APPENDIX K

MODELING OF HUMAN HEALTH IMPACTS

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MODELING OF HUMAN HEALTH IMPACTS

1.0 INTRODUCTION

This appendix describes in greater detail the modeling performed to support the data presented in Section 3.3, IMPACT ON WORKER AND PUBLIC RISK. The sections in this appendix are described below. Section 1.0 describes the way scaling factors were used, a general discussion of how they were developed, and the relationships between the available data and the scaling factors developed. Section 2.0 presents the data used from the Waste Management Programmatic Environmental Impact Statement (PEIS). Section 3.0 presents a brief description of the waste volume data, the source, and use of the data. Section 4.0 is a discussion of the Full-Time Equivalent (FTE) curves, the development of scaling factors from the data in those curves, and the application of the derived scaling factors. Section 5.0 describes the site specific risk models and scaling factors developed from those models. Sections 2.0 through 5.0 deal primarily with modeling for waste handling and processing facilities throughout the U.S. Department of Energy (DOE) system. Section 6.0 details the models used to estimate the human health impacts from specific Waste Isolation Pilot Plant (WIPP) waste handling and disposal activities including aboveground waste handling, emplacement below ground, and installation of backfill materials after emplacement of the waste.

2.0 GENERAL SCALING PRINCIPLES USED IN SECTION 3.3

As described in Section 3.3.2.1 of the report, estimation of the impacts to the various groups for differing activities performed at multiple sites and combinations of sites requires very complex models and involves large data sets, both of which are beyond the needs and scope of this report. The method used to analyze the numerous combinations of waste processes and processing configurations was to develop scaling factors specific to the available analytical results. The PEIS data include DOE system-wide summations for an adequate range of risk endpoints but only for a limited number of processes and processing configurations (see Section 2.0 for a complete discussion of results available from the PEIS). Overall scaling factors are needed to apply to the site-wide risk data to model additional treatment facility configurations and additional types of processing. Risk factors are available for sites with a significant amount of transuranic (TRU) waste but only for certain combinations of risk factors. Modeling was performed to adjust the available data to account for more recent estimates of TRU waste currently available and estimated to be generated in the future. This allowed the development of system-wide scaling factors to be applied to the PEIS system-wide data for those processes and configurations applicable to the selected engineered alternatives (EA).

Additional modeling was required to adjust the individual site estimates of risk found in the PEIS for differences between processes and configurations in the PEIS and those analyzed in the EA report. This involved not only the modeling of waste processing of varying amounts of waste at processing facilities, but also risks involved with retrieving and preparing the waste for shipment to the waste processing facilities. In the case of alternates involving supercompaction of waste, data were combined from both the PEIS and another source to develop the scaling factors to be applied to the appropriate PEIS data. The new estimates of site risks were combined and used to calculate system-wide scaling factors to be applied to the most appropriate PEIS system-wide risk data.

3.0 PEIS DATA

The cases for which program-wide and individual facility risk data are available in the PEIS are described in Section 3.3.3 of the report. The March 1995 draft of the PEIS (DOE, 1995b) included program-wide risk data for the four cases that are used as the basis of the EA risk estimations by applying appropriate scaling factors. Tables K-1[1] through K-4 show the applicable system-wide data from the March draft of the PEIS.

The PEIS also listed site-specific risk data but did not use the same breakdown of risk parameters. Table K-5 shows the acronyms used to identify the sites in the remainder of the appendix. Tables K-6 through K-9 show the PEIS site-specific data for the four applicable cases. The fatalities shown for the individual sites include fatalities associated with both radiation exposures and physical hazards. The cancer incidence shown on these tables includes those associated with both radiation and chemical carcinogen exposures.

The waste volumes on which the PEIS risk estimates were based are shown in Table K-10. The source for these data was the November 4, 1994, draft of the PEIS (DOE, 1994a). For each site, the PEIS data included the total assumed to be in storage and an estimated annual generation rate. The total waste shown in the last column was calculated by multiplying the annual rate shown by the 20-year waste processing period and adding that to the waste in storage at that facility.

4.0 SCALING FACTORS FOR CO-LOCATED WORKERS AND OFF-SITE INDIVIDUALS

The major contributor to the risks for off-site personnel is the material released to the air during waste handling. That is also true for co-located worker personnel. The model assumes that air releases are a function of the process and throughput. The relationship between process and release rate is too complex to be addressed in this model so each process is treated uniquely. That is, there is no effort to use releases from shred and compact waste to estimate the releases from plasma processing. The model treats airborne releases as proportional to throughput. That is, if throughput is increased by 20 percent, the normal airborne releases also increase by 20 percent.

The airborne releases from a given process or module may be proportional to the waste throughput, but the impact of those releases is not. For a given amount of material released to the air, the impact on off-site personnel and co-located workers is a very complex function of meteorology, population density, and distribution around the facility, and the location of the individuals who may be candidates for the most exposed individual. However, for long-term

[1]Please note that throughout this appendix, the following notation is frequently used in tables: 1.23e-4 is equivalent to 1.23×10^{-4}.

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TABLE K-1

SYSTEM-WIDE HUMAN HEALTH IMPACTS MEET WIPP WAC AT 10 LOCATIONS PEIS CASE 4

Receptor	Endpoint	Radionuclides	Hazardous Chemicals: Carcinogens	Hazardous Chemicals: Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	2.30e-02			
	Excess Fatalities	1.10e-05			
	Excess Cancers		3.40e-08		
Most Exposed Co-located Individual	Dose (rem)	9.50e-06			
	Excess Risk	4.80e-09			
	Excess Cancers		8.90e-12		
	Hazard Index			1.40e-09	
Offsite Population	Dose (person-rem)	2.40e-01			
	Excess Fatalities	1.20e-04			
	Excess Cancers		1.30e-07		
Most Exposed Offsite Individual	Dose (rem)	1.10e-05			
	Excess Risk	5.70e-09			
	Excess Cancers		2.80e-12		
	Hazard Index			1.50e-10	
Workers	Dose (FTE-rem)	1.50e+03			
	Excess Fatalities	6.00e-01			
	Excess Cancers		1.00e-05		
	Exposure Index			3.10e-05	
	Construction Fatalities				7.80e-01
	Construction Injuries				6.70e+02
	Operations Fatalities				1.40e+00
	Operations Injuries				5.90e+02

1 TABLE K-2

SYSTEM-WIDE HUMAN HEALTH IMPACTS
SHRED AND GROUT AT 5 LOCATIONS
PEIS CASE 5

Receptor	Endpoint	Radionuclides	Hazardous Chemicals		Physical Hazards
			Carcinogens	Noncarcinogens	
Co-located Workers	Dose (person-rem)	3.20e-01			
	Excess Fatalities	1.60e-05			
	Excess Cancers		5.80e-08		
Most Exposed Co-located Individual	Dose (rem)	1.50e-05			
	Excess Risk	7.70e-09			
	Excess Cancers		1.50e-11		
	Hazard Index			2.50e-09	
Offsite Population	Dose (person-rem)	3.40e-01			
	Excess Fatalities	1.70e-04			
	Excess Cancers		2.30e-07		
Most Exposed Offsite Individual	Dose (rem)	1.40e-05			
	Excess Risk	6.90e-09			
	Excess Cancers		4.80e-12		
	Hazard Index			2.20e-10	
Workers	Dose (FTE-rem)	1.60e+03			
	Excess Fatalities	6.30e-01			
	Excess Cancers		2.00e-05		
	Exposure Index			3.10e-05	
	Construction Fatalities				1.00e+00
	Construction Injuries				8.70e+02
	Operations Fatalities				1.70e+00
	Operations Injuries				7.50e+02

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TABLE K-3

SYSTEM-WIDE HUMAN HEALTH IMPACTS
INCINERATE AT 5 LOCATIONS
PEIS CASE 6

			Hazardous Chemicals		
Receptor	Endpoint	Radionuclides	Carcinogens	Noncarcinogens	Physical Hazards
Co-located Workers	Dose (person-rem)	6.90e+02			
	Excess Fatalities	3.40e-01			
	Excess Cancers		5.60e-08		
Most Exposed Co-located Individual	Dose (rem)	4.90e-01			
	Excess Risk	2.40e-04			
	Excess Cancers		1.50e-11		
	Hazard Index			1.30e-07	
Offsite Population	Dose (person-rem)	6.70e+03			
	Excess Fatalities	3.30e+00			
	Excess Cancers		2.20e-07		
Most Exposed Offsite Individual	Dose (rem)	1.30e-01			
	Excess Risk	6.70e-05			
	Excess Cancers		4.80e-12		
	Hazard Index			1.10e-08	
Workers	Dose (FTE-rem)	1.50e+03			
	Excess Fatalities	6.10e-01			
	Excess Cancers		2.50e-05		
	Exposure Index			8.60e-04	
	Construction Fatalities				1.80e+00
	Construction Injuries				1.50e+03
	Operations Fatalities				2.60e+00
	Operations Injuries				1.10e+03

1 **TABLE K-4**

SYSTEM-WIDE HUMAN HEALTH IMPACTS
INCINERATE AT 1 LOCATION
PEIS CASE 9

Receptor	Endpoint	Radionuclides	Hazardous Chemicals		Physical Hazards
			Carcinogens	Noncarcinogens	
Co-located Workers	Dose (person-rem)	9.90e+01			
	Excess Fatalities	5.00e-02			
	Excess Cancers		6.60e-08		
Most Exposed Co-located Individual	Dose (rem)	3.80e-01			
	Excess Risk	1.90e-04			
	Excess Cancers		1.50e-11		
	Hazard Index			4.60e-07	
Offsite Population	Dose (person-rem)	1.20e+03			
	Excess Fatalities	6.10e-01			
	Excess Cancers		2.30e-07		
Most Exposed Offsite Individual	Dose (rem)	3.20e-01			
	Excess Risk	1.60e-04			
	Excess Cancers		4.80e-12		
	Hazard Index			7.60e-08	
Workers	Dose (FTE-rem)	1.70e+03			
	Excess Fatalities	6.80e-01			
	Excess Cancers		8.60e-05		
	Exposure Index			1.10e-03	
	Construction Fatalities				1.20e+00
	Construction Injuries				1.10e+03
	Operations Fatalities				1.80e+00
	Operations Injuries				7.90e+02

1 **TABLE K-5**

FACILITY ACRONYMS

Department of Energy Facility	Acronym
Ames Laboratory	Ames
Argonne National Laboratory-East	ANL-E
Bettes	BT
Energy Technology Engineering Center	ETEC
Hanford	Hanford
Idaho National Engineering Laboratory	INEL
Knolls Atomic Propulsion Laboratory	KAPL
Los Alamos National Laboratory	LANL
Lawrence Berkeley Laboratory	LBL
Lawrence Livermore National Laboratory	LLNL
Mound Plant	Mound
University of Missouri at Columbia	UMC
Nevada Test Site	NTS
Oak Ridge National Laboratory	ORNL
Paducah Gaseous Diffusion Plant	PGDP
Pantex Plant	Pantex
Rocky Flats Environmental Technology Site	RFETS
Sandia National Laboratories	SNL
Savannah River Site	SRS

1 # TABLE K-6

PEIS RISK DATA
TREAT TO MEET WIPP WAC (CASE 4)

	Fatalities			Cancer Incidence		
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.80e-06	9.90e-12	1.00e-01	6.10e-06	3.40e-11	3.00e-02
Hanford	1.40e-06	2.90e-11	3.30e-01	4.80e-06	9.90e-11	3.60e-01
INEL	1.10e-06	1.40e-10	1.00e+00	3.80e-06	4.80e-10	8.70e-01
LANL	5.40e-05	5.70e-09	4.90e-01	1.80e-04	1.90e-08	5.00e-01
LBL	6.30e-09	9.40e-14	8.40e-03	2.10e-08	3.20e-13	7.60e-09
LLNL	3.50e-06	5.70e-11	1.10e-01	1.20e-05	2.00e-10	2.00e-03
Mound	8.40e-07	4.80e-11	3.20e-02	2.90e-06	1.60e-10	4.80e-04
NTS	1.10e-10	3.00e-14	6.80e-02	3.90e-10	1.00e-13	7.30e-04
ORNL	0.00e+00	0.00e+00	4.70e-04	0.00e+00	0.00e+00	7.90e-14
PGDP	3.50e-09	3.50e-09	1.30e-02	1.20e-08	1.30e-12	1.60e-06
RFETS	9.30e-06	1.30e-10	2.20e-01	3.20e-05	4.30e-10	2.70e-02
SNL	2.70e-09	1.10e-13	8.70e-03	9.10e-09	3.60e-13	2.10e-08
SRS	5.10e-05	4.80e-10	3.50e-01	1.70e-04	1.60e-09	3.10e-01

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TABLE K-7

PEIS RISK DATA
SHRED AND GROUT (CASE 5)

		Fatalities			Cancer Incidence	
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.50e-06	8.50e-12	4.50e-02	5.20e-06	2.90e-11	3.00e-02
Hanford	2.30e-06	4.70e-11	5.30e-01	7.70e-06	1.60e-10	4.50e-01
INEL	1.40e-06	1.80e-10	1.20e+00	4.90e-06	6.00e-10	8.70e-01
LANL	6.50e-05	6.90e-09	6.40e-01	2.20e-04	2.30e-08	5.00e-01
LBL	9.80e-09	1.50e-13	1.80e-04	3.40e-08	5.00e-13	7.50e-09
LLNL	3.60e-06	5.90e-11	5.70e-02	1.30e-05	2.10e-10	2.00e-03
Mound	1.50e-06	8.60e-11	1.40e-02	5.10e-06	2.90e-10	4.70e-04
NTS	1.50e-10	3.90e-14	4.20e-02	5.10e-10	1.30e-13	7.00e-04
ORNL						
PGDP	5.30e-09	5.90e-13	2.50e-03	1.80e-08	2.00e-12	1.70e-06
RFETS	1.50e-05	2.00e-10	3.40e-01	5.10e-05	6.90e-10	2.70e-02
SNL	3.50e-09	1.40e-13	4.50e-04	1.20e-08	4.80e-13	2.10e-08
SRS	8.10e-05	7.70e-10	4.60e-01	2.80e-04	2.60e-09	3.10e-01

TABLE K-8

PEIS RISK DATA
INCINERATE AT 5 SITES (CASE 6)

		Fatalities			Cancer Incidence	
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.50e-06	8.50e-12	4.50e-02	5.20e-06	2.90e-11	3.00e-02
Hanford	4.50e-03	9.40e-08	8.10e-01	1.60e-02	3.20e-07	4.90e-01
INEL	7.30e-03	9.10e-07	1.80e+00	2.50e-02	3.10e-06	8.30e-01
LANL	6.40e-01	6.70e-05	9.60e-01	2.20e+00	2.30e-04	4.80e-01
LBL	9.80e-09	1.50e-13	1.80e-04	3.40e-08	5.00e-13	7.50e-09
LLNL	3.60e-06	5.90e-11	5.70e-02	1.30e-05	2.10e-10	2.00e-03
Mound	1.50e-06	8.60e-11	1.40e-02	5.10e-06	2.90e-10	4.70e-04
NTS	1.50e-10	3.90e-14	4.20e-02	5.10e-10	1.30e-13	7.00e-04
ORNL						
PGDP	5.30e-09	5.90e-13	2.50e-03	1.80e-08	2.00e-12	1.70e-06
RFETS	1.10e-01	1.50e-06	5.70e-01	3.70e-01	5.00e-06	2.50e-02
SNL	3.50e-09	1.40e-13	4.50e-04	1.20e-08	4.80e-13	2.10e-08
SRS	2.60e+00	2.40e-05	6.80e-01	8.80e+00	8.20e-05	3.00e-01

TABLE K-9

PEIS RISK DATA
INCINERATE AT 1 SITE (CASE 9)

		Fatalities			Cancer Incidence	
Site	Public	Offsite MEI	Worker	Public	Offsite MEI	Public
ANL-E	1.50e-06	8.50e-12	4.50e-02	5.20e-06	2.90e-11	3.00e-02
Hanford	1.30e-06	2.70e-11	2.40e-01	4.40e-06	9.10e-11	3.30e-01
INEL	1.60e-06	2.00e-10	7.60e-01	5.30e-06	6.60e-10	8.50e-01
LANL	7.10e-05	7.40e-09	3.80e-01	2.40e-04	2.50e-08	5.00e-01
LBL	9.80e-09	1.50e-13	1.80e-04	3.40e-08	5.00e-13	7.50e-09
LLNL	3.60e-06	5.90e-11	5.70e-02	1.30e-05	2.10e-10	2.00e-03
Mound	1.50e-06	8.60e-11	1.40e-02	5.10e-06	2.90e-10	4.70e-04
NTS	1.50e-10	3.90e-14	4.20e-02	5.10e-10	1.30e-13	7.00e-04
ORNL						
PGDP	5.30e-09	5.90e-13	2.50e-03	1.80e-08	2.00e-12	1.70e-06
RFETS	1.20e-05	1.60e-10	1.60e-01	4.10e-05	5.60e-10	1.00e-01
SNL	3.50e-09	1.40e-13	4.50e-04	1.20e-08	4.80e-13	2.10e-08
SRS	6.40e-05	6.00e-10	2.20e-01	2.20e-04	2.00e-09	3.30e-01

TABLE K-10

PEIS TRANSURANIC WASTE VOLUMES
TOTAL WASTE IN STORAGE AND GENERATED OVER 20 YEARS

Site	Stored Waste (cubic meters)	Annual Generation (cubic meters / year)	Total (cubic meters)
ANL-E	15.00	47.00	955.00
Hanford	9987.00	465.00	19287.00
INEL	38095.00	14.00	38375.00
LANL	8199.00	125.00	10699.00
LBL	0.80	0.01	1.00
LLNL	200.00	74.00	1680.00
Mound	255.00	60.00	1455.00
NTS	612.00	0.00	612.00
ORNL	670.00	18.00	1030.00
PGDP	14.00	0.00	14.00
RFETS	1480.00	238.00	6240.00
SNL	1.00	0.00	1.00
SRS	5371.00	605.00	17471.00
UMC	0.10	2.00	40.10
Total	64899.90	1648.01	97860.10

releases, the impacts at individual sites may be modeled as a function of waste throughput.

Therefore, the modeling is performed for each process at each site and the impacts combined to establish a combined impact for all facilities.

Waste throughput at each site may vary for three reasons. One reason is that the total amount of waste processed in the PEIS would not be the amount needed to fill WIPP to capacity. The second reason is that more recent estimates of waste currently stored at sites or likely to be generated at sites have a different distribution throughout the DOE system than were used in the PEIS calculations. Thirdly, as the consolidation configuration changes, the throughput at individual sites varies from that used in the PEIS. For example, the PEIS Case 5 involves transporting waste from throughout the system to five selected sites where it is processed by shredding and grouting the waste. More recent data on waste volumes and estimated generation make the amounts to be treated at each of the five selected sites different in this model from the PEIS model. The EA model must also assume a greater total waste, distributed among the five sites, to meet WIPP's design limit. Finally, this model must also estimate the impact of the shredding and grouting of waste at 10 selected sites and a single site.

The first two volume effects are treated simultaneously by comparing the waste to be handled at each site in the PEIS, without regard to what process is to be performed, to that estimated to be handled in the EA model. The latter data were determined as part of the estimation of cost and schedule and are explained in Section 3.7.2.1 of the report. The EA scaled waste totals are shown in Table K-11. A linear scaling factor was determined for each site by dividing the EA scaled throughput for each site by the PEIS throughput for that site.

The volume effect from consolidating waste at various sites was performed in an analogous way for each consolidation configuration. For each site where waste is to be consolidated, the sum of waste from all sites contributing to that site was determined. Table K-12 shows the consolidation configurations used. This was done based on both the PEIS waste total for each site and the EA waste total. Scaling factors for each consolidation configuration were developed by dividing the total EA throughput by the PEIS throughput for the same combination of sites. For example, in the distributed configuration, where waste processing is performed at 10 sites, Hanford processes only it's own waste. Therefore, the volume scaling factor for Hanford in the distributed configuration (10 sites) is

$$\text{Scaling Factor}_{\text{Hanford, 10 site}} = \frac{\text{EA Throughput}_{\text{Hanford}}}{\text{PEIS Throughput}_{\text{Hanford}}} = \frac{48044.55}{19287.00} = 2.49$$

In the regional (five site) configuration, the wastes from Lawrence Berkeley Laboratory (LBL) and Lawrence Livermore National Laboratory (LLNL) are shipped to Hanford for treatment. The scaling factor for Hanford in the regional configuration (five sites) is

These scaling factors are then used to estimate corrections to the PEIS risk data by multiplying the appropriate PEIS risk factor for the Hanford site by the desired scaling factor. See

TABLE K-11

ENGINEERED ALTERNATIVES SCALED TOTAL WASTE VOLUMES TOTAL WASTE IN STORAGE AND GENERATED OVER 20 YEARS

Site	Total Waste (cubic meters)
Ames	0.13
ANL-E	31.31
BT	159.90
ETEC	8.61
Hanford	48044.55
INEL	39203.61
KAPL	2.40
LANL	20805.18
LBL	6.57
LLNL	1158.04
Mound	263.29
UMC	2.14
NTS	612.60
ORNL	1124.94
PGDP	2.10
Pantex	0.62
RFETS	6249.25
SNL	17.11
SRS	26653.39
Total	144345.73

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TABLE K-12

WIPP ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS
TRU WASTE CONSOLIDATION CONFIGURATIONS

Consolidation Configuration	Processing Site	Sites Supplying Waste
Distributed (10 sites)	ANL-E	Ames, ANL-E, UMC
	Hanford	Hanford
	INEL	INEL
	LANL	LANL, Pantex, SNL
	LLNL	LBL, LLNL
	Mound	BT, KAPL, Mound, WVDP
	NTS	ETEC, NTS
	ORNL	ORNL, Paducah
	RFETS	RFETS
	SRS	SRS
Regional (5 Sites)	Hanford	Hanford, LBL, LLNL
	INEL	ETEC, INEL, NTS
	LANL	LANL, Pantex, SNL
	RFETS	RFETS
	SRS	Ames, ANL-E, BT, KAPL, Mound, MU, ORNL, Paducah, SRS, WVDP
Centralized (1 Site)	WIPP	All sites

$$\text{Scaling Factor}_{Hanford,\ 5\ site} = \frac{\text{EA Throughput}_{Hanford+LBL+LLNL}}{\text{PEIS Throughput}_{Hanford+LBL+LLNL}}$$

$$= \frac{48044.55 + 6.57 + 1158.04}{19287.00 + 1.00 + 1680.00}$$

$$= 2.35$$

Section 5.0 of this appendix for a more extended explanation of the use of the scaling factors.

5.0 SCALING FACTORS FOR WASTE HANDLING WORKERS

The primary influences on the impacts to workers are materials released to the working environment, especially the air, and external exposures from radioactive material, especially from waste and processing equipment. Exposures from these sources are more a function of the time spent in the work area than the amount of material processed. The amount of work time is expressed in FTEs. The number of injuries and fatalities from physical hazards are also a function of the FTEs. FTEs are a function of waste throughput, but because of volume efficiencies and other factors, the function is not linear with respect to waste throughput. Therefore, scaling factors for adjusting the PEIS risk data for workers are based on variations in the total number of FTEs projected for the 20-year processing facility lifetime.

The PEIS analysis used selections of individual process modules (waste receiving and inspection, waste compaction, incineration, etc.) to model different types of waste process streams. Curves of FTEs as a function of waste throughput were developed to model each module (Feizollahi and Shropshire, 1994). For each type of module, curves have been plotted for construction, preoperational activities, 10- and 20-year operations and maintenance (O&M), decontamination and decommissioning (D&D), and 10- and 20-year total FTEs. Polynomial equations were developed to fit each of the curves. Table K-13 shows an example of the curves and curve equations.

Two of the components of the greatest importance in estimating worker impacts are the 20-year O&M total FTEs and the construction FTEs. The O&M activities are not only the major contributor to the total FTEs, but it is during O&M activities that most worker exposures are expected to occur. Construction activities are of particular importance because they involve a large number of FTEs and often represent a time of increased risks from physical hazards. Equations were used to calculated O&M and construction FTEs for the following modules: waste retrieval, receipt and inspection, waste characterization, waste compaction, shred and grout, incineration, vitrification, and certification and shipping. Table K-14 lists the equations developed for each of the modules. The equations were used to calculate the total FTEs required for each type of module at each site for each consolidation configuration based on the throughputs used in the PEIS. Because the PEIS throughputs were given in cubic meters, the conversion to kilograms per hour (kg/hr) was made based on 20 years of operation, 4,032 hours per year, and an average waste density of 594 kg/cubic meter. Similar calculations were also performed based on the mass-flows representing the EA volumes shown in Table K-11.

TABLE K-13

FULL TIME EQUIVALENTS (FTES) AS A FUNCTION OF WASTE THROUGHPUT
WASTE RECEIPT AND INSPECTION

TABLE K-14

MODELING
FULL TIME EQUIVALENTS AS A FUNCTION OF WASTE THROUGHPUT (KG/HR)

Waste Handling Module	Construction Curve Fit Equation	O&M Curve Fit Equation
Retrieval	1.79e-0x + 10.1	3.64x + 181.37
Receipt and Inspection	-3.3e-6x^2 +4.68e-2x + 9.37	4.50e-9x^3 - 6.00e-5x^2 +3.45e-1x + 16.27
Waste Characterization	4.78x + 156.89	9.56x + 313.77
Compaction	1.13e-1x +170.18	1.70e-7x^3 - 6.70e-4x^2 + 1.20x + 491.7
Shred and Grout	-3.9e-5x^2 + 1.85e-1x + 214.4	9.1e-8x^3 - 3.80e-4x^2 + 6.13e-1x + 264.4
Incineration	3.14e-1x + 275	1.09x + 767.2
Vitrification	-3.5e-8x^4 + 4.1e-5x^3 - 0.0173x^2 +3.582x +480.1	1.61e-3x^2 +2.95x + 937
Certification and Shipping	1.22e-2x + 45.752	1.02e-1x + 298.61

System-wide FTE scaling factors were calculated for each alternative case and configuration. The methods used to calculate the scaling factor were the same for each case and configuration but the details of what combination of modules and waste throughputs were used were different for each case and configuration. The following paragraphs describe the common method used. Details are presented in tabular form. All calculations were performed for both construction and O&M scaling factors. Only one set of calculations will be described. The only difference between the calculations for construction and O&M scaling factors is the values for the individual FTE totals, the initial database.

For each PEIS case, modules were selected that would be used in the particular waste process. Table K-15 lists the modules used for each PEIS case. It was assumed that the process of shipping waste to another site for treatment, including the necessary inspections, is numerically equivalent in FTEs and exposures to the receipt and inspection of incoming waste at a processing facility. For each PEIS case, the total FTEs were calculated for each site by summing the FTEs from the individual modules. FTE site totals were calculated for each waste processing used in the alternatives in the same way as the PEIS totals. Table K-15 shows which modules were used in each EA waste processing.

Site FTE scaling factors were calculated for each EA waste process and each consolidation configuration. Whenever possible, the site FTE total for the EA waste process was divided by the site FTE total from the equivalent PEIS case. However, there are more combinations of EA waste processes and consolidation configurations than there are PEIS cases that are equivalent. In these cases, the ratio was formed between EA and PEIS cases that involved different consolidation configurations or between two EA alternatives, one of which was established by comparing it to an equivalent PEIS case. Table K-16 lists the combinations of cases used to assess each alternative and consolidation configuration.

It should be noted that not all modules apply to each site in a particular PEIS case or EA alternative; nor are the EA and PEIS sets of modules necessarily the same. Each site must be considered individually in each waste processing and configuration combination. As an example of how modules were combined, Table K-17 displays the module combinations used to establish the FTE scaling factor for plasma processing at 10 sites by comparing FTEs for EA modules at 10 sites with the PEIS modules at 5 sites.

As described in Section 5.0, the site-specific scaling factors were used to adjust the PEIS-based worker risk estimates.

6.0 SYSTEM-WIDE SCALING FACTORS

6.1 Volume-based Scaling Factors

In order to extend the PEIS system-wide risk estimates, as shown in Tables K-1 through K-4, to additional consolidation configurations and processes, the analysis model must provide system-wide scaling factors. These were developed by comparing the total of the PEIS site risk results with the totals of the scaled site-specific data. The effect is to produce a weighted average of the individual site scaling factor for co-located worker/off-site personnel risks and for worker risks for each waste process and consolidation configuration. As an example, Table K-18 shows the

TABLE K-15

TRU WASTE HANDLING MODULES USED TO MODEL WASTE PROCESSING PEIS CASES AND ENGINEERED ALTERNATIVES

	RETRV[1]	INSHP[2]	RCINS[3]	GROUT[4]	CSHIP[5]	CMPCT[6]	INCIN[7]	WCHA[8]	VITRFY[9]
PEIS									
Treat to Meet WIPP WAC	●				●			●	
Shred and Grout	●	●	●	●	●				
Incinerate	●	●	●		●		●		
Engineered Alternatives									
Baseline	●				●			●	
Shred and Grout	●	●	●	●	●				
Incinerate	●	●	●		●				●
Supercompaction	●	●	●		●	●			

[1]Waste Retrieval
[2]Waste Inspection and Shipping (Numerically identical to Waste Receipt and Inspection)
[3]Waste Receipt and Inspection
[4]Shred and Grout
[5]Certification and Shipping
[6]Compaction
[7]Incineration
[8]Waste Characterization
[9]Vitrification

1

TABLE K-16

TRU WASTE FULL-TIME EQUIVALENT SCALING FACTORS CASES USED FOR EACH WASTE PROCESS AND CONSOLIDATION CONFIGURATION

Treatment Process	Configuration	FTE Modules for Base Numbers	FTE Modules for Scaled Numbers
Baseline	10 sites	PEIS Case 4	EA Scaled for all sites
Supercompaction	10 sites	Scaled Shred & Grout at 10 sites	Scaled Supercompaction at 10 sites
Supercompaction	5 sites	Scaled Shred & Grout at 5 sites	Scaled Supercompaction at 5 sites
Supercompaction	1 site	Scaled Shred & Grout at 1 site	Scaled Supercompaction at 1 site
Shred and Compact	10 sites	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 10 sites
Shred and Compact	5 sites	PEIS Shred & Grout at 5 sites	Scaled Shred & Grout at 5 sites
Shred and Compact	1 site	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 1 site
Plasma Processing	10 sites	PEIS Vitrify at 5 sites	Scaled Vitrify at 10 sites
Plasma Processing	5 sites	PEIS Incinerate at 5 sites	Scaled up Vitrify at 5 sites
Plasma Processing	1 site	PEIS Incinerate at 1 site	Scaled up Vitrify at 1 site
Shred and Add Clay	10 sites	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 10 sites
Shred and Add Clay	5 sites	PEIS Shred & Grout at 5 sites	Scaled Shred & Grout at 5 sites
Shred and Add Clay	1 site	Scaled Shred & Grout at 5 sites	Scaled Shred & Grout at 1 site

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TABLE K-17

TRU WASTE HANDLING MODULES USED TO MODEL WASTE PROCESSING INCINERATION AT 10 SITES COMPARED TO PEIS INCINERATION AT 5 SITES

	PEIS Incineration at 5 Sites					Engineered Alternatives Incineration at 10 Sites				
Location[1]	RETRV[2]	INSHP[3]	RCINS[4]	VITRFY[5]	CSHIP[6]	RETRV	INSHP	RCINS	VITRFY	CSHIP
ANL-E	•	•				•		•	•	•
Hanford	•		•	•	•	•		•	•	•
INEL	•		•	•	•	•		•	•	•
LANL	•		•	•	•	•		•	•	•
LBL	•	•				•	•			
LLNL	•	•				•		•	•	•
Mound	•	•				•		•	•	•
NTS	•	•				•		•	•	•
ORNL	•	•				•		•	•	•
PGDP	•	•				•	•			
RFETS	•		•	•	•	•		•	•	•
SNL	•	•				•	•			
SRS	•		•	•	•	•		•	•	•

[1]See Table XX-5
[2]Waste Retrieval
[3]Waste Inspection and Shipping
[4]Waste Receipt and Inspection
[5]Vitrification
[6]Certification and Shipping

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TABLE K-18

ENGINEERED ALTERNATIVES HUMAN HEALTH IMPACTS CALCULATION OF SYSTEM-WIDE SCALING FACTORS FOR BASELINE

	PEIS Risk Value						Volume Scaling Factor	FTE Scaling Factor	Scaled Risk Value					
	Fatalities			Cancer Incidence					Fatalities			Cancer Incidence		
Location	Public	Offsite MEI	Worker	Public	Offsite MEI	Worker			Public	Offsite MEI	Worker	Public	Offsite MEI	Worker
ANL-E	1.80e-06	9.90e-12	1.00e-01	6.10e-06	3.40e-11	3.00e-02	0.03	0.89	5.90e-08	3.25e-13	8.89e-02	2.00e-07	1.11e-12	2.67e-02
Hanford	1.40e-06	2.90e-11	3.30e-01	4.80e-06	9.90e-11	3.60e-01	2.49	1.97	3.49e-06	7.22e-11	6.49e-01	1.20e-05	2.47e-10	7.08e-01
INEL	1.10e-06	1.40e-10	1.00e+00	3.80e-06	4.80e-10	8.70e-01	1.02	1.02	1.12e-06	1.43e-10	1.02e+00	3.88e-06	4.90e-10	8.85e-01
LANL	5.40e-05	5.70e-09	4.90e-01	1.80e-04	1.90e-08	5.00e-01	1.94	1.48	1.05e-04	1.11e-08	7.25e-01	3.50e-04	3.69e-08	7.40e-01
LBL	6.30e-09	9.40e-14	8.40e-03	2.10e-08	3.20e-13	7.60e-09	6.57	1.00	4.14e-08	6.17e-13	8.41e-03	1.38e-07	2.10e-12	7.61e-09
LLNL	3.50e-06	5.70e-11	1.10e-01	1.20e-05	2.00e-10	2.00e-03	0.69	0.96	2.41e-06	3.93e-11	1.06e-01	8.27e-06	1.38e-10	1.93e-03
Mound	8.40e-07	4.80e-11	3.20e-02	2.90e-06	1.60e-10	4.80e-04	0.18	0.88	1.52e-07	8.69e-12	2.83e-02	5.25e-07	2.90e-11	4.24e-04
NTS	1.10e-10	3.00e-14	6.80e-02	3.90e-10	1.00e-13	7.30e-04	1.00	1.00	1.10e-10	3.00e-14	6.80e-02	3.90e-10	1.00e-13	7.30e-04
ORNL	0.00e0	0.00e0	4.70e-04	0.00e0	0.00e0	7.90e-14	1.09	1.01	0.00e0	0.00e0	4.76e-04	0.00e0	0.00e0	7.99e-14
PGDP	3.50e-09	3.50e-09	1.30e-02	1.20e-08	1.30e-12	1.60e-06	0.15	1.00	5.25e-10	5.25e-10	1.30e-02	1.80e-09	1.95e-13	1.60e-06
RFETS	9.30e-06	1.30e-10	2.20e-01	3.20e-05	4.30e-10	2.70e-02	1.00	1.00	9.31e-06	1.30e-10	2.20e-01	3.20e-05	4.31e-10	2.70e-02
SNL	2.70e-09	1.10e-13	8.70e-03	9.10e-09	3.60e-13	2.10e-08	17.11	1.00	4.62e-08	1.88e-12	8.72e-03	1.56e-07	6.16e-12	2.10e-08
SRS	5.10e-05	4.80e-10	3.50e-01	1.70e-04	1.60e-09	3.10e-01	1.53	1.38	7.78e-05	7.32e-10	4.83e-01	2.59e-04	2.44e-09	4.27e-01
Total	1.23e-04		2.73e+00	4.12e-04		2.10e+00			1.99e-04		3.42e+00	6.67e-04		2.82e+00
Maximum										1.11e-08			3.69e-08	
System-Wide Scaling Factor									1.62		1.25	1.62		1.34

calculation of the effective scaling factors for the Baseline. The PEIS values are those from PEIS Case 4 (also shown on Table K-6). The Volume Scaling Factor column is made up of the site-specific scaling factors for the Baseline calculated as described in Section 3.0. The FTE Scaling Factors are those calculated for the Baseline as described in Section 4.0. The Scaled Risk Values for the public and off-site maximum exposed individual (MEI) are calculated by multiplying the equivalent PEIS risk value by the appropriate Volume Scaling Factor. The Scaled Risk Values for the workers are calculated by multiplying the equivalent PEIS worker risk values by the appropriate FTE Scaling Factor. The System-Wide Scaling Factor is calculated for the public and worker risk values by dividing the total Scaled Risk Value for all sites by the total PEIS Risk Value summed over all sites. A weighted average risk value is not meaningful for the off-site MEI. Instead, the site with the maximum value for the scaled risk is reported as the off-site MEI risk.

In addition to the Baseline, three other waste processing alternatives have PEIS equivalents and use the same calculation method: Shred and Grout at five sites, Incineration at five sites, and Incineration at one site.

6.2 Supercompaction Scaling Factors

The system-wide scaling factors for the three consolidation configurations for supercompaction are calculated using a single technique. Because supercompaction does not add to the airborne releases, the public and off-site MEI risk numbers are the same as for the respective configurations of Shred and Grout. The worker risk estimates are calculated using the following formulas:

$$\textit{Worker cancers} = \textit{shred \& grout worker cancers} + (\textit{Cancer Risk Factor} \times \textit{supercompactor FTEs})$$
$$\textit{Worker fatalities} = \textit{shred \& grout worker fatalities} + (\textit{Fatality Risk Factor} \times \textit{supercompactor FTEs})$$

where

$$\textit{Cancer Risk Factor} = \textit{SARF doses} \times \frac{\textit{ICRP Cancer Risk Coefficent}}{\textit{SARF FTEs}}$$
$$\textit{Fatality Risk Factor} = \textit{SARF doses} \times \frac{\textit{ICRP Fatality Risk Coefficent}}{\textit{SARF FTEs}}$$

and

$$\begin{array}{l} \textit{ICRP Cancer Risk Coefficient} = 8.00 \times 10^{-5} \\ \textit{ICRP Fatality Risk Coefficient} = 4.00 \times 10^{-4} \end{array} \quad \text{(ICRP,1990)}$$

The supercompactor FTEs are calculated as described in Section 4.0. Supercompaction and Repackaing Facility doses and FTEs are taken from the environmental assessment of the supercompactor at the Rocky Flats Environmental Technology Site (DOE, 1990a).

6.3 Scaling Factors for Significant Configuration Cases

Three of the consolidation configurations did not parallel PEIS configurations: Shred and Grout at 10 sites, Shred and Grout at 1 site, and Incineration at 10 sites. In these circumstances, the calculation of each site was analyzed separately and the sum of the risk factors for all sites was used to calculate the system-wide scaling factors. The calculation methods for each site could be classed as one of four types of formulas.

6.3.1 Site Actions Unchanged from Other Cases

Five sites (LANL, LBL, PGDP, RFETS, and SNL) do not change activities between regional consolidation (5 sites) and distributed (10 sites). In these circumstances, all the risk values remain the same so data used in the regional configuration was used in the distributed configuration.

6.3.2 Site Actions Involve Only Retrieval and Shipping

With the exception of the WIPP, all sites in the Shred and Grout at one site perform exactly the same activities as they do for incinerate at one site, PEIS Case 9. Because the activities and volumes involved are the same, all non-WIPP risk values are the same in Shred and Grout at one site and Incinerate at one site.

6.3.3 Waste Volume Adjustments

Five of the processing sites in the distributed (10 site) configuration are also processing sites in the regional (5 site) configuration. These five sites perform the same activities and have the same facilities. Only the volume processed is changed. The risk values for these five sites were calculated by applying the correct scaling factors in the same manner as described in Section 5.1 except that the scaled regional risk values (which are based on PEIS values) are used in place of the PEIS values.

6.3.4 Process Ratio Adjustments

The remaining sites in these three configurations are designated as waste processing sites for a particular process in the EA but not in the PEIS. Because FTE curves were available for the necessary processes and worker impacts are not dependant on site characteristics like the public or co-located worker impacts, the FTE Scale Factor was calculated and applied as described in Section 5.3.3. To permit estimation of the public and co-located worker risk values, the concept of process ratio was introduced.

For any given site, the impact on the public and co-located workers was modeled at a function of the total releases from the facility. The risks values are modeled as a function of the process and the throughput. That is,

$$Risk_{process,\ throughput}$$

If the Risk Rate is defined as the risk value divided by the throughput:

$$\frac{Risk_{process,\ throughput}}{throughput} = Risk\ Rate_{process}$$

For two selected processes (p1 and p2), the ratio of the Risk Rates, called the process ratio, is a constant:

$$\frac{Risk\ Rate_{p1}}{Risk\ Rate_{p2}} = K_{p1,p2}$$

Process p1 was chosen to have PEIS data for all sites, such as preparation for shipment to WIPP from PEIS Case 9. Process p2, for which PEIS data did not exist for the sites of interest, was known for other sites. $K_{p1,p2}$ was calculated for one or more sites for which the risks for both p1 and p2 were represented in the PEIS. Then the unknown risk value was calculated as:

$$Risk_{p1} = k_{p1,p2} \times Risk\ Rate_{p2} \times throughput$$

Using the scaled throughputs, risk values for the remaining sites may be calculated, allowing the summing of risk values for all sites and calculation of the system-wide scaling factor as described previously.

7.0 WASTE HANDLING, EMPLACEMENT, AND BACKFILL

Modeling for waste handling and emplacement was performed separately from the modeling for backfill activities. The total impacts were calculated as the sum of the two models.

7.1 Waste Handling and Emplacement

As described in Section 3.3.2.2 of the report, radiation doses for emplacement are modeled as being the same for all emplacement alternatives and waste forms because the amount of radioactivity is unchanged. While some waste forms may decrease the dose rate from the package, the increased handling time for those heavier waste forms offsets the decrease in dose rate. Chemical and radioactive material releases are modeled as being linear with waste volume handled. All risk values for released material are compared to those given in the Final Supplement Environmental Impact Statement Waste Isolation Pilot Plant (DOE, 1990b) using the following formula:

$$Case\ risk\ value = FEIS\ risk\ value \times \frac{case\ waste\ volume}{FEIS\ waste\ volume}$$

Case waste volumes were taken from the summary of waste inventories.

Doses are converted to risk estimates using the dose conversion factors from the 1990 Recommendations of the International Commission of Radiological Protection (ICRP,1990):

Doses to the public: 5.00×10^{-4} cancer fatalities per rem
Doses to worker: 4.00×10^{-4} cancer fatalities per rem

Injuries and fatalities from industrial accidents were calculated based on the number of FTEs expected to be working multiplied by the appropriate incident rate (IR). The total FTEs were calculated from the following formula:

$$\textit{Total FTEs} = \textit{Daily FTEs} \times \textit{activity hours/shift} \times \textit{days per year} \times \textit{WIPP operational lifetime}$$

Table K-19 shows the daily FTEs estimated for aboveground waste handling, emplacement, and backfill activities for each of the EAs. The number of FTEs per shift was provided by WIPP personnel.

As explained in Section 3.3.3.7 of the report, the IR for underground work was taken from industry data for salt mine operation (USDL, 1978–1993) adjusted for types of accidents that were judged not likely to be applicable to WIPP. Because of a lack of applicable data for aboveground IR data, it was assumed that waste handling above ground would have half the mining IR. The following formula was used to calculate the injury and accident risks for the 35-year lifetime of the WIPP:

$$\textit{Accident Impact} = \frac{\textit{Total FTEs}}{200000} \times \textit{IR} \times \textit{Effective Fraction}$$

where:

IR (injuries, waste handling) = 2.3603
IR (injuries, underground) = 4.7206
Effective Fraction (injuries) = 0.805
IR (fatalities, waste handling) = 0.02059
IR (fatalities, underground) = 0.04118
Effective Fraction (fatalities) = 0.275

Effective Fraction is the fraction of salt mining industry average incident rates that are likely to occur at the WIPP. It excludes incidents involving falls of the roof, face, or sides of panels; explosives handling; fires; and explosions (D'Appolonia, 1976). The formula includes the divisor of 200,000 because the data from which the IR values were taken are based on incidents per 200,000 person-hours worked.

7.2 Backfill Operations

Backfill operations only impact workers. The calculation of injuries and fatalities from physical hazards was calculated the same way as for emplacement activities. No chemical risks are calculated because it is assumed that all leakage from waste containers was addressed during waste handling and emplacement activities and no further leakage routinely occurs. Radiation doses from working around the emplaced waste during backfill operations was modeled using the

TABLE K-19

WASTE HANDLING, EMPLACEMENT, AND BACKFILL ACTIVITIES NUMBER OF FULL-TIME EQUIVALENTS PER DAY REQUIRED

		Full-Time Equivalents per Shift to accomplish the task		
Identifier	Case Description	Waste Handling	Emplacement	Backfill
0	Baseline	44	20	0
1	Compact Waste	33	18	0
6	Shred and Compact	33	18	0
10	Plasma Processing	32	10	0
33	Salt + Clay backfill	44	20	15
35(a)	*Salt Aggregate Grout*	44	20	23
35(b)	Cementitious Grout	44	20	23
111	Clay-based backfill	44	20	13
77(a)	Supercompact, salt aggregate	33	18	10
77(b)	Supercompact, clay based	33	18	9
77(c)	Supercompact, clay/sand	33	18	11
77(d)	Supercompact, CaO backfill	33	18	8
83	CaO Backfill	44	20	11
94(a)	Shred & add clay	44	20	0
94(b)	Shred & add clay, clay/sand	44	20	16
94(c)	Shred & add clay, cementitious	44	20	29
94(d)	Shred & add clay, salt aggregate	44	20	14
94(e)	Shred & add clay, clay based	44	20	13
94(f)	Shred & add clay, CaO backfill	44	20	11

same dose rate as emplacement. The radiation doses were calculated using the following formula:

$$\text{Backfill Impact} = \text{Emplacement Impact} \times \frac{\text{backfill total FTEs}}{\text{emplacement total FTEs}}$$

The impacts from backfill operations were added to those from waste handling and emplacement for the totals shown in the report.

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