose, Risk Within 50 mi of plant, Manrem	410,000	116,000	19,000	110,000		0.046	0.046
Change from Option 1, Reference Case, Manrem	Reference	-294,000	-391,000	-300,000		-410,000	-410,000
Population Dose from Natural Radiation, Manrem[b]	10×10^{12}	10×10^{12}	10×10^{12}	10×10^{12}		—	—
Potential Impacts During Processing Activities[c]:							
Occupational Exposures at INEL, Manrem	Reference	800	1,300	1,700		950	1,100
Occupational Exposure during Transportation, Manrem	—	—	—	—		50	75
Total Occupational Exposure, Manrem	—	800	1,300	1,700		1,000	1,200
Offsite Population Dose, Risk Manrem	Reference	10	10	310		240	310
Total Dose, Risk Manrem	—	810	1,310	2,000		1,200	1,500
Population Dose from Natural Radiation, Manrem[d]	1.4×10^{6}	1.4×10^{6}	1.4×10^{6}	1.4×10^{6}		1.4×10^{6}	1.4×10^{6}

16

TABLE 14 (CONT)

QUANTIFIABLE ENVIRONMENTAL IMPACTS OVER 100 MILLION YEARS[a]

	Disposal at INEL			Disposal at Federal Offsite Repository			
	Option 1 Calcine in CSSF	Option 2 Pellets in CSSF	Option 3 Glass in Engineered Storage	Option 4 Calcine in CSSF	Option 4 Actinide Glass in Canisters	Option 5 Stabilized Calcine in Canisters	Option 6 Glass in Canisters
Non-nuclear (Occupational) Lost Time accidents	18	64	41	110		30	34
Non-nuclear (Occupational) Fatalities	0	<1	<1	<1		<1	<1
Cost to Reduce Dose (Risk) to Future Generations, $/Manrem:							
Estimated Costs (1977 dollars)[e]	$35x10^6	$138x10^6	$360x10^6	$256x10^6		$460x10^6	$770x10^6
Cost per Manrem Saved, for Future Generations	Reference	$470	$920	$850		$1,120	$1,880

[a] Period of 100 x 10^6 yr after 2100.
[b] Calculated for 700,000 population x 0.15 manrem/yr x 100x10^6 yr.
[c] Period 1990 to 2020.
[d] 310,000 average population x 0.15 rem/yr x 30 yr.
[e] Cost to get waste on a current basis, assumed 12 yr after implementation of waste management option (except Option 1).

the money that must be spent now to reduce the radiation risk by a given amount.

For comparison, radiation doses from natural background radiation are shown. According to the Nuclear Regulatory Commssion (NRC) Regulatory Guide,[13] value of $1000 per man-rem should be used for cost-benefit analyses for nuclear radioactive waste systems. This value is used to determine the cost effectiveness of each option. Tables 14 and 15 show that for all options other than Option 2, a period of greater than 10,000 years but less than one million years is required for the dollar cost per man-rem to approach the criterion of $1,000 per man-rem for reducing radiation risks to the public.

The validity of interpreting man-rem exposure to a population as actual risk is in doubt and may result in gross overestimates when exposure to the involved individuals is very low. The following excerpts are from the National Council on Radiation Protection (NCRP):[14]

"The indications of significant dose rate influence on radiation effects would make completely inappropriate the summing of doses at all levels of dose and dose rate in the form of total person-rem for purposes of calculating risks to the population on the basis of extrapolation of risk estimates derived from data at high doses and dose rates.

"The NCRP wishes to caution governmental policy-making agencies of the unreasonableness of interpreting or assuming 'upper limit' estimates of carcinogenic risks at ow radiation levels as actual risks, and of basing unduly restrictive policies on such an interpretation or assumption."

The population dose to future generations from any option is insignificant compared with that received from natural background radiation during the same time frame.

Another comparison can be attained by using a factor of 200 cancer deaths per million man-rem total body irradiation (as developed in the BEIR report[15] and recommended by the EPA[16].

Using this factor, the dose to future populations caused by implementing any option and the population dose commitment from natural background radiation can be expressed as possible health effects. Again, using Option 1 and the 1,000-year period (Table 13), the exposure attributable to implementing the option can be expressed as less than one cancer death compared with 20,000 cancer deaths from natural background radiation. The EPA cautions that these health effects may be used as the best available numbers for the purposes of making risk and cost-benefit analyses (for comparative purposes only), *but they cannot be used to predict the number of* casualties accurately.(17)

Serious occuptional (lost time) accidents and fatalities can be expected from the construction of a facility and any operational activities required for an option. The numbers of these accidents and fatalities were calculated from construction and manufacturing industries data(18) and are presented in Tables 13 through 16. The accident and fatality rates are higher than are calculated for radiation effects but are routinely accepted voluntarily by industrial workers.

The costs of the options differ significantly. The dollar requirements for the most expensive alternative (Option 6) is more than ten times as high as that of the least expensive alternative (Option 1). These monetary costs are the same for all time periods considered because it was assumed that no additional expenses will accrue for any option after the waste is disposed of and decontamination of decommissioning is completed.

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