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RISKS AND IMPACTS OF INCIDENT-FREE HIGHWAY TRANSPORTATION OF RADIOACTIVE MATERIALS

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ABSTRACT

Annual radiation doses and risks to the public living near, and traveling on, public highways, and occupational doses are calculated for highway shipments of radioactive materials under accident-free and incident-free conditions; i.e., under normal transportation conditions. The database developed by Sandia National Laboratories is used, and calculations are made using RADTRAN 4.0. This report is one of two reports estimating radiological risk associated with transportation of radioactive materials.

KEY WORDS: Risk assessment, transportation risk, transportation, radiological risk, truck transportation, highways

1.0 INTRODUCTION

Incident-free highway transportation of radioactive material can have environmental consequences and can pose risks to travelers on the highway, to people residing alongside the route, and to the drivers and handlers of the vehicle. Material transported to interim storage or distribution, and thence to a final destination, poses risks on each leg of its journey. Packages may be transported in more than one mode during a trip: light duty vehicles to transfer terminals, semi-detached trailer truck or a rail car along with other parcels to the destination. Packages may also be consolidated with other packages into a single shipment, which may consist of a number of packages obtained from a number of different shippers, and separated into individual packages for delivery to the consignees.

Package transfers, consolidation, and secondary modes become important when risks for transportation accidents are being analyzed, because all of these factors bear on accident probabilities and consequences. However, analyzing the risk for each of these steps in the incident-free transportation of a package increases the uncertainty of the risk estimates without necessarily increasing their accuracy. Therefore, the present study considers shipments as going directly from origin to destination.

In most cases, the radioactive material to be shipped is in a package that complies with the Department of Transportation (DOT) regulations of 49 CFR Parts 171 through 178[1] and the Nuclear Regulatory Commission (NRC) regulations of 10 CFR Part 71[2]. Occasionally packages may be exempted from these regulations under special circumstances.

Transportation is incident-free when it occurs without unusual delay, loss of or any damage to the package or its contents, or any accident involving the transporting vehicle. Cases in which shipments are not timely, the packages are damaged, or the contents are lost or destroyed or released without being involved in a vehicular accident are abnormal transport occurrences, or incidents. Transportation accidents, which are not considered here, occur when packages are involved in vehicular accidents.

2. RADIOLOGICAL IMPACTS

The principal emphasis of this study is on radiation doses and risks to people; i.e., the direct impact on the human environment. Incident-free transportation of radioactive material has no indirect radiological impact on people (as through the human food chain, for example) since the package is not breached. There may be impacts on other elements of the ecosystem and on inanimate objects that could merit consideration but would be equal to or less than those to people and probably present no significant impact.

The direct radiological impact of incident-free transportation of a package containing radioactive material depends on the transport index (TI): the radiation dose rate in mrem per hour at a distance of one meter from the package surface. Although the radionuclide content of the package and the characteristics of the packaging determine the TI, dose may be determined directly from TI without ascertaining the radionuclide content. However, radionuclide content and packaging characteristics may govern whether the material can be shipped by a given transportation mode and may limit the total number of packages in a given shipment.

The principal environmental impact during incident-free transportation is direct exposure of nearby individuals to radiation from the unbreached package. The impact may be quantified in terms of annual population dose and the risk may be estimated in terms of the annual latent cancer fatalities (LCF) projected from this population dose.

Radiation dose rates decrease rapidly with distance from the package. Thus people who handle the package directly are exposed to the highest dose rates, although these exposures are usually for relatively short periods of time. Bystanders and persons traveling or living along a travel route generally are subjected to lower dose rates from incident-free transportation, but the number of people to whom the small doses are delivered make the total population dose comparable to total occupational doses.

In most cases, exposures are for a relatively short duration, but the number of persons who can be exposed may become very large during a trip of considerable distance. Exposure can result from stops for meals, crew rest, repair, and refueling. Access to the area around the vehicle during stops is not limited, so there is potential for exposure. Occupants of vehicles caught in slow traffic next to the vehicle carrying radioactive material may also sustain relatively long exposure.

3. DATABASE AND METHODS

The transportation database[4] and methods used in this study are described in another paper[3]. Methods will be described here which extend the methods described in Ref. 3 to highway transportation.

A conservative expression for dose rate (dose per unit time) from a radioactive package is given below[5,6].

(1) $D(r) = K_o(TI)/r^2$

$D(r)$ = dose rate at distance r (in meters) from center of package
TI = transport index: the dose in mrem/hr at 1 meter from package surface
K_o = a package shape factor which extrapolates dose rate at 1 m from package surface to the basis of a point source at the center of the package.

The dose rate to an individual at a distance r from a shipment containing Ps packages is given by Equation 2[5]. The dose rate to the truck crew and individuals who are near the shipment at stops is best represented by Equation 2.

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(2) $D_i(r) = Q(P_s)(K_o)(TI)/r^2$

$D_i(r)$ = dose rate to the individual in question
Q = unit conversion factor

Integrated doses may be obtained from the dose rates of Equations 1 and 2 by multiplying the dose rates by the exposure times.

Expressions for the integrated dose to a person who is either present in a zone along either side of the roadway ("off-link") or traveling on the highway while the shipment of radioactive material is moving ("on-link") must take the shipment speed into account. The integrated off-link population dose, considering travel through rural, suburban, and urban zones is given by

(3) $$D = 2\pi Q(P_s)(FMPS)(K_o)(TI)\{(f_r)(PD_r)\ln(d_r/min_r)/V_r + (f_s)(PD_s)\ln(d_s/min_s)/V_s + (f_u)(PD_u)\ln(d_u/min_u)/V_u\}$$

FMPS = total distance traveled by shipment
f = fraction of travel in a particular zone
PD = population density
d = maximum distance perpendicular to the shipment route over which exposure is evaluated
min = minimum distance from population to shipment centerline
V = shipment speed
r = subscript denoting rural travel
s = subscript denoting suburban travel
u = subscript denoting urban travel

Other expressions provide the on-link dose to persons traveling in the same direction and in the opposite direction as the shipment. The application of the various equations is discussed more fully in Ref. 5.

RADTRAN calculations are based on the packages listed in the database. Distances of travel and fractions of travel in each population density zone were generated using the highway routing code available on TRANSNET[6]. Origin and destination information were taken from the database. Table 1 gives the operational details for the packages which were common to all of the RADTRAN calculations. Packages listed in the database with a TI of zero, indicating no measurable activity one meter from the package surface, are included in determination of the median TI and in the totals given in Table 2.

In calculating the dose to truck crew, it was assumed that shielding is provided to limit the dose to 20 μSv per hour as required by the regulations for exclusive-use vehicles, and as a practical limit in any case. Population doses to crew assume that there are two crew members per vehicle, and that they are in the cab only during periods of actual travel. Thus, the duration of exposure to the crew is approximately the same as the distance traveled divided by the average speed while moving. Measurements indicate that dose rates to truck crew are about 0.7 μSv per hour in the truck cab, and between 0.7 μSv and 30 μSv per hour at the edge of the truck trailer[7].

The population dose received while the vehicle is in motion results from the exposure of persons in other vehicles occupying the transportation link (on-link), and that received by persons along the transportation link (off-link). The on-link population dose considers persons traveling in the same direction as the shipment as well as those traveling in the direction opposite to the shipment. Calculation of the off-link dose assumes building shielding options such that people inside the buildings along the route receive a smaller dose than the pedestrian dose. Population densities and building shielding factors are given in Table 1.

The off-link calculations explicitly take into account the effects of building shielding, in addition to shielding by the packaging that might act to absorb radiation and therefore mitigate the population dose. Building shielding is likely to be most effective in cities where buildings are constructed from relatively good radiation absorbers such as concrete and steel and in hilly terrain where topographic features may provide shielding. Only building shielding factors were considered in this study; topographic shielding was not considered.

At the beginning and end of the transportation cycle and at intermediate terminals, radioactive material packages may be stored temporarily while awaiting a truck that is proceeding to the final destination. The potential therefore exists for irradiation of truck terminal employees and surrounding population during these periods of temporary storage. Storage was not included in the calculations of this study.

Latent cancer fatalities (LCF) were calculated from doses using Table 4-2 of Ref. 8. Continuous exposures were used to calculate both the occupational and public annual LCF. For comparison, LCF not attributable to exposure to transported radioactive materials - "background" cancers - were calculated using the LCF annual individual risk of 1.6×10^{-3}[9] and assuming an off-link exposed population which occupies 800 meters on either side of the highway along every kilometer traveled by the shipment. Population densities and fractions of travel are given in Table 1.

4. RESULTS

Table 2 gives the total shipments and packages by highway for six identified end uses. These end uses are industrial use, radiography (industrial radiography), medical, fuel cycle, research and development and waste. Totals are also given for shipments whose end use was unknown, and for other shipments, whose end use did not fall into the six identified categories[4].

The number of <u>shipments</u> by highway is a little more than twice the number of air shipments, but the number of <u>packages</u> shipped by highway is approximately five times the number shipped by air. The difference comes about for several reasons. Fuel cycle materials are essentially never shipped by air, waste and "other" packages are shipped about 100 times as often by highway as by air, and for all other end uses except medical use, the number of packages shipped by highway is from four to ten times as large as the number shipped by air (more than 500 times for waste packages). These differences are offset to some extent by the number of medical packages, which still dominate radioactive materials transportation in the United States.

About 40% of the packages of radioactive material shipped by highway, and about 75% of the highway shipments, are for medical use. About 11% of the highway shipments are industrial, about 5% are industrial radiography, and about 6% are waste shipments. The fraction of total TI shipped for each end use is approximately the same as the fraction of shipments for that end use, except for medical shipments (65% of the TI and 74% of the shipments) and fuel cycle (5% of the TI but only 0.6% of the shipments). (The total TI for these calculations is not the product of total packages and median TI for each end use, but the actual total summed from the data base.) The number of packages per shipment is usually higher than for air shipments. Highway shipments of radioactive materials thus operate much closer to the TI limit for a single shipment, and are much more often limited by it. Some exclusive use highway shipments operate in excess of the normally limiting TI of 50 by special permit[9].

Table 3 shows the parameters of the RADTRAN 4.0 calculations for the maximum-TI package, Table 4 shows population doses and risks and maximum individual doses for the maximum-TI package for each end use and Table 5 shows population doses and maximum individual doses for the maximum-TI package, extrapolated to all of the highway shipments in the database, for each end use. Tables 6, 7 and 8 show the analogous parameters, population doses, maximum individual doses, and extrapolated doses for the median-TI package for each end use. Tables 5 and 8 give the total maximum individual dose, extrapolated from the maximum-TI and median-TI packages, respectively, as 1.04 mSv and 1.37 μSv.

The extrapolations of Table 5 are tantamount to assuming that all packages for a particular end use have the maximum TI for that end use, while the extrapolations of Table 8 are tantamount to assuming that all packages for a particular end use have the median TI for that end use. A reasonable approximation of radiation dose from transportation of radioactive materials, which reflects the database used in this study, is given in Table 8, the population doses extrapolated from the median-TI package for each end use. The median TI is not skewed, as the mean might be, by a few very high-TI packages. Moreover, since there are exactly as many package TIs greater than the median as less than the median, it forms the best basis for extrapolation. It may be noted then that the total occupational population dose is approximately the same as the total population dose to the general public (both on-link and off-link). The population doses are dominated by the contributions of medical, industrial radiography and fuel cycle shipments, even though fuel cycle packages comprise less than one percent of the total number of packages shipped.

The population doses extrapolated from the maximum-TI packages, shown in Table 5, present an almost implausibly conservative picture, since no single group of individuals will be exposed to all of the shipments. These doses can be considered to provide an upper bound to what the doses and risks might be. The doses are dominated by the maximum-TI waste package (which was, in fact, more radioactive than is usually permitted), which contributes 69% of the occupational population dose and 36% of the population dose to the general public. The other large contributor to the population dose is the maximum-TI medical use package. The two together contribute 87% of the occupational population dose and 81% of the population dose to the public.

Tables 9 through 12 show the risks of latent cancer fatalities (LCF). Tables 9 and 11 show the risk of LCF for the single maximum-TI and median-TI package, respectively. The risk attendant on transporting a single package has some intrinsic interest, and is also the basis for the extrapolations of Tables 10 and 12, which show the risk of latent cancer fatalities for the extrapolated maximum-TI and median-TI packages, respectively. The risk from the extrapolated median-TI package is about one excess cancer fatality in the general public exposed to the transported material, and about one excess occupational cancer fatality, for a total of two excess cancer fatalities per year. The risk from the extrapolated maximum-TI package is about 81 excess cancer fatalities in the general public exposed to the transported material, and about 104 excess occupational cancer fatalities, for a total of 185 excess cancer fatalities per year (Table 10).

LCF risk to the general population from exposure to shipments of radioactive materials may be compared with LCF risk in the absence of such transportation from two points of view: comparison with LCF risk from background radiation, and comparison with LCF risk from all causes, including but not limited to background ionizing radiation. The LCF risk from background ionizing radiation was calculated using Equations 4a; the LCF risk from all causes, using Equation 4b.

(4a) $LCF_{ir} = (R_{ir})(3.6\text{mSv/yr})(D)(1.6\text{km}^2)(10^{-5})(1/70\text{yr})\{(f_r)(PD_r) + (f_s)(PD_s) + (f_u)(PD_u)\}$

LCF_{ir} = annual LCF risk from background radiation
R_{ir} = annual LCF risk from continuous lifetime exposure to 1 mSv/yr per 100,000 persons = 5.60 (from Table 4-2, Ref. 8)
D = distance traveled by the shipment in question
PD = population per km^2
r = subscript denoting rural travel
s = subscript denoting suburban travel
u = subscript denoting urban travel

(4b) $LCF_{bg} = (R_{bg})(D)(1.6\text{km}^2)(10^{-5})(1/70\text{yr})\{(f_r)(PD_r) + (f_s)(PD_s) + (f_u)(PD_u)\}$

LCF_{bg} = annual LCF risk from background radiation
R_{bg} = annual normal expectation of LCF per 100,000 persons = 19,040 (from Table 4-2, Ref. 8)

An area of 1.6 square kilometers per kilometer traveled is used in RADTRAN to delineate the exposed population. 3.6 mSv per year is the average U. S. background ionizing radiation(8).

Table 13 shows both of these risks for both the population exposed to the extrapolated maximum-TI package and the population exposed to the extrapolated median-TI package. The population exposed to the maximum-TI shipments would experience 2,079 LCF per year from background ionizing radiation and a total of 19,626 LCF per year from all causes of cancer, exclusive of occupational risk. The population exposed to the median-TI shipments would experience 1,965 LCF per year from background ionizing radiation and a total of 18,559 LCF per year from all causes of cancer, exclusive of occupational risk (Table 13). A number of comparisons of background radiation doses and risks are given in Table 13.

5. CONCLUSIONS

Both doses and risks are compared below, although comparing doses may be more reliable than comparing risks, since the uncertainty in risk estimates is approximately plus 100% or minus 50%[8]. Maximum individual doses from radioactive materials transportation can be compared to background radiation in the United States. The BEIR V study[8] cites the annual average background effective dose equivalent as 3.6 mSv, of which 55%, on the average, is from radon and its decay products. The maximum total individual dose from the extrapolated median-TI packages (Table 8) is thus about 0.04% of the average background effective dose equivalent (Table 13). The maximum total individual dose from the extrapolated maximum-TI packages (Table 5) is about 29% of the average background effective dose equivalent (Table 13). The maximum individual dose is an overstatement because one individual will not be exposed to all of the shipments of radioactive material.

The extrapolated population doses present a slightly different picture from the maximum individual doses. The population background dose to the general public, both on-link and off-link, is 16,235 person-Sv for the population exposed to the extrapolated maximum-TI shipments and 15,352 person-Sv for the population exposed to the extrapolated median-TI shipments. From Table 13, it follows that the population dose for the extrapolated maximum-TI shipments is 6% of the background population dose, and the population dose for the extrapolated median-TI shipments is 0.09% of the background population dose.

The risk to the general public from the extrapolated median-TI packages is calculated to be about 0.05% of the cancer risk from background radioactivity and about 0.005% of the normally expected cancer risk from all causes for that population (Table 13). The risk to the general public from the extrapolated maximum-TI packages is calculated to be about 4% of the cancer risk from background radioactivity and about 0.04% of the normally expected cancer risk from all causes for that population (Table 13).

The dose and risk extrapolated from the maximum-TI package for each end use not only represents an upper bound to the 1982 annual risk but is based on the very conservative assumption that all packages shipped for any end use exhibited the maximum TI. However, it is still significant that this dose and risk are a relatively small fraction of background exposures.

A considerable fraction of the maximum-TI dose and risk are due to the maximum-TI waste shipment (TI=300), which traveled 664 km (about 400 miles) and was extrapolated to almost a million packages (Table 2). This extrapolation is itself excessively conservative, since a package with a TI of 300 is an exception to the regulated TI limit. As may be seen from the results in Table 13, the population dose from such an extrapolation is about 55% of the population dose due to background radiation. The LCF risk to the subject population is about 34% of the LCF risk from background radiation and about 0.04% of the normally expected LCF risk from all causes for that population.

Cashwell, et al.[10] have calculated doses and risks from transportation of research reactor spent fuel, and calculate total population doses of 0.022 person-Sv to 0.48 person-Sv over ten years with an average population dose (averaged over both shipments and years) of 0.082 person-Sv. This result compares quite reasonably to the population dose extrapolated from the median-TI package for fuel cycle materials transportation (2.2 person-Sv, from Table 8) considering that spent research reactor fuel is a very small part of the amount of radioactive material transported. An earlier study by the Nuclear Regulatory Commission, NUREG-0170(11) gives the total 1975 population dose for transportation of radioactive materials as 97.9 person-Sv and projects the risk as 1.2 LCF. These figures may be compared with the present results from the extrapolated median-TI shipments: 13.7 person-Sv and 1.1 LCF. NUREG-0170 calculated doses and risks from a constructed standard shipment model rather than using maximum-TI or median-TI shipments from the available data. Table 13 includes the results of these studies. Only doses and LCF for the general public are compared in this table and in most of the text; comparisons involving occupational doses were too cumbersome to contribute to the discussion.

The projected risks discussed in this paper assume that incident-free transportation is carried out in complete conformity with applicable regulations and permits. Although these risks are considerably less than the background risks, they can be reduced further. Travel through suburban and urban areas increases population dose substantially, and could be minimized or eliminated altogether for some types of large-TI shipments. On-link doses can also be minimized by restricting travel on heavily used routes to the times of least heavy traffic. Finally, it should be remembered that the numbers given here are calculated projections, and that some measurements of roadside accumulated dose would help to clarify the results considerably.

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TABLE 1

NORMAL OPERATING DETAILS FOR
HIGHWAY TRANSPORTATION OF RADIOACTIVE MATERIALS

OPERATIONAL DETAIL	VALUE USED IN RADTRAN
Velocity in rural population zone	88.6 km/hr
Velocity in suburban population zone	40.3 km/hr
Velocity in urban population zone	24.2 km/hr
Rural population density	6 persons/km^2
Suburban population density	719 persons/km^2
Urban population density	3861 persons/km^2
Rural building shielding factor	1.0
Suburban building shielding factor	0.87
Urban building shielding factor	0.018
Ratio of pedestrian density to population density	6
Number of crew per shipment	2
Average distance from source to crew	10 m.
Stop time per shipment	0.011 hr/km
Persons exposed while stopped	25
Average exposure distance while stopped	20 m.
Persons per vehicle on the transport link	2
Fraction of urban travel during rush hour	0.10
Fraction of urban travel on city streets	0.05
Fraction of rural/suburban travel on freeways	0.75
Vehicles per hour, rural zones (one way)	470
Vehicles per hour, suburban zones (one way)	780
Vehicles per hour, urban zones (one way)	2,800

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TABLE 2

SUMMARY OF RADIOACTIVE MATERIALS TRANSPORTATION BY HIGHWAY

END USE	SHIPMENTS/YEAR	PACKAGES/YEAR
Industrial	171,251	200,859
Radiography	78,375	78,375
Medical	1,116,829	1,228,297
Fuel Cycle	9,722	120,176
R & D	23,724	24,511
Unknown	11,773	11,773
Waste	92,829	994,258
Other	10,694	567,826
TOTAL	1,516,197	3,226,075

TABLE 3

SHIPMENT PARAMETERS FOR MAXIMUM-TI HIGHWAY SHIPMENTS

END USE	PKG TYPE	PKG TI[a]	DISTANCE (KM)	FRACTION OF TRAVEL RURAL	SUBURBAN	URBAN	NUCLIDE
Industrial	A	9.9	990	0.71	0.27	0.02	Am-241
Radiography	B	6.0	5,652	0.74	0.25	0.01	Co-60
Medical	A	6.5	3,056	0.67	0.31	0.02	Mo-99
Fuel Cycle	B	6.5	813	0.71	0.27	0.02	U(enr)
R & D	A	5.0	545	0.68	0.31	0.01	Am-241
Unknown	B	1.0	723	0.56	0.43	0.01	Ir-192
Waste	LSA[b]	300.0	664	0.70	0.28	0.02	Mixed
Other	B	2.0	1,885	0.80	0.19	0.01	Cs-137

[a]The units of TI are mrem/hour at 1 meter.

[b]LSA is low specific activity.

TABLE 4

POPULATION DOSES FROM THE
MAXIMUM-TI PACKAGE SHIPPED BY HIGHWAY FOR EACH END USE

END USE	POPULATION DOSES (PERSON-μSv) OCCUPATIONAL	PUBLIC	MAX INDIVIDUAL DOSE (pSv)
Industrial	321	392	33.2
Radiography	176	474	23.8
Medical	244	369	21.8
Fuel Cycle	425	171	25.8
R & D	129	92.2	16.8
Unknown	65.4	26.2	3.97
Waste	1,170	369	1,010
Other	140	85.1	7.94

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TABLE 5

ANNUAL POPULATION DOSES FOR DOSES FOR MAXIMUM-TI PACKAGES SHIPPED BY HIGHWAY FOR EACH END USE EXTRAPOLATED FOR THE TOTAL HIGHWAY SHIPMENTS FOR 1982

END USE	POPULATION DOSES (PERSON-Sv)[a] OCCUPATIONAL	PUBLIC	MAX INDIVIDUAL DOSE (μSv)
Industrial	64.4	79.0	6.68
Radiography	13.7	36.9	1.86
Medical	301	454	26.8
Fuel Cycle	51.0	20.5	3.10
R & D	3.18	2.26	0.411
Unknown	0.771	0.310	0.0469
Waste	1,160	367	1,000
Other	79.7	48.5	4.51
TOTAL	1,673.75	1,008.47	1,043.4

[a] The unit is person-Sv, not person-μSv as in the previous table.

TABLE 6

SHIPMENT PARAMETERS FOR MEDIAN-TI HIGHWAY SHIPMENTS

END USE	PKG TYPE	PACKAGE TI[a]	DISTANCE (KM)	FRACTION OF TRAVEL RURAL	SUBURBAN	URBAN	NUCLIDE
Industrial	A	0.1	5,075	0.73	0.25	0.02	Am-241
Radiography	B	0.8	529	0.56	0.43	0.01	Ir-192
Medical	A	0.1	1,337	0.56	0.43	0.01	I-131
Fuel Cycle	LSA	1.0	554	0.68	0.31	0.01	U(nat)
R & D	SM	0.06	489	0.72	0.26	0.02	Mixed
Unknown	LSA	0.06	3,829	0.71	0.27	0.02	Tc-99m
Waste	B	0.01	1,339	0.61	0.38	0.01	Ir-192
Other	A	0.1	1,885	0.80	0.19	0.01	Mixed

[a] The units of TI are mrem/hour at 1 meter.

TABLE 7

POPULATION DOSES FROM THE
MEDIAN-TI PACKAGE SHIPPED BY HIGHWAY FOR EACH END USE

	POPULATION DOSES (PERSON-μSv)		MAX INDIVIDUAL
END USE	OCCUPATIONAL	PUBLIC	DOSE (pSv)
Industrial	4.57	8.39	0.336
Radiography	52.5	41.7	3.18
Medical	3.04	3.31	0.336
Fuel Cycle	26	18.6	3.36
R & D	1.54	1.05	0.201
Unknown	2.44	4	0.201
Waste	0.688	0.373	0.0397
Other	3.12	3.60	0.336

TABLE 8

ANNUAL POPULATION DOSES FOR MEDIAN-TI PACKAGES
SHIPPED BY HIGHWAY FOR EACH END USE
EXTRAPOLATED FOR THE TOTAL HIGHWAY SHIPMENTS FOR 1982

	POPULATION DOSES (PERSON-Sv)[a]		MAX INDIVIDUAL
END USE	OCCUPATIONAL	PUBLIC	DOSE (μSv)
Industrial	0.92	1.68	0.0675
Radiography	4.08	3.25	0.248
Medical	3.75	4.06	0.413
Fuel Cycle	3.11	2.23	0.403
R & D	0.0377	0.0256	0.00494
Unknown	0.0287	0.0473	0.00238
Waste	0.684	0.371	0.0395
Other	1.77	2.04	0.191
TOTAL	14.1	13.7	1.37

TABLE 9

ANNUAL LATENT CANCER FATALITIES FOR EACH END USE FOR THE MAXIMUM-TI SHIPMENT BY HIGHWAY

	FATAL CANCERS($x10^{-5}$)			
	OCCUPATIONAL		PUBLIC	
END USE	MALE	FEMALE	MALE	FEMALE
Industrial	1.5	0.53	1.5	1.7
Radiography	1.7	0.29	1.8	2.0
Medical	1.1	0.40	1.4	1.6
Fuel Cycle	2.0	0.69	0.64	0.73
R & D	0.59	0.21	0.34	0.40
Unknown	0.30	0.11	0.097	0.11
Waste	5.4	1.9	1.4	1.6
Other	0.64	0.23	0.32	0.37
TOTAL	12.3	4.36	7.35	8.48

TABLE 10

ANNUAL LATENT CANCER FATALITIES FOR MAXIMUM-TI PACKAGES SHIPPED BY HIGHWAY FOR EACH END USE EXTRAPOLATED FOR THE TOTAL HIGHWAY SHIPMENTS FOR 1982

	FATAL CANCERS			
	OCCUPATIONAL		PUBLIC	
END USE	MALE	FEMALE	MALE	FEMALE
Industrial	3.0	1.1	2.9	3.4
Radiography	0.63	0.22	1.4	1.6
Medical	14	4.9	17	19
Fuel Cycle	2.5	0.83	0.76	0.88
R & D	0.15	0.052	0.084	0.097
Unknown	0.035	0.013	0.012	0.013
Waste	53	19	14	16
Other	3.7	1.3	1.8	2.1
TOTAL	76.9	27.3	37.5	43.2

TABLE 11

ANNUAL LATENT CANCER FATALITIES FOR EACH END USE FOR THE MEDIAN-TI SHIPMENT BY HIGHWAY

	FATAL CANCERS($x10^{-7}$)			
	OCCUPATIONAL		PUBLIC	
END USE	MALE	FEMALE	MALE	FEMALE
Industrial	2.1	0.75	3.1	3.6
Radiography	24	8.6	16	18
Medical	1.4	0.50	1.2	1.4
Fuel Cycle	12	4.2	6.9	8.0
R & D	0.71	0.25	0.39	0.45
Unknown	1.1	0.40	1.5	1.7
Waste	0.32	0.11	0.14	0.16
Other	1.4	0.51	1.3	1.5
TOTAL	43.2	15.3	30.1	34.7

TABLE 12

ANNUAL LATENT CANCER FATALITIES FOR MEDIAN-TI PACKAGES
SHIPPED BY HIGHWAY FOR EACH END USE
EXTRAPOLATED FOR THE TOTAL HIGHWAY SHIPMENTS FOR 1982

	FATAL CANCERS			
	OCCUPATIONAL		PUBLIC	
END USE	MALE	FEMALE	MALE	FEMALE
Industrial	0.042	0.02	0.062	0.072
Radiography	0.19	0.067	0.12	0.14
Medical	0.17	0.061	0.15	0.17
Fuel Cycle	0.14	0.051	0.083	0.10
R & D	0.0017	0.00062	0.00095	0.0011
Unknown	0.0013	0.00047	0.0018	0.0020
Waste	0.031	0.011	0.014	0.016
Other	0.082	0.029	0.076	0.087
TOTAL	0.66	0.240	0.51	0.59

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TABLE 13

COMPARISONS OF CALCULATED ANNUAL DOSES AND LCF
TO BACKGROUND RISKS AND TO RESULTS OF OTHER STUDIES

	POPULATION DOSE (Person-Sv)	INDIV. DOSE (μSv)	RISK (LCF)
Extrapolated max-TI shipments	1,008.5	1,043.4 (max)	81
Extrapolated med-TI shipments	13.7	1.37(max)	1.1
Background (total population): max-TI shipments	16,235	3,600 (av)	2,078[a] 19,626[b]
Background (total population): med-TI shipments	15,352	3,600 (av)	1,965[a] 18,559[b]
Waste: max-TI shipments	367	1,000 (max)	30
Waste: med-TI shipments	0.371	0.0395(max)	0.03
Background (waste shipments)[c]: max-TI shipments	676	3,600 (av)	87[a] 817[b]
Background (waste shipments)[c]: med-TI shipments	1,521	3,600 (av)	195[a] 1,838[b]
Fuel cycle: max-TI shipments	20.5	3.10(max)	1.6
Fuel cycle: med-TI shipments	2.23	0.403(max)	0.18
Background (fuel cycle ship.)[d]: max-TI shipments	521	3,600 (av)	280[a] 2,646[b]
Background (fuel cycle ship.)[d]: med-TI shipments	529	3,600 (av)	68[a] 640[b]
Cashwell, et al. (spent research reactor fuel)	0.082		0.0016
NUREG-0170 for 1975	97.9	0.005(av)	1.2

[a]This risk is the LCF anticipated when the population in question is exposed to average background radiation of 3.6 mSv/yr.

[b]This is the background LCF, or LCF from all causes, anticipated for the population in question.

[c,d]These are the populations exposed to waste shipments and fuel cycle shipments, respectively. The background doses and LCFs are those that a population of that size would experience in the absence of radioactive materials transportation.