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RISKS AND IMPACTS OF INCIDENT-FREE TRANSPORTATION OF RADIOACTIVE MATERIALS BY AIR

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ABSTRACT

Annual radiation doses and risks to passengers and crew are calculated for shipments of radioactive materials in passenger aircraft under accident-free and incident-free conditions; i.e., under normal transportation conditions. The 1982 database developed by Sandia National Laboratories is used, and calculations are made using RADTRAN 4.0. This paper is one of two papers estimating radiological risk associated with incident-free transportation of radioactive materials.

KEY WORDS: Risk assessment, transportation, transportation risk, radiological risk, air transportation

1. INTRODUCTION

Incident-free transportation of a radioactive material, often referred to as "normal" transportation, can have environmental consequences and can pose risks. When radioactive materials are transported by air, there are risks to the crew and passengers in the plane, and risks to ground crew, including cargo handlers, and others who happen to be in the vicinity of the plane when it is on the ground. About 50 persons are usually near the plane, and the population dose to these persons is negligibly low. Therefore, this study concerns itself with doses and risks to ground crew (primarily cargo handlers) the crew of the aircraft (flight crew and flight attendants) and passengers in the aircraft. Occupational risks and risks to the public from ground transportation are discussed in a separate paper. Doses to handlers from transportation of the packages by van from the shipping terminal to the plane are included in the occupational doses calculated in this paper.

In virtually all air shipments, the radioactive material to be shipped 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). Packages traveling by surface transportation modes may be exempted from these regulations under certain circumstances, but packages travelling in passenger aircraft are not.

The packages transported by air are always transported in more than one mode during a trip. For example, a truck or light duty vehicle may take the package to a terminal where it is transferred to a semi-detached trailer truck or a rail car along with other parcels. Near the airport, the package may again be transferred to a light-duty vehicle. Packages may also be picked up by or delivered to a freight forwarder and then consolidated with other packages into a single shipment, which may consist of a number of packages obtained from a number of different shippers.

Transportation is incident-free when it occurs without unusual delay, loss of, or 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 released although the transporting vehicle is not involved in a vehicular accident are abnormal transport occurrences, or incidents. Transportation accidents occur when the transporting vehicle is involved in a vehicular accident and the packages of radioactive material which it is carrying are affected. Accidents and incidents are not considered here.

2. RADIOLOGICAL IMPACTS

Incident-free transportation by passenger aircraft results in radiation doses and risks to people, and thus has direct impact on the human environment. Moreover, as long as accidents and incidents are not considered, there is no radiological impact on people through the human food chain, since the package is not breached. The principal environmental impact during incident-free transportation is direct radiation exposure to nearby persons from the radioactive material in the package.

The impact of incident-free transportation of radioactive materials may be quantified in terms of annual population dose and the risk may be estimated in terms of the annual latent cancer fatalities expected from this population dose. Because of the altitude of airplane flight, there is essentially no dose in incident-free transportation to people on the ground along the flight path. Any radiological effects are the result of radiation from the unbreached package. The principal radiological impact on inanimate objects is the effect on undeveloped photographic film. The regulations for spacing between radioactive material packages and film are designed to minimize this problem.

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. Those who work in the vicinity of the package but do not actually handle it or who are transported with it (e.g., aircraft passengers and crew) are subjected to lower dose rates than handlers but are generally exposed for longer periods of time than handlers. The crew will endure greater exposure than passengers by virtue of making more trips. The data did not differentiate between commercial air passenger service and commercial air cargo service. This study treats all air transportation as transportation on vehicles carrying passengers as well as cargo.

The direct radiological impact of incident-free transportation of a package containing radioactive material depends primarily on the transport index (TI) and the duration of exposure. TI is the radiation dose rate in mrem per hour at a distance of one meter from the package surface. The radiological impact of incident-free transportation for a given TI is independent of the radionuclide content of the package and the characteristics of the packaging. 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.

3. DATABASE AND METHODS

Radiological impact of incident-free air transportation was evaluated from shipments of various packages by various modes as documented in the the 1982 database provided by Sandia National Laboratory[3]. It is difficult to estimate the overall dose and risk to the entire United States from shipments of radioactive material because of the limited data base available. A three-step approach to dose calculation is taken in this study, and is outlined below.

1. The packages in the database were categorized by the end use of the shipment: industrial, industrial radiography, medical, research and development, waste, end use unknown, and a miscellaneous end use category identified as "other" (it should be noted that radioactive material used for nuclear power generation is not shipped by air).

2. For each end use category the maximum-TI package and the median-TI package were selected from the database. Shipments of these packages were all single-package shipments. For end use categories in which there was more than one maximum-TI or median-TI package, the package with the longest shipping distance was selected, yielding greater passenger and crew exposure.

3. The doses were calculated using RADTRAN 4.0[4,5] for the maximum-TI and median-TI packages for each end use, respectively, for the maximum-TI package extrapolated to total annual packages for each end use and for the median-TI package extrapolated to total annual packages for each end use (and thus to all shipments). "Extrapolation" in this instance consisted of multiplying the dose calculated for the selected maximum-TI or median-TI package for each end use by the total number of packages for that end use. The median TI was selected for extrapolation instead of the mean because the median 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. All package activity was assumed to be gamma activity.

Maximum and median shipments for each end-use were compiled by searching the database for the appropriate records. The appropriate records could be extracted because, in the original data, each package and each shipment are uniquely identified.

The significance of these dose calculations is discussed in the next section. The results of extrapolating the median-TI package give approximations of the total occupational and passenger doses for each end use for 1982 (since 1982 data were used). The results of extrapolating the maximum-TI package approximates an upper bounding dose.

The basic equation for the incident-free annual population dose calculation[4,5] for persons traveling by air is given below. It is based on an empirical dose rate of 3×10^{-7} Sv/hr/TI derived by Barker <u>et al</u>[6,7]. This dose rate is an average obtained from measurements made throughout several aircraft, included thermoluminescent dosimetry of flight attendants and passengers[7].

(1) $D = 3 \times 10^{-7} Q_3 (PPS)(SPY)(TI) N_c (FMPS/V)$

D = integrated population dose (person-Sv)
PPS = packages per shipment
SPY = shipments per year
N_c = number of flight attendants or passengers

FMPS = total distance travelled
V = airplane speed
Q_3 = appropriate unit conversion factor

Risks were calculated from doses using dose-to-risk conversion factors derived from the models preferred by the National Research Council's

Committee on the Biological Effects of Ionizing Radiation (BEIR Committee)[8]. The BEIR leukemia model assumes a linear-quadratic dependence of leukemia incidence on dose, while the BEIR models for other cancers assume linear dependence with different slopes for different types of cancer. A detailed discussion of these models is found in Ref. 8. In making these calculations for 1982 data, a worker (crew and handler) population of 75% males and 25% females, and a passenger population of 50% males and 50% females, was assumed. A lifetime was assumed to be 70 years and a working lifetime, 47 years (age 18 to age 65). Risks were calculated for the maximum-TI package shipments, for the maximum-TI package shipments extrapolated to all shipments, and for the median-TI package shipments extrapolated to all shipments. The calculations of risk using Table 4-2 of Ref. 8 are given in equations 2a and 2b.

(2a) $R_{LP} = (F_P)(D_P)(R_{TP})/70$ yrs

F_P = fraction of the population of each sex, since Ref. 8 calculates latent cancer fatalities separately for males and females. F_P is 0.5 for males and 0.5 for females.

R_{LP} = annual risk to the public of excess latent cancer fatalities (Tables 9, 10, 11).

D_P = dose in person-Sv from Tables 3, 4 or 7.

R_{TP} = risk per 100,000 persons per lifetime annual exposure of 1 mSv per year (from Table 4-2 of Ref. 8). R_{TP} is 5.20 for males and 6.00 for females.

(2b) $R_{LO} = (F_O)(D_O)(R_{TO})/47$ yrs

F_O = fraction of the worker population of each sex, since Ref. 8 calculates latent cancer fatalities separately for males and females. F_O is 0.75 for males and 0.25 for females.

R_{LO} = annual occupational risk of excess fatal cancer (Tables 9, 10, 11).

D_O = dose in person-Sv from Tables 3, 4 or 7.

R_{TO} = risk per 100,000 persons per working lifetime annual exposure of 0.01 Sv per year (from Table 4-2 of Ref. 8). R_{TO} is 2.880 for males and 3.070 for females.

4. RESULTS

Table 1 gives the total shipments by air and highway for five identified end uses. These end uses are industrial use, industrial radiography, medical, 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 five identified categories. These totals are the results of a survey of shippers for the year 1982. Details of the survey are given in Ref. 3. Earlier studies[9,10] indicated that the 1982 totals were not significantly different from 1975 totals.

As may be seen from Table 1, approximately 96% of the air shipments (80% of the shipments by air and highway) were medical shipments. Considering one package per shipment, Table 2 indicates that medical shipments comprise about 14% of the TI shipped by air, while industrial shipments comprise about 67% of the TI shipped by air. Since the present study is concerned only with incident-free transportation, the results depend directly on TI. Radiological risk depends on activity only in transportation incidents or accidents in which the container is breached.

The tables of doses are arranged as follows: Tables 2, 3 and 4 deal with maximum-TI packages for each end use, Tables 5, 6 and 7 deal with median-TI packages for each end use, Tables 8, 9 and 10 show risks, and Table 11 compares doses from exposure to packages of radioactive material to cosmic ray doses.

Tables 2 and 5 give the parameters used in the RADTRAN 4.0 calculations for maximum-TI and median-TI packages, respectively. In the tables, the dominant radionuclide for each end use (as taken from the database) is listed for interest. The radionuclide content will vary from package to package within each end use group, but this variation does not affect the calculation of risks and doses for incident-free transportation. Table 3 shows the population doses for the maximum-TI single package for each end use, and Table 4 shows the population doses for the maximum-TI package for each end use extrapolated to all packages for that end use. Table 6 shows the population doses for the median-TI single package for each end use, and Table 7 shows the population doses for the median-TI package for each end use extrapolated to all packages for that end use.

Annual risks were calculated as indicated above from the doses given in Tables 3, 4, and 7. Table 8 shows the annual risks for the maximum dose package for each end use calculated from the doses given in Table 3. Table 9 gives the annual risks, in terms of latent cancer fatalities, for the maximum dose shipments extrapolated to all shipments calculated from the doses given in Table 4. Table 10 gives the annual risks, in terms of latent cancer fatalities, for the median dose shipments extrapolated to all shipments calculated from the doses given in Table 7.

RADTRAN 4.0 calculates doses to crew, handlers and passengers separately. The assumption in RADTRAN is that each airplane carrying a shipment of radioactive material is full and carries 160 passengers and seven crew members. The crew is assumed to fly 22 days per month. The population doses given in Tables 3, 4, 6 and 7 are doses to the crew and handlers of the radioactive package (occupational doses), and doses to passengers who travel in the same plane as the radioactive material, who are the only members of the public with non-negligible exposure to the radioactive package.

Results for the single maximum-TI package are an indication of the maximum dose and risk that can result from air shipment of a single package for a given end use, at least for the year 1982. Results for the median-TI packages extrapolated to all packages for each end use are an indication of the population doses for 1982, while doses from the maximum-TI packages extrapolated to all packages for each end use are shown to indicate the results of conservative assumptions. In air travel, there is virtually no dose to anyone except crew and passengers when the airplane is at cruising altitude.

The population doses to crew, handlers, and airplane passengers from the maximum-TI packages for each end use are within an order of magnitude of each other (Table 3). The population doses to handlers and passengers are larger than those to crew because a considerably larger population is exposed. When the maximum TI packages are extrapolated to all packages for each end use, the dose from medical packages predominates (Table 4). This dose reflects the number of medical packages: the dose is two to three orders of magnitude greater than doses from packages for other end uses, just as the number of medical packages is approximately two orders of magnitude larger than the number of packages for any other end use.

Although Table 4 can be said to represent a sort of upper bound for the dose, it has less significance than Table 7. The extrapolation undertaken is more relevant for the median-TI packages than for the maximum-TI packages. Tables 5, 6 and 7 show, respectively, the package parameters for the median TI packages, population doses for the median packages, and extrapolations of the median doses to all of the air packages in the data base for that particular end use.

In comparing these doses to doses from other sources of ionizing radiation in the environment, it is first necessary to estimate the exposed population. The annual cosmic radiation dose to the passengers during air travel, as calculated from Table 3.3 of Ref. 9, is 68 person-Sv. The 1982 dose to passengers, calculated by extrapolating the median dose to all air shipments of radioactive material (Table 7), is 8.0 person-Sv. Similarly, assuming that the crew fly 22 days per month, the annual cosmic radiation dose to the crew during flight is 680 person-Sv. The 1982 dose to crew from Table 7 is 0.809 person-Sv. Extrapolation of the maximum dose to all packages (instead of extrapolating the median dose) yields a calculated 1982 dose of 433 person-Sv to passengers and a calculated 1982 dose of 48.7 person-Sv to crew (Table 4). These data are summarized in Table 11.

Measurements made in Oklahoma City and Boston indicate that the maximum dose rate to an attendant in the tourist section of an aircraft carrying the maximum amount of radioactive material permitted by regulation is between 0.006 and 0.008 mSv per hour[10], or between 6 and 8 mSv per year, assuming 1000 hours of flight time per year. The "maximum amount of radioactive material permitted by regulation" means a maximum package TI of 3, a maximum total TI of 50, and separation distances as specified by Subsection 175.701(b)(2) of Ref. 1. Assuming a crew of seven, the measured annual dose can thus be compared to the annual dose per crew member of 116 mSv calculated from extrapolation of the median-TI package (Table 7). Comparison may also be drawn with a cosmic radiation dose of 1.73 mSv per year (1000 hours per year x 0.0023 mSv per hour x 0.75), assuming that three quarters of the flying time is spent at 9 km altitude.

Maximum individual dose is not a meaningful calculation for air shipments and is not presented here. Population dose is given here because risk (latent cancer fatalities) can be more informatively estimated from population doses than from maximum individual doses.

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]. Comparison of the risk estimates may be less significant than comparing dose estimates, since dose-to-risk conversions involve both a high degree of uncertainty and a number of essentially unverifiable assumptions. Even comparison of doses should be made in recognition of the following assumptions, which result in conservative dose calculations:

1. No shielding by other packages was assumed.

2. No other shielding was assumed between the passengers in a plane and the packages of radioactive material.

3. All radioactive packages transported by air were assumed to be on passenger aircraft carrying the full complement of crew and passengers.

One may question how representative a year 1982 was. The total numbers of packages and shipments in 1982 were very similar to those of 1975[9]. However, the distances associated with the selected median-TI and maximum-TI shipments were not necessarily the greatest distances those shipments could have gone, and the particular distances could be different in a different year. Since passenger and crew exposure depend on the distance which the airplane in question travels, the maximum-TI and median-TI doses could differ in different years. An order of magnitude difference would not be anticipated from differences in distance, however.

The doses to crew and passengers from air transportation of radioactive material are small, and the associated risks are estimated to be small compared to other sources of risk in modern life. Thus, the discrete results of this study are most meaningful when compared with each other rather than with risks or doses resulting from other activities. Risks to the public - the airline passengers in this instance - can be compared to excess fatal cancer risk from non-specific sources. Occupational risks are most meaningfully compared to risk from cosmic ray exposure for airline crews. Extrapolating doses and risks from the shipments with the largest TI to all shipments for a particular end use - assuming, in effect, that the package delivering the highest dose was characteristic of all shipments - is a worst case assumption for radionuclide transportation.

About 16,500 cancer deaths would be expected annually in the passenger population[8] in the absence of packages of radioactive material as a source of ionizing radiation. From Table 9, the most conservative extrapolation of risk, 36 deaths would be expected annually in the passenger population. The more realistic approximation given in Table 10 projects about 0.6 excess cancer deaths per year in this population. From these data, then, transportation of radioactive materials by air appears to increase the annual cancer risk by between 0.0036% and 0.22%. Projected excess occupational cancer deaths are between 0.1 and seventeen per year, or between 0.01% and 2% of the projected excess cancer deaths from cosmic ray exposure among crew members.

The dose to passengers, and to some crew members can be reduced very effectively by shipping radioactive materials in cargo aircraft rather than in passenger aircraft. The dose should also be calculated more precisely by taking shielding into account. Moreover, validation of the model by dosimetry would appear to be a straightforward and informative research project.

Radionuclides used in medicine and medical research result in the largest doses, followed closely by industrial radiography and other industrial uses. These doses depend directly on the number of packages shipped (and thus on the number of shipments). The growth of cargo air services suggests that such cargo air services could provide a mode of shipment for air transportation of radioactive materials which would reduce passenger exposure. Substitution of surface shipping for air shipping (when surface shipments are possible) cannot be suggested until a comparison is made with doses and risks from surface shipments of radioactive materials.

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REFERENCES

1. Code of Federal Regulations, Transportation, V. 49, Parts 173 through 178, Office of the Federal Register, National Archives and Records Administration, Revised as of July 1, 1989.

2. Code of Federal Regulations, Energy, V. 10; Part 71, Office of the Federal Register, National Archives and Records Administration, Revised as of July 1, 1989.

3. H. S. Javitz, T. R. Lyman, C. Maxwell, E. L. Myers, C. R. Thompson Transport of Radioactive Material in the United States: Results of a Survey, SAND84-7174, Sandia National Laboratories, Albuquerque N. M. 1985.

4. M. M. Madsen, J. M. Taylor, R. M. Ostmeyer, P. C. Reardon, RADTRAN III, SAND84-0036, Sandia National Laboratories, Albuquerque, N. M. 1986

5. K. S. Neuhauser and P. C. Reardon, RADTRAN 4.0, SAND89-1137c, Sandia National Laboratories, Albuquerque, N. M. 1989

6. R. Barker, D. Hopkins and A. Tse, Radiation Dose to Population Resulting from the Transportation of Radioactive Material by Passenger Aircraft in the U. S., IAEA-SM-184/15, International Atomic Energy Agency, Vienna, Austria, 1974.

7. D. Hopkins and A. Tse, personal communications.

8. National Research Council Committee on the Biological Effects of Ionizing Radiation, Health Effects of Exposure to Low Levels of Ionizing Radiation; BEIR V, National Academy Press, Washington, D. C. 1990.

9. U. S. Nuclear Regulatory Commission, Office of Standards Development, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, U. S. Nuclear Regulatory Commission, Washington, D. C. 1977.

10. R. F. Weiner, P. A. LaPlante, J. P. Hageman, F. Bennett, J. Buckingham, Risks in Transporting Radioactive Materials: Comparison of Data with NUREG-0170 Projections, Waste Management 90, University of Arizona, Tucson, Ariz., in press.

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TABLE 1

SUMMARY OF RADIOACTIVE MATERIALS TRANSPORTATION BY AIR

END USE	SHIPMENTS/YEAR	PACKAGES/YEAR
Industrial	12,674	22,800
Radiography	7,674	11,500
Medical	674,100	674,100
R & D	6,875	7,400
Waste	1,076	1,740
Unknown	1,150	1,330
Other	1,507	5,180

TABLE 2

SHIPMENT PARAMETERS FOR MAXIMUM-TI PACKAGE AIR SHIPMENTS

END USE	PKG TYPE	PKG/ SHIPMENT	PKG TI[a]	DISTANCE (KM)	NUCLIDE
Industrial	A	1	9.7	1,351	Am-241
Radiography	B	1	2.5	6,289	Ir-192
Medical	A	1	2	3,684	P-32
R & D	A	1	7.3	322	Na-24
Unknown	B	1	3.8	1,448	S-35
Waste	A	1	1	595	Ir-192
Other	A	1	0.1	772	Xe-133

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

TABLE 3

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

	POPULATION DOSES (PERSON-µSv)		
END USE	CREW	HANDLERS	PASSENGERS
Industrial	93.7	146	904
Radiography	44.4	204	386
Medical	76.2	347	679
R & D	55.5	110	162
Unknown	42.6	194	379
Waste	27.4	30.0	466
Other	0.851	1.50	5.33
TOTAL	340.7	932.5	2,971

TABLE 4

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

	POPULATION DOSES (PERSON-Sv)[a]		
END USE	CREW	HANDLERS	PASSENGERS
Industrial	2.15	3.33	20.7
Radiography	0.511	2.35	4.45
Medical	45.5	208	406
R & D	0.411	0.810	1.23
Unknown	0.0566	0.258	0.501
Waste	0.477	0.522	0.812
Other	0.0044	0.0078	0.0277
TOTAL	49.1	215.3	432.9

[a] The units for population dose in this table are person-sieverts, not person-microsieverts as in Tables 3 and 6.

TABLE 5

SHIPMENT PARAMETERS FOR MEDIAN-TI PACKAGES SHIPPED BY AIR

END USE	PKG TYPE	PKG/ SHIPMENT	PKG TI[a]	DISTANCE (KM)	NUCLIDE
Industrial	A	1	0.1	418	Mixed
Radiography	B	1	1.2	588	Ir-192
Medical	A	1	0.1	360	I-131
R & D	A	1	0.3	300	Br-82
Unknown	A	1	0.1	630	Mixed
Waste	A	1	2	3,379	Ir-192

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

TABLE 6

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

	POPULATION DOSES (PERSON-μSv)		
END USE	CREW	HANDLERS	PASSENGERS
Industrial	1.09	1.50	13.6
Radiography	19.1	61.3	312
Medical	0.889	1.50	6.67
R & D	2.27	4.50	6.21
Unknown	0.822	1.50	4.35
Waste	8.17	15.0	41.6
TOTAL	32.34	85.33	84.4

TABLE 7

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

	POPULATION DOSES (PERSON-Sv)[a]		
END USE	CREW	HANDLERS	PASSENGERS
Industrial	0.025	0.034	0.312
Radiography	0.220	0.705	3.59
Medical	0.532	0.897	3.98
R & D	0.017	0.033	0.046
Unknown	0.001	0.002	0.0058
Waste	0.014	0.026	0.072
TOTAL	0.809	1.70	8.006

[a] The units for population dose in this table are person-sieverts, not person microsieverts as in Tables 3 and 6.

TABLE 8

ANNUAL LATENT CANCER FATALITIES FOR EACH END USE FOR THE MAXIMUM-TI PACKAGE SHIPPED BY AIR

	FATAL CANCERS($x10^{-5}$)			
	OCCUPATIONAL		PASSENGERS	
END USE	MALE	FEMALE	MALE	FEMALE
Industrial	1.1	0.39	3.4	3.9
Radiography	1.1	0.41	1.4	1.7
Medical	1.9	0.69	2.5	2.9
R & D	0.76	0.27	0.6	0.7
Unknown	1.1	0.39	1.4	1.6
Waste	0.53	0.19	3.5	4.0
Other	0.01	0.0	0.01	0.01
TOTAL	6.5	2.3	12.8	15.8

TABLE 9

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

	FATAL CANCERS			
	OCCUPATIONAL		PASSENGERS	
END USE	MALE	FEMALE	MALE	FEMALE
Industrial	0.25	0.090	0.77	0.89
Radiography	0.132	0.047	0.17	0.19
Medical	11.8	4.1	15.1	19.1
R & D	0.056	0.020	0.046	0.053
Unknown	0.015	0.0051	0.019	0.022
Waste	0.0047	0.0017	0.030	0.035
Other	0.0006	0.0002	0.001	0.0012
TOTAL	12.25	4.26	16.13	20.29

TABLE 10

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

	FATAL CANCERS			
	OCCUPATIONAL		PASSENGERS	
END USE	MALE	FEMALE	MALE	FEMALE
Industrial	0.0027	0.001	0.012	0.013
Radiography	0.043	0.015	0.13	0.15
Medical	0.066	0.023	0.15	0.17
R & D	0.0023	0.00082	0.0017	0.0020
Unknown	0.00014	0.00005	0.00022	0.00025
Waste	0.0018	0.00065	0.0027	0.0058
TOTAL	0.115	0.041	0.297	0.341

TABLE 11

COMPARISON OF DOSES FROM AIR SHIPMENTS OF RADIOACTIVE MATERIAL WITH COSMIC RAY DOSES

	ANNUAL DOSE (PERSON-Sv) CREW	PASSENGERS
Median dose extrapolated to all shipments	0.809	8.0
Maximum dose extrapolated to all shipments	49.1	433
Cosmic radiation	680	136