EEG-11

NEW MEXICO
HEALTH AND ENVIRONMENT
DEPARTMENT

# CALCULATED RADIATION DOSES FROM RADIONUCLIDES BROUGHT TO THE SURFACE IF FUTURE DRILLING INTERCEPTS THE WIPP REPOSITORY AND PRESSURIZED BRINE

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# FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of available data concerning the proposed site, the design of the repository, its planned operation, and its long-term stability. These analyses include assessments of reports issued by the U.S. Department of Energy (DOE) and its contractors, other Federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

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Robert H Neill

Robert H. Neill
Director

# INTRODUCTION

If brine filled the void space in the waste storage areas of the proposed WIPP repository sometime after closing, it could initiate leaching and exchange actions between the brine, the waste, and the salt used for backfilling. This action would result in a radionuclide contaminated brine. A subsequent penetration of the repository, could bring contaminated brine to the surface if there was adequate pressure.

Several pressurized brine reservoirs have been encountered by drilling in the vicinity of the WIPP site and significant discharges have occurred at the surface. At the time this report was written in draft form all except one of the known brine reservoirs were associated with the Capitan Reef and its deformation front, rather than the Delaware Basin (where the proposed WIPP repository is located). However, this report was written because of the belief that the location and occurrence of these reservoirs is not well enough understood to completely rule out their existence under the site.

On November 22, 1981 a pressurized brine reservoir was encountered at the WIPP-12 borehole. The point where this brine reservoir was intercepted was only 558 feet horizontally and 786 feet vertically from the proposed location of the northernmost waste storage room. Since more definitive information on this brine reservoir will not be available for several weeks or months, it was decided to proceed with this report using the original assumptions and to prepare a new report in the future if the data from WIPP-12 suggest that significant changes in the assumptions are appropriate.*

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*Preliminary information indicates that the WIPP-12 brine reservoir will affect at least the following two assumptions:

(1) The probability per borehole of hitting a brine resevoir beneath the site will be greater than the value of 0.04 used in this analysis.

(2) Greater than 75,000 cubic feet of brine may be brought to the surface during normal drilling operations.

This report describes a scenario in which an exploratory borehole connects an underlying brine reservoir with the repository and results in saturation of the waste storage area. A subsequent borehole brings portions of this radionuclide contaminated brine to the surface. Radiation doses are calculated for time periods of 125, 400, and 1,000 years after repository closing for the following:

(1) external radiation doses for workers at the borehole location
(2) inhalation doses for workers at the borehole location,
(3) external and inhalation doses for a resident located 360 meters downwind,
(4) ingestion doses for the downwind resident from locally grown produce, milk, and meat, and
(5) Population doses from inhalation within a 50-mile radius.

The probability of the various calculated doses occurring was estimated. Probability was included in the report because of a belief that probability considerations are useful in evaluating the acceptability of unlikely events and to encourage others to provide a more detailed evaluation using more sophisticated methodology. Since the probabilities presented in this report were calculated using a simple methodology, with some parameter values chosen arbitrarily, they should be considered as approximate examples, not accurate numbers.

The reasonableness of the scenario and the significance of the results are also discussed.

## SUMMARY AND CONCLUSIONS

1. Calculated radiation doses from radionuclides brought to the surface from a postulated interaction between a pressurized brine reservoir, the repository, and an exploratory borehole are summarized below.

Radiation Doses From Brine Reservoir Scenario
(50-year Dose Commitment from One Year's Intake)

| | tc+125y* | | tc+400y | | tc+1000y *** | |
|---|---|---|---|---|---|---|
| | w.b** | Bone | w.b. | Bone | w.b. | Bone |
| Drilling crew | | Rem | | | | |
| inhalation | 0.049 | 1.3 | 0.30 | 12. | 0.78 | 32. |
| external | 0.045 | - | 0.084 | - | 0.084 | - |
| Downwind Resident | | | | | | |
| inhalation | 0.049 | 1.3 | 0.30 | 12. | 0.80 | 32. |
| external | <.001 | - | <.001 | - | - | - |
| produce | 0.47 | 1.9 | 0.001 | 0.026 | - | - |
| milk | 0.032 | 0.13 | - | - | - | - |
| meat | 0.009 | 0.035 | - | - | - | - |
| | | Person - rem | | | | |
| Area population | 1.0 | 24. | 5.9 | 220. | 15. | 600 |

*tc+125y = 125 years after closure of the repository

**w.b. = whole body

***The tc+1000y doses are not considered plausible

2. Inhalation and external radiation doses increase with time after the repository is flooded due to the continued leaching of long-lived actinides. Ingestion doses are dominated by the 29-year half-life of $^{90}$Sr and become negligible in less than 300 years after closure of the repository (tc+300y).
3. Preliminary estimates were made of the cumulative probabilities of doses equal to or greater than the tc+125y doses occurring during the lifetime of the repository. The estimated probabilities were $5 \times 10^{-7}$ for the inhalation pathway and $5 \times 10^{-8}$ for the ingestion pathway. The estimated probability of some radionuclides being brought to the surface and resulting in doses between zero and those summarized above is much greater, about one part in 4,000.
4. A preliminary estimate indicated a probability of $3 \times 10^{-5}$ that 175 Ci of $^{239}$Pu (or equivalent) would be brought to the surface by this scenario. Since the draft EPA HLW standards would be violated only if the probability of bringing this quantity of radionuclides to the surface in 10,000 years is $> 10^{-4}$--the estimate indicates the standard would be met. However, since the values are only a factor of 3 apart a more refined analysis would be worthwhile.
5. The ingestion dose estimates are not great enough to be of particular concern after tc+125y because they: (a) have a low probability of occurrence; (b) are below recommended guidelines for accidental releases; and (c) decrease rapidly (2.4%/y) with time.
6. Calculated inhalation doses to workers about the site and to residents 360m downwind are undesirably high at tc+400y. The bone dose exceeds that permitted for the general population either for routine exposure or accidental conditions. However, the dose from one year's inhalation is well below that which would result in noticeable health effects to an individual.
7. Inhalation doses calculated for tc+1000y years are even higher than those at tc+400y. However, because of pressurization and solubility limitations these doses would not be expected to occur. Consequently, the tc+400y calculated doses are considered to be the highest that would occur.
8. Radiation doses to the population residing within 50 miles of the WIPP site due to inhalation are low on an annual basis but, in the absence

of remedial measures, would be expected to continue for hundreds of years as resuspension continues. The total cumulative dose over 1500 years might result in 1 or 2 cancer fatalities (compared to an estimated 500,000 cancer fatalities from all other causes).

9. The calculated amounts of surface contamination and resuspended radionuclide concentrations are great enough to warrant a more detailed evaluation of the probability of this scenario occurring.
10. The maintaining of sufficient active institutional controls over the site to be able to detect surface contamination for up to about 600 years after closure should be considered unless the probability of occurrence can be shown to be less than estimated here.

# PROCEDURE

## Scenario Description

An exploratory borehole is drilled through the repository at a future time when institutional control has been lost. This borehole strikes a pressurized brine reservoir in the Castile formation and portions of this brine reach the surface. The well is capped to stop the brine flow, subsequently plugged, and then abandoned. Geopressurized brine infiltrates into the void space in the repository before the reservoir is plugged because the backfilled material is much more permeable than surrounding formations. The brine remains in contact with the salt and the waste for an extended period of time (25 years or more). During this time exchange occurs between brine, salt and waste.

A second exploratory bore hole at least 25 years later, penetrates backfilled portions of the repository. Some of this brine, which is still pressurized from the brine reservoir, from gases generated in the repository, or from salt creep is carried to the surface before the borehole can be capped. This brine is unrecognized or ignored as a possible radiological problem and is ponded with subsequent evaporation of the liquid.

The residue of this brine, which contains radionuclides from the repository, remains in the pond after evaporation and is available for resuspension. A largely self-sufficient farm family resides downwind and produces most of its produce, milk, and meat from the surrounding land. Annual radiation doses received by an adult from inhalation, ingestion and external radiation are calculated. Radiation doses received by drilling crew workers in the brine pond area from inhalation and external radiation are also calculated. Doses received by the population within a 50-mile radius from inhalation of resuspended radionuclides were estimated.

## Assumptions

### General

Several institutional assumptions must be made in order for the calculated doses to occur:

1) There must be a loss of institutional control so that drilling can occur without any requirements for determining the existence of a radiological hazard.
2) Drilling must occur and the drillers, either through ignorance of the repository or complacency about radiation dangers, do not determine if a radiological problem exists or take any protective measures.
3) Residence must be occurring on the land. The residence must be in the maximum downwind direction for the calculated doses to occur. Conditions (especially the availability of adequate water) must exist where subsistence farming is possible in order for calculated ingestion doses to occur.

### Specific

The key physical and technical assumptions that must occur are:

1) A geopressurized brine reservoir must exist below the repository, be intercepted by a borehole and enter the repository. This event occurs 100 years or more after repository closure.
2) The exchange that occurs between waste and brine in a 25 year period results in all of the $^{90}$Sr going into solution. The fraction going into solution is 0.01%/y for the actinides and 0.12%/y for cesium. These leaching values come from data reported in Reference 2.
3) A second borehole intersects the repository at least 25 years after the first borehole brings brine into the repository. For the maximum $^{90}$Sr dose this event is assumed to occur 25 years after the first event (tc+125y).
4) Seventy-five thousand cubic feet of brine escapes to the surface before the well is sealed, the brine is diverted to a 20,000 m$^2$ pond and evaporated, leaving a residue of solids that is ≃3 cm thick. This volume of brine represents 0.93% of that in the repository and carries with it 0.93% of the $^{90}$Sr. The fraction of the actinide inventory in the brine brought to the surface is .0023% after 25 years of leaching and 0.028% after 300 years.

5) The amount of this residue that is resuspended and carried downwind to the residence is assumed to be 0.2% per year of the total residue. Radionuclides are evenly mixed in the residue and are resuspended at the same rate. This value is more conservative than the value of 0.07% found at Rocky Flats (Ref. 3) but is less than the 0.7% expected to be lost from the top 3 cm of the WIPP salt pile (Ref. 7).

6) The downwind residence and farm is located 360m from the center of the 2 hectare evaporation pond. Since the source term is modeled as a virtual point source it is appropriate to use an annual $\frac{\chi}{Q}$ value for 804m. The value used (from the Final EIS) is $(5.0 \times 10^{-5}) \frac{s}{m^3}$

7) Radionuclide transit, adult intake, and dose conversion factors are taken from Regulatory Guide 1-109 and NUREG-0172 (References 4 and 5).

## FINDINGS

Source Term. The total curies of each significant radionuclide reaching the surface 125, 400 and 1000 years after closure are shown in Table I.

Table I

Quantity of Radionuclides Brought to Surface

(Curies)

| Radionuclides | Radionuclide Quantities - Ci | | | |
|---|---|---|---|---|
| | Repository Total, $t_c$ | $t_c$+125y | $t_c$+400y | $t_c$+1000y |
| $^{90}$Sr | 2.5 + 6* | 1,200. | 1.6 | - |
| $^{137}$Cs | 1.3 + 4 | 0.21 | - | - |
| $^{238}$Pu | 3.5 + 4 | 0.34 | 0.51 | |
| $^{239}$Pu | 3.9 + 5 | 9.0 | 110. | 310. |
| $^{240}$Pu | 9.3 + 4 | 2.1 | 27. | 79. |
| $^{241}$Am** | 4.5 + 3 | 1.7 | 14. | 14. |

*2.5 + 6 = 2.5 x $10^6$

**$^{241}$Am ingrows from decay of $^{241}$Pu, inventory at $t_c$+125y = 7.5 + 4

Concentration in Air. The assumption is made that 0.2% of the radionuclides brought to the surface are resuspended and carried downwind per year. The amount of atmospheric dilution occurring at 360m in the maximum downwind direction is assumed to have an annual average of $(5.0 \times 10^{-5}) \frac{s}{m^3}$ Resulting concentrations are shown in Table II.

### Table II
### Atmospheric Concentrations of Radionuclides at Downwind Residence

| Radionuclide | $t_c$+125y | | $t_c$+400y | | $t_c$+1000y | |
|---|---|---|---|---|---|---|
| | Ci/y resuspended | $\frac{pCi}{m^3}$* | Ci/y resuspended | $\frac{pCi}{m^3}$ | Ci/y resuspended | $\frac{pCi}{m^3}$ |
| $^{90}$Sr | 2.4 | 3.8 | .0032 | 0.0051 | - | - |
| $^{137}$Cs | 0.0004 | 0.0007 | - | - | - | - |
| $^{238}$Pu | .0007 | .0011 | .0010 | .0016 | - | - |
| $^{239}$Pu | .018 | .029 | 0.22 | 0.35 | 0.62 | 0.99 |
| $^{240}$Pu | .0043 | .0068 | .054 | 0.086 | 0.16 | 0.26 |
| $^{241}$Am | .0034 | .0054 | .028 | 0.045 | 0.024 | 0.045 |

*pCi/m$^3$ = 1.6 (Ci/y resuspended)

Inhalation Dose. The inhalation dose that the maximum individual would receive for 100% occupancy at the nearest residence is shown in Table III. An annual intake of 8000 m$^3$ of air is assumed. The calculated whole body and bone doses use dose conversion factors from Reference 5 and are expressed as the 50 year dose commitment in rems resulting from one year's inhalation. Since the residence time for actinides in the body is very long the dose actually delivered in the maximum year from a one-year intake is only about 2.2% of the dose commitment.

The inhalation dose that would be received by drill crew operators working in the brine pond area is shown in Table IV. This calculation assumes 200 hours per year of presence on site, a breathing rate of 1.25 m$^3$/hr, and a resuspension factor of 6x10$^{-9}$/m of the radionuclides in the top centimeter of the brine pond.

# Table III
# 50-Year Dose Commitment From One Year's Inhalation at Downwind Residence
# (Rem)

| Radionuclide | Dose Conversion F. mrem/pCi* | | $t_c$+125y | | | $t_c$+400y | | | $t_c$+1000y | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Intake pCi/y | Dose | | Intake pCi/y | Dose | | Intake pCi/y | Dose | |
| | w.b. | Bone | | w.b. | Bone | | w.b. | Bone | | w.b. | Bone |
| $^{90}Sr$ | 7.6 - 4 | 1.2 - 2 | 3.0 + 4 | 0.023 | 0.36 | 4.1+1 | - | - | - | - | - |
| $^{137}Cs$ | 5.4 - 5 | 6.0 - 5 | 5.3 + 0 | - | - | - | - | - | - | - | - |
| $^{238}Pu$ | 6.9 - 2 | 2.7 + 0 | 8.8 + 0 | .0006 | .002 | 1.3+1 | 0.001 | 0.035 | - | - | - |
| $^{239}Pu$ | 7.8 - 2 | 3.2 + 0 | 2.3 + 2 | .018 | 0.74 | 2.8+3 | 0.22 | 9.0 | 7.9+3 | 0.62 | 25. |
| $^{240}Pu$ | 7.7 - 2 | 3.2 + 0 | 5.5 + 1 | 0.004 | 0.18 | 6.9+2 | .053 | 2.2 | 2.1+3 | 0.16 | 6.6 |
| $^{241}Am$ | 6.7 - 2 | 1.0 + 0 | 4.3 + 1 | .003 | 0.043 | 3.6+2 | .024 | .36 | 3.6+2 | 0.024 | 0.36 |
| | | TOTALS | | 0.049 | 1.3 | | 0.30 | 12. | | 0.80 | 32. |

*From Reference 5, Table 8.

## Table IV
## 50-Year Dose Commitment From One Year's Inhalation for Workers at the Brine Pond
## (Rem)

| Radionuclide | $t_c$+125y | | | $t_c$+400y | | | $t_c$+1000y | | |
|---|---|---|---|---|---|---|---|---|---|
| | Intake pCi/y | Dose | | Intake pCi/y | Dose | | Intake pCi/y | Dose | |
| | | w.b. | Bone | | w.b. | Bone | | w.b. | Bone |
| $^{90}$Sr | 3.0 + 4 | .023 | .36 | 4.0+1 | .0001 | .0005 | - | - | - |
| $^{238}$Pu | 8.5 + 0 | .0006 | .023 | 1.3+1 | .0009 | .035 | - | - | - |
| $^{239}$Pu | 2.3 + 2 | .018 | .74 | 2.8+3 | .22 | 9.0 | 7.8+3 | .61 | 25. |
| $^{240}$Pu | 5.3 + 1 | .0041 | .17 | 6.8+2 | .052 | 2.2 | 2.0+3 | .15 | 6.4 |
| $^{241}$Am | 4.3 + 1 | .0029 | .043 | 3.5+2 | .023 | .35 | 3.5+2 | .023 | .35 |
| | TOTALS | .049 | 1.3 | | .30 | 12. | | .78 | 32. |

Ingestion Doses. Ingestion doses are calculated assuming the downwind resident obtains 76% of his fruits, vegetables, and grain; 100% of his milk; and 100% of his meat from the surrounding land which is contaminated by deposition of the resuspended radionuclides. A deposition rate of ($8.0\times10^{-5}$) per meter of plume length is assumed (Ref. 6). Stable element transfer data, annual consumption rates, maximum individual intake rates, and other parameters are taken from Tables E-1, E-3, E-9, and E-15 of Reference 4.

# Table V
## Radionuclide Intake From One Year's Ingestion of Fruits, Vegetables, and Grain
## (Picocuries)

| Radionuclides | $t_c$+125 years | | | $t_c$+400y | | |
|---|---|---|---|---|---|---|
| | $Q(\frac{pCi}{s})$ | $C(\frac{pCi}{kg})$ | Intake (pCi) | $Q(\frac{pCi}{s})$ | $C(\frac{pCi}{kg})$ | Intake (pCi) |
| $^{90}Sr$ | 7.7 + 4 | 5.9 + 2 | 2.5 + 5 | 1.1 + 2 | 8.4 - 1 | 3.3 + 2 |
| $^{137}Cs$ | 1.3 + 1 | 1.0 - 1 | 4.3 + 1 | - | - | - |
| $^{238}Pu$ | 2.1 + 1 | 1.6 - 1 | 6.6 + 1 | 3.2 + 1 | 2.5 - 1 | 1.0 + 2 |
| $^{239}Pu$ | 5.7 + 2 | 4.4 + 0 | 1.8 + 3 | 6.8 + 3 | 5.2 + 1 | 2.1 + 4 |
| $^{240}Pu$ | 1.4 + 2 | 1.1 + 0 | 4.4 + 2 | 1.8 + 3 | 1.4 + 1 | 5.6 + 3 |
| $^{241}Am$ | 1.1 + 2 | 8.5 - 1 | 3.4 + 2 | 9.0 + 2 | 6.9 + 0 | 2.8 + 3 |

$$\text{Ccrops} = .0077\frac{s}{kg}\ Q\ \frac{pCi}{s}$$

$$Q\ \frac{pCi}{s} = (3.17 + 4)\ \frac{pCi - y}{Ci - s}\ \left[\frac{Ci}{y}\ \text{resuspended}\right]$$

## Table VI

## 50-Year Dose Commitment From One Year's Ingestion of Fruits, Vegetables, & Grain

| Radionuclide | Dose Conversion* Factors (mrem/pCi) | | Dose in millirem | | | |
|---|---|---|---|---|---|---|
| | | | $t_c$+125y | | $t_c$+400y | |
| | w.b. | Bone | w.b. | Bone | w.b. | Bone |
| $^{90}$Sr | 1.9 - 3 | 7.6-3 | 4.7 + 2 | 1.9+3 | 6.3 - 1 | 2.5+0 |
| $^{137}$Cs | 7.1 - 5 | 8.0-5 | 3.0 - 3 | 3.4-3 | - | - |
| $^{238}$Pu | 1.7 - 5 | 6.8-4 | 1.1 - 3 | 4.5-2 | 1.7 - 3 | 6.8-2 |
| $^{239}$Pu | 1.9 - 5 | 7.9-4 | 3.4 - 2 | 1.4+0 | 4.0 - 1 | 1.7+1 |
| $^{240}$Pu | 1.9 - 5 | 7.9-4 | 8.4 - 3 | 3.5-1 | 1.1 - 1 | 4.4+0 |
| $^{241}$Am | 5.4 - 5 | 8.2-4 | 1.8 - 2 | 2.8-1 | 1.5 - 1 | 2.3+0 |
| | | Totals, mrem | 4.7 + 2 | 1.9+3 | 1.3 + 0 | 2.6+1 |
| | | Rem | 0.47 | 1.9 | 0.001 | 0.026 |

*From Reference 5, Table 4.

## Table VII
## Radionuclide Intake From One Year's Ingestion of Milk
## (Picocuries)

| Radionuclide | Fm (d/ℓ) | $t_c$+125y |  |  | $t_c$+400y |  |  |
|---|---|---|---|---|---|---|---|
|  |  | Cpast $(\frac{pCi}{Kg})$ | Cmilk $(\frac{pCi}{\ell})$ | Annual Intake (pCi) | Cpast $(\frac{pCi}{kg})$ | Cm$(\frac{pCi}{\ell})$ | Annual Intake(pCi) |
| $^{90}$Sr | 8.0 - 4 | 1.4 + 3 | 5.5 + 1 | 1.7 + 4 | 1.9 + 0 | 7.3 - 2 | 2.3 + 1 |
| $^{137}$Cs | 1.2 - 2 | 2.3 - 1 | 1.3 - 1 | 4.1 + 1 | - | - | - |
| $^{238}$Pu | 1.5 - 6 | 3.7 - 1 | 2.8 - 5 | 8.7 - 3 | 5.8 - 1 | 4.3 - 5 | 1.3 - 2 |
| $^{239}$Pu | 1.5 - 6 | 1.0 + 1 | 7.5 - 4 | 2.3 - 1 | 1.2 + 2 | 9.0 - 3 | 2.8 + 0 |
| $^{240}$Pu | 1.5 - 6 | 2.6 + 0 | 1.9 - 4 | 5.9 - 2 | 3.3 + 1 | 2.5 - 3 | 7.8 - 1 |
| $^{241}$Am | 5.0 - 6 | 2.0 + 0 | 5.0 - 4 | 1.6 - 1 | 1.6 + 1 | 4.0 - 3 | 1.2 + 0 |

Fm = pCi/ℓ in milk per pCi/day ingested by the animal

Cpasture = .018 $\frac{s}{kg}$ (Q $\frac{pCi}{s}$)

Cmilk = 50 Cp Fm

Intake = 310 ℓ/y

## Table VIII
## 50-Year Dose Commitment From One Year's Ingestion of Milk
## (millirem)

| | $t_c$+125y | | $t_c$+400y | |
|---|---|---|---|---|
| Radionuclide | w.b. | Bone | w.b. | Bone |
| $^{90}$Sr | 3.2 + 1 | 1.3 + 2 | 4.4 - 2 | 1.7 - 1 |
| $^{137}$Cs | 3.0 - 3 | 3.4 - 3 | - | - |
| $^{238}$Pu | 1.5 - 7 | 5.9 - 6 | 2.2 - 7 | 8.8 - 6 |
| $^{239}$Pu | 4.4 - 6 | 1.8 - 4 | 5.3 - 5 | 2.2 - 3 |
| $^{240}$Pu | 1.1 - 6 | 4.7 - 5 | 1.5 - 5 | 6.2 - 4 |
| $^{241}$Am | 8.6 - 6 | 1.3 - 4 | 6.5 - 5 | 9.8 - 4 |
| Total Doses (mrem) | 32. | 130. | 0.044 | 0.17 |

## Table IX
## Radionuclide Intake From One Year's Ingestion of Meat
## (Picocuries)

| Radionuclide | Ff (d/kg) | $t_c$+125y | | $t_c$+400y | |
|---|---|---|---|---|---|
| | | Cmeat $(\frac{pCi}{Kg})$ | Annual Intake (pCi/y) | Cmeat $(\frac{pCi}{kg})$ | Annual Intake (pCi/y) |
| $^{90}$Sr | 6.0 - 4 | 4.2 + 1 | 4.6 + 3 | 5.7 - 2 | 6.3 + 0 |
| $^{137}$Cs | 4.0 - 3 | 4.6 - 2 | 4.9 + 0 | - | - |
| $^{238}$Pu | 3.0 - 6 | 5.6 - 5 | 6.2 - 3 | 8.7 - 5 | 9.6 - 3 |
| $^{239}$Pu | 3.0 - 6 | 1.5 - 3 | 1.7 - 1 | 1.8 - 2 | 2.0 + 0 |
| $^{240}$Pu | 3.0 - 6 | 3.9 - 4 | 4.3 - 2 | 5.0 - 3 | 5.5 - 1 |
| $^{241}$Am | 3.0 - 6 | 3.0 - 4 | 3.3 - 2 | 2.4 - 3 | 2.6 - 1 |

Ff = pCi/kg in meat per pCi/d ingested by the animal

Cmeat = 50 (Cpast) Ff

Intake = 110 kg/y

### Table X
### 50-Year Dose Commitment From One Year's Ingestion of Meat
### (millirem)

| Radionuclide | $t_c$+125y |  | $t_c$+400y |  |
|---|---|---|---|---|
|  | w.b. | Bone | w.b. | Bone |
| $^{90}$Sr | 8.7 + 0 | 3.5 + 1 | 1.2 - 2 | 4.8 - 2 |
| $^{137}$Cs | 3.4 - 4 | 3.9 - 4 | - | - |
| $^{238}$Pu | 1.1 - 7 | 4.2 - 6 | 1.6 - 7 | 6.5 - 6 |
| $^{239}$Pu | 3.3 - 6 | 1.3 - 4 | 3.9 - 5 | 1.6 - 3 |
| $^{240}$Pu | 8.3 - 7 | 3.3 - 5 | 1.1 - 5 | 4.4 - 4 |
| $^{241}$Am | 1.8 - 6 | 2.7 - 5 | 1.4 - 5 | 2.1 - 4 |
| Totals | 8.7 | 35. | 0.012 | 0.050 |

## External Radiation

External radiation can occur at two locations: (1) the brine pond area where the radionuclide will be deposited once the brine has evaporated; and (2) the residence located 360m downwind. The maximum dose at the pond would occur during the first year following the release. The year when the maximum concentration would appear in the brine is a function of leaching rate and half-life and will vary for each nuclide. The maximum soil concentrations at the downwind residence would occur many years later since resuspension from the pond and deposition downwind is an on-going process. In this case the half-life of the nuclide is a factor, with the maximum concentration occurring when the decay of the deposited radionuclides equals the rate of deposition. Key assumptions are: (1) the 0.2%/y resuspension and transport rate will continue indefinitly; (2) 20% of the amount deposited each year will attach to foliage and be removed from the site; (3) the remaining radionuclides at the residence will be evenly mixed in the top 15 cm of soil and appropriate soil attenuation factors will be used for the various energy gamma radiations; and (4) occupancy factors are .023 for the pond area (based on 200 hours per year for an occupational worker) and 0.7 for the residence area.

Table XI

Maximum External Radiation Doses

| Nuclide | Brine Pond Area | | Downwind Residence | |
|---|---|---|---|---|
| | Max dose mrem/y | Time of ocurrence | Max dose mrem/y | Time of Occurrence |
| $^{90}Sr/^{90}Y$ | 26. | $t_c$+125y | 0.014 | $t_c$+165y |
| $^{137}Cs$ | 6.6 | $t_c$+140y | 0.005 | $t_c$+180y |
| $^{154}Eu$ | .056 | $t_c$+125y | - | - |
| $^{241}Am$ | 97. | $t_c$+700y | 0.70 | $t_c$+1100y |

## Population Dose

The population about the WIPP site would receive some radiation dose if the scenario described in this report were to occur. The inhalation dose is expected to be much greater than the other pathways because:

1. (1) It is the dominant pathway near the site where the ingestion and external pathways are assumed to be plausible;
2. (2) The mechanism (i.e. winds and atmospheric dispersion) exists for the inhalation pathway whereas an ingestion pathway is not expected to impact the population as a whole since food crops are not extensively grown in the area. Also a logical water supply pathway does not exist for the population.

Table XII shows an estimated population dose (50-year dose commitment from one year's inhalation) within a 50-mile radius of the site for the tc+400y release. Annual $\chi/Q$ values are taken from Table H-49 of Reference 7. Plume depletion was taken from Figure 3 in Reference 6. The projected 2010 population values from Table M-6 in Reference 7 are assumed to be applicable at tc+400y. Population doses for tc+125y and tc+1000y can be obtained by ratio of actinide activities brought to the surface (Table 1).

Although Table XII shows the dose commitment for only one year and uses the quantities calculated for a tc+400y breach it should be recognized that the release could occur anytime after about tc+125y. This projected tc+400y dose is expected to be the maximum that could occur (because of repository pressurization and radionuclide solubility considerations) although the assumption used in the calculation suggest greater doses for several thousand years. Resuspension and transport of the contaminated material would continue for many years. If the depletion rate of 0.002 per year continued indefinitely this would eventually lead to an integrated dose commitment to a stable population at about 500 times the annual calculated dose. About 95% of this dose would be delivered in the first 1500 years. However, it is more likely that the depletion rate would decrease with time and that significant amounts of the radionuclides would never be resuspended because of fixation or migration into the soil.

## Table XII

## Population Doses within a 50-mile Radius of the WIPP Site from Inhalation of Resuspended Contamination

(50-year Dose Commitment From One Year's Inhalation)

| Location* | $\chi/Q$ s/$m^3$ | Fraction Remaining in Plume | Max Adult whole body dose (mrem) | Projected** 2010 Population | Population Dose(person-rem)*** | |
|---|---|---|---|---|---|---|
| | | | | | w.b. | Bone |
| Carlsbad | (1.7-8) | .57 | 0.056 | 49,465 | 2.7 | 100. |
| Loving | (3.5-8) | .66 | 0.14 | 2,645 | .35 | 13. |
| Artesia | (3.2-8) | .48 | 0.088 | 15,770 | 1.4 | 53. |
| Hobbs | (8.6-10) | .48 | 0.0024 | 52,850 | .12 | 4.8 |
| Lovington | (2.0-8) | .48 | 0.055 | 21,800 | 1.2 | 46. |
| Other Locations | | .53 | - | 11,825 | .16 | 6.4 |
| | | | Totals | 154,355 | 5.9 | 220. |

* includes populations in the vicinity. In some cases $\chi/Q$ values are averages of more than one section.

** projected 2010 population from Appendix M of Reference 7.

*** population dose assumed to be 0.95 (adult dose) (population) from Reference 4 population mix and inhalation rate assumptions.

## PROBABILITY CONSIDERATIONS

There are a chain of events that must occur before the doses calculated above would be incurred. Each of these events has a probability of occurring that may be near zero or approach one. The probability of all the necessary events occurring is:

$$P \text{ total} = (P_1)\ (P_2)\ (P_3)\ (P_{n-1})\ P_n$$

The following events are the key ones that must all occur for the doses to materialize:

(1) Institutional control of the repository is lost 100 years after closure.

(2) A geopressurized brine reservoir of sufficient size must exist under the Site.

(3) The brine reservoir and the repository must both be intersected by an exploratory borehole which is capped shortly after discovery.

(4) This brine reservoir must saturate the pore space in the repository where it is in intimate contact with salt and waste.

(5) The assumed amount of leaching and exchange between the waste and salt occurs.

(6) A second borehole must intercept the repository.

(7) There must be sufficient pressure in the reservoir to drive 75,000 cubic feet of brine to the surface.

(8) The drilling crew must require approximately 16 hours before capping the well in order for 75,000 cubic feet to flow to the surface (assuming a flow rate of 20,000 barrels/d).

(9) The possibility of a radiological hazard is not recognized by the drillers and no radiological analyses are made of the brine. (This requires either loss of knowledge of the repository or a complacency about potential hazards).

(10)There is a home located 360m in the maximum downwind direction from the center of the evaporation pond.

(11)This home is inhabited by a largely self-sufficient farm family.

The absence of some of these assumptions (e.g. 1, 2, 3, 4, 6, and 7) would prevent any radiation dose from occurring. The other conditions could be less critical than estimated here and still lead to some radiation exposure (less than calculated above).

The values assigned to each event are given below with an explanation of why they were chosen.

(1) 1.0 DOE assumes this may occur in their evaluations. Also, EPA's draft HLW standard would require that credit cannot be taken for longer periods of control.

(2) 0.04 per drill hole. This value was chosen from the map on page 146 of Reference 8 which shows that 1 out of 27 holes drilled into the Castile formation in the Delaware Basin (not including those on the reef or deformation belt) struck a brine reservoir.

(3) 0.049 bore holes penetrate the backfilled area of the repository in each century. This estimate is taken from an EPA suggested value of 2.0 boreholes per century for an 8 $km^2$ area (Ref. 9). The effective cross-sectional area of the repository is the sum of the backfilled rooms, subentries, and main entry areas in the waste storage portion of the repository and is about 0.19 $km^2$. Because of pressurization and closure phenomena in the repository the time period when this borehole would be effective is 100 to 500 years after closure (see Appendix A).

(4) 0.5 There is a possibility the brine would go into other permeable zones.

(5) 0.5 The 25 year period may be too-short a time for all of the $^{90}Sr$ to go into the brine solution. Longer time periods would reduce the probability and dose but not eliminate the pathway. Also, the assumed degree of equilibration may be less. The value of this event is taken as 1.0 for the transuranic elements since an annual leach rate is used in that calculation.

(6) Same assumptions as in (3) except that the effective period is 125-600 years after closure of the repository.

(7) 0.5 There is a possibility that much of the pressure would be lost during the first borehole penetration and movement of brine to the repository. However, this could be offset by pressure from gases generated within the repository from organic decomposition or by the pressure generated from salt creep (see Appendix A).

(8) 0.4 It should be possible to cap the borehole in a period shorter than 16 hours. A shorter capping time would reduce the consequences, but not eliminate the scenario.

(9) 0.5 Either lack of knowledge of the repository or a lack of appreciation for possible radiological problems could cause the contamination to go unrecognized. However, it is possible that the unusual occurrence will result in recognition of the problem. Recognition of the problem would drastically reduce, but not eliminate radiation doses.

(10) 0.01 There is only a 6% probability that a nearby house would be located in the maximum downwind direction. The probability that any housing will occur within one-half mile of the repository is certainly less than one. Lesser doses would occur to residents located in any direction and greater distances away. Also, agricultural use of the land, without residency, would lead to lesser doses.

(11) 0.2 The area is more conducive to ranching and not self-sufficient farming. This factor would effect the ingestion dose only.

Probability Calculation Examples

The overall probability can be determined by combining the above probabilities. The calculation of events (2), (3), and (6) (which gives the probability that a borehole will hit a brine reservoir and the repository followed by a second borehole hitting the repository later) varies depending on the time frame chosen for the first hit and that chosen for the second hit. For example, to calculate the cumulative probability that a dose equal to or greater than the tc+125y inhalation dose would occur during the lifetime of the repository, it is necessary to determine the summation of:

$$\sum \; .04 \; (P_i/y)t_i \; P_2/y \; [600-(t_i+25)]$$

for each year i between tc+100y and tc+500y. This cumulative probability is about 0.001.

The overall probability of this minimum tc+125y inhalation dose occurring after closure is then:

$$P_{(tc+125y\ dose)} = (1.0)\;[0.001]\;(0.5)\;(1.0)\;(0.5)\;(0.4)\;(0.5)\;(0.01)$$
$$= 5\text{x}10^{-7} \text{ for inhalation}$$

The probability that both the inhalation and ingestion dose would occur in $5\text{x}10^{-8}$. The probability that there will be some dose delivered is somewhat greater than this because several of the events [(5), (8), (9), (10), and (11)] are ones that are non-critical, i.e. they affect the magnitude of the doses assumed, not the existence of any dose. The possibility there will be some dose to either drillers, clean-up personnel, or to nearby residents or agricultural users can be estimated by setting the non-critical event probabilities to 1.0.

$$P \text{ some dose} = (1.0)\ [0.001]\ (0.5)\ (0.5) = \underline{0.00025}$$

An example of a dose that may be plausible is for an individual to reside 1/2 time at a distance of 800m in any direction from the brine pond. This would raise assumption (10) by a factor of 16 but the value would still be only 0.16 rather than 1.0. This would give a probability of $8\times10^{-6}$ that an inhalation dose $\geq$ 0.07 or the maximum dose would occur.

## Draft High Level Waste Standard

Another use of the probabilistic approach is to determine whether the release would meet the Draft EPA High Level Waste Standard for quantities of radionuclides released to the environment in a 10,000 year period. The draft standards would permit 100 Ci of $^{239}$Pu, 10 Ci of $^{241}$Am, and 80 Ci of $^{90}$Sr to be released per 3 million curies of alpha emitting TRU wastes initially in the repository for a "reasonably foreseeable release" ($p \geq .01$ during 10,000 year period) and 10 times these amounts for a "very unlikely release" ($.01 > p > .0001$).

Since the WIPP repository is projected to have an initial inventory of 0.52 million curies of alpha emitting TRU waste, a total of 175 Ci of $^{239+240}$Pu, 17.5 Ci of $^{241}$Am, or 140 Ci of $^{90}$Sr would be permitted for a "very unlikely release". Combinations of these nuclides must meet the following relationship:

$$\frac{\text{Ci Pu}}{175} + \frac{\text{Ci Am}}{17.5} + \frac{\text{Ci Sr}}{140} \leq 1.0$$

When the assumed leaching rate of $10^{-4}$/y for the actinides is factored into this expression it is found that the minimum leaching time necessary to exceed the standard is about 225 years. The probability that a second borehole would hit the repository 225 or more years after the first hit is about .0003. When this probability is combined with those parameters necessary to bring waste to the surface one gets.

$$P= 1.0\ (.0003)\ (0.5)\ (1.0)\ (0.5)\ (0.4) = \underline{\underline{3 \times 10^{-5}}}$$

This calculated probability is one-third of that allowed in the draft standards and (considering the crudeness of the approximation) suggests that a more refined analysis would be worthwhile.

## Discussion

This probabilistic approach is a simplified one and the values chosen for some of the parameters are arbitrary (although they are considered plausible). Consequently, undue value should not be placed on the probabilities calculated in the above examples.

This approach is presented here for several reasons:

(1) A probabilistic approach is considered preferable to a consequence analysis because it gives some basis for estimating whether a scenario is reasonable or incredible.

(2) It is time to begin applying this approach to analyses of long-term releases from repositories. Hopefully, reaction to this approach will lead to a more sophisticated methodology and a sounder basis for values chosen.

(3) The approach can be useful in pointing out key parameters that need to be better quantified in order to assess the probability. For example, in this case a greater understanding of brine reservoir occurrence might change the value chosen for this probability by an order-of-magnitude or more. Or, the implementation of a positive institutional control program could reduce that probability by 1 to 2 orders-of-magnitude.

# DISCUSSION

## Reasonableness of Assumptions

The existence of a brine reservoir beneath the site is considered unlikely but possible. Further investigations of the brine reservoir phenomena and the structure beneath the site may significantly change the estimated probability of 4% per borehole used in this report.

In the absence of institutional control over drilling after time of closing plus 100 years, it must be assumed some exploratory drilling will occur. The values chosen for the frequency of drilling were taken from Reference 9.

The probability that a plugged borehole connecting repository and brine reservoir would result in flooding of the more permeable void space in waste storage rooms throughout the repository was assumed to be 0.5. This phenomena is reasonable, unless the repository is backfilled so that the waste storage rooms are hydraulically isolated from each other. Also, other highly permeable zones along the borehole could receive the brine before it entered the repository.

The presence of sufficient pressure to bring repository brine to the surface is another uncertainty because much pressure may be lost due to the venting of the first borehole. However, another possible source of pressure is the generation of gases in the repository from decomposition of the organic wastes. The possibility of near lithostatic gas pressures developing within a few hundred years has been estimated (Ref. 10). Also, salt creep of the backfilled area over a period of perhaps 200 years will cause pressurization of any brine present. This probability was taken as 0.5.

It should be noted that, if repository generated gas pressures develop, this scenario could occur without the presence of a pressurized brine reservoir. All that would be needed would be for water to enter the repository (from whatever sources) to be followed some years later by a single borehole into the repository. The probability of a scenario developing in this manner was not estimated.

Leaching rates of the actinides and cesium were taken from experimental work carried out on fuel fragments and borosilicate glass in various waters, including WIPP "B" brine (Ref. 2 and 11). It was assumed that CH-TRU wastes would leach at the same rate as these materials, which may or may not be conservative. Solubility considerations would probably limit the concentrations of actinides in brine to less than the tc+400y values. (Experimental solutions were typically <0.02 mg/ℓ which would have been reached in less than ten years at the assumed leaching site. However, these experiments were not carried to saturation).

The assumption that all strontium would go into solution was taken from Reference 12. The choice of a 25-year period for the reaction to occur was arbitrary.

There is a possibility that some of the leached radionuclides would become sorbed onto the 1-2% of clay present in the salt backfill, settle out of solution, and not be brought to the surface along with the brine. The percentage of radionuclides that might be removed from solution by this mechanism was not estimated.

The presence of administrative control over the site longer than 100 years after closing has not been assumed by DOE for the WIPP site. Also, both the NRC and the EPA policies are currently using the philosophy that controls after 100 years should not be relied upon.

It seems probable that knowledge of the repository would not be lost. Plans to have an extensive marker system and maintenance of records should give a high probability that drillers would know there is a repository in the vicinity. However, knowledge of the repository does not assure that drillers will forego the drilling or take the necessary precautions to minimize radiation exposure. Recent history shows numerous cases where persons who should have had knowledge of the presence and dangers of radiation acted foolishly. For example: (1) use of uranium mill tailings for household construction purposes; (2) diversion of radioactive material from a low-level waste disposal site; and (3) careless use of industrial radiography sources.

The quantity of brine (and radionuclides) reaching the surface is dependent on how long it takes to control the brine flow. At a flow rate of 20,000 barrels per day (which has been observed in nearby brine reservoirs) the assumed volume of brine would be released in 16 hours. The probability that it would take longer than 16 hours to stop the flow was taken as 0.4. This is probably conservative but is certainly not an upper limit.

No separate probability was calculated for the presence of occupational workers about the brine pond. However, if a well is developed, there will be some occupancy at the site, perhaps for several years. Also reuse of the site many years later could still result in a significant dose due to the presence of long-lived radionuclides and relatively slow removal by wind erosion.

The presence of a residence 370m away in the maximum downwind sector is of low probability. The low probability is partially because there is only a 1 in 16 probability that the residence would be located in the maximum downwind sector. However, the presence of a residence in some direction within about 1 mile of the brine pond is not considered unlikely. Inhalation doses at 1 mile would vary from 0.02 - 0.19 times those calculated here.

The existence of a full-pledged family farm at this location is considered unlikely because of the absence of economically recoverable water of good quality. However, the meat pathway exists at the site now and could be expected to continue.

## Significance of Calculated Radiation Doses

### General Background

At present the consensus in the health physics profession is that any radiation dose received probably has the potential to harm an individual. The possibility of harm, however, becomes very small as the annual dose received becomes less than the dose that man has always received from natural background radiation.

The relation between health effects (H.E.) and dose received (D) can be expressed by:

$$H.E. = CD^n$$

where C is a constant. If the value of $n=1$, the relationship is linear; if $n<1$ the resulting health effects are greater than for the linear condition (super linear); if $n>1$ the health effects are sub-linear. Most mandatory or advisory standards assume the relation is linear although many professionals believe the relationship is actually sub-linear and that the linear assumption is conservative.

Regardless of the actual shape of the response curves at low radiation doses, the following philosophies are pertinent:

(1) Radiation doses should be maintained as low as reasonably achievable because the possibility of damage even at very low levels cannot be ruled out.

(2) Annual doses received by non-radiation workers from routine (or expected) releases should be a fraction of that received from natural background radiation. Thus EPA's Uranium Fuel Cycle (40 CFR 190) and Drinking Water (40 CFR 141) Standards allow maximums of 25 and 4 mrem/y (to the whole body or any organ except the thyroid) to the population (compared to a natural background average of about 100 mrem/y.

(3) Allowable doses to nonradiation workers from accidents can be set much higher than this because an individual is not expected to receive such a dose more than once in a lifetime. Typically, guidance limits the dose to less than the lifetime dose a person would receive from natural background (e.g. 1 to 5 rem might be permitted, compared to lifetime natural background doses of 5-10 rem).

(4) Contamination of the accessible environment with long-lived radionuclides is in itself undesirable because there are many ways these nuclides can eventually get back to man. Also, contamination from multiple sources could result in a radionuclide buildup in the environment. This is the reason that limits are set on the quantities of long-lived radionuclides released in both EPA's Uranium Fuel Cycle Standard and in their draft High Level Waste Disposal Standard (40 CFR 191).

The radiation doses calculated in this report are more appropriately considered to be accidental doses because the events are not expected to happen. However, if the event were to occur and these long-lived radionuclides were brought to the surface, they could be a potential source of radiation exposure for decades or centuries. Consequently, the potential exists for a few individuals or a larger population to receive radiation doses over a number of years. For this reason, it should be recognized that these doses may not really be a one-shot event and to treat them as such is non-conservative.

## Ingestion Doses

The 50-year dose commitments from one year's intake total only 0.51 rem to the whole body and 2.0 rem to the bone at 125 years after closure. While the whole body doses are high compared to those permitted from continuous exposure to routine planned releases (25 mrem/y) they are an order-of-magnitude below the suggested guidelines for a once-in-a-lifetime accident. Furthermore, since the calculated doses would decrease with the 29-year half-life of $^{90}$Sr a whole body dose greater than 25 mrem/y would not occur after tc+250y. The calculated probability of this event occurring before tc+250y would be about ($4 \times 10^{-9}$). Note that with shorter time before breach the $^{90}$Sr could become more of a problem, e.g. at tc+75y the whole body 50-year dose commitment would be 1.7 rem, and for tc+50y it would be 3.1 rem.

The calculated bone dose is about 4 times the whole body dose and would not fall below the 25 mrem/y limit until about tc+310y. Also, the dose at tc+125y is within the 1-5 rem range suggested by EPA as a protective action guide for accidential releases. However, it is not reasonable to equate bone dose to whole body doses since the relative health effect ratio (H.E. whole body/H.E. bone) has been estimated to be as high as 20 (Ref. 13).

Because of the above considerations of a relatively low dose commitment and unlikely occurrence it is concluded that after tc+100y plausible doses via the ingestion pathway are not significant enough to require protective measures.

## Inhalation Doses

Inhalation doses are somewhat greater than ingestion doses and have a higher probability of occurrence. Consequently, they are of greater concern than ingestion doses.

The dose to occupational workers about the brine pond at tc+400y is significant (a 50-year dose commitment of 0.30 rem to the whole body and 12 rem to the bone from one year's exposure). Since approximately 2.2% of the 50-year dose commitment from these radionuclides would be delivered in the maximum year, the maximum annual dose resulting from a tc+400y breach would be .0066 rem to the whole body and 0.26 rem to the bone. The bone dose is below permissible standards for radiation workers (5 rem/y) but is above the lower dose limits applicable to the general population and to non-radiation workers (which the drillers would be). Even though these calculated doses are undesirably high they should not be considered as hazardous, since they represent only an estimated one in 6,000 probability of inducing a fatal cancer (compared to a natural incidence of about one in 6 from all causes). Also, it is unlikely that one individual would spend more than 200 hours about the site.

The downwind 50-year dose commitment from one years inhalation at tc+400y is 0.3 rem whole body and 12 rem to the bone. If the resident was exposed for only one year the maximum annual dose delivered would be 7 mrem to the whole body and 260 mrem to the bone. The annual bone dose would remain well above any permissible standard or guideline for non-radiation workers as long as the recipient lives. Clearly this is an undesirable situation. However, the probability that the dose commitment from one year's inhalation would result in a fatal cancer to an individual is slight, only about one in 6,000.

Population dose estimates for the population within a 50-mile radius total 5.9 and 220 person-rem to the whole body and the bone at tc+400y. These doses represent a negligible hazard to any of the 154,000 individuals (projected 2010 population) in the affected population. However, if this resuspension rate continued for a period of 1500 years it would deliver a cumulative dose to a stable population about 480 times the first year dose. This would result in cumulative doses of about 110,000 person-rem to the bone and 2,800 to the whole body and might result in 1 or 2 fatal cancers. However, it is unlikely that all of the material would be resuspended; most studies show that significant amounts of material become fixed or migrate into the soil.

These consequences are small when one considers the large number of persons involved and the number of generations over which any health effect would occur. For example, a stable population of 154,000 persons would be expected to incur over 500,000 cancer deaths in 1500 years if present cancer mortality rates continue. Obviously, any health effect that actually did occur would not be visible among the much more prevelant effects from other causes.

Nonetheless, the presence of significant undetected contamination remaining on the surface for long periods of time must be considered as undesirable and precautions should be taken to minimize its occurrence. This concern comes from the realization that over a period of several hundred years large numbers of persons could come and go about the site and within the 50-mile radius. Prediction of all the human activity that might be impacted by the contamination would be very speculative. For these reasons steps should be taken to avoid situations where significant surface contamination could exist for decades without detection and remedial action.

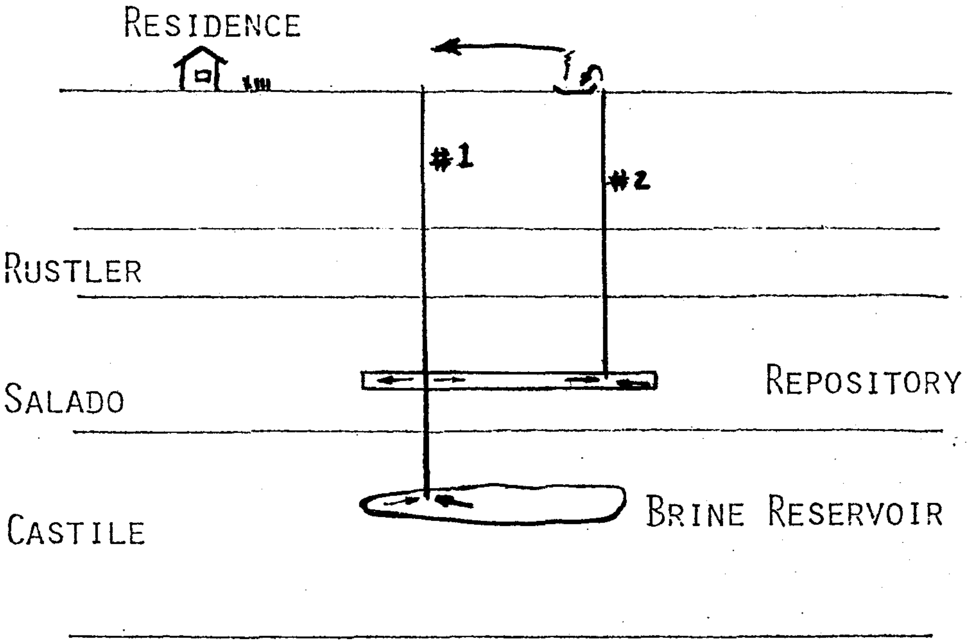

FIG. 1. SCHEMATIC OF SCENARIO

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