EEG-5

HEALTH & ENVIRONMENT department

Calculated Radiation Doses From Deposition of Material Released in Hypothetical Transportation Accidents Involving WIPP-Related Radioactive Wastes

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APPENDIX

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 Waste Isolation Pilot Plant (WIPP), a Federal radioactive waste repository proposed for construction underground in an area near Carlsbad, New Mexico. The objective of the EEG evaluation is to protect the public health and safety and ensure that there is no 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 by EEG of reports issued by the U. S. Department of Energy (DOE) and its contractors, other Federal agencies and other organizations, as they relate to the potential health, safety and environmental impacts of WIPP. These analyses may involve public meetings, site visits and consultations with agencies, professional associations and scientific experts.

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INTRODUCTION

A severe transportation accident resulting in the release of radioactive material during WIPP site operation is unlikely, but possible. Radioactive material deposited on the ground following an accident could deliver a radiation dose to people from the following pathways:

1) ingestion of contaminated food, milk or water;
2) inhalation of deposited material that is resuspended;
3) external radiation from material remaining near the surface.

The total dose from these pathways may occur over a period of many years.

This report presents the results of an analysis that estimates the maximum short-term (first year) and lifetime (70 years) doses that exposed individuals might receive. Also, the population doses that would result from contamination of irrigated food and animal feed crops are estimated. The expected reduction of these doses by protective actions was also considered.

Background

The U. S. Department of Energy's proposed Waste Isolation Pilot Plant would be located approximately 25 miles east of Carlsbad, New Mexico. The project is projected to receive approximately 3600 rail and 5200 truck shipments of Contact Handled-Transuranic Wastes (CH-TRU) during its operational lifetime (based on a 6 million cubic foot waste volume). The total number of shipments of Remote Handled-Transuranic Wastes (RH-TRU) would be about 1200 by rail and 3100 by truck. Up to 43 rail shipments of high-level wastes (HLW) for experiments may be coming to the WIPP site and an equal number leaving after the experimental phase is over. Most of the CH-TRU wastes are expected to come from the Idaho National Engineering Laboratory

(INEL) or the Rocky Flats Plant (RFP) although significant quantities are also expected from the Hanford, Los Alamos (LASL), Oak Ridge (ORNL), and Savannah River (SRP) facilities. Most of the RH-TRU wastes will probably come from ORNL and INEL with lesser amounts from Hanford and LASL. The HLW will probably come from either Hanford or the SRP (Ref. 1). A much greater number of shipments could occur if the repository size is eventually increased to as much as 70 million cubic feet (Ref. 2). There is obviously a concern about the probability and consequences of transportation accidents involving these waste shipments. The DOE has evaluated the probability of accidents involving violent wrecks and fires. The DOE has also estimated releases of radionuclides from these accidents and the resulting radiation doses to the public from inhalation. However, doses to the public from ingestion were not evaluated "because health authorities; acting after an accident, would remove contaminated food from distribution" (Ref. 1). Neither were possible long-term doses from external irradiation and inhalation of resuspended material considered (Ref. 1).

EEG believes that an assessment of possible radiation doses by these pathways is important for two reasons:

1) to indicate if radiation doses could be high enough to require short-term protective measures or long-term land use controls;
2) to estimate the amount of low-level, long-term dose that may be unavoidable if such a release occurs.

SUMMARY AND CONCLUSIONS

1) A transportation accident involving a radioactive waste shipment which is severe enough to result in releases of radioactive material is not expected to occur during the lifetime of the WIPP repository. The number of such accidents estimated by DOE to occur in New Mexico during the lifetime of a 6 million cubic foot repository are: 0.039 for CH-TRU wastes; 0.0079 for RH-TRU wastes; and 0.00038 for experimental HLW. Thus, the total number of WIPP-related transportation accidents expected to result in the release of radioactive material in New Mexico is much less than one.

2) If this type of situation did occur, postulated releases from CH-TRU and RH-TRU transportation accidents could result in measurable radiation doses to individuals and populations via ingestion, external irradiation, and resuspension. These doses are estimated to be below proposed protective action levels.

3) Postulated releases from an experimental HLW accident or from a sabotage incident involving either RH-TRU or HLW could result in estimated individual and population doses that are unacceptably high and would require protective action (such as the condemnation of food). Protective measures would be required to reduce the 50-year radiation dose commitments that would result from ingestion during both the first year and the 1-70 year period.

4) There appears to be no physical reason why doses that exceed protective action guides could not be avoided by protective measures that are economically justifiable (at a cost of $100 per person-rem of dose prevented). In some cases the reduction of doses to well below the protective action guide may be "reasonably achievable."

5) An adequate emergency response plan must include the capability to determine the degree of contamination on critical food items and on the ground surface and to estimate the resulting doses from ingestion, external irradiation, and resuspension and to take necessary protective measures in a timely manner. Responsible state, Federal, and local authorities should insure that such a plan is in existence prior to the beginning of radioactive waste shipments to the WIPP site.

PROCEDURE

Exposed Persons

The area of contamination from the transportation accident was assumed to be a 22.5 degree downwind sector. The average deposition in each of 6 zones was computed out to a distance of 20 kilometers (see Appendix A). The assumptions of transfer, intake, and dose conversion factors are primarily from U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 (Ref.3).

The individual receiving the maximum ingestion dose was assumed to be one of the members of a farm family consisting of an infant, a child, a teenager and two adults living in the 22.5 degree downwind sector at a distance of 500-1000 meters from the accident (Zone I). The family is largely self-sufficient, obtaining all milk, meat, leafy vegetables, and 76% of other produce from Zone I. More detail in methodology is provided in Appendix A.

Population doses were computed assuming that a railroad accident occurred randomly in a 30 mile stretch of irrigated land. An average mix of irrigated crops was assumed (Ref. 4). These assumptions result in higher dose calculations than would occur at the most likely location (range land), but there are locations in New Mexico where the same assumptions would lead to higher doses than those presented in this report (see Appendix C).

Source Terms

The radionuclides considered were those projected by DOE to be released in various hypothetical transportation accidents. These include the transuranics from truck and rail accidents involving CH-TRU wastes and Cesium-137 from truck and rail accidents involving RH-TRU or HLW. In addition DOE assumed that intentional destructive acts (sabotage) could release fractions of all nuclides in processed CH-TRU, RH-TRU, and HLW. Those release fractions are shown in Table 1.

Table 1

Release Fractions Assumed by DOE for Various Transportation Accidents

Type of Waste	Accident	Release Fractions	Nuclides Released
CH-TRU	Truck, train, fire	.0005*	all TRU
CH-TRU	Sabotage	.0005*	all TRU
RH-TRU	Truck, train, fire	.001 *	Cs-137 only
HLW	Truck, train, fire	.001 **	Cs-134, 137 only
RH-TRU/HLW	Sabotage	.0007***	all

* These values are obtained from Reference 1.
** The reasons for choosing this value are discussed on page 10.
***This value is from Reference 5.

FINDINGS

Maximum Individual Doses

Contact Handled-TRU Rail Accident

The source term for this accident (modified from Reference 1), is shown in Appendix B.

Doses were estimated from food, resuspension, and external radiation. The results are summarized in Table 2. The 50-year dose commitment for the first year and the cumulative dose commitment from all pathways during the first 70 years are also shown. These doses, with the assumptions used, are low and, except for those from radionuclides deposited on crops, occur after the first year. There are significant uncertainties in some assumptions that need to be kept in mind when using these numbers. Probably the greatest uncertainties involve the resuspension assumptions and the long-term soil-to-crop-to-man transfer coefficients (see Appendix A). It is noted that these doses are one to two orders of magnitude less than the inhalation doses calculated (in Reference 1) for an individual 800 meters downwind from the accident.

Since the source term for a truck accident with CH-TRU wastes is 0.33 times the source term used for a railroad accident, it is assumed the doses resulting from a truck accident will be one-third of those in a rail accident (Ref. 1).

Table 2

Estimated Radiation Doses Received by the Maximum Individual from a CH-TRU Rail Accident(1)

Pathway	Time Period (years)	Radiation Dose - Millirem(2)		
		Whole body	Bone	Lung
Air-crops-man	0-1	5.7	240.	-
Soil-crops-man	1-70	0.79	12.	-
Soil-air-man (Resuspension)	0-70	4.0	170.	110.
Soil-man (external radiation)	0-70	0.36	0.36	
Total Dose	0-1	5.7	240.	0.74
Total Dose	0-70	11.	420.	110.

(1) Assumes no protective actions are taken. The probability of these doses occurring in New Mexico during the lifetime of the repository is estimated to be $\leq$ 0.0007.

(2) Radiation doses from ingestion are expressed as the 50-year dose commitment resulting from intake of radionuclides during the 0-1 or 1-70 year time period. The resuspension dose is the actual dose delivered during the 70-year period.

Remote Handled-TRU Rail Accident

The source term is 0.22 Ci Cesium-137 (Ref. 19). The 50-year dose commitments received by an infant, a child, a teenager, and an adult due to ingestion of milk, meat and produce during the first year following an accident are tabulated in Appendix B and summarized in Table 3. Table 3 includes the estimated dose resulting from ingestion during the period from 1 to 70 years after the accident. (The individual is assumed to be a one-year old child at the start of the period.) Doses from external irradiation are also included. The inhalation dose from resuspension is negligible compared to other doses.

Table 3

Estimated 50-Year Radiation Dose Commitment to the Maximum Exposed Individual Following an RH-TRU Rail Accident (millirem)*

Person	Doses from Ingestion			External Radiation (Whole Body)	Total Whole Body Dose
	Liver	Bone	Whole Body		
First Year					
Infant	210.	180.	15.	3.9	19.
Child	630.	660.	93.	3.9	97.
Teenager	380.	290.	130.	3.9	130.
Adult	260.	190.	170.	3.9	170.
1-70 years	15.	14.	5.8	73.	79.

*Assumes no protective actions are taken. The probability of these doses occurring in New Mexico during the lifetime of the repository is estimated to be $\leq$ 0.00011.

Some of the first-year ingestion doses estimated for the RH-TRU rail accident are in the range (greater than 500 millirem to any organ other than the thyroid) where preventive protective measures should be considered (Ref. 6). Also, these doses are about one to two orders of magnitude greater than the inhalation doses presented in Reference 1.

External and long-term doses are a few percent of background and are at a level where protective measures would normally not be recommended.

The RH-TRU truck accident has an assumed source term that is 20% of that for the rail accident. Consequently its first year doses are projected to be less than background levels and below the point at which preventive protective measures would normally be considered.

High-Level Waste Accident

DOE has not yet published a scenario for a HLW transportation accident nor an estimation of the release fractions. Estimating a release fraction is further complicated by the uncertainty of the waste form as well as the canister and cask design. Several studies give an indication of plausible release fractions for cesium. (No other radioactive elements in the waste are volatile enough to be of concern.) Reference 21 uses the results of fuel rod rupture tests performed at ORNL to evaluate the various mechanisms and quantities of Cs-137 that might be released from spent fuel rods. The conclusion was that up to 0.06% of the cesium might be released from a fuel rod in a high temperature environment. The integrity of various solidified HLW forms subjected to various environments is evaluated in Reference 22. This study estimates that a glass waste matrix subjected to high temperatures might release 0.000005% to 0.75% of its Cs-137 content from the canister due to volatilization. Calcined wastes would release somewhat greater percentages. A conclusion was also made that high speed impacts (20 to 40 m/s) of a bare canister could fracture 0.00005-0.005% (by weight) of a glass waste matrix into respirable sized particles ($\leq$ 10µm diameter).

The assumption chosen for use in this report was that 0.1% of the Cs-137 would escape from the canister and cask due to volatilization. This assumption is believed to be conservative since the higher values reported (Ref. 22) were observed only for temperature (2000° F) and fire duration (4 hours) conditions that were somewhat greater than the design accident conditions.

Possible release of respirable sized particles was ignored because the release fractions are about two orders of magnitude less than for volatilization.

The source term from a 0.1% release is 1420 Ci Cs-137 and 13 Ci Cs-134. The doses, which can be obtained by simple ratio from the RH-TRU accident, are shown in Table 4.

Table 4

Estimated 50-Year Dose Commitment to the Maximum Exposed Individual Following a Railroad Accident Involving Experimental High-Level Waste*

Person	Dose From Ingestion - Rem			External Irradiation (Whole Body) - Rem
	Liver	Bone	Whole Body	
First Year				
Infant	1400.	1200.	99.	25.
Child	4000.	4300.	600.	25.
Teenager	2400.	1900.	860.	25.
Adult	1600.	1200.	1100.	25.
Years 1-70	97.	90.	37.	470.

* Assumes no protective actions are taken.
The probability of these doses occurring in New Mexico during the lifetime of the repository is $\leq$ 0.0000078.

The first year ingestion doses are clearly unacceptable, and would not be permitted. Also, the external irradiation level is higher than permissible limits for radiation workers or individuals in the general population. It should be noted that this estimated dose commitment would be delivered over a period of many months and would not be expected to result in acute fatalities even if no protective actions were taken.

Table 5 lists possible doses that would occur to members of the farm family after protective actions are taken. The specific protective actions used to calculate these residual doses are examples only of possible actions, not necessarily the preferred ones. A detailed discussion of various protective measures, their probable dose reduction factors, and the costs of implementation is outside the scope of this report.

Table 5

Estimated 50-Year Dose Commitment to the Maximum Exposed Individual Following a Railroad Accident Involving Experimental High-Level Waste
(After Protective Actions are Taken)

Person	Dose From Ingestion - Rem			External Irradiation and Resuspension (Whole body) - Rem
	Liver	Bone	Whole Body	
First Year				
Infant, Child, Teenager	0.0	0.0	0.0	0.08
Adult	0.0	0.0	0.0	0.16
Years 1-70				
Adult, Case 1	2.5	1.8	1.6	1.1
Adult, Case 2	0.55	0.40	0.36	0.47
Infant, Case 1	3.4	3.2	1.3	0.86
Infant, Case 2	0.97	0.90	0.37	0.34

Assumptions:

(a) No food ingested during first year.

(b) Children exposed to 24 hours external irradiation, adults to 48 hours.

(c) The residence cannot be reoccupied due to high external irradiation level.

(d) In Case 1, 40,000 m^2 of contaminated land (dairy pasture, garden, and about house) are cleared of vegetation; the top 2-4 inches of soil are removed and buried on site; the soil is replaced and the land plowed. The same food is raised on the land as before the accident (beginning 1 year later).

Beef cattle graze on contaminated pasture. The cost of this action is estimated to be about $68,000.

(e) Case 2 is the same as Case 1 except that the beef cattle pasture (an additional 80,000 m^2) is decontaminated in the same manner as the 40,000 m^2 in Case 1. The total cost of this action is estimated to be about $180,000.

(f) The adult ingests food from the farm and spends 500 hours per year on the property for 40 years after the accident. Ten hours of this time are spent in the contaminated (Case 1) pasture land.

(g) The infant at the time of the accident ingests food from the farm from years 1-70. From year 20 to year 70, he also works on the farm for 500 hours per year.

(h) The doses to workers decontaminating the land are not included in the table.

There are no guidelines or standards for permissible long-term doses due to a contaminating event. Reference 9 contains proposed EPA guidance for transuranic elements only. These proposed guides would permit a maximum annual dose of 3 millirads (∿ 60 millirem) to the bone and 1 millirad (∿ 20 millirem) to the lung. Case 2 conditions would be below these dose levels, but for Case 1 conditions the resulting doses would be above 60 mrem/y for over 15 years. The only conclusions that can be drawn here are:

(1) The residual dose levels in Cases 1 and 2 are likely to be near the acceptable level.

(2) Other protective measures exist to further reduce the residual dose levels if this is necessary.

Sabotage Incidents

From the release fractions listed in Table 1 it can be seen that the doses from a CH-TRU sabotage incident would be similar to those received in a severe train accident involving CH-TRU wastes.

For the RH-TRU and HLW sabotage incidents release fractions for cesium are only 70% of those expected from a severe accident with fire. However, all other radionuclides in these shipments are assumed to have the same release fraction and the effect of these nuclides must be considered. The quantities released are shown in Table B-8. Also, Appendix B describes the procedure used to determine which radionuclides would be significant. The radionuclides considered for the various pathways are shown in Table 6.

Table 6

Radionuclides Used to Calculate Radiation Doses for Sabotage Incidents Involving RH-TRU and Experimental High-Level Waste

Waste Type	Pathway	Nuclides
RH-TRU		
	Ingestion	Sr-90
	External	Co-60, Cs-137, Eu-152, Eu-154
	Resuspension	Sr-90, Transuranics
HLW		
	Ingestion	Cs-137, Sr-90
	External	Cs-137
	Resuspension	Transuranics, Cs-137, Sr-90

The calculated doses from ingestion following an RH-TRU and a HLW sabotage incident are shown in Tables 7 and 8. Doses from external radiation for RH-TRU are shown in Table B-14. The external radiation dose for the HLW sabotage incident is 0.7 of that in Table 4 (17 rem the first year and 330 rem total for 70 years). Resuspension doses are also given in Appendix B, Table B-13.

Table 7

Estimated 50-Year Dose Commitment to the Maximum Exposed Individual From Ingestion of Strontium-90 Released in a Sabotage Incident Involving a Remote Handled-Transuranic Rail Shipment*

Person Impacted	Whole Body Dose (Rem)	Bone Dose (Rem)
First Year		
Infant	15.	59.
Child	870.	3500.
Teenager	510.	2000.
Adult	390.	1600.
Years 1-70	40.	160.

* Assumes no protective actions are taken.
The probability of occurrence was not estimated.

Table 8

Estimated 50-Year Dose Commitment to the Maximum Exposed Individual From Ingestion of Cesium-137 and Strontium-90 Released in a Sabotage Incident Involving an Experimental High-Level Rail Shipment*

Person Impacted	Whole Body Dose (Rem)		Bone Dose (Rem)	
	Cs-137	Sr-90	Cs-137	Sr-90
First Year				
Infant	70.	23.	810.	90.
Child	420.	1300.	3000.	5300.
Teenager	600.	780.	1300.	3100.
Adult	770.	600.	840.	2500.
Years 1-70	29.	61.	51.	250.

* Assumes no protective actions are taken.
The probability of occurrence was not estimated.

The estimated doses from ingestion and the external radiation for a HLW sabotage incident are in the range of tens to thousands of rem to a maximum exposed individual and are clearly unacceptable. Doses from external radiation for an RH-TRU sabotage incident and resuspension from both incidents are in the millirem range and negligible compared to those from ingestion. These doses could be reduced by the same protective measures used in the HLW accident and the residual doses should be similar to those presented in Table 5.

Population Doses

Population doses were calculated for release accidents occurring in the 30 mile stretch of irrigated land south of Roswell along the Atchison, Topeka, and Santa Fe Railroad and the alternate 285 Highway route. This choice avoids using an average condition (which would be range land) that would give doses much less than average doses. Yet the choice does use an existing land-use condition rather than one that does not exist now and is unlikely to exist in the future. This rail route is the most direct from Colorado and Idaho to the WIPP site and might be the most likely rail route. It was estimated (see Appendix C) that if the postulated accident were to occur on this route in New Mexico there would be approximately a 1% probability that it would occur in this irrigated stretch under meteorological and cropping conditions as severe as those assumed in the evaluation. Correction was also made for the fact that in the 2 mile wide band of irrigated land much of the deposition would occur beyond the crops and would result in little or no ingestion dose.

The estimated population dose from a CH-TRU accident is 0.31 person-rem to the whole body and 13 person-rem to the bone. The population ingestion doses from the RH-TRU and HLW accidents and sabotage incidents are summarized in Tables 9-12. The size of the exposed population is discussed in Appendix C.

Table 9

Estimated 50-Year Population Dose Commitment From Ingestion of Cesium-137 Released in a Railroad Accident Involving Remote Handled Transuranic Waste (Person-Rem)*

Pathway	Dose in New Mexico		Dose out of State	
	Whole Body	Bone	Whole Body	Bone
Food Crops	4.6	7.0	4.6	7.0
Milk	1.9	4.5	1.2	3.0
Beef	8.0	12.	8.0	12.
Totals(Rounded)	15.	24.	14.	22.

* Assumes no protective actions are taken. The estimated probability of these doses occurring in New Mexico during the lifetime of the repository is 0.00011.

Table 10

Estimated 50-Year Population Dose Commitment From Ingestion of Cesium-137 Released in a Railroad Accident Involving Experimental High-Level Waste (Person-Rem)*

Pathway	Dose in New Mexico		Dose out of State	
	Whole Body	Bone	Whole Body	Bone
Food Crops	30,000	45,000	30,000	45,000
Milk	12,000	29,000	8,000	19,000
Beef	52,000	77,000	52,000	77,000
Totals (Rounded)	94,000	150,000	90,000	140,000

* Assumes no protective actions are taken. The estimated probability of these doses occurring in New Mexico during the lifetime of the repository is 0.0000078.

Table 11

Estimated 50-Year Population Dose Commitment From Ingestion of Strontium-90 Released in a Sabotage Incident Involving Railroad Shipment of RH-TRU Waste (Person-Rem)*

Pathway	Dose in New Mexico		Dose out of State	
	Whole Body	Bone	Whole Body	Bone
Food Crops	19,000	80,000	19,000	80,000
Milk	700	2,600	400	1,700
Meat	4,600	19,000	4,600	19,000
Totals (Rounded)	24,000	100,000	24,000	100,000

* Assumes no protective actions are taken. The probability of occurrence was not estimated.

Table 12

Estimated 50-Year Population Dose Commitment From Ingestion of Strontium-90 and Cesium-137 Released in a Sabotage Incident Involving a Railroad Shipment of Experimental HLW (Person-Rem)*

Nuclide	Dose in New Mexico		Dose out of State	
	Whole Body	Bone	Whole Body	Bone
Cs-137	66,000	110,000	62,000	98,000
Sr-90	37,000	150,000	37,000	150,000
Totals (Rounded)	100,000	260,000	99,000	250,000

* Assumes no protective actions are taken. The probability of occurrence was not estimated.

The first year population dose commitments estimated for the HLW accident and the sabotage incidents (Tables 10-12) are unacceptably high and protective actions would have to be taken. Condemnation of all crops contaminated by deposition from the accident would virtually eliminate the first year dose commitments shown in Tables 9-12. The 1-70 year dose commitment from the soil-crop-man pathway would be only about 2 to 3% of the first year ingestion dose commitment even if no decision were made to shift to less sensitive land uses. External radiation from the HLW accident and sabotage incident would be a greater source of radiation dose than the ingestion pathway during the 1-70 year period and would preclude persons from residing in the inner zones for a period of many years. The residual doses (after protective actions have been taken) to any individuals are expected to be equal to or less than those projected in Table 5 for the maximum individual in Zone I.

DISCUSSION

Uncertainty and Conservatism* of Assumptions

The calculated dose is only one of the values in a range of possible doses that might occur in the event of an accident. Each of the chain of assumptions leading to a given dose contains a range of values that may be large. Furthermore, the distribution of individual parameter values about their mean is usually not well known. Consequently, any attempt to quantify the overall variance would be difficult and unreliable. The reasons for choosing many of the values used is given at various places in this report. An attempt was made to choose values that were a mixture of "most-likely" and conservative rather than to pick either all highly conservative or all most-likely values. The intent of this approach was to obtain an answer that is conservative, but not bounding. The discussion below, which is not exhaustive, mentions some of the parameters that are thought to be conservative or non-conservative.

Regulatory Guide 1.109

Most of the food pathway parameters were taken from Regulatory Guide 1.109 without modification. These parameters all vary and have a degree of uncertainty. A recent investigation (Reference 18) using Monte Carlo Techniques concluded that for Iodine-131 in milk the Regulatory Guide 1.109 parameters led to a prediction that was at the 77th percentile (i.e. would be exceeded 23% of the time). This value was about 2.2 times the median and 1.3 times the average values but was only 0.36 and 0.19 of the 95th and 99th percentile values. This evaluation is consistent with the NRC's stated philosophy "to use model parameters that lead to conservatively realistic dose estimates. Thus NRC estimated doses are most likely higher than the actual doses received, but not by more than a factor of 2 or 3" (Ref. 23).

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* A conservative assumption results in a calculated consequence that is worse than the most likely consequence (e.g. it would predict a higher radiation dose).

All modifications made in this report to Regulatory Guide 1.109 parameters resulted in reducing the calculated doses. However, some of these reductions appear reasonable (because of the one-time occurrence of contamination in an accident as compared to the continuous release assumed in the Guide) and do not necessarily result in reduced conservatism.

Meteorology

The meteorological parameters chosen are a mixture of conservative and non-conservative values. The stability category (Pasquill Type F) and wind speed (1.0 meters per second) calculates a close-in deposition concentration that would be equalled or exceeded only 16% of the time with Southeastern New Mexico conditions.

Other assumptions could give higher concentration than calculated in this report. One would be to assume a ground level or 10 meter release height rather than 20 meters. Also, for Type F conditions the lateral dispersion of the plume is predicted to cover only about 40% of the 22.5 degree sector. This results in deposition concentrations along the center line that are several times as high as the sector average (which is used throughout this report).

Contamination would also occur during the 84% of the time that less stable meteorological conditions exist with the resulting deposition patterns being influenced by stack height, wind speed, and stability category. Contamination levels at certain distances from the accident could be as high as predicted for the assumed conditions.

Probability of Accident

The DOE used actual accident data to estimate probability of accidents occurring that are believed to be severe enough to cause releases from Type B packages and casks. The accident rates used were not route specific. The maximum possible release from an accident of this severity was estimated. The assumption was made by DOE that accidents less severe would never result in radionuclide releases. Also, no estimate was made by DOE of the distribution of releases (above and below the assumed level) that might occur from accidents equal to or greater than the design level. An additional uncertainty is that final designs of containers and casks to be used for WIPP wastes have not been selected nor have prototypes been tested. Furthermore, the possible contribution of defective containers and casks or operational errors to the frequency or severity of accidents has not been evaluated. No attempt will be made in this report to estimate uncertainties in the accident frequency or source term assumptions.

The overall probability that the various accidents would occur in New Mexico under conditions that would lead to doses equal to or greater than those calculated in this report is estimated in Appendix C. Table C-1 shows that the estimated probability of a design level accident occurring in New Mexico during the lifetime of the repository is only about 1 in 20. The RH-TRU and HLW population dose accidents evaluated in this report have probabilities of about 1 in 9,200 and 1 in 130,000 of occurring during the lifetime of the repository. The probability that an individual would receive the maximum individual doses calculated in this report is assumed to be equal to or less than the probability of the population dose occurring.

It is difficult to assign a probability to a successful act of sabotage and this will not be attempted. This probability is considered highly unlikely, but possible.

Significance of Radiation Dose

The significance of these estimated doses can be better understood by comparing them to radiation received from other sources and to the possible health effects that would occur in the absence of protective measures. The ability to avoid the dose is also very important and will be discussed in more detail later.

Natural background radiation in New Mexico from cosmic radiation, terrestrial radiation, and from radionuclides deposited in the body varies from about 110 millirem per year in the Carlsbad area, to over 200 mrem/year at high elevations and in areas where the natural radiation in the soil is greater. Approximate values for Albuquerque and Santa Fe are 160 and 190 mrem/year (Ref. 7).

It is important to keep in mind the variabilities of dose with location; a person moving within New Mexico could change his annual exposure from natural background by as much as 100 mrem/year. Studies have not shown a correlation between health effects and variations in natural background radiation levels.

In addition to natural background radiation, the average person in the U. S. receives about 20 mrem/year (genetically significant dose) from diagnostic x-rays and a 4 mrem/year whole body dose due to fallout from atmospheric weapons testing. The U. S. population also receives exposures from the uranium mining and milling industry, nuclear power reactors, and from technologically enhanced natural radioactivity but the sum of these exposures probably adds less than 1 mrem/year to the whole body dose of the average person in the U. S. population (Ref. 8)

The linear non-threshold theory of radiation damage is commonly used to estimate the statistical probability of damage received by a population exposed to radiation doses below those which produce an acute effect. Since this theory assumes the amount of radiation damage at these low levels is independent of the amount and rate at which it is received by an individual, the calculated health effects depend only on the total dose received by a population and not upon the number of persons exposed. The theory also holds that doses received from natural background lead to equivalent health effects as doses received from any type of man-made radiation. The health effects risk factors used in this report are from Reference 16 (see Appendix A) and are similar to those adopted by various national and international organizations.

This risk factor is:

1 million person-rem = 50-500 fatal cancers

As an example, this risk factor predicts that the population receiving 29 person-rem of whole body radiation from the RH-TRU rail accident would incur 0.0014 to 0.014 fatal cancers as a result of the accident. The number of fatal cancers expected in the exposed population ($\geq$ 35,000 persons) from non-radiation causes would be greater than 5,000.

Radiation Protection Philosophy

It is an accepted health physics practice that radiation doses to occupational workers and to the public from normal operations should be maintained as low as practicable even though the calculated consequences are very low. Regulations and guidelines typically limit the maximum permissible doses to individuals. The extent that further control is required is based on practical considerations, including a benefit-cost evaluation.

Guidance appropriate to a food contamination type of accident has been proposed by the Department of Health, Education and Welfare, Public Health Service, Food and Drug Administration and is scheduled for final issuance in 1980 as 21 CFR Part 1090.400 (Ref. 6).

The guidance states that preventive measures (such as removal of cows from pasture) should be considered if a dose reduction of 500 millirems to the maximum exposed individual can be obtained. Emergency measures (including condemnation of food) should be considered if a dose reduction of 5,000 millirem (5 rem) can be obtained. This proposed guidance is, in effect, saying that preventive measures are usually not worthwhile if the potential dose savings is less than 500 millirem per person and may not be cost-effective for dose savings up to 5 rem. One reason why these radiation levels are expressed as guidelines rather than absolute standards is because the negative aspects of taking action must also be considered. For example, the removal of food (especially milk) from the marketplace could result in shortages which have an adverse effect on public health greater than that resulting from the low-level radiation exposure.

An approach commonly used to determine feasible protective measures is to assign a monetary value to a reduction of one person-rem population dose. Values used have ranged from $10 to $1000/person-rem. The analysis in Appendix D uses $100/person-rem.

Possible Preventive Measures

The benefit-cost analyses in Appendix D indicate that doses received by individuals or populations from a CH-TRU or RH-TRU railroad accident are not expected to be great enough to require protective actions. The doses projected for the RH-TRU accident are similar to the annual background dose and several times the Environmental Protection Agency's Uranium Fuel Cycle Standard (40CFR 190) of 25 mrem/year (this standard is applicable only to routine emissions from fixed nuclear facilities and the implication is that it would be acceptable each year). Consequently, while these doses should not be considered as negligible, they probably would be considered so low that the cost of avoiding them is not justified.

The doses projected to be received from the HLW accident or from the RH-TRU and HLW sabotage incidents are much greater than for the other accidents and the first year doses that could occur are unacceptable. There are several procedures that can be used to reduce the first year dose:

(1) condemn food crops;
(2) condemn feed crops and provide uncontaminated feed to dairy and beef cattle;
(3) evacuate people from the area if the external contamination levels are too high.

The long-term problems that would be associated with a release of the magnitude calculated for the HLW accident are equally serious. The external radiation and contaminated food that would occur in Zone I would be too high to permit residence or family farming for over 70 years unless remedial action were taken. Decontamination factors of 20 to over 100 can be obtained by the removal of the top 2 to 4 inches of contaminated soil (Ref. 20). Other land uses (for example raising non-food crops, such as cotton) may also be permissible, especially in the outer zones where initial contamination is somewhat less.

It is realistic to assume that such high predicted doses can and would be largely avoided once their magnitude has been determined. The cost of decontamination may exceed $5,000 per acre (Ref. 20) or some land may be declared unusable for years but the doses can be largely avoided.

Time is also a significant factor in responding to a large release because significant exposures can occur during the first few days from external radiation, milk, stored feed that is contaminated, and any crops harvested before their degree of contamination has been determined. For this reason it will be necessary to have an emergency response plan that can insure a rapid response and evaluation of critical pathways. This evaluation would be required for all releases to insure that those which are not expected to require a response are actually as low as projected. Such a plan might include only the state of New Mexico. However, due to the number of states involved and the expected infrequency of major accidents, it may be preferable to have one specialized response team to respond to accidents that have ingestion pathway implications.

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APPENDIX A

ACCIDENT SCENARIOS, METHODOLOGY AND ASSUMPTIONS USED

This Appendix will describe: (1) the radionuclide release assumptions used for various radioactive waste transportation accidents; (2) the methodology used to determine radionuclide deposition, concentration in food items, and resuspension; (3) the determination of internal radiation doses from ingestion and inhalation, and external doses from deposited radionuclides; and (4) the determination of estimated health effects from calculated radiation doses.

Accident and Release Assumptions

The possible transportation accidents that could lead to a release of radioactive waste being shipped to the proposed WIPP site are described in detail by the Department of Energy in Chapter 6 of the April, 1979 Draft Environmental Impact Statement on the WIPP project. These include both rail and truck accidents and involve Contact Handled-Transuranic Wastes (CH-TRU); Remote Handled-TRU Waste (RH-TRU); and experimental High-Level Waste (HLW). All assume a severe accident resulting in fire which causes a partial release of the contents of the waste containers. Release fractions were also given for intentionally destructive acts (sabotage) for each waste category (Ref. 1).

The accidents described by DOE are accepted in this report. Also, their release fractions are accepted, with one modification. For CH-TRU waste the Draft EIS lists only the respirable fraction (62%) of the powder assumed to be entrained in air following the accident. This source term was modified to include the non-respirable fraction since it would not be a factor in ingestion and external radiation dose determinations. The use of larger particles in determining the resuspension dose is also appropriate since the Environmental Protection Agency's (EPA) proposed "screening level" which was used to estimate the resuspension dose considers particles up to 2 millimeters in size (Ref. 9). The source terms used for each of the accidents are included in this report.

The analysis evaluated all radionuclides (the transuranics and Cs-137) reported to be released in the CH-TRU and RH-TRU accidents. Cesium-134 was not evaluated in the experimental high level waste accident because its activity was only about 1% of the Cs-137 activity. A sabotage incident involving RH-TRU and experimental HLW would release a large number of radionuclides. These are evaluated in Appendix B to determine which are the most significant.

Methodology - Deposition

The deposition (source-depletion fractions) are obtained from Meteorology and Atomic Energy (Ref.10). Pasquill Type F conditions and a release height of 20 meters are assumed. From this curve (Figure A-1) it is possible to estimate the fraction of the plume that is deposited in various zones in the downwind sector. It was assumed that the deposition was in the entire width of the 22.5 degree sector. Diffusion equations predict that virtually all of the deposition will be within the central 40% of the sector. Consequently, the assumption is not conservative for a farm family that is located on the center line of the plume. Population dose calculations, which are area dependent would not be affected by this assumption.

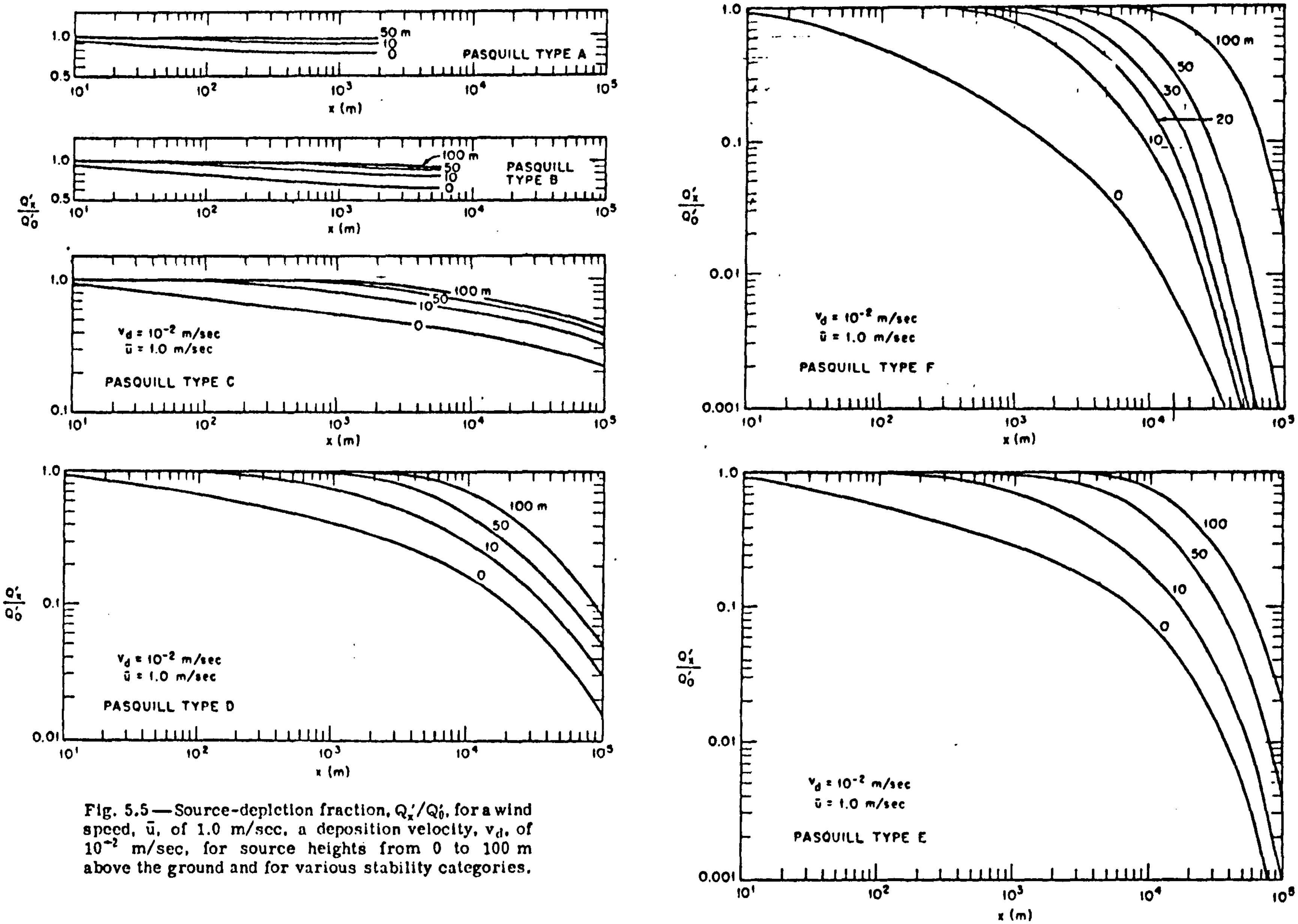

Fig. 5.5—Source-depletion fraction, Q'_x/Q'_0, for a wind speed, $\bar{u}$, of 1.0 m/sec, a deposition velocity, v_d, of 10^{-2} m/sec, for source heights from 0 to 100 m above the ground and for various stability categories.

Figure A-1

Source Depletion Fractions

(From Meteorology and Atomic Energy, 1968, p. 205)

The 22.5 degree downwind sector was divided into 6 zones as shown in Figure A-2. The farm family was assumed to be in Zone I only. For the population dose calculations all Zones were used. The deposition in each Zone is tabulated in Table A-1.

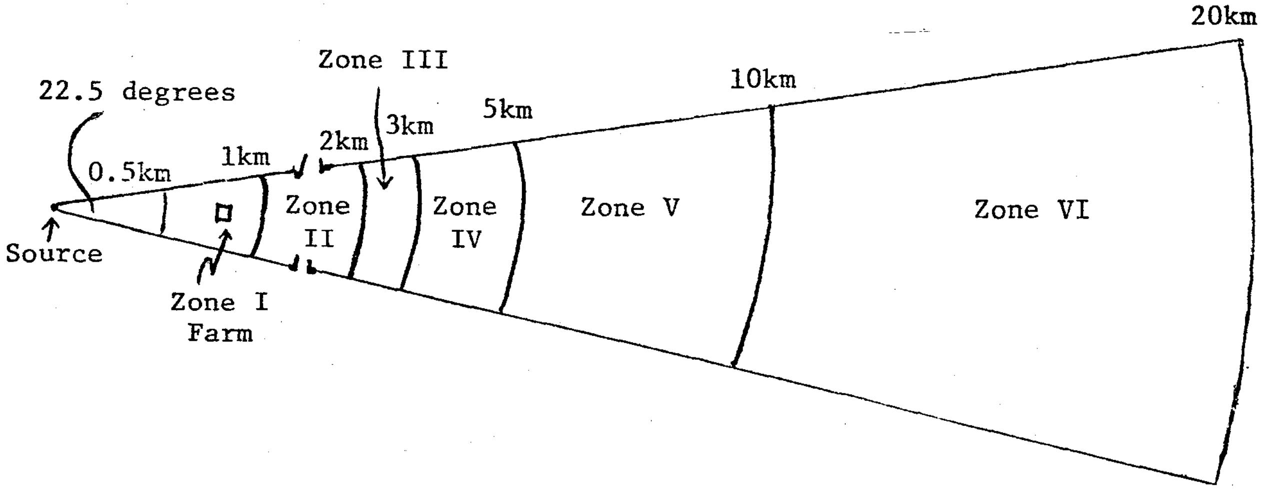

Figure A-2

Zones of Radionuclide
Deposition From Transportation Accident

Table A-1

Deposition From Transportation Accident

Zone	Distance (Km)	(a) Fraction Depleted in Zone	(b) Zone Area (M^2)	(c) Fraction Deposited, Fqd $\left(\frac{1}{M^2}\right)$
I	0.5 - 1.0	0.10	1.47+5(d)	6.8-7
II	1 - 2	0.17	5.88+5	2.9-7
III	2 - 3	0.13	9.82+5	1.3-7
IV	3 - 5	0.20	3.14+6	6.4-8
V	5 - 10	0.22	1.47+7	1.5-8
VI	10 - 20	0.14	5.88+7	2.4-9

(a) Fraction depleted is from Meteorology and Atomic Energy, 1968, page 205, Pasquill Type F Conditions, 20 m release height (Figure A-1).

(b) Area of Sector = $\frac{\Pi}{16}$ $(r_2^{\,2} - r_1^{\,2})$

(c) Fraction Deposited, Fqd = $\frac{\text{Fraction Depleted in Zone}}{\text{Zone Area in square meters}}$

(d) 1.47+5 = 1.47×10^5

Methodology - Food Pathway Model

Virtually all assumptions and evaluations are from U.S. Nuclear Regulatory Guide 1.109 (Ref. 3). Some modifications were necessary because Regulatory Guide 1.109 is based on continuous, long-term releases, whereas the accident is assumed to be a one-hour release.

Equation C-5 (Ref. 3, p.25) is the basic equation used to calculate concentrations of radioactivity in forage, produce, and leafy vegetables. For all radioiodines and particulate radionuclides, except tritium and Carbon-14, the concentration of nuclide i in and on vegetation at the location (r,θ) is estimated using:

$$C_i^v(r,\theta) = d_i(r,\theta)\left[\frac{r[1-\exp(-\lambda_{Ei}t_e)]}{Y_v\lambda_{Ei}} + \frac{B_{iv}[1-\exp(-\lambda_i t_b)]}{P\lambda_i}\right]\exp(-\lambda_i t_h)$$

Where:

C_i^v	is the concentration of radionuclide i in vegetation, in pCi/kg;
d_i	is the deposition rate of nuclide i, in pCi/m^2 per hr;
r	is the fraction of deposited activity retained on crops, dimensionless;
Y_v	is the agricultural productivity (yield), in kg(wet weight)/m^2;
λ_{Ei}	is the effective removal rate constant for radionuclide i from crops, in hr^{-1}, where $\lambda_{Ei} = \lambda_i + \lambda_w$, λ_i is the radioactive decay constant, and λ_w is the removal rate constant for physical loss by weathering;
λ_i	is the radioactive decay constant for nuclide i, in hr^{-1};
B_{iv}	is the concentration factor for uptake of radionuclide i from soil by edible parts of crops, in pCi/kg (wet weight) per pCi/kg dry soil;

P is the effective "surface density" for soil, in kg(dry soil)/m^2;

t_e is the time period that crops are exposed to contamination during the growing season, in hours;

t_h is a holdup time that represents the time interval between harvest and consumption of the food, in hours;

t_b is the time period over which the accumulation is evaluated, which is 15 years (mid-point of plant operating life) for a nuclear power reactor. This is a simplified method of approximating the average deposition over the operating lifetime of the facility.

Modification and Simplification

The exponential expression exp $(-\lambda_i t_h)$ can be ignored since radiological decay time between harvest and consumption is very short compared to the half-lives of the transuranics, Cs-137, and Sr-90.

Short-Term Intake

The first exponential term within the brackets expresses an approach to equilibrium which occurs because of an effective removal rate (a 14-day weathering half-life is assumed) of deposited radionuclides from crops and the time that crops are exposed to contamination during the growing season. The second exponential term expresses the buildup of radionuclides in soil over the lifetime of the release. This soil contamination is a source of long-term radionuclide uptake via the soil to root pathway. Neither of these expressions is appropriate to a single release. However, it is accurate to say that the concentration on the crops at the end of the deposition period is:

$$C = QFqd \left(\frac{pCi}{m^2}\right) \left[\frac{r}{Yv \quad \frac{kg}{m^2}}\right] = \frac{QFqd\ r}{Yv} \ \frac{pCi}{kg} \qquad (1)$$

where: Q = total release of a radionuclide during the accident in picocuries.

Fqd = fraction of the total release of a radionuclide deposited per square meter of surface area (from Table A-1).

For the values used in Reg. Guide 1.109, Equation (1) becomes;

$$\begin{aligned} C &= 0.285\ QFqd \quad \text{for pasture} && (1a) \\ &= 0.10\ QFqd \quad \text{for produce} && (1b) \end{aligned}$$

The soil pathway term can be expressed in the same manner.

$$C = QFqd\left(\frac{pCi}{m^2}\right)\left[\frac{Biv}{P\left(\frac{kg}{m^2}\right)}\right] = \frac{QFqd\ Biv}{P}\left(\frac{pCi}{kg}\right) \qquad (2)$$

Actually the soil pathway is negligible compared to the deposition pathway in the weeks following the contaminating event even if it is assumed that uptake occurs in plants that are near maturity at the time of the accident (questionable). Consequently, it is appropriate to use equation (1) for the initial radionuclide concentration and (2) for the long-term radionuclide concentration.

The initial concentration determined by equation (1) will decrease with a weathering half-life of 14 days and this must be factored into an evaluation of the total radionuclide intake that individuals or populations will receive from the event. The appropriate calculation is discussed below for the separate pathways.

Concentrations of the non-transuranic radionuclides in milk and meat are obtained by multiplying equations (1) or (2) with the product of the feed intake (kg/d) times the stable element transfer factor for milk (Fm in pCi/ℓ milk per pCi/d in feed), and meat (F_f in pCi/kg meat per pCi/d in feed). These factors are in Tables E-1 and E-3 of Regulatory Guide 1.109. Milk and meat doses for the transuranic elements were not calculated because of the indication that concentrations in meat would be only about 10^{-5} of that in the food they eat (Ref. 11).

Long-Term Food Intake

Equation (2) is used to calculate the concentration predicted to be obtained in food and fodder from the soil-to-crop pathway. Equation (2) can be modified to obtain an average concentration in the crops over a 70-year period.

$$\bar{C} = \frac{\bar{A}\ \mathrm{Biv}}{P} \qquad (\text{in pCi/kg}) \qquad (3)$$

The value of P is taken as 240 kg/m^2 (the weight of the top 15 cm of soil into which the contamination is mixed). The term Biv expresses the stable element transfer factor relating pCi/kg in vegetation to pCi/kg in soil. This value is 0.017 for strontium, .010 for cesium, .0001 for the plutonium isotopes, and 0.080 for americium.

The term $\bar{A}$ is the average activity of a radionuclide in the soil. For simple radioactive decay, it can be obtained by evaluating the integral:

$$\bar{A} = \frac{A_o}{69} \int_{t_1 = 1}^{t_2 = 70} e^{-\lambda t}\ dt \qquad (4)$$

The value of A_o is taken as 80% of the quantity deposited per square meter of surface area (QFqd) since the 20% falling on foliage is assumed to be lost. Since it is assumed that the person receiving the 70-year dose is a one-year old at the beginning of year 1, it is necessary to determine $\bar{A}$ values for each period of time to apply to their respective intake and dose conversion factors. The years are 1-11 for a child, 11-17 for a teenager, and 17-70 for an adult.

Americium Ingrowth

Since Am-141 is incorporated from soil into crops 800 times as effectively as plutonium, it will dominate the long-term radiation dose from a CH-TRU accident (Ref. 11). Furthermore, its concentration will increase significantly during the 70-year period of interest due to the decay of Pu-241:

$$ {}^{241}_{94}\mathrm{Pu} \xrightarrow[T_{1/2} = 14.7y]{\beta^-} {}^{241}_{95}\mathrm{Am} \xrightarrow[T_{1/2} = 432y]{\alpha} \qquad (5) $$

The increase with time of Am-241 can be determined from the following expression:

$$ (A_{Am})_t = \frac{\lambda_{Am} \; A^{\circ}_{Pu}}{\lambda_{Am} - \lambda_{Pu}} \left[e^{-\lambda_{Pu} t} - e^{-\lambda_{Am} t} \right] + A^{\circ}_{Am} \left(e^{-\lambda_{Am} t} \right) \qquad (6) $$

The average concentrations of Am-241 over the 70 year period can be obtained by determining the area under the ingrowth curve. Because of the large amount of Pu-241 in the CH-TRU waste, the average Am-241 activity over the 70-year period will be 10 times the initial activity. The person accumulating the maximum dose from the accident via the food pathway would be a 1-year old at the time of the accident who receives a child's dose for one year from deposited radionuclides and 9 years from soil-crop contamination. Subsequently this individual would receive a teenager's dose for 6 years and an adult's dose for 54 years.

Americium-241 ingrowth is also used in determining 70-year doses from resuspension and from external radiation in the CH-TRU accident.

Some research has indicated that chelation may increase the uptake of plutonium by a factor as high as 1,000. Since chelation agents are being added to soils, with trace metals, in fertilizers it is possible that significantly increased concentrations of plutonium may occur in future years (Ref. 12). Consequently, the human intake of plutonium via the soil-crop pathway calculated here may be nonconservative.

Methodology - Human Ingestion

The quantities of food intake for the maximum exposed individuals are taken from Table E-5 in the Regulatory Guide. Food intake for the average individuals in the population are taken from Table E-4. Ingestion doses, expressed in millirem per picocurie ingested, are obtained from Table E-11 through E-14 for the non-transuranic radionuclides and from NUREG-0172 (Ref. 17) for the transuranics. All age groups (infant, child, teen, and adult) are considered in evaluating individual and population doses.

The doses from Reg. Guide 1.109 and NUREG-0172 are expressed as the 50-year dose commitment from the quantity of radionuclides taken in during the first year. This dose may be delivered in a much shorter time than 50 years depending on the effective half-life of a radionuclide in the body. The 70-year doses from inhalation of transuranic radionuclides are the actual doses delivered over the 70-year period.

Modifications for Specific Food Items

It was necessary to modify the food intake assumptions because of the one-time nature of the contaminating event. These modifications vary for each pathway as described below.

Milk

Milk is harvested daily and consumed shortly thereafter. However, since a cow is assumed (Regulatory Guide 1.109, page 15) to return to the same spot and eat new grass each 30 days, it is appropriate to include only that milk produced in the first 30 days after the accident. The total intake must also be adjusted for the 14-day weathering half-life.

The average concentration of the milk ingested during the 30 days is:

$$\bar{A} = \frac{1}{30} A_0 \int_{t_1}^{t_2} e^{-\lambda_{Ei} t} dt = \frac{A_0}{30} \int_{0}^{30} e^{-\frac{.693}{14} t} dt = 0.52 A_0 \qquad (7)$$

Meat

The Regulatory Guide uses the same grazing assumption for beef cattle as for dairy cattle. This report assumes that the concentration in the meat is one-half that which would be predicted from the A_0 value (essentially the same as the average concentration of the grass consumed in 30 days). Calculations using this assumption would predict higher than actual concentrations in the meat if the 30 day grazing period were not long enough to attain the same degree of equilibrium assumed in Regulatory Guide 1.109.

In the population dose calculation both dairy and beef cattle were assumed to be fed alfalfa and feed grains which had a contamination level at the time of ingestion of one-half the initial concentration.

Produce

Regulatory Guide 1.109 assumes that, for the maximum individual, all of the leafy vegetables and 76% of the remainder of the produce (fruits, vegetables, and grains) are grown in the garden of interest. The calculations in this report reduced the intake that would be obtained during the first year from these assumptions as follows:

1) The quantity of contaminated produce ingested by the farm family was assumed to be one-half of the annual intake because of the assumption that only one-half of the year's produce would be in the field at the time of the accident.

2) The calculated radionuclude concentrations in all produce used by the farm family were reduced by one-half before ingestion to allow for some loss in weathering and in food preparation before eating.

3) The concentration of radionuclides in food crops ingested by the general population was reduced to one quarter of the calculated concentration to allow for losses due to weathering, spoilage, waste, and food preparation.

The amount of reduction that takes place due to food preparation is quite variable between food items and between studies. Furthermore, studies with sprayed-on contamination tend to yield much higher percent reductions than those observed from weapons testing fallout in the early 1960's. The decision to reduce farm family concentrations to one-half and population intake to one-fourth was based largely on studies with fallout Sr-90 by Laug and Thompson.

E. P. Laug found that preparation for industrial canning reduced Sr-90 in carrots, tomatoes, spinach, peaches, and snap beans by 19, 21, 22, 50, and 62% respectively (Ref.13). J. D. Thompson studied the percent reduction of Sr-90 during home preparation of carrots, potatoes, tomatoes, green beans, onions, and cabbage (Ref. 14). Observed reductions were 19, 24, 28, 36, 37, and 55% respectively.

No intake reductions were made in subsequent years for the radionuclides that became incorporated into food crops via the soil pathway.

Methodology - Resuspension

The methodology chosen to determine resuspension doses was adopted from the conclusions reached by the Environmental Protection Agency in developing their proposed "Federal Radiation Protective Action Guides (PAG) for Persons Exposed to Transuranic Elements in the Environment" (Ref. 9). EPA's proposed PAG would limit the maximum individual to a pulmonary lung dose of 1 millirad per year at equilibrium and to a bone dose of 3 millirad per year after a 70-year intake. The agency also concluded that in the absence of site specific information, it could be assumed that a transuranic deposition of 0.2 microcuries per square meter in the top centimeter of soil would meet these criteria.

The pulmonary lung dose at equilibrium and the bone dose after 70 years were obtained by direct ratio of the calculated deposition from the various transportation accidents and the 0.2 $\mu Ci/m^2$ Proposed Guide. The average concentration during the 70 years was determined by allowing for the decay of Pu-238 and the ingrowth of Am-241. (The Pu-241 concentration was not included since it is a beta emitter.) The integrated pulmonary lung dose was obtained by assuming equilibrium after 6 years (effective half-life of 1.0 years). The integrated bone dose was determined by evaluation of the expression:

$$D_\Sigma = \int_0^{70} D_0 \, te^{-\lambda t} dt \tag{8}$$

λ is obtained from a biological (and effective) half-life of 200 years. This is a slight simplification because of the shorter lived Pu-238 and Am-241 nuclides. However, their average concentrations for the 70 year period were used in the calculation and decayed with an effective half-life of 200 years. This simplification would cause an error of only about 1% in the total dose. Furthermore, the rough approximation that 0.2 $\mu Ci/m^2$ of TRU is equal to 3 millirad per year presumes there will be some variation in the radionuclide mixture.

The known dose at 70 years can be used to determine D_0 by use of the expression:

$$D_0 = \frac{D_{70} \lambda}{(1-e^{-\lambda(70)})} \tag{9}$$

The cumulative dose turns out to be equal to 2090 D_0 or 33.7 D_{70}.

It was assumed that 1 millirad = 20 millirem when converting these doses to millirem.

It should be recognized that the resuspension factor is difficult to estimate within several orders of magnitude. The EPA values chosen here are assumed by most to be conservative (some would say unrealistically so) yet EPA only assumes a resuspension factor of 10^{-8} m^{-1} whereas some other investigators have observed initial values as high as 10^{-5} m^{-1} with an exponential decay (half-life $\leq$ 1 year) that approaches a value of about 10^{-9} m^{-1} within a few years (Ref. 20). Consequently these values are probably conservative after the first few years, but may not be during the first year.

External Radiation

The doses that would be received from gamma radiation of radionuclides deposited in Zone I-VI were calculated. The dose conversion factors (expressed in mrem/h per pCi/m^2 of contaminated ground) were obtained from Table E-6 of Regulatory Guide 1.109 or from ORNL-4992 (Ref. 15).

The following assumptions were made:

1) Shielding and occupancy factors in the first year reduce the dose to 0.7 of the value calculated from Table E-6.

2) Twenty percent of total deposition is lost from pasture at the end of the first year; the remainder is tilled into the soil to a depth of 15 cm. This results in an additional reduction of (0.8)(0.7 for soil shielding) = 0.56. Combined with the first year shielding and occupancy factor this reduced the dose to 0.39 of that calculated from Table E-6.

3) The calculations include correction for radiological decay of fission products and for buildup of Am-241.

Health Effects Determination

To obtain estimated health effects, it is necessary to multiply the person-rem doses calculated for specific organs by a risk factor. Risk factors are typically expressed as health effects per million person-rem of dose to an exposed population. Numerical values of risk factors reported in the literature vary over an order of magnitude. The ones used in this report are from Table E-2, in Reference 16. These risk factors are shown in Table A-2.

Table A-2

Health Effects Risk Factors

Type of Risk	Predicted Incidence per 10^6 person-rem
Fatal Cancers	
Whole Body Exposure	50-500
Lung Exposure	5-50
Bone Exposure	2-10
Thyroid Exposure	3-15
Specific Genetic Effects to all Generations from Whole Body Exposure	50-300

APPENDIX B

MAXIMUM INDIVIDUAL DOSES

This appendix contains detailed tabulations of source items and the doses received by maximum exposed individuals in the different accidents from the various food items and other pathways. Total doses are summarized in the report.

CH-TRU Accident

Table B-1 shows the assumed releases from a rail accident involving CH-TRU waste. The data are modified from Reference 1 to include releases due to both air entrainment and combustion mechanisms. Also, the fraction of the particles that are larger than respirable size are also included since they could be ingested.

Table B-1
Assumed Releases from Rail Accident
Involving Contact Handled-Transuranic Waste

Nuclide	Curies Released
Pu-238	1.4-3
Pu-239	1.6-2
Pu-240	4.0-3
Pu-241	9.9-2
Am-241	2.6-4

RH-TRU Accident

All tabulations assume a release of 0.22 Ci Cesium-137. Tables B-2 through B-5 present the whole body, bone, and liver doses to an infant, a child, a teenager, and an adult from milk, meat and produce using the assumptions in Appendix A.

Table B-2

Estimated 50-Year Radiation Dose Commitment to the Maximum Exposed Infant From Ingestion of Cesium-137 Following an RH-TRU Rail Accident

Pathway	pCi Intake	Doses (Millirem)[a] Whole Body	Bone	Liver
Milk	3.5+5	15.	180.	210.
Meat	0			
Produce	0			
TOTAL	3.5+5	15.	180.	210.

(a) Dose commitment in millirem per pCi ingested: (4.33-5) for whole body, (5.22-4) for bone, and (6.11-4) for liver.

Table B-3

Estimated 50-Year Radiation Dose Commitment to the Maximum Exposed Child From Ingestion of Cesium-137 Following an RH-TRU Rail Accident

Pathway	pCi Intake	Doses (Millirem)[a] Whole Body	Bone	Liver
Milk	3.5+5	16.	110.	110.
Meat	1.7+5	8.	57.	55.
Produce	1.5+6	69.	490.	470.
TOTAL	2.0+6	93.	660.	630.

(a) Dose commitment in millirem per pCi ingested: (4.62-5) whole body; (3.27-4) bone; (3.13.-4) liver.

Table B-4

Estimated 50-Year Radiation Dose Commitment to the Maximum Exposed Teenager From Ingestion of Cesium-137 Following an RH-TRU Rail Accident

Pathway	pCi Intake	Doses (Millirem)[a]		
		Whole Body	Bone	Liver
Milk	4.3+5	23.	48.	63.
Meat	2.7+5	14.	32.	40.
Produce	1.8+6	95.	210.	280.
TOTAL	2.5+6	130.	290.	380.

(a) Dose commitment in millirem per pCi ingested: (5.19-5) whole body; (1.12-4) bone; (1.49-4) liver.

Table B-5

Estimated 50-Year Radiation Dose Commitment to the Maximum Exposed Adult From Ingestion of Cesium-137 Following an RH-TRU Rail Accident

Pathway	pCi Intake	Doses (Millirem)[a]		
		Whole Body	Bone	Liver
Milk	3.2+5	23.	25.	36.
Meat	4.6+5	34.	38.	50.
Produce	1.5+6	110.	130.	170.
TOTAL	2.3+6	170.	190.	260.

(a) Dose Commitment in millirem per pCi ingested: (7.14-5) whole body; (7.97-5) bone; (1.09-4) liver.

Table B-6 shows the maximum dose that would occur to an individual from ingestion of food contaminated by the soil to crop pathway in the period from one to 70 years following an RH-TRU rail accident. This individual is assumed to be an infant at the time of the accident and to continue to live at this location with the same eating habits as the farm family. Table B-7 shows the external radiation dose that an individual would receive during the 70-year period. These doses have been reduced to allow for shielding and occupancy factors, and for radioactive decay.

The estimated doses from a HLW accident (in the absence of protective measures) would be about 6,000 times the doses from the RH-TRU accident, in direct proportion to the quantities of Cs-137 released in the two accidents.

Table B-6

Long-Term Dose to the Maximum Individual in Zone I From Ingestion of Cesium-137 During the Period of 1-70 Years Following an RH-TRU Rail Accident

Age	Years Ingested	Total 50-Year Dose Commitment - millirem		
		Whole Body	Bone	Liver
Child	10	0.62	4.4	4.2
Teen	6	0.51	1.1	1.5
Adult	53	5.2	5.0	8.0
TOTAL LIFETIME DOSE		6.3	11.	14.

Table B-7

External Radiation Dose in Zone I From Deposition of Cesium-137 Following an RH-TRU Rail Accident

Period	Whole Body Dose - millirem
First Year	3.9
1-70 Years	73.
TOTAL (Rounded)	77.

Releases From Sabotage Incident

The expected releases from a sabotage incident of the more abundant radionuclides contained in RH-TRU and experimental HLW are shown in Table B-8. Also included in the Table are dose commitment factors, stable element transfer data and external dose factors. These factors are used along with the quantity of release to determine which radionuclides should be used to compute doses to individuals or populations.

It is apparent from inspection of the table that most nuclides make a negligible contribution to the radiation dose. The radionuclides that need to be considered are shown in Table 5 in the main report.

Ingestion Doses From Sabotage Incidents

Tables B-9 through B-12 present the doses to maximum exposed individuals in the four age groups from intake of Strontium-90 via milk, meat, and produce.

Table B-8

Radionuclide Release Quantities, Dose Factors, and Transfer Data From Sabotage Incident Involving RH-TRU and Experimental HLW Shipments

Nuclide	Curies Released(1)		Dose C. Factor(2)		Transfer Data(3)		External(4) Dose F.
	RH-TRU	Ex-HLW	Ing.	Inh.	Fm	Ff	
Co-60	0.375	0.247	4.7-6	1.8-6	1.0-3	1.3-2	1.7-8
Sr-90	29.5	45.2	1.9-3	7.6-4	8.0-4	6.0-4	2.2-12
Ru-106	0.258	2.58	3.5-7	1.1-6	1.0-6	4.0-1	1.5-9
Cs-134	-	9.25	1.2-4	9.1-5	1.2-2	4.0-3	1.2-8
Cs-137	0.154	995.	7.1-5	5.3-5	1.2-2	4.0-3	4.2-9
Ce-144	-	16.7	2.6-8	2.3-5	1.0-4	1.2-3	5.2-10
Pm-147	-	33.0	2.9-9	3.2-6	-	-	-
Eu-152	0.075	0.004	3.9-8	4.8-5	-	-	4.2-9
Eu-154	0.030	3.93	5.4-8	6.5-5	-	-	1.1-8
Pu-238	.0025	1.87	-	6.9-2	-	-	-
Pu-239	.027	0.061	-	7.8-2	-	-	-
Pu-240	.0065	0.037	-	7.7-2	-	-	-
Pu-241	0.164	8.3	-	1.3-3	-	-	-
Am-241	0.0003	0.078	-	6.7-2	-	-	8.6-10

(1) Source of Inventory is Reference 19, Table 3.1-4.

(2) 50-year Dose Commitment to Whole Body of Adult from Ingestion or Inhalation of One Picocurie. From NUREG-0172 (Reference 17).

(3) Stable Element Transfer Data from Table E-1, Reference 3.

(4) From Table E-6, Reference 3. Units are mrem/hr per pCi/m^2.

Table B-9

Doses from Ingestion of Strontium-90 Released in a Sabotage Incident Involving RH-TRU Wastes (Rem)

	INFANT			CHILD		
		Dose (Rem)[a]			Dose (Rem)	
Pathway	pCi Intake	Bone	Whole Body	pCi Intake	Bone	Whole Body
Milk	3.2+6	59.	15.	3.2+6	55.	14.
Meat				3.5+6	59.	15.
Produce				2.0+8	3300.	840.
TOTAL	3.2+6	59.	15.	2.1+8	3400.	870.

(a) Dose commitment factors in millirem per pCi ingested are (1.85-2) and (4.71-3) for infant bone and whole body and (1.70-2) and (4.31-3) for child bone and whole body. Assumed release is 29.5 Ci.

Table B-10

Doses from Ingestion of Strontium-90 Released in a Sabotage Incident Involving RH-TRU Wastes (Rem)

	TEENAGER			ADULT		
		Dose (Rem)[a]			Dose (Rem)	
Pathway	pCi Intake	Bone	Whole Body	pCi Intake	Bone	Whole Body
Milk	3.9+6	32.	8.0	3.0+6	23.	5.6
Meat	5.6+6	46.	11.	9.4+6	71.	17.
Produce	2.4+8	1900.	490.	2.0+8	1500.	370.
TOTAL	2.5+8	2000.	510.	2.1+8	1600.	390.

(a) Dose commitment factors in millirem per pCi ingested are (8.30-3) and (2.05-3) for teenager bone and whole body and (7.58-3) and (1.86-3) for adult bone and whole body. Assumed release is 29.5 Ci.

Table B-11

Doses from Ingestion of Strontium-90 Released in a Sabotage Incident Involving Experimental HLW

	INFANT			CHILD		
		Dose (Rem)[a]			Dose (Rem)	
Pathway	pCi Intake	Bone	Whole Body	pCi Intake	Bone	Whole Body
Milk	4.9+6	90.	23.	4.9+6	84.	21.
Meat				5.4+6	90.	23.
Produce				3.1+8	5100.	1300.
TOTAL	4.9+6	90.	23.	3.2+8	5300.	1300.

(a) Dose commitment factors in millirem per pCi ingested are (1.85-2) and (4.71-3) for infant bone and whole body and (1.70-2) and (4.31-3) for child bone and whole body. Assumed release is 45.2 Ci.

Table B- 12

Doses from Ingestion of Strontium-90 Released in a Sabotage Incident Involving Experimental HLW

	TEENAGER			ADULT		
		Dose (Rem)[a]			Dose (Rem)	
Pathway	pCi Intake	Bone	Whole Body	pCi Intake	Bone	Whole Body
Milk	6.0+6	49.	13.	4.6+6	35.	8.6
Meat	8.6+6	71.	17.	1.4+7	110.	26.
Produce	3.7+8	3000.	750.	3.1+8	2300.	570.
TOTAL	3.8+8	3100.	780.	3.3+8	2500.	600.

(a) Dose commitment factors in millirem per pCi ingested are (8.3-3) and (2.05-3) for teenager bone and whole body and (7.58-3) and (1.86-3) for adult bone and whole body. Assumed release is 45.2 Ci.

Resuspension Dose From Sabotage Incidents

Resuspension dose estimates for the sabotage incidents are shown in Table B-13. These doses assume that 80% of deposited radionuclides remain and are uniformly mixed into the top 15 centimeters of soil. This assumption would not lead to conservative estimates for all land uses. Also, the doses are expressed in slightly different terms. The transuranic doses are related to the proposed EPA regulations and are the maximum that would be delivered in any year whereas the cesium and strontium are 50-year dose commitments from an annual intake. A resuspension factor of $10^{-8}m^{-1}$ is used for cesium and strontium. These doses are negligible compared to those that would be received from other pathways as a result of the same accident.

Table B-13

Resuspension Doses From Sabotage Incident Involving RH-TRU and Experimental HLW Shipments (Millirem)

Nuclide	Maximum Annual Dose		70-Year Dose	
	Lung	Bone	Lung	Bone
			RH-TRU WASTE	
TRU	2.7	8.2	180.	280.
Sr-90	0.13	1.3	4.2	44.
Cs-137	- (all less than 0.001 millirem)			
			EXP HLW	
TRU	230.	300.	15,000.	10,000.
Sr-90	0.20	2.0	6.4	67.
Cs-137	0.027	0.17	0.90	6.0

External Radiation Doses From Sabotage Incidents

The external radiation dose from the significant gamma emitting radionuclides released in an RH-TRU sabotage incident is shown in Table B-14.

The external dose from a sabotage incident involving HLW is simply 0.7 times that of a HLW accident since no radionuclides other than Cs-137 are significant.

Table B-14

External Radiation Dose From RH-TRU

Sabotage Incident - Millirem

Nuclide	Initial Dose Rate mrem/y	Dose(1) First Year	Dose(2) 1-70 Years
Co-60	38.	25.	99.
Cs-137	3.8	2.7	50.
Eu-152	1.9	1.3	13.
Eu-154	1.9	1.3	16.
Total		30.	180.

(1) Corrected for Radiological Decay and a 0.70 shielding/occupancy factor

(2) Corrected for Radiological Decay and a 0.39 shielding/occupancy factor

APPENDIX C

METHODOLOGY FOR POPULATION DOSE DETERMINATION

This appendix explains typical agricultural land use along possible routes to the WIPP site, why the assumed location was chosen for population dose calculations, the cropping patterns, how the percent probability of occurrence was determined, and how the percent deposition within crop lands was determined.

New Mexico Agricultural Land Use

Approximately 1,360,000 acres of land in New Mexico are irrigated for crop production. An additional 600,000 acres are dry farmed. These acreages comprise about 1.75% and 0.75% of the total land in New Mexico. Approximately 200,000 irrigated acres are in food crops with wheat (149,000 acres), pecans (14,600 acres), chili peppers (10,900 acres) and peanuts (9,400 acres) being the principal crops. Also, about 400,000 acres of non-irrigated wheat is grown (Ref. 4).

To relate the effect of possible transportation accidents on New Mexico agriculture, it is preferable to estimate the proximity and distribution of cultivated lands along possible routes. This estimate was made by using the county-specific data in Reference 4 and by personal observation of the extent that cultivation was concentrated along the routes.

Locations were observed where significant irrigation was concentrated along rail and/or highway routes. The most significant of these were:

(1) Along the Rio Grande between the Texas border and Albuquerque where approximately 120 miles (about 1/2 the distance)

were irrigated. Rail and highway routes were located alongside of or within the irrigated areas the entire distance.

(2) In the 40-mile stretch from the Texas border on Highway 70/84 through Clovis and for 17 miles south of Portales there were about 30 miles of cultivation, often on both sides of the highway. The Atchison, Topeka, and Santa Fe Railroad follows the highway along this stretch.

(3) Along Alternate 285 (Route 2) south of Roswell to the Eddy County line, there were about 30 miles of irrigation along the east side and 15-20 miles along the west side of Route 2 in a 34 mile stretch. There were at least one dairy and several cattle feed lots in this area. The AT & SF Railroad is along Route 2 in this area.

Accident Location Chosen

It was decided that the location chosen for the population dose assessment should be one that actually exists in New Mexico. The most likely location for an accident would involve range land with little or no cultivation. However, this would be non-conservative and would also underestimate the average dose that would be received along the route. On the other hand, it seems reasonable to choose a scenario that might occur in a few percent of accidents rather than the worst possible situation.

The location chosen was for the accident to occur randomly anywhere in a 30-mile stretch of irrigation at location (3) above (Route 2 south of Roswell). It was further assumed that lands would be 100% irrigated on the east side of the route and 60% irrigated on the west side. The width of irrigated lands was assumed to be one mile on each side of the railroad. These assumptions approximate the actual condition. The distribution of crops through the irrigated area was assumed to be the average for Chaves County.

This location was chosen because it is on the most direct rail route from the Idaho National Engineering Laboratory, Rocky Flats, and Hanford to the WIPP site. This would also be a possible route for wastes from Oak Ridge or Savannah River.

The area of irrigation along the Rio Grande (location 1) in Dona Ana County is similar to the Chaves County configuration and includes a higher percentage of food crops and dairy cattle. Consequently the dose received under the same set of assumptions would be approximately 1.5 to 2 times as great as at the chosen location. However, this is a longer route to the site and may be used less frequently.

An accident along location (2), which is on the same route as the chosen location, may also lead to a higher population dose due to the large amount of wheat grown and the higher percentage of dairy cows fed in Roosevelt County. However, the dose estimates would be at least partially offset due to the more scattered occurence of cultivated lands.

Cropping Pattern

The assumption was made that average county agricultural land use would exist. This leads to the conclusion (which appears consistent with visual observations along location 2) that most land use is either in alfalfa or other hay (57%), feed grains (11%) or cotton (26%). The only major food items are wheat (4.5%) and pecans (1.6%). Only 5.5% of the livestock being fed are dairy cows.

The radiation dose to people from contaminating this land would occur from ingestion of wheat, intake of milk from cows fed with contaminated hay or grains, and eating meat from cattle fed contaminated feed. Resuspension and external irradiation doses were not considered. The actual number of persons receiving the ingestion dose would be expected to be large since individuals purchasing food rarely obtain most of it from a small area.

However, it is useful to estimate the number of persons that would be fed by contaminated food if it constituted their entire diet. The food contaminated by this hypothetical accident would provide a 4-month food supply for the following number of persons:

milk - 1,300;
wheat - 3,400;
beef - 30,000.

Almost one-half of these persons would reside outside of New Mexico.

The distribution of doses to populations within New Mexico and out of state were made after consideration of the relative amounts of the various crops that are consumed within the state. These values must be considered approximate since no local knowledge was available on crop exporting patterns. It was assumed that 60% of the milk, 50% of the meat, and 50% of the wheat remains within New Mexico.

The distributing of doses within and outside of the state is useful to highlight the portion of a dose that might be ingested by New Mexicans. However, it has no effect on the radiological consequences of an accident since a population dose is assumed to have the same effect wherever it is delivered.

Probable Number of Accidents

The probable number of transportation accidents occurring during the lifetime of the repository and leading to the population doses calculated in this report can be estimated from the following expression:

$$N = P_{acc} F_{nm} F_{irr} F_{met}$$

where:

N = number of accidents projected to occur during the lifetime of the repository at location (2) plus location (3).

P_{acc} = the probability that an accident of design level severity will occur somewhere during the lifetime of the repository and lead to the postulated releases.

F_{nm} = fraction of design level accidents assumed to occur in New Mexico.

F_{irr} = fraction of route miles that border irrigated lands times the fraction of the year that crops are in the field.

F_{met} = fraction of time that meteorological conditions would lead to deposition equal to or greater than assumed in the dose calculations.

Reasonable estimates can be made for all of the parameters. The probability that an accident of design level severity (P_{acc}) will occur has been estimated on a per shipment basis in Reference 1 for each waste classification and method of shipment. The total number of accidents expected in the lifetime of the repository can be obtained by multiplying this value by the number of shipments expected. F_{nm} can be estimated by assuming the fraction of accidents occurring in New Mexico is equal to the fraction of enroute miles that are in the State. From the mixture of waste shipments assumed in Reference 1, the mileage can be estimated for each type of shipment. The values chosen were: 0.13 for CH-TRU and RH-TRU rail shipments; 0.15 for HLW shipments; 0.41 for CH-TRU truck shipments; and 0.33 for RH-TRU truck shipments. The irrigation factor (F_{irr}) is obtained from adding the miles of irrigation along the route (30 each for locations 2 and 3), dividing by the 225 miles of track in New Mexico on this route and multiplying by 0.5 for the fraction of time crops may be in the field. The calculated value of F_{irr} is 0.13. The meteorology factor, F_{met}, is taken as the fraction of time that stability categories F and G occur when wind speed is less than 1.4 m/s. This value, obtained from Appendix H of Reference 1, is 0.16. This procedure assumes an equal probability of wind blowing in all sectors. The resulting average amount of crop land in each sector that is contaminated is calculated in the next section for this particular geometry.

There are, of course, uncertainties in all of the parameters. P_{acc} is the most uncertain factor, especially the estimate of the releases that will occur due to a design level accident. The other three parameters are less uncertain and their product may be accurate within ± 100% for the rail accident at location (3).

The projected number of accidents for each category of waste shipment is shown in Table C-1. The F_{irr} factor developed for the AT & SF rail route is also used for the truck routes because better data are not available. This assumption is undoubtedly conservative.

The very low probability of these severe accidents occurring at all is apparent from a study of Table C-1. Nineteen accidents of all levels of severity are expected to occur in New Mexico during the repository lifetime. However, the calculated number of accidents of design level severity is only 0.048. For the RH-TRU rail accident there is a 0.0053 probability of a design level accident in New Mexico, a 0.00069 probability that this accident would occur in irrigated areas with crops in the field, and a 0.00011 probability of occurring with the restrictive meteorological conditions assumed in calculating doses in this report. Probabilities for HLW are less than one-tenth of this.

The probability of the maximum individual dose occurring was assumed to be equal to or less than the population dose. Observations about the state gave the impression that self-sufficient family farms occur along a much smaller fraction of the routes than do concentrations of irrigation. Consequently, this assumption is undoubtedly conservative. The probability of sabotage incidents occurring was not estimated.

Percent Deposition on Crops

It is necessary to determine the percentage of the deposition occurring in each zone that would probably fall on crop land. The key factors are the orientation of the track and irrigation and where within the 48 km stretch the accident occurs. From Figure C-1, it is apparent the average amount of crop land that is contaminated will be twice as great if the accident occurs in the middle of the 48 km stretch rather than at the end. The fraction of the deposition that occurs for each zone was estimated graphically and is shown in Table C-2.

Table C-1
Projected Number of Transportation Accidents Occurring from WIPP Project Operations (1)

Accident Conditions	Number of Accidents in Lifetime of Repository				
	CH-TRU Rail	CH-TRU Truck	RH-TRU Rail	RH-TRU Truck	HLW Rail
Number of Shipments	3600	5200	1200	3100	86
All Accidents					
Total	65.	13.	20.	7.8	1.3
In New Mexico (2)	8.5	5.3	2.6	2.6	0.2
Design Level					
Total	0.26	0.013	0.041	0.0078	0.0025
In New Mexico	0.034	0.0053	0.0053	0.0026	0.00038
In New Mexico + irrigation (3)	0.0044	0.00069	0.00069	0.00033	0.000049
In New Mexico, irrigation + meteorology	0.00071	0.00011	0.00011	0.000054	0.0000078

(1) Derived from Reference 1 for 6 million cubic foot repository with 300 experimental HLW canisters.

(2) Accidents prorated to NM based on fraction of average mileage expected to be in the State.

(3) Percentage of highway miles bordered by irrigation assumed to be the same as for rail miles.

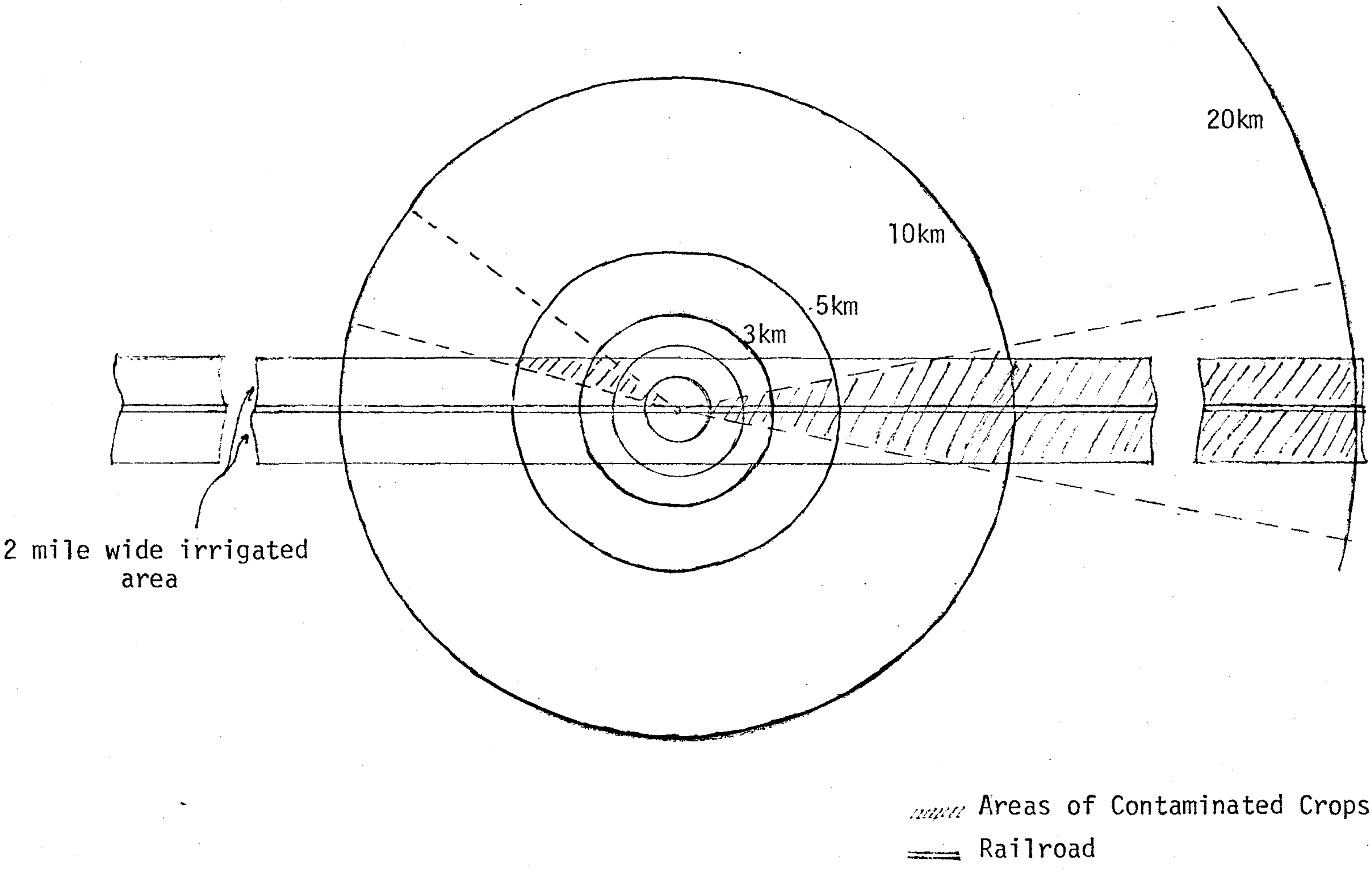

Figure C-1

Model Irrigated Area and Contamination Patterns

The maximum fraction of each zone that could contain crop land is shown in the last column of Table C-2. This would be for a condition where the wind was blowing along the track and at least 20 km of irrigated land lay downwind. The resulting dose would be about 150% greater than the average dose calculated here and would be expected to occur in about 7% of all accidents occurring in this 30-mile stretch.

Table C-2

Fraction of the Total Deposition in a Zone That is Expected to Fall on Crop Lands

Zone	Fraction of Zone With Crops	Area of Contaminated Crops (m^2) (1)	Maximum Fraction of Zone (2)
I	0.79	8.7+4	0.80
II	0.67	2.9+5	0.80
III	0.34	2.5+5	0.80
IV	0.20	4.7+5	0.80
V	0.070	7.6+5	0.78
VI	0.039	1.7+6	0.45

(1) area does not include the 26% of irrigated land planted in cotton;

(2) when wind is blowing down the railroad track and train is greater than 20 km upwind from the end of irrigation.

APPENDIX D

BENEFIT-COST TRADE-OFFS

This appendix demonstrates how one might make a benefit-cost analysis to determine when protective actions are warranted. Protective action levels calculated in this manner should be considered as guidelines for decision-making, not as binding values. In any specific case there may be reasons why protective actions are not taken (such as causing food shortages) or it may be convenient to take protective actions at lower levels. Also, the benefit-cost comparison can only be a crude one at best.

There are problems in precisely determining the cost of taking a specific action. It is appropriate to consider all costs that would occur as a result of the decision to take protective action. Other costs of the accident (such as extensive field monitoring and laboratory analyses to determine the extent and degree of contamination) that have been incurred before the decision or would be incurred even if a negative decision were made should not be included.

A benefit determination is even more approximate. The average number of rems of low-level ionizing radiation necessary to cause a statistical cancer death is uncertain within a factor of 10. The actual value of a human life is a theological and philosophical one rather than an economic one. Ideally, the amount of money society expends to save a human life should be similar regardless of the cause of death (e.g. one should be willing to spend as much money per statistical life saved by providing better ambulance service as by reducing radiation exposure). However, in practice little effort is made to treat risks equally since society perceives some types of risks as more objectionable than others.

The approach used in this appendix to determine the level where protective measures are cost-effective is to assign a dollar value to a person-rem of dose prevented. Values ranging from $10 to $1000 per person-rem avoided have been used in various analyses. The value chosen here is $100 per person-rem of whole body dose avoided. Since 2,000 to 20,000 person-rem of whole body dose are required for a statistical cancer death, a value of $100 per person-rem places a value of 0.2 to 2.0 million dollars on a statistical cancer death avoided. No additional credit is taken for avoidance of dose to the bone, liver, or other organs because: (a) much of the resulting health effects is already included in the whole body dose; and (b) the health effects per person-rem are much less than for whole body radiation.

Farm Family

Milk Pathway

A whole body dose of 0.10 person-rem would be obtained by the critical family from an intake of (1.8 + 6) pCi Cs-137. However, since this family cow is expected to produce an average of 17.1 ℓ/d and the family uses only 4.6 ℓ/d, it could be assumed that the excess milk was fed to neighboring families and would result in a total dose of 0.37 person-rem. If the value of a person-rem saved is taken as $100 and the retail cost of a liter of milk is 55 cents, then it is cost effective to condemn milk until:

$$\text{pCi} = .55\ \$/\ell\left(\frac{1.8 \times 10^{6}}{37}\right)\ \frac{\text{pCi}}{\$} = 27{,}000\ \text{pCi}/\ell \text{ of Cs-137}$$

However, since the initial activity in the milk is only 25,000 pCi/ℓ, it would never be cost effective to condemn milk following the RH-TRU accident. The HLW accident would cause an initial concentration of (1.6 + 8) pCi/ℓ and 99.95% could be avoided.

However, it would be even more cost-effective to remove the cow from contaminated pasture and provide stored (uncontaminated) feed. If the cost of feed were taken at \$0.20 per liter of milk the cows could be kept off pasture as long as the concentration in milk was $\geq$ 9,700 pCi/ℓ. Thus, it would be cost-effective to use uncontaminated feed for the RH-TRU accident until the concentration in the milk dropped to 9,700 pCi/ℓ. This would be for a period of 19 days and would save 79% of the dose. For the HLW accident it would be feasible to avoid 99.99% of the dose. Since the time for the residual pasture contamination to decay to 0.01% of its initial concentration is longer than the 30-day period assumed for ingesting contaminated feed, all of the HLW dose would theoretically be avoided.

Meat

The dose to the whole body from eating meat is 0.09 person-rem from the RH-TRU accident and 580 person-rem for the HLW accident. Since the family would eat 326 kg of meat in a year (with a replacement value of perhaps \$800-1000) it is obviously not cost-effective to condemn the meat for the RH-TRU accident, but it would be feasible for the HLW accident. Also, it will not be cost-effective to place the animals on stored feed for the RH-TRU accident. For the HLW accident (and with the assumption that the cost of supplemental feed is \$3.50 per cow per day, and two cows are being kept), the stored feed could be used until the fraction of the initial contamination that decays in a day is:

$$\frac{7.0\ \$/d}{58{,}000\ \$} = .00012\ A_o$$

This occurs when:

$$At = \frac{.00012\ A_o}{\left(1 - e^{\frac{-.693}{14}(1)}\right)} = .0025\ A_o$$

Since this time is well beyond the 30 days that pasture is assumed contaminated, all of the initial dose can be avoided from the HLW accident.

Produce

This food item delivers a whole body radiation dose to the farm family of 0.39 person rem from the RH-TRU accident and 2500 person-rem for the HLW accident. The amount of produce ingested is 854 kg, which might have a retail value as high as $800. In this case no action is justified for the RH-TRU accident. For the HLW accident it would be worthwhile to condemn the entire crop.

Summary

The examples of RH-TRU and HLW accidents indicate the full range of protective measures that are possible. For the RH-TRU release the only protective measure that can be justified is replacement of milk cow pasture with uncontaminated feed if one limits the negative value of a person-rem to $100. Thus, the farm family would be expected to accept most of the ingestion dose (0.50 person-rem of whole body radiation). However, the cost of avoiding all of this dose would be only about $1000 and may well be considered as "reasonably achievable". For the HLW accident the potential doses are so high that it is cost-effective to completely avoid the dose by condemnation and/or replacement with uncontaminated feed. Intermediate levels of contamination would justify protective measures that would eliminate varying percentages of the dose.

Population Doses

The extent that population doses could be avoided can be determined by the procedure described for the farm family.

RH-TRU Accident

The condemnation of wheat grown in Zone I could be justified (for a value of $100/person-rem) even though the maximum individual dose saving would be only about 200 mrem. This would reduce the population dose by 2.5 person-rem (9%) and the value of wheat lost would be about $200. No other protective actions would be justifiable. The impracticality of preventing the population dose is apparent when the crop value (for all 6 zones) of about $250,000 is compared to the residual population dose of 26.5 person-rem. Even the condemnation of crops in Zone II would cost about $27,000 for a dose reduction of only 11.4 person-rem.

HLW Accident

Contamination levels are high enough from this accident to justify condemnation of all food crops in all 6 zones. Feed grains grown in Zones I-V should not be used. Feed crops grown in Zone VI should not be fed to dairy cattle but are borderline for beef cattle and should be usable if they can be allowed to weather for a few extra weeks before harvesting.

Long-Term Exposure

It is apparent from Tables 2 and 3 that the predicted long-term (70 years) doses would not be high enough from CH-TRU or RH-TRU accidents to justify remedial measures. However, projected doses (Table 4) from the HLW accident are much too high in Zone I to be permitted. Even in the 70th year the external dose would be 2.8 rem/year and the ingestion doses would be several hundred millirem per year. The severity of the contamination decreases significantly in the outer zones, with the concentrations in Zones V and VI being only 2.2% and 0.4% of those in Zone I.

Avoiding long-term exposures from a HLW accident could be expensive. There are several possibilities: (1) complete abandonment and quarantine of the area; (2) removal of contaminated top soil; and (3) changes in land-use. The preferred choice will depend on the level of contamination and the relative value of land in various uses.

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