J-22

Exhibit 7

RAE-8339/12-1

PREPARED FOR:

U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
WASHINGTON. D.C.

EXPOSURES AND HEALTH EFFECTS FROM SPENT FUEL TRANSPORTATION

G.M. SANDQUIST
V.C. ROGERS
A.A. SUTHERLAND
G.B. MERRELL

NOVEMBER 29, 1985

Rogers & Associates Engineering Corporation
P.O. Box 330, Salt Lake City,
Utah 84110 (801) 263-1600

RAE

Prepared by the Weston Civilian Radioactive Waste Management Technical Support Team Under Contract DE-AC01-83NE44301

NOTICE

RAE-8339/12-1

EXPOSURES AND HEALTH EFFECTS FROM SPENT FUEL TRANSPORTATION

November 29, 1985

G.M. Sandquist
V.C. Rogers
A.A. Sutherland
G.B. Merrell

Prepared for

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, D.C.

Rogers and Associates Engineering Corporation
P.O. Box 330
Salt Lake City, Utah 84110

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Nuclear Waste Policy Act of 1982 established the process for the selection of sites for the disposal of spent nuclear fuel and high-level radioactive waste (HLW). Sites nominated and recommended by the U.S. Department of Energy (DOE) for characterization are described in the Environmental Assessments (EA) for each of the nine potentially acceptable sites. Comments were solicited by the DOE from the public regarding the draft EAs.

This study was performed in response to public comments on the completeness and appropriateness of the risk analyses reported in the draft EAs. The study was meant to provide rapid and generic estimates of risks to individuals and populations from transportation of spent fuel to a high-level waste repository or to temporary storage. These estimates were intended for inclusion in the final EAs. The assumptions used in this study tend to be very conservative, but the risks calculated are still relatively low.

In the future, more detailed analyses will be performed as part of the preparation of Environmental Impact Statements. Also, procedures to reduce dose rates will be determined and route-specific risk calculations will be made. It is expected that as a consequence of these refinements subsequent risk estimates will be considerably lower than those reported here.

Chapter 2 of this report describes estimates of risks to individuals from normal operations in the transportation of spent commercial reactor fuel by truck or rail. Chapter 3 describes estimates of risks to individuals and populations from several kinds of very severe but credible accidents involving a rail cask containing spent fuel. It also gives estimates of areas contaminated by releases of nuclides from these accidents and a few cost estimates for cleaning up contaminated areas. Chapter 4 gives brief statements of the conclusions drawn from these analyses. The appendices provide examples of the computer-generated information employed in the study.

2. RADIATION EXPOSURE FROM NORMAL TRANSPORT OF SPENT FUEL BY TRUCK AND RAIL CASK

Large quantities of spent fuel from power reactors will be shipped by truck or rail from the point of generation or temporary storage to the designated nuclear waste repository. This activity has the potential for increasing radiation exposures of individuals above their normal background levels in the near vicinity of the transportation route. This chapter provides estimates of the neutron and gamma radiation field surrounding spent fuel truck and rail casks. It examines radiation doses that could result from representative activities of individuals within the influence of this radiation field during normal, accident-free transport of spent fuel by truck or rail.

The transportation casks that will be employed to ship spent fuel via truck or rail must satisfy numerous regulatory and design requirements imposed by NRC, DOT, DOE, etc. Truck and rail spent fuel casks must satisfy DOT regulations that require that the radiation dose equivalent (dose) rate not exceed "10 millirem per hour at any point 2 meters (6.6 feet) from the vertical planes represented by the outer lateral surfaces of the transport vehicle, or in the case of an open transport vehicle, at any point 2 meters from the vertical planes projected from the outer edges of the conveyence" (Ref 1). The outer edges of the conveyence are conservatively assumed to establish this boundary for both the truck and rail casks. Therefore, it has been assumed that the total maximum dose rate 2 meters from the outer edges of the transport conveyence is no greater than 10 mrem/hr regardless of the type of radiation (viz., gamma photons and neutrons) and the shielding material composition and configuration assumed by the actual truck or rail cask systems used for spent fuel transport (Ref 2). This conservative assumption eliminates the need to account for the composition and configuration of shielding and containment materials used in the casks, which are still being developed. Of course it is possible that current federal regulations may be changed regarding allowable radiation doses and spent fuel transportation.

2.1 DEVELOPMENT OF THE GAMMA RADIATION EXPOSURE MODEL

In this analysis the spent fuel transported in a truck or rail cask was treated as a uniform line source of gamma radiation with a length equal to a typical pressurized water reactor (PWR) fuel assembly.

The assumption of a uniform linear source to represent the fuel assembly or assemblies, rather than a source that is greater at the center and smaller at the ends, is conservative. The highest radiation dose rate in either case will occur at a point adjacent to the center of the radiation source. Using the uniform source model the projected dose rate will be greater at the ends of the cask than with the non-uniform representation. Since the maximum allowable dose rate is the same for either case, the result is higher calculated dose rates at the ends of the transport cask than would occur if a non-uniform gamma source was used.

The gamma dose rate radiation field $\dot{H}$ at radial position r and axial position z from the cask's axis is shown in Figure 2-1. The mathematical model for the dose rate $\dot{H}$ is given by the following equation (Ref 3):

$$\dot{H}(r,z) = \frac{S\ B(r,z)}{4\pi r}\left\{\text{Arctan}\left[\frac{1}{r}\left(\frac{L}{2} + z\right)\right] + \text{Arctan}\left[\frac{1}{r}\left(\frac{L}{2} - z\right)\right]\right\} \quad (1)$$

where

S = effective line gamma radiation source strength (mrem · m/hr)

$B(r,z)$ = effective gamma buildup factor (dimensionless)

L = length of the line radiation source, e.g., a spent LWR fuel assembly (m)

r,z = the radial and axial position from the center of the line source (m)

It can be shown from Equation 1 that the location which dictates the radiation field for compliance with DOT regulations (Ref 1) is the position $r = R$ and $z = 0$. The value of the effective line source strength, S, can be found by requiring that

$$\dot{H}(R,0) = 10\ f(\gamma)\ \text{mrem/hr}$$

where

$f(\gamma)$ = fraction of the dose rate at R due to gamma photons

R = radial position for 10 mrem/hr boundary

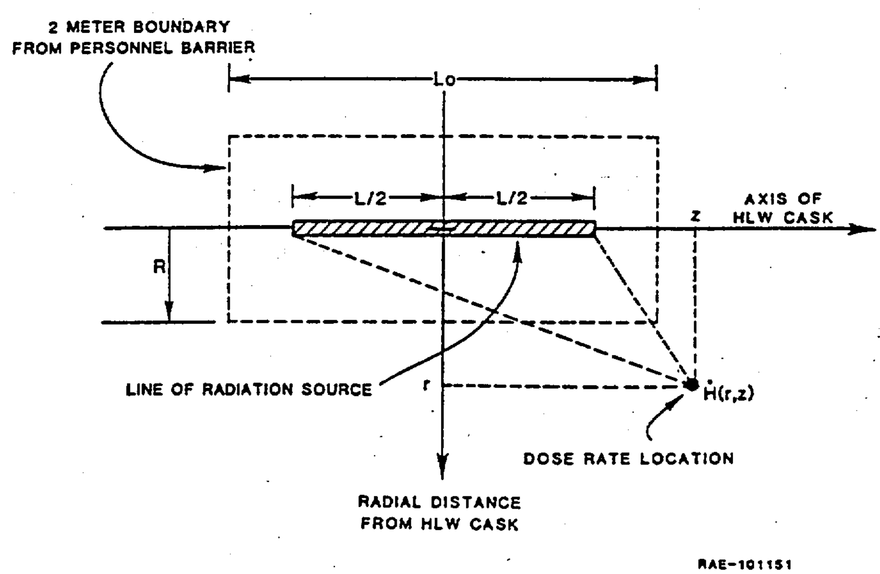


FIGURE 2-1. SCHEMATIC AND COORDINATES FOR RADIATION FIELD AROUND A SPENT FUEL CASK.

From Equation 1 it is found that the gamma source strength is given by

$$S = \frac{2\pi R\ \dot{H}(R,0)}{B(R,0)\ \mathrm{Arctan}(L/2R)}$$

The radiation buildup factor $B(r,z)$ is defined as the ratio of the total gamma dose rate to the direct gamma dose rate, i.e., the total dose rate due to collided and uncollided photons divided by that due only to uncollided photons. The buildup factor accounts for those photons that are scattered by the atmosphere (referred to as skyscatter) and those scattered by the ground (referred to as groundscatter).

It has been observed experimentally that the presence of ground scattering in practical gamma-ray source configurations can result in significant buildup of the radiation exposure (Refs 4, 5, 6). The buildup of the photon dose due to skyscatter and groundscatter is assumed to be given by:

$$B(r,z) = 1 + B(\text{atmosphere}) + B(\text{ground}) \qquad (2)$$

A simple but adequate linear model for atmospheric skyscatter is (Ref 7):

$$B(\text{atmosphere}) = c\ \mu_a \sqrt{r^2 + z^2} \qquad (3)$$

where

c = a constant

μ_a = the effective photon attenuation coefficient for air (1/m)

r,z = the radial and axial positions from the center of the line source as shown in Figure 2-1 (m)

Evaluation of the component of the buildup factor for the groundscatter, B(ground), is more complicated than skyscatter. Although both components arise primarily due to Compton scattering of photons, the marked increase in atom density of the ground over the atmosphere (viz., about a three orders of magnitude increase), requires special consideration.

The mathematical model employed to describe photons emitted from the line source (the spent fuel) which undergo Compton scattering with the ground is given by

$$B(\text{ground}) = \left[1 + \frac{(h_0 - h_1)^2}{r^2 + z^2}\right] \frac{N}{2e\mu} I \qquad (4)$$

where

h_0 = effective height of the spent fuel line source above the ground (m)

h_1 = effective height of the point of dose measurement (m)

N = mean atom density of ground materials (atoms/m^3)

μ = effective photon attenuation coefficient for ground materials (1/m)

e = effective ground penetration factor (dimensionless)

I = the expression which accounts for Compton scattering of photons from the spent fuel to the point of dose measurement, integrated over the ground surface (m^2/atom)

The full expression for the term I is given by

$$I = \int_0^\infty \int_0^\pi \frac{d\sigma}{d\Omega} \frac{x^2 d\theta dx}{(s^2 + x^2)^{3/2} (1 + t^2 + x^2 - 2x\cos\theta)}$$

where

$$s^2 = \frac{h_0^2}{r^2 + z^2} \quad , \quad t^2 = \frac{h_1^2}{r^2 + z^2}$$

θ = the Compton scattering angle

and

$$\frac{d\sigma}{d\Omega} = A - \frac{B}{1 + x^2 + t^2 - 2x\cos\theta}$$

The expression given for $d\sigma/d\Omega$ is an approximate differential Compton cross section (Ref 8) for photon scattering from the ground. The parameters A and B represent constants chosen to best fit the Compton scattering cross section for the photon energy distribution from the cask.

2.2 DEVELOPMENT OF THE NEUTRON RADIATION EXPOSURE MODEL

The spent fuel also contains transuranic elements which are produced as a result of neutron capture in uranium (and thorium, if present). Many of these nuclides (including isotopes of uranium, plutonium, curium, etc.) undergo spontaneous fission resulting in the emission of neutrons. A predominant neutron emitter encountered in spent fuel from light water reactors is the isotope curium-244 (Cm-244) which has a half-life of 18.1 years. A typical PWR spent fuel assembly 5 years out of the reactor contains about 600 curies of Cm-244 which decays predominantly by alpha emission and 0.00013 percent of the time by spontaneous fission, emitting neutrons with a standard fission energy spectrum.

The energy dependent neutron flux field from the spontaneous fission neutron emitters was calculated for a standard truck and rail spent fuel cask using DISNEL, a generalized one-dimensional, multiple energy group, neutronics computer code (Ref 9). The spontaneous fission neutrons were assumed to be uniformly distributed within the spent fuel regions of the casks. Standard spent fuel cask configurations and material compositions for both truck and rail casks as specified by Reference 10 were employed. The outer boundary condition used for the calculations was conservatively set to 300 meters from each cask so that the principal region of interest for neutron dose evaluation (i.e., $\leq$ 150 meters) would not be significantly affected by the choice of boundary conditions.

The neutron equivalent dose rate H(r) was determined from the neutron energy dependent flux distribution $_i(r)$ as follows:

$$\dot{H}(r) = \sum_{i=1}^{NG} \phi_i(r)\ DF_i \qquad (5)$$

where

r = position vector

$\dot{H}(r)$ = neutron dose rate (mrem/hr)

$\phi_i(r)$ = neutron flux for the i^{th} energy group (neutrons/m^2 sec)

DF_i = dose conversion factor for the i^{th} energy group (mrem · m^2 · sec/neutron · hr)

NG = number of neutron energy groups

A graph of the dose conversion factor is given in Figure 2-2.

Once the neutron dose rate field was established, it was normalized to satisfy the relation

$$H(R,0) = 10\ f(n)\ \text{mrem/hr}$$

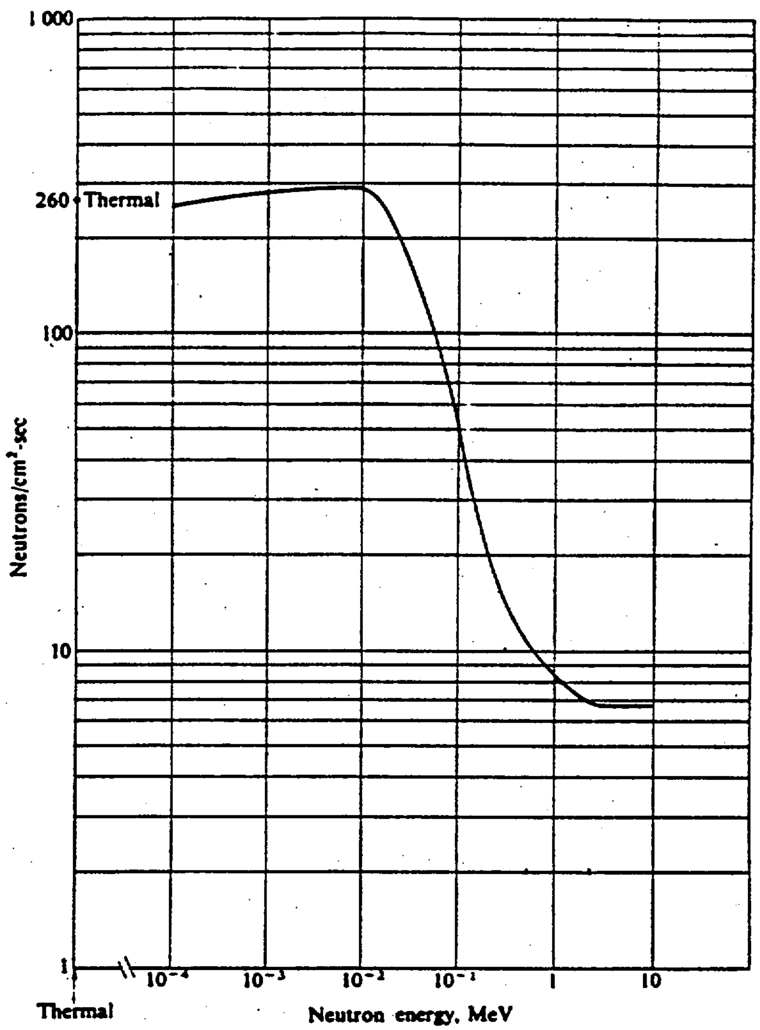
where

$f(n)$ = fraction of the dose rate at R due to neutrons

R = radial position for 10 mrem/hr boundary

2.3 COMPUTER PROGRAM FOR ESTIMATING THE DOSE RATE FROM A SPENT FUEL CASK

A program called PATHRAE-T (Ref 11) has been developed from an Environmental Protection Agency computer code to provide the total dose rate field arising from neutrons and gamma photons for any position around truck or rail casks. The code permits the cask and the point of dose assessment to be located at any position above the ground and



RAE-101235

FIGURE 2-2. NEUTRON FLUX DOSE CONVERSION FACTOR (NEUTRON FLUX THAT GIVES DOSE EQUIVALENT RATE OF 1 mrem/hr AS A FUNCTION OF NEUTRON ENERGY). BASED ON APPENDIX 6, ICRP PUBLICATION 21.

conservatively accounts for radiation buildup due to both air and ground scattering.

The PATHRAE-T code provides a convenient table of dose rates and a "pictorial mapping" output of the position-dependent radiation field surrounding the cask. This permits the easy assessment of the total dose for any proposed activity or sequence of events in the vicinity of the cask.

2.4 DOSE RATES AND DOSES FOR TYPICAL SPENT FUEL TRUCK AND RAIL CASKS

The gamma and neutron dose field around the casks was calculated from Equations 1, 2, and 5 by PATHRAE-T. The factors $f(\gamma)$ and $f(n)$ (i.e., the fractions of the dose rate from gamma radiation and neutrons at the 2 m boundary from the truck cask surface) were assumed to be as given in Table 5.2 of Reference 10 for 5 year old spent fuel in a cask with a wet neutron shield and dry fuel cavity. This distribution for the truck cask was determined to be 65 percent gamma dose rate and 35 percent neutron dose rate. For the rail cask the distribution was 50 percent gamma dose rate and 50 percent neutron dose rate. The rail cask distribution comes from Table 5.1 in Ref 10 for a wet neutron shield and dry fuel cavity.

Figure 2-3 shows the dose rate field obtained from PATHRAE-T (see Appendix A) surrounding a spent fuel truck cask. Isodose lines are given in units of microrem per minute as functions of distance from the center of the cask. Because of symmetry of the field, only one quadrant is shown. Thus the radiation dose rate at the trailer's front or rear wheels is about 100 microrem per minute, while the dose rate outside the cab door of the tractor is about 50 microrem per minute.

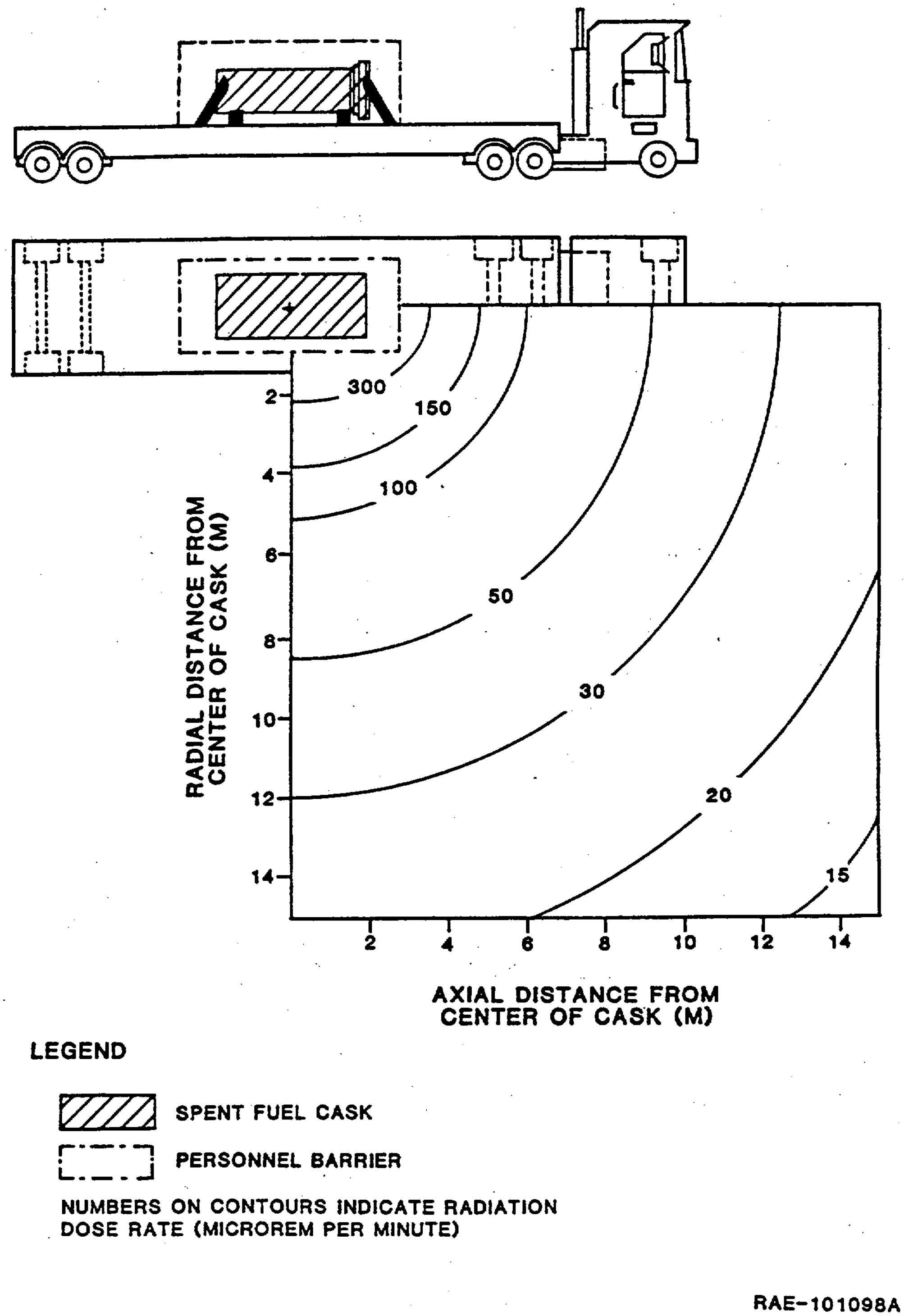


FIGURE 2-3. RADIATION ISODOSE MAP FOR TRUCK TRANSPORT

Figure 2-4 shows the dose rate field surrounding the spent fuel rail cask.

Appendix A of this report provides the detailed dose rate maps produced by the computer code PATHRAE-T for both the near field (0 to 15 meters) and far field (0 to 150 meters) for both truck and rail casks. The appendix also provides a table of the data employed for describing the truck and rail casks and the environmental parameters.

Tables 2-1 and 2-2 provide tabulations of maximum individual exposure events which might occur within the radiation field of a spent fuel cask in normal transport. Many of these potential exposure events (e.g., caravan and traffic obstruction) will not necessarily occur with each spent fuel shipment. Furthermore, the distances and exposure times are chosen to repreent unlikely values which in combination result in maximum credible individual exposures. Four classes of normal spent fuel transportation exposure are postulated for both truck and rail casks. The first class is the caravan scenario, which includes all exposures arising from events in which people are traveling along the same transportation route as the spent fuel cask. For example, passengers in vehicles traveling ahead, to the side, or behind the truck cask might be subject to exposures. For this scenario class, the minimum nominal distance between the passengers and the cask is estimated at 10 meters for a maximum exposure time of 30 minutes. From Figure 2-3, the dose rate at about 10 meters from the truck cask is about 40 microrem per minute. Therefore, the maximum individual dose is estimated to be

$$40 \frac{\mu\text{rem}}{\text{min}} \times 30 \text{ min} = 1200 \ \mu\text{rem}$$

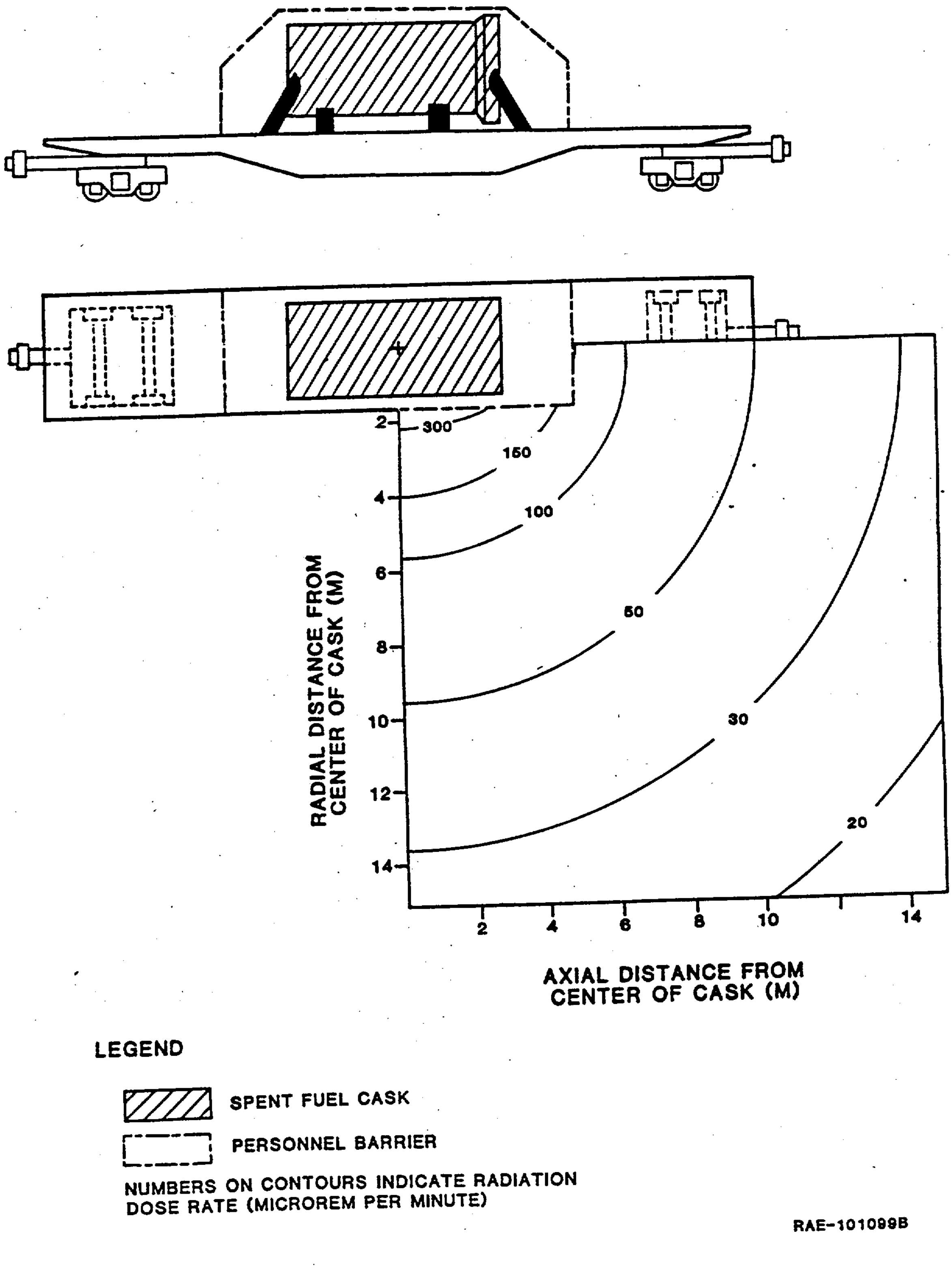


FIGURE 2-4. RADIATION ISODOSE MAP FOR RAIL TRANSPORT

TABLE 2-1

PROJECTED MAXIMUM INDIVIDUAL EXPOSURES FROM NORMAL SPENT FUEL TRANSPORT BY TRUCK CASK*

Description (Service or Activity)	Distance To Center of Cask	Exposure Time	Maximum Dose Rate and Total Dose
Caravan			
Passengers in vehicles traveling in adjacent lanes in the same direction as cask vehicle	10 m	30 min	40 µrem/min 1 mrem
Traffic Obstruction			
Passengers in stopped vehicles in lanes adjacent to the cask vehicle which have stopped due to traffic obstruction	5 m	30 min	100 µrem/min 3 mrem
Residents and Pedestrians			
Slow transit (due to traffic control devices through area with pedestrians)	6 m	6 min	70 µrem/min 0.4 mrem
Truck stop for driver's rest. Exposures to residents and passers-by.	40 m	8 hours (assumes overnight)	6 µrem/min 3 mrem
Slow transit through area with residents (homes, businesses, etc.)	15 m	6 min	20 µrem/min 0.1 mrem
Truck Servicing			
Refueling (100 gallon capacity)	7 m (at tank)		60 µrem/min
- 1 nozzle from 1 pump		40 min	2 mrem
- 2 nozzles from 1 pump		20 min	1 mrem
Load inspection/enforcement	3 m (near personnel barrier)	12 min	160 µrem/min 2 mrem
Tire change or repair to cask trailer	5 m (inside tire nearest cask)	50 min	100 µrem/min 5 mrem
State weight scales	5 m	2 min	80 µrem/min 0.2 mrem

* These exposures should not be multiplied by the expected number of shipments to a repository in an attempt to calculate total exposures to an individual; the same person would probably not be exposed for every shipment, nor would these maximum exposure circumstances necessarily arise during every shipment.

TABLE 2-2

PROJECTED MAXIMUM INDIVIDUAL EXPOSURES FROM NORMAL SPENT FUEL TRANSPORT BY RAIL CASK*

Description (Service or Activity)	Distance To Center of Cask	Exposure Time	Maximum Dose Rate and Total Dose
Caravan			
Passengers in rail cars or highway vehicles traveling in same direction and vicinity as cask vehicle	20 m	10 min	30 μrem/min 0.3 mrem
Traffic Obstruction			
Exposures to persons in vicinity of stopped/slowed cask vehicle due to rail traffic obstruction	6 m	25 min	100 μrem/min 2 mrem
Residents and Pedestrians			
Slow transit (through station or due to traffic control devices) through area with pedestrians	8 m	10 min	70 μrem/min 0.7 mrem
Slow transit through area with residents (homes, businesses, etc.)	20 m	10 min	30 μrem/min 0.3 mrem
Train stop for crew's personal needs (food, crew change, first aid, etc.)	50 m	2 hours	5 μrem/min 0.6 mrem
Train Servicing			
Engine refueling, car changes, train maintenance, etc.	10 m	2 hours	50 μrem/min 6 mrem
Cask inspection/enforcement by train, state or federal officials	3 m	10 min	200 μrem/min 2 mrem
Cask car coupler inspection/maintenance	9 m	20 min	70 μrem/min 1 mrem
Axle, wheel or brake inspection/lubrication/maintenace on cask car	7 m	30 min	90 μrem/min 3 mrem

* These exposures should not be multiplied by the expected number of shipments to a repository in an attempt to calculate total exposures to an individual; the same person would probably not be exposed for every shipment, nor would these maximum exposure circumstances necessarily arise during every shipment.

or about 1 mrem for the truck caravan scenario. This dose estimate neglects shielding afforded by passenger vehicles and is believed to be conservatively high. Furthermore, the probability of such an occurrence (i.e., to remain within 10 meters of the cask for 30 minutes) is low and is very unlikely to be experienced by the same exposed individuals more than once.

Traffic obstructions which result in stopping (or significant slowing) of the transportation cask constitute the second class of exposures. The occurrence of an obstruction for 30 minutes which results in a 5 meter separation between the truck cask and an exposed individual is recognized as highly conservative and unlikely to be repeated for the same exposed individuals. The dose rate of 100 microrem per minute at 5 meters from the truck cask for a 30 minute exposure results in a maximum individual dose of 3 mrem. The maximum dose estimated for a rail cask involved in a traffic obstruction event is 2 mrem.

Another class of individual exposures results from the transit of the cask through areas where pedestrians and residents are located within the significant radiation field of the cask. Slow transit events assume average cask transport speeds much less than 1 mph through these areas. Maximum doses range downward from about 3 mrem for truck casks and 0.7 mrem for rail casks, depending upon the specific scenario assumed.

The final class of individual exposure events during normal transport operations are those associated with the servicing (refueling, inspection, maintenance, repair, etc.) of the cask transporter. Doses are about 6 mrem or less for various servicing activities, as shown in Tables 2-1 and 2-2.

The individual radiation exposures given in Tables 2-1 and 2-2 are projected maximum exposures that an individual could receive in the normal transport of spent fuel. Exposures this large are unlikely to occur with most shimpents. Therefore, they should not be multiplied by the number of shipments to estimate accumulated doses that may arise from repetitive shipments of spent fuel. It is expected that more detailed analyses that include additional effects not accounted for in these analyses will indicate lower dose rates. Also, administrative action, such as route planning, can reduce radiation exposures.

3. POTENTIAL RADIATION EXPOSURES FROM A SPENT FUEL RAIL CASK ACCIDENT

3.1 BACKGROUND

It is important to recognize that there has never been a transportation accident involving spent fuel which has resulted in a release of radioactive material to the environment (Ref 12). Furthermore, no release of radioactive material has occurred from any package designed as an accident-resistant package. This excellent safety record provides no historical data to fully confirm theoretical models and controlled field and laboratory experiments, but the record does demonstrate that the probability for a cask failure and radioactive material release is very small.

3.2 ACCIDENT WITH NO RELEASE OF RADIOACTIVE MATERIALS TO THE ENVIRONMENT

Spent fuel rail casks each containing up to 14 PWR spent fuel assemblies could conceivably be involved in a variety of rail related transportation accidents. A well documented history of the nature, causes, and consequences of all classes of railroad transportation accidents exists and reasonable estimates are available for predicting accident frequency, type, freight involved, and consequences. However, no accidents have occurred to date involving spent fuel rail casks (Ref 12). For potential future accidents involving rail casks, the most likely outcome will be that no radioactive material release from the cask will occur. This will be true even if the accident involves derailment and overturn of the rail cask car. Furthermore, even detachment of the spent fuel cask from the rail car would, with high probability, result in no release of radioactive contents from the cask.

If none of the radioactive contents of the cask are released to the environment, then the total radiation field around the cask can be represented by the radiation isodose maps for both the near and far fields given in Appendix A. (See specifically Figures A-3 and A-4, and Tables A-4 and A-5.) This is essentially true even if internal damage to the fuel assemblies and redistribution of crud within the cask results in radioactive releases to the interior of the cask. The radiation exposures to emergency responders, accident victims, and observers can be assessed at any location from these isodose maps. For example, someone standing on or by the spent fuel rail cask would receive radiation exposure at a rate of about 400 microrem per minute. If the individual spent one hour fighting a fire or performing a personnel rescue at that location by the cask then the accumulated exposure after one hour would be about 24 millirem. This is comparable to exposure from a single medical x-ray procedure.

3.3 ACCIDENTS WITH RELEASE OF RADIOACTIVE MATERIALS TO THE ENVIRONMENT

3.3.1 Description of Release

The release of radioactive materials from spent fuel to the cavity of a spent fuel shipping cask and then to the environment, with subsequent internal or external radiation exposure to humans, is a complex, improbable process with many possible variations and consequences. The probability of spent fuel transportation accident that results in the release of radioactive materials into the environment are is estimated to be no greater than 2 occurences in a million rail transport accidents (Ref 13). The specific scenario set considered here constitutes selected, very severe, but credible accidents involving a spent fuel rail cask which contains 14

PWR spent fuel assemblies, each five years out of the reactor. Although a maximum of five rail cask cars might be coupled together in a single, dedicated train, it was assumed that the credible potential for release of radioactive material to environment exists for only a single rail cask involved in the accident. The probability of release from two or more spent fuel rail casks in the same accident is so small that such an event is not considered here.

There are at least six physical mechanisms (Ref 13) which can contribute to the release of radioactive materials from spent reactor fuel contained in a cask. These mechanisms, each of which have distinct, quantifiable processes associated with them, are 1) impact rupture, 2) burst rupture, 3) diffusion, 4) leaching, 5) rapid oxidation, and 6) crud release. Diffusion, leaching, and heating (which produces rapid oxidation) are important transport processes, however, only if rupture of both the cask and fuel has occurred, providing a pathway for movement of radioactive materials from the fuel to the interior of the cask and then to the environment.

Impact rupture of the spent fuel is the release of radioactive material due to mechanical disruption and failure of the fuel cladding followed by depressurization of the fuel rod. Burst rupture of the spent fuel is the release of radioactive material due to external heating which produces internal pressures in the fuel sufficient to deform and burst the cladding and fuel rod. Rapid oxidation can enhance the release of radioactive materials from the fuel. After failure of the protective fuel cladding, severe heating combined with air flow over the exposed uranium dioxide fuel (UO_2 is the standard fuel material used in PWR and BWR fuel assemblies) may further oxidize the fuel, resulting in macroscopic cracking and enhanced release of radioactive fission products.

Crud release is associated with the liberation of certain radionuclides, most of which are not fission products. These nuclides are contained in materials which have deposited on the fuel assembly external surfaces and cask interior from corrosion products and trace contaminant deposition. In a rail cask accident these "crud" products could be dislodged and transported to the environment if the cask were breached, even if the fuel cladding and assemblies maintained their integrity.

A large, catastrophic failure and full breaching of the cask is not considered credible and has never been observed (Ref 13). However, casks which employ valves for access to the cask interior volume could be breached by valve failure in credible accident scenarios despite protective design measures. Furthermore, leakage past the cask closure seals or even a small breach due to a fine stress crack in the cask wall are also considered credible, although all experimental tests on casks have failed to provide evidence of such cask failures.

The set of accident scenarios examined here for radiation dose consequences is considered to include the worst credible scenarios for radioactive material releases which might occur from an air-cooled rail cask. In this worst case scenario set, the rail cask and its spent fuel assemblies can suffer impact rupture, or both impact and burst rupture, or a combined impact and burst rupture accompanied by enhanced release due to oxidation. These can result from severe mechanical disruption and intense heating from a fire fueled by petroleum or other highly flammable materials. Spent fuel assemblies which are five years or older (i.e., have been out of the reactor core for five years or more) do not produce sufficient self-heating from radioactive decay to support a rapid oxidation process. Therefore a large external source of heat, similar to a burning rail tank car of petroleum, is needed to create any substantial enhancement of release above that from impact and burst rupture.

Table 3-1 provides a tabulation of the major radioactive nuclides and their inventory in a rail cask containing 14 PWR spent fuel assemblies, each five years old. On the basis of the projected worst case rail accidents for an air-cooled rail cask, the credible releases of nuclides to the environment and the fraction of this environmental release that is respirable have been estimated by Wilmot (Ref 13). These releases are tabulated for each accident class, viz., impact rupture, burst with impact rupture and, finally, oxidation with impact and burst rupture.

Table 3-2 shows the dose conversion factors used to convert nuclide-specific intakes or nuclide concentrations to dose commitments from inhalation, ingestion, and direct gamma radiation exposures from ground deposition and airborne radioactivity. The dose conversion factors for inhalation and ingestion are for 50 year dose commitments. They are for whole-body equivalent doses based on cancer risk weightings given in ICRP-26 (Ref 14).

Although numerous radioactive nuclides are found in typical spent fuel, the 8 nuclides listed in Tables 3-1 and 3-2 have been found to have the greatest human health consequences if they are inhaled, ingested or deposited on the ground (Ref 13).

TABLE 3-1

ENVIRONMENTAL RELEASES AND RESPIRABLE FRACTIONS OF NUCLIDES IN SPENT FUEL RAIL ACCIDENT

		Environmental Release (Ci)**			Respirable Fraction**		
Nuclide	Cask Inventory* (Ci)	Impact	Impact and Burst	Impact, Burst and Oxidation	Impact	Impact and Burst	Impact, Burst and Oxidation
Co-60 (as crud)	645	8.06	8.06	8.06	0.05	0.05	0.05
Kr-85	42,700	512	4,360	4,780	1.00	1.00	1.00
Sr-90	417,000	0.0042	0.379	0.379	0.05	0.05	0.05
Ru-106	114,000	0.0011	0.104	4.67	0.05	0.05	0.05
I-129	0.213	0	0	0.001	0.05	1.00	0.12
Cs-134	192,000	0.0019	34.6	326	0.05	1.00	0.15
Cs-137	613,000	0.0061	110	1,040	0.05	1.00	0.15
Pu-239	2,870	0.0	0.0026	0.0026	0.05	0.05	0.05
Totals (Ci)	1.38×10^6	520	4513	6159	512	4505	4990

* Based upon a cask inventory of 14 PWR spent fuel assemblies, each 5 years out of the reactor.

** Source: Reference 13.

TABLE 3-2

DOSE CONVERSION FACTORS FOR DETERMINING EXPOSURES FOR SPENT FUEL RAIL ACCIDENTS

Nuclide	Ingestion Dose Factors[a] (mrem/pCi)	Inhalation Dose Factors[b] (mrem/pCi)	Ground Gamma Dose Factors[c] $\frac{mrem/hr}{pCi/m^2}$	Cloud Gamma Dose Factors[d] $\frac{mrem/yr}{pCi/m^3}$
Co-60	2.50E-05[e]	3.50E-04	2.90E-8	1.45E-02
Kr-85	0	0	2.89E-11	1.23E-05
Sr-90	1.30E-04	2.20E-03	8.53E-09	5.55E-10
I-129	2.70E-04	1.60E-04	2.93E-10	4.85E-05
Cs-137	4.60E-05	2.90E-05	7.38E-9	3.25E-03
Pu-239	4.30E-04	5.70E-01	4.11E-12	4.25E-07
Ru-106	2.10E-05	8.10E-04	2.57E-9	1.13E-03
Cs-134	6.70E-05	4.10E-05	1.91E-8	8.47E-03

a Source: Reference 15.

b These factors represent maximum effective 50-year committed doses for inhaled nuclides with particle activity median aerodynamic diameters (AMAD) of 0.3 micrometers. The respiratory clearance class of the nuclide is Y class. Data source is Reference 15.

c The factors represent whole-body dose rates for exposure 1 meter above a contaminated ground surface. Source: Reference 16.

d These factors represent whole-body dose rates for exposure to an airborne cloud of radioactivity. Source is Reference 16.

e 2.50E-05 = 2.50×10^{-5}.

3.3.2 PATHRAE-T Computer Code

The PATHRAE-T computer code (Ref 11) was used to provide estimates of the magnitude of radiation doses which could occur if nuclides from spent fuel were released to the environment during a rail cask accident. The PATHRAE-T code can be used to calculate whole body dose equivalents to individuals or population groups under diverse hydrogeologic, climatic, and demographic settings.

An effluent released at a point into the atmosphere moves in a complex manner controlled by numerous atmospheric transport processes. However, the generalized motion of airborne gases and particulates from a cask release is best described as a turbulent diffusion process characterized by the cumulative effects of turbulent eddies in the atmosphere and gravity. The PATHRAE-T code uses the Gaussian puff atmospheric dispersion model (Ref 17). Time integration of the puff at a fixed location yields an expression similar to the Gaussian plume model for continuous releases. The code uses both the centerline concentration and areally averaged concentrations, as appropriate, for the analyses. The puff model employs the following mathematical description (Ref 17) for the ground level nuclide concentration (x,y,t) at any downwind position x,y from the source:

$$\chi(x,y,t) = \frac{2\,Q}{(2\pi)^{3/2}\sigma_y{}^2\sigma_z} \exp\left[-\frac{1}{2}\left\{\frac{h^2}{\sigma_z{}^2} + \frac{y^2}{\sigma_y{}^2} + \frac{(x-ut)^2}{\sigma_y{}^2}\right\}\right]$$

where

t = time after puff release (s)

x = horizontal distance from the source, downwind

y = horizontal distance from the source, crosswind

$\chi(x,y,t)$ = concentration at x, y and t (Ci/m^3)

Q = total release to atmosphere (Ci)

u = wind velocity in the x direction (m/s)

h = effective release height above the ground (m)

σ_y = horizontal dispersion coefficient, a function of x (m)

σ_z = vertical dispersion coefficient, a function of x (m)

Particulate deposition is calculated by the standard puff depletion method in which Q in the above equation is replaced by a smaller Q' (Ref 17). Use of the Briggs expression for σ_z allows an analytic solution to the puff depletion equation for the ratio of Q'/Q. This expression is contained in Reference 11. PATHRAE-T also contains the flexibility of using two different deposition velocities if desired. The deposition velocity used for over-land scenarios corresponds to an equilibrium deposition which includes the effects of resuspension. For over-water scenarios a different deposition velocity may be used because there is no resuspension. Ground concentrations from atmospheric deposition are calculated by the time integration of the product of the air concentration at ground level and the deposition velocity. The entire nuclide release is assumed to occur in a time short compared to the residence time of the exposed individuals.

The PATHRAE-T methodology can model numerous recognized pathways through which humans can be exposed to radiation. These pathways include atmospheric transport, surface (wind or water) erosion and groundwater transport. Other pathways and transport associated with activities such as living and growing edible vegetation on the contaminated site and using contaminated water for irrigation or drinking can also be modeled.

For each of the pathways which have been included in PATHRAE-T, the dose from each nuclide is calculated as a function of time. These individual doses are then summed to give the total dose for a given pathway. The dose rates to the population and selected individuals from all pathways is then computed.

The radiation doses described in Section 3.3.3 and 3.3.4 from rail cask accident are assumed to result from the following radiation exposure pathways:

1. Inhalation of gaseous and airborne particulate nuclides from the release plume.

2. Direct gamma ray exposure from nuclides in the atmosphere (i.e., plume gamma exposure).

3. Direct gamma ray exposure from nuclides deposited on the ground by the atmosphere (i.e., ground gamma exposure).

4. Inhalation of airborne particulate nuclides resuspended in the atmosphere from disturbed ground dust (i.e., dust exposure).

5. Human ingestion of water contaminated with nuclides deposited on surface water and soil.

Radiation exposures arising from the consumption of food grown on contaminated land were found to be negligible compared to the above exposure pathways and were not considered further.

3.3.3 Projected Individual and Population Exposures From Atmospheric and Ground Pathways

The very severe, credible spent fuel rail accident was evaluated for various geographic settings and population densities. Although the geographic and population characteristics did not affect individual doses, the characteristics do strongly influence population radiation doses and latent health effect estimates. Population densities for areas assumed to be contaminated by rail cask accidents were typical of U.S. urban and rural areas. The urban area population density was assumed to be 3,860 persons/km^2, equivalent to 10,000 people per square mile. The rural area

sq mi = 2.590 km^2

population density was assumed to be 6 persons/km^2 or 15.5 people per square mile. The average population density for the continental United States is about 24 persons/km^2. Population doses were calculated for the population within 80 km of the release point.

Neutral stability conditions (viz., Type-D Pasquill stability) were used to represent plume dispersion. The estimated exposures and health effects are based on the presence of the maximally exposed individual directly downwind from the release point during the entire nuclide release period and continuous residency by the population for 50 years after the accident. The majority of the individual exposure comes from inhalation during the time in which the entire nuclide release is assumed to occur. The individual exposure is based on the conservative assumption that no protective action is taken by the individual to reduce exposure (e.g., movement away from the nuclide path or use of a breathing apparatus, etc.).

Tables 3-3 and 3-4 indicate the estimated radiation doses for maximally exposed individuals and the general population received by persons located generally downwind of the accident. The location for the maximum individual exposure occurs at a position about 70 meters directly downwind from the point of release in the cask.

From Table 3-3 it is observed that about 90 percent or more of the radiation dose to the maximally exposed individual is, for all three classes of release, associated with inhalation of radionuclides in the atmosphere. Ground and plume gamma exposures are smaller and similar to each other in value, while dust inhalation accounts for a very small fraction of the total dose to the individual. The highest release (impact, burst, and oxidation) results in a maximum individual dose of about 10.2 rem. This dose is considered to have no consequence other than a

TABLE 3-3

MAXIMUM INDIVIDUAL RADIATION DOSE ESTIMATES FOR RAIL CASK ACCIDENTS

Accident Class	Dose (mrem)*			
	Inhalation	Plume Gamma	Ground Gamma	Dust Inhalation
Impact	179	10.7	12.3	0.0001
Impact and Burst	6130	71.1	90.9	0.004
Impact, Burst and Oxidation	8950	547	707	0.0006

* Maximum individual dose occurs about 70 m downwind of the release point and assumes that the individual remains at this location for the duration of the passage of the plume of nuclides that are released.

TABLE 3-4

50-YEAR POPULATION DOSE ESTIMATES FOR SPENT FUEL RAIL CASK ACCIDENTS*
NO CLEANUP OF DEPOSITED NUCLIDES

Accident Class	Urban Area (3860 people/km^2)				Rural Area (6 people/km^2)			
	Inhalation	Plume Gamma	Ground Gamma	Total	Inhalation	Plume Gamma	Ground Gamma	Total
Impact								
Dose (person-rem)	3.09	0.33	936	939	0.005	0.0005	1.45	1.45
Latent Health Effects**				0.19				0.00029
Impact and Burst								
Dose (person-rem)	106	2.23	13,400	13,500	0.16	0.0034	20.8	21
Latent Health Effects**				2.7				0.0042
Impact, Burst and Oxidation								
Dose (person-rem)	154	17.2	112,000	112,000	0.24	0.027	174	174
Latent Health Effects**				22				0.035

* The ground gamma dose is what would be recieved if each member of the population stayed at the same location for 50 years. The inhalation dose is a 50-year dose committment from inhalation of the passing plume. Doses are for the population within 80 km of the release point. It is assumed that there is no cleanup of deposited nuclides and that no other measures are used to reduce radiation exposures.

** Based on 1 person-rem = 2x10^{-4} latent health effects. A latent health effect here is defined as an early cancer death by an exposed person or a serious genetic health problem in the two generations after those exposed. About half of the latent health effects are expected to be cancers and the rest genetic health problems.

possible small increase in the probability of incurring cancer in later years (Table 6.6a of REF 18).

Table 3-4 shows that nuclides deposited on the ground account for 99 percent or more of the population dose; while inhalation and plume exposures are incurred only during the passage of the airborne nuclides, exposures from ground deposition continues for the entire 50-year period of residence assumed in the analysis. Exposure from dust resuspension is low because it was assumed that the nuclides migrate a few centimeters into the ground in the first year after the accident and are absent from airborne dust thereafter. The population doses from ground exposure shown in Table 3-4 would also be reduced by natural weathering and dispersal of nuclides in the soil, which are conservatively ignored in this analysis. Futhermore, cleanup or other dose limiting actions that were conservatively neglected in this analysis would undoubtedly be performed.

For the urban population density a worst case rail cask accident with impact and burst rupture enhanced by oxidation could result in about 22 latent health effects if the nuclides deposited on the ground are not cleaned up or other measures to reduce radiation exposure are not implemented. For the rural population density, the same accident could result in about 0.035 latent health effects.

These health effects may be put in perspective by considering cancer fatalities in the same population from all other sources over 50 years. The populations within the 80 km radius for which population doses were calculated are 4,800,000 persons for the urban population density and 7,500 persons for the rural density. Using a cancer rate of 0.00194 fatal cancers per person per year from all other sources (Ref 19), the urban and rural populations represented in Table 3-4 would experience about 470,000 and 730 cancer fatalities, respectively, from all other causes in the same time period. Clearly, the severe but credible rail cask accident does not contribute significantly to the number of cancer fatalities in the region.

The value of cleaning up the deposited radionuclides as a means of reducing population dose was investigated. Section 3.4 discusses cost of cleanup as a function of the cleanup criterion. The cleanup criterion is the maximum permissible ground surface concentration (in microcuries per square meter) after cleanup is complete.

For a cleanup criterion of 0.5 $\mu Ci/m^2$* the PATHRAE-T code calculates that an area of about 45 km^2 would have to be cleaned up after the impact, burst and oxidation accident. If this area is treated within a short time after the accident to remove contamination down to the 0.5 $\mu Ci/m^2$ level, the number of latent health effects predicted is reduced from 22 to about 17. If 1 $\mu Ci/m^2$ or 0.2 $\mu Ci/m^2$ are used as cleanup criteria, the cleanup areas are 22 km^2 and 110 km^2, respectively, but the number of latent health effects is essentially unchanged. The fact that there is no significant difference in latent health effects with the three cleanup levels is a consequence of the fact that most of the radionuclides are deposited on the ground at concentrations less than the smallest criterion of 0.2 $\mu Ci/m^3$.

3.3.4 Projected Population Exposures from the Water Pathway For Severe But Credible Rail Cask Accident

The three classes of accidents (i.e., impact, impact and burst, and impact, burst and oxidation) were considered in an appropriate setting to

* A ground surface concentration of 0.5 $\mu Ci/m^2$ of the nuclides released from an impact, burst, and oxidation accident results in an annual exposure of 25 mrem to individuals in the first year after cleanup. This exposure rate declines in subsequent years due to radioactive decay.

maximize the water pathway exposure that would result from a rail cask accident. The release puff or plume was assumed to be transported over a large reservoir that is wider than the transverse extent of the puff or plume. The reservoir was assumed to have a surface area of 400,000 m^2 (about 100 acres) and to contain about 3.8 million cubic meters (about one billion gallons) of water. The plume or puff from the release passes over the reservoir as it travels from 100 meters to about 1400 meters downwind of the release point.

The nuclides deposited on the water surface were assumed to become thoroughly mixed and remain suspended within the reservoir water. The contaminated water was assumed to be used solely for domestic purposes by the surrounding population. If intensive use for irrigation is also assumed the effect would be to increase population doses by a factor of less than 2. No reduction in the radioactive nuclide inventory deposited on the water body surface was assumed due to radioactive decay or water treatment. The conservative assumption was also made that one percent of the contaminated water was ultimately ingested by humans through drinking water. The 1980 U.S. average consumptive use of water reported by the U.S. Water Resources Council was 163 gallons per person per day. About 0.16 percent of this consumption (i.e., 1.0 liters or 1.1 quarts per person per day) was associated with human ingestion.

Table 3-5 provides estimates of the population doses that would be received from a worst case spent fuel rail cask accident upwind from a reservoir. The accident class (impact, burst and oxidation) that releases the largest amount of radionuclides results in a maximum of about 13 latent health effects (LHE's). The impact and burst class accident results in about 1.4 LHE's and about 0.036 LHE's result from an impact accident.

TABLE 3-5

POPULATION RADIATION EXPOSURE FROM
WATER INGESTION FOR SEVERE BUT CREDIBLE SPENT FUEL
RAIL CASK ACCIDENTS

Accident Class	Total Release from Rail Cask (Ci)*	Population Dose Effects from Water Ingestion
Impact	8.07	182 person-rem 0.036 LHE**
Impact and Burst	153	6870 person-rem 1.4 LHE**
Impact, Burst and Oxidation	1379	63,000 person-rem 12.6 LHE**

* The noble gas Kr-85 is omitted because of its negligible uptake by a surface water body.
** Latent health effect (LHE) estimates are based upon 1 person-rem = 2×10^{-4} LHE.

It is important to recall the conservative assumptions made in arriving at these estimates for the maximum consequences of severe but credible rail accidents that result in significant water contamination. The probability of a rail cask accident with radionuclide release is no greater than 2 occurences per millcon rail transport accidents. Futhermore, the probability that such an accident would occur near a major reservoir and that prevailing weather conditions would combine to result in significant reservoir water contamination is extremely small. In the very unlikely event that a water reservoir were actually contaminated by a spent fuel accident release it is reasonable to assume that normal water treatment processes, combined with monitoring and emergency actions, would significantly reduce doses received by the affected population to levels well below those predicted by this maximum consequence analysis.

It is also helpful to put the impacts in Table 3-5 into perspective. Assuming an annual water ingestion of 400 quarts per year by each person, for the water consumption assumed in the calculations (one percent of one billion gallons), this water quantity would service about 37 million people. In a single year, using the same cancer risk factor as used in Section 3.3 (Ref 19), those people would experience about 72,000 cancer fatalities from other causes. Again, even using very conservative calculations of accident effects, the worst case rail cask accident that could contaminate a water supply does not pose a significant health impact.

3.4 CLEANUP TIME AND COST ESTIMATES FOR SPENT FUEL RAIL CASK ACCIDENTS

The risk of injuries and fatalities resulting from releases of radioactive material as a consequence of a severe but credible rail cask accident can be reduced if a cleanup of the more highly contaminated areas is carried out. However, the total economic costs associated with cleanup and reclamation for a substantial radionuclide release could be very high and the net reduction in associated health effects relatively low (see Section 3.3).

Detailed estimates of the costs incurred for cleanup and recovery from a shipping cask accident in a highly developed urban environment have previously been made in several studies (Refs 20 and 21). Total cost estimates of about 2 billion dollars have been projected following the atmospheric release of about a 1000 curies in a city. The bulk of these costs are attributed to the denial of public access to contaminated areas while cleanup occurs.

The economic costs for cleanup and recovery will be strongly dependent on the amount and type of radioactive material released, the particular setting (rural, urban, plain, mountainous, sea shore, etc.) and the level of cleanup (i.e., the minimum residual activity level that is permitted to remain after cleanup).

In this analysis the cost and manpower estimates for cleanup and recovery from worst case rail cask accidents are for a contaminated rural setting. The three classes of rail cask accidents described previously were considered.

Table 3-6 provides the ground areas calculated by the PATHRAE-T code as being contaminated after a spent fuel rail cask accident. The areas are shown for contamination above various levels of surface activity. For example, a level of 10 $\mu Ci/m^2$ for the 1380 curie release from an impact, burst and oxidation class accident is associated with a contaminated area of 2.16 km^2. The characteristics for other contamination levels and accident classes are similarly defined.

TABLE 3-6

CONTAMINATED AREAS FROM SPENT FUEL RAIL CASK ACCIDENTS

Accident Class	Radiation Release (Ci)*	Level of Contamination ($\mu Ci/m^2$)	Contaminated Area (km^2)
Impact	8.1	10	0.013
		5	0.025
		1 (250 mrem/yr)	0.13
		0.5	0.26
		0.2	0.67
Impact and Burst	153	10	0.24
		5 (500 mrem/yr)	0.48
		1	2.4
		0.5	4.9
		0.2	13
Impact, Burst and Oxidation	1380	10	2.2
		5 (500 mrem/yr)	4.3
		1	22
		0.5	45
		0.2	110

* Activity for Kr-85 (and all other radioactive noble gases) is omitted. All other nuclides are eventually assumed to be deposited in the soil.

The various levels of soil contamination listed in Table 3-6 can be related approximately to average annual radiation exposure that would be incurred by individuals living in the contaminated area immediately after cleanup. The three principal nuclides that account for over 99.5 percent of the activity deposited on the ground are Co-60, Cs-134 and Cs-137. Healy (Ref 22) estimates that a uniform soil activity of 80 pCi/g of Cs-137 or Cs-134 will result in a total annual individual dose from all pathways combined (inhalation, ingestion, and external radiation) of about 500 mrem per year to an individual living on the contaminated site and consuming food from a home garden. A soil activity of 80 pCi/g (Cs-134 or Cs-137) is conservatively associated with a surface contamination of about 5 $\mu Ci/m^2$.

For Co-60, which is the dominant nuclide for the impact class spent fuel accident, a soil activity of about 20 pCi/g, or 2 $\mu Ci/m^2$ is associated with the equivalent 500 mrem per year dose to an individual living on the contaminated site. In view of Federal policy (both EPA and NRC) to minimize doses to both individuals and population groups, it is difficult to predict the actual cleanup levels that would be required. The EPA (Ref 23) has recommended a cleanup level of 0.2 $\mu Ci/m^2$ for transuranic elements in the general environment.

Using the data from Table 3-6 it was possible to project a set of cost and time requirements for different cleanup levels in a rural setting. Knowing the ground area of contamination and assuming an acceptable depth of soil removal, the volume of contaminated soil was estimated.

Rough estimates of cleanup costs and recovery time requirements are given in Table 3-7, for cleanup to a level that limits individual dose rates from radionuclides to 500 mrem/yr. For a given rail cask accident class, the volume of contaminated soil that was removed was estimated by

TABLE 3-7

CLEANUP COSTS AND RECOVERY TIME ESTIMATES FOR RURAL SPENT FUEL RAIL CASK ACCIDENTS*

Accident Class	Contaminated Land Area (m^2)	Total Cost Range ($) Low	High	Cleanup and Recovery Time (Calendar Days)
I - Impact	6.3E+4	2.0E+5	9.5E+6	25
II - Impact and Burst	4.8E+5	1.4E+6	7.0E+7	68
III - Impact, Burst and Oxidation	4.3E+5	1.3E+7	6.2E+8	460

* Cleanup is to a level that reduces individual dose rates from deposited radionuclides down to a maximum value of 500 mrem/yr.

assuming a 10 cm excavation depth. Costs per cubic meter of soil removed were then assessed for the four categories:

- Monitoring, excavating, loading and packaging. These costs vary with terrain, equipment accessibility and packaging (if necessary) requirements.
- Transportation costs to the nearest acceptable disposal site. These costs vary with travel distance and transportation routes.
- Disposal costs. This varies with the disposal site selected and necessary site preparations to accomodate the given waste form.
- Site restoration costs. This includes costs for fill material, hauling, spreading, and seeding. Also, erosion protection and replacement of existing improvements and utilities may be required.

Estimates for cleanup and restoration costs range from \$10/m^3 for simple monitoring, excavation and loading of contaminated soil in open trucks to \$430/m^3 for extensive monitoring, packaging the contaminated soil in sealed drums and loading the drums in trucks. Similar ranges of extremes exist for transportation (\$15/m^3 to \$530/m^3) and disposal (\$5/m^3 to \$510/m^3) costs depending upon the specific cleanup scenario projected. The low cost estimates are based on costs projected for cleanup of the Vitro uranium mill tailings in Salt Lake City, Utah (Ref 24). The Vitro cleanup represents rail transportation over about 100 miles. The high cost estimates are based on transportation and waste preparation cost estimates for low-level radioactive wastes from Reference 25 and disposal costs for the Barnwell, South Carolina low-level waste facility (Ref 26). For the latter, a highway transportation distance of about 400 miles was assumed. All cost estimates are adjusted to 1985 dollars.

Estimated cleanup and recovery times in calendar days are also provided for each scenario shown in Table 3-7. These time estimates assume about 4 to 7 calendar days for emergency response, radiation monitoring, and evaluation of the contaminated area. The remaining time is devoted to actual cleanup and removal of contaminated materials. The mathematical relationship assumed for the cleanup and recovery time is approximately linearly dependent upon the contaminated land area, with a correction applied for economy of scale for large areas.

4. CONCLUSIONS

From the information presented in this report several conclusions can be drawn regarding radiation exposures from normal transportation of high-level radioactive waste and spent nuclear fuel. They include:

- Situations that could potentially result in exposure of members of the general public on an infrequent basis, such as trucks caught in traffic or truck tire repair, produce doses on the order of 5 mrem or less. Considering the fact that the recipients of these doses are not likely to be in a similar situation more than once and that the likelihood of these events is low, this dose is insignificant. Specific likelihoods of these events will be site-specific and route-specific.

- Activities that are likely to be performed repeatedly during the period waste is being shipped, such as truck refueling, driver overnight stops, vehicle inspection enroute, etc., produce doses per event, that range downward from a few mrem. While a person repeatedly carrying out these activities could receive a significant annual dose, procedures for performing these operations can be changed to limit the total annual dose to any one individual.

- Situations that may occur repeatedly, such as the slowing or stopping of a waste transportation vehicle near an occupied building, can produce doses approaching the order of one mrem per truck or rail car. While there can be hundreds or thousands of spent fuel transport movements in a year, they will not necessarily pass the same geographic point. Concentration of the movements to one or two routes will only take place close to the repository.

A number of conclusions can be drawn from the information in this report regarding radiation exposures and health effects from the worst case accidents analyzed. They include:

- A person responding to the emergency caused by the severe but credible rail car accident--a severe impact followed by a massive fire fed by large quantities of fuel--could receive a dose of up to 10 rem in a few hours if no protective equipment is worn and no attempt is made to avoid inhalation of radionuclides in the atmosphere. This dose is not unreasonable, considering the circumstances and small probability of occurence.

- For the highest population assumed to be exposed from a severe but credible rail accident--severe impact and massive fire--up to 22 latent health effects* might be expected over the succeeding 50 years. However, this compares to 470,000 cancer fatalities that the same population would experience over 50 years from all causes.

- For a severe but credible rail car accident involving a water pathway--severe impact followed by fire, alongside a reservoir--up to 13 latent health effects could result among the general population. This figure assumes no measure, either ordinary or remedial in nature, removes radionuclides from the accident from the water consumed by the population. Also, the population that might experience 13 latent health effects due to the accident would experience about 72,000 cancer deaths per year from all causes.

- While cleanup of contaminated soil near the rail accident studied could reduce the 50-year exposures and health effects to the surrounding populace, over the range of likely cleanup levels the reduction is not dramatic (from 24 to 17 latent cancer fatalities) and is highly insensitive to the cleanup level used.

* Of the latent health effects, about half would be cancers to the exposed generation and about half would be serious genetic health problems to the two succeeding generations.

APPENDIX A

RADIATION FIELDS AROUND SPENT FUEL CASKS IN NORMAL TRANSPORTATION

APPENDIX A

RADIATION FIELDS AROUND SPENT FUEL CASKS IN NORMAL TRANSPORTATION

This appendix provides the detailed isodose maps and dose rate tables generated by the computer code PATHRAE-T for both truck and rail casks. The near field maps and tables, which cover the distance from 0 to 15 meters, provide dose rate values at 0.2 meter (radially) and 0.1 meter (axially) intervals for the truck cask (see Figure A-1 and Table A-2) and the rail cask (see Figure A-3 and Table A-4). The far field maps and tables, which cover distances out to 150 meters from the cask, provide dose rate values at 2 meter (radially) and 1 meter (axially) intervals for the truck cask (see Figure A-2 and Table A-3) and the rail cask (see Figure A-4 and Table A-5).

Since the horizontal radiation field around the cask is assumed to be symmetric, only a single quadrant is shown in the figures and tables. Horizontal data entries moving from left to right represent dose rates as functions of increasing distance parallel to the axis of the cask. Vertical data entries moving from top to bottom represent dose rates as functions of increasing radial distance perpendicular to the axis of the cask. The orientation of the cask and truck and rail transporters is the same as that shown in Figures 2-2 and 2-3 in Chapter 2 of this report.

A legend at the bottom of each figure provides a key to the letter and number symbols used to represent the dose rate at a given position. For example, in Figure A-1, the region surrounding the truck cask which contains the number "8" represents that area around the cask for which the dose rate lies within the range of 200 to 250 microrem per minute. Observe that the letter "A" represents the 160 to 170 microrem per minute dose rate. This corresponds to about 10 mrem per hour which is the DOT requirement imposed at the 2 meter boundary from the personnel barrier of the cask.

Table A-1 provides the data used for generating the dose maps and tables given in this appendix.

TABLE A-1

DATA SET FOR RADIATION DOSE CALCULATIONS FOR SPENT FUEL TRUCK AND RAIL CASKS

Parameter	Truck Cask	Rail Cask
L = effective line source length (m)	4.50	4.50
S = effective line source strength for gamma radiation (μrem · m/min)	5168	6867
R = minimum radius to 10 mrem/hr boundary (m)	3.5	3.6
μ_a = effective air attenuation coefficient (1/m)	0.00924	0.00924
μ = effective ground attenuation coefficient (1/m)	12.4	12.4
h_0 = effective height of line source (m)	2.00	2.00
h_1 = effective height of dose measurement point (m)	1.00	1.00
$f(\gamma)$ = fraction of limit dose rate (10 mrem/hr) at regulatory boundary due to gamma radiation	0.65	0.50
$f(n)$ = fraction of limit dose rate (10 mrem/hr) at regulatory boundary due to neutrons	0.35	0.50

TABLE A-2

NEAR FIELD RADIATION DOSE RATE TABLE
FOR SPENT FUEL TRUCK CASK

DIST. (M)	0		2		4		6		8		10		12		14	
0	-1.00	-1.00	-1.00	541.52	224.29	138.67	98.86	75.85	60.90	50.43	42.73	36.85	32.22	28.49	25.45	22.92
	-1.00	-1.00	-1.00	526.41	223.00	138.32	98.71	75.78	60.86	50.41	42.71	36.83	32.21	28.49	25.45	22.92
	-1.00	-1.00	-1.00	490.17	219.48	137.36	98.33	75.59	60.75	50.34	42.67	36.80	32.19	28.48	25.44	22.91
	-1.00	-1.00	-1.00	444.63	214.04	135.83	97.70	75.27	60.57	50.23	42.59	36.75	32.15	28.45	25.42	22.89
	-1.00	-1.00	-1.00	398.73	207.12	133.79	96.84	74.84	60.32	50.07	42.49	36.68	32.10	28.41	25.39	22.87
	-1.00	-1.00	-1.00	356.77	199.17	131.29	95.78	74.29	60.00	49.87	42.36	36.59	32.03	28.36	25.35	22.84
	-1.00	-1.00	-1.00	320.04	190.61	128.42	94.52	73.64	59.62	49.63	42.20	36.47	31.95	28.30	25.30	22.80
	-1.00	-1.00	-1.00	288.44	181.81	125.27	93.10	72.89	59.18	49.36	42.01	36.34	31.86	28.23	25.25	22.76
	450.51	438.70	375.94	261.40	173.04	121.90	91.53	72.05	58.69	49.04	41.80	36.20	31.75	28.15	25.19	22.71
	388.72	377.30	326.78	238.23	164.47	118.39	89.85	71.14	58.14	48.69	41.56	36.03	31.63	28.06	25.12	22.66
2	339.72	330.25	288.31	218.27	156.24	114.79	88.07	70.15	57.55	48.31	41.31	35.85	31.50	27.96	25.04	22.60
	301.57	292.55	257.42	201.00	148.42	111.17	86.21	69.10	56.91	47.89	41.02	35.65	31.35	27.85	24.96	22.53
	270.08	261.76	232.25	185.95	141.04	107.56	84.31	68.01	56.23	47.45	40.72	35.43	31.19	27.73	24.87	22.46
	243.74	236.21	211.29	172.75	134.11	103.99	82.36	66.87	55.52	46.98	40.40	35.20	31.02	27.60	24.77	22.39
	221.45	214.71	193.56	161.02	127.64	100.50	80.40	65.70	54.78	46.49	40.06	34.96	30.84	27.47	24.66	22.30
	202.41	196.58	178.38	150.59	121.59	97.10	78.43	64.50	54.01	45.98	39.70	34.70	30.65	27.32	24.55	22.22
	186.18	181.00	165.24	141.29	115.85	93.81	76.47	63.28	53.22	45.45	39.33	34.43	30.45	27.17	24.44	22.12
	172.07	167.48	153.77	132.95	110.51	90.60	74.53	62.06	52.42	44.90	38.94	34.15	30.24	27.01	24.31	22.03
	159.73	155.66	143.58	125.45	105.53	87.47	72.62	60.83	51.60	44.33	38.54	33.86	30.03	26.85	24.18	21.92
	148.85	145.24	134.52	118.66	100.89	84.47	70.69	59.60	50.77	43.76	38.13	33.56	29.80	26.68	24.05	21.82
4	139.20	135.92	126.44	112.49	96.57	81.60	68.81	58.35	49.94	43.17	37.71	33.25	29.57	26.50	23.91	21.71
	130.49	127.57	119.20	106.74	92.53	78.85	66.96	57.11	49.09	42.58	37.28	32.93	29.33	26.31	23.76	21.59
	122.69	120.10	112.68	101.49	88.76	76.23	65.17	55.88	48.23	41.98	36.84	32.61	29.08	26.12	23.61	21.47
	115.69	113.37	106.76	96.68	85.17	73.72	63.43	54.67	47.38	41.37	36.40	32.28	28.83	25.93	23.46	21.35
	109.37	107.30	101.26	92.25	81.79	71.33	61.73	53.47	46.53	40.75	35.95	31.94	28.57	25.73	23.30	21.22
	103.63	101.71	96.24	88.17	78.62	69.02	60.09	52.30	45.68	40.13	35.49	31.59	28.31	25.52	23.14	21.09
	98.28	96.55	91.65	84.39	75.65	66.79	58.51	51.15	44.84	39.51	35.03	31.24	28.04	25.31	22.98	20.96
	93.40	91.85	87.45	80.80	72.86	64.67	56.95	50.02	44.01	38.90	34.56	30.89	27.77	25.10	22.81	20.82
	88.94	87.55	83.58	77.46	70.24	62.64	55.43	48.92	43.19	38.28	34.10	30.53	27.49	24.88	22.63	20.69
	84.85	83.59	79.92	74.36	67.75	60.71	53.97	47.82	42.39	37.67	33.63	30.17	27.21	24.66	22.46	20.54
6	81.09	79.90	76.52	71.47	65.36	58.88	52.55	46.75	41.59	37.07	33.17	29.82	26.93	24.44	22.28	20.40
	77.51	76.44	73.37	68.77	63.11	57.12	51.19	45.71	40.79	36.47	32.71	29.45	26.64	24.21	22.10	20.25
	74.21	73.23	70.45	66.22	60.99	55.42	49.87	44.69	40.01	35.87	32.25	29.09	26.36	23.98	21.91	20.10
	71.15	70.27	67.73	63.79	58.98	53.78	48.61	43.70	39.24	35.28	31.79	28.73	26.07	23.76	21.73	19.95
	68.32	67.51	65.15	61.51	57.09	52.22	47.37	42.74	38.49	34.69	31.33	28.38	25.79	23.52	21.54	19.80
	65.68	64.91	62.71	59.37	55.27	50.73	46.17	41.80	37.75	34.11	30.87	28.01	25.50	23.29	21.35	19.64
	63.14	62.44	60.43	57.36	53.53	49.31	45.01	40.89	37.03	33.54	30.42	27.65	25.21	23.06	21.16	19.49
	60.78	60.14	58.29	55.47	51.88	47.95	43.90	39.99	36.33	32.97	29.97	27.29	24.92	22.83	20.97	19.33
	58.58	57.99	56.29	53.64	50.31	46.64	42.82	39.11	35.63	32.42	29.52	26.94	24.64	22.59	20.78	19.17
	56.51	55.97	54.39	51.91	48.82	45.36	41.79	38.27	34.95	31.88	29.09	26.58	24.35	22.36	20.59	19.02
8	54.57	54.05	52.57	50.27	47.41	44.15	40.79	37.45	34.28	31.34	28.65	26.23	24.06	22.12	20.40	18.86
	52.70	52.23	50.85	48.73	46.04	42.99	39.81	36.65	33.62	30.81	28.22	25.88	23.78	21.89	20.20	18.69
	50.95	50.50	49.23	47.26	44.73	41.87	38.87	35.88	32.99	30.28	27.80	25.54	23.49	21.66	20.01	18.53
	49.29	48.88	47.70	45.85	43.48	40.81	37.96	35.12	32.36	29.77	27.38	25.19	23.21	21.42	19.81	18.37
	47.73	47.35	46.25	44.50	42.29	39.77	37.08	34.38	31.76	29.27	26.96	24.85	22.93	21.19	19.62	18.21
	46.26	45.90	44.85	43.22	41.16	38.77	36.24	33.66	31.16	28.78	26.56	24.52	22.65	20.96	19.43	18.05
	44.83	44.50	43.53	42.01	40.07	37.81	35.42	32.97	30.58	28.30	26.16	24.18	22.37	20.73	19.23	17.88
	43.48	43.17	42.27	40.85	39.01	36.89	34.62	32.30	30.01	27.82	25.76	23.85	22.10	20.50	19.04	17.72
	42.21	41.92	41.07	39.74	38.00	36.01	33.85	31.64	29.45	27.36	25.37	23.53	21.83	20.27	18.85	17.56
	41.00	40.72	39.93	38.67	37.04	35.16	33.10	31.01	28.91	26.90	24.99	23.21	21.56	20.04	18.66	17.40
10	39.85	39.59	38.83	37.64	36.11	34.33	32.38	30.38	28.39	26.45	24.61	22.89	21.29	19.82	18.47	17.24
	38.73	38.49	37.78	36.67	35.23	33.53	31.69	29.78	27.87	26.01	24.24	22.58	21.02	19.59	18.28	17.07
	37.67	37.44	36.78	35.73	34.37	32.76	31.02	29.19	27.37	25.58	23.88	22.27	20.76	19.37	18.09	16.91
	36.66	36.45	35.82	34.84	33.54	32.02	30.36	28.62	26.88	25.17	23.52	21.96	20.51	19.15	17.90	16.75
	35.70	35.50	34.91	33.97	32.74	31.31	29.73	28.07	26.40	24.75	23.17	21.66	20.25	18.93	17.72	16.59
	34.78	34.59	34.03	33.14	31.98	30.62	29.11	27.54	25.93	24.35	22.82	21.36	19.99	18.72	17.53	16.43
	33.88	33.70	33.18	32.34	31.25	29.95	28.52	27.01	25.47	23.95	22.48	21.07	19.74	18.50	17.35	16.28
	33.03	32.86	32.37	31.58	30.54	29.30	27.94	26.50	25.03	23.57	22.15	20.79	19.50	18.29	17.16	16.12
	32.22	32.06	31.59	30.85	29.85	28.68	27.38	26.00	24.60	23.19	21.82	20.50	19.25	18.08	16.98	15.96
	31.44	31.29	30.85	30.13	29.19	28.08	26.84	25.52	24.17	22.82	21.50	20.22	19.01	17.87	16.80	15.81
12	30.69	30.55	30.12	29.45	28.56	27.50	26.31	25.05	23.75	22.46	21.18	19.95	18.78	17.67	16.62	15.65
	29.97	29.83	29.43	28.79	27.95	26.93	25.80	24.60	23.35	22.10	20.87	19.68	18.54	17.46	16.45	15.50
	29.27	29.14	28.76	28.16	27.35	26.39	25.31	24.15	22.96	21.75	20.57	19.41	18.31	17.26	16.27	15.35
	28.60	28.48	28.12	27.55	26.78	25.86	24.83	23.72	22.57	21.41	20.27	19.15	18.08	17.06	16.10	15.20
	27.96	27.84	27.51	26.95	26.22	25.35	24.36	23.30	22.20	21.08	19.97	18.90	17.86	16.87	15.93	15.05
	27.34	27.23	26.91	26.38	25.69	24.85	23.91	22.89	21.83	20.75	19.69	18.64	17.63	16.67	15.76	14.90
	26.74	26.64	26.33	25.83	25.17	24.37	23.46	22.49	21.47	20.44	19.40	18.39	17.42	16.48	15.59	14.75
	26.17	26.07	25.77	25.30	24.67	23.90	23.04	22.10	21.12	20.12	19.13	18.15	17.20	16.29	15.42	14.61
	25.61	25.52	25.24	24.79	24.18	23.45	22.62	21.72	20.78	19.82	18.86	17.91	16.99	16.10	15.26	14.46
	25.08	24.99	24.72	24.29	23.71	23.01	22.22	21.35	20.45	19.52	18.59	17.67	16.78	15.92	15.10	14.32
14	24.56	24.47	24.22	23.80	23.25	22.58	21.82	20.99	20.12	19.23	18.33	17.44	16.57	15.74	14.94	14.17
	24.06	23.97	23.73	23.34	22.81	22.17	21.44	20.64	19.80	18.94	18.07	17.21	16.37	15.56	14.78	14.03
	23.57	23.49	23.26	22.89	22.38	21.77	21.07	20.30	19.49	18.66	17.82	16.99	16.17	15.38	14.62	13.89
	23.10	23.03	22.81	22.45	21.97	21.38	20.70	19.97	19.19	18.39	17.57	16.77	15.97	15.20	14.46	13.76
	22.65	22.58	22.37	22.03	21.56	21.00	20.35	19.64	18.89	18.12	17.33	16.55	15.78	15.03	14.31	13.62
	22.22	22.15	21.94	21.61	21.17	20.63	20.01	19.33	18.60	17.85	17.10	16.34	15.59	14.86	14.16	13.48

NOTE: TABLE VALUES OF -1.00 INDICATE A LOCATION WITHIN THE CASK INTERIOR WHERE DOSE RATES ARE NOT EVALUATED

TABLE A-3

FAR FIELD RADIATION ISODOSE RATE TABLE
FOR SPENT FUEL TRUCK CASK

DIST. (M)	0		20		40		60		80		100		120		140	
0	-1.00	42.73	14.85	8.11	5.31	3.84	2.94	2.35	1.94	1.66	1.43	1.27	1.09	1.01	0.88	0.82
	113.19	41.24	14.73	8.08	5.29	3.82	2.93	2.35	1.94	1.64	1.42	1.24	1.10	0.98	0.89	0.81
	76.83	37.47	14.39	8.00	5.26	3.81	2.93	2.35	1.94	1.64	1.42	1.24	1.10	0.98	0.89	0.81
	58.05	32.79	13.87	7.87	5.21	3.78	2.91	2.34	1.93	1.64	1.41	1.24	1.10	0.98	0.89	0.81
	47.05	28.21	13.22	7.69	5.15	3.75	2.90	2.33	1.93	1.63	1.41	1.24	1.10	0.98	0.89	0.81
	39.84	24.20	12.48	7.48	5.07	3.71	2.88	2.32	1.92	1.63	1.41	1.23	1.09	0.98	0.89	0.81
	30.29	20.85	11.70	7.24	4.97	3.67	2.85	2.30	1.91	1.62	1.40	1.23	1.09	0.98	0.88	0.81
	24.14	18.12	10.92	6.98	4.86	3.62	2.82	2.29	1.90	1.62	1.40	1.23	1.09	0.98	0.88	0.80
	19.92	15.89	10.17	6.71	4.75	3.56	2.79	2.27	1.89	1.61	1.39	1.22	1.09	0.97	0.88	0.80
	16.87	14.01	9.45	6.43	4.62	3.50	2.76	2.24	1.87	1.60	1.39	1.22	1.08	0.97	0.88	0.80
20	14.59	12.37	8.79	6.15	4.49	3.43	2.72	2.22	1.86	1.59	1.38	1.21	1.08	0.97	0.88	0.80
	12.64	11.02	8.18	5.88	4.36	3.36	2.68	2.20	1.84	1.58	1.37	1.21	1.07	0.96	0.87	0.80
	11.11	9.90	7.59	5.61	4.22	3.29	2.64	2.17	1.83	1.57	1.36	1.20	1.07	0.96	0.87	0.79
	9.88	8.95	7.06	5.35	4.09	3.21	2.59	2.14	1.81	1.55	1.35	1.19	1.06	0.96	0.87	0.79
	8.88	8.15	6.58	5.09	3.95	3.13	2.54	2.11	1.79	1.54	1.34	1.19	1.06	0.95	0.86	0.79
	8.04	7.44	6.14	4.85	3.82	3.06	2.50	2.08	1.77	1.53	1.33	1.18	1.05	0.95	0.86	0.79
	7.31	6.82	5.75	4.62	3.69	2.98	2.45	2.05	1.75	1.51	1.32	1.17	1.05	0.94	0.86	0.78
	6.68	6.29	5.39	4.40	3.56	2.90	2.40	2.02	1.73	1.50	1.31	1.16	1.04	0.94	0.85	0.78
	6.14	5.82	5.06	4.19	3.43	2.82	2.35	1.99	1.70	1.48	1.30	1.15	1.03	0.93	0.85	0.78
	5.68	5.42	4.76	4.00	3.31	2.74	2.30	1.95	1.68	1.46	1.29	1.15	1.03	0.93	0.85	0.78
40	5.28	5.05	4.48	3.82	3.19	2.67	2.25	1.92	1.66	1.45	1.28	1.14	1.02	0.92	0.84	0.77
	4.91	4.72	4.23	3.64	3.08	2.59	2.20	1.89	1.63	1.43	1.26	1.13	1.01	0.92	0.84	0.77
	4.59	4.42	4.01	3.48	2.97	2.52	2.15	1.85	1.61	1.41	1.25	1.12	1.01	0.91	0.83	0.76
	4.30	4.16	3.80	3.33	2.86	2.45	2.10	1.82	1.59	1.40	1.24	1.11	1.00	0.91	0.83	0.76
	4.04	3.92	3.60	3.19	2.76	2.38	2.06	1.78	1.56	1.38	1.23	1.10	0.99	0.90	0.82	0.76
	3.81	3.71	3.42	3.05	2.67	2.31	2.01	1.75	1.54	1.36	1.21	1.09	0.98	0.89	0.82	0.75
	3.60	3.51	3.26	2.93	2.58	2.25	1.96	1.72	1.51	1.34	1.20	1.08	0.98	0.89	0.81	0.75
	3.41	3.33	3.11	2.81	2.49	2.19	1.92	1.68	1.49	1.32	1.18	1.07	0.97	0.88	0.81	0.74
	3.23	3.16	2.97	2.70	2.41	2.12	1.87	1.65	1.46	1.31	1.17	1.06	0.96	0.88	0.80	0.74
	3.07	3.01	2.84	2.59	2.33	2.07	1.83	1.62	1.44	1.29	1.16	1.05	0.95	0.87	0.80	0.74
60	2.93	2.87	2.71	2.49	2.25	2.01	1.79	1.59	1.42	1.27	1.14	1.03	0.94	0.86	0.79	0.73
	2.79	2.74	2.60	2.40	2.18	1.95	1.74	1.56	1.39	1.25	1.13	1.02	0.93	0.85	0.79	0.73
	2.67	2.62	2.50	2.32	2.11	1.90	1.70	1.53	1.37	1.23	1.11	1.01	0.92	0.85	0.78	0.72
	2.55	2.51	2.40	2.23	2.04	1.85	1.66	1.50	1.35	1.21	1.10	1.00	0.92	0.84	0.77	0.72
	2.45	2.41	2.31	2.15	1.98	1.80	1.62	1.47	1.32	1.20	1.09	0.99	0.91	0.83	0.77	0.71
	2.35	2.31	2.22	2.08	1.92	1.75	1.59	1.44	1.30	1.18	1.07	0.98	0.90	0.83	0.76	0.71
	2.25	2.22	2.14	2.01	1.86	1.70	1.55	1.41	1.28	1.16	1.06	0.97	0.89	0.82	0.76	0.70
	2.17	2.14	2.06	1.95	1.81	1.66	1.52	1.38	1.26	1.14	1.04	0.96	0.88	0.81	0.75	0.70
	2.09	2.06	1.99	1.88	1.75	1.62	1.48	1.35	1.23	1.13	1.03	0.95	0.87	0.80	0.75	0.69
	2.01	1.99	1.92	1.82	1.70	1.58	1.45	1.33	1.21	1.11	1.02	0.94	0.86	0.80	0.74	0.69
80	1.94	1.92	1.86	1.77	1.66	1.54	1.42	1.30	1.19	1.09	1.00	0.92	0.85	0.79	0.73	0.68
	1.87	1.85	1.80	1.71	1.61	1.50	1.38	1.27	1.17	1.08	0.99	0.91	0.84	0.78	0.73	0.68
	1.81	1.79	1.74	1.66	1.57	1.46	1.35	1.25	1.15	1.06	0.98	0.90	0.84	0.77	0.72	0.67
	1.75	1.73	1.69	1.61	1.52	1.43	1.32	1.23	1.13	1.04	0.96	0.89	0.83	0.77	0.71	0.67
	1.69	1.68	1.64	1.57	1.48	1.39	1.30	1.20	1.11	1.03	0.95	0.88	0.82	0.76	0.71	0.66
	1.64	1.63	1.59	1.52	1.45	1.36	1.27	1.18	1.09	1.01	0.94	0.87	0.81	0.75	0.70	0.66
	1.59	1.58	1.54	1.48	1.41	1.33	1.24	1.16	1.07	1.00	0.93	0.86	0.80	0.75	0.70	0.65
	1.54	1.53	1.50	1.44	1.37	1.30	1.22	1.13	1.06	0.98	0.91	0.85	0.79	0.74	0.69	0.65
	1.50	1.49	1.45	1.40	1.34	1.27	1.19	1.11	1.04	0.97	0.90	0.84	0.78	0.73	0.68	0.64
	1.46	1.45	1.42	1.37	1.31	1.24	1.17	1.09	1.02	0.95	0.89	0.83	0.77	0.72	0.68	0.64
100	1.42	1.41	1.38	1.33	1.28	1.21	1.14	1.07	1.00	0.94	0.88	0.82	0.77	0.72	0.67	0.63
	1.38	1.37	1.34	1.30	1.25	1.18	1.12	1.05	0.99	0.92	0.86	0.61	0.76	0.71	0.67	0.63
	1.34	1.33	1.31	1.27	1.22	1.16	1.10	1.03	0.97	0.91	0.85	0.80	0.75	0.70	0.66	0.62
	1.30	1.30	1.27	1.24	1.19	1.13	1.08	1.02	0.95	0.90	0.84	0.79	0.74	0.69	0.65	0.62
	1.27	1.26	1.24	1.21	1.16	1.11	1.05	1.00	0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61
	1.24	1.23	1.21	1.18	1.14	1.09	1.03	0.98	0.92	0.87	0.82	0.77	0.72	0.68	0.64	0.61
	1.21	1.20	1.18	1.15	1.11	1.07	1.01	0.96	0.91	0.86	0.81	0.76	0.72	0.67	0.64	0.60
	1.18	1.17	1.15	1.13	1.09	1.04	1.00	0.95	0.89	0.84	0.80	0.75	0.71	0.67	0.63	0.59
	1.15	1.14	1.13	1.10	1.06	1.02	0.98	0.93	0.88	0.83	0.79	0.74	0.70	0.66	0.62	0.59
	1.12	1.12	1.10	1.08	1.04	1.00	0.96	0.91	0.87	0.82	0.78	0.73	0.69	0.65	0.62	0.58
120	1.10	1.09	1.08	1.05	1.02	0.98	0.94	0.90	0.85	0.81	0.77	0.72	0.68	0.65	0.61	0.58
	1.07	1.07	1.05	1.03	1.00	0.96	0.92	0.88	0.84	0.80	0.75	0.71	0.68	0.64	0.61	0.57
	1.05	1.04	1.03	1.01	0.98	0.95	0.91	0.87	0.83	0.79	0.75	0.71	0.67	0.63	0.60	0.57
	1.03	1.02	1.01	0.99	0.96	0.93	0.89	0.85	0.81	0.77	0.74	0.70	0.66	0.63	0.60	0.56
	1.00	1.00	0.99	0.97	0.94	0.91	0.88	0.84	0.80	0.76	0.73	0.69	0.65	0.62	0.59	0.56
	0.98	0.98	0.97	0.95	0.92	0.89	0.86	0.83	0.79	0.75	0.72	0.68	0.65	0.61	0.58	0.55
	0.96	0.96	0.95	0.93	0.91	0.88	0.85	0.81	0.78	0.74	0.71	0.67	0.64	0.61	0.58	0.55
	0.94	0.94	0.93	0.91	0.89	0.86	0.83	0.80	0.77	0.73	0.70	0.66	0.63	0.60	0.57	0.55
	0.92	0.92	0.91	0.89	0.87	0.85	0.82	0.79	0.75	0.72	0.69	0.66	0.63	0.60	0.57	0.54
	0.91	0.90	0.89	0.88	0.86	0.83	0.80	0.77	0.74	0.71	0.68	0.65	0.62	0.59	0.56	0.54
140	0.89	0.89	0.88	0.86	0.84	0.82	0.79	0.76	0.73	0.70	0.67	0.64	0.61	0.58	0.56	0.53
	0.87	0.87	0.86	0.85	0.83	0.80	0.78	0.75	0.72	0.69	0.66	0.63	0.61	0.58	0.55	0.53
	0.85	0.85	0.84	0.83	0.81	0.79	0.77	0.74	0.71	0.68	0.65	0.63	0.60	0.57	0.55	0.52
	0.84	0.84	0.83	0.82	0.80	0.78	0.75	0.73	0.70	0.67	0.65	0.62	0.59	0.57	0.54	0.52
	0.82	0.82	0.81	0.80	0.78	0.76	0.74	0.72	0.69	0.67	0.64	0.61	0.59	0.56	0.54	0.51
	0.81	0.81	0.80	0.79	0.77	0.75	0.73	0.71	0.68	0.66	0.63	0.60	0.58	0.55	0.53	0.51

NOTE: TABLE VALUES OF -1.00 INDICATE A LOCATION WITHIN THE CASK INTERIOR WHERE DOSE RATES ARE NOT EVALUATED

TABLE A-4

NEAR FIELD RADIATION DOSE RATE TABLE
FOR SPENT FUEL RAIL CASK

DIST. (m)	0		2		4		6		8		10		12		14	
0	-1.00	-1.00	-1.00	-1.00	-1.00	149.95	108.35	84.09	68.19	56.98	48.65	42.26	37.20	33.09	29.73	26.90
	-1.00	-1.00	-1.00	-1.00	-1.00	149.59	108.20	84.02	68.15	56.95	48.64	42.25	37.19	33.09	29.72	26.90
	-1.00	-1.00	-1.00	-1.00	-1.00	148.58	107.78	83.81	68.03	56.87	48.59	42.21	37.16	33.07	29.71	26.89
	-1.00	-1.00	-1.00	-1.00	-1.00	146.97	107.12	83.47	67.83	56.75	48.51	42.15	37.12	33.04	29.68	26.87
	-1.00	-1.00	-1.00	-1.00	-1.00	144.81	106.21	83.01	67.57	56.58	48.40	42.07	37.06	33.00	29.65	26.85
	-1.00	-1.00	-1.00	-1.00	-1.00	142.18	105.08	82.43	67.23	56.37	48.25	41.97	36.99	32.95	29.61	26.82
	-1.00	-1.00	-1.00	-1.00	-1.00	139.17	103.75	81.73	66.82	56.11	48.08	41.85	36.90	32.88	29.56	26.78
	-1.00	-1.00	-1.00	-1.00	-1.00	135.85	102.24	80.93	66.35	55.81	47.88	41.71	36.80	32.80	29.50	26.73
	-1.00	-1.00	-1.00	-1.00	-1.00	132.30	100.58	80.03	65.81	55.47	47.64	41.55	36.68	32.71	29.43	26.68
	391.73	383.55	338.20	251.10	176.18	128.60	98.79	79.05	65.23	55.09	47.39	41.36	36.54	32.61	29.35	26.62
2	344.70	337.56	299.41	230.56	167.60	124.82	96.91	78.00	64.59	54.67	47.10	41.16	36.40	32.50	29.27	26.55
	307.93	300.59	268.26	212.79	159.45	121.01	94.94	76.88	63.90	54.23	46.80	40.94	36.24	32.38	29.18	26.48
	277.38	270.29	242.87	197.30	151.76	117.21	92.91	75.71	63.17	53.75	46.47	40.71	36.06	32.25	29.07	26.40
	251.69	245.06	221.71	183.73	144.54	113.46	90.85	74.49	62.40	53.24	46.12	40.46	35.88	32.11	28.96	26.31
	229.83	223.76	203.79	171.66	137.80	109.79	88.77	73.24	61.61	52.71	45.74	40.19	35.68	31.96	28.85	26.22
	211.08	205.75	188.43	160.93	131.50	106.21	86.68	71.96	60.78	52.15	45.35	39.91	35.47	31.80	28.72	26.12
	195.03	190.23	175.12	151.36	125.52	102.74	84.60	70.66	59.93	51.57	44.95	39.61	35.25	31.63	28.59	26.02
	181.02	176.71	163.48	142.77	119.94	99.36	82.54	69.35	59.07	50.98	44.52	39.30	35.02	31.45	28.46	25.91
	168.71	164.85	153.12	135.04	114.75	96.07	80.51	68.03	58.18	50.37	44.09	38.98	34.78	31.27	28.31	25.79
	157.83	154.37	143.89	128.03	109.90	92.90	78.46	66.72	57.29	49.74	43.64	38.65	34.53	31.08	28.16	25.67
4	148.14	144.96	135.65	121.66	105.39	89.87	76.46	65.38	56.39	49.11	43.18	38.31	34.27	30.88	28.01	25.55
	139.36	136.51	128.25	115.71	101.17	86.97	74.50	64.05	55.48	48.47	42.71	37.96	34.00	30.67	27.84	25.42
	131.47	128.92	121.57	110.27	97.23	84.20	72.59	62.73	54.55	47.81	42.24	37.61	33.73	30.46	27.68	25.29
	124.36	122.08	115.49	105.28	93.47	81.55	70.73	61.43	53.63	47.14	41.75	37.24	33.45	30.25	27.51	25.15
	117.93	115.89	109.83	100.68	89.92	79.03	68.92	60.14	52.71	46.47	41.25	36.87	33.17	30.02	27.33	25.01
	112.08	110.16	104.66	96.44	86.60	76.58	67.17	58.88	51.79	45.80	40.75	36.49	32.88	29.80	27.15	24.86
	106.60	104.87	99.92	92.51	83.47	74.22	65.48	57.65	50.88	45.13	40.25	36.11	32.58	29.56	26.96	24.71
	101.59	100.03	95.56	88.75	80.54	71.97	63.82	56.43	49.99	44.46	39.74	35.72	32.28	29.33	26.78	24.56
	97.00	95.59	91.55	85.27	77.78	69.82	62.19	55.25	49.10	43.79	39.23	35.32	31.97	29.08	26.58	24.40
	92.78	91.50	87.75	82.02	75.15	67.77	60.62	54.07	48.22	43.12	38.72	34.93	31.66	28.84	26.38	24.24
6	88.88	87.67	84.21	78.99	72.63	65.81	59.11	52.91	47.36	42.46	38.21	34.53	31.35	28.59	26.18	24.08
	85.17	84.07	80.92	76.16	70.25	63.95	57.65	51.79	46.50	41.81	37.70	34.14	31.04	28.34	25.98	23.92
	81.73	80.73	77.86	73.48	68.00	62.13	56.24	50.69	45.65	41.16	37.20	33.74	30.72	28.08	25.78	23.75
	78.55	77.63	75.01	70.91	65.87	60.38	54.88	49.62	44.81	40.51	36.70	33.34	30.40	27.83	25.57	23.58
	75.58	74.75	72.31	68.51	63.86	58.72	53.55	48.58	43.99	39.86	36.19	32.94	30.08	27.57	25.36	23.41
	72.82	72.02	69.74	66.25	61.93	57.12	52.26	47.57	43.19	39.23	35.69	32.54	29.77	27.31	25.15	23.23
	70.16	69.43	67.33	64.12	60.08	55.60	51.01	46.58	42.40	38.60	35.19	32.14	29.45	27.06	24.94	23.06
	67.67	67.00	65.07	62.11	58.31	54.15	49.81	45.60	41.63	37.98	34.69	31.75	29.13	26.80	24.72	22.88
	65.35	64.73	62.95	60.16	56.64	52.73	48.65	44.65	40.88	37.38	34.20	31.35	28.80	26.53	24.51	22.70
	63.17	62.60	60.94	58.32	55.05	51.36	47.53	43.73	40.13	36.78	33.72	30.96	28.48	26.27	24.29	22.52
8	61.11	60.57	59.00	56.58	53.54	50.06	46.45	42.84	39.40	36.19	33.24	30.57	28.16	26.01	24.08	22.35
	59.13	58.63	57.17	54.92	52.07	48.80	45.39	41.97	38.68	35.61	32.77	30.18	27.85	25.74	23.86	22.16
	57.26	56.80	55.45	53.36	50.66	47.60	44.37	41.13	37.99	35.03	32.30	29.80	27.53	25.48	23.64	21.98
	55.50	55.07	53.82	51.85	49.32	46.45	43.38	40.31	37.30	34.47	31.83	29.42	27.22	25.22	23.42	21.80
	53.84	53.44	52.27	50.40	48.04	45.33	42.43	39.50	36.64	33.91	31.38	29.04	26.90	24.96	23.20	21.61
	52.26	51.88	50.77	49.03	46.81	44.25	41.51	38.72	35.99	33.37	30.92	28.66	26.59	24.70	22.99	21.43
	50.74	50.38	49.34	47.72	45.64	43.21	40.62	37.96	35.35	32.84	30.48	28.29	26.28	24.44	22.77	21.25
	49.29	48.96	47.99	46.47	44.50	42.21	39.75	37.22	34.72	32.32	30.04	27.93	25.98	24.19	22.55	21.06
	47.92	47.61	46.70	45.27	43.40	41.25	38.91	36.50	34.11	31.80	29.61	27.56	25.67	23.93	22.34	20.88
	46.61	46.32	45.48	44.11	42.36	40.32	38.09	35.81	33.51	31.30	29.19	27.21	25.37	23.67	22.12	20.70
10	45.38	45.10	44.29	43.01	41.35	39.42	37.31	35.12	32.93	30.80	28.77	26.85	25.07	23.42	21.91	20.52
	44.17	43.91	43.15	41.95	40.39	38.55	36.55	34.46	32.37	30.32	28.36	26.51	24.77	23.17	21.69	20.33
	43.02	42.78	42.06	40.94	39.46	37.71	35.81	33.81	31.81	29.84	27.95	26.16	24.48	22.92	21.48	20.15
	41.93	41.70	41.03	39.96	38.55	36.90	35.09	33.19	31.27	29.38	27.55	25.82	24.19	22.67	21.27	19.97
	40.89	40.67	40.04	39.02	37.69	36.13	34.39	32.58	30.74	28.92	27.16	25.48	23.90	22.43	21.06	19.79
	39.89	39.68	39.08	38.11	36.85	35.37	33.72	31.99	30.22	28.47	26.77	25.15	23.62	22.18	20.85	19.61
	38.92	38.72	38.15	37.24	36.06	34.64	33.07	31.41	29.71	28.03	26.40	24.82	23.34	21.94	20.64	19.43
	37.99	37.81	37.27	36.41	35.28	33.93	32.43	30.84	29.22	27.60	26.02	24.50	23.06	21.70	20.43	19.25
	37.10	36.93	36.42	35.61	34.53	33.24	31.82	30.29	28.74	27.18	25.65	24.19	22.78	21.46	20.23	19.07
	36.25	36.09	35.61	34.83	33.80	32.58	31.22	29.76	28.27	26.77	25.29	23.87	22.51	21.23	20.02	18.90
12	35.43	35.28	34.81	34.08	33.10	31.94	30.63	29.25	27.81	26.37	24.94	23.56	22.25	21.00	19.82	18.72
	34.64	34.49	34.05	33.35	32.43	31.32	30.07	28.74	27.36	25.97	24.59	23.26	21.98	20.77	19.62	18.55
	33.87	33.73	33.32	32.66	31.78	30.71	29.52	28.24	26.92	25.58	24.25	22.96	21.72	20.54	19.42	18.37
	33.14	33.01	32.62	31.99	31.14	30.13	28.99	27.76	26.49	25.20	23.92	22.67	21.46	20.32	19.23	18.20
	32.44	32.31	31.94	31.33	30.53	29.56	28.47	27.30	26.07	24.83	23.59	22.38	21.21	20.09	19.03	18.03
	31.76	31.64	31.28	30.70	29.93	29.02	27.97	26.84	25.66	24.46	23.27	22.10	20.96	19.87	18.84	17.86
	31.10	30.98	30.64	30.09	29.36	28.48	27.48	26.40	25.26	24.11	22.95	21.82	20.71	19.66	18.65	17.69
	30.46	30.35	30.03	29.50	28.81	27.96	27.00	25.96	24.87	23.76	22.64	21.54	20.47	19.44	18.46	17.53
	29.85	29.74	29.43	28.94	28.27	27.46	26.54	25.54	24.49	23.41	22.33	21.27	20.23	19.23	18.27	17.36
	29.26	29.16	28.86	28.39	27.74	26.97	26.09	25.13	24.12	23.08	22.03	21.00	19.99	19.02	18.09	17.20
14	28.69	28.59	28.31	27.85	27.24	26.50	25.65	24.72	23.75	22.75	21.74	20.74	19.76	18.81	17.90	17.03
	28.13	28.04	27.77	27.33	26.75	26.04	25.22	24.33	23.39	22.43	21.45	20.48	19.53	18.61	17.72	16.87
	27.59	27.50	27.25	26.83	26.27	25.59	24.80	23.95	23.04	22.11	21.17	20.23	19.30	18.41	17.54	16.71
	27.07	26.99	26.74	26.34	25.81	25.15	24.40	23.58	22.70	21.80	20.89	19.98	19.08	18.21	17.36	16.56
	26.57	26.49	26.26	25.87	25.35	24.73	24.01	23.21	22.37	21.50	20.62	19.73	18.86	18.01	17.19	16.40
	26.08	26.01	25.78	25.41	24.92	24.31	23.62	22.86	22.05	21.20	20.35	19.49	18.64	17.82	17.01	16.24

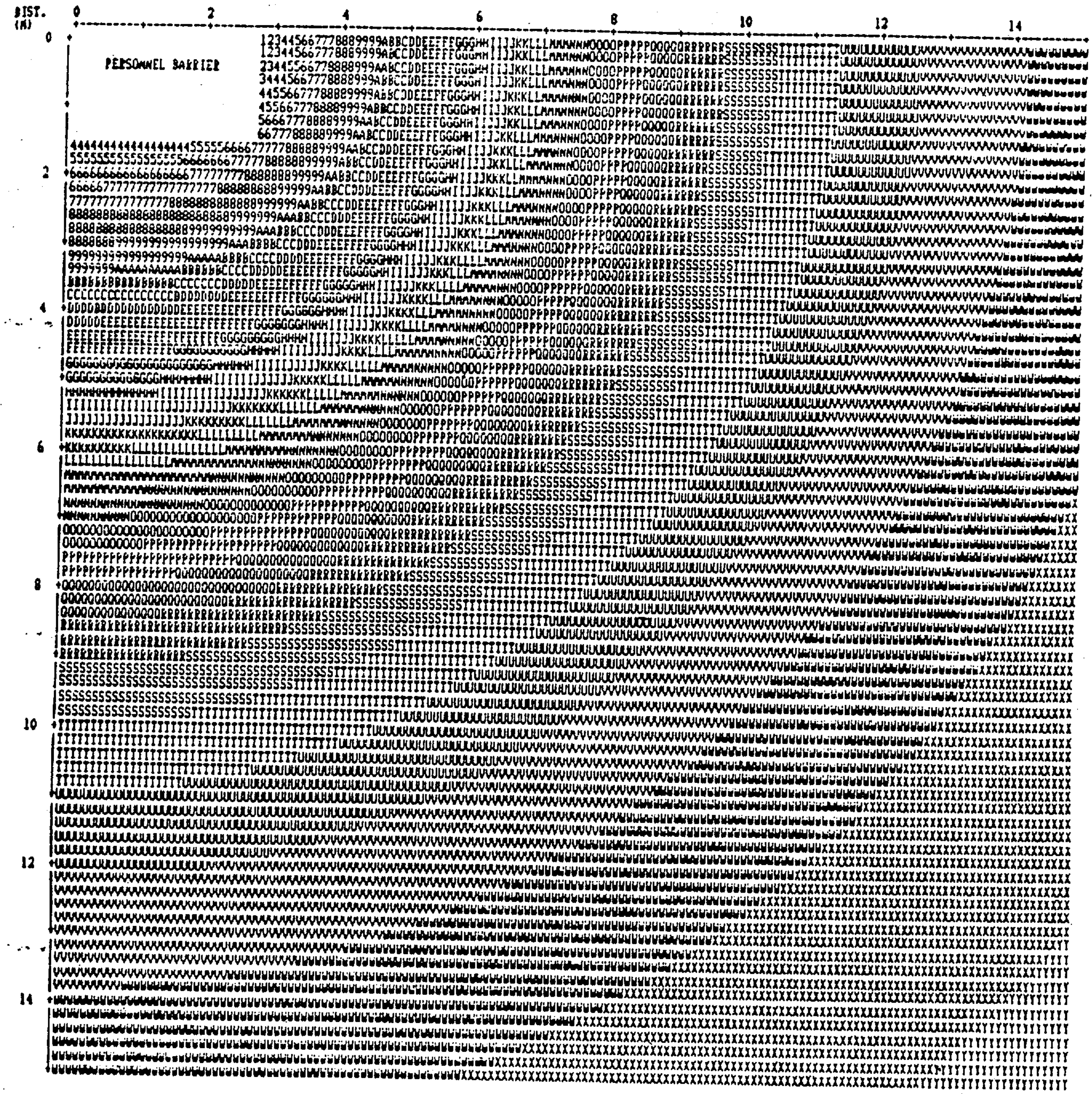
NOTE: TABLE VALUES OF -1.00 INDICATE A LOCATION WITHIN THE CASK INTERIOR WHERE DOSE RATES ARE NOT EVALUATED

TABLE A-5

FAR FIELD RADIATION DOSE RATE TABLE
FOR SPENT FUEL RAIL CASK

DIST. (M)	0		20		40		60		80		100		120		140	
0	-1.00	48.65	17.81	10.02	6.70	4.92	3.81	3.08	2.57	2.21	1.91	1.71	1.48	1.38	1.20	1.13
	114.85	47.03	17.68	9.99	6.67	4.89	3.80	3.08	2.57	2.19	1.90	1.67	1.49	1.34	1.22	1.11
	81.77	42.91	17.29	9.89	6.64	4.88	3.80	3.07	2.56	2.19	1.90	1.67	1.49	1.34	1.22	1.11
	63.63	37.77	16.69	9.74	6.58	4.85	3.78	3.07	2.56	2.18	1.90	1.67	1.49	1.34	1.21	1.11
	52.70	32.73	15.94	9.53	6.50	4.81	3.76	3.05	2.55	2.18	1.89	1.67	1.49	1.34	1.21	1.11
	45.37	28.28	15.09	9.28	6.40	4.77	3.73	3.04	2.54	2.17	1.89	1.66	1.48	1.34	1.21	1.11
	34.97	24.55	14.19	9.00	6.29	4.71	3.70	3.02	2.53	2.16	1.88	1.66	1.48	1.33	1.21	1.11
	28.20	21.49	13.29	8.69	6.16	4.65	3.67	3.00	2.52	2.15	1.88	1.65	1.48	1.33	1.21	1.11
	23.50	18.98	12.42	8.37	6.02	4.57	3.63	2.97	2.50	2.14	1.87	1.65	1.47	1.33	1.21	1.10
	20.08	16.85	11.59	8.04	5.87	4.50	3.59	2.95	2.48	2.13	1.86	1.64	1.47	1.32	1.20	1.10
20	17.50	14.96	10.81	7.70	5.71	4.42	3.54	2.92	2.46	2.12	1.85	1.64	1.46	1.32	1.20	1.10
	15.27	13.40	10.10	7.38	5.55	4.33	3.49	2.89	2.44	2.10	1.84	1.63	1.46	1.32	1.20	1.10
	13.51	12.10	9.41	7.05	5.38	4.24	3.43	2.85	2.42	2.09	1.83	1.62	1.45	1.31	1.19	1.09
	12.08	11.00	8.78	6.74	5.22	4.15	3.38	2.82	2.40	2.07	1.82	1.61	1.45	1.31	1.19	1.09
	10.91	10.07	8.21	6.43	5.06	4.05	3.32	2.78	2.37	2.06	1.81	1.60	1.44	1.30	1.19	1.09
	9.94	9.23	7.69	6.14	4.89	3.96	3.26	2.74	2.35	2.04	1.79	1.59	1.43	1.30	1.18	1.08
	9.07	8.50	7.22	5.86	4.73	3.86	3.20	2.70	2.32	2.02	1.78	1.58	1.42	1.29	1.18	1.08
	8.33	7.86	6.79	5.59	4.57	3.76	3.14	2.66	2.29	2.00	1.77	1.57	1.42	1.28	1.17	1.08
	7.69	7.31	6.39	5.34	4.42	3.67	3.08	2.62	2.27	1.98	1.75	1.56	1.41	1.28	1.17	1.07
	7.14	6.82	6.03	5.11	4.27	3.57	3.02	2.58	2.24	1.96	1.74	1.55	1.40	1.27	1.16	1.07
40	6.66	6.38	5.70	4.89	4.12	3.48	2.96	2.54	2.21	1.94	1.72	1.54	1.39	1.26	1.16	1.06
	6.21	5.98	5.40	4.68	3.98	3.38	2.89	2.50	2.18	1.92	1.70	1.53	1.38	1.26	1.15	1.06
	5.82	5.62	5.12	4.48	3.85	3.29	2.83	2.45	2.15	1.89	1.69	1.52	1.37	1.25	1.14	1.05
	5.48	5.31	4.86	4.29	3.72	3.21	2.77	2.41	2.12	1.87	1.67	1.50	1.36	1.24	1.14	1.05
	5.16	5.02	4.63	4.12	3.59	3.12	2.71	2.37	2.08	1.85	1.65	1.49	1.35	1.23	1.13	1.04
	4.88	4.75	4.41	3.95	3.48	3.04	2.65	2.33	2.05	1.83	1.64	1.48	1.34	1.22	1.12	1.04
	4.62	4.51	4.21	3.80	3.36	2.95	2.59	2.28	2.02	1.80	1.62	1.46	1.33	1.22	1.12	1.03
	4.39	4.29	4.02	3.65	3.25	2.87	2.53	2.24	1.99	1.78	1.60	1.45	1.32	1.21	1.11	1.03
	4.17	4.09	3.85	3.51	3.15	2.80	2.48	2.20	1.96	1.76	1.58	1.43	1.31	1.20	1.10	1.02
	3.98	3.90	3.68	3.38	3.05	2.72	2.42	2.16	1.93	1.73	1.57	1.42	1.30	1.19	1.10	1.02
60	3.80	3.73	3.53	3.26	2.95	2.65	2.37	2.12	1.90	1.71	1.55	1.41	1.29	1.18	1.09	1.01
	3.63	3.57	3.39	3.14	2.86	2.58	2.32	2.08	1.87	1.69	1.53	1.39	1.27	1.17	1.08	1.00
	3.48	3.42	3.26	3.04	2.78	2.51	2.26	2.04	1.84	1.66	1.51	1.38	1.26	1.16	1.07	1.00
	3.33	3.28	3.14	2.93	2.69	2.45	2.21	2.00	1.81	1.64	1.49	1.36	1.25	1.15	1.07	0.99
	3.20	3.15	3.02	2.83	2.61	2.39	2.17	1.96	1.78	1.62	1.47	1.35	1.24	1.14	1.06	0.98
	3.08	3.03	2.91	2.74	2.54	2.32	2.12	1.92	1.75	1.59	1.46	1.34	1.23	1.13	1.05	0.98
	2.96	2.92	2.81	2.65	2.47	2.27	2.07	1.89	1.72	1.57	1.44	1.32	1.22	1.12	1.04	0.97
	2.85	2.82	2.72	2.57	2.40	2.21	2.03	1.85	1.69	1.55	1.42	1.31	1.20	1.12	1.04	0.96
	2.75	2.72	2.63	2.49	2.33	2.16	1.98	1.82	1.66	1.53	1.40	1.29	1.19	1.11	1.03	0.96
	2.65	2.62	2.54	2.42	2.27	2.10	1.94	1.78	1.64	1.50	1.38	1.28	1.18	1.10	1.02	0.95
80	2.56	2.54	2.46	2.35	2.21	2.05	1.90	1.75	1.61	1.48	1.37	1.26	1.17	1.09	1.01	0.95
	2.48	2.46	2.38	2.28	2.15	2.00	1.86	1.72	1.58	1.46	1.35	1.25	1.16	1.08	1.00	0.94
	2.40	2.38	2.31	2.21	2.09	1.96	1.82	1.69	1.56	1.44	1.33	1.23	1.15	1.07	1.00	0.93
	2.32	2.30	2.24	2.15	2.04	1.91	1.78	1.65	1.53	1.42	1.31	1.22	1.13	1.06	0.99	0.92
	2.25	2.23	2.18	2.09	1.99	1.87	1.74	1.62	1.51	1.40	1.30	1.21	1.12	1.05	0.98	0.92
	2.19	2.17	2.12	2.04	1.94	1.83	1.71	1.59	1.48	1.38	1.28	1.19	1.11	1.04	0.97	0.91
	2.12	2.11	2.06	1.98	1.89	1.78	1.68	1.56	1.46	1.36	1.26	1.18	1.10	1.03	0.96	0.90
	2.06	2.05	2.00	1.93	1.84	1.75	1.64	1.54	1.43	1.34	1.25	1.16	1.09	1.02	0.95	0.90
	2.00	1.99	1.95	1.88	1.80	1.71	1.61	1.51	1.41	1.32	1.23	1.15	1.08	1.01	0.95	0.89
	1.95	1.94	1.90	1.84	1.76	1.67	1.58	1.48	1.39	1.30	1.22	1.14	1.07	1.00	0.94	0.88
100	1.90	1.89	1.85	1.79	1.72	1.64	1.55	1.46	1.37	1.28	1.20	1.12	1.05	0.99	0.93	0.88
	1.85	1.84	1.80	1.75	1.68	1.60	1.52	1.43	1.35	1.26	1.18	1.11	1.04	0.98	0.92	0.87
	1.80	1.79	1.76	1.71	1.64	1.57	1.49	1.41	1.32	1.24	1.17	1.10	1.03	0.97	0.91	0.86
	1.76	1.75	1.72	1.67	1.61	1.54	1.46	1.38	1.30	1.23	1.15	1.09	1.02	0.96	0.91	0.86
	1.71	1.70	1.67	1.63	1.57	1.51	1.43	1.36	1.28	1.21	1.14	1.07	1.01	0.95	0.90	0.85
	1.67	1.66	1.64	1.59	1.54	1.48	1.41	1.33	1.26	1.19	1.12	1.06	1.00	0.94	0.89	0.84
	1.63	1.62	1.60	1.56	1.51	1.45	1.38	1.31	1.24	1.18	1.11	1.05	0.99	0.93	0.88	0.84
	1.59	1.59	1.56	1.52	1.48	1.42	1.36	1.29	1.22	1.16	1.10	1.04	0.98	0.92	0.87	0.83
	1.56	1.55	1.53	1.49	1.45	1.39	1.33	1.27	1.21	1.14	1.08	1.02	0.97	0.92	0.87	0.82
	1.52	1.52	1.49	1.46	1.42	1.37	1.31	1.25	1.19	1.13	1.07	1.01	0.96	0.91	0.86	0.81
120	1.49	1.48	1.46	1.43	1.39	1.34	1.29	1.23	1.17	1.11	1.05	1.00	0.95	0.90	0.85	0.81
	1.46	1.45	1.43	1.40	1.36	1.32	1.26	1.21	1.15	1.10	1.04	0.99	0.94	0.89	0.84	0.80
	1.43	1.42	1.40	1.37	1.34	1.29	1.24	1.19	1.13	1.08	1.03	0.98	0.93	0.88	0.84	0.79
	1.40	1.39	1.37	1.35	1.31	1.27	1.22	1.17	1.12	1.07	1.01	0.96	0.92	0.87	0.83	0.79
	1.37	1.36	1.35	1.32	1.29	1.25	1.20	1.15	1.10	1.05	1.00	0.95	0.91	0.86	0.82	0.78
	1.34	1.33	1.32	1.29	1.26	1.22	1.18	1.13	1.09	1.04	0.99	0.94	0.90	0.85	0.81	0.78
	1.31	1.31	1.29	1.27	1.24	1.20	1.16	1.12	1.07	1.02	0.98	0.93	0.89	0.85	0.81	0.77
	1.29	1.28	1.27	1.25	1.22	1.18	1.14	1.10	1.06	1.01	0.97	0.92	0.88	0.84	0.80	0.76
	1.26	1.26	1.25	1.22	1.20	1.16	1.12	1.08	1.04	1.00	0.95	0.91	0.87	0.83	0.79	0.76
	1.24	1.23	1.22	1.20	1.18	1.14	1.11	1.07	1.03	0.98	0.94	0.90	0.86	0.82	0.78	0.75
140	1.22	1.21	1.20	1.18	1.15	1.12	1.09	1.05	1.01	0.97	0.93	0.89	0.85	0.81	0.78	0.74
	1.19	1.19	1.18	1.16	1.14	1.11	1.07	1.04	1.00	0.96	0.92	0.88	0.84	0.81	0.77	0.74
	1.17	1.17	1.16	1.14	1.12	1.09	1.06	1.02	0.98	0.95	0.91	0.87	0.83	0.80	0.76	0.73
	1.15	1.15	1.14	1.12	1.10	1.07	1.04	1.01	0.97	0.93	0.90	0.86	0.83	0.79	0.76	0.72
	1.13	1.13	1.12	1.10	1.08	1.05	1.02	0.99	0.96	0.92	0.89	0.85	0.82	0.78	0.75	0.72
	1.11	1.11	1.10	1.08	1.06	1.04	1.01	0.98	0.94	0.91	0.88	0.84	0.81	0.78	0.74	0.71

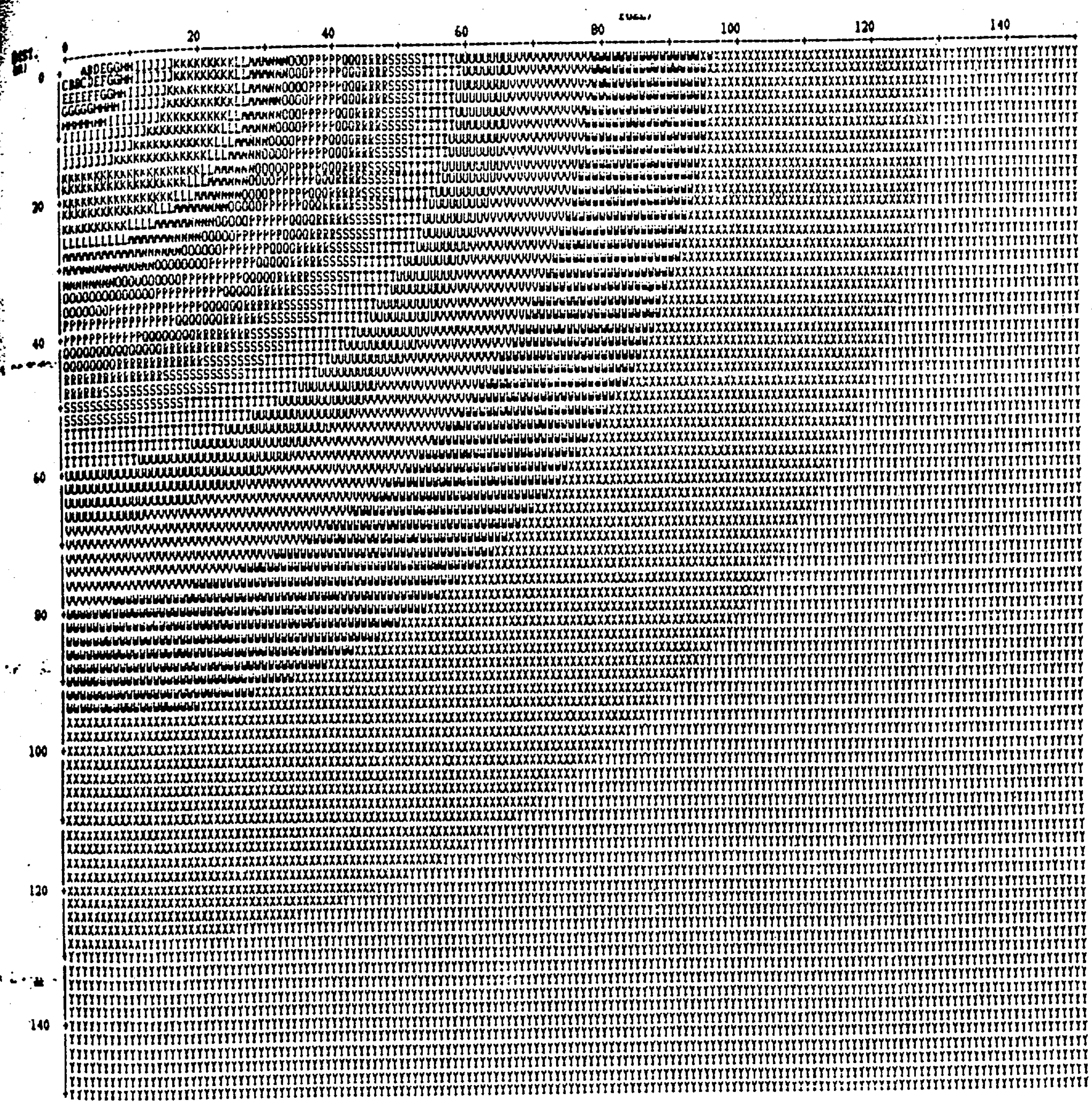
NOTE: TABLE VALUES OF -1.00 INDICATE A LOCATION WITHIN THE CASK INTERIOR WHERE DOSE RATES ARE NOT EVALUATED



KEY TO LETTER SYMBOLS (MICROREM/MIN)

LETTER	RANGE	LETTER	RANGE	LETTER	RANGE	LETTER	RANGE
0	800-1000	A	160-170	K	80-85	U	30-35
1	700-800	B	150-160	L	75-80	V	25-30
2	600-700	C	140-150	M	70-75	W	20-25
3	500-600	D	130-140	N	65-70	X	15-20
4	400-500	E	120-130	O	60-65	Y	10-15
5	350-400	F	110-120	P	55-60	Z	5-10
6	300-350	G	100-110	Q	50-55	A	.32-5
7	250-300	H	95-100	R	45-50	-	< .32
8	200-250	I	90-95	S	40-45		
9	170-200	J	85-90	T	35-40		

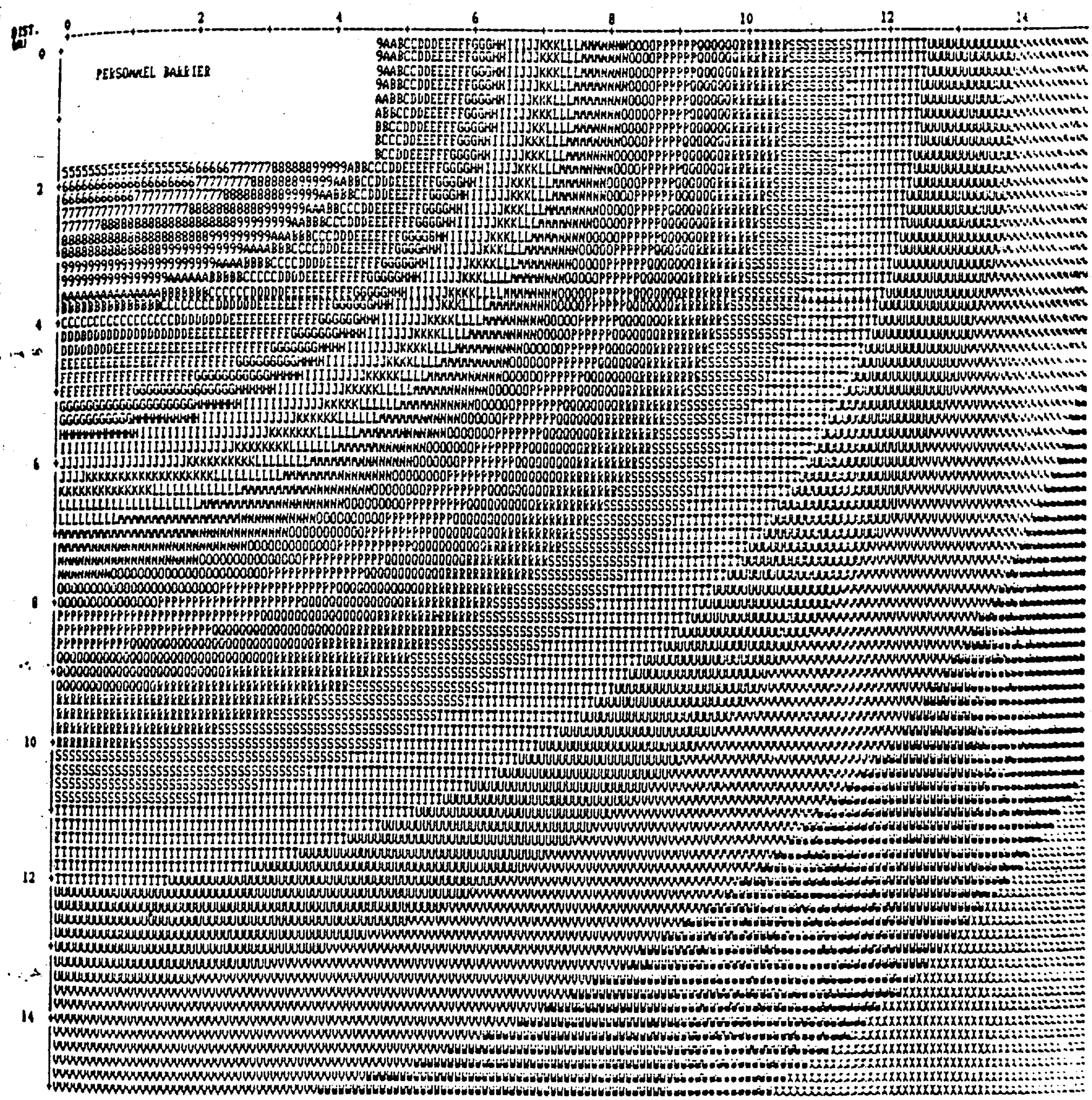
FIGURE A-1. NEAR FIELD RADIATION ISODOSE MAP FOR SPENT FUEL TRUCK CASK



KEY TO LETTER SYMBOLS (MICROREM/MIN)

LETTER	RANGE	LETTER	RANGE	LETTER	RANGE	LETTER	RANGE
A	>150	J	20-30	S	3.5-4.0		
B	120-150	K	10-20	T	3.0-3.5		
C	100-120	L	9-10	U	2.5-3.0		
D	80-100	M	8-9	V	2.0-2.5		
E	70-80	N	7-8	W	1.5-2.0		
F	60-70	O	6-7	X	1.0-1.5		
G	50-60	P	5-6	Y	0.5-1.0		
H	40-50	Q	4.5-5.	Z	.32-.50		
I	30-40	R	4.0-4.5	-	< .32		

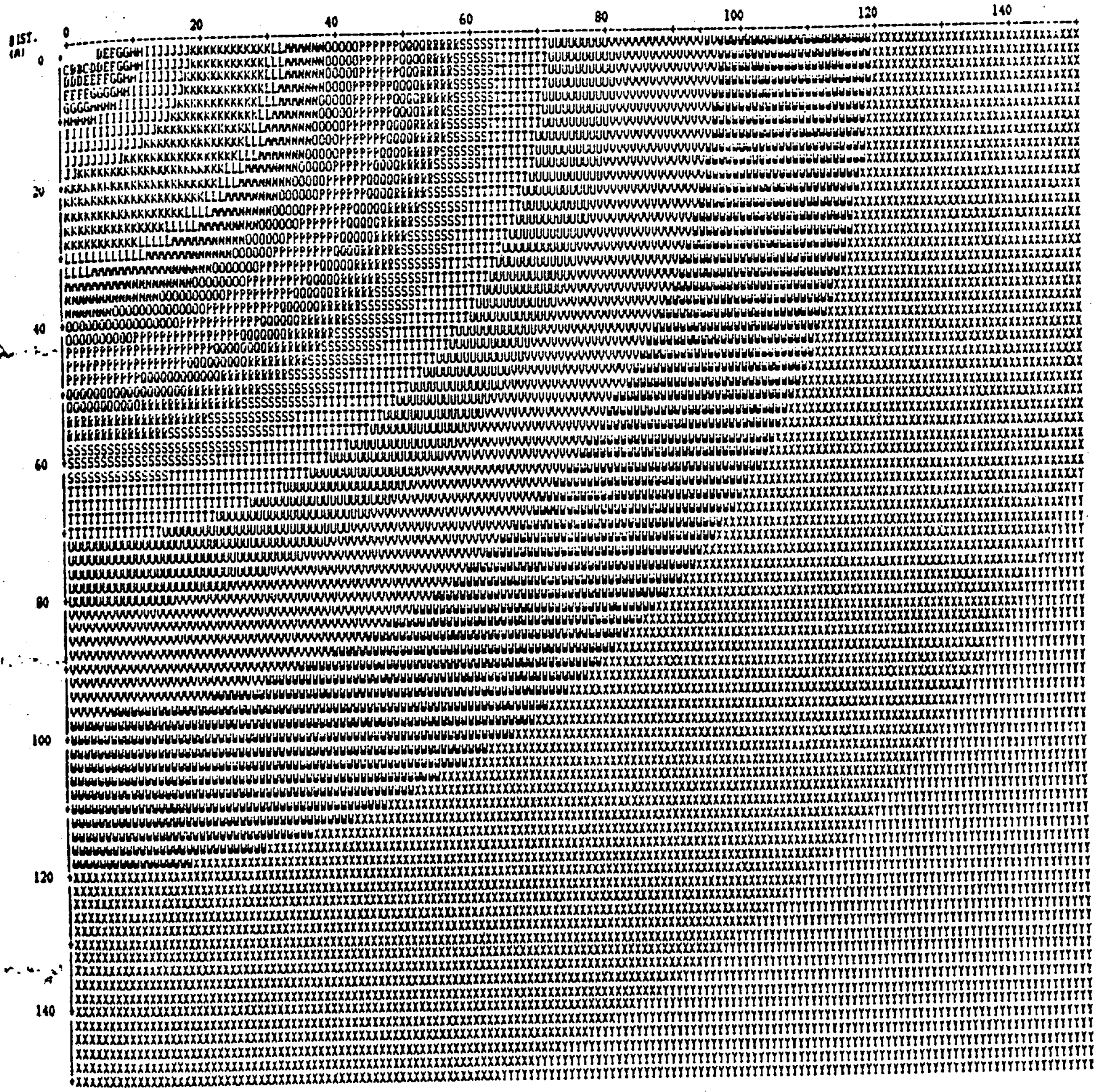
FIGURE A-2. FAR FIELD RADIATION ISODOSE MAP FOR SPENT FUEL TRUCK CASK



KEY TO LETTER SYMBOLS (MICROREM/MIN)

LETTER	RANGE	LETTER	RANGE	LETTER	RANGE	LETTER	RANGE
0	800-1000	A	160-170	K	80-85	U	30-35
1	700-800	B	150-160	L	75-80	V	25-30
2	600-700	C	140-150	M	70-75	W	20-25
3	500-600	D	130-140	N	65-70	X	15-20
4	400-500	E	120-130	O	60-65	Y	10-15
5	350-400	F	110-120	P	55-60	Z	5-10
6	300-350	G	100-110	Q	50-55	*	.32-5
7	250-300	H	95-100	R	45-50	-	< .32
8	200-250	I	90-95	S	40-45		
9	170-200	J	85-90	T	35-40		

FIGURE A-3. NEAR FIELD RADIATION ISODOSE MAP FOR SPENT FUEL RAIL CASK



KEY TO LETTER SYMBOLS (MICROREM/MIN)

LETTER	RANGE	LETTER	RANGE	LETTER	RANGE	LETTER	RANGE
A	>150	J	20-30	S	3.5-4.0		
B	120-150	K	10-20	T	3.0-3.5		
C	100-120	L	9-10	U	2.5-3.0		
D	80-100	M	8-9	V	2.0-2.5		
E	70-80	N	7-8	W	1.5-2.0		
F	60-70	O	6-7	X	1.0-1.5		
G	50-60	P	5-6	Y	0.5-1.0		
H	40-50	Q	4.5-5.	Z	.32-.54		
I	30-40	R	4.0-4.5	-	< .32		

FIGURE A-4. FAR FIELD RADIATION ISODOSE MAP FOR SPENT FUEL RAIL CASK

APPENDIX B

EXAMPLE USE OF PATHRAE-T TO CALCULATE RADIATION EXPOSURES FROM AN ACCIDENT

APPENDIX B

EXAMPLE USE OF PATHRAE-T TO CALCULATE RADIATION EXPOSURES FROM AN ACCIDENT

PATHRAE-T has been developed to estimate radiation doses associated with the transportation of radioactive materials. A complete description of the models, methodology, transport pathways considered, and operation are detailed in Reference 11. Figure B-1 provides a diagram of the input and output data flow for the code. Following Figure B-1 are copies of computer inputs and outputs for the runs that produced the estimates of maximum individual and population doses from rail cask accidents described in Section 3.3.3.

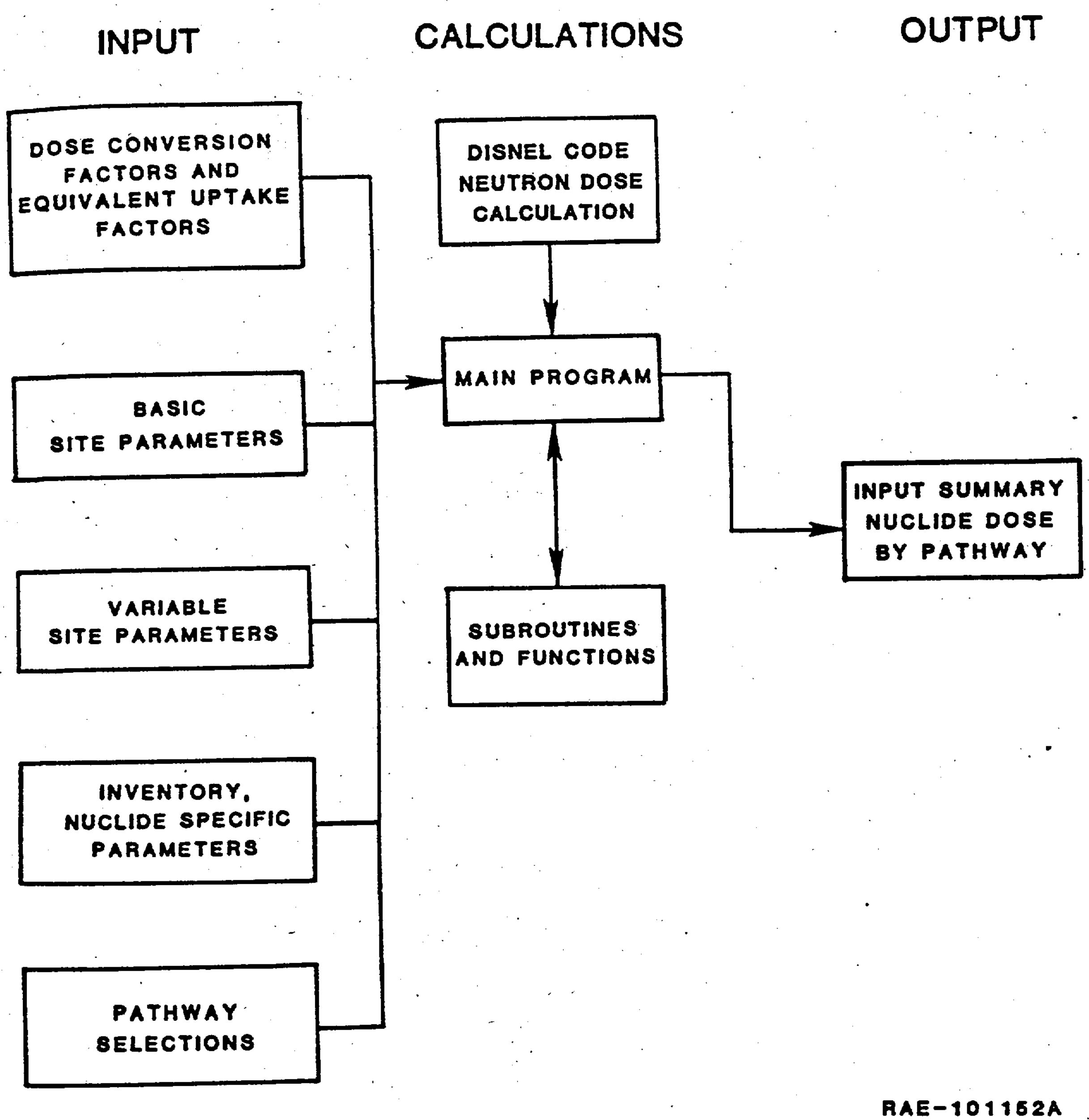


FIGURE B-1. INPUT AND OUTPUT DATA FLOW FOR PATHRAE-T.

********** PATHRAE INPUT SUMMARY **********

THERE ARE 45 ISOTOPES IN THE DOSE FACTOR LIBRARY
THE CUTOFF VALUE FOR NUCLIDE HALF LIVES IS 0.0 YEARS
DEFAULT INVENTORY VALUE FOR CUTOFF NUCLIDES IS 0.00E-01 CI
NUMBER OF TIMES FOR CALCULATION IS 1
YEARS TO BE CALCULATED ARE ...

1.00

THERE ARE 8 ISOTOPES IN THE INVENTORY FILE
THE VALUE OF IFLAG IS 1
NUMBER OF PATHWAYS IS 1

PATHWAY	TYPE OF USAGE FOR UPTAKE FACTORS
10 ATMOSPHERIC TRANSPORT	0

TIME OF OPERATION OF WASTE FACILITY IN YEARS	0.
FLOW RATE OF RIVER (CUBIC METERS/YEAR)	4.50E+08
DISTANCE TO RIVER (METERS)	1000.
DENSITY OF AQUIFER (KG/CUBIC METER)	1700.
LONGITUDINAL DISPERSIVITY (M)	1.00E-05
LATERAL DISPERSION COEFFICIENT (M**2/YR)	0.00E-01
NUMBER OF MESH POINTS FOR DISPERSION CALCULATION	1
FLAG FOR GAMMA PATHWAY OPTIONS	0
FLAG FOR ATMOSPHERIC PATHWAY	0
DISTANCE TO WELL -- X COORDINATE (METERS)	50.
DISTANCE TO WELL -- Y COORDINATE (METERS)	0.
DENSITY OF WASTE (KG/M**3)	1600.
FRACTION OF FOOD CONSUMED THAT IS GROWN ON SITE	0.500
FRACTION OF YEAR SPENT IN DIRECT RADIATION FIELD	0.000
DEPTH OF PLANT ROOT ZONE (METERS)	1.000
AREAL DENSITY OF PLANTS (KG/M**2)	0.000
AVERAGE DUST LOADING IN AIR (KG/M**3)	5.00E-07
ANNUAL ADULT BREATHING RATE (M**3/YR)	8000.
FRACTION OF YEAR EXPOSED TO DUST	0.000
CANISTER LIFETIME (YEARS)	0.
INVENTORY SCALING FACTOR	1.00E+00
ATMOSPHERIC STABILITY CLASS	4
AVERAGE WIND SPEED (M/S)	0.30
FRACTION OF TIME WIND BLOWS TOWARD RECEPTOR	1.0000
RECEPTOR DISTANCE FOR ATMOSPHERIC PATHWAY (M)	100.0

ACCIDENT SCENARIO FOR ATMOSPHERIC RELEASE

DUST RESUSPENSION RATE FOR OFFSITE TRANSPORT (M**3/S)	3.18E-10
DEPOSITION VELOCITY (M/S)	0.0100
STACK HEIGHT (M)	0.0
STACK INSIDE DIAMETER (M)	0.40
STACK GAS VELOCITY (M/S)	1.5
DECAY CHAIN FLAGS	0 0 0 0 0 0 0
FLAG FOR INPUT SUMMARY PRINTOUT	1
FLAG FOR DIRECTION OF TRENCH FILLING	0
FLAG FOR GROUNDWATER PATHWAY OPTIONS	0
AMOUNT OF WATER PERCOLATING THROUGH WASTE ANNUALLY (METERS)	0.10
HORIZONTAL VELOCITY OF AQUIFER (METERS/YR)	1.0
POROSITY OF AQUIFER	0.10
DISTANCE FROM AQUIFER TO WASTE (METERS)	10.0
AVERAGE VERTICAL GROUNDWATER VELOCITY (M/YR)	1.0
MIXING THICKNESS OF AQUIFER (METERS)	10.000
SURFACE EROSION RATE (M/YR)	1.000E-04

NUCLIDE NUMBER	NAME	INGESTION DOSE FACTORS (MREM/PCI)	INHALATION DOSE FACTORS (MREM/PCI)	DIRECT GAMMA DOSE FACTORS (MREM-M**2/PCI-HR)	CLOUD GAMMA DOSE FACTORS (MREM-M**3/PCI-YR)
4	CO-60	2.500E-05	3.500E-04	2.900E-08	1.450E-02
7	KR-85	0.000E-01	0.000E-01	2.890E-11	1.230E-05
8	SR-90	1.300E-04	2.200E-03	8.530E-09	5.550E-10
15	I-129	2.700E-04	1.600E-04	2.930E-10	4.850E-05
17	CS-137	4.600E-05	2.900E-05	7.380E-09	3.250E-03
31	PU-239	4.300E-04	5.700E-01	4.110E-12	4.250E-07
42	RU-106	2.100E-05	8.100E-04	2.570E-09	1.130E-03
44	CS-134	6.700E-05	4.100E-05	1.910E-08	8.470E-03

PATHWAY 10
ATMOSPHERIC TRANSPORT

INDIVIDUAL AT DISTANCE OF MAXIMUM CONCENTRATION, 70.70 METERS

***** DOSES FOR HLW RAIL CASK ACCIDENT SCENARIO WITH IMPACT *****

		INDIVIDUAL (MREM)				POPULATION (MAN-REM)			
		INHALATION	PLUME GAMMA	GROUND GAMMA	DUST	INHALATION	PLUME GAMMA	GROUND GAMMA	DRINKING WATER
4	CO-60	1.77E+02	1.01E+01	1.16E+01	1.10E-04	3.06E+00	3.17E-01	1.10E+02	1.81E+02
7	KR-85	0.00E-01	5.45E-01	7.33E-01	0.00E-01	0.00E-01	1.71E-02	6.95E+00	0.00E-01
8	SR-90	5.78E-01	2.00E-10	1.76E-03	3.57E-07	9.98E-03	6.28E-12	1.67E-02	4.88E-01
15	I-129	2.15E-08	8.95E-12	3.09E-11	1.33E-14	3.71E-10	2.80E-13	2.93E-10	5.17E-07
17	CS-137	1.12E-02	1.73E-03	2.24E-03	6.91E-09	1.93E-04	5.41E-05	2.12E-02	2.54E-01
31	PU-239	1.03E+00	1.06E-09	5.84E-09	6.38E-07	1.78E-02	3.31E-11	5.54E-08	1.11E-02
42	RU-106	5.81E-02	1.12E-04	1.45E-04	3.59E-08	1.00E-03	3.50E-06	1.38E-03	2.15E-02
44	CS-134	4.95E-03	1.41E-03	1.82E-03	3.06E-09	8.55E-05	4.41E-05	1.72E-02	1.16E-01
TOTALS:									
8		1.79E+02	1.07E+01	1.23E+01	1.11E-04	3.09E+00	3.34E-01	1.17E+02	1.82E+02

NUCLIDE NUMBER,NAME,HALFLIFE,AND INVENTORY (CI)

(TIMES IN YEARS)		HALFLIFE	
4	CO-60	5.25E+00	8.06E+00
7	KR-85	1.07E+01	5.12E+02
8	SR-90	2.86E+01	4.17E-03
15	I-129	1.70E+07	2.13E-09
17	CS-137	3.01E+01	6.13E-03
31	PU-239	2.42E+04	2.87E-05
42	RU-106	1.01E+00	1.14E-03
44	CS-134	2.06E+00	1.92E-03

PATHWAY 10
ATMOSPHERIC TRANSPORT

INDIVIDUAL AT DISTANCE OF MAXIMUM CONCENTRATION, 70.70 METERS

***** DOSES FOR HLW RAIL CASK ACCIDENT SCENARIO WITH IMPACT - BURST *****

		INDIVIDUAL (MREM)				POPULATION (MAN-REM)			
		INHALATION	PLUME GAMMA	GROUND GAMMA	DUST	INHALATION	PLUME GAMMA	GROUND GAMMA	DRINKING WATER
4	CO-60	1.77E+02	1.01E+01	1.16E+01	1.10E-04	3.06E+00	3.17E-01	1.10E+02	1.81E+02
7	KR-85	0.00E-01	4.64E+00	6.24E+00	0.00E-01	0.00E-01	1.46E-01	5.92E+01	0.00E-01
8	SR-90	5.32E+01	1.82E-08	1.60E-01	3.29E-05	9.18E-01	5.71E-10	1.52E+00	4.43E+01
15	I-129	1.37E-02	2.86E-07	9.89E-07	8.48E-09	2.37E-04	8.98E-09	9.38E-06	1.66E-02
17	CS-137	4.01E+03	3.10E+01	4.02E+01	2.48E-03	6.93E+01	9.70E-01	3.81E+02	4.55E+03
31	PU-239	9.47E+01	9.61E-08	5.31E-07	5.85E-05	1.63E+00	3.01E-09	5.04E-06	1.01E+00
42	RU-106	5.34E+00	1.02E-02	1.32E-02	3.30E-06	9.22E-02	3.19E-04	1.25E-01	1.96E+00
44	CS-134	1.78E+03	2.54E+01	3.27E+01	1.10E-03	3.08E+01	7.95E-01	3.10E+02	2.09E+03
TOTALS: 8		6.13E+03	7.11E+01	9.09E+01	3.79E-03	1.06E+02	2.23E+00	8.62E+02	6.87E+03

NUCLIDE NUMBER,NAME,HALFLIFE,AND INVENTORY (CI)

(TIMES IN YEARS)		HALFLIFE	
4	CO-60	5.25E+00	8.06E+00
7	KR-85	1.07E+01	4.36E+03
8	SR-90	2.86E+01	3.79E-01
15	I-129	1.70E+07	6.82E-05
17	CS-137	3.01E+01	1.10E+02
31	PU-239	2.42E+04	2.61E-03
42	RU-106	1.01E+00	1.04E-01
44	CS-134	2.06E+00	3.46E+01

PATHWAY 10
ATMOSPHERIC TRANSPORT

INDIVIDUAL AT DISTANCE OF MAXIMUM CONCENTRATION, 70.70 METERS

***** DOSES FOR HLW RAIL CASK ACCIDENT SCENARIO WITH IMPACT - BURST - OXIDATION *****

		INDIVIDUAL (MREM)				POPULATION (MAN-REM)			
		INHALATION	PLUME GAMMA	GROUND GAMMA	DUST	INHALATION	PLUME GAMMA	GROUND GAMMA	DRINKING WATER
4	CO-60	1.77E+02	1.01E+01	1.16E+01	1.10E-04	3.06E+00	3.17E-01	1.10E+02	1.81E+02
7	KR-85	0.00E-01	5.09E+00	6.84E+00	0.00E-01	0.00E-01	1.60E-01	6.49E+01	0.00E-01
8	SR-90	5.32E+01	1.82E-08	1.60E-01	3.29E-05	9.18E-01	5.71E-10	1.52E+00	4.43E+01
15	I-129	2.23E-02	3.85E-06	1.33E-05	1.38E-08	3.85E-04	1.21E-07	1.26E-04	2.22E-01
17	CS-137	5.81E+03	2.93E+02	3.80E+02	3.59E-03	1.00E+02	9.17E+00	3.60E+03	4.30E+04
31	PU-239	9.47E+01	9.61E-08	5.31E-07	5.85E-05	1.63E+00	3.01E-09	5.04E-06	1.01E+00
42	RU-106	2.44E+02	4.57E-01	5.94E-01	1.51E-04	4.21E+00	1.43E-02	5.63E+00	8.82E+01
44	CS-134	2.57E+03	2.39E+02	3.08E+02	1.59E-03	4.44E+01	7.49E+00	2.92E+03	1.96E+04
TOTALS: 8		8.95E+03	5.47E+02	7.07E+02	5.53E-03	1.54E+02	1.72E+01	6.71E+03	6.30E+04

NUCLIDE NUMBER,NAME,HALFLIFE,AND INVENTORY (CI)

(TIMES IN YEARS)		HALFLIFE	
4	CO-60	5.25E+00	8.06E+00
7	KR-85	1.07E+01	4.78E+03
8	SR-90	2.86E+01	3.79E-01
15	I-129	1.70E+07	9.16E-04
17	CS-137	3.01E+01	1.04E+03
31	PU-239	2.42E+04	2.61E-03
42	RU-106	1.01E+00	4.67E+00
44	CS-134	2.06E+00	3.26E+02

REFERENCES

1. 40CFR173.441(b)(3).

2. J.A. Bucholz, "A Summary Report on Optimized Designs for Shipping Casks Containing 2-, 2-, 5-, 7-, or 10-Year Old PWR Spent Fuel," Oak Ridge National Laboratory, ORNL/CSD-TIM-150, April 1983.

3. "Engineering Compendium on Radiation Shielding," Edited by R.G. Jaeger, et al., Volume I, Shielding Fundamentals and Methods, pp. 367, 393, Springer-Verlag, 1968.

4. F. Titus, "Measurements of the Gamma-Ray Dose Near the Interface Between Two Media," Nuclear Science and Engineering, Volume 3, p. 600, 1958.

5. F.F. Haywood, "Spatial Dose Distribution in Air-Over-Ground Geometry," Health Physics, Volume 11, p. 185, 1965.

6. "Transportation of Radionuclides in Urban Environs: Draft Environmental Assessment," NUREG/CR-0743, Sandia National Laboratories, prepared for U.S. Nuclear Regulatory Commission, p. B-4, July 1980.

7. A.B. Chilton, "The Close-In Exposure Field From Point Isotropic Gamma-Ray Source Located at an Air-Ground Interface," Nuclear Science and Engineering, Volume 27, p. 406, 1967.

8. O.I. Leipunskii, et al., The Propagation of Gamma Quanta in Matter, p. 4, Pergamon Press, 1965.

9. J.F. Kunze, "Users Guide for the Reactor Physics Code DISNET," Idaho Nuclear Corporation, February 1971.

10. C.V. Parks, O.W. Hermann, J.R. Knight, "Parametric Study of Radiation Dose Rates from Rail and Truck Spent Fuel Transport Casks," Oak Ridge National Laboratory, ORNL/CSD/TM-227, August 1985.

11. "The PATHRAE-T Performance Assessment Code For Analyzing Risks From Radioactive Wastes," RAE-8339/12-2, Rogers and Associates Engineering Corporation, December 1985.

12. E.L. Emerson and J.D. McClure, "Radioactive Material Accident/Incident Data Analysis Programs," Sandia National Laboratories, SAND82-2156, 1983.

13. E.L. Wilmot, "Transportation Accident Scenarios for Commercial Spent Fuel," Sandia National Laboratories, SAND 80-2124, TTC-0156, February 1981.

14. Annals of the ICRP, "Recommendations of the International Commission on Radiation Protection," ICRP-26, January 1977.

15. Dunning, D.E., "Estimates of Internal Dose Equivalents from Inhalation and Ingestion of Selected Nuclides," WIPP-DOE-176, Evaluation Resarch Corp.

16. D.C. Kocher, "Dose-Rate Conversion Factors for External Exposure to Photon and Electron Radiation from Radionuclides Occurring in Routine Releases From Nuclear Fuel Cycle Facilities," Health Physics, Volume 38, pp. 543-621, April 1980.

17. "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," U.S. Nuclear Regulatory Commission, Reg. Guide 1.111, Revision 1, July 1977.

18. Annals of the ICRP, "Radionuclide Release into the Environment: Assessment of Doses to Man," International Commission on Radiation Protection, ICRP-29, 1978.

19. 1985 Cancer Facts and Figures, American Cancer Society, 1985.

20. E.W. Schmidt, et al., "Final Report on Shipping Cask Sabotage Source Term Investigation," U.S. Nuclear Regulatory Commission, NUREG/CR-2472, p. 66, October 1982.

21. N.C. Finley, et al., "Transportation of Radionuclides in Urban Environs: Draft Environmental Assessment," NUREG/CR-0743, U.S. Nuclear Regulatory Commission, p. 57, July 1980.

22. J.W. Healey, et al., "Interim Soil Limits for D&D Projects," LA-UR-1865-Rev., p. 42, Los Alamos Scientific Laboratory, September 12, 1979.

23. "Proposed Guidelines on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment," EPA 520/4-77-016, U.S. Environmental Protection Agency, September 1977.

24. "Remedial Action Plan and Site Conceptual Design for Stabilization of the Inactive Uranium Mill Tailings Site at Salt Lake City, Utah," Appendix B, U.S. Department of Energy, UMTRA-DOE/AL-1041, September 1984.

25. Oyen, L.C. and R.F. Tucker, Jr., "Advanced Low-Level Radwaste Treatment Systems," Interim Report, The Electric Power Research Institute, EPRI Report No. NP-1600, October 1980.

26. "Barnwell Low-Level Radioactive Waste Disposal Facility Rate Schedule," Chem-Nuclear Systems, Inc., January 1984.