CHAPTER 6
ALTERNATIVES

6.1 INTRODUCTION

The analysis of the impact of transportation of radioactive materials presented in Chapters 1 through 5 was based on current shipping practices as revealed in the 1975 survey and in the 1985 projections of those shipping practices. In this chapter, the environmental effects of various alternatives to shipping practice as projected for 1985 are evaluated. The 1985 standard shipments model was used rather than the 1975 model because it was felt that by the time any new regulation to implement a particular alternative went into effect, the shipping activity would be more accurately described by the 1985 model. Thus, the impacts of various alternatives are evaluated by using the 1985 standard shipments model and are compared with the 1985 baseline, i.e., the risk computed in the previous chapter for 1985.

An alternative that results in a lower annual population dose is desirable from a radiological point of view but should be balanced against nonradiological impacts and the cost of implementation. Similarly, one alternative may be desirable from a safeguards viewpoint but undesirable from a radiological safety viewpoint. Thus, a quantitative comparison of the radiological impacts may be made in terms of the number of excess latent cancer fatalities (LCFs) produced, but the assessment of the total impact of a given alternative on the environment often will include qualitative consideration of other factors.

Three radiological impacts relative to 1985 shipping activity are quantified for each alternative: (1) the annual normal population dose in terms of both person-rem per year and the annual LCF, (2) the annual expected number of LCFs due to accidents, and (3) the annual probability of one or more early fatalities resulting from accidents. Comparison is made to the 1985 baseline case, the radiological impact of which is summarized in Table 6-1.

TABLE 6-1

RADIOLOGICAL IMPACTS FOR THE BASELINE CASE

1985 STANDARD SHIPMENTS WITH MODEL II RELEASE FRACTIONS

Annual normal population dose	25,360 person-rem (3.07 LCF)
Annual expected number of LCFs due to accidents	0.017 LCF
Annual probability of one or more early fatalities due to radiological exposure from accidents	9.12×10^{-4}

Certain alternatives considered in the draft version were eliminated as a result of comments from authoritative sources concerning their impracticality. These include shifting all material carried by all-cargo aircraft to passenger aircraft, flights only under VFR (visual flight rules), daytime-only flights, and specific aircraft model requirements.

Where appropriate, the cost of implementing an alternative is estimated, and this cost is compared to the benefit resulting from the alternative. Benefits are expressed in terms of the estimated reduction in annual population dose or LCFs resulting from implementation of the alternative. To compare benefits to incremental costs, it is necessary to assign a monetary value to an LCF. For the purposes of this assessment, the official NRC estimate of $1000 per person-rem (Ref. 6-1) is used along with the whole-body dose-effect value of 121 LCF per 10^6 person-rem (Ref. 6-2), resulting in a value of $\$8.22 \times 10^6$ for each LCF.

The alternatives discussed in this chapter may be classified by three general types:

1. Transport mode shifts
2. Operational constraints
3. Packaging or material constraints

Transport mode shifts involve additional or alternative regulations that would eliminate the use of certain transport modes for either all radioactive material shipments or for certain of the potentially more hazardous materials, e.g., polonium or plutonium. In evaluating the effects of these mode shifts, the assumption is made that the material involved would continue to be transported in the same total annual quantities but by a different mode.

The alternatives of the second type are those that would require specific operational constraints on transport to limit accident rates or consequences, e.g., restricting route, lowering speed limits for surface modes, no weekend driving, monitoring airport packages, and lowering allowable radiation levels in aircraft.

The alternatives of the third type are those that would:

1. Restrict the form of the material shipped to reduce its dispersibility and/or respirability in the case of an accident severe enough to breach the packaging.

2. Reduce the quantity of material shipped on a given transport vehicle to reduce the amount that could be dispersed in a severe accident.

3. Introduce new packaging standards to require the use of extradurable packaging for shipments involving Type B and large quantities of the potentially more hazardous isotopes.

4. Lower the package quantity limits or package transport index (TI) limits.

Each of these general alternative types is discussed in detail in Sections 6.2 through 6.4 of this chapter. Risk estimates are made and compared to the risks due to current shipments. The results are summarized in Section 6.5.

6.2 TRANSPORT MODE SHIFTS

In this section, the effects expected from shifting various classes of radioactive material from one transport mode to another are assessed. Various combinations that have been suggested as likely to yield a decrease in radiological impact are considered.

6.2.1 ALL AIR TRANSPORT BY TRUCK

This section considers the effects of transporting by truck all materials considered for transportation by either passenger aircraft or all-cargo aircraft in the 1985 standard shipments model. No change is assumed for the average distance per shipment for each scenario. However, because transport by truck is considerably slower, this alternative might necessitate shipping a greater number of curies and TIs per package for the short half-life materials to compensate for the additional radioactive decay.

It is estimated that the minimum time required from shipment to use is approximately 20 hours (essentially 1 day) for shipments by aircraft within the continental United States. In a similar time period, destinations within about 1290 kilometers could be served by truck with no additional radioactive material required to compensate for the loss resulting from radioactive decay. However, for longer distances, shipments must contain more radioactivity at the time of shipment. The amount required can be estimated using the following relationship:

$$\frac{A_t}{A_a} = \exp\left[\frac{0.693\left(\frac{x}{u} - 20\right)}{t_{1/2}}\right], \text{ where } \frac{x}{u} \geq 20 \qquad (6\text{-}1)$$

and A_t = initial activity for truck shipment
A_a = initial activity for air shipment
x = destination distance from shipper
u = mean transport speed for trucks
$t_{1/2}$ = nuclide half-life (in hours)

The only isotopes listed in the standard shipments model that have half-lives sufficiently short to require additional radioactivity when transported by truck are Tc-99m, Au-198, Ga-167, and Mo-99. Of these isotopes, only Mo-99 is transported an average distance greater than 1290 kilometers. Equation (6-1) suggests that about 10 percent more radioactivity would be required for Mo-99 shipments transported by truck instead of by air. This small change in amount carried will have a negligible effect on the radiological impact but might result in some significant increase in expense for the radiopharmaceutical supplier.

6.2.1.1 Radiological Impacts

The radiological impacts computed with this alternative are:

Annual normal population dose	26,290 person-rem (3.18 LCF)
Annual LCFs from accidents	0.021 LCF
Annual probability of one or more early fatalities	9.28×10^{-4}

Comparison of the radiological impact of this alternative with that of the baseline case (Table 6-1) indicates an increase of 930 person-rem per year in the normal population dose. The additional dose received by crewmen is the largest contributor to the overall increase. The annual accident LCF is increased as a result of the higher accident rate for trucks as compared to aircraft. The annual early fatality probability is also increased slightly.

6.2.1.2 Nonradiological Impacts and Cost-Benefit Balance

The shift of all radioactive materials from an air mode to truck mode implies an increase in the number of truck shipments from 2.34×10^6 to 4.14×10^6 shipments per year in 1985 or a factor of approximately 2. In order to estimate the freight cost savings resulting from shifting all air shipments to truck, an average package mass of 22.7 kilograms and an average distance of 1600 kilometers are assumed. The freight rates for such a package were obtained from local (Albuquerqûe, New Mexico) airfreight and truck offices and were found to be \$0.70 per kilogram for airfreight shipments under 45.4 kilograms and \$0.26 per kilogram for truck shipments under 45.4 kilograms. Thus, the transport of a 22.7-kilogram package for 1600 kilometers costs \$10.11 more by airfreight than by truck. The shift of 1.8×10^6 packages per year from air transport to truck transport would therefore result in an estimated annual saving of about $\$18 \times 10^6$.

An additional saving would be realized for the cargo aircraft shipments that are shifted to truck because of the decreased secondary mode distance (160 kilometers per shipment for cargo aircraft versus 80 kilometers per shipment for truck). The shift of cargo aircraft shipments to truck involves about 1.4×10^5 packages. With each package traveling, on the average, 80 fewer kilometers by secondary surface mode, about 5.6×10^6 fewer kilometers by secondary mode transport would be required, assuming an average of two packages per shipment. Assuming that delivery vehicles get 12.8 kilometers per liter, that gasoline costs \$0.14 per liter, that driver salaries and other costs amount to \$5 per hour, and that the average speed is 48 kilometers per hour, the additional saving for the decreased secondary mode travel would be $\$0.8 \times 10^6$. The radiological cost would be the additional annual population dose of 930 person-rem. At \$1000 per person-rem, this amounts to $\$0.93 \times 10^6$ per year. Based on these assumptions, this alternative appears to be cost effective with a net saving of $\$17.9 \times 10^6$.

6.2.2 ALL PASSENGER AIR TRANSPORT BY ALL-CARGO AIRCRAFT

This section considers the effect of transporting by all-cargo aircraft all materials transported by passenger aircraft in the 1985 baseline calculation. All other baseline shipments are left unchanged. This shift necessarily involves an increase in secondary surface mode transportation because all-cargo aircraft serve fewer airports than passenger aircraft. This assessment assumes a 160-kilometer average secondary mode distance per shipment for cargo aircraft and 80-kilometer for passenger aircraft.

The mode shift described in this alternative may not be readily achievable without shifting some shipments entirely to the truck mode, but, for the purposes of this comparison, that possibility will not be considered. Rather, it is assumed that the required coverage can be achieved by the package airfreight lines that have begun to serve many parts of the United States. It should be noted that a shift to package airfreight would involve transport in smaller aircraft and therefore would result in greater exposure to crew members. However, because of the lack of quantitative information, this was not taken into account in the calculation.

No significant increase in package curie content has been postulated in this alternative to account for increased time between shipment and use. While it is expected that shipments will be slightly slower, the effect is not expected to be significant because the ground transport link is limited to 160 kilometers.

6.2.2.1 Radiological Impacts

The radiological impacts computed with this alternative are as follows:

Annual normal population dose	21,830 person-rem (2.64 LCF)
Annual LCFs from accidents	0.017 LCF
Annual probability of one or more early fatalities	9.12×10^{-4}

The decrease of 3,530 person-rem in annual normal population dose from the baseline case (Table 6-1) results from the elimination of the dose to airline passengers and attendants, although this decrease is partially offset by an increased dose to the surrounding population resulting from the increased secondary mode travel.

6.2.2.2 Nonradiological Impacts and Cost-Benefit Balance

If the secondary (ground) link is not considered, no significant additional nonradiological impacts result from this alternative other than the possibility of the increased costs required to serve outlying cities by package airlines. Some scheduling difficulties are likely as a result of fewer flights of all-cargo aircraft as compared to those of passenger aircraft.

However, the additional secondary mode distance required by this alternative is significant. The shift of all passenger aircraft shipments to cargo aircraft involves about 1.7×10^6 packages. Using the cost parameters introduced in Section 6.2.1, the increased secondary mode distance will cost $\$9.2 \times 10^6$. The 3,530 person-rem decrease in normal population dose is equivalent to only $\$3.5 \times 10^6$ savings at $1000 per person-rem. Thus, from a cost-effectiveness viewpoint, the alternative of shifting all passenger aircraft shipments to cargo aircraft does not appear desirable.

6.2.3 ALL ALL-CARGO AIR SHIPMENTS BY TRUCK

In this alternative, all-cargo air shipments in the 1985 baseline are transferred to the truck mode. The actual distance in the truck mode is estimated to be approximately the same as the airline distance. As in the first alternative, which considered the shift of both cargo aircraft and passenger aircraft shipments to the truck mode, this alternative would require that Mo-99 shipments contain about 10 percent more radioactivity than in the baseline case to make up for the Mo-99 that decays during the extra travel time required by the truck mode. An 80-kilometer average secondary van link was assumed for the additional truck shipments resulting from this alternative.

6.2.3.1 Radiological Impacts

The radiological impacts computed with this alternative are as follows:

Annual normal population dose	26,160 person-rem (3.16 LCF)
Annual LCFs from accidents	0.020 LCF
Annual probability of one or more early fatalities	9.28×10^4

Just as in the alternative shifting all air shipments to truck, this alternative results in an increase in annual normal population dose and an increase in LCFs over the baseline case (Table 6-1). However, the increase is not as great as in the previous alternative since fewer shipments are involved. The increase in normal dose is principally due to higher crew dose.

6.2.3.2 Nonradiological Impacts and Cost-Benefit Balance

In the discussion of the alternative shifting all air shipments to the truck mode, it was estimated that for an average size package (22.7 kg) traveling an average distance (1600 km) the truck mode rate would be lower by $10.11 per package. This shift of 1.4×10^5 packages from all-cargo aircraft to truck would be expected to result in an annual saving of about $\$1.4 \times 10^6$ based on this rate difference. Since the secondary mode distance for trucks is 80 kilometers per shipment while 160 kilometers per shipment are estimated for all-cargo air shipments, an additional saving of $\$7.7 \times 10^6$ would be realized from the decreased secondary mode travel (using the same secondary mode assumptions as in Section 6.2.1). The cost would be an additional 800 person-rem population dose from normal transport and an additional 0.003 LCF from accidents, which is a dollar equivalent of $815,000 per year. Thus, this alternative, as well as the one in which all air shipments are shifted to truck, appears to be cost effective.

6.2.4 HIGH-HAZARD DISPERSIBLE MATERIAL BY TRUCK OR BY RAIL

Certain dispersible materials in the standard shipments model are more hazardous than others. This section considers the effect of requiring certain of the more hazardous of the 1985 standard shipments to be transported by truck or rail. The shipments considered are those dispersible materials with both a curie-per-package value greater than 100 and a rem-per-curie (inhaled) value greater than 10^6 The materials that meet these criteria are MF + MC (large quantity), Po-210 (large quantity), Pu-239B, Pu-239B (large quantity), U-Pu mixture, and recycle plutonium.

Shipments by aircraft could be shifted to either truck or rail without additional physical constraints. The packages used are typically the size of 206-liter (55-gallon) drums or smaller and weigh a few hundred kilograms or less. The materials' half-lives are sufficiently long that loss by radioactive decay during transport is not important. Because of tne value of plutonium as weapon material, a mode shift for plutonium (or any other special nuclear material) shipments in strategic quantities requires careful consideration of the security required for protection against theft or sabotage. Because that aspect of the problem is discussed in Chapter 7, consideration in this section will be confined to the radiological and other nonradiological aspects of the environmental impact.

Truck shipments of MF + MC, Po-210, and Pu-239 (1169 curies) are assumed to be made in exclusive-use trucks. Truck shipments of Pu-239 (1.2 x 10^6 curies) and U-Pu mixture are assumed to take place in Integrated Container Vehicles (ICV, see Section 5.2.3). For rail shipments of Pu-239 (1.2 x 10^6 curies) and U-Pu mixture, the ICV trailer is assumed to ride "piggyback" on the rail car.

6.2.4.1 Radiological Impacts

If the dispersible materials considered above are transported by rail only, the following results are obtained:

Annual normal population dose	25,260 person-rem (3.06 LCF)
Annual LCFs from accidents	0.019 LCF
Annual probability of one or more early fatalities	9.08 x 10^{-4}

If these materials are shipped by truck only, the radiological impacts are:

Annual normal population dose	25,400 person-rem (3.07 LCF)
Annual LCFs from accidents	0.019 LCF
Annual probability of one or more early fatalities	9.25 x 10^{-4}

Since the costs of ICVs cannot be evaluated at this time, a definitive statement on cost effectiveness cannot be made. However, the radiological changes resulting from this alternative do not appear to be significant.

6.2.5 ALL SPENT FUEL BY TRUCK

Truck casks for transporting irradiated fuel carry fewer fuel elements than rail casks. Thus, if all spent fuel were transported by truck, more shipments would be required. Considering that truck casks transport only a single element while rail casks transport seven fuel elements in a single cask, as much as a sevenfold increase in the number of shipments might be required under this alternative (Ref. 6-3).

6.2.5.1 Radiological Impacts

The radiological impacts computed with this alternative are summarized as follows:

Annual normal population dose	26,250 person-rem (3.18 LCF)
Annual LCFs from accidents	0.017 LCF
Annual probability of one or more early fatalities	9.12 x 10^{-4}

The 890 person-rem increase in normal dose ($9 x 10^5 equivalent) over the baseline case (Table 6-1) results from the increase in the number of truck shipments.

6.2.5.2 Nonradiological Impacts and Cost-Benefit Balance

The estimated costs for shipment of irradiated fuel by rail and by truck are listed in Table 6-2. It is evident from the table that the cost for transporting seven single-element casks by legal-weight truck is about the same as for transporting one 7-element cask by a unit train. It is assumed in this assessment that about 6.5 times as much spent fuel is carried in a rail cask as in a truck cask (Ref. 6-3).

TABLE 6-2

ECONOMICS OF RAIL-TRUCK MODE SHIFT FOR SPENT FUEL

Mode	Cost per Shipment*
Legal-weight truck	$10,000
Non-unit train**	45,000
Unit train**	73,000

*1200-1300 MWe reactor, 1600-kilometer shipment, 68 truck or 11 rail shipments per year.
**A unit train is one devoted exclusively to the carriage of a particular cargo, spent fuel in this case.

An additional consideration is the procurement cost of a truck cask versus that of a rail cask. Costs of three representative casks are shown on Table 6-3.

TABLE 6-3

COSTS OF REPRESENTATIVE SHIPPING CASKS

Cask Model	Use	Purchase Cost	Lease Cost
Transnucleaire TN-9	truck	$1 x 10^6	$1600/day + maintenance contract
General Electric IF 300	rail	$4 x 10^6	$1 x 10^6/year (4-5 year minimum)
National Lead NL 1024	rail	$2 x 10^6	$2400/day

Assuming a 3-day truck trip (plus 3 days return) and an 8-day rail trip (plus 8 days return) (Ref. 6-3) and 10 maintenance days per year, each truck cask can be used 59 times per year and each rail cask can be used 22 times per year. Using the 1985 baseline shipment information, 26 truck casks and 30 rail casks would be required at a purchase cost of $116 x 10^6 (assuming half the rail casks are purchased from each supplier) or an annual lease cost of $43 x 10^6 If all irradiated fuel were shipped by truck, 98 truck casks would be required at a purchase cost of $98 x 10^6 or an annual lease cost of $57 x 10^6.

Using these data and assumptions, the alternative of changing from the combination truck plus non-unit train shipments of irradiated fuel described in the 1985 standard shipments model to all truck shipments would cost an additional $\$14 \times 10^6$ in cask leasing charges, and the 5,768 total shipments would cost an additional $\$13 \times 10^6$ for shipping. When these costs are combined with the equivalent of $\$9 \times 10^5$ additional radiological costs, the alternative of shipping all irradiated fuel by truck is not cost effective to the extent of $\$28 \times 10^6$ per year.

6.2.6 ALL SPENT FUEL BY RAIL

As discussed above, rail casks have up to seven times the capacity of truck casks for irradiated fuel. The annual number of shipments would therefore be reduced if rail were the only mode used to ship irradiated fuel.

6.2.6.1 Radiological Impacts

The radiological impacts computed with this alternative are summarized as follows:

Annual normal population dose	24,900 person-rem (3.01 LCF)
Annual LCFs from accidents	0.017 LCF
Annual probability of one or more early fatalities	9.12×10^{-4}

The reduction of 460 person-rem per year in normal population dose as compared to the baseline case (Table 6-1) has a dollar equivalent of $460,000 per year.

6.2.6.2 Nonradiological Impacts and Cost-Benefit Balance

Using the data and assumptions in Section 6.2.5, the alternative of changing from the combination truck plus non-unit train shipments of irradiated fuel described in the 1985 standard shipments model to all non-unit train shipments is found to be cost effective. The 887 annual rail shipments would save $\$6 \times 10^6$ in cask leasing charges, $\$5 \times 10^6$ in shipping charges, and $\$5 \times 10^5$ in equivalent radiological costs. This alternative would therefore be cost effective by about $\$11 \times 10^6$ per year.

6.2.7 ALL FEASIBLE IRRADIATED FUEL BY BARGE

It has been suggested that a viable means of transporting irradiated fuel from nuclear power plants to reprocessing sites would be to use barges on the navigable waterways in and around the United States. A preliminary review was made of the feasibility of this alternative by examining the location of reactor sites as projected to 1985 (Refs. 6-4 and 6-5) and their proximity to navigable waterways (Refs. 6-6 and 6-7). This analysis revealed that approximately 74 percent of the projected 1985 nuclear generating capacity will be sited within 80 kilometers of navigable waterways (including the ocean), and 88 percent will be sited within 240 kilometers of navigable waterways. The only currently projected reprocessing site (Barnwell, South Carolina) is approximately 48 kilometers from navigable water.

If it is assumed that the only barge shipments would be those in which the total secondary link distance is less than 240 kilometers and if shipments through the Panama Canal are excluded, approximately 48 percent of the 1985 projected total MWe (71 percent of the sites) could be serviced by barge. Under these assumptions, the average distance by barge would be about 3500 kilometers, and the average distance by secondary mode (truck) would be about 130 kilometers. This would amount to 212 barge shipments per year, each barge carrying two rail casks.

6.2.7.1 Radiological Impacts

If it is assumed that the remainder of the plants are serviced by rail (460 shipments per year), the radiological impacts are as follows:

Annual normal population dose	25,040 person-rem (3.03 LCF)
Annual LCFs from accidents	0.017 LCF
Annual probability of one or more early fatalities	9.12×10^{-4}

If the remainder are serviced by truck (3,000 shipments per year) instead of rail, the results are:

Annual normal population dose	25,700 person-rem (3.11 LCF)
Annual LCFs from accidents	0.017 LCF
Annual probability of one or more early fatalities	9.23×10^{-4}

The first case results in a decrease of 320 person-rem per year ($320,000 equivalent) as compared to the baseline case (Table 6-1); the second case results in an increase of 340 person-rem per year ($340,000 equivalent).

6.2.7.2 Nonradiological Impacts and Cost-Benefit Balance

These radiological impacts must be considered in light of the cost necessary to accomplish this mode shift. The cost of a barge/tug combination is estimated by the American Waterways Operations, Inc., of Washington, D.C., at 0.0027 to 0.0041 dollars per tonne-kilometer (0.004-0.006 dollars per ton-mile). If the average irradiated fuel load is 1360 metric tons (1270 metric tons for the two loaded rail casks (Ref. 6-3) and 91 metric tons for auxiliaries, including generators, emergency equipment, etc), the water portion of an average trip will cost between $13,000 and $20,000. The secondary link will add an additional $1625 (at $6.25 per kilometer for truck and assuming two truck loads per barge load). Thus, the 212 barge shipments projected for 1985 would cost approximately $\$3.8 \times 10^6$. The additional rail or truck service to the remaining 29 percent of the sites would cost between $\$47 \times 10^6$ per year (remainder by truck) and $\$16 \times 10^6$ per year (remainder by train) for a total annual cost of between $19 million and $51 million. The annual cost of the 1985 baseline truck/rail mix is $\$46.4 \times 10^6$, using the truck/rail costs from Table 6-2 (trucks and non-unit trains). Thus, the barge alternative can provide a net saving of up to $27 million if the remainder is serviced by rail. These figures include only transport costs.

The barge alternative requires 46 rail casks and 51 truck casks (if the remainder goes by truck) or 67 rail casks (if the remainder goes by rail). In both cases, a 19-day one-way barge shipment (3520 kilometers at 8 kilometers per hour) plus a 10-day annual maintenance period is assumed. This results in a range of $67 x 10^6 to $76 x 10^6 for annual lease costs. The 1985 baseline lease cost is $43 x 10^6.

Thus, the overall nonradiological effect could be a saving of as much as $3 x 10^6 if the remainder is serviced by rail.

In addition to transport costs, various one-time site-specific costs may be required to give a site the capability to handle barge traffic. These costs would include dredging (at $1-$13 per cubic meter (Ref. 6-8)), pier construction (at $100,000 to $500,000, as estimated by Williams Crane and Rigging of Washington, D.C.), etc. These costs should not alter the apparent cost effectiveness of this alternative.

The fact that transportation costs are so much lower for barges than for other modes makes this alternative certainly worth additional investigation. Barge transportation of irradiated fuel may be a viable alternative, at least for some specific reactor sites, if not as a nationwide scheme.

6.3 OPERATIONAL CONSTRAINTS ON TRANSPORT

In this section, the effects of various alternatives designed to reduce risk by the use of constraints on transport operations are considered. No transport mode shifts are involved, nor are there any restrictions on packaging. Restrictions considered in this section would apply to carriers.

6.3.1 RESTRICT RADIOACTIVE MATERIAL TRANSPORT TO AVOID HIGH-POPULATION ZONES

In this alternative, using airports in suburban-population zones rather than major metropolitan airports and ground link routing around cities is considered. An example of such a change would be using Ontario Airport in Ontario, California, in place of Los Angeles International Airport. This alternative is modeled by changing the fraction of travel in high-population zones for trucks, aircraft, and the associated van links. Travel fractions for trucks are changed from .05 urban/.05 suburban to .01 urban/.09 suburban; the corresponding fractions for aircraft are changed from .02/.10 to 0/.12 and, for vans, from .4/.6 to .2/.8. If aircraft routes are chosen to avoid high-population-density zones, the radiological risk resulting from aircraft accidents would be reduced since most airplane accidents occur in the vicinity of airports during takeoff or landing (Ref. 6-9) and since the consequences of air or ground accidents are more severe if they occur near urban centers. However, most destination points are in or near cities, so that deliveries would still have to be made in urban areas. By appropriate controls, delivery vehicles could be routed to use beltways or outlying roads and avoid the central city as much as possible. For these reasons, the average secondary mode distances are assumed to increase to a minimum of 160 kilometers per shipment.

If shipments through high-population zones are restricted, the probabilities of occurrence of accidents with potentially large consequences, as discussed in Chapter 5, would be reduced.

6.3.1.1 Radiological Impacts

The radiological risks computed for this alternative are as follows:

Annual normal population dose	23,850 person-rem (2.89 LCF)
Annual LCFs from accidents	0.018 LCF
Annual probability of one or more early fatalities	9.49×10^{-4}

The increases in accident LCFs and early fatality probability over the baseline case (Table 6-1) are due to the substantially increased secondary mode distance, with its associated higher accident rate. The decrease in normal dose is due to the reduced exposure to on- and off-link populations resulting from travel in lower-population-density zones. This effect is partially offset by a slight increase in the secondary mode crew dose that results from higher secondary distances.

6.3.1.2 Nonradiological Impacts and Cost-Benefit Balance

Some additional considerations relating to this alternative are:

1. The choice of available air carriers could be restricted since not all major carriers, particularly cargo air carriers, provide comprehensive service to smaller airports.

2. An examination of the 1985 standard shipments model, with an additional 80 kilometers per shipment added to most scenarios, reveals an additional 320×10^6 kilometers in secondary mode travel. Using the same assumptions used in Section 6.2.1 for estimating secondary mode costs except for allowing for a higher average speed (72 kilometers per hour), the cost of the additional secondary mode travel resulting from this alternative is computed to be about $\$33 \times 10^6$ per year.

3. It should be noted that some major urban airports are already located in lower-population-density zones (e.g., Dulles International Airport).

This alternative is clearly not cost effective since there is a saving of $\$1.5 \times 10^6$ associated with the decreased radiological impact but a cost of $\$33 \times 10^6$ associated with the additional secondary mode distance.

6.3.2 ROUTE TRUCKS ON TURNPIKES OR INTERSTATE HIGHWAYS

The effect of this alternative is to reduce the truck accident rate by about 10 percent (Ref. 6-10).

6.3.2.1 Radiological Impacts

The lower accident rate causes a significant reduction in the annual accident LCFs and early fatality probability. The normal population dose is reduced from the baseline case (Table 6-1) because of less exposure to surrounding population. The radiological impacts computed for this alternative are as follows:

Annual normal population dose	24,290 person-rem (2.94 LCF)
Annual LCFs from accidents	0.015 LCF
Annual probability of one or more early fatalities	8.22×10^{-4}

6.3.2.2 Nonradiological Impacts and Cost-Benefit Balance

Turnpike routing is used by most long-haul carriers because limited-access highways usually provide the most direct routes and minimum driving time. However, the truck must still pick up merchandise, make deliveries, and refuel in populated areas. Thus, the nonradiological impacts of this alternative are considered negligible. Because of the net reduction in normal dose (equivalent to $\$1.1 \times 10^6$ per year), this alternative is considered cost effective.

6.3.3 RESTRICT TRUCK DRIVING TO GOOD WEATHER

The effect of this alternative would be a reduction in the truck accident rate by 10 percent (Ref. 6-10).

6.3.3.1 Radiological Impacts

The radiological impacts of this accident reduction below the baseline case (Table 6-1) are as follows:

Annual normal population dose	25,360 person-rem (3.07 LCF)
Annual LCFs from accidents	0.015 LCF
Annual probability of one or more early fatalities	8.21×10^{-4}

6.3.3.2 Nonradiological Impacts and Cost-Benefit Balance

Restricting trucks to good-weather driving has the potential problem that a truck could be forced to stop for several days to wait for clear weather. Increased warehouse storage, schedule delays, and loss of additional radioactive material by decay would result. The costs associated with these nonradiological impacts would appear to outweigh the reduction in accident risk.

6.3.4 RESTRICT TRUCKS CARRYING RADIOACTIVE MATERIALS TO A MAXIMUM SPEED OF 72 KM/HR (45 MPH)

Restricting trucks to a lower speed limit (for instance, 16 kilometers per hour below posted limits) reduces the highway accident rates by about 5 percent (Ref. 6-10).

6.3.4.1 Radiological Impacts

The computed radiological impacts are as follows:

Annual normal population dose	26,770 person-rem (3.24 LCF)

Annual LCFs from accidents	0.016 LCF
Annual probability of one or more early fatalities	8.67×10^{-4}

The accident risk is reduced only slightly from the 1985 baseline case (Table 6-1). However, since truck shipments take longer, the dose received by people living along the highway and by people sharing the highway with such trucks is increased.

6.3.4.2 Nonradiological Impacts and Cost-Benefit Balance

A nonradiological impact of this alternative would be the additional travel time required. In the 1985 standard shipments model, the 2.7×10^9 annual truck kilometers traveled at 72 kilometers per hour rather than 89 kilometers per hour would require an additional 7.2×10^6 hours per year. Assuming each shipment requires two drivers at $5 per hour, $72 x 10^6 in additional salaries would be required annually. The costs might be partially offset by a small decrease in operating expenses resulting from improved fuel consumption and reduced maintenance. Since all trucks would not be affected, law enforcement officials would be hampered in their ability to enforce the reduced speed limit. The increase in normal population dose of 1410 person-rem corresponds to an additional cost of $1.4 x 10^6 per year. This alternative does not appear to be cost effective.

6.3.5 RESTRICT TRUCKS FROM TRAVELING ON WEEKENDS

Prohibiting intercity truck travel on weekends provides a significant reduction of 50 percent in truck accident rates (Ref. 6-11).

6.3.5.1 Radiological Impacts

The resulting radiological impacts are as follows:

Annual normal population dose	25,360 person-rem (3.07 LCF)
Annual LCFs from accidents	0.0074 LCF
Annual probability of one or more early fatalities	4.62×10^{-4}

Although the normal dose is unchanged from the baseline case (Table 6-1), the accident LCFs and the early fatality probability are substantially reduced. In the analysis of this alternative, it is assumed that secondary mode transport is not restricted to weekdays so that the air and rail shipping modes continue to be served.

6.3.5.2 Nonradiological Impacts and Cost-Benefit Balance

Prohibition of weekend truck travel might prove to be a burden to radiopharmaceutical shippers and users since a large number of short half-life isotopes are shipped on Saturday evening to arrive for use on Monday morning. If these shipments had to be made on Friday instead of Saturday evening, an increase in the amount of material shipped would be required in some cases to allow for additional radioactivity decay. The package TI values would be increased and more shielding required. In order to circumvent this problem, a restructuring of radiopharmaceutical use by physicians might be possible.

The monetary equivalent of this reduction in accident LCFs would be $75,000 per year. This relatively small benefit would probably be offset by the cost of equipment "dead time" on weekends and holidays. Since this type of restriction would prevent shipment roughly 30 percent of the time, exclusive-use vehicles, special loading equipment, etc., would be idle. In addition, if a shipment were only halfway to its destination when the weekend arrived, temporary storage would be required and thereby add to the population dose. Thus, this alternative is not considered cost effective.

6.3.6 RESTRICT IRRADIATED FUEL SHIPMENTS TO SPECIAL TRAINS ONLY

The Association of American Railroads has recommended that shipments of irradiated (or spent) fuel be made in special trains the significant characteristics of which are as follows:

1. No freight other than the spent fuel casks is carried.

2. Special trains travel at speeds not faster than 56 kilometers per hour (35 mph).

3. When a special train transporting an irradiated fuel cask passes or is passed by another train, one of the trains is to remain stationary while the other train passes at a speed not faster than 56 kilometers per hour.

At present, irradiated fuel shipments by rail are handled by ordinary freight trains in which other freight accompanies the irradiated fuel. For ERDA irradiated fuel shipments, the railcar carrying the irradiated fuel cask is usually placed at the rear of the train just in front of the caboose.

Items requiring excess clearance or having excess weight are currently transported by special trains. To date, we know of only one accident involving special train service, and it caused no damage to the lading and no injuries. There have been no railcar accidents involving irradiated fuel shipments by regular train out of a total of nearly 2000 shipments (Ref. 6-12). Thus, an assessment of the advantages of special trains as opposed to regular trains for irradiated fuel shipments on the basis of past accident experience is not possible since there are insufficient accident data to use for the comparison.

In a special ERDA study (Ref. 6-12) on the safety of special trains, the conclusion, based on regular freight train accident data, indicated that the maximum reduction in the freight train accident rate resulting from a 56-kilometer-per-hour speed limitation is 19 percent. A "train accident" was defined as one that resulted in more than $750 damage to railroad equipment, truck, or roadbed. A 50-percent reduction in the number of serious accidents (those resulting in more than $75,000 damage) was determined to be the maximum reduction possible.

However, the direct application of accident rate data for ordinary freight trains to special trains overlooks some very important points mentioned in certain comments on the draft version of this document. Some of these points, which should be considered in evaluating the advantages of special trains, are the following:

1. With special trains, less damage is likely if an accident does occur. Irradiated fuel casks are designed to withstand a 9.1-meter drop onto an unyielding surface; real impacts occurring in accidents involving special trains would be less severe since the speeds are less than 56 kilometers per hour and real, rather than unyielding, surfaces are involved. Crush forces would also be expected to be less than for regular trains since only a few railcars are involved and no other freight is carried. No prolonged fires would be expected since no flammable freight is transported along with the shipment.

2. A serious derailment would be less likely because of the shorter train length. Not only are there fewer cars to become derailed but the entire train may be kept under constant surveillance from both the caboose and the engine. Should one of the cars become derailed, the train crew can promptly note the occurrence and take immediate action to stop the train, probably before the car overturns or other serious damage occurs. The train can also be stopped much more quickly because of the shorter length.

3. Fewer switching mishaps would be expected because there is much less switching. No switching of the irradiated fuel car would be required and the train could proceed to its destination without intermediate switching because no other freight is carried. The reduction in the amount of switching required would also decrease the doses received by brakemen and others who carry out the switching operations.

4. Cleanup operations, should major derailment occur, might be easier if the accident involved a special train. Special railroad cranes of large capacity would be required to rerail a heavy car carrying a spent fuel cask. The crane itself would usually have to be transported to the accident site by rail, and cleanup time would probably be less than that for a major derailment of a regular freight train. For a regular train, more debris would probably have to be removed in order to reach the spent fuel car.

5. The actual transit time of the spent fuel cask is likely to be quite a bit less than it would be in regular train service. In an example cited in one of the comments to the draft version of this document, an actual special train shipment of three casks containing nuclear cores from Proviso, Illinois, to Council Bluffs, Iowa, took less than 16 hours. In a detailed accounting of the same shipment made by regular train service, the commenter estimated that the shipment would have taken more than 70 hours, most of which time is spent in holding or switch yards (Ref. 6-13)

Nevertheless, the actual reduction in both normal and accident risks in 1975, had all rail shipments of spent fuel been handled by special train service, is negligible because the shipments of spent fuel by rail in 1975 contributed only 0.08 percent of the normal risk and 0.1 percent of the accident risk. Thus, even if both risks were reduced to zero, there were so few irradiated fuel shipments by rail in 1975 that the risk reduction would have been insignificant.

In 1985, however, 652 shipments of irradiated fuel by rail are expected. Assume that, under special train service, the accident risk could be reduced to zero. The accident risk from spent fuel shipments by regular train in the 1985 baseline is 2.5 x 10^{-4} LCFs per year. Thus, under the assumption of no accidents with special trains, the total accident risk would be reduced by 2.5 x 10^{-4} LCFs per year. Now consider the cost effectiveness of this alternative by comparing the additional cost for special train service to savings in cleanup costs following an accident with regular train service and to the radiological benefits.

An irradiated fuel cask for rail shipments is estimated to carry 3.2 MT of irradiated fuel (Ref. 6-3) and to contain the following amounts of releasable radioactivity, as discussed in Appendix A: 11,000-Ci Kr-85, 0.14-Ci I-131, and 1280 Ci of other fission products. Using the release fraction model and accident probabilities discussed in Chapter 5, it is estimated that accidents of severity greater than or equal to category V would result in 100 percent release of these quantities and that the probability of such a rail accident with regular train service is about 1.86 x 10^{-9} per kilometer. For the 1985 level of irradiated fuel shipping activity by rail (652 shipments per year at 750 miles per shipment), the annual probability of an irradiated fuel accident of sufficient severity to release 100 percent of the releasable contents would be such that one accident might be expected about every 700 years. A category IV irradiated fuel railcar accident might be expected once every 76 years but with a release of only 10 percent of the releasable contents. A category III accident might be expected once every 7.6 years with a release of only 1 percent of the releasable contents. The decontamination costs for cleanup of the fission products only for these accidents are determined from Figure 5-13 and listed in Table 6-4.

It is estimated (Ref. 6-14) that each accident involving a release, regardless of its severity, results in a loss of the use of mainline track during cleanup for 5 days. At an estimated cost of $2000 per hour, this amounts to $240,000 per occurrence. Amortizing this figure over the average occurrence periods in Table 6-4 for each accident category and summing all accident categories involving a release result in an average annual cost of $35,000 per year.

Thus, assuming that all rail shipments of irradiated fuel in 1985 were made by special train and that special train service did, in fact, reduce to zero the probability of an accident of sufficient severity to release radioactivity or cause partial loss of shielding, the annual savings would be the sum of the amortized annual decontamination cost, the annual cost for loss of mainline track, and the accident LCF dollar equivalent ($2000 per year) for a total of $6.6 x 10^5 per year. Assume, in addition, that the use of special trains also reduced to zero the normal dose (0.036 LCF per year) resulting from irradiated fuel rail shipments in 1985 because of reduced handling and storage time. An additional saving of 0.036 LCF per year, or equivalently, $300,000 per year would result. The total savings would be about $1 x 10^6 per year.

The extra cost to transport spent fuel by special train rather than regular train is computed by using the cost estimates made in the ERDA study (Ref. 6-12): $15.60 per kilogram of spent fuel by regular train and $24.80 per kilogram of spent fuel by special trains. These figures are for a 1740-kilometer shipment and assume two casks per shipment in the case of special trains for optimum cost effectiveness. The cost for shipping a cask carrying 3.2 metric tons of irradiated fuel is $49,920 by regular train and $79,360 by special train. The annual additional cost for the 652 rail casks to be transported by special train in 1985 is ($79,360 - $49,920) x 652 = $19.2 x 10^6

TABLE 6-4

ESTIMATED FREQUENCIES OF OCCURRENCE AND DECONTAMINATION COSTS FOR RAILCAR ACCIDENTS INVOLVING IRRADIATED FUEL SHIPMENTS BY REGULAR TRAIN SERVICE IN 1985*

Accident Severity Category	Average Frequency of Occurrence (1 accident per)	Fission Product Release (curies)	Decontamination Cost ($$10^6$)**	Average Decontamination Cost per year ($)
I, II	1.7 years	0	0	0
III	7.6 years	12.8	1.1	1.45×10^5
IV	76 years	128	20	2.63×10^5
V,VI,VII,VIII	700 years	1280	150	2.14×10^5
TOTAL				6.22×10^5

*652 shipments per year at 1200 kilometers per shipment.

**Assuming all accidents occur in suburban zone.

When this cost is compared to the annual savings calculated under the assumption that special train service completely eliminates the accident risk and normal population dose, it does not appear to be a cost-effective alternative. The annual additional cost is about 19 times the annual savings.

The calculation for annual decontamination costs with regular train service is made under the assumption that all accidents would occur in suburban areas. An examination of Figure 5-13 reveals that the decontamination costs for urban areas would be approximately the same. If all accidents occurred in rural areas, the decontamination costs would be substantially reduced and make the use of special trains still less cost effective. Furthermore, since special trains probably would not completely eliminate the normal dose and accident risk of spent fuel shipments by rail, the 19:1 cost-benefit ratio is probably a minimum; the actual ratio is probably even greater.

6.3.7 ENVIRONMENTAL PROTECTION AGENCY RECOMMENDATIONS OF 0.5 MREM PER HOUR MAXIMUM RADIATION AT SEAT LEVEL IN PASSENGER AIRCRAFT

The analysis of maximum radiation dose to passengers performed in Chapter 4 was based on a maximum average dose rate of 1.3 mrem per hour in the rear third of a fully loaded passenger aircraft. The U.S. Environmental Protection Agency has recommended that the maximum radiation dose at seat level in the passenger compartment be limited to 0.5 mrem per hour (Ref. 6-15) in order to minimize individual radiation dose. Three approaches for achieving this goal were suggested: (1) additional shielding of packages, (2) placement options on aircraft, and (3) modified shipping procedures. While any of the three approaches would reduce the maximum individual dose, only additional shielding that resulted in a reduction in the total TI transported annually would be effective also in reducing the annual normal population dose. Spacing of packages or reducing the TI allowed on passenger aircraft would not reduce the total TI transported and would therefore result in no change in the normal population dose.

In Chapter 4, it was estimated that an individual who flies 500 hours per year could receive 108 mrem per year from the radioactive material on board. If the radiation level were limited to 0.5 mrem per hour, his annual dose would be reduced by the factor 1.3/0.5 = 2.6 to a dose of 42 mrem per year.

6.3.8 AIRPORT PACKAGE MONITORING

The effects of abnormal transport occurrences within normal transport, i.e., those occurrences that resulted in release of radioactive material or excessive exposure but that were not the result of a vehicular accident, were discussed in Chapter 4. The Federal Aviation Administration has proposed that airline personnel be required to monitor radioactive material packages presented to them for shipment before they are loaded onto the aircraft. It is suggested that this procedure might eliminate unnecessary exposure of passengers, attendants, and crew resulting from damaged, defective, or improperly packaged materials.

Airport package monitoring would probably have prevented only one of the 12 releases reported to the Department of Transportation during the period 1971-1975 in incidents involving aircraft shipments of radioactive materials. In this one incident, a source was improperly positioned in its container, and the shipper's monitoring system failed to detect the error. Most of the other incidents involved packages damaged by handling operations during transit.

Most aircraft incidents involve Type A packages and, if such a package were to completely lose its shielding, the radiation level at 3 meters from the package would be less than 1 rem per hour since this is one basis upon which Type A limits are determined (see Chapter 2). Assuming that such a package were inadvertently placed on an aircraft carrying 60 passengers for a 2-hour flight, the total population dose would be 120 person-rem if the average dose rate in the cabin were 1 rem per hour. Assuming such incidents occurred only once every 5 years, as the limited experience would indicate, the average additional population dose would be about 25 person-rem per year or less than 0.1 percent of the total annual dose in 1985. At $1000 per person-rem, the dollar equivalent would be $25,000 per year. If the monitoring of the estimated 1.7×10^6 packages in 1985 were to be handled by freight handlers in addition to their other work, if each monitoring required approximately 30 seconds, and if freight handlers were paid $3 per hour, the additional cost would be $42,000. The monitoring procedure itself would add about 30 person-rem per year to the normal dose, assuming 30 seconds to monitor one package and an average radiation level of 2 mrem per hour experienced by the person monitoring the package. Thus, this alternative does not appear to be cost effective.

6.4 RESTRICTIONS ON MATERIAL FORM, QUANTITY SHIPPED, OR PACKAGING

The physical and chemical form of the radionuclides transported can strongly influence the amount of material released in an accident and the pathway to eventual radiation exposure of man. Restricting the maximum quantities of radioactivity allowed on a vehicle limits the amount of material available for release in an accident and hence the magnitude of the consequences.

6.4.1 RESTRICTING THE PHYSICAL AND/OR CHEMICAL FORM OF SHIPPED MATERIAL

As noted in Chapter 5, the release of dispersible alpha-emitting isotopes in an accident presents an inhalation hazard since lung deposition may occur for particles having aerodynamic diameters of less than 10 micrometers. Larger-diameter particles have a much smaller probability of pulmonary deposition and, consequently, do not constitute as severe a health hazard to man. The consequences of an accident are directly proportional to the respirable fraction of the material released.

A fabrication technique for production of fuel containing plutonium to be used in reactors involves precipitation of the oxalate and calcination to produce PuO_2 powder. The effect of calcining temperature on particle size distribution is shown in Figure 6-1. It should be possible to control the respirable fraction by controlling the calcining temperature. Another possible method of reducing the quantity of respirable material available for release in an accident is pelletizing the PuO_2 powder prior to shipment. It might be possible by either technique to reduce the respirable fraction of particles released in an accident to 1 percent of the total quantity shipped. These techniques might also be applied to other high-hazard materials such as polonium.

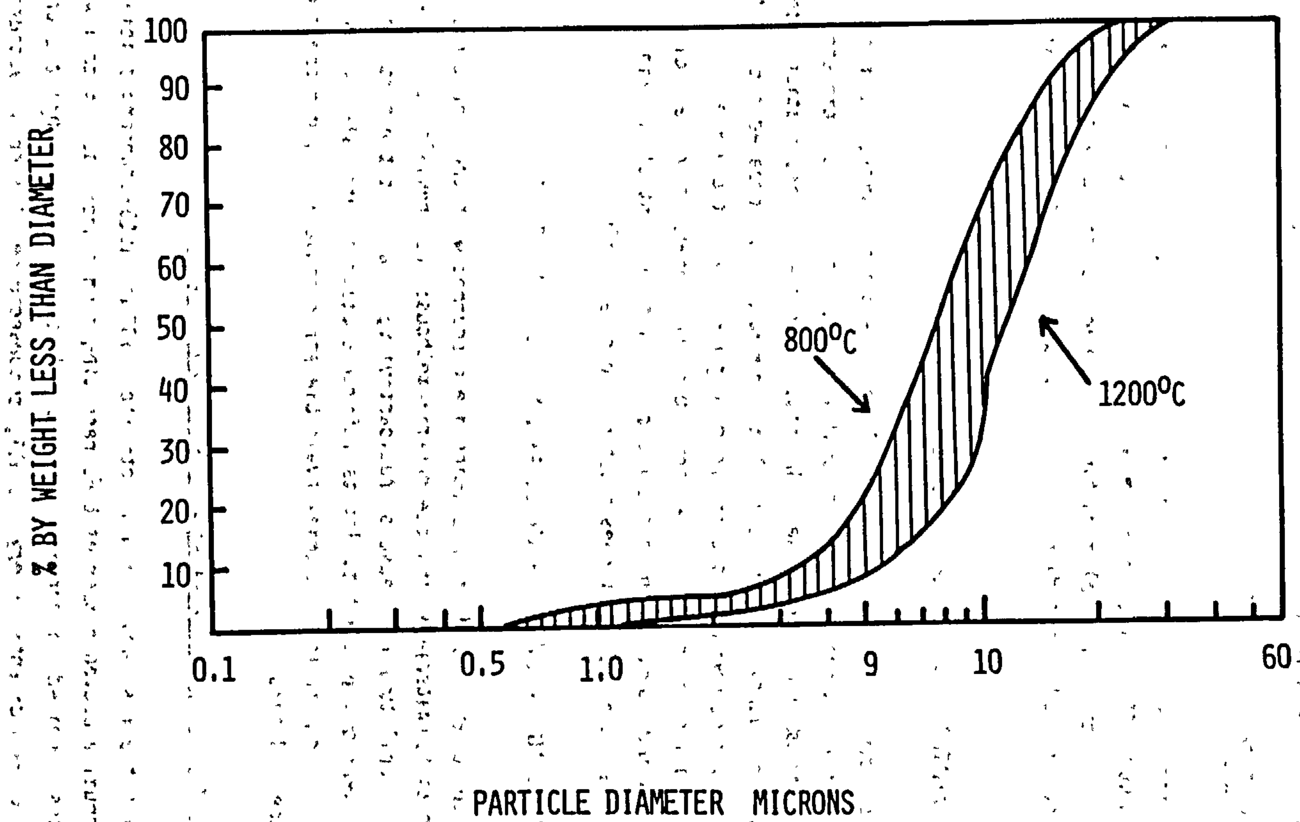

FIGURE 6-1. VARIATION IN PLUTONIUM DIOXIDE PARTICLE SIZE DISTRIBUTION FOR A RANGE OF CALCINING TEMPERATURE BETWEEN 800°C AND 1200°C (Ref. 6-16).

Assuming the respirable fractions for high-hazard dispersible materials (as defined in Section 6.2.4) are limited to 1 percent (as opposed to 20 percent in the baseline case), the annual radiological effects are as follows:

Annual normal population dose	25,360 person-rem (3.07 LCF)
Annual LCFs from accidents	0.012 LCF
Annual probability of one or more early fatalities	8.88×10^{-4}

The annual normal dose is unchanged from the baseline case (Table 6-1) by this alternative. However, the accident LCF is reduced by 0.005 LCF per year or, equivalently, $41,000 per year. In addition, there is a substantial reduction in the worst-case accident consequence for the large shipments considered. Depending on process modification costs, this alternative may be cost effective.

6.4.2 RESTRICTING MATERIAL SHIPPED PER VEHICLE

Assuming the same amount of material would be transported anyway, the reduction of the amount allowed on any given vehicle would result in more shipments and therefore in the possibility of more accidents involving those shipments. Increased transportation costs and, for shipments of strategic quantities of special nuclear material, increased security costs would result from this restriction without a corresponding reduction in the annual population dose or in the risk resulting from accidents. However, the consequence of any one accident, should it occur, would be reduced in proportion to the reduction of the amount of material on the vehicle. From a risk viewpoint, the alternative does not appear cost effective.

6.4.3 REVISING PACKAGING STANDARDS, PACKAGE QUANTITY LIMITS, AND TI LIMITS

The alternatives considered in this section are concerned with the reduction in the risk of transporting radioactive materials by three general methods: (1) revising the packaging standards to ensure survivability (no release of radioactivity) in all but the most extreme accident conditions, (2) lowering the quantity limits for radioactive materials packages and thereby limiting the amount of radioactive material available for release in any given accident, and (3) lowering the package TI limits.

6.4.3.1 Revising the Packaging Standards for Type B Containers

The results of the risk analysis for both the 1975 and 1985 standard shipments models showed that the annual expected number of LCFs resulting from accidents is much lower than that expected from doses received in normal transport. However, even though the probability of occurrence of a severe accident is very small, the consequence of such an accident could be large. For this reason, alternatives that reduce the amount of radioactive material dispersed in an accident are considered.

Since it is generally acknowledged that current packagings are better than the regulatory standards require, new packaging standards could be introduced that would, in effect, require that all new packaging designs be at least as good as those currently in use. Such an action would not result in a decrease in risk due to accidents but would ensure that the risk would not increase as a result of the introduction of new packagings inferior to present ones.

To see the effect of packaging standards revisions, a different release fraction model is considered. It postulates that all Type B packagings are constructed to match the 1985 plutonium packaging criteria discussed in Chapter 5, i.e., only a 1-percent release would occur in a class VII accident and only a 10-percent release would occur in a class VIII accident.

The annual radiological risks if this alternative were implemented are as follows:

Annual normal population dose	25,360 person-rem (3.07 LCF)
Annual LCFs from accidents	0.010 LCF
Annual probability of one or more early fatalities	1.05×10^{-8}

Both the accident LCF figure and the annual early fatality probability are reduced significantly from the baseline case (Table 6-1).

The reduction in annual accident LCFs is equivalent to $58,000 per year. Recent tests of plutonium shipping containers (Refs. 6-17 and 6-18) indicate that presently used plutonium packagings may already have the required level of accident resistance called for in this alternative. Further consideration of this alternative would require an assessment of the level of accident resistance of the designs of all Type B packagings now in use.

6.4.3.2 Lowering the Package Quantity Limits

A second possible method of risk reduction considered in this section is lowering the package quantity limits. Such action would reduce the amount of radioactive material per package available for release, and, if the same amount of shielding were used, the TI per package would also be reduced. However, unless a package TI reduction were required along with the quantity reduction, it would probably be more cost effective to reduce the amount of shielding in order to lighten and reduce the cost of transporting an individual package. Consequently, the same total amount of material would continue to be transported, but in a larger number of packages. Thus, there would be an increase in the annual expected number of LCFs. However, the risk of early fatalities might be reduced.

With the TI per package remaining the same but a larger number of packages transported, the number of TI transported annually would be increased, and the routine exposure due to normal transport would be increased accordingly. Since normal transport accounts for over 90 percent of the risk in the 1985 baseline, the total risk would be substantially increased over the baseline case (Table 6-1).

If the action lowering the quantity limits were accompanied by a corresponding requirement to reduce the package TI by the same proportion, the total TI transported annually would be unchanged. In this case, there would be no change in either the accident or normal contribution to the risk, assuming, as before, that the total quantity of radioactive material transported annually remains the same. The net effect would be to transport the same quantity of radioactive material per shipment and per vehicle, except in a larger number of packages. In either case, shipping costs would be higher, particularly in the case where the action is accompanied by a required reduction in TI because the total weight transported annually would be significantly higher. Higher costs with no change in annual LCFs indicate an unfavorable cost-benefit ratio.

6.4.3.3 Lowering the Package TI Limits

The final possible risk-reduction method considered in this section is lowering the package TI limits. Current standards allow up to 10 TI for packages with a Radioactive Yellow III label. The reduction of the package TI can be accomplished by either or both of the following methods·

1. A reduction of the quantity of material per package.

2. An increase in the amount of shielding used per package.

The first method was discussed in the preceding paragraphs and was shown to produce, at best, no change in the total annual risk. The second method, an increase in the amount of shielding per package without reducing the quantity of material per package, could result in a reduction in the number of TI shipped annually and in a corresponding reduction in the routine risk in normal transport. The effect of reduction in the maximum allowable package TI on the annual risk of normal transport would depend on the amount of the reduction and on detailed information concerning current TI per package values. The current effective radiopharmaceutical industry limit is 3 TI per package (Ref. 6-19). Radiopharmaceuticals constitute a large portion of the radioactive material shipments and, as a result, make a significant contribution to the annual risk. A reduction in the 10-TI package limit by a factor of two or three is estimated to have very little, if any, effect on the overall risk since it appears that most package TIs for other than exclusive-use shipments are already at or below that level.

A previous study (Ref. 6-19) has compared the effects of package limits of 10, 5, and 1 TI with the effective present limit of 3 TI for transporting radiopharmaceuticals by passenger aircraft. The results showed that when the cost-benefit ratios are considered, the 5-TI limit is most cost effective, and a TI limit of 3 exceeds the point of cost effectiveness by a substantial margin. However, a TI limit of 1 was found to result in costs exceeding benefits by a factor of four.

Therefore, just as currently used packagings are much better than the standards require, the effective TI package limits are lower than required by the regulations. The TI limits could be lowered to the cost-effective level of 5, for example, without affecting current shipping practice significantly and with no change in the overall risk. The result of such an action would be to ensure that the present voluntary package limits are maintained. Unlike introducing new standards for packaging durability, lowering the TI limits from 10 to 5 would not require expensive container-qualification tests. A reduction of the TI limits to less than 3, however, may not be cost effective.

6.5 SUMMARY OF COST-EFFECTIVE ALTERNATIVES

A summary of the various alternatives considered in this chapter that appear to be cost effective is presented in Table 6-5. The alternative of shipping spent fuel by barge, where feasible, appears to be the most cost effective.

The analysis of alternatives performed in this chapter was done to determine which, if any, may be cost effective and therefore merit further study. A considerable number of alternatives were considered but none in the depth required for an environmental impact statement prior to actual implementation of the specific alternative.

TABLE 6-5

SUMMARY OF COST-EFFECTIVE ALTERNATIVES

Alternative	Applicable Paragraph	Annual Savings
All air shipments by truck	6.2.1	$\$18 \times 10^6$
All all-cargo air shipments by truck	6.2.3	$\$8.3 \times 10^6$
All spent fuel by rail	6.2.6	$\$11 \times 10^6$
All feasible spent fuel by barge (remainder by rail)	6.2.7	$\$3 \times 10^6$
Route trucks on turnpikes	6.3.2	$\$1.1 \times 10^6$
Restrict respirable fraction of high-hazard dispersible materials to 1.0%	6.4.1	*
Revise packaging standards for Type B containers	6.4.3.1	**
Lower package TI limits	6.4.3.3	***

*May be cost effective depending on the cost of process modifications.

**May be cost effective depending on development costs for new containers.

***May be cost effective depending on level of reduction.

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CHAPTER 7
SECURITY AND SAFEGUARDS

7.1 INTRODUCTION

The rapid growth of the nuclear power industry coupled with an increase in terrorist activities have increased concern over theft of nuclear materials, sabotage of nuclear facilities, and other associated acts of terrorism. The possibilities of illegal acts and the nature and extent of potential threats have been and are continuing to be examined by the NRC as part of the overall safeguards program described in Section 7.3. Countermeasures have been established to protect both fixed sites and nuclear material in transit.*

Two categories of material have been examined relative to the in-transit protection of the material against theft and sabotage: (1) special nuclear material (SNM) such as enriched uranium and plutonium and (2) radioactive isotopes and wastes such as cobalt-60 and spent fuel.

7.2 RADIOACTIVE MATERIALS - POTENTIAL FOR MISUSE

7.2.1 LOW ENRICHED URANIUM

Low enriched uranium, the fuel used in light-water-cooled power reactors, cannot be used directly to fabricate a nuclear explosive. Furthermore, the radioactivity of this material is so low that dispersal by manual means or acts of sabotage would not produce a significant radiological hazard.

Requirements for physical protection of shipments of low enriched uranium in transit are not specified in NRC regulations.

7.2.2 IRRADIATED (SPENT) FUEL

Irradiated fuel removed from light-water-cooled power reactors contains low enriched uranium, fission products, and plutonium and other transuranics. It is highly radioactive and requires heavy shielding for safe handling. Massive, durable containers (casks) weighing 25 to 100 tons are used for transport of the spent fuel assemblies (both by road and rail). The contained plutonium is not readily separable from the other radioactive materials.

*In March of 1974, specific requirements for the protection of significant quantities of strategic special nuclear material (SSNM) in transit in 10 CFR Part 73 became effective. In May of 1976, licensees were directed to provide additional protection for road shipments through the use of a separate escort vehicle and improved communications. In February of 1977, in order to formalize security measures currently being employed, license conditions were issued requiring the use of an armored transporter plus an escort vehicle and a minimum of five armed guards for the protection of road shipments.

The design features that enable the shipping container to withstand severe transportation accidents (e.g., multiplicity of heavy steel shells, thick dense shields, and neutron-absorbing jackets) also enable the containers to withstand attack by small arms fire and explosives. A massive rupture of the containers by mechanical means or high explosives that would result in the radioactive contents being ejected or removed is considered to be essentially impossible. Although unlikely, the possibility exists that the container could be breached to the extent that the gaseous inventory and a small portion of the solids would be dispersed into the atmosphere. For a release from a truck cask containing three PWR elements, the effects in a population density of 2000 people per square mile are calculated to be about 1 early death and about 220 latent cancer fatalities (Ref. 7-1).*

Spent fuel in transit is considered to be neither an attractive nor a practical target for theft or sabotage and is specifically exempt from the physical protection requirements of 10 CFR Part 73.

7.2.3 LOW-LEVEL WASTES

Soft waste material generated at nuclear reactors and associated fuel cycle facilities, e.g., contaminated paper and clothing, are compacted and placed (typically) in 55-gallon drums for shipment. Each drum may contain 500 pounds of compacted material with up to one curie of activation and fission products.

The low specific activity and low radiation levels allow the contaminated trash to be shipped without shielding. Because the radioactive contamination is bound on the compacted material, it is unlikely to be released in the event the drums are broken open by accident or criminal acts. Even if an entire truckload of 50 drums were to be consumed by fire, the amount of radionuclides that would become widely dispersed would be quite small. It has been estimated that as much as 99 percent of the 50-curie inventory would remain in the ashes, and only 1 percent or 0.5 curie (primarily cesium-137) would become airborne (Ref. 7-2).

Liquid fuel cycle and reactor wastes such as contaminated resins and sludges are dewatered, consolidated by mixing with concrete (or other solidifying agents), and placed (typically) in 55-gallon drums.

The majority of these drums contain less than 20 curies and are shipped as Type A packages. A small percentage contain up to 100 curies (average of 20 curies) and are shipped as Type B packages. The cemented, solidified form of the waste materials contributes significantly to the retention of the radioactive inventory in case of container failure.

If each container of a 50-drum Type A shipment of cemented wastes were broken open by acts of sabotage, the total activity released to the atmosphere would be quite small. (Reference 7-2 indicates that approximately 2×10^{-3} curies of gaseous and volatile fission products would become airborne.)

*For different population densities the effects would vary proportionately. However, no credit is given in the calculations to evacuation of downwind areas that could reduce these consequences by a factor of 10.

It would be extremely difficult to breach the Type B package to the extent of breaking open the inner container and exposing the solidified wastes. In the unlikely event this were to occur, approximately 0.2 curie of fission products (primarily cesium-134 and -137) would be released to the atmosphere for each 55-gallon drum ruptured (Ref. 7-2). For a 42-drum load, which would probably be the limit for a Type B truck shipment, the total activity released would be 8.4 curies. Because of the form of the material, it is unlikely that the presence of an open fire would significantly increase the activity that would become airborne.

The breach of the Type B package and the exposure of the cemented wastes would contaminate the transport vehicle and nearby ground and produce a radiation field. However, the hazard would be limited to the vicinity of the vehicle.

Because of the form of the materials and the relatively low levels of radioactivity, low-level wastes are considered unlikely targets for sabotage. Even if subjected to criminal acts, no major hazard would result.

7.2.4 HIGH-LEVEL WASTES

High-level wastes (HLW) generated from the reprocessing of spent reactor fuel, even though cooled for many years before shipment, have many of the same fission products found in the spent fuel but little plutonium. These wastes are intended to be solidified (e.g., in the form of a dense glass) for shipment and storage. They are highly radioactive and will require heavy shielding for safe handling.

HLW shipping casks would be similar in design to a spent fuel shipping cask and would have many of the same features (steel liners, lead or depleted uranium gamma shielding, a cooling system, neutron shields, and sacrificial impact limiters). The resistance to sabotage would be essentially the same as for a spent fuel cask; if either were breached by criminal acts, the consequences are estimated to be of the same order of magnitude.

High-level waste shipments are considered to be neither an attractive nor a practical target for theft or sabotage. (There are currently no HLW shipments and few if any are anticipated by 1985.)

7.2.5 NON-FISSILE RADIOISOTOPES (SMALL SOURCE)

Small-quantity shipments (less than 20 curies) have little potential for harm to the general public through misuse. Dispersal of the contents of a shipping container following a theft or by sabotage would result in a relatively minor localized contamination. (The radiation from an unshielded 20-curie source of cobalt-60 would be only about 25 R/hr at 1 meter. On the other hand, the radiation would be extemely hazardous to a terrorist who directly handled the source without intervening shielding.)

7.2.6 NON-FISSILE RADIOISOTOPES (LARGE SOURCE)

Large-quantity shipments (10 to 10^6 curies) may have a limited potential for endangering the public health and safety through misuse.

Containers used for the shipment of these amounts of material must meet DOT and NRC regulatory requirements for Type B or large-quantity packages. These packages are designed to prevent the loss or dispersal of the contents, to retain shielding efficiency, and to provide for heat dissipation under both normal transport conditions and specific accident damage test conditions.

The size, weight (which varies from hundreds of pounds to forty tons for a 500,000-Ci Co-60 source), and construction of these containers make theft a difficult endeavor and dispersal of the contents an impractical event. In addition, the high level of radiation associated with the isotopes prevents handling without mass shielding. If a shipping container were diverted, it would be almost impossible to use the contents to cause any significant harm other than through explosive breaching and subsequent dispersal of the contents.

If sufficient amounts of explosives are used, the possibility exists that the radioisotopes could be dispersed to the atmosphere (for gases or volatiles) or locally dispersed on the ground (for solids). Tables 5-12, 5-13, and 5-14 show the consequences of worst-case accidents for several large-quantity shipments of Po-210 and Co-60. It is believed that these results are representative of the possible effects of worst-case credible criminal acts during transport.

Although terrorists might perceive large-quantity shipments of non-fissile radioisotopes to be attractive weapons, the protection afforded by the shipping container and the high level of radioactivity of the contents make theft and dispersal difficult and deliberate manipulation very difficult. The consequences associated with worst-case acts of sabotage would not constitute a significant radiological hazard.

7.2.7 URANIUM HIGHLY ENRICHED IN U-235

Highly enriched uranium (uranium enriched to 20 percent or more in the U-235 isotope) could be used to fabricate a nuclear explosive and therefore has significant potential for misuse. Depending on their form, these materials could be used directly (e.g., U metal) or after processing (e.g., HTGR fuel).

Because of its low radioactivity, sabotage of U-235 would not, in general, constitute a threat to the general public. Conceivably, it might be possible to bring about criticality by actions involving both removal of neutron absorbers and rearrangement of the uranium materials. It certainly would be a dangerous task and probably would irradiate the perpetrator. If successful, the hazard, although dangerous, would be restricted to the general vicinity of the nuclear materials.

NRC regulations require that highly enriched uranium in quantities of 5 kilograms or more be protected against theft and sabotage in accordance with the physical security requirements of 10 CFR Part 73. Additional requirements have been established for fixed site and transport protection by license conditions. (These include requirements for the use of an armored transport vehicle that has a cargo compartment with barriers or containers that deter or delay penetration, a separate escort vehicle, and a minimum of five armed guards for road shipments.) Physical security requirements are not specified for quantities smaller than this amount.

7.2.8 PLUTONIUM AND URANIUM-233

Reactor grade plutonium and U-233* (like U-235) could be used to fabricate a crude nuclear explosive. Depending on their form, the plutonium or U-233 could be used directly (e.g., Pu or U metal) or after processing (e.g., Pu nitrate). In addition, because of their radioactivity, plutonium and U-233 are potentially hazardous, particularly when in the form of respirable aerosols. Therefore, for significant quantities of these materials, the potential exists for misuse both as illicit explosives and as dispersal weapons.

Plutonium and U-233 in quantities of 2 kilograms or more are protected against theft and sabotage in accordance with the physical security requirements of 10 CFR Part 73. Additional protection has been required at both fixed sites and in transit by specific license conditions as in the case of highly enriched uranium discussed earlier.

7.3 SAFEGUARDS OBJECTIVES AND PROGRAM

Safeguards are defined as those measures employed to deter, prevent, or respond to (1) the unauthorized possession or use of significant quantities of nuclear materials through theft of diversion and (2) the sabotage of nuclear materials and facilities. The NRC safeguards program has the general objective of providing a level of protection against such acts that will ensure against significant increase in the overall risk of death, injury, and property damage to the public from other causes beyond the control of the individual. To be acceptable, safeguards must take realistic account of the risks involved and of burdens on the public in terms of impacts on civil liberties, institutions, the economy, and the environment.

The following functional elements are utilized by the NRC to ensure effective protection of the radiological health and safety of the public and protection of the environment:

1. Consideration of the nature and dimensions of the postulated threat in the development of regulatory requirements

2. Imposition of safeguards requirements on the industry directed toward countering the postulated threat.

3. Licensing activities, including review of safeguards procedures proposed by industry, as required by regulations.

4. Inspection of safeguards implementation to ensure adequacy.

5. Enforcement of requirements through administrative, civil, or criminal penalties.

6. Administrative and technical support for response and recovery.

*There are currently no strategic quantities of privately owned U-233, and no shipments are expected in the next several years.

7. Confirmatory research related to the development and testing of methods, techniques, and equipment necessary to the effective implementation of safeguards.

8. Frequent program review in the light of industrial/technical or social/political changes to ensure that any needed revisions are made to the elements above.

Current programs are directed at protecting against theft or diversion of certain types and quantities of nuclear materials that could be used for nuclear explosives or contaminants and protecting against the sabotage of nuclear facilities and materials.

The Commission's regulations in 10 CFR Part 70 require a license in order to own, acquire, deliver, receive, possess, use, transport, import, or export special nuclear materials. The NRC publishes specific safeguards requirements for materials and plant protection in 10 CFR Parts 70 and 73 and carries out the following activities to ensure compliance:

1. Prelicensing evaluation of applicants' proposed nuclear activities, including safeguards procedures in the case of applicants for significant quantities of special nuclear material;

2. Issuance of a license to authorize activities subject to specific safeguards requirements; and

3. Inspection and enforcement to ensure that applicable safeguards requirements are met by implementation of approved plans.

The provisions in 10 CFR Part 73 include specific physical protection requirements that apply to licensees who ship 5 kilograms of U-235 (contained in uranium enriched to 20% or more), 2 kilograms of plutonium or U-233, or a weighted combination of these.

The NRC conducts inspections of a licensed plant and its related transportation links to ensure continued effective implementation of material control and physical protection requirements. Each licensee is required to afford the NRC opportunity to inspect the nuclear materials, to perform or permit the NRC to perform necessary tests of materials and equipment, and to make available any records pertaining to possession, use, or transfer of nuclear material.

If items of noncompliance or deficiencies are found in the implementation of safeguards requirements by the licensee, the licensee is instructed to take prompt corrective action and to inform the NRC of the results. The NRC has the authority to modify, suspend, or revoke licenses and to impose civil penalties on licensees for noncompliance with the items and conditions of the license.

Early in 1976, the NRC established an Information Assessment Team (IAT) for the purpose of determining in a timely fashion the credibility, seriousness, and immediacy of hazards associated with threats to nuclear facilities or transportation. This team is charged with the responsibility for receiving and reviewing all incoming threat notifications, performing multi-source correlation, assessing the validity of sources and data, judging the degree of seriousness, and recommending options for alternative courses of action. In the event that a threat escalates into an attempt to steal SNM or sabotage nuclear facilities or transportation, the IAT forms the nucleus of the NRC Incident Response Action Coordination Team (IRACT). This team is responsible for initiating, planning, and coordinating incident response actions.

7.4 PHYSICAL PROTECTION OF HIGHLY ENRICHED URANIUM AND PLUTONIUM DURING TRANSIT

7.4.1 INTRODUCTION

As noted in Section 7.2, the only radioactive materials that require physical protection against theft and sabotage during transit are strategically significant quantities of uranium enriched to 20% or more in the U-235 isotope, U-233, and plutonium. The potential for misuse of shipments of other radioisotopes is sufficiently low that no additional protection is presently believed necessary.

It is estimated that during calendar years 1977 and 1978 there will be less than 30 shipments per year of strategic quantities of uranium and plutonium in the commercial sector. Most of these will be transfers of UF_6 from Piketon, Ohio, and Oak Ridge, Tennessee, to O'Hare airport for export overseas.

The following paragraphs contain a description of current requirements (both regulations and specific license conditions) for physical protection during transit and an assessment of the adequacy of these requirements relative to a postulated threat consisting of an internal threat of one employee occupying any position and an external threat of a determined violent assault by several well-armed, well-trained persons who might possess inside knowledge or assistance.*

7.4.2 ROAD SHIPMENTS

Shipments are required to be made in a vehicle that has an armored cab with a crew of three armed guards and a cargo compartment that is constructed to resist penetration and delay entry. A separate vehicle with two additional armed guards must escort the transporter.

Communication requirements include radiotelephones in both vehicles for communication to the licensee, his agent, or the police, radios for intervehicle communication, and citizen band radios in both vehicles for use in emergencies.

Shipments are required to be made on primary roads during daylight hours. (If a trip is to extend into the night, a second escort vehicle with two additional guards is required.) Transfers from vehicle to storage, from one vehicle to another, and from storage to vehicle as well as material in storage must be monitored by guards who are equipped with communications to local police and who must keep the shipment under continuous visual surveillance.

*On the basis of intelligence and other relevant information available to the NRC, there are no known groups in this country having the combination of motivation, skill, and resources required to carry out an assault against a protected shipment or facility.

Many other specific requirements, such as requirements for vehicle markings, scheduled calls, guard training, route selection, notification of shipment, are contained in NRC regulations and license conditions.

The combination of five well-trained armed guards, armor protection, and penetration-resistant cargo compartments is considered adequate to withstand an assault by a small group for a prolonged period of time. The requirements for multiple means of communication and the restriction of travel to daylight hours on well-traveled roads are designed to ensure that local police forces would be notified and would be able to respond in time to seal off and neutralize the threat. (As noted above a second escort vehicle is required if travel extends into the night.)

The protection system does not necessarily fail even if the attack is conducted by a large force that outnumbers the guards. The margin of safety might be less and casualties perhaps higher. However, the capabilities of the local and state police relative to communication networks, area isolation, response force numbers, armament, and transportation provide protection against threats larger than that postulated.

The penetration-resistant transport vehicle provides resistance to penetration and containment against acts of sabotage directed at dispersal of the plutonium. It is estimated that, for a wide range of assaults, including road mines, gunfire, hand-carried explosives, and vehicle-to-vehicle and other crash environments, this type of vehicle would prevent wide-scale dispersal of the plutonium cargo. There is, of course, a practical limit to the protection against unlimited amounts of explosives. A trailer truckload of TNT (40,000 lb) detonated next to the transporter would cause massive damage to the vehicle and to the surrounding environment. The consequence of such a blast might exceed the consequences of the plutonium contamination.

Transfers or material stored while awaiting transfer (24 hours or less) are protected by armed guards. In addition, all U.S. airports and sea terminals used for transfer of SNM have security systems that provide control of access and a reserve of armed individuals that could respond to a security emergency.

Plutonium shipments in quantities less than 2 kilograms do not fall within the physical protection requirements of 10 CFR Part 73. The cutoff point was established at this level in order to provide a substantial margin of safety below the quantity of plutonium generally accepted as being required to construct an improvised nuclear explosive.

While this level is not directly related to risks associated with dispersal weapons, it can be shown that the possible consequences from dispersal of such quantities would be of the same order as malevolent use of chemical explosives and small compared to a nuclear explosion. (It has been estimated in Reference 7-3 that plutonium dispersed in a city having a high population density could result in one fatality for each 15 grams dispersed.)

The protection afforded to road shipment and storage in transit is considered to be as effective as that provided by ERDA (now DOE) during the transport of government-owned SNM.

7.4.3 RAIL SHIPMENTS

At present, no physical protection plans have been approved by the NRC for rail shipments, and no shipments of NRC-licensed SNM are being made using this mode of transport. In order for a security plan utilizing this mode to be approved, protection comparable to that currently afforded road shipments would have to be provided. Such features of the plan as guard strength and deployment, communications, armor, penetration resistance of the cargo compartment, and route selection would be assessed to ensure that the escort force could withstand an attack by a small group until police response was ensured. For plutonium shipments, the resistance to penetration or sabotage of the cargo compartment would be evaluated to ensure a level equivalent to that for road shipments.

7.4.4 SHIPMENT BY INLAND WATERWAYS

No physical protection plans have been approved by the NRC for shipment by inland waterway, and no shipments of NRC licensed SNM are currently being made using this mode of transport. A security plan for shipment by inland waterway would be approved only if the protection against assault and sabotage were equal to that presently applied to road shipments.

7.4.5 AIR SHIPMENTS

Shipments of strategically significant quantities of SNM are required to be made in cargo-only aircraft. SNM being transferred to or from such aircraft (including periods while in storage) must be protected by guards equipped with a capability for radio communications to either a local law enforcement agency or an air terminal guard force. Preplanned in-transit storage may not exceed 24 hours. Guard surveillance of the cargo compartment whenever the compartment containing SNM is open and observation of the aircraft until it departs are required.

The combination of assigned guards, communications to local police, and a reserve of armed airport security personnel stationed at the flight lines at major commercial airports provide significant protection against an assault or covert attempts by unauthorized personnel to board the plane. (The only air shipments currently being made or projected through 1978 are imports and exports at O'Hare airport. These flights are escorted by an unarmed employee or agent of the licensee. U.S. safeguards responsibilities in the transportation of nuclear materials for export end when the shipment is unloaded at a foreign terminal. The NRC regional offices inspect every import and export shipment for compliance with requirements.) The surveillance of the transfer onto the aircraft plus the normal preflight check of the cargo compartment by the flight crew make it unlikely a stowaway could board and occupy the aircraft undetected. An attempt at diversion of the aircraft by a member of the flight crew once airborne is considered to be unlikely.

Transport of plutonium by air presents a unique problem. If both the aircraft were damaged and the shipping container were breached during flight, the altitude and velocity of the aircraft might aid in the plutonium dispersal. Similarly, a high velocity crash of an aircraft might cause or contribute to the rupture of a shipping container and the scattering of the contents.

However, no shipments of plutonium by air will be licensed by the NRC (except for individual medical applications) until the Nuclear Regulatory Commission has certified to the Joint Committee on Atomic Energy of the Congress, as required by law, that a safe container that will not rupture under crash and blast-testing equivalent to the crash and explosion of a high-flying aircraft has been developed and tested.

7.4.6 SEA SHIPMENTS

Shipments of SNM by sea are conducted in accordance with physical protection provisions similar to those applied to air shipments. Guards equipped with radio equipment capable of communicating with local police or a nearby commercial guard force maintain surveillance over the SNM during transfer operations. Vessels are observed by these guards until they depart the harbor. Sea shipments are escorted by an unarmed employee or agent of the licensee. Ship-to-shore contact is made at least every 24 hours to relay position information and status of the shipment. It is considered unlikely that a shipment, while at sea, could be successfully diverted or sabotaged to the extent that a significant radiological hazard would result.

7.5 ALTERNATIVES

The present in-transit physical security requirements provide protection, at a minimum, against theft or sabotage by a postulated threat consisting of an internal threat of one employee occupying any position and an external threat of a determined violent assault by several well-armed, well-trained persons who might possess inside knowledge or assistance. This protection is the responsibility of and is supplied by the licensee or his agent and consists of privately owned facilities and equipment under the control of private guard forces.

Consideration has been given to using such other means of protecting SNM in transit as a Federal guard force, the ERDA transport system, Department of Defense escorts, and systems designed to withstand a larger, more violent assault. These alternatives are discussed below.

7.5.1 FEDERAL GUARD FORCE

The need for and feasibility of an NRC security agency to assume operating responsibility for security forces to protect the nuclear industry was the subject of a special review by the NRC in 1975-76 (Security Agency Study, Ref. 7-4). The principal conclusion was:

> "The study has found that creation of a Federal guard force for maintaining security in the nuclear industry would not result in a higher degree of guard force effectiveness than can be achieved by the use of private guards, properly qualified, trained and certified (by NRC). Analysis of the existing regulatory structure indicates that NRC can fulfill its responsibilities to assure adequate physical protection of licensed facilities and materials through stringently enforced regulations."

7.5.2 THE ERDA (DOE) TRANSPORT SYSTEM

The Security Agency Study also addressed the question of whether a Federal transport system was necessary for privately owned strategic special nuclear material. The study concluded:

> "With regard to shipping containers and transportation vehicles, the private sector can provide a level of security equivalent to that provided by the ERDA system which is responsible for transport of government-owned special nuclear material. Equivalent security can be provided by the private sector using drivers, guards and operating techniques under stringent standards now being established by NRC. Reliable and effective communications can be provided by a system such as the ERDA communication system if commercial carriers are required to use it."

The present level of transport protection provided by the licensed industry is considered to be comparable to that required by ERDA (now DOE). While the licensee (or transport company) does not always have the capability of communicating directly to a command and control center while in transit (as does the ERDA system), the use of radiotelephone, intervehicle radio, and citizens band radio combined with restrictions that normally limit travel to daylight hours on primary highways is considered adequate to provide timely notification of local police of a security emergency.

7.5.3 DEPARTMENT OF DEFENSE ESCORTS

The Posse Comitatus Act prohibits the use of Armed Forces for civil law enforcement, which would include protection of private property, unless expressly authorized by the Constitution or by statutes. None of the present authorizations would permit the use of Armed Forces personnel except in emergencies caused by civil disorder, calamity, or disturbance or when State authority has broken down or there is armed insurrection. Even if this legal impediment did not exist, there is no need or justification for using military forces and equipment to protect against the postulated threat. The physical protection deemed necessary to defeat this threat can and is being provided by the private sector.

7.5.4 PROTECTION AGAINST A HIGHER THREAT LEVEL

The NRC is continuously evaluating the nature and extent of potential threats against nuclear materials and facilities. The threat assessment program has developed the following information:

- The intelligence community has no evidence that there are groups in this country having the motivation, skill, and resources to attack either a fuel facility or a fuel shipment.
- There have been no assaults in this country against facilities or shipments with the specific intent to cause a radiological release or to steal nuclear material.
- To date, there is no evidence to indicate any loss by theft or diversion to unauthorized use of significant quantities of special nuclear materials.
- An examination of over 1200 acts of violence characterized as terrorism occurring in the decade 1965-1975 revealed that 97% were carried out by 6 or less people and 86% by 3 or less.

Since there is no identifiable threat, the decision as to the level or protection to be applied (or the magnitude of the postulated threat against which defenses are to be established) demands the use of subjective judgment.

Based on the above threat assessment, it is believed that the requirements placed on the licensees by NRC provide a capability to protect against the postulated threat and are in the public interest. For purposes of a planned review in a public rulemaking proceeding, NRC has under preparation proposed new regulations that have as their objective the achievement of safeguards that would counter hypothetical threats more severe than those postulated in evaluating the adequacy of current safeguards for licensed operations, including transportation activities. In addition, consideration is being given to the protection of material during anomalous occurrences such as unscheduled emergency stops enroute.

7.5.5 RESTRICTING TRANSPORT TO A PARTICULAR MODE

Regardless of the mode of transportation, adequate protection against theft and acts of sabotage that would result in a significant radiological hazard can be provided. For example, while it might be argued that air shipments (fixed wing or helicopter) made from secure terminal to secure terminal are better protected than are road-air-road or all-road shipments (the evidence is not conclusive that this argument is correct), this is not sufficient justification to prohibit transport by these latter two methods when it can be shown that they have sufficient physical protection.

7.6 CONCLUSIONS

- o Existing physical security requirements are adequate to protect, at a minimum, against theft or sabotage of strategic special nuclear materials (uranium enriched to 20% or more in the U-235 isotope, U-233, and plutonium) in transit by a postulated threat consisting of an internal threat of one employee occupying any position and an external threat of a determined violent assault by several well-armed, well-trained persons who might possess inside knowledge or assistance.

- o The level of protection provided by these requirements reasonably ensures that transportation of strategic special nuclear material does not endanger the public health and safety or common defense and security. However, prudence dictates that safeguards policy be subject to close and continuing review. Thus, the NRC is conducting a public rulemaking proceeding to consider upgraded interim requirements and longer-term upgrading actions. The objective of the rulemaking proceeding is to consider additional safeguards measures to counter the hypothetical threats of internal conspiracies among licensee employees and determined violent assaults that would be more severe than those postulated in evaluating the adequacy of current safeguards.

- o The use of the ERDA (now DOE) transport system is not, at this time, considered to be necessary for the protection of privately owned strategic special nuclear material because the present level of transport protection provided by the licensed industry is considered to be comparable to that presently required by ERDA (DOE). Similarly, the use of Department of Defense escorts is not presently needed to protect domestic shipments against the postulated threat because the physical protection deemed necessary to defeat this threat can and is being provided by the private sector.

- Shipments of radioactive materials not now covered by NRC physical protection requirements, such as spent fuel and large source nonfissile radioisotopes, do not constitute a threat to the public health and safety either because of their limited potential for misuse (due in part to the hazardous radiation levels which preclude direct handling) or because of the protection afforded by safety considerations, e.g., shipping containers.

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APPENDIX A
STANDARD SHIPMENTS MODEL

A.1 INTRODUCTION

The transportation of radioactive materials involves such a diversity of isotopes, package types, quantities of material, package radiation levels, and transport modes that a detailed consideration of every shipment becomes impractical. In order to realistically assess the radiological risk associated with the transportation of radioactive materials, it is necessary to select a finite number of shipment types that dominate the radiological risk.

The standard shipments model used in the draft version of this document was based on a 1972 shipper survey (Ref. A-1) extrapolated to 1975 and on interviews with a few major shippers. The results of a detailed 1975 shipper survey (Ref. A-2) were not available in time to be included in the draft document. The standard shipments model used in this document is much more extensive than the previous one and is based on the 1975 survey data. The purpose of this appendix is to illustrate the methods used to derive the various standard shipments models. In the remainder of this appendix, "the survey report" refers to the report of the survey data listed as Reference A-2.

In the 1975 survey, certain shippers completed "detailed questionnaires" while others completed "summary questionnaires." The detailed questionnaires requested information based on actual shipping records while the summary questionnaires requested information based on shipper estimates. Most major shippers, i.e., those known to ship large numbers of packages annually, and all special nuclear material licensees completed detailed questionnaires, although a few were missed and were sent summary questionnaires. Summary questionnaires sent to a cross section of licensees were intended to represent the entire licensee population on a sampling basis. Thus, the summary questionnaire data base was divided into two separate groups: one for minor shippers and the other for apparent major shippers. There exist, therefore, three data bases: one from the detailed questionnaires, one from the summary questionnaires completed by minor shippers, and one from the summary questionnaires completed by apparent major shippers. Each data base was extrapolated differently to include the entire shipper population. The set of standard shipments on which this risk assessment is based was determined from these three data bases.

Each standard shipment is specified by the isotope or material being shipped, the package type, the number of packages shipped per year, the average number of packages per shipment, the average quantity of material per package, the average transport index (TI) per package, the average distance traveled per shipment, and the primary and secondary transport modes.

A.2 COMPILATION OF STANDARD SHIPMENTS LIST

The selection of standard shipments was made as follows. First, groups of isotopes and materials were selected from Reports X.H,* XIII.H,* and XIV.H* of Reference A-2. The isotopes selected accounted for 97.9% of the total packages, 99.1% of the total kilometers, 97% of the total TI, and over 99% of the total curies or grams, as determined from the detailed questionnaires. All uranium-plutonium mixtures were combined into a single group with an average reactor grade plutonium content of 25% by weight.

Having selected the isotopes and materials that accounted for the vast majority of packages, curies or grams, TI, and kilometers in the detailed questionnaire data, it was necessary to determine the distribution of shipments according to package type and transport mode for each material. For example, one needs to know how many Type B packages of Co-60 were transported by truck. Such information was not directly obtainable from the survey report. Certain of the computer reports (I.D and II.D) gave the breakdown for each isotope according to package type, but not by transport mode, while others (X.A-G and XI.A-G) listed the breakdown by transport mode but not by package type.

In order to obtain a breakdown by both package type and transport mode, two tabulations were made. First, the number of packages of each isotope was listed by package type, independent of transport mode, using Reports I.D and II.D. Next, the number of packages of each isotope was tabulated according to primary transport mode, independent of package type, using Reports X.A-G and XI.A-G. Then, the two tabulations were combined to form a composite distribution of numbers of packages (extrapolated to account for the unsurveyed shipper population) as a function of both package type and primary transport mode. The results are shown in Table A-1. The primary uses of each isotope (M = medical, I = industrial, FC = fuel cycle, W = waste) are also included in the table.

Implicit in the tabulation of data in Table A-1 is the assumption that all packages of a given isotope have the same transport mode split, regardless of package type. This assumption was necessary in order to combine the package data and transport mode data. Thus, Table A-1 constitutes a first approximation to the breakdown according to package type and transport mode. An exception was made for Co-60 when it was noted that there were no reported aircraft shipments of Co-60 greater than 20 curies in the detailed questionnaire data. Thus, Type B and large-quantity Co-60 shipments were assumed to be transported by truck.

Entries listed as "Blank Entry" in Reports I.D and II.D or "unknown" in the transport mode breakdown of Reports X and XI were added to the category containing the largest percentage of packages for that isotope. Certain obvious discrepancies (such as very massive shipments by aircraft) were adjusted prior to tabulating the results in Table A-1. Two large shipment types, Co-60 LQ-2 and Pu-239 LQ, were not listed in the survey data, but shipment data were obtained from other sources.

*The raw data for Reference A-2 are contained in a series of computer reports specified by a Roman numeral combined with an alphabetic character.

TABLE A-1

TOTAL PACKAGES* EXTRAPOLATED FROM DETAILED QUESTIONNAIRE (NON-URANIUM)

Material	Major Use**	Package Type	Air Freight	Passenger Aircraft	Truck	Mail	Rail	Ship	Total
Am-241	I	A	2172	254	4548	63	0	14	7052
		B	48	6	100	1	0	0	155
Au-198	M	A	192	1568	2299	0	0	0	4059
Co-57	M	A	1907	7063	5474	0	0	0	14444
		LSA	7	28	21	0	0	0	56
Co-60	I,M	A	114	62	1763	0	0	0	1940
		B	19	11	299	0	0	0	329
		LSA	259	141	3995	0	0	0	4395
		LQ1	4	2	67	0	0	0	73
		LQ2	0	0	4	0	0	0	4
Cs-137	I	A	81	190	3771	0	0	0	4042
		B	1	1	23	0	0	0	25
		LSA	2	4	79	0	0	0	85
C-14	M	A	6356	7415	4865	981	0	0	19617
Ga-67	M	A	1390	5720	12750	0	0	0	19860
H-3	I	A	7996	11820	8227	956	0	0	28970
		B	112	166	115	13	0	0	406
		LSA	14	20	14	2	0	0	49
Ir-192	I	A	627	22	432	0	0	0	1081
		B	2819	97	1944	0	0	0	4861
I-131 + I-125	M	A	30714	209442	86587	0	0	0	326743
		B	83	568	235	0	0	0	886
		LSA	6	44	18	0	0	0	68
Kr-85	I	A	243	126	640	0	0	66	1075
		B	54	28	143	0	0	15	241
		LSA	5	3	13	0	0	1	22
MC+MF	FC	A	0	0	20154	0	0	0	20154
		B	0	0	4687	0	0	0	4687

TABLE A-1 (continued)

Material	Major Use**	Package Type	Air Freight	Passenger Aircraft	Truck	Mail	Rail	Ship	Total
MC+MF	FC	LQ	0	0	11	0	0	0	11
		LSA	0	0	31191	0	0	0	31191
Mo-99	M	A	25460	56421	46058	0	0	0	127939
		B	869	1927	1573	0	0	0	4369
Po-210	I	A	72	1	68	35	8	0	184
		LQ	7	0	6	3	1	0	17
P-32	M	A	2014	5634	3558	0	0	0	11206
Ra-226	I	A	12	5	104	0	0	0	122
		B	66	27	555	0	0	0	648
Tc-99m	M	A	10090	20649	203910	0	0	0	234649
Waste	W	A	0	0	12877	0	0	0	12877
		B	0	0	806	0	0	0	806
		LSA	0	0	19736	0	0	0	19736
Xe-133	I	A	6844	6154	12538	0	0	0	25536
Mixed	M	A	930	1445	21842	269	0	0	24486
		B	3	5	83	1	0	0	92
		LSA	211	328	4963	61	0	0	5564
Pu-238	M	A	12	75	139	0	0	0	226
		B	15	93	174	0	0	0	282
		LQ	0	3	5	0	0	0	8
		LSA	2	12	22	0	0	0	36
Pu-239	FC	A	2	1	63	0	0	0	66
		B	135	40	3804	0	0	0	3979
		LQ	1	0	22	0	0	0	23
Pu	FC	A	0	0	1	0	0	0	1
		B	5	1	132	0	0	0	138
U-Pu	FC	A	4	0	17	0	0	0	21
		B	62	9	303	0	0	0	374
		LQ	0	0	1	0	0	0	1
Spent fuel	FC	Cask	0	0	254	0	17	0	271

*Limited quantity shipments in limited packagings are listed as "various" isotopes in Table A-3.

**I - industrial; M - medical, FC - fuel cycle; W - waste material.

Uranium shipment data are tabulated separately in Table A-2 because they were determined differently. It was recognized that most of the uranium transported is for use in the nuclear fuel cycle for the production of power in nuclear reactors. Two previous studies (Refs. A-3 and A-4) have addressed the environmental effects of transport of uranium and identified the shipment types listed in Table A-2. The amounts per package, the numbers of packages per shipment, and the average distances per package shown in the table were taken from these two previous studies.

The first two shipment types in Table A-2 involve natural uranium. The total grams of natural uranium transported were determined from the survey data, from both the summary and detailed questionnaires. Natural uranium shipments were considered to be those listed in the survey data as "U-238," "U-235 Z," "U-235 A, B, and C," and "U." A total of 9.1×10^{10} grams of natural and depleted uranium was transported in 1 year, as determined from the survey data. Half of this was assumed to be shipment type 1 and half shipment type 2, since the two shipments are sequential and the total amount of uranium must be conserved. The total packages per year of each shipment type were determined by dividing the total grams transported by the amount per package. The number of packages of enriched uranium for each of the remaining three shipment types was determined in the [illegible] way from the total grams of enriched uranium transported (3.9×10^9 grams total).

All entries in the survey tables listed as "U-235 D-Y" or "U-235" were considered as enriched uranium.* The total amount of material in grams was determined by dividing the amount shown (amount of U-235 only) in the tables by the fractional enrichment. Thus, the total amounts of enriched uranium are considerably greater than those determined from Report XIV.H, for example, since Report XIV.H shows only the amount of U-235 contained in the U-235/U-238 mixture.

The total number of packages of uranium determined in this way does not agree with the total number determined from the survey, but the total number of grams, of course, does agree. Since it is only the total amount of material shipped (not the total packages) that determines the risk in the accident case, this simplified model is considered adequate in determining the accident risk.

The average TI per package assigned to each uranium shipment was computed by first determining the total TI for both natural and enriched uranium from the survey data, distributing the natural uranium TI equally among packages of shipment types 1 and 2 (as defined in Table A-2), and distributing the enriched uranium TI equally among packages of shipment types 3, 4, and 5. The result is an average TI of 2.6 each for types 1 and 2 and 1.4 each for types 3, 4, and 5. Since the normal dose depends upon the total TI transported annually, it is unimportant how the TI are distributed among packages, as long as the total TI is accounted for. The normal dose computed for the enriched uranium shipments is an overestimate, since the TI reported in the survey data was most likely fissile TI rather than radiation TI. In the section of Chapter 4 where maximum individual doses are considered, a dose rate value from Reference A-4 was used in place of the TI per package computed here.

The summary questionnaire data for numbers of packages were added to those from the detailed questionnaires. The resulting package totals are shown in Table A-3, listed by isotope, package

*The letters A-Y following the symbol U-235 in the survey data indicate the percentage enrichment in the isotope U-235.

TABLE A-2

URANIUM SHIPMENTS USED IN THE STANDARD SHIPMENTS

Ship. Type	Material	From	To	Form/ Package*	Amount per Pkg (grams)	Pkgs per shipment	Total pkgs. per yr	Avg. Distance (km)
1	U_3O_8	Mill	UF_6 Prod.	LSA	3.8×10^5	40	1.2×10^5	1600
2	UF_6	UF_6 Prod.	Enrich Pl.	LSA	1×10^7	2	4550	800
3	UF_6(enr)	Enrich Pl.	UO_2 Pl.	AF	2.2×10^6	5	591	1200
4	UO_2(enr)	UO_2 Pl	Fuel Fab.	AF	1.1×10^5	40	11818	1200
5	UO_2(enr)	Fuel Fab.	Reactors	SF	8.3×10^5	6	1566	1600

*LSA = low specific activity; AF = Type A - fissile; SF = special form.

TABLE A-3

COMPILATION OF TOTAL PACKAGES SHIPPED PER YEAR

Material	Package Type	Mode*	Packages per Year
Various	limited**	AF	138508
		PAC	172992
		T	391008
Am-241	A	AF	4201
		PAC	491
		T	20330
		M	73
		S	16
	B	AF	55
		PAC	7
		T	115
		M	1
Au-198	A	AF	201
		PAC	1644
		T	2411
Co-57	A	AF	2146
		PAC	7947
		T	6183
	LSA	AF	8
		PAC	31
		T	24
Co-60	A	AF	158
		PAC	86
		T	17447
	B	AF	37
		PAC	21
		T	1397
	LQ	AF	6
		PAC	3
		T	92
	LSA	AF	359
		PAC	195
		T	5535
Cs-137	A	AF	333
		PAC	792
		T	31023
	B	AF	2
		PAC	3
		T	69
Cs-137	LSA	AF	5
		PAC	12
		T	233
C-14	A	AF	8691
		PAC	10140
		T	6655
		M	1341
Ga-167	A	AF	1407
		PAC	5789
		T	12904
H-3	A	AF	10510
		PAC	15536
		T	10984
		M	1256
	B	AF	147
		PAC	218
		T	151
		M	17

TABLE A-3 (continued)

Material	Package Type	Mode	Packages per Year
H-3	LSA	AF	18
		PAC	27
		T	18
		M	2
Ir-192	A	AF	2788
		PAC	97
		T	1922
	B	AF	12751
		PAC	440
		T	13654
I-131+I-125	A	AF	38133
		PAC	260034
		T	107817
	B	AF	103
		PAC	220
		T	292
	LSA	AF	8
		PAC	54
		T	22
Kr-85	A	AF	1079
		PAC	559
		T	3446
		S	291
	B	AF	241
		PAC	125
		T	634
		S	65
	LSA	AF	22
		PAC	12
		T	58
		S	6
MF+MC	A	T	21517
	B	T	5004
	LQ	T	12
	LSA	T	33301
Mo-99	A	AF	25838
		PAC	57008
		T	54929
		M	109
	B	AF	882
		PAC	1947
		T	1876
		M	4
Po-210	A	AF	86
		PAC	1
		T	81
		M	42
		R	10
	LQ	AF	9
		T	7
		M	3
		R	1
P-32	A	AF	2164
		PAC	6052
		T	3823
Ra-226	A	AF	58
		PAC	24
		T	25893
	B	AF	312
		PAC	128
		T	2620

TABLE A-3 (continued)

Material	Package Type	Mode	Package per Year
Tc-99m	A	AF	10329
		PAC	21138
		T	208740
Waste	A	T	131120
	B	T	821
	LSA	T	20097
Xe-133	A	AF	7058
		PAC	6347
		T	12930
Mixed	A	AF	930
		PAC	1445
		T	26773
		M	269
	B	AF	3
		PAC	5
		T	100
		M	1
	LSA	AF	211
		PAC	328
		T	5970
		M	61
Pu-238	A	AF	272
		PAC	1724
		T	3230
	B	AF	15
		PAC	93
		T	174
	LSA	AF	2
		PAC	12
		T	22
	LQ	PAC	3
		T	5
Pu-239	A	AF	2
		PAC	1
		T	63
	B	AF	135
		PAC	40
		T	3804
	LQ	AF	1
		T	22
Pu	A	T	1
	B	AF	5
		PAC	1
		T	132
U-Pu mix	A	AF	4
		T	17
	B	AF	62
		PAC	9
		T	303
	LQ	T	1
Spent fuel	Cask	T	254
		R	17
U_3O_8 (nat)	LSA	T	54000
		R	66000
UF_6 (nat)	A	T	2048
		R	2502
UF_6 (enr)	B	T	485
		S	106
UO_2 (enr)	B	T	9691
		S	2127
UO_2 (fuel)	B	T	1284
		S	282

*AF = air freight; PAC = passenger aircraft; T = truck; S = ship; R = rail; M = mail.

**All limited shipments have been grouped together.

type, and transport mode. Data from apparent major shippers were obtained from Table 4.8 of Reference A-2. The air/land transport mode splits listed in Table 4.8 were used. Further subdivision of packages between passenger and cargo for air transport and between truck and rail for land transport was made using the corresponding mode splits in the detailed questionnaire data. The minor shipper summary questionnaire data were obtained from Summary Questionnaire Report I.D. Since this report presented only package totals for each isotope, the package type split and transport mode split were taken to be the same as for the detailed questionnaire data.

A.3 SIMPLIFICATION OF STANDARD SHIPMENTS LIST

All shipments in limited (exempt) packagings were grouped together in Table A-3, with the transport mode split preserved. In Table A-4, limited quantities shipped in other packagings were combined with other limited shipments, using the limited mode split. In order to minimize the number of scenarios (isotope - transport mode - package type combinations), scenarios with fewer than 1% of the total packages of that isotope and package type were combined in the transport mode with the largest number of packages.

The total of all packages (except limited) transported by airfreight in Table A-3 was 7.32×10^5 However, for the 12-month period ending in June 1975, CAB data (Ref. A-5) indicate a total of 31,000 all-cargo aircraft departures. If all airfreight packages were transported by all-cargo aircraft, there would be about 100 packages per flight, assuming an RTF of 1/24. This does not appear to be reasonable. Many respondents to the 1975 survey probably entered the symbol AF (freight-only aircraft) under the heading "transport mode" for all airfreight shipments. However, the CAB data indicate that only 12.4% of the total domestic airfreight tonnage goes by cargo-only aircraft, the majority being shipped by passenger aircraft. To account for this, 87.6% of the packages of each isotope and package type transported by airfreight in Table A-3 were transferred to the passenger aircraft category, with the exception of the large-quantity shipments.

The transfer of packages from cargo aircraft to passenger aircraft results in a total of 5.12×10^5 nonlimited packages by passenger aircraft. The total number of passenger aircraft departures in 1975 was about 4.5×10^6. Assuming only one package per flight, approximately 10% of all passenger aircraft flights, on the average, carried radioactive material. Since many materials are shipped in multipackage consignments, these data appear to be compatible with the RTFs of 1/10-1/30 discussed in Chapter 4.

The actual split between all-cargo aircraft and passenger aircraft probably lies somewhere between these extremes, i.e., some of the respondents to the 1975 survey probably did interpret the symbol "AF" to mean all-cargo flights as was intended. However, since there is no way of determining how many responded correctly, the latter more conservative approach (transferring a large number of packages from all-cargo aircraft to passenger aircraft) was taken in this assessment.

The net result of these simplifications is shown in Table A-4. This table serves as the basis for the analysis in the body of the report.

TABLE A-4

PACKAGE TOTALS FOR STANDARD SHIPMENTS - 1975 (PACKAGES PER YEAR)

Material	Package Type	Air Freight	Passenger Aircraft	Truck	Rail	Ship
Various	Limited	1.72E+4	2.95E+5	3.91E+5	-	-
Am-241	A	521	4170	2.04E+4	-	-
	B	7	55	116	-	-
Au-198	A	25	1820	2410	-	-
Co-57	A	267	9860	6180	-	-
Co-60	A	-	-	1.77E+4	-	-
	B	5	53	1400	-	-
	LQ1	-	-	101	-	-
	LQ2	-	-	4	-	-
	LSA	45	509	5540	-	-
C-14	A	1080	1.91E+4	6660	-	-
Cs-137	A	41	1080	3.10E+4	-	-
	B	5	-	69	-	-
Ga-67	A	175	7030	1.29E+4	-	-
H-3	A	1300	2.6E+4	1.10E+4	-	-
	B	18	364	151	-	-
	LSA	2	45	18	-	-
Ir-192	A	346	2540	1920	-	-
	B	1590	1.17E+4	1.37E+4	-	-
I-131+I-125	A	4720	2.93E+5	1.08E+5	-	-
	B	13	310	292	-	-
Kr-85	A	136	1530	3500	-	297
	B	30	336	634	-	-
MF+MC	A	-	-	2.15E+4	-	-
	B	-	-	5000	-	-
	LQ	-	-	12	-	-
	LSA	-	-	3.33E+4	-	-
Mo-99	A	3200	7.97E+4	5.49E+4	-	-
	B	109	2720	1880	-	-
Po-210	A	16	113	81	10	-
	LQ	1	11	7	1	-
P-32	A	268	7940	3820	-	-
Ra-226	A	-	-	2.60E+4	-	-
	B	39	401	2620	-	-
Tc-99m	A	1280	3.01E+4	2.09E+5	-	-
Waste	A	-	-	1.31E+5	-	-
	B	-	-	821	-	-
	LSA	-	-	2.03E+4	-	-
Xe-133	A	875	1.22E+4	1.29E+4	-	-
Mixed	A	115	2260	2.70E+4	-	-
	B	-	8	101	-	-
	LSA	26	513	5830	-	-
Pu-238	A	34	1980	3250	-	-
	B	2	109	179	-	-
Pu-239	B	17	165	4030	-	-
	LQ	1	-	-	-	-
U-Pu	B	8	58	330	-	-
Spent Fuel(T)	Cask	-	-	254	-	-
Spent Fuel(R)	Cask	-	-	-	17	-
U_3O_8 (Nat)	LSA	-	-	5.40E+4	6.60E+4	-
UF_6 (Nat)	A	-	-	2050	2500	-
UF_6 (Enr)	B	-	-	485	-	106
UO_2 (Enr)	B	-	-	9690	-	2130
UO_2 Fuel	B	-	-	1280	-	282

In addition to the number of packages per year for each isotope and transport mode combination, four other parameters are required to characterize each shipment: average distance per shipment, average number of packages per shipment, average number of curies per package, and average TI per package. These parameters were determined by averaging values given in Reports I.D and II.D in the 1975 survey for each isotope and package type. Values for uranium shipments were determined from Reference A-3 as discussed earlier. The results for all shipments are summarized in Table A-5. The TI value of 1.0 assigned for spent fuel shipments is an artifact, which, when combined with a K value of 1000, produces a dose-rate factor of 90 mrem-m^2/hr (1000 mrem-ft^2/hr), as discussed in Appendix D.

The average distances per shipment were determined for each isotope and package type by dividing the TI miles for each entry in Reports I.D and II.D by the TI for that entry and then summing over all entries for that isotope and package type. Distances for uranium shipments were taken directly from References A-3 and A-4.

Certain shipments, such as large irradiator sources or truck shipments of irradiated fuel, are loaded directly onto the primary mode vehicle and transported directly to the receiver with no secondary link. However, most other shipments involve a secondary mode link such as a van or courier vehicle to move the material from the shipper to the primary mode terminal (e.g., airport, freight dock) and to take the material from another primary mode terminal to the consignee at the end of the trip. For shipments by passenger aircraft, truck, and rail, the secondary mode distance is assumed to be 40 kilometers at each end or 80 kilometers per shipment. For shipments by all-cargo aircraft, which do not service all major airports, the assumed distance is 80 kilometers at each end for a total of 160 kilometers per shipment. In the case of transport by ship, the distance from the port to the user may be still larger; a value of 320 kilometers per shipment is assumed (not necessarily the case for barge shipments, as discussed in Chapter 6).

In the absence of data to the contrary, one package per shipment was assumed. Data do exist for some uranium fuel cycle and some waste shipments (Ref. A-3), and these data were incorporated into the model. These data are reflected in the numbers of packages per shipment for the materials listed in Table A-5.

A.4 DOSIMETRIC PARAMETERS FOR STANDARD SHIPMENTS

The consequences of an accident involving a release of radioactive material depend on certain dosimetric parameters, including the rem-per-curie value, the particular organ or organs affected, the fraction aerosolized, and the resuspension factor. Each of these is discussed below.

A.4.1 REM-PER-CURIE VALUES AND AFFECTED ORGANS

For dispersible materials (gases, liquids, and volatile or dispersible solids), the rem-per-curie value used in this analysis is the dose in rem received by an individual per curie of radioactive material inhaled. The inhalation of a radionuclide primarily affects one or more critical organs characteristic of that nuclide. For example, inhaled plutonium may cause biological damage to bone and lung tissue. Table A-6 lists the rem-per-curie values and critical

TABLE A-5

SHIPMENT PARAMETERS FOR STANDARD SHIPMENTS

Material	Package Type	Curies per Package	TI per Package	Kilometers per Shipment	Packages per Shipment
Various	Limited	.003	.01	1600 [1]	1
Am-241	A	3.51	2.1	633	1
	B	107	0.9	2450	1
Au-198	A	.84	2.6	958	1
Co-57	A	.003	.08	2420	1
Co-60	A	7.9	4.6	1480	1
	B	1760	1.5	1280	1
	LQ1	40000	.14	2010	1
	LQ2	$3.2x10^5$	1.0 [2]	3200	1
	LSA	.16	4.8	898	1
C-14	A	.02	.02	2140	1
Cs-137	A	.67	2.7	346	1
	B	1350	2.0	950	1
Ga-67	A	.16	.2	700	1
H-3	A	8.6	.002	1770	1
	B	134	0	1600 [1]	1
	LSA	1.7	2.6	800	1
Ir-192	A	64	1.3	1820	1
	B	157	2.1	2030	1
I-131 +	A	.01	.7	1430	1
I-125	B	9.7	0.6	1340	1
Mixed	A	.332	.4	544	1
	B	146	3.8	850	1
	LSA	1.3	.73	980	1
MF+MC	A	.48	5.9	889	50
	B	.23	.07	794	50
	LQ	392	3.0	2330	1
	LSA	.59	1.9	692	50
Mo-99	A	1.2	1.9	1690	1
	B	94	4.4	3230	1
Po-210	A	.007	.04	1210	1
	LQ	144	1.95	2330	1
P-32	A	.24	.25	1600	1
Xe-133	A	1.6	.14	1850	1
Waste	A	.33	22.4	1090	50
	B	273	6.5	725	50
	LSA	.32	2.0	879	50
Ra-226	A	.002	.07	839	1
	B	.04	.3	253	1
Kr-85	A	16	.8	2420,13500 [3]	1
	B	91	.04	2010	1
Pu-238	A	13.3	.02	594	1
	B	2630	.82	1930	1
Pu-239	B	1169	.98	1660	1
Plutonium	LQ	$1.23x10^6$	2.0	1600	1
Spent Fuel	Cask	$1.4x10^6$ [4]	1.0 [2]	2530 [5]	1
	Cask	$9.1x10^6$ [4]	1.0 [2]	1210 [5]	1
U (nat depl) (U_3O_8)	LSA	.13 [6]	2.6	1600	40
U (nat depl) (UF_6)	LSA	3.5 [7]	2.6	800	2
U (enr) (UF_6)	A	.85	1.4	1210,9660 [8] [9]	5
U (enr) (UO_2)	B	.042	1.4	1210,9660 [9]	40

TABLE A-5 (continued)

Material	Package Type	Curies per Package	TI per Package	Kilometer per Shipment	Packages per Shipment
UO_2 (enr) (fuel rods)	B	.32	.5	1600,9660 [9]	6
U-Pu mix	B	38,300	3.3	2750	1
Tc-99m	A	1.03	.16	209	1
Tl-201[10]	A	8.2	.37	2690	1
Recycle Pu [10]	ICV	$6.2x10^6$	2.0	1600	1

Assumptions

[1] Certain isotopes with TI's of zero were assigned primary mode distances of 1600 kilometers.

[2] Large casks are assigned a TI of 1 to force a dose rate factor of 90 mrem-m^2/hr (1000 mrem-ft^2/hr) - see Appendix D.

[3] Kr-85 Type A goes 2420 kilometers in domestic traffic and 13500 kilometers by ship overseas.

[4] The spent fuel curies are divided into releasable material (Kr-85, I-131, and volatile fission products) and exposure-source materials. The curie breakdown is as follows:

	Curies			
	Kr-85	I-131	Volatile Fission Products	Exposable
Truck cask	1,700	.022	200	1.4×10^6
Rail cask	10,900	.138	1280	9.1×10^6

[5] Spent fuel when shipped by truck goes 2530 kilometers and when shipped by rail goes 1210 kilometers.

[6] Shipped in 40-package lots.

[7] Shipped in 2-package lots.

[8] Shipped in 5-package lots.

[9] Overseas uranium shipments go 9660 kilometers by ship. Domestic shipments go 1210 kilometers by truck.

[10] These shipments occur in 1985 only.

TABLE A-6

REM-PER-CURIE (INHALED) VALUES FOR STANDARD SHIPMENTS

Material	Physical Form	Rem/Ci Inhaled	Organ	Time Period	Ref.
Limited [1]	liquid	1.1×10^{6}	thyroid	60 d	A-6
AM-241	special form	3.1×10^{-2}*	WB	1 hr	A-7, A-8
Au-198	liquid	1.4×10^{4}	LLI	168 hr/wk	A-9
Co-57	liquid	1.4×10^{3}	LLI	168 hr/wk	A-9
Co-60	dispersible solid	1.3×10^{6}	lung	50 y	A-6
	special form	1.34*	WB	1 hr	A-7, A-8
C-14	liquid	700	WB	168 hr/wk	A-9
Cs-137	liquid	3.7×10^{4}	WB	50 y	A-6
	special form	3.4×10^{-1}*	WB	1 hr	A-7, A-8
Ga-67	special form	9.0×10^{-2}*	WB	1 hr	A-7, A-8
H-3 [2]	liquid/gas	64	WB	70 d	A-10
Ir-192	special form	4.0×10^{-1}*	WB	1 hr	A-7, A-8
I-131+I-125	liquid	1.1×10^{6}	thyroid	60 d	A-6
Mixed [3]	liquid	1.1×10^{6}	thyroid	60 d	A-6
MC+MF [4]	dispersible solid	1.3×10^{6}	lung	50 y	A-6
Mo-99	liquid	2.1×10^{4}	LLI	60 d	A-6
Tl-201	liquid	2280	LLI	168 hr/wk	A-9
Po-210	dispersible solid	7.1×10^{7}	lung	168 hr/wk	A-9
P-32	liquid	7.1×10^{4}	bone	168 hr/wk	A-9
Xe-133	gas	476	WB	168 hr/wk	A-9
Waste [5]	dispersible solid	3.7×10^{4}	WB	50 y	A-6, A-9
Ra-226 [6]	special form	7.0×10^{-1}*	WB	1 hr	A-7, A-8

TABLE A-6 (continued)

Material	Physical Form	Rem/Ci Inhaled	Organ	Time Period	Ref.
Kr-85	gas	0.61	WB	50 y	A-6
Tc-99m	liquid	89	lung	2 d	A-6
Pu-238	dispersible solid	1.2×10^{8}	lung	1 y	A-6
		3.1×10^{8}	lung	50 y	A-6
		7.6×10^{8}	bone	50 y	A-6
	special form	-	-	-	A-7, A-8
Spent fuel					
I-131	gaseous fission product	1.1×10^{6}	thyroid	60 d	A-6
Kr-85	gaseous fission product	0.61	WB	50 y	A-6
Mixed fission prod. [7]	volatile fission product	3.7×10^{4}	WB	50 y	A-6
Exposure [8]	special form	1.2×10^{-1}*	WB	1 hr	A-6, A-7, A-8
U (nat & depl) [9]	dispersible solid, volatile solid	1.94×10^{7}	bone	50 y	A-11
		4.73×10^{7}	lung	50 y	A-11
	special form	5.7×10^{-3}*	WB	1 hr	A-7, A-8
U (enr) [10]	dispersible solid	1.94×10^{7}	bone	50 y	A-11
		4.74×10^{7}	lung	50 y	A-11
	special form	5.2×10^{-2}*	WB	1 hr	A-7, A-8
plutonium [11]	dispersible solid	3.99×10^{6}	lung	1 y	A-6, A-12
		1.06×10^{7}	lung	50 y	A-6, A-12
		3.74×10^{7}	bone	50 y	A-6, A-12
	special form	2.9×10^{-5}	WB	1 hr	A-7, A-8

*Rem/hr/Ci for nondispersible materials.

TABLE A-6 (continued)

Notes:

1. Modeled as I-131.
2. Taken for individuals older than 10-15 years and for a body half-time of 10 days.
3. Modeled as I-131 since most of this material is radiopharmaceutical byproduct material.
4. Modeled as Co-60 since that isotope is both a fission product and corrosion product.
5. Modeled as Cs-137.
6. The radiation comes from the decay of Bi-214.
7. Modeled as Cs-137.
8. The gamma source for irradiated fuel was derived from isotopic mixture in Reference A-8, allowing for 150-day cooling. The principal contributors are Zr-95 and Ru-106.
9. 99.3 percent U-238/.007 percent U-235.
10. 3 percent enrichment assumed.
11. The calculation for rem-per-curie for recycle plutonium is detailed in Appendix C.

organs for each material in the standard shipments list, including special form and other nondispersible materials. Critical organs were determined from rem-per-curie values from References A-6, A-10, and A-11, and from the list of critical organs in the ICRP/NRCP tabulation of maximum permissible concentrations.

For materials whose rem-per-curie values are not specifically tabulated, values were computed based on the ICRP/NCRP maximum permissible concentrations in air for chronic exposure at 168 hours per week as follows:

$$D = \frac{10^6 \times D_o}{K(BR)(MPC_a)} \qquad \text{(A-1)}$$

where

D_o = statutory organ dose limit (15 rem/year for internal organs)

BR = breathing rate

MPC_a = maximum permissible concentration in air

K = unit conversion factor

For breathing rate of 20 liters per minute, this becomes:

$$\begin{matrix}\text{Rem/curie} \\ \text{(inhaled)}\end{matrix} = \frac{1.427 \times 10^{-3}}{MPC_a} \qquad \text{(A-2)}$$

Nondispersible materials present only a direct radiation hazard in the accident case (as well as the normal case); therefore, the dose received is a whole-body dose. The computational method of determining whole-body doses from direct external exposure sources is discussed in Appendix G. For nondispersible materials, the gamma-ray doses delivered in 1 hour at a distance of 1 meter from a 1-curie source are listed in Table A-6.

A.4.2 RESPIRABLE FRACTION

The fraction of material that is respirable (able to be inhaled and deposited in the pulmonary region of the lungs) was chosen conservatively to be 1.0 unless data were available to the contrary. A respirable fraction of unity is probably a reasonable choice for gases and liquids, but it is probably very conservative for most dispersible solids. Specific data (Refs. A-13 and A-14) were available for plutonium and for U_3O_8 and were used in the calculation. The respirable fractions used for each standard shipment are listed in Table A-7.

A.4.3 AEROSOLIZED FRACTION

The aerosolized fraction of material released in an accident depends on the accident environment. A container may be crushed beneath a truck, in which case very little material is aerosolized, or it may bounce into the air following the impact and disperse its entire contents. The aerosolized fraction estimated for each standard shipment is listed in Table A-7. For most packages, the aerosolized fraction was assumed to be 1.0. However, certain shipments, notably uranium, involve large quantities of material (10^5 to 10^6 grams per package). An assumption of

TABLE A-7

ADDITIONAL DOSIMETRIC FACTORS

Material	Respirable Fraction	Aerosolized Fraction	Resuspension Dose Factor
"Limited" [1]	1.0	1.0	1.0
Am-241 [2]	0.0	0.0	0.0
Au-198	1.0	1.0	1.03
Co-57	1.0	1.0	1.0
Co-60 [2]	0.0,1.0	0.0,1.0	0.0,1.6
C-14	1.0	1.0	1.0
Cs-137	0.0,1.0	0.0,1.0	0.0,1.62
Ga-67 [2]	0.0	0.0	0.0
H-3	1.0	1.0	1.0
Ir-192	0.0	0.0	0.0
MF+MC	1.0	1.0	1.6
I-131 + I-125	1.0	1.0	1.09
Mixed	1.0	1.0	1.09
Mo-99	1.0	1.0	1.0
Po-210	1.0	1.0	1.5
Ra-226 [2]	0.0	0.0	0.0
P-32	1.0	1.0	1.1
Xe-133	1.0	1.0	1.0
Waste	1.0	1.0	1.62
Kr-85	1.0	1.0	1.0
Pu-238 [2]	0.0	0.0	0.0
Pu [2,3]	0.0,0.2	0.0,1.0	0.0,1.60
Pu [4]	0.2	.05	1.6
Spent fuel-I-131	1.0	1.0	1.09
Kr-85	1.0	1.0	1.0
FP	1.0	1.0	1.62
U_3O_8	0.06	.05	1.63
UF_6	1.0	.01	1.63
U-Pu	0.2	1.0	1.6
Tc-99m	1.0	1.0	1.0
UO_2 [2]	0.0,0.2	0.0,.05	0.0,1.63

[1] "Limited" is modeled as I-131.

[2] Special form materials are assigned value of 0.0. If a material appears both in special and normal form, both sets of values are shown.

[3] Small plutonium shipments.

[4] Large plutonium shipments.

unity aerosolized fraction for such shipments should be excessively conservative, since complete aerosolization of such large amounts of material would be quite difficult.

The mechanisms of aerosolization can be divided into four principal categories: wind resuspension of spilled contents, impact or fire-driven pressure rupture, fire entrainment of spilled contents, and explosion. By examination of potential accident environments, it was determined that the pressure-rupture accident is the only mechanism that occurs in a significant proportion of accidents and with a significant potential release. Even when it does occur, not all of the material ejected from the container would be aerosolized. The situation would be analogous to throwing a handful of sand into the air; most of it would fall back down, with only a small portion of it becoming aerosolized. Based on these considerations, it was estimated that, on the average, no more than 5% of the released material is aerosolized.

A 1% aerosolized fraction was selected for UF_6. Since UF_6 is a solid up to a temperature of 64°C, it was considered to remain essentially non-aerosolized except when involved in a fire, in which case it was considered 100% aerosolized. Since UF_6 is transported principally by truck or rail and since fires occur in only about 1% of all truck or rail accidents, an average aerosolized fraction of 1% was considered appropriate.

A.4.4 RESUSPENSION FACTOR

The resuspension dose factors take into account the doses received by individuals after the initial debris cloud passes. The dose results from radioactive particles deposited on the ground during the cloud passage which are resuspended and inhaled. A discussion of the methods used to estimate resuspension factors is provided in Chapter 5 and will not be repeated here. The resuspension factors for each shipment considered are listed in Table A-7.

A.5 1985 STANDARD SHIPMENTS

The numbers of radioactive material packages expected to be shipped in 1985 are listed in Table A-8. All industrial and most radiopharmaceutical (non-SNM, nonsource material) shipments and all Pu-238 packages were scaled upward by a factor of 2.6 from their 1975 values. This corresponds to an average increase of 10% per year during the 10-year period 1975 to 1985.

Pu-239 shipments were estimated to be unchanged from their 1975 values since these involve principally research reactors and weapon-production facilities. However, a new type of plutonium shipment, "recycle Pu," was added to account for the recycling of plutonium recovered from spent fuel and the fabricating of mixed oxide (MOX) fuel by 1980. For an estimated (Ref. A-12) 20,535 kg per year transported in 1985, 41 packages per year will be shipped in integrated container vehicles (ICV) in 504-kg quantities. This plutonium is considered as "once-through" plutonium, and the average number of curies per package is determined from the isotopic content discussed in Appendix C.

Spent fuel shipments for 1985 are based on an estimated total amount of 2,849 tonnes per year (Ref. A-12). Each truck shipment is estimated to contain 0.5 tonne, and each rail shipment 3.2 tonnes (Ref. A-3). The transport mode split between truck and rail is taken to be the same

TABLE A-8

STANDARD SHIPMENTS - 1985 (PACKAGES PER YEAR)

Material	Package Type	AF	P A/C	Truck	Rail	Ship
Limited	Ex	$4.47x10^4$	$7.67x10^5$	$1.02x10^6$	-	-
Am-241	A	$1.22x10^4$	-	$5.30x10^4$	-	-
	B	161	-	302	-	-
Au-198	A	25	1820	2410	-	-
Co-57	A	694	$2.56x10^4$	$1.61x10^4$	-	-
Co-60	A	-	-	$4.60x10^4$	-	-
	B	-	-	3800	-	-
	LQ1	-	-	262	-	-
	LQ2	-	-	10	-	-
	LSA	1440	-	$1.44x10^4$	-	-
C-14	A	2810	$4.97x10^4$	$1.73x10^4$	-	-
Cs-137	A	2920	-	$8.06x10^4$	-	-
	B	13	-	179	-	-
Ga-67	A	455	$5.18x10^4$	-	-	-
H-3	A	3380	$6.76x10^4$	$2.86x10^4$	-	-
	B	47	946	393	-	-
	LSA	5	117	47	-	-
Ir-192	A	7500	-	4990	-	-
	B	$3.45x10^4$	-	$3.56x10^4$	-	-
I-131+I-125	A	4720	$2.93x10^5$	$1.08x10^5$	-	-
	B	13	310	292		
Kr-85	A	354	3980	9100	-	772
	B	78	874	1650	-	-
MF+MC	A	-	-	$8.9x10^4$	-	-
	B	-	-	$2.07x10^4$	-	-
	LQ	-	-	50	-	-
	LSA	-	-	$1.38x10^5$	-	-

TABLE A-8 (continued)

Material	Package Type	AF	P A/C	Truck	Rail	Ship
Mo-99	A	8320	$2.07x10^5$	$1.43x10^5$	-	-
	B	283	7070	4890	-	-
Po-210	A	336	-	211	260	-
	LQ	32	-	18	3	-
P-32	A	697	$2.06x10^4$	9930	-	-
Ra-226	A	-	-	$2.6x10^4$	-	-
	B	440	-	2620	-	-
Tc-99m	A	3330	$7.83x10^4$	$5.43x10^5$	-	-
Tl-201	A	-	7500	$4.25x10^4$	-	-
Waste	A	-	-	$5.4x10^5$	-	-
	B	-	-	3300	-	-
	LSA	-	-	$8.4x10^4$	-	-
Xe-133	A	2280	$3.17x10^4$	$3.35x10^4$	-	-
Mixed	A	299	5880	$7.02x10^4$	-	-
	B	-	21	263	-	-
	LSA	68	1330	$1.52x10^4$	-	-
Pu-238	A	88	5150	8450	-	-
	B	288	-	465	-	-
Pu-239	B	182	-	4030	-	-
	LQ	1	-	-	-	-
Spent fuel	Cask	-	-	1530	652	-
U_3O_8	LSA	-	-	$2.24x10^5$	$2.73x10^5$	-
UF_6 Nat.	A	-	-	8440	$1.04x10^4$	-
UF_6 Enr.	B	-	-	2010	-	439
UO_2 Enr	B	-	-	$4.01x10^4$	-	8820
UO_2 Fuel	B	-	-	5300	-	1170
U-Pu Mix	B	33	240	1370	-	-
Recycle Pu	ICV	-	-	41	-	-

as that predicted by Blomeke et al. (Ref. A-15). The results are 1,530 truck shipments and 652 rail shipments.

Uranium fuel cycle shipments for 1985 were determined using an estimated 5,383 tonnes of enriched uranium produced in 1985 (Ref. A-12). When compared to the 1300 tonnes determined from the 1975 survey, an industry growth factor of 4.14 was determined. All uranium and uranium-plutonium-mixture shipments were scaled upward by this factor from their 1975 values. Only the total numbers of packages were scaled; the average number of curies per package (or shipment), the TI per package, and the distance per package were assumed to be the same as in 1975.

The projected package totals for certain of the 1985 standard shipments were not obtained in any of the above ways. An executive of a major U.S. radioisotope supplier estimated that:

1. The use of I-131, Ra-226, and Au-198 is not expected to expand by 10% per year as suggested for other radioisotopes.

2. Several isotopes are not expected to be transported by passenger aircraft in the future. The isotopes Am-241, Co-60, Ir-192, Po-210, Ra-226, Pu-238, and Pu-239 were transferred to air-freight mode.

3. Ga-67 will be shipped by air instead of truck.

4. Tl-201 is expected to be significant in 1985.

A.6 EXPORT-IMPORT MODEL

The standard shipment list in Table A-4 was determined from information contained in the 1975 survey report. In order to determine the impacts of export shipments explicitly, a standard shipment list similar to that of Table A-4 was compiled from the detailed questionnaire survey data for exports only. Imports are discussed in Section A.6.2.

A.6.1 EXPORT STANDARD SHIPMENTS LIST

A list of total packages by package type and transport mode and corresponding package parameters for export shipments is shown in Table A-9. The data were obtained by sorting the export-shipments data in the 1975 survey by isotope, package type, and transport mode and determining the total number of packages (extrapolated), the average number of curies or grams per package, the average TI per package, and the average distance traveled per package.

Materials included in the standard shipments list used in the total impact calculation were included in the export standard shipments list. These materials accounted for more than 99% of the total packages, curies, and TI exported, as indicated in the 1975 survey data.

Exports account for about 5×10^6 curies, or about 1% of the total number of curies transported in the United States. About 95% of the number of curies exported are Co-60, Ir-192,

TABLE A-9

1975 STANDARD SHIPMENTS MODEL FOR EXPORT SHIPMENTS - TOTAL PACKAGES PER YEAR BY PACKAGE TYPE, TRANSPORT MODE, AVERAGE CURIES/PACKAGE, AVERAGE TI/PACKAGE, AND AVERAGE MILES/PACKAGE

					Extrapolated Total Packages								
					Air Freight		Pass. A/C		Ship		Truck		Total
Material	Package Type	Ci Package	TI Package	Form	Package	Km/Pkg	Package	Km/Pkg	Package	Km/Pkg	Package	Km/Pkg	Package
Am-241	A	2.8	2.2	SF	14	6440	18	4990	7	11500	14	1450	53
Am-241	B	13.1	0.4	SF	6	8050	1	8050	-	-	-	-	7
Au-198	A	16.0	6.0	L	1	2090	-	-	-	-	-	-	1
Co-57	A	.086	0.5	L	3	644	17	1210	-	-	-	-	20
Co-60	A	7.3	0.5	SF	4	6120	-	-	-	-	-	-	4
Co-60	B	2670	1.0	SF	-	-	-	-	-	-	13	2450	13
Co-60	LSA	.0001	0	L	1	11300	-	-	-	-	-	-	1
Cs-137	A	2.0	5.0	SF	-	-	-	-	-	-	3	1770	3
C-14	A	0.27	3.1	L	32	9340	64	4030	-	-	-	-	96
H-3A	A	.06	0	L	53	12900	119	11900	-	-	-	-	172
H-3T	A	50	0	G	-	-	-	-	-	-	1	1260	1
Ir-192	A	66	1.0	NS	10	4830	-	-	-	-	-	-	10
	B	126	2.3	NS	64	1240	-	-	-	-	-	-	64
I-131	A	.09	.48	L	14	3010	146	4030	-	-	-	-	160
Kr-85	A	2.2	.28	G	78	10400	11	11900	42	13500	4	1380	135
MF	A	9.6	3.1	G	36	3880	-	-	-	-	-	-	36
Mo-99	A	2.64	3.3	L	125	6730	70	5230	-	-	22	2430	217
	B	76.7	3.0	L	7	11700	11	7570	-	-	-	-	18
Pu-238	B	359	0.84	SF	10	8050	1	6600	-	-	1	1830	12
Pu-239	B	1.45	0.0	SF	12	8050	4	96[illegible]	-	-	-	-	16
P-32	A	0.13	0.43	L	7	5430	21	3380	-	-	-	-	28
Ra-226	A	0.004	1.6	SF	10	3860	-	-	-	-	-	-	10
Xe-133	A	5.4	0.28	G	3	9660	24	4380	-	-	1	1260	28
Mixed	A	0.016	0.1	L	.1	403	13	1290	-	-	-	-	14
Limited	Lim	$6x10^{-5}$	0	L	10	12600	8	7570	-	-	-	-	18
U-Pu	B	0.11	0	L	41	4030	-	-	-	-	-	-	41
UO_2 (enr)	B	0.013	.26	DS	18	9140	29	10500	$1.24x10^{[illegible]}$	14000	18	7580	1.25x10[illegible]
UF_6 (enr)	B	0.34	3.4	DS	117	9660	-	-	261	760	27	869	405
UO_2-Rx	B	$1.48x10^{-[illegible]}$	3.5	SF	34	9820	-	-	-	-	-	-	34
U-238	A	.0044	.27	SF	3	8050	-	-	81	16100	9	483	93

Mo-99, and Pu-238. Over 80% of the approximately 15,000 packages exported are enriched UO_2, although these represent only a small number of the total curies.

Enriched UO_2 and UF_6 account for about 72% of the approximately 6,500 annual TI exported. The total TI exported is about 0.1% of the total TI transported annually.

A.6.2 IMPORT MODEL

An examination of the import shipments reported in the 1975 shipper survey indicated the following unextrapolated totals:

19 packages
7.2×10^6 curies
40 TI (estimated)

Virtually all the curies were contained in the four special-form Co-60 packages averaging 1.83×10^5 curies per package. Thus, the accident risk is evaluated in Chapter 5 for these four truck shipments only. The normal risk is discussed in Chapter 4 based on the total TI transported. Although the packages arrived in the U.S. by passenger and cargo aircraft, mail, ship, and truck, the environmental impacts of these shipments (evaluated only from the time the shipments enter the U.S. until they reach their U.S. destination) were made by assuming they traveled by truck from their port of entry to their destination. The reported imports included Type A packages of I-125, Yb-169, Cf-252, and C-14, exempt packages of enriched UO_2 and natural uranium metal, one Type B package of Pu-239, one Type B (fissile) package of enriched UO_2, and four Type B packages of Co-60.

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APPENDIX B

EXCERPTS FROM FEDERAL REGULATIONS

B.1 NUCLEAR REGULATORY COMMISSION REGULATIONS

B.1.1 10 CFR Part 71, Packaging of Radioactive Material for Transport and Transportation of Radioactive Material under Certain Conditions

UNITED STATES NUCLEAR REGULATORY COMMISSION

RULES and REGULATIONS

TITLE 10, CHAPTER 1, CODE OF FEDERAL REGULATIONS—ENERGY

PART 71

PACKAGING OF RADIOACTIVE MATERIAL FOR TRANSPORT AND TRANSPORTATION OF RADIOACTIVE MATERIAL UNDER CERTAIN CONDITIONS *

AUTHORITY. The provisions of this Part 71 issued under secs 53, 63, 81, 161, 182, 183, 68 Stat 930, 933, 935, 948, 953, 954, as amended, 42 U.S.C. 2073, 2093, 2111, 2201, 2232, 2233, unless otherwise noted. For the purposes of sec 223, 68 Stat 958, as amended, 42 U.S.C. 2273, §§ 71.61—71.63 issued under sec. 1610, 68 Stat 950, as amended, 42 U.S.C. 2201(o) Secs 202, 206, Pub. L. 93-438, 88 Stat 1244, 1246, 42 U.S.C. 5842, 5846

§ 71.1 Purpose.

38 FR 10437

(a) This part establishes requirements for transportation and for preparation for shipment of licensed material and prescribes procedures and standards for approval by the Nuclear Regulatory Commission of packaging and shipping procedures for fissile material (uranium-233, uranium-235, plutonium-238, plutonium-239, and plutonium-241) and for quantities of licensed materials in excess of type A quantities, as defined in § 71.4(q), and prescribes certain requirements governing such packaging and shipping.

(b) The packaging and transport of these materials are also subject to other parts of this chapter and to the regulations of other agencies having jurisdiction over means of transport. The requirements of this part are in addition to, and not in substitution for, other requirements.

§ 71.2 Scope.

37 FR 3985

The regulations in this part apply to each person authorized by specific license issued by the Commission to receive, possess, use or transfer licensed materials, if he delivers such materials to a carrier for transport or transports such material outside the confines of his plant or other place of use.

§ 71.3 Requirement for license.

No licensee subject to the regulations in this part shall (a) deliver any licensed materials to a carrier for transport or (b) transport licensed material except as authorized in a general license or specific license issued by the Commission, or as exempted in this part.

§ 71.4 Definitions.

31 FR 9941

As used in this part:

(a) "Carrier" means any person engaged in the transportation of passengers or property, as common, contract, or private carrier, or freight forwarder, as those terms are used in the Interstate Commerce Act, as amended, or the U.S. Post Office;

(b) "Close reflection by water" means immediate contact by water of sufficient thickness to reflect a maximum number of neutrons;

(c) "Containment vessel" means the receptacle on which principal reliance is placed to retain the radioactive material during transport;

(d) "Fissile classification" means classification of a package or shipment of fissile materials according to the controls needed to provide nuclear cri-

*Amended 37 FR 3985

ticality safety during transportation as follows:

(1) Fissile Class I: Packages which may be transported in unlimited numbers and in any arrangement, and which require no nuclear criticality safety controls during transportation. For purposes of nuclear criticality safety control, a transportation index is not assigned to Fissile Class I packages. However, the external radiation levels may require a transport index number.

(2) Fissile Class II: Packages which may be transported together in any arrangement but in numbers which do not exceed an aggregate transport index of 50. For purposes of nuclear criticality safety control, individual packages may have a transport index of not less than 0.1 and not more than 10. However, the external radiation levels may require a higher transport index number but not to exceed 10. Such shipments require no nuclear criticality safety control by the shipper during transportation.

(3) Fissile Class III: Shipments of packages which do not meet the requirements of Fissile Classes I or II and which are controlled in transportation by special arrangements between the shipper and the carrier to provide nuclear criticality safety.

33 FR 17621

(e) "Fissile materials" means uranium-233, uranium-235, plutonium-238, plutonium-239, and plutonium-241;

(f) "Large quantity" means a quantity of radioactive material, the aggregate radioactivity of which exceeds any one of the following:

(1) For transport groups as defined in paragraph (p) of this section:

(i) Group I or II radionuclides: 20 curies;

(ii) Group III or IV radionuclides: 200 curies;

(iii) Group V radionuclides: 5,000 curies;

(iv) Group VI or VII radionuclides: 50,000 curies; and

(2) For special form material, as defined in paragraph (o) of this section: 5,000 curies.

(g) "Low specific activity material" means any of the following:

(1) Uranium or thorium ores and physical or chemical concentrates of those ores;

(2) Unirradiated natural or depleted uranium or unirradiated natural thorium;

(3) Tritium oxide in aqueous solutions provided the concentration does not exceed 5.0 millicuries per milliliter:

(4) Material in which the activity is essentially uniformly distributed and in which the estimated average concentration per gram of contents does not exceed:

(i) 0.0001 millicurie of Group I radionuclides; or

(ii) 0.005 millicurie of Group II radionuclides; or

(iii) 0.3 millicurie of Groups III or IV radionuclides.

NOTE This includes, but is not limited to, materials of low radioactivity concentration such as residues or solutions from chemical processing, wastes such as building rubble, metal, wood, and fabric scrap, glassware, paper, and cardboard, solid or liquid plant waste, sludges, and ashes.

33 FR 17621

(5) Objects of nonradioactive material externally contaminated with radioactive material, provided that the radioactive material is not readily dispersible and the surface contamination, when averaged over an area of 1 square meter, does not exceed 0.0001 millicurie (220,000 disintegrations per minute) per square centimeter of Group I radionuclides or 0.001 millicurie (2,200,000 disintegrations per minute) per square centimeter of other radionuclides.

31 FR 9941

(h) "Maximum normal operating pressure" means the maximum gauge pressure which is expected to develop in the containment vessel under the normal conditions of transport specified in Appendix A of this part;

(i) "Moderator" means a material used to reduce, by scattering collisions and without appreciable capture, the kinetic energy of neutrons;

(j) "Optimum interspersed hydrogenous moderation" means the occurrence of hydrogenous material between containment vessels to such an extent that the maximum nuclear reactivity results;

(k) "Package" means packaging and its radioactive contents;

(l) "Packaging" means one or more receptacles and wrappers and their contents excluding fissile material and other radioactive material, but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and for absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment;

(m) "Primary coolant" means a gas, liquid, or solid, or combination of them, in contact with the radioactive material or, if the material is in special form, in contact with its capsule, and used to remove decay heat;

(n) "Sample package" means a package which is fabricated, packed, and closed to fairly represent the proposed package as it would be presented for transport, simulating the material to be transported, as to weight and physical and chemical form;

31 FR 9941

(o) "Special form" means any of the following physical forms of licensed material of any transport group:

(1) The material is in solid form having no dimension less than 0.5 millimeter or at least one dimension greater than five millimeters; does not melt, sublime, or ignite in air at a temperature of 1,000° F.; will not shatter or crumble if subjected to the percussion test described in Appendix D of this part; and is not dissolved or converted into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68° F. or in air at 86° F.; or

(2) The material is securely contained in a capsule having no dimension less than 0.5 millimeter or at least one dimension greater than five millimeters, which will retain its contents if subjected to the tests prescribed in Appendix D of this part; and which is constructed of materials which do not melt, sublime, or ignite in air at 1,475° F., and do not dissolve or convert into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68° F. or in air at 86° F.

33 FR 17621

(p) "Transport group" means any one of seven groups into which radionuclides in normal form are classified, according to their toxicity and their relative potential hazard in transport, in Appendix C of this part.

(1) Any radionuclide not specifically listed in one of the groups in Appendix C shall be assigned to one of the Groups in accordance with the following table:

Radionuclide	Radioactive half-life: 0 to 1000 days	1000 days to 10^6 years	Over 10^6 years
Atomic number 1-81.	Group III	Group II	Group III.
Atomic number 82 and over	Group I	Group I	Group III.

(2) For mixtures of radionuclides the following shall apply:

(i) If the identity and respective activity of each radionuclide are known, the permissible activity of each radionuclide shall be such that the sum, for all groups present, of the ratio between the total activity for each group to the permissible activity for each group will not be greater than unity.

(ii) If the groups of the radionuclides are known but the amount in each group cannot be reasonably determined, the mixture shall be assigned to the most restrictive group present.

(iii) If the identity of all or some of the radionuclides cannot be reasonably determined, each of those unidentified radionuclides shall be considered as belonging to the most restrictive group which cannot be positively excluded.

(iv) Mixtures consisting of a single radioactive decay chain where the radionuclides are in the naturally occurring proportions shall be considered as consisting of a single radionuclide. The group and activity shall be that of the first member present in the chain, except that if a radionuclide "x" has a half-life longer than that of that first member and an activity greater than that of any other member, including the first, at any time during transportation, the transport group of the nuclide "x" and the activity of the mixture shall be the maximum activity of that nuclide "x" during transportation.

Terms defined in Parts 20, 30 to 36 inclusive, and 70 of this chapter have the same meaning when used in this part.

(q) "Type A quantity" and "type B quantity" means a quantity of radioactive material the aggregate radioactivity of which does not exceed that specified in the following table:

Transport groups see § 71.4(p)	Type A quantity (in curies)	Type B quantity (in curies)
I	0.001	20
II	0.05	20
III	3	200
IV	20	200
V	20	5,000
VI and VII	1,000	50,000
Special form	[1] 20	5,000

§ 71.5 Transportation of licensed material.

(a) No licensee shall transport any licensed material outside of the confines of his plant or other place of use, or deliver any licensed material to a carrier for transport, unless the licensee complies with the applicable requirements of the regulations appropriate to the mode of transport, of the Department of Transportation in 49 CFR Parts 170-189, 14 CFR Part 103 and 46 Part 146, and the U.S. Postal Service in 39 CFR Parts 14 and 15 insofar as such regulations relate to the packaging of byproduct, source, or special nuclear material, marking and labeling of the packages, loading and storage of packages, placarding of the transportation vehicle, monitoring requirements and accident reporting.

(b) When Department of Transportation regulations are not applicable to shipments of licensed material by rail, highway, or water because the shipment or the transportation of the shipment is not in interstate or foreign commerce, or to shipments of licensed material by air because the shipment is not transported in civil aircraft, the licensee shall conform to the standards and requirements of the Department of Transportation specified in paragraph (a) of this section, to the same extent as if the shipment or transportation were in interstate or foreign commerce or in civil aircraft. Any requests for modifications, waivers, or exemptions from those requirements, and any notifications referred to in those requirements shall be filed with or made to, the Nuclear Regulatory Commission.

(c) Paragraph (a) of this section shall not apply to the transportation of licensed material, or to the delivery of licensed material to a carrier for transport, where such transportation is subject to the regulations of the Department of Transportation or the U.S Postal Service.

EXEMPTIONS

***§ 71.6 Specific exemptions.**

On application of any interested person or on its own initiative, the Commission may grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not endanger life or property or the common defense and security.

***§ 71.7 Exemption for no more than Type A quantities.†**

A licensee is exempt from all the requirements of this part to the extent that he delivers to a carrier for transport:

(a) Packages each of which contains no licensed material having a specific activity in excess of 0.002 microcurie/gram; or

(b) Shipments subject to the regulations of the Department of Transportation in 49 CFR parts 170—189, 14 CFR part 103, or 46 CFR part 146 or the U.S. Postal Service in 39 CFR parts 14 and 15 of packages each of which contains no more than a type A quantity of radioactive material, as defined in § 71.4(q), which may include one of the following:

(1) Not more than 15 grams of fissile material; or

(2) Thorium, or uranium containing not more than 0.72 percent by weight of fissile material; or

(3) Uranium compounds, other than metal (e.g., UF_6, UF_4, or uranium oxide in bulk form, not pelleted or fabricated into shapes) or aqueous[1] solutions of uranium, in which the total amount of uranium-233 and plutonium present does not exceed 1.0‡ percent by weight of the uranium-235 content, and the total fissile content does not exceed 1.00‡ percent by weight of the total uranium content; or

(4) Homogenous hydrogenous[2] solutions or mixtures containing not more than:

(i) 500 grams of any fissile material, provided the atomic ratio of hydrogen to fissile material is greater than 7,600, or

(ii) 800 grams of uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of other fissile material is not more than 1 percent by weight of the total uranium-235 content; or

(iii) 500 grams of uranium-233 and uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of plutonium is not more than 1 percent by weight of the total uranium-233 and uranium-235 content; or

(5) Less than 350 grams of fissile material: *Provided*, That there is not more than 5 grams of fissile material in any cubic foot within the package.

***§ 71.8 Exemption of physicians.**

Physicians, as defined in § 35.3(b) of this chapter, are exempt from the regulations in this part to the extent that they transport licensed material for use in the practice of medicine.

§ 71.9 Exemption for fissile material.

A licensee is exempt from requirements in §§ 71.33, 71.35(b), 71.36(b), 71.37, 71.38, 71.39, and 71.40 to the extent that he delivers to a carrier for transport packages each of which contains one of the following:

(a) Not more than 15 grams of fissile material; or

(b) Thorium, or uranium containing not more than 0.72 percent by weight of fissile material; or

(c) Uranium compounds, other than metal (e.g., UF_6, UF_4, or uranium oxide

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[1] Except that for californium-252, the limit is 2 Ci

*Redesignated by 38 FR 10437.

†Amended 38 FR 10437.

[1] This applies to light water and does not apply to heavy water.

[2] This applies to light hydrogen and does not apply to heavy hydrogen (i.e., deuterium or tritium).

‡ Amended 38 FR 16347

in bulk form, not pelletted or fabricated into shapes) or aqueous[1] solutions of uranium, in which the total amount of uranium-233 and plutonium present does not exceed 1.0‡ percent by weight of the uranium-235 content, and the total fissile content does not exceed 1.00‡ percent by weight of the total uranium content; or

(d) Homogeneous hydrogenous[2] solutions or mixtures containing not more than:

(1) 500 grams of any fissile material, provided the atomic ratio of hydrogen to fissile material is greater than 7,600; or

(2) 800 grams of uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of other fissile material is not more than 1 percent by weight of the total uranium-235 content; or

(3) 500 grams of uranium-233 and uranium-235: *Provided*, That the atomic ratio of hydrogen to fissile material is greater than 5,200, and the content of plutonium is not more than 1 percent by weight of the total uranium-233 and uranium-235 content; or

(e) Less than 350 grams of fissile material: *Provided*, That there is not more than 5 grams of fissile material in any cubic foot within the package.

§ 71.10 Limited exemption for shipment of type B quantities of radioactive material.

A person delivering a type B quantity of radioactive material, as defined in § 71.4(q), to a carrier for transport in accordance with the provisions of a special permit, which has been issued by the Department of Transportation and is in effect on June 30, 1973, is exempt from the requirements in this part with respect to such shipments. The exemption granted by this section shall terminate on December 31, 1973, or on the date on which the DOT special permit expires, whichever is later, except as to activities described both in the special permit and in an application for a license which the person has, prior to the termination date of the exemption, filed with the Commission. If the person has filed such an application, the exemption granted by this section shall continue until the application has been finally determined by the Commission.

GENERAL LICENSES**

[1] This applies to light water and does not apply to heavy water.

[2] This applies to light hydrogen and does not apply to heavy hydrogen (i.e., deuterium or tritium).

**Added 38 FR 10437.

‡Amended 38 FR 16347.

§ 71.11 General license for shipment of licensed material.

A general license is hereby issued, to persons holding specific licenses issued pursuant to this chapter, to deliver licensed material to a carrier for transport, without complying with the package standards of Subpart C of this part, when either:

(a) The material is shipped as a Fissile Class III shipment with the following limitations on its contents:

(1) No single package contains more than a type A quantity of radioactive material, as defined in § 71.4(q); and

(2) The fissile material contents of the shipment do not exceed:

(i) 500 grams of uranium-235; or

(ii) 300 grams total of uranium-233, plutonium-238, plutonium-239, and plutonium-241; or

(iii) Any combination of uranium-233, uranium-235, and plutonium in such quantities that the sum of the ratios of the quantity of each of them to the quantity specified in subdivisions (i) and (ii) of this subparagraph does not exceed unity; or

(iv) 2500 grams of plutonium-238, plutonium-239, and plutonium-241 encapsulated as plutonium-beryllium neutron sources, with no one package containing in excess of 400 grams of plutonium-238, plutonium-239, and plutonium-241; or

(b) The material is shipped as Fissile Class II packages with the following limitations on the contents of each package:

(1) No single package contains more than a type A quantity of radioactive material, as defined in § 71.4(q); and

(2) No package contains fissile material in excess of the amounts specified in the following table, and each package is labeled with the corresponding transport index:

Maximum quantity of fissile material in a single package				Corresponding transport index
U 235 (grams)	U-233 (grams)	Plutonium (grams)	Plutonium as Pu Be neutron sources (grams)	
35-40	27-30	23-25	320-400	10
30 35	24 27	21-23	240-320	8
25 30	21-24	19 21	160-240	6
20-25	18-21	17-19	80-160	4
15 20	15-18	15-17	15-80	2

NOTE. Combinations of fissile materials are authorized. For combinations of fissile materials, the transport index is the sum of the individual corresponding transport indexes. The total transport index shall not exceed 10.

*Redesignated 38 FR 10437.

§ 71.12 General license for shipment in DOT specification containers, in packages approved for use by another person, and in packages approved by a foreign national competent authority.

A general license is hereby issued, to persons holding a general or specific license issued pursuant to this chapter, to deliver licensed material to a carrier for transport:

(a) In a specification container for fissile material as specified in § 173.396 (b) or (c) or for a type B quantity of radioactive material as specified in § 173.394(b) or § 173.395(b), or for a large quantity of radioactive material as specified in § 173.394(c) or § 173.395(c) of the regulations of the Department of Transportation, 49 CFR part 173; or

(b) In a package for which a license, certificate of compliance or other approval has been issued by the Commission's Director of Nuclear Material Safety and Safeguards or the Atomic Energy Commission, provided that:

(1) The person using a package pursuant to the general license provided by this paragraph:

(i) Has a copy of the specific license, certificate of compliance, or other approval authorizing use of the package and all documents referred to in the license, certificate, or other approval, as applicable;

(ii) Complies with the terms and conditions of the license, certificate, or other approval, as applicable, and the applicable requirements of this part; and

(iii) Prior to first use of the package submits in writing to the Director of Nuclear Material Safety and Safeguards or the Atomic Energy Commission, his name and license number, the name and license or certificate number of the person to whom the package approval has been issued, and the package identification number specified in the package approval

(2) The package approval authorizes use of the package under general license provided in this paragraph.

(c) In a package which meets the pertinent requirements in the 1967 regulations of the International Atomic Energy Agency and the use of which has been approved in a foreign national competent authority certificate which has been revalidated by the Department of Transportation, *Provided*, That the person using a package pursuant to the general license provided by this paragraph:

(1) Has and complies with the applicable certificate, the revalidation, and the documents referenced in the certificate relative to the use and maintenance of the packaging, and the actions to be taken prior to shipment, and

(2) Complies with the applicable requirements of this part, and the Department of Transportation regulations in 49 CFR part 173, 14 CFR part 103, and 46 CFR part 146

38 FR 10437

§ 71.13 Communications.

All communications concerning the regulations in this part should be addressed to the Nuclear Regulatory Commission, Washington, D C 20555, Attention. Director of Nuclear Material Safety and Safeguards, or may be delivered in person at the Commission's offices at 1717 H Street NW., Washington, D.C. or at 7920 Norfolk Avenue, Bethesda, Maryland.

40 FR 8774

*§ 71.14 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding on the Commission.

*§ 71.15 Additional requirements.

The Commission may by rule, regulation, or order impose upon any licensee such requirements, in addition to those established in this part, as it deems necessary or appropriate to protect health or to minimize danger to life or property.

31 FR 9941

***§ 71.16 Amendment of existing licenses.

(a) Licenses issued pursuant to this part and in effect on October 4, 1968, which authorize Fissile Class II packages are hereby amended by increasing the minimum number of units specified for each Fissile Class II package by a factor of 1.25. The new number, shall be rounded up to the first decimal. In addition, the term "radiation units" is changed to "transport index" wherever used in the license.

(b) The reference to § 71.7(b) in licenses issued pursuant to this part prior to March 26, 1972,** is changed to § 71.9(b).

37 FR 3985

(c) The reference to § 71.9(b) in licenses issued pursuant to this part prior to June 30, 1973, is changed to 71.12(b)

38 FR 10437

*Redesignated by FR 10437.

***Amended 37 FR 3985

**Effective date of this amendment.

Subpart B—License Applications

§ 71.21 Contents of application.

An application for a specific license under this part may be submitted as an application for a license or license amendment under this chapter and shall include, for each proposed packaging design and method of transport, the following information in addition to any otherwise required:

(a) A package description as required by § 71.22;

(b) A package evaluation as required by § 71.23,

(c) A description of proposed procedural controls as required by § 71.24;

(d) In the case of fissile material, an identification of the proposed fissile class

§ 71.22 Package description.

The application shall include a description of the proposed package in sufficient detail to identify the package accurately and to provide a sufficient basis for evaluation of the packaging. The description should include:

(a) With respect to the packaging

(1) Gross weight,

(2) Model number;

(3) Specific materials of construction, weights, dimensions, and fabrication methods of.

(i) Receptacles, identifying the one which is considered to be the containment vessel;

(ii) Materials specifically used as nonfissile neutron absorbers or moderators;

(iii) Internal and external structures supporting or protecting receptacles;

(iv) Valves, sampling ports, lifting devices, and tie-down devices;

(v) Structural and mechanical means for the transfer and dissipation of heat; and

(4) Identification and volumes of any coolants and of receptacles containing coolant.

(b) With respect to the contents of the package:

(1) Identification and maximum radioactivity of radioactive constituents;

(2) Identification and maximum quantities of fissile constituents;

(3) Chemical and physical form;

(4) Extent of reflection, the amount and identity of non-fissile neutron absorbers in the fissile constitutents, and the atomic ratio of moderator to fissile constituents;

(5) Maximum weight; and

(6) Maximum amount of decay heat

31 FR 9941

§ 71.23 Package evaluation.

The applicant shall:

(a) Demonstrate that the package satisfies the standards specified in Subpart C;

(b) For a Fissile Class II package, ascertain and specify the number of similar packages which may be transported together in accordance with § 71.39, and

(c) For a Fissile Class III shipment, describe any proposed special controls and precautions to be exercised during transport, loading, unloading, and handling, and in the event of accident or delay.

§ 71.24 Procedural controls.

The applicant shall describe the regular and periodic inspection procedures proposed to comply with § 71.51(c).

37 FR 3985

§ 71.25 Additional information.

The Commission may at any time require further information in order to enable it to determine whether a license, certificate of compliance, or other approval should be granted, denied, modified, suspended, or revoked.

39 FR 22131

Subpart C—Package Standards

§ 71.31 General standards for all packaging.

(a) Packaging shall be of such materials and construction that there will be no significant chemical, galvanic, or other reaction among the packaging components, or between the packaging components and the package contents.

(b) Packaging shall be equipped with a positive closure which will prevent inadvertent opening.

(c) Lifting devices:

(1) If there is a system of lifting devices which is a structural part of the package, the system shall be capable of supporting three times the weight of the loaded package without generating stress in any material of the packaging in excess of its yield strength.

(2) If there is a system of lifting

31 FR 9941

devices which is a structural part only of the lid, the system shall be capable of supporting three times the weight of the lid and any attachments without generating stress in any material of the lid in excess of its yield strength.

(3) If there is a structural part of the package which could be employed to lift the package and which does not comply with subparagraph (1) of this paragraph, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

(4) Each lifting device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the containment or shielding properties of the package.

(d) Tie-down devices:

(1) If there is a system of tie-down devices which is a structural part of the package, the system shall be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a horizontal component in the transverse direction of 5 times the weight of the package with its contents. (31 FR 9941)

(2) If there is a structural part of the package which could be employed to tie the package down and which does not comply with subparagraph (1) of this paragraph, the part shall be securely covered or locked during transport in such a manner as to prevent its use for that purpose.

(3) Each tie-down device which is a structural part of the package shall be so designed that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this subpart.

§ 71.32 Structural standards for type B and large quantity packaging.

(38 FR 10437) Packaging used to ship a type B or a large quantity of radioactive material, as defined in § 71.4 (q) and (f), shall be designed and constructed in accordance with the structural standards of this section.

(31 FR 9941) Standards different from those specified in this section may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

(a) *Load resistance*. Regarded as a simple beam supported at its ends along any major axis, packaging shall be capable of withstanding a static load, normal to and uniformly distributed along its length, equal to 5 times its fully loaded weight, without generating stress in any material of the packaging in excess of its yield strength.

(b) *External pressure*. Packaging shall be adequate to assure that the containment vessel will suffer no loss of contents if subjected to an external pressure of 25 pounds per square inch gauge.

§ 71.33 Criticality standards for fissile material packages.

(a) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that water leaks into the containment vessel, and:

(1) Water moderation of the contents occurs to the most reactive credible extent consistent with the chemical and physical form of the contents; and

(2) The containment vessel is fully reflected on all sides by water.

(31 FR 9941) (b) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that it would be subcritical if it is assumed that any contents of the package which are liquid during normal transport leak out of the containment vessel, and that the fissile material is then:

(1) In the most reactive credible configuration consistent with the chemical and physical form of the material;

(2) Moderated by water outside of the containment vessel to the most reactive credible extent; and

(3) Fully reflected on all sides by water.

(c) The Commission may approve exceptions to the requirements of this section where the containment vessel incorporates special design features which would preclude leakage of liquids in spite of any single packaging error and appropriate measures are taken before each shipment to verify the leak tightness of each containment vessel.

§ 71.34 Evaluation of a single package.

(a) The effect of the transport environment on the safety of any single package of radioactive material shall be evaluated as follows:

(1) The ability of a package to withstand conditions likely to occur in normal transport shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the normal conditions of transport as specified in § 71.35; and

(2) The effect on a package of conditions likely to occur in an accident shall be assessed by subjecting a sample package or scale model, by test or other assessment, to the hypothetical accident conditions as specified in § 71.36.

(31 FR 9941) (b) Taking into account controls to be exercised by the shipper, the Commission may permit the shipment to be evaluated together with or without the transporting vehicle, for the purpose of one or more tests.

(c) Normal conditions of transport and hypothetical accident conditions different from those specified in § 71.35 and § 71.36 may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment.

§ 71.35 Standards for normal conditions of transport for a single package.

(38 FR 10437) (a) A package used for the shipment of fissile material or more than a type A quantity of radioactive material, as defined in § 71.4(q), shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in appendix A of this part:

(31 FR 9941) (1) There will be no release of radioactive material from the containment vessel;

(2) The effectiveness of the packaging will not be substantially reduced;

(3) There will be no mixture of gases or vapors in the package which could, through any credible increase of pressure or an explosion, significantly reduce the effectiveness of the package;

(4) Radioactive contamination of the liquid or gaseous primary coolant will not exceed 10^{-7} curies of activity of Group I radionuclides per milliliter, 5×10^{-6} curies of activity of Group II radionuclides per milliliter, 3×10^{-4} curies of activity of Group III and Group IV radionuclides per milliliter; and

(5) There will be no loss of coolant.

(b) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in Appendix A of this part:

(1) The package will be subcritical;

(2) The geometric form of the package contents would not be substantially altered;

(3) There will be no leakage of water into the containment vessel. This requirement need not be met if, in the

evaluation of undamaged packages under § 71.38(a), § 71.39(a)(1), or § 71.40(a), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material; and

(4) There will be no substantial reduction in the effectiveness of the packaging, including:

(i) Reduction by more than 5 percent in the total effective volume of the packaging on which nuclear safety is assessed,

(ii) Reduction by more than 5 percent in the effective spacing on which nuclear safety is assessed, between the center of the containment vessel and the outer surface of the packaging; or

(iii) Occurrence of any aperture in the outer surface of the packaging large enough to permit the entry of a 4-inch cube.

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(c) A package used for the shipment of more than a type A quantity of radioactive material as defined in § 71.4(q), shall be so designed and constructed and its contents so limited that under the normal conditions of transport specified in appendix A of this part, the containment vessel would not be vented directly to the atmosphere.

38 FR 10437

§ 71.36 Standards for hypothetical accident conditions for a single package.

(a) A package used for the shipment of more than a type A quantity of radioactive material, as defined in § 71.4(q), shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in appendix B of this part as the free drop, puncture, thermal, and water immersion conditions in the sequence listed in appendix B, it will meet the following conditions:

(1) The reduction of shielding would not be sufficient to increase the external radiation dose rate to more than 1,000 millirems per hour at 3 feet from the external surface of the package.

(2) No radioactive material would be released from the package except for gases and contaminated coolant containing total radioactivity exceeding neither:

(i) 0.1 percent of the total radioactivity of the package contents, nor

(ii) 0.01 curie of Group I radionuclides, 0.5 curie of Group II radionuclides, 10 curies of Group III radionuclides, 10 curies of Group IV radionuclides, and 1,000 curies of inert gases irrespective of transport group.

33 FR 17823

A package need not satisfy the requirements of this paragraph if it contains only low specific activity materials, as defined in § 71.4(g), and is transported on a motor vehicle, railroad car, aircraft, inland water craft, or hold or deck of a seagoing vessel assigned for the sole use of the licensee.

33 FR 17823

(b) A package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that if subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Puncture, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, the package would be subcritical. In determining whether this standard is satisfied, it shall be assumed that:

(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents;

(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and

(3) There is reflection by water on all sides and as close as is consistent with the damaged condition of the package.

31 FR 9941

§ 71.37 Evaluation of an array of packages of fissile material.

(a) The effect of the transport environment on the nuclear safety of an array of packages of fissile material shall be evaluated by subjecting a sample package or a scale model, by test or other assessment, to the hypothetical accident conditions specified in § 71.38, § 71.39, or § 71.40 for the proposed fissile class, and by assuming that each package in the array is damaged to the same extent as the sample package or scale model. In this case of a Fissile Class III shipment, the Commission may, taking into account controls to be exercised by the shipper, permit the shipment to be evaluated as a whole rather than as individual packages, and either with or without the transporting vehicle, for the purpose of one or more tests.

(b) In determining whether the standards of §§ 71.38(b), 71.39(a)(2), and 71.40(b) are satisfied, it shall be assumed that:

(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package, the chemical and physical form of the contents, and controls exercised over the number of packages to be transported together; and

(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.

§ 71.38 Specific standards for a Fissile Class I package.

A Fissile Class I package shall be so designed and constructed and its contents so limited that:

(a) Any number of such undamaged packages would be subcritical in any arrangement, and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered; and

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(b) Two hundred fifty such packages would be subcritical in any arrangement, if each package were subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, with close reflection by water on all sides of the array and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in § 71.37.

§ 71.39 Specific standards for a Fissile Class II package.

(a) A Fissile Class II package shall be so designed and constructed and its contents so limited, and the number of such packages which may be transported together so limited, that:

(1) Five times that number of such undamaged packages would be subcritical in any arrangement if closely reflected by water; and

(2) Twice that number of such packages would be subcritical in any arrangement if each package were subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, with close reflection by water on all sides of the array and with optimum interspersed hydrogenous moderation unless there is a greater amount of interspersed moderation in the packaging, in which case that greater amount may be considered. The condition of the package shall be assumed to be as described in § 71.37.

(b) The transport index for each Fissile Class II package is calculated by dividing the number 50 by the number of

33 FR 17624 such Fissile Class II packages which may be transported together as determined under the limitations of paragraph (a) of this section. The calculated number shall be rounded up to the first decimal place.

§ 71.40 Specific standards for a Fissile Class III shipment.

A package for Fissile Class III shipment shall be so designed and constructed and its contents so limited, and the number of packages in a Fissile Class III shipment shall be so limited, that:

(a) The undamaged shipment would be subcritical with an identical shipment in contact with it and with the two shipments closely reflected on all sides by water; and

(b) The shipment would be subcritical if each package were subjected to the hypothetical accident conditions specified in Appendix B of this part as the Free Drop, Thermal, and Water Immersion conditions, in the sequence listed in Appendix B, with close reflection by water on all sides of the array and with the packages in the most reactive arrangement and with the most reactive degree of interspersed hydrogenous moderation which would be credible considering the controls to be exercised over the shipment. The condition of the package shall be assumed to be as described in § 71.37. Hypothetical accident conditions different from those specified, in this paragraph may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to assure the safety of the shipment. 31 FR 9941

§ 71.41 Previously constructed packages for irradiated solid nuclear fuel.

Notwithstanding any other provisions of this Subpart, a package, the use of which has been authorized by the Commission for the transport of irradiated solid nuclear fuel on or after September 23, 1961, and which has been completely constructed prior to January 1, 1967, shall be deemed to comply with the package standards of this subpart for that purpose.

§ 71.42 Special requirements for plutonium shipments after June 17, 1978.

39 FR 20960 (a) Notwithstanding the exemption in § 71.9, plutonium in excess of twenty (20) curies per package shall be shipped as a solid.

(b) Plutonium in excess of twenty (20) curies per package shall be packaged in a separate inner container placed within outer packaging that meets the requirements of Subpart C for packaging of material in normal form. The separate inner container shall not release plutonium when the entire package is subjected to the normal and accident test conditions specified in Appendices A and B. Solid plutonium in the following forms is exempt from the requirements of this paragraph: 39 FR 20960

(1) Reactor fuel elements;

(2) Metal or metal alloy; or

(3) Other plutonium bearing solids that the Commission determines should be exempt from the requirements of this section.

(c) Authority in licenses issued pursuant to this part for delivery of plutonium to a carrier for transport under conditions which do not meet the limitations of paragraphs (a) and (b) of this section shall expire on June 17, 1978.

Subpart D—Operating Procedures

§ 71.51 Establishment and maintenance of procedures.

The licensee shall establish and maintain:

(a) Operating procedures adequate to assure that the determinations and controls required by this chapter are accomplished; 37 FR 3985

(b) Procedures for opening and closing packages in which licensed material is transported to provide safety and to assure that, prior to delivery to a carrier for transport, each package is properly closed for transport; and

(c) Regular and periodic inspection procedures adequate to assure that the procedures required by paragraphs (a) and (b) of this section are followed.

§ 71.52 Assumptions as to unknown properties.

When the isotopic abundance, mass, concentration, degree of irradiation, degree of moderation, or other pertinent property of fissile material in any package is not known, the licensee shall package the fissile material as if the unknown properties have such credible values as will cause the maximum nuclear reactivity. 31 FR 9941

§ 71.53 Preliminary determinations.

(a) Prior to the first use of any packaging for the shipment of licensed materials, the licensee shall ascertain that there are no cracks, pinholes, uncontrolled voids or other defects which could significantly reduce the effectiveness of the packaging.

(b) Prior to the first use of any packaging for the shipment of licensed materials, where the maximum normal operating pressure will exceed 5 pounds per square inch gauge, the licensee shall test the containment vessel to assure that it will not leak at an internal pressure 50 percent higher than the maximum normal operating pressure.

(c) Packaging shall be conspicuously and durably marked with its model number. Prior to applying the model number, the licensee shall determine that the packaging has been fabricated in accordance with the design approved by the Commission.

§ 71.54 Routine determinations.

Prior to each use of a package for shipment of licensed material the licensee shall ascertain that the package with its contents satisfies the applicable requirements of Subpart C of this part and of the license, including determinations that: 31 FR 9941

(a) The packaging has not been significantly damaged;

(b) Any moderators and nonfissile neutron absorbers, if required, are present and are as authorized by the Commission;

(c) The closure of the package and any sealing gaskets are present and are free from defects;

(d) Any valve through which primary coolant can flow is protected against tampering;

(e) The internal gauge pressure of the package will not exceed, during the anticipated period of transport, the maximum normal operating pressure;

(f) Contamination of the primary coolant will not exceed, during the anticipated period of transport, the limits specified in § 71.35(a)(4).

The provisions of this section shall not be applicable for packages authorized in the general licenses granted by § 71.6. In such cases the licensee shall ascertain that the contents of the package are as authorized in the general license.

§ 71.55 Opening instructions.

37 FR 3985 Prior to delivery of a package to a carrier for transport, the licensee shall assure that any special instruction needed to safely open the package are sent to or have been made available to the consignee.

§ 71.61 Reports.

31 FR 9941 The licensee shall report to the Director of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, within 30 days any instance in which

there is substantial reduction in the effectiveness of any authorized packaging during use.

38 FR 10437

§ 71.62 Records.

(a) The licensee shall maintain for a period of 2 years after its generation a record of each shipment of fissile material or of more than a type A quantity of radioactive material as defined in § 71.4(q), in a single package, showing, where applicable:

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(1) Identification of the packaging by model number;

(2) Details of any significant defects in the packaging, with the means employed to repair the defects and prevent their recurrence;

(3) Volume and identification of coolant;

(4) Type and quantity of licensed material in each package, and the total quantity in each shipment;

(5) For each item of irrad[illegible]e material,

(i) Identification by model number;

(ii) Irradiation and decay history to the extent appropriate to demonstrate that its nuclear and thermal characteristics comply with license conditions;

(iii) Any abnormal or unusual condition relevant to radiation safety.

(6) Date of the shipment;

(7) For Fissile Class III, any special controls exercised;

(8) Name and address of the transferee;

(9) Address to which the shipment was made; and

(10) Results of the determinations required by §§ 71.53 and 71.54.

(b) The licensee shall make available to the Commission for inspection, upon reasonable notice, all records required by this part.

§ 71.63 Inspection and tests.

(a) The licensee shall permit the Commission at all reasonable times to inspect the licensed material, packaging, and premises and facilities in which the licensed material or packaging are used, produced, tested, stored or shipped.

(b) The licensee shall perform and permit the Commission to perform, such tests as the Commission deems necessary or appropriate for the administration of the regulations in this chapter.

40 FR 8774

§ 71.64 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule, regulation, or order issued thereunder, or any term, condition, or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction may be punished by fine or imprisonment or both, as provided by law.

APPENDICES

APPENDIX A—NORMAL CONDITIONS OF TRANSPORT

Each of the following normal conditions of transport is to be applied separately to determine its effect on a package

1 *Heat*—Direct sunlight at an ambient temperature of 130° F in still air

2 *Cold*—An ambient temperature of −40° F in still air and shade

3 *Pressure*—Atmospheric pressure of 0.5 times standard atmospheric pressure

4 *Vibration*—Vibration normally incident to transport

5 *Water Spray*—A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period 30 minutes

6 *Free Drop*—Between 1-1/2 and 2 1/2 hours after the conclusion of the water spray test, a free drop through the distance specified below onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

FREE FALL DISTANCE

Package weight (pounds)	*Distance (feet)*
Less than 10 000	4
10,000 to 20,000	3
20,000 to 30 000	2
More than 30,000	1

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7 *Corner Drop*—A free drop onto each corner of the package in succession, or in the case of a cylindrical package onto each quarter of each rim, from a height of 1 foot onto a flat essentially unyielding horizontal surface. This test applies only to packages which are constructed primarily of wood or fiberboard, and do not exceed 110 pounds gross weight, and to all Fissile Class II packagings

8 *Penetration*—Impact of the hemispherical end of a vertical steel cylinder 1-1/4 inches in diameter and weighing 13 pounds dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture. The long axis of the cylinder shall be perpendicular to the package surface

9 *Compression*—For packages not exceeding 10 000 pounds in weight, a compressive load equal to either 5 times the weight of the package or 2 pounds per square inch multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally be transported

APPENDIX B—HYPOTHETICAL ACCIDENT CONDITIONS

The following hypothetical accident conditions are to be applied sequentially, in the order indicated, to determine their cumulative effect on a package or array of packages.

1. *Free Drop*—A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

2. *Puncture*—A free drop through a distance of 40 inches striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.

3. *Thermal*—Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiation environment of 1,475° F. for 30 minutes with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hours after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hours.

4. *Water Immersion* (fissile material packages only)—Immersion in water to the extent that all portions of the package to be tested are under at least 3 feet of water for a period of not less than 8 hours.

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APPENDIX C—TRANSPORT GROUPING OF RADIONUCLIDES

Element*	Radionuclide***	Group
Actinium (89)	Ac 227	I
	Ac 228	I
Americium (96)	Am 241	I
	Am 243	I
Antimony (51)	Sb 122	IV
	Sb 124	III
	Sb 125	III
Argon (18)	Ar-37	VI
	Ar-41	II
	Ar-41 (uncompressed)**	V
Arsenic (33)	As 73	IV
	As 74	IV
	As 76	IV
	As 77	IV
Astatine (85)	At 211	III
Barium (56)	Ba 131	IV
	Ba-133	II
	Ba 140	III
Berkelium (97)	Bk 249	I
Beryllium (4)	Be 7	IV
Bismuth (83)	Bi 206	IV
	Bi 207	III
	Bi 210	II
	Bi 212	III
Bromine (35)	Br 82	IV
Cadmium (48)	Cd 109	IV
	Cd 115 m	III
	Cd 115	IV
Calcium (20)	Ca 45	IV
	Ca 47	IV
Californium (98)	Cf 249	I
	Cf 250	I
	Cf 252	I
Carbon (6)	C 14	IV
Cerium (58)	Ce 141	IV
	Ce 143	IV
	Ce 144	III
Cesium (55)	Cs 131	IV
	Cs 134 m	III
	Cs 134	III
	Cs 135	IV
	Cs 136	IV
	Cs 137	III
Chlorine (17)	Cl 36	III
	Cl 138	IV
Chromium (24)	Cr 51	IV
Cobalt (27)	Co 56	III
	Co 57	IV
	Co 58 m	IV
	Co 58	IV
	Co 60	III
Copper (29)	Cu 64	IV
Curium (96)	Cm 242	I
	Cm 243	I
	Cm 244	I
	Cm 245	I
	Cm 246	I
Dysprosium (66)	Dy 154	III
	Dy 165	IV
	Dy 166	IV
Erbium (68)	Er 169	IV
	Er 171	IV
Europium (63)	Eu 150	III
	Eu 152 m	IV
	Eu 152	III
	Eu 154	II
	Eu 155	IV
Fluorine (9)	F 18	IV
Gadolinium (64)	Gd 153	IV
	Gd 159	IV
Gallium (31)	Ga 67	III
	Ga 72	IV
Germanium (32)	Ge 71	IV
Gold (79)	Au 193	III
	Au 194	III
	Au 195	III

See footnotes at end of table.

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APPENDIX C—TRANSPORT GROUPING OF RADIONUCLIDES—Continued

Element*	Radionuclide***	Group
	Au 196	IV
	Au 198	IV
	Au 199	IV
Hafnium (72)	Hf 181	IV
Holmium (67)	Ho 166	IV
Hydrogen (1)	H 3 (see tritium)	
Indium (49)	In 113 m	IV
	In 114 m	III
	In 115 m	IV
	In 115	IV
Iodine (53)	I 124	III
	I 125	III
	I 126	III
	I 129	III
	I 131	III
	I 132	IV
	I 133	III
	I 134	IV
	I 135	IV
Iridium (77)	Ir 190	IV
	Ir 192	III
	Ir 194	IV
Iron (26)	Fe 55	IV
	Fe 59	IV
Krypton (36)	Kr 85 m	III
	Kr 85 m (uncompressed).**	V
	Kr 85	III
	Kr 85 (uncompressed).**	VI
	Kr 87	II
	Kr 87 (uncompressed) **	V
Lanthanum (57)	La 140	IV
Lead (82)	Pb 203	IV
	Pb 210	II
	Pb 212	II
Lutecium (71)	Lu 172	III
	Lu 177	IV
Magnesium (12)	Mg 28	III
Manganese (25)	Mn 52	IV
	Mn 54	IV
	Mn 56	IV
Mercury (80)	Hg 197 m	IV
	Mn 56	IV
Mercury (80)	Hg 197 m	IV
	Hg 197	IV
	Hg 203	IV
Mixed fission products MFP.		II

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Element*	Radionuclide***	Group
Molybdenum (42)	Mo 99	IV
Neodymium (60)	Nd 147	IV
	Nd 149	IV
Neptunium (93)	Np 237	I
	Np 239	I
Nickel (28)	Ni 56	III
	Ni 59	IV
	Ni 63	IV
	Ni 65	IV
Niobium (41)	Nb 93 m	IV
	Nb 95	IV
	Nb 97	IV
Osmium (76)	Os 185	IV
	Os 191 m	IV
	Os 191	IV
	Os 193	IV
Palladium (46)	Pd 103	IV
	Pd 109	IV
Phosphorus (15)	P 32	IV
Platinum (78)	Pt 191	IV
	Pt 193	IV
	Pt 193 m	IV
	Pt 197 m	IV
	Pt 197	IV
Plutonium (94)	Pu 238 (F)	I
	Pu 239 (F)	I

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See footnotes at end of table.

APPENDIX C—TRANSPORT GROUPING OF RADIONUCLIDES—Continued

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Element*	Radionuclides***	Group
	Pu 240	I
	Pu 241 (F)	I
	Pu 242	I
Polonium (84)	Po 210	I
Potassium (19)	K 42	IV
	K 43	III
Praseodymium (59)	Pr 142	IV
	Pr 143	IV
Promethium (61)	Pm 147	IV
	Pm 149	IV
Protactinium (91)	Pa 230	I
	Pa 231	I
	Pa 233	II
Radium (88)	Ra 223	II
	Ra 224	II
	Ra 236	I
	Ra 228	I
Radon (86)	Rn 220	IV
	Rn 222	II
Rhenium (75)	Re 183	IV
	Re 186	IV
	Re 187	IV
	Re 188	IV
	Re Natural	IV
Rhodium (45)	Rh 103 m	IV
	Rh 105	IV
Rubidium (37)	Rb 86	IV
	Rb 87	IV
	Rb Natural	IV
Ruthenium (44)	Ru 97	IV
	Ru 103	IV
	Ru 105	IV
	Ru 106	III
Samarium (62)	Sm 145	III
	Sm 147	III
	Sm 151	IV
	Sm 153	IV
Scandium (21)	Sc 46	III
	Sc 47	IV
	Sc 48	IV
Selenium (34)	Se 75	IV
Silicon (14)	Si 31	IV
Silver (47)x11	Ag 105	IV
	Ag 110 m	III
	Ag 111	IV
Sodium (11)	Na 22	III
	Na 24	IV
Strontium (38)	Sr 85 m	IV
	Sr 85	IV
	Sr 89	III
	Sr 90	II
	Sr 91	III
	Sr 92	IV
Sulphur (16)	S 35	IV
Tantalum (73)	Ta 182	III
Technetium (43)	Tc 96 m	IV
	Tc 96	IV
	Tc 97 m	IV
	Tc 97	IV
	Tc 99 m	IV
	Tc 99	IV
Tellurium (52)	Te 125 m	IV
	Te 127 m	IV
	Te 127	IV
	Te 129 m	III
	Te 129	IV
	Te 131 m	III
	Te 132	IV
Terbium (65)	Tb 160	III
Thallium (81)	Tl 200	IV
	Tl 201	IV
	Tl 202	IV
	Tl 204	III
Thorium (90)	Th 227	II
	Th 228	I
	Th 230	I
	Th 231	I
	Th 232	III
	Th 234	II
	Th Natural	III
Thulium (69)	Tm 168	III
	Tm 170	III
	Tm 171	IV
Tin (50)	Sn 113	IV
	Sn 117 m	III
	Sn 121	III
	Sn 125	IV
Tritium (1)	H 3	IV
	H 3 (as a gas, as luminous paint, or adsorbed on solid material)	VII
Tungsten (74)	W 181	IV
	W 185	IV
	W 187	IV
Uranium (92)	U 230	II
	U 232	I
	U 233 (F)	II
	U 234	II
	U 235 (F)	III
	U 236	II
	U 238	III
	U Natural	III
	U Enriched (F)	III
	U Depleted	III
Vanadium (23)	V 48	IV
	V 49	III
Xenon (54)	Xe 125	III
	Xe 131 m	III
	Xe 131 m (uncompressed).**	V
	Xe 133	III
	Xe 133 (uncompressed).**	VI
	Xe 135	II
	Xe 135 (uncompressed).**	V
Ytterbium (70)	Yb 175	IV
Yttrium (39)	Y 88	III
	Y 90	IV
	Y 91 m	III
	Y 91	III
	Y 92	IV
	Y 93	IV
Zinc (30)	Zn 65	IV
	Zn 69 m	IV
	Zn 69	IV
Zirconium (40)	Zr 93	IV
	Zr 95	III
	Zr 97	IV

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See footnotes at end of table.

*Atomic number shown in parentheses

**Uncompressed means at a pressure not exceeding one atmosphere

***Atomic weight shown after the radionuclide symbol.

m—Metastable state.

(F) Fissile material

APPENDIX D—TESTS FOR SPECIAL FORM LICENSED MATERIAL

1. *Free Drop*—A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in such a position as to suffer maximum damage.

2. *Percussion*—Impact of the flat circular end of a 1 inch diameter steel rod weighing 3 pounds, dropped through a distance of 40 inches. The capsule or material shall be placed on a sheet of lead, of hardness number 3.5 to 4.5 on the Vickers scale, and not more than 1 inch thick, supported by a smooth essentially unyielding surface.

3. *Heating*—Heating in air to a temperature of 1,475° F. and remaining at that temperature for a period of 10 minutes.

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4. *Immersion*—Immersion for 24 hours in water at room temperature. The water shall be at pH 6–pH 8, with a maximum conductivity of 10 micromhos per centimeter.

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The record keeping and reporting requirements contained in this part have been approved by the Bureau of the Budget in accordance with the Federal Reports Act of 1942.

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PHYSICAL PROTECTION OF SPECIAL NUCLEAR MATERIAL IN TRANSIT

§ 73.30 General requirements.

(a) Except as specified in § 73.38(a) or as otherwise authorized pursuant to § 73.30(f), each licensee who transports or who delivers to a carrier for transport either uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope), uranium-233, or plutonium, or any combination of these materials, which is 5,000 grams or more computed by the formula, grams=(grams contained U-235)+2.5 (grams U-233+grams plutonium), shall make arrangements to assure that such special nuclear material will, if a common or contract carrier is used, be transported under the established procedures of a carrier which provides a system for the physical protection of valuable material in transit and requires an exchange of hand-to-hand receipts at origin and destination and at all points enroute where there is a transfer of custody.

(b) Transit times of shipments other than those specified in § 73.1(b)(3) shall be minimized and routes shall be selected to avoid areas of natural disaster or civil disorders. Such shipments shall be preplanned to assure that deliveries occur at a time when the receiver at the final delivery point is present to accept receipt of shipment.

(c) Special nuclear material shall be shipped in containers which are sealed by tamper indicating type seals. The container shall also be locked if it is not in another container or vehicle which is locked. If inspection of the container or vehicle is not required by State or local authorities before final destination, the outermost container or vehicle shall also be sealed by tamper indicating type seals. No container weighing 500 pounds or less shall be shipped in open trucks, railroad flat cars or box cars and ships. This paragraph does not apply to shipments of quantities specified in § 73.1(b)(3).

(d) When guards are used pursuant to §§ 73.31(c)(1), 73.31(c)(2), 73.33 and 73.35, the licensee shall not permit an individual to act as a guard unless there is documentation that the individual has been qualified by demonstrating an understanding of his duties and responsibilities. The licensee or his agent shall have documentation that guards have been requalified annually.

(e) By January 7, 1974, each licensee shall submit a plan outlining the procedures that will be used to meet the requirements of §§ 73.30 through 73.36 and 73.70(g) including a plan for the selection, qualification, and training of armed escorts, or the specification and design of a specially designed truck or trailer as appropriate. This plan shall be followed by the licensee after March 6, 1974.

(f) A licensee or applicant for a license may apply to the Commission for approval of proposed procedures for transport of special nuclear material in a manner not otherwise authorized by the regulations of this part. Such application shall include a description and quantity of the special nuclear material involved, the origin and destination, the carriers to be used, the expected time in transit, the number of transfer points, the communications to be used, the vehicle visual identification, and the cargo security and surveillance measures to be used.

(g) Paragraphs (b), (c), (d), and (f) of this section are effective March 6, 1974.

§ 73.31 Shipment by road.

(a) All shipments by road shall be made without any scheduled intermediate stops to transfer special nuclear material or other cargo between the facility from which it is shipped and the facility of the receiver.

(b) All motor vehicles used to transport special nuclear material shall be equipped with a radiotelephone which can communicate with a licensee or his agent. The licensee or agent with whom communications shall be maintained for different segments of the shipment shall be predesignated before a shipment is made. Calls to such licensee or agent shall be made at least every 2 hours when radiotelephone or conventional telephone coverage along the route is available to relay position and projected route. Call frequency may extend up to 5 hours when radiotelephone or conventional telephone coverage is not available along the preplanned route, at which time a conventional telephone call shall be made. In the event no call is received in accordance with these requirements, the licensee or his agent shall immediately notify an appropriate law enforcement authority and the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of this part.

(c) A shipment shall be accompanied by at least two people in the vehicle containing the shipment, which may be two drivers or one driver and an authorized individual. The vehicle containing the shipment shall be under continuous visual surveillance, or one of the drivers or authorized individuals shall be in the cab of the vehicle, awake, and not in a sleeper berth. The shipment shall be further protected by one of the following methods:

(1) An armed escort consisting of at least two guards shall accompany the shipment in a separate escort vehicle. Escorts shall maintain continuous vigilance for the presence of conditions or situations which might threaten the security of the shipment, take such action as circumstances might require to avoid interference with continuous safe passage of the cargo vehicle, provide assistance to, or summon aid for crew of cargo vehicles in case of emergency, check seals and locks at each stop where time permits, and observe the cargo vehicle and adjacent areas during stops or layovers. Continuous radio communication capability shall be provided between the cargo vehicle and the escort vehicle. Escort vehicles shall also be equipped with a radiotelephone. The licensee may use his own employees as armed escorts or he may use an agent. Only the driver is required in the vehicle containing special nuclear material for shipments involving an average of less than an hour in transportation, if communication is maintained during the course of the shipment with the licensee or agent monitoring the shipment.

(2) The shipment shall be made in a specially designed truck or trailer which reduces the vulnerability to diversion. Design features of the truck or trailer shall permit immobilization of the van and provide barriers or deterrents to physical penetration of the cargo compartment unless armed guards are also used in which case immobilization of the vehicle is not required.

(d) Transfers to and from other modes of transportation shall be in accordance with § 73.35.

(e) Vehicles shall be marked on top with identifying letters or numbers which will permit identification of the vehicle under daylight conditions from the air in clear weather at 1,000 feet above ground level. The same code of letters and numbers as those used on the top shall also be marked on the sides and rear of the vehicle to permit identification from the ground.

(f) This section is effective March 6, 1974.

§ 73.32 Shipment by air.

(a) Except as specifically approved by the Nuclear Regulatory Commission, no shipment of special nuclear material shall be made in passenger aircraft in excess of (1) 20 grams or 20 curies, whichever is less, of plutonium or uranium-233, or (2) 350 grams of uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope).

(b) In shipments on cargo aircraft of either uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope), uranium-233 or plutonium, or any combination of these materials which is 5,000 grams or more computed by the formula, grams=(grams contained U-235) + 2.5(grams U-233 + grams plutonium), transfers shall be in accordance with § 73.35. Transfers shall be minimized.

(c) Export shipments shall be escorted by an unarmed authorized individual, who may be a crew member, from the last terminal in the United States until the shipment is unloaded at a foreign terminal. He shall perform monitoring duties at foreign terminals as described in § 73.35.

(d) Paragraph (c) of this section is effective March 6, 1974.

§ 73.33 Shipment by rail.

(a) A shipment by rail shall be escorted by two guards, in the shipment car or an escort car of the train, who shall keep the shipment cars under observation and who shall detrain at stops when practicable and time permits to guard the shipment cars under observation, and check car or container locks and seals. Radiotelephone communication shall be maintained with a licensee or his agent to relay position every 2 hours or less, and at scheduled stops in the event that radiotelephone coverage was not available in the last 5 hours before the stop. The licensee or agent with whom communications shall be maintained for different segments of the shipment shall be predesignated before a shipment is made. In the event no call is received in accordance with these requirements, the licensee or his agent shall immediately notify an appropriate law enforcement authority and the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of this part.

(b) Transfers shall be in accordance with § 73.35.

(c) This section is effective March 6, 1974.

§ 73.34 Shipment by sea.

(a) Shipments shall be made on vessels making the minimum ports of call. Transfers to and from other modes of transportation shall be in accordance with § 73.35. There shall be no scheduled transfers to other ships. At domestic ports of call where other cargo is transferred, the shipments shall be protected in accordance with § 73.35(a).

(b) The shipment shall be placed in a secure compartment which is locked and sealed. Locks and seals shall be periodically inspected in transit, if accessible, by an escort or crew member.

(c) Export shipments shall be escorted by an unarmed authorized individual, who may be a crew member, from the last port in the United States until the shipment is unloaded at a foreign port. He shall perform monitoring duties at foreign ports as described in § 73.35.

(d) Ship-to-shore communications shall be available, and a ship-to-shore contact shall be made every twenty-four hours to relay position information, and the status of the shipment, which shall be determined by a daily inspection where possible. This information shall be sent, as often as it is available, to the licensee or his agent who makes the arrangements for the protection of the shipment.

(e) This section is effective March 6, 1974.

§ 73.35 Transfer of special nuclear material.

All transfers shall be monitored by a guard. An alternate guard shall be designated at all transfer points to substitute, if necessary. Monitoring of special nuclear material transfers shall be conducted as follows:

(a) At scheduled intermediate stops where special nuclear material is not scheduled for transfer, the guard shall observe the opening of the cargo compartment and assure that the shipment is not removed. The guard shall maintain continuous visual surveillance of the cargo compartment. Continuous visual surveillance of the cargo compartment shall be maintained up to the time the vehicle is ready to depart. The guard shall observe the vehicle until it has departed, and shall notify the licensee or his agent of the latest status immediately thereafter.

(b) At points where special nuclear material is transferred from a vehicle to storage, from one vehicle to another, or from storage to a vehicle, the guard shall keep the shipment under continuous visual surveillance by observing the opening of the cargo compartment of the incoming vehicle and assuring that the shipment is complete by checking locks and/or seals. Continuous visual surveillance of a shipment shall be maintained at all times it is in the terminal or in storage. Shipments shall be preplanned in order to avoid storage times in excess of 24 hours. Continuous visual surveillance of the cargo compartment shall be maintained up to the time the vehicle is ready to depart from the terminal. The guard shall observe the vehicle until it has departed, and shall notify the licensee or his agent of the latest status immediately thereafter.

(c) The guard shall be required to immediately notify the carrier and the licensee who made the arrangements for protection of special nuclear material of any deviation from or attempted interference with schedule or routing.

(d) This section is effective March 6, 1974.

§ 73.36 Miscellaneous requirements.

(a) Each licensee who takes delivery of special nuclear material free on board (f.o.b.) the point at which it is delivered to a carrier for transport shall make the arrangements to assure that such special nuclear material will be protected in transit as prescribed in §§ 73.30 through 73.35, rather than the person who delivers such shipment to the carrier for transport.

(b) Each licensee who imports special nuclear material shall make arrangements to assure that such material will be protected in transit as follows:

(1) An individual designated by the licensee or his agent, or as specified by a contract of carriage, shall confirm the container count and examine locks and/or seals for evidence of tampering, at the first place in the United States at which the shipment is discharged from the arriving carrier.

(2) The shipment shall be protected at the first terminal at which it arrives in the United States and all subsequent terminals as provided in §§ 73.30 through 73.35 and paragraphs (c) and (f) of this section.

(c) (1) Each licensee who delivers special nuclear material to a carrier for transport shall immediately notify the consignee by telephone, telegraph, or teletype, of the time of departure of the shipment, and shall notify or confirm with the consignee the method of transportation, including the names of carriers, and the estimated time of arrival of the shipment at its destination. (2) In the case of a shipment free on board (f.o.b.) the point where it is delivered to a carrier for transport, each licensee shall, before the shipment is delivered to the carrier, obtain written certification from the licensee who is to take delivery of the shipment at the f.o.b. point that the physical protection arrangements required by §§ 73.30 through 73.35 for licensed shipments have been made. When a contractor exempt from the requirements for a Commission license is the consignee of a shipment, the licensee shall, before the shipment is delivered to the carrier, obtain written certification from the contractor who is to take delivery of the shipment at the f.o.b. point that the physical protection arrangements required by ERDA Manual or NRC Manual Chapters 2401 or 2405, as appropriate, have been made.

(c) (3) Each licensee who delivers special nuclear material to a carrier for transport or releases special nuclear material f.o.b. at the point where it is delivered to a carrier for transport shall also make arrangements with the consignee to be notified immediately by telephone and telegraph or teletype, of the arrival of the shipment at its destination.

(d) In addition to complying with the requirements specified in paragraphs (c) and (f) of this section, each licensee who exports special nuclear material shall comply with the requirements specified in §§ 73.30 through 73.35, as applicable, up to the first point where the shipment is taken off the vehicle outside the United States. The licensee shall also make arrangements with the consignee to be notified immediately by telephone and telegraph, teletype, or cable, of the arrival of the shipment at its destination, or of any such shipment that is lost or unaccounted for after the estimated time of arrival at its destination.

(e) Each licensee who receives a shipment of special nuclear material shall immediately notify by telephone and telegraph or mailgram, or facsimile,† the person who delivered the material to a carrier for transport and the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of the arrival of the shipment at its destination. When an Energy Research and Development Administration (ERDA) license-exempt contractor is the consignee, the licensee who is the consignor shall notify by telephone and telegraph, or mailgram, or facsimile,† the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of the arrival of the shipment at its destination immediately upon being notified of the receipt of the shipment by the license-exempt contractor as arranged pursuant to paragraph (c)(3) of this section. In the event such a shipment fails to arrive at its destination at the estimated time, the consignee, if a licensee, or in the case of an export shipment, the licensee who exported the shipment, shall immediately notify by telephone and telegraph, or mailgram, or facsimile,† the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of this part, and the licensee or other person who delivered the material to a carrier for transport. The licensee who made the physical protection arrangements shall also immediately notify by telephone and telegraph, or teletype, the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix A of the action being taken to trace the shipment.

(f) Each licensee who makes arrangements for physical protection of a shipment of special nuclear material as required by §§ 73.30 through 73.36 shall immediately conduct a trace investigation of any shipment that is lost or unaccounted for after the estimated arrival time and file a report with the Commission as specified in § 73.71. If the licensee who conducts the trace investigation is not the consignee, he shall also immediately report the results of his investigation by telephone and telegraph, or teletype to the consignee.

(g) Paragraphs (a), (b), (c) and (d) of this section are effective March 6, 1974.

B.1.3 10 CFR §20.205, PROCEDURES FOR PICKING UP, RECEIVING, AND OPENING PACKAGES

§ 20.205 Procedures for picking up, receiving, and opening packages.

(a)(1) Each licensee who expects to receive a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section shall:

(i) If the package is to be delivered to the licensee's facility by the carrier, make arrangements to receive the package when it is offered for delivery by the carrier; or

(ii) If the package is to be picked up by the licensee at the carrier's terminal, make arrangements to receive notification from the carrier of the arrival of the package, at the time of arrival.

(2) Each licensee who picks up a package of radioactive material from a carrier's terminal shall pick up the package expeditiously upon receipt of notification from the carrier of its arrival.

(b)(1) Each licensee, upon receipt of a package of radioactive material, shall monitor the external surfaces of the package for radioactive contamination caused by leakage of the radioactive contents, except:

(i) Packages containing no more than the exempt quantity specified in the table in this paragraph;

(ii) Packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, carbon-14, sulfur-35, or iodine-125;

(iii) Packages containing only radioactive material as gases or in special form;

(iv) Packages containing only radioactive material in other than liquid form (including Mo-99/Tc-99m generators) and not exceeding the Type A quantity limit specified in the table in this paragraph; and

(v) Packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries.

The monitoring shall be performed as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or eighteen hours if received after normal working hours.

(2) If removable radioactive contamination in excess of 0.01 microcuries (22,000 disintegrations per minute) per 100 square centimeters of package surface is found on the external surfaces of the package, the licensee shall immediately notify the final delivering carrier and, by telephone and telegraph, mailgram, or facsimile,† the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

TABLE OF EXEMPT AND TYPE A QUANTITIES

Transport group [1]	Exempt quantity limit (in millicuries)	Type A quantity limit (in curies)
I	.01	0.001
II	0.1	0.050
III	1	3
IV	1	20
V	1	20
VI	1	1000
VII	25,000	1000
Special Form	1	20

(c)(1) Each licensee, upon receipt of a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section, other than those transported by exclusive use vehicle, shall monitor the radiation levels external to the package. The package shall be monitored as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or 18 hours if received after normal working hours.

(2) If radiation levels are found on the external surface of the package in excess of 200 millirem per hour, or at three feet from the external surface of the package in excess of 10 millirem per hour, the licensee shall immediately notify by telephone and telegraph, mailgram, or facsimile, the director of the appropriate NRC Regional Office listed in Appendix D, and the final delivering carrier.

(d) Each licensee shall establish and maintain procedures for safely opening packages in which licensed material is received, and shall assure that such procedures are followed and that due consideration is given to special instructions for the type of package being opened.

B.2 DEPARTMENT OF TRANSPORTATION REGULATIONS

B.2.1 49 CFR §173.393, GENERAL PACKAGING AND SHIPPING REQUIREMENTS

§ 173.393 General packaging and shipment requirements.

(a) Unless otherwise specified, all shipments of radioactive materials must meet all requirements of this section, and must be packaged as prescribed in §§ 173.391 through 173.396.

(b) The outside of each package must incorporate a feature such as a seal, which is not readily breakable and which, while intact, will be evidence that the package has not been illicitly opened.

(c) The smallest outside dimension of any package must be 4 inches or greater.

(d) Each radioactive material must be packaged in a packaging which has been designed to maintain shielding efficiency and leak tightness, so that, under conditions normally incident to transportation, there will be no release of radioactive material. If necessary, additional suitable inside packaging must be used. Each package must be capable of meeting the standards in §§ 173.398(b) and 173.24.

(1) Internal bracing or cushioning, where used, must be adequate to assure that, under the conditions normally incident to transportation, the distance from the inner container or radioactive material to the outside wall of the package remains within the limits for which the package design was based, and the radiation dose rate external to the package does not exceed the transport index number shown on the label. Inner shield closures must be positively secured to prevent loss of the contents.

(e) The packaging must be designed, constructed, and loaded so that during transport:

(1) The heat generated within the package because of the radioactive materials present will not, at any time during transportation, affect the efficiency of the package under the conditions normally incident to transportation, and

(2) The temperature of the accessible external surfaces of the package will not exceed 122° F. in the shade when fully loaded, assuming still air at ambient temperature. If the package is transported in a transport vehicle consigned for the sole use of the consignor, the maximum accessible external surface temperature shall be 180° F.

(f) Pyrophoric materials, in addition to the packaging prescribed in this subpart, must also meet the packaging requirements of § 173.134 or § 173.154. Pyrophoric radioactive liquids may not be shipped by air.

(g) Liquid radioactive material in Type A quantities must be packaged in or within a leak-resistant and corrosion-resistant inner containment vessel. In addition:

(1) The packaging must be adequate to prevent loss or dispersal of the radioactive contents from the inner containment vessel if the package were subjected to the 9 meter (30-foot) drop test prescribed in § 173.398(c)(2)(i); and either

(2) Enough absorbent material must be provided to absorb at least twice the volume of radioactive liquid contents. The absorbent material may be located outside the radiation shield only if it can be shown that if the radioactive liquid contents were taken up by the absorbent material the resultant dose rate at the surface of the package would not exceed 1,000 millirem per hour; or

(3) A secondary leak-resistant and corrosion-resistant containment vessel must be provided to retain the radioactive contents under the normal conditions of transport as prescribed in § 173.398(b), assuming the failure of the inner primary containment vessel.

(h) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(i) Except for shipments described in paragraph (j) of this section, all radioactive materials must be packaged in suitable packaging (shielded, if necessary) so that at any time during the normal conditions incident to transportation the radiation dose rate does not exceed 200 millirem per hour at any point on the external surface of the package, and the transport index does not exceed 10.

(j) Packages for which the radiation dose rate exceeds the limits specified in paragraph (i) of this section, but does not exceed at any time during transportation any of the limits specified in paragraphs (j) (1) through (4) of this section may be transported in a transport vehicle which has been consigned as exclusive use (except aircraft). Specific instructions for maintenance of the exclusive use (sole use) shipment controls must be provided by the shipper to the carrier. Such instructions must be included with the shipping paper information:

(1) 1,000 millirem per hour at 3 feet from the external surface of the package (closed transport vehicle only);

(2) 200 millirem per hour at any point on the external surface of the car or vehicle (closed transport vehicle only);

(3) Ten millirem per hour at any point 2 meters (six feet) from the vertical planes projected by the outer lateral surface of the car or vehicle; or if the load is transported in an open transport vehicle, at any point 2 meters (six feet) from the vertical planes projected from the outer edges of the vehicle.

(4) 2 millirem per hour in any normally occupied position in the car or vehicle, except that this provision does not apply to private motor carriers.

(k) [Reserved]

(l) Packages consigned for export are also subject to the regulations of the foreign governments involved in the shipment. See §§ 173.8, 173.9, and 173.393b. (The regulations of the International Atomic Energy Agency (IAEA) are used by most foreign governments.)

(m) Prior to the first shipment of any package, the shipper shall determine by examination or appropriate test that:

(1) The packaging meets the specified quality of design and construction; and

(2) The effectiveness of the shielding and containment, and, where necessary, the heat transfer characteristics of the package are within the limits applicable to or specified for the package design.

(n) Prior to each shipment of any package, the shipper shall insure by examination or appropriate test that:

(1) The package is proper for the contents to be shipped;

(2) The packaging is in unimpaired physical condition except for superficial marks;

(3) Each closure device of the packaging, including any required gasket, is properly installed and secured and free of defects;

(4) For a fissile material, any moderator and neutron absorber, if required, is present in proper condition;

(5) Any special instructions for filling, closing, and preparation of the package for shipment have been followed;

(6) Each closure, valve, and any other opening of the containment system through which the radioactive content might escape is properly closed and sealed;

(7) Each package containing liquid in excess of a Type A quantity and destined for air shipment is tested to demonstrate that it is leak tight under an ambient atmospheric pressure differential of at least 0.5 atmosphere (absolute) (7.3 p.s.i.a. or 0.5 kg./cm.^{2}); the test may be conducted on the entire containment system or on any receptacle or vessel within the containment system, as appropriate to determine compliance with the requirement;

(8) If the maximum normal operating pressure of a package is likely to exceed 0.35 kg./cm.^{2} (gage), the internal pressure of the containment system will not exceed the design pressure during transportation; and

(9) External radiation and contamination levels are within the allowable limits.

(o) No person may offer for transportation a package of radioactive materials until the temperature of the packaging system has reached equilibrium (see also paragraph (e) of this section) unless, for the specific contents, he has ascertained that the maximum applicable surface temperature limits cannot be exceeded.

(p) No person may offer for transportation aboard a passenger carrying aircraft any radioactive material unless that material is intended for use in, or incident to, research, or medical diagnosis or treatment, or is excepted under the provisions of § 175.10 of this subchapter.

[Amdt 173-3, 33 FR 14926, Oct. 4, 1968, as amended by Amdt. 173-6, 34 FR 7162, May 1, 1969, Amdt. No 173-66, FR 17970, Sept. 2, 1972; Amdt. 173-90, 39 FR 45241, Dec. 31, 1974; Amdt. 173-94A, 41 FR 40684, Sept. 20, 1976]

§ 173.391 Limited quantities of radioactive materials and radioactive devices.

(a) Limited quantities of radioactive materials in normal form not exceeding 0.01 millicurie of Group I radionuclides; 0.1 millicurie of Group II radionuclides; 1 millicurie of Groups III, IV, V, or VI radionuclides; 25 curies of Group VII radionuclides; tritium oxide in aqueous solution with a concentration not exceeding 0.5 millicuries per milliliter and with a total activity per package of not more than 3 curies; or 1 millicurie of radioactive material in special form; and not containing more than 15 grams of uranium-235 are excepted from specification packaging, marking, and labeling, and are excepted from the provisions of § 173.393, if the following conditions are met:

(1) The materials are packaged in strong tight packages such that there will be no leakage of radioactive materials under conditions normally incident to transportation.

(2) The package must be such that the radiation dose rate at any point on the external surface of the package does not exceed 0.5 millirem per hour.

(3) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(4) The outside of the inner container must bear the marking "Radioactive."

(b) Manufactured articles such as instruments, clocks, electronic tubes or apparatus, or other similar devices, having limited quantities of radioactive materials (other than liquids) in a nondispersible form as a component part, are excepted from specification packaging, marking, and labeling, and are excepted from the provisions of § 173.393, if the following conditions are met:

NOTE 1: For radioactive gases, the requirement for the radioactive material to be in a nondispersible form does not apply.

(1) Radioactive materials are securely contained within the devices, or are securely packaged in strong, tight packages, so that there will be no leakage of radioactive materials under conditions normally incident to transportation.

(2) The radiation dose rate at four inches from any unpackaged device does not exceed 10 millirem per hour.

(3) The radiation dose rate at any point on the external surface of the outside of the package may not exceed 0.5 millirem per hour. However, for exclusive use shipments only, the radiation at the external surface of the package or the item may exceed 0.5 millirem per hour, but must not exceed 2 millirem per hour.

(4) There must be no significant removable radioactive surface contamination on the exterior of the package (see § 173.397).

(5) The total radioactivity content of a package containing radioactive devices must not exceed the quantities shown in the following table:

Transport group	Quantity in curies	
	Per device	Per package
I	0.0001	0.001
II	0.001	0.05
III	0.01	3
IV	0.05	3
V or VI	1	1
VII	25	200
Special form	0.05	20

(6) No package may contain more than 15 grams of fissile material.

(c) A manufactured article, other than a reactor fuel element, in which the only radioactive material is metallic natural or depleted uranium or natural thorium or alloys thereof, is excepted from specification packaging, marking, and labeling, and is excepted from the provisions of § 173.393, if the following conditions are met:

(1) The radiation dose rate at any point on the external surface of the outside container does not exceed 0.5 millirem per hour;

(2) There must be no significant radioactive surface contamination on the exterior of the package. To determine whether "significant," the standard in § 173.397 must be used.

(3) The total radioactivity content of each article must not exceed 3 curies.

(4) The outer surface of the uranium or thorium is enclosed in a non-radioactive, sealed, metallic sheath.

NOTE: Such articles may be packagings for the transportation of radioactive materials.

(d) Shipments made under this section for transportation are not subject to Subpart F of Part 172 of this subchapter, to Part 174 of this subchapter except § 174.24 and to Part 177 of this subchapter except § 177.817.

APPENDIX C
PLUTONIUM

C.1 HISTORICAL BACKGROUND (Refs. C-1 and C-2)

The element plutonium was first artificially formed by deuteron bombardment of uranium oxide:

$$_{92}U^{238} + {}_1H^2 \longrightarrow {}_{93}Np^{238} + 2n$$

$$_{93}Np^{238} \xrightarrow[\text{(2.1 days)}]{\beta-} {}_{94}Pu^{238}$$

This was performed in February 1941 by Arthur Wall, Glenn T. Seaborg, and Joseph Kennedy at the University of California at Berkeley using a 152 cm (60-inch) cyclotron. When an isotope (Pu-239) of the new element was shown to be fissionable in March 1941, continuing research became shrouded in the secrecy of the Manhattan Project.

The initial focus of plutonium research was aimed at production of enough Pu-239 to manufacture a nuclear weapon. The only practical means of accomplishing this task was through the use of thermal reactors with sufficient neutron flux to produce significant quantities of the material through the following capture/decay chain:

$$_{92}U^{238} + n \longrightarrow {}_{92}U^{239} \xrightarrow[\text{(23.5 min)}]{\beta-} {}_{93}Np^{239} \xrightarrow[\text{(2.33 days)}]{\beta-} {}_{94}Pu^{239}$$

With the advent of the Atoms for Peace program, the thrust of the plutonium research program was directed toward the possibilities of using Pu-239 as a reactor fuel as well as exploiting the useful aspects of other plutonium isotopes.

In the 35 years since its initial manufacture, plutonium has become one of the most studied and best understood heavy elements in the periodic table.

C.2 CHEMISTRY AND METALLURGY

Plutonium is the fifth element in the actinide series. It is a reactive silvery-white metal that can exist in four valence states (+3, +4, +5, +6), with the +4 state being the most stable under physiological conditions (Ref. C-3). It rapidly oxidizes in moist air, forming mixtures of oxides and hydrides. Plutonium reacts with all common gases at elevated temperatures, is soluble in most dilute acids and in most mineral acids, and forms numerous organic and inorganic compounds (Ref. C-4).

Metallurgically, plutonium is very unusual. It exhibits six distinct allotropic phases and is a very dense metal (19.86 g/cm^3 in the most dense form) with a low melting point (640°C). It has a very low latent heat of fusion (2856 Joule/g-atom) and is second only to manganese in the magnitude of its electrical resistivity (1.45 microohm-m at room temperature).

C.3 NUCLEAR PROPERTIES (Refs. C-4 and C-5)

Fifteen isotopes of plutonium, Pu-232 to Pu-246, have been identified. The most common isotope, Pu-239, has a 24,390 year half-life and decays by energetic alpha emission (4.64 to 5.16 meV (Ref. C-6)). This isotope is used in nuclear weapons and is a potential fuel for nuclear reactors because of its high thermal neutron fission cross-section and high neutron yield.

Pu-238 is another important plutonium isotope. Because of its energetic alpha particles (4.7 to 5.5 MeV (Ref. C-6)) and relatively short half-life (86.4 years), it has been used as an isotopic heat source for cardiac pacemakers and for thermoelectric power generation devices such as the SNAP systems used in lunar missions.

The isotopes Pu-240, Pu-241, and Pu-242 are formed from Pu-239 by successive neutron capture. Of these three, Pu-241 is a relatively short-lived (13 years) beta emitter whose daughter product, americium-241, is used in neutron sources. Am-241 is a relatively long-lived (458 years) alpha emitter that constitutes a radiological health hazard comparable to Pu-239 on a dose per curie basis.

In this study, three types of plutonium shipments are considered: shipments of pure isotopic material (i.e., Pu-238 or Pu-239), shipments of uranium-plutonium mixtures, and shipments of light-water-reactor-produced plutonium. Table C-1 lists the specific activitity (curies per gram) and the biological hazard from inhalation (rem per curie inhaled) for some isotopes of plutonium, americium, and curium. Clearly, the biological hazard of a shipment of plutonium is highly dependent on its isotopic makeup. In the case of plutonium associated with the nuclear fuel cycle, the isotopic content and dosimetric impact predicted in Reference C-10 (see Table C-2) were used.

C.4 PHYSIOLOGICAL ASPECTS

The data base for conclusions concerning the physiological effect of plutonium exposure in man is quite limited. It consists of five principal sources:

1. A group of 25 Los Alamos Scientific Laboratory personnel who were exposed to plutonium during the early 1940s (Ref. C-11),

2. A group of 18 critically ill people who were injected with plutonium in the late 1940s (Ref. C-12),

3. 452 members of the United States Transuranium Registry (Ref. C-13),

TABLE C-1

SPECIFIC ACTIVITY AND DOSE COMMITMENT FROM SOME ISOTOPES OF PLUTONIUM, AMERICIUM, AND CURIUM (Refs. C-7, C-9)

Isotope	Specific Activity (ci/gm)	Type of Radiation	50-Year Bone Dose (rem/ci inhaled)	50-Year Lung Dose (rem/ci inhaled)
Pu-238*	17.1	α	7.6×10^8	3.1×10^8
Pu-239*	0.06	α	8.7×10^8	2.9×10^8
Pu-240*	0.228	α	8.7×10^8	2.9×10^8
Pu-241*	98.98	β	1.7×10^7	5.9×10^5
Pu-242**	0.00382	α	5.5×10^8	4.6×10^8
Am-241*	3.43	α	9.0×10^8	3.2×10^8
Cm-243**	46.0	α	2.8×10^8	5.3×10^8
Cm-244*	83.3	α n	4.2×10^8	3.1×10^8
Cm-246*	0.26	α	4.1×10^8	5.1×10^8

*Dose from Reference C-7 with 1 μ median diameter.

**Dose from Reference C-9 with 1 μ median diameter.

ISOTOPIC CONTENT (WEIGHT PERCENT) AND DOSIMETRIC IMPACT OF VARIOUS MIXTURES OF PLUTONIUM ASSOCIATED WITH LIGHT-WATER REACTORS (Refs. C-8, C-10)

Isotope	High-Burnup LWR Fuel*	Predicted 1990 Industry Average	Predicted Equilibrium Recycle
Pu-238	1.9	1.2	3.4
Pu-239	63.0	53.0	41.7
Pu-240	19.0	25.8	27.1
Pu-241	12.0	13.5	15.4
Pu-242	3.8	6.0	11.7
Am-241	0.6	0.7	0.7
Specific Activity (ci/gm)**	12.3 (0.4)	13.68 (0.32)	15.93 (0.69)
50 year lung dose (rem/ci)***	1.06×10^7	7.13×10^6	1.85×10^7
50 year bone dose (rem/ci)***	3.47×10^7	3.5×10^7	5.03×10^7

*35,000 MWD/tonne Yankee fuel
**Values for the alpha component of activity are shown in parentheses
***Including both α and β components.

4. A group of 25 Rocky Flats workers exposed to aerosolized plutonium during a fire in October 1965 (Ref. C-14), and

5. Approximately 200 accidental exposure cases among other government contractors (Ref. C-15).

Because of the nature of these exposures (largely accidental), detailed and accurate dosimetry is not possible. However, there has been no evidence of cancer, other illnesses, or death that can be attributed unequivocably to plutonium exposure in human beings. A large amount of experimental data has been gathered concerning the behavior of various chemical and physical forms of plutonium in several species of animals (dogs, rats, pigs, sheep, and primates), and inferences concerning man can be drawn from these data.

Under the circumstances of an accidental exposure, the plutonium will be deposited on the skin, in a wound, in the gastrointestinal tract, or in the respiratory tract. After this deposition, plutonium may be transported by the blood or lymphatic system to other organs or tissues of the body or it may be eliminated directly. The rate and amount of translocation and the eventual destination are strongly dependent on the site of deposition and the physical and chemical properties of the plutonium compound (Ref. C-16) to which the person was exposed.

C.4.1 SKIN DEPOSITION

Animal data on systemic uptake of plutonium through intact or abraded skin show wide variations. The largest observed uptake in animals was 1-2% with $Pu(NO_3)_4$ in 10M HNO_3 through rat skin. The degree of absorption seems to be strongly influenced by the area of skin exposed, the mass of plutonium applied, and the pathological effects of the solvent on the skin (Refs. C-3 and C-16). Plutonium appears to be less extensively absorbed through human skin. In two cases where humans have been exposed to plutonium-bearing solutions with significant plutonium concentrations, absorption (as determined from urinalysis data) was less than 2×10^{-7} of the incident amount (Refs. C-4 and C-16). If plutonium is introduced into a puncture wound, abrasion, or cut, a higher percentage (0.3% to 2.7%) may be absorbed (Ref. C-4). The remainder is sloughed from the wound by normal healing and drainage processes. Using the very limited data base, it appears that most of the material absorbed from wounds translocates to bone or liver tissue (Ref. C-16).

C.4.2 GASTROINTESTINAL TRACT DEPOSITION

The presence of large amounts of plutonium in the gastrointestinal (GI) tract following an accident would not normally be expected. The two routes to the GI tract are consumption of contaminated foodstuffs and passage from the nasopharyngeal or tracheobronchial regions of the respiratory tract. The presence of significant quantities of plutonium in food is unlikely because of its very low uptake by plant roots. Under ideal conditions for plant uptake, only .0002 of the concentration in soil appeared in the plants growing there (Ref. C-17). Even if soluble plutonium enters the GI tract, only a small fraction is absorbed. This low absorption is a result of the hydrolysis of the soluble salt to form insoluble species (Ref. C-3). Experimental values for rats and pigs range from 7×10^{-7} for PuO_2 to 1.9×10^{-2} for $Pu(NO_3)_4$ (Refs. C-3 and C-16). The material absorbed is translocated mostly to skeletal structure and, to a lesser extent, to the liver. The amount of absorption appears to be strongly dependent on the valence of available Pu ions and on the pH of the administered solution. In fact, the maximum value of 2% was for a highly acid nitrate that man would not normally encounter (Ref. C-17). The maximum permissible concentration (MPC) for Pu in water set by the ICRP is based on 0.003% absorption, which is conservative based on the pH data.

C.4.3 RESPIRATORY DEPOSITION

Because of the chemical nature of plutonium, deposition of insoluble particles, probably oxides, in the respiratory tract is considered the most likely route to man (Ref. C-18). Once the particles enter the respiratory tract, their behavior is very dependent upon the particle size and solubility. The various pathways that may be taken are shown in Figure C-1. The effect of particle size on deposition location is illustrated in Figure C-2 and discussed in greater detail below.

Large particles (>10 microns in equivalent aerodynamic diameter) are filtered out of the inspired air by the cilia in the nasopharyngeal passages. They are captured in the mucoid lining of the passages, transported with the mucus drainage, and eventually swallowed (pathway b on Figure C-1). Intermediate sized particles (1 to 10 microns in equivalent aerodynamic diameter) are deposited principally in the pulmonary or nasopharyngeal region with a small fraction depositing in the tracheobronchial region (Refs. C-7 and C-8). Some of these particles also become entrained in the mucoid lining and are moved upward towards the pharynx by mucociliary action for eventual deposition into the upper GI tract (pathway d in Figure C-1). In addition, a small number of these particles are dissolved in blood (pathway c on Figure C-1). Small particles (<1 micron in equivalent aerodynamic diameter) are preferentially deposited in the pulmonary region. They come in direct contact with the alveoli and are rapidly phagocytized* and localized in the reticuloendothelial cells of the alveoli (Ref. C-16).

Soluble plutonium readily diffuses from the reticuloendothelial cells of the alveoli into the blood and lymphatic systems and is translocated into skeletal and liver tissue with a clearance half-time of 150-200 days (Ref. C-16).

Insoluble plutonium, notably PuO_2, has much longer lung clearance half-time (200-1000 days). Clearance mechanisms include tracheobronchial mucociliary action (pathways f and k on Figure C-1), some dissolution (pathway e on Figure C-1), and lymphatic absorption (pathway g on Figure C-1). The overall pattern of the plutonium translocation (in beagles) is shown on Figure C-3. The buildup in the thoracic lymph nodes appears to be an endpoint in that there is very little movement of the plutonium from the thoracic lymph nodes to systemic blood (pathway h on Figure C-1).

Studies indicate that different isotopes of plutonium may exhibit different biological behavior. For instance, Pu-238 appears to translocate faster than other plutonium isotopes,

*Phagocytosis is a process by which special cells, such as white blood cells, rid the body of bacteria and unwanted debris in the tissue. During phagocytosis, the foreign matter is actually surrounded and ingested by the cell (Ref. C-19).

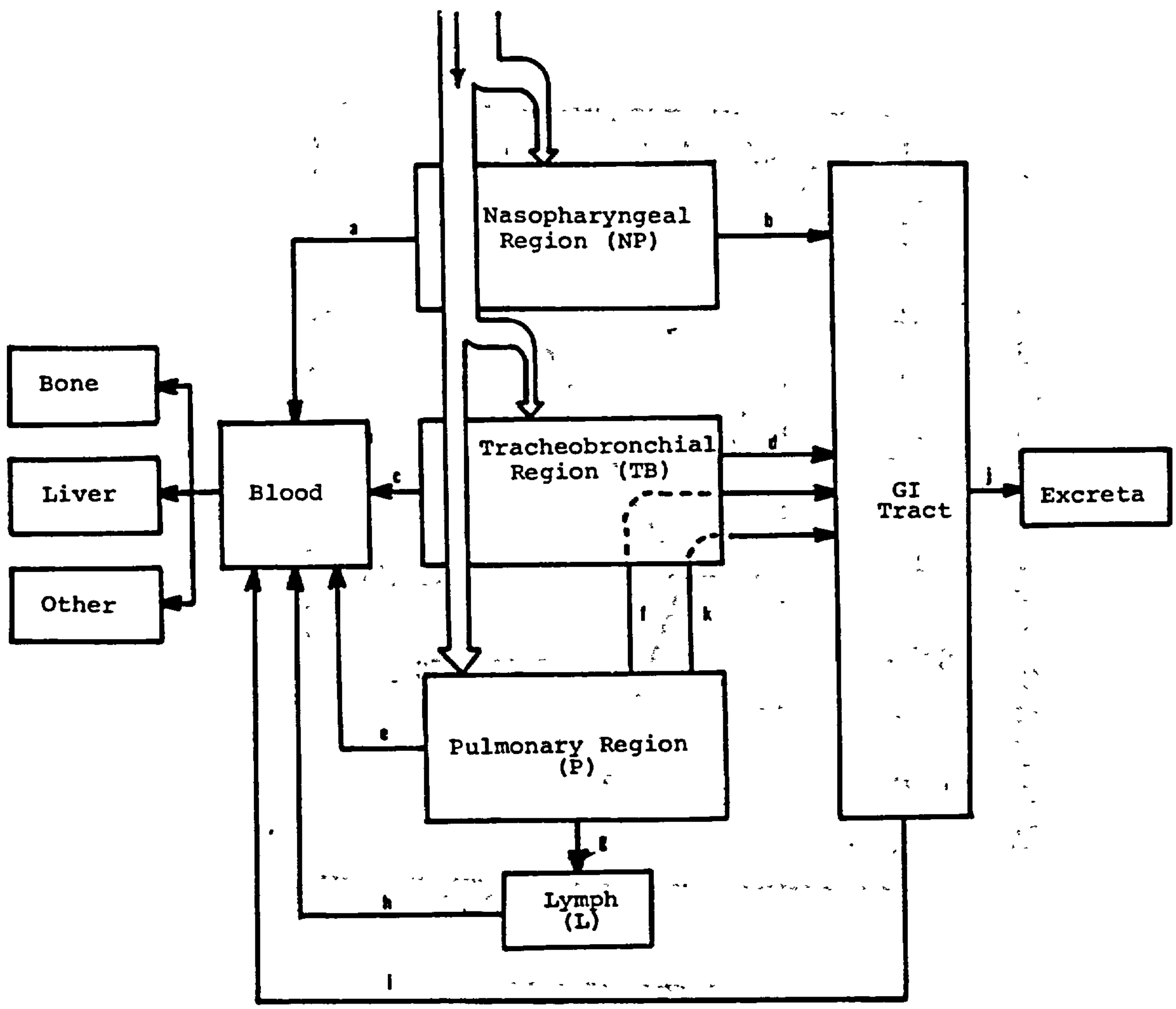

FIGURE C-1. BIOLOGICAL PATHWAYS FOR INHALED MATERIAL (Refs. C-3, C-7, C-19, C-20)

(a) Nasopharyngeal absorption in blood

(b) and (d) Mucociliary translocation to upper GI tract

(c) Tracheobronchial absorption in blood

(e) Alveolar diffusion

(f) Short-term and (k) long-term mucociliary translocation of phagocytized material to tracheobronchial region

(g) Absorption into lymphatic system

(h) Transfer to venous system

(i) Gastrointestinal absorption in blood

(j) Excretion from GI tract as feces or absorption from GI tract and excretion as urine

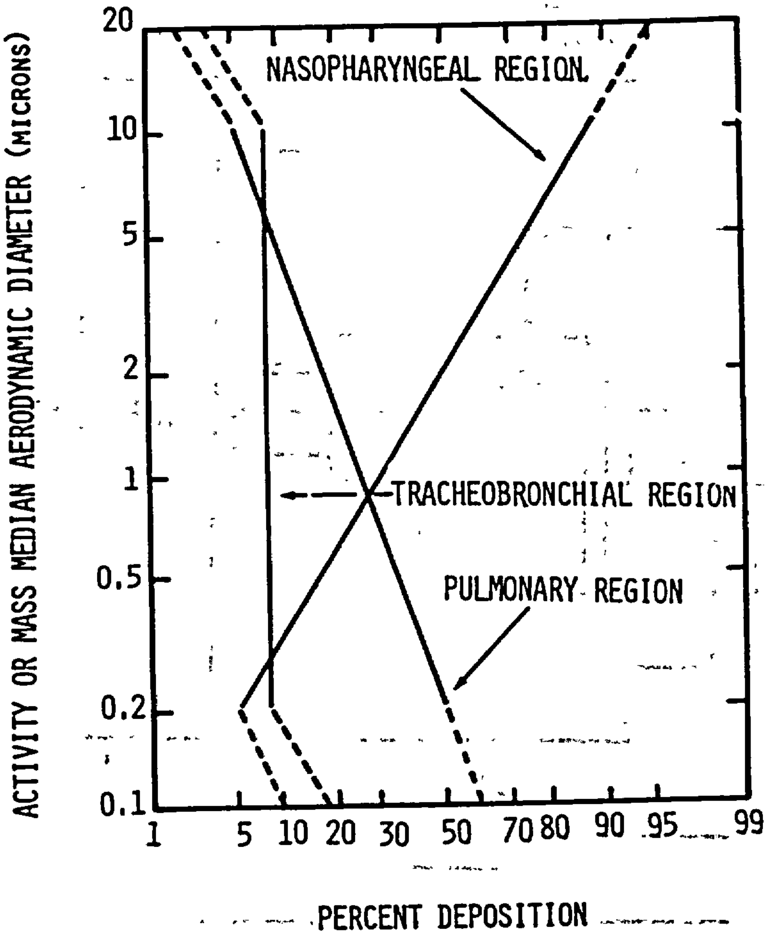

FIGURE C-2. DEPOSITION MODEL (Ref. C-7).

The radioactive or mass fraction of an aerosol that is deposited in the nasopharyngeal, tracheobronchial, and pulmonary regions is given in relation to the activity of mass median aerodynamic diameter (AMAD) or (MMAD) of the aerosol distribution. The model is intended for use with aerosol distributions that have an AMAD or MMAD between 0.2 and 10 microns with geometric standard deviations of less than 4.5. Provisional deposition estimates further extending the size range are given by the broken lines. For the unusual distribution having an AMAD or MMAD greater than 20 microns, complete nasopharyngeal deposition can be assumed. The model does not apply to aerosols with AMADs or MMADs below 0.1 micron.

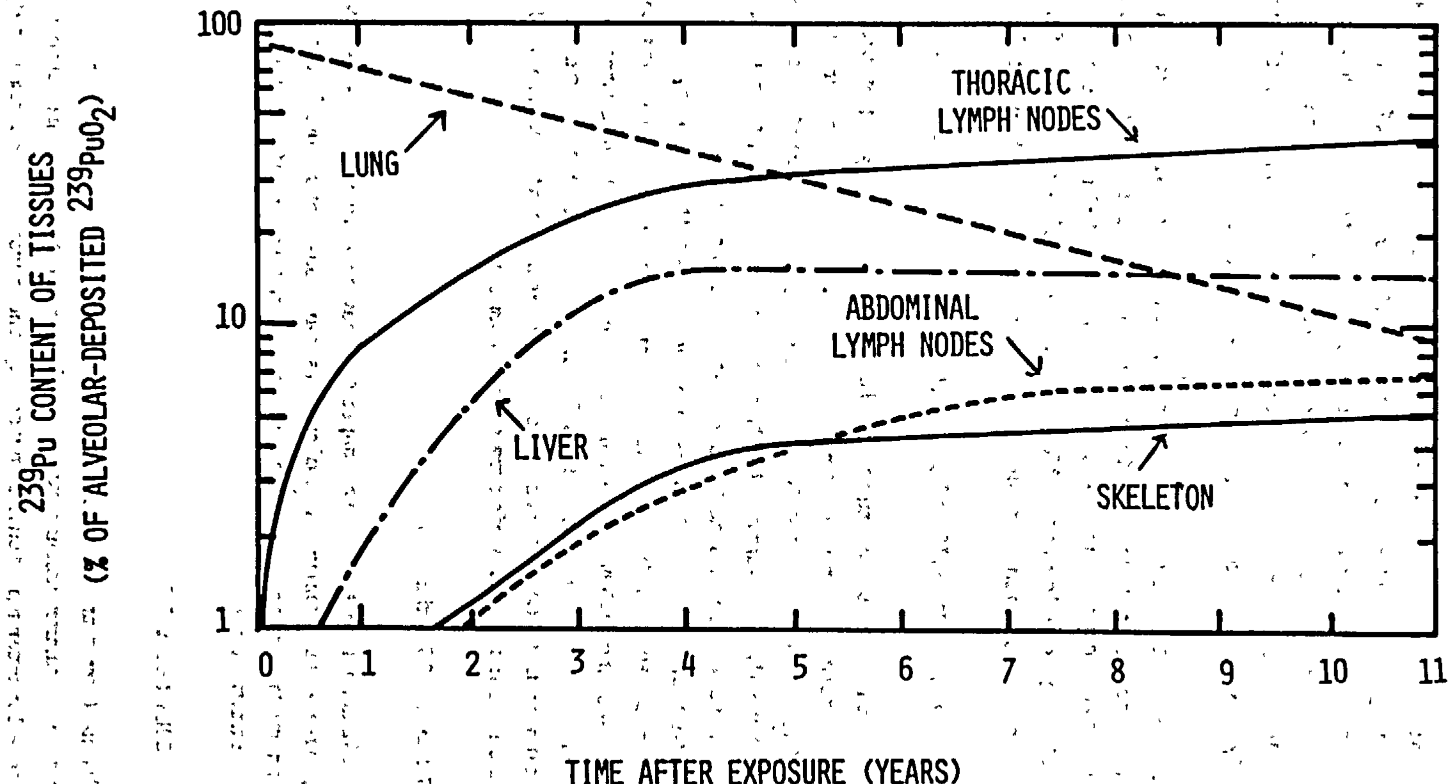

FIGURE C-3. TRANSLOCATION OF PULMONARY-DEPOSITED Pu-239 IN BEAGLE DOGS (Ref. C-16).

apparently due to particle disintegration or surface fragmentation caused by its higher specific activity.

C.5 BIOLOGICAL EFFECTS

The effects of plutonium on tissue are largely a function of the high-energy alpha and beta radiation emitted during radioactive decay. Because of the nature of alpha and beta particles, their energy deposition occurs in a relatively small amount of body tissue. When tissue of laboratory animals is exposed to a sufficient quantity of plutonium, the energy deposition results in early effects ranging over several degrees of illness including death. In smaller doses, the radiation appears to act as a carcinogenic agent.

It should be noted here that no evidence of cancer, other illness, or death that can be attributed unequivocably to accidental or intentional plutonium exposure in human beings has occurred (Refs. C-4, C-11, C-12, C-13, C-14, C-15, C-16, C-17, and C-18). This record does not exclude the possibility of long-term low-dose effects that may require more than 20-30 years to reveal themselves. Specific effects within organs of interest are discussed in detail below.

C.5.1 EFFECTS ON SKELETAL AND HEMATOPOIETIC SYSTEMS (Refs. C-3, C-4, C-16, C-19, and C-21)

If plutonium is translocated to skeletal sites, it is preferentially deposited on the bone surfaces. Depending on the rate of growth or remodeling of the bone (and hence on the age of the exposed individual) the deposit may remain on the surface or be buried. Very large bone accumulations of plutonium result in suppressed osteogenesis and eventual tissue necrosis. At lower doses, pathological bone fractures may occur. At low doses, the incidence of osteogenic sarcoma also shows a marked increase. All of these effects are on the skeletal tissue itself. The effect on hematopoietic tissue within the bone structure can result in depression of granular leukocytes at low doses and lymphophenia at higher doses. The evidence from either experimental or clinical studies that plutonium produces leukemia is, at present, scanty. However, theoretical consideration and clinical investigation of persons injected with Th-232 indicate that leukemia should not be excluded as a risk from plutonium exposure.

C.5.2 EFFECT ON LIVER (Refs. C-16 and C-17)

Very low doses of plutonium to the liver appear to have no effect in laboratory animals. As the dose increases, bile duct tumors and cirrhosis have been observed although bile duct tumors also occurred in control animals. The correlation of liver results from animals to man remains somewhat unclear at this time.

C.5.3 EFFECT ON LYMPH NODES (Ref. C-16)

It has been concluded from the rodent and dog experiments that the lymph nodes are not especially susceptible to the carcinogenic action of alpha radiation from plutonium. However, the question of possible long-term plutonium-induced lymphosarcoma is not completely addressed by these results. Information obtained from long-term studies on occupationally exposed plutonium workers should provide more definitive information on lymph-system effects.

C.5.4 EFFECTS ON LUNGS (Refs. C-16 and C-22)

The data on plutonium effects in the lungs are heavily based on beagle experiments. Large deposits (>0.5 μCi/g of lung) in the pulmonary tissue of these animals have caused severe inflammation, edema, hemorrhage, and death within a relatively short period of time (1 week). At somewhat lower doses (0.05 - 0.1 μCi/g of lung) pulmonary fibrosis occurs, resulting in respiratory insufficiency and eventual death. At lower deposition levels (0.6 to 14 μCi total lung burden), bronchiolo-alveolar carcinomas have developed. Although the pathogenesis is not well known, it appears that the bronchiolo-alveolar carcinogenesis may be related to the fibrotic repair of the localized radiation damage.

C.5.5 GENETIC EFFECTS (Ref. C-23)

It has been known for several years that doses of high linear energy transfer (LET) radiation are more effective at producing somatic damage than low-LET radiation. However, the correlation of LET to mutation induction has not been well established. Based on recent mouse data, it appears that the RBE for genetic effects from low doses and dose rates of high LET radiation may be higher than anticipated. However, the ICRP feels that the quality factors in use are adequate. In view of the very small gonadal uptake of plutonium, the genetic risk is clearly less than the risk to lung or skeletal tissue.

C.5.6 MITIGATION OF PLUTONIUM CONTAMINATION (Ref. C-16)

Several techniques have been developed to mitigate the effects of plutonium exposure. The most common method of dealing with exposure to soluble plutonium compounds involves intravenous injection of DTPA (diethylenetinaminepentacetic acid). This acid forms stable plutonium complexes and increases urinary excretion of the element, in some cases by orders of magnitude.

In cases involving insoluble pulmonary plutonium deposits, pulmonary lavage with physiological saline has been used with some success. This is a relatively high-risk medical procedure, however, so the actual hazard of the deposited material must be carefully evaluated.

C.6 PLUTONIUM TOXICITY

The toxicity of plutonium has been the subject of considerable discussion. It has been alleged that plutonium is one of the most potent respiratory carcinogens known (Refs. C-24 and C-25). These assertions are based on two principal premises:

1. The so-called "hot particle" theory, which states that the dose received by an organ should be computed using the very small mass of irradiated tissue surrounding the deposited particle rather than the entire organ mass (Ref. C-24) and

2. The ciliary impairment that is alleged to be present in smokers (Ref. C-26).

Neither of these theories has gained widespread acceptance in the medical or health physics communities, and both have been strongly refuted by experts in the specific areas (Refs. C-18, C-27, C-28, C-29, C-30, C-31, and C-32)

The more widely accepted feeling is that, although plutonium is certainly a potent carcinogen, it is not "the most toxic substance known to man." As an acute toxin, plutonium is much less potent than several of the substances considered as "super toxins" shown in Table C-3 (Ref. C-33). As a carcinogen, comparison with chemical substances is more tenuous due to a multitude of units and exposure periods, although attempts have been made (Refs. C-20 and C-34). Comparisons of long-term toxicity have been made, however, with other radioactive materials (Ref. C-33) based on maximum permissible concentrations, and these results show plutonium to be the isotope of highest risk to bone from inhalation but of comparable or less risk than that of other isotopes in terms of ingestion hazard and hazaru to other organs.

TABLE C-3

ACUTE TOXICITY OF SOME SUBSTANCES (REF. C-33)

Substances	Criterion**	Species	Route++	Quantity* (per kg body weight)
Botulinus toxin A	LD_{50}	Mouse	Ipr	3×10^{-6} μg/kg
Botulinus toxin A (crystalline)	LD_{50}	Mouse	Ipr	7×10^{-9} μg/kg
Tetanus toxin	LD_{50}	Mouse	Ipr	1×10^{-4} μg/kg
Diptheria toxin	LD_{50}	Mouse	Ipr	0.3 μg/kg
Nerve Gas				
GB	50% deaths in 1-2 hr.	Human	INH	16 μg/kg+
VX	"	Human	INH	8 μg/kg+
Bufotoxin	LD_{50}	Cat	IV	390 μg/kg
Curare	LD_{50}	Mouse	Ipr	500 μg/kg
Strychnine	LD_{50}	Mouse	Ipr	500 μg/kg
Pu-239	$LD_{50/30}$	Dog	INH	500-800 μg/kg
Pu-239	$LD_{50/30}$	Rat	INH	2000 μg/kg

*After Wacholz (1975) assuming a 75 kg man and 17 liter/min breathing rate.

**The items marked LD_{50} are actually the lowest figures found in the literature for classical LD_{50}. Except for the confusion of terminology engendered, they might be labelled "LD_{LO}."

+Estimate.

++Ipr - percentaneous injection; INH - inhalation; IV - intravenously.

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APPENDIX D

POPULATION DOSE FORMULAS FOR NORMAL TRANSPORT

The formulation for the assessment of population dose is based on an expression for dose rate as a function of distance from a point source of radiation. This point source approximation is acceptable for distances between the receptor and the source of more than two source characteristic lengths. At smaller distances, the point-source approximation overpredicts exposure and, therefore, will provide a conservative estimate of dose. The dose rate formulation is given by:

$$\dot{D}(d) = \frac{Ke^{-\mu d} \; B(d)}{d^2} \qquad \text{(D-1)}$$

where $\dot{D}(d)$ = dose rate at a distance d (mrem/hr)

d = distance from source (ft)

μ = absorption coefficient for air (.00118 ft^{-1})

B(d) = Berger buildup factor in air, where in this case B(d) = .0006d + 1 (dimensionless) (Ref. D-1)

K = dose rate factor (mrem-ft^2/hr)

D.1 DOSE TO PERSONS SURROUNDING THE TRANSPORT LINK WHILE THE SHIPMENT IS MOVING

An expression for the total integrated dose absorbed by an individual at a distance x from the path of a radioactive shipment with dose rate factor K passing at velocity V has been derived (Ref. D-1) from Equation (D-1) and is given by

$$D(x) = 2\frac{K}{V}I(x) \qquad \text{(D-2)}$$

where V = shipment speed (ft/hr)

x = perpendicular distance of individual from shipment path (ft)

$$I(x) = \int_x^{\infty} \frac{e^{-\mu r} \; B(r)dr}{r(r^2-x^2)^{\frac{1}{2}}}$$

By appropriate transformations, this integral can be expressed in terms of modified Bessel functions of the second kind of order zero, which can be evaluated. For a K of 1 mrem-ft^2/hr and a V of 1 mile/hr, the absorbed dose as a functon of x is as shown in Figure D-1.

In order to obtain integrated population dose in sectors of length L and width d on both sides of the roadway (Figure D-2), Equation (D-2) is multiplied by the average population density and L and integrated over the width of the strip

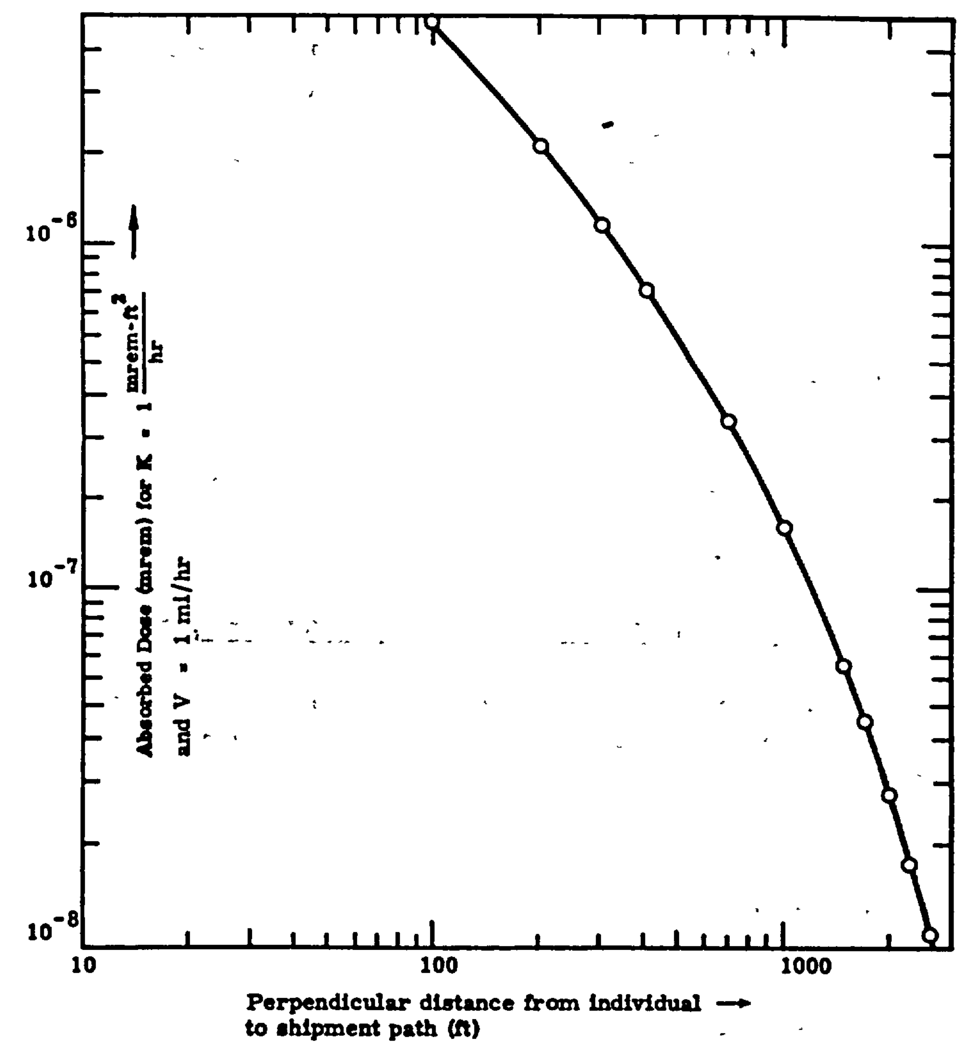
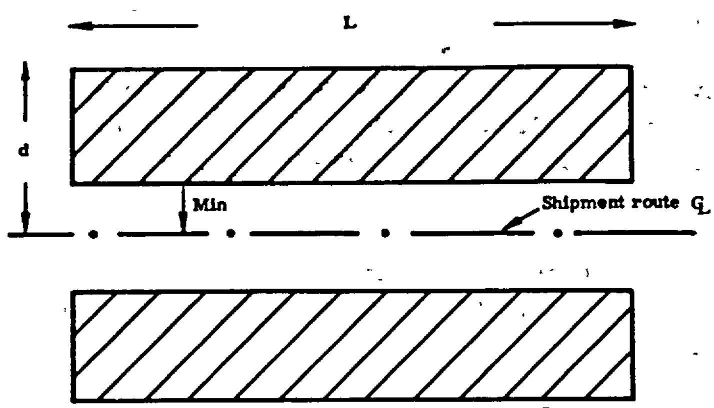


FIGURE D-1. DOSE RECEIVED BY AN INDIVIDUAL AS A SHIPMENT PASSES



- populated zone with uniform population density PD

L - length of populated strip

d - maximum distance over which exposure is evaluated

min - smallest distance between exposable population and shipment centerline.

FIGURE D-2. DOSE TO PERSON LIVING ALONG THE TRANSPORT LINK

$$\text{Dose} = 2(PD)(L)\int_{min}^{d} D(x)dx \qquad \text{(D-3)}$$

where Dose = integrated population dose in strip (person-mrem)

PD = average population density (person/ft^2)

L = length of strip (ft)

min = minimum distance from population to shipment centerline (ft)

d = maximum distance over which exposure is evaluated (ft)

D(x)dx = incremental dose function from Equation (D-2) (mrem-ft)

Equation D-3 predicts an infinite dose as min approaches 0; thus a limit on this value must be set. Values for min were selected based on actual roadway dimensions. A value of 2,600 feet was selected for d based on a previous assessment (Ref. D-1).

Consider a single trip made by a radioactive package with dose rate factor K. The trip is considered to involve three population density zones: rural, suburban, and urban. The total population dose resulting from the trip of length L (feet) is made up of the sum of the doses received in each of the three zones:

$$\text{Dose} = \text{Dose}_r + \text{Dose}_s + \text{Dose}_u$$

where the subscripts r, s, and u refer to rural, suburban, and urban, respectively. The use of the integrated dose expression of Equation D-3 results in the following expression:

$$\text{Dose} = 4K(L)\left[\frac{f_r PD_r}{V_r} I_r + \frac{f_s PD_s}{V_s} I_s + \frac{f_u PD_u}{V_u} I_u\right] \qquad \text{(D-4)}$$

where f_r = fraction of distance traveled in rural population density zone

f_s = fraction of distance traveled in suburban population density zone

f_u = fraction of distance traveled in urban population density zone

PD_r = population density (rural) (people/ft^2)

PD_s = population density (suburban) (people/ft^2)

PD_u = population density (urban) (people/ft^2)

$$I_r = \int_{min_r}^{d} I(x)dx$$

$$I_s = \int_{min_s}^{d} I(x)dx$$

$$I_u = \int_{min_u}^{d} I(x)dx$$

min_r = minimum distance from exposable population to shipment centerline (ft) (rural)

min_s = minimum distance from exposable population to shipment centerline (ft) (suburban)

min_u = minimum distance from exposable population to shipment centerline (ft) (urban)

V_r = average speed in rural area (ft/hr)

V_s = average speed in suburban area (ft/hr)

V_u = average speed in urban area (ft/hr)

Long-haul shipments use freeways or four-lane roads in most low and medium population density zones. However, in high density zones, use of city streets is often unavoidable. Since the minimum exposure distance (min) is smaller under these circumstances, the last term of Equation (D-4) is modified as follows:

$$Dose_u = \frac{4K(f_u)(PD_u)(L)}{V_u} I_u(f_o + K'f_1) \qquad \text{(D-5)}$$

where f_o = fraction of high density zone distance traveled on freeways or four-lane roads

f_1 = fraction of high density zone distance traveled on city streets

K' = constant that accounts for closer minimum distance on city streets. This constant K' is given by

$$K' = \frac{\int_{min_1}^{d} I(x)dx}{\int_{min_u}^{d} I(x)dx}$$

where min_1 = is the minimum distance of the exposable population from the shipment centerline for shipments on city streets.

The upper integration limit d was taken to be 2,600 ft, and the lower limits $min_r = min_s = min_u$ = 100 ft in all three population density zones. A value of 30 ft was selected for min_u on city streets, resulting in a value of 1.636 for K'. With these limits, the dimensionless integral $I_r = I_s = I_u$ was evaluated numerically and found to be equal to 2.42

When the expression for urban dose D_u of Equation (D-5) is substituted into Equation (D-4), the following expression results:

$$Dose = 4KL(2.42)\left[\frac{f_rPD_r}{V_r} + \frac{f_sPD_s}{V_s} + \frac{f_uPD_u}{V_u}(f_o + 1.636f_1)\right] \qquad \text{(D-6)}$$

If the population densities (PD) are expressed as persons/mi^2 and the velocities (V) are expressed in miles per hour (mph), the dose received per mile traveled is:

$$\text{Dose (person-rem/mile)} = 3.47 \times 10^{-10}(K)\left[\frac{f_r PD_r}{V_r} + \frac{f_s PD_s}{V_s} + \frac{f_u PD_u}{V_u}(f_o + 1.636 f_1)\right] \quad \text{(D-7)}$$

The annual normal population dose for this shipment scenario is obtained by multiplying the above equation by the total number of package-miles per year for this type of shipment, or PPS x SPY x FMPS,

where PPS = average number of packages per shipment
SPY = number of shipments per year
FMPS = average distance traveled (miles) per shipment

The dose rate factor K may be expressed as $K = K_o TI$, where K_o is a transport index to dose rate conversion factor:

$$K_o = (3 + d)^2$$

where 2d = typical package dimension in feet.

In this assessment:

K_o = 13.4 ft^2 for a typical Type A package
K_o = 16.0 ft^2 for a typical Type B package

An irradiated fuel cask, however, is treated simply as a source with a dose rate factor K = 1000 mrem-ft^2/hr; no TI is assigned.

The final expression for the annual population dose for a given shipment scenario, and the one used in this assessment to evaluate the normal population dose to surrounding population while the shipment is moving, is the following:

$$\left.\begin{matrix}(\text{Dose})_{mov} \\ (\text{person-rem/} \\ \text{year})\end{matrix}\right\} = 3.47 \times 10^{-10}(K_o)(TI)(PPS)(SPY)(FMPS) \left[\frac{f_r PD_r}{V_r} + \frac{f_s PD_s}{V_s} + \frac{f_u PD_u}{V_u}(f_o + 1.636 f_1)\right] \quad \text{(D-8)}$$

where K_o = 13.4 ft^2 for a Type A package and 16.0 ft^2 for a Type B package
TI = average TI per package
PPS = average number of packages per shipment
SPY = number of shipments per year
FMPS = average distance (miles) per shipment
f_r, f_s, f_u = fraction of distance traveled in rural, suburban, and urban areas, respectively
PD_r, PD_s, PD_u = population density (person/mi^2) in rural, suburban, and urban areas, respectively
V_r, V_s, V_u = average speed (mph) in rural, suburban, and urban areas, respectively
f_o = fraction of urban travel on freeways or four-lane roads
f_1 = fraction of urban travel on city streets

D.2 DOSE TO POPULATION DURING SHIPMENT STOPS

If the shipment stops for crew change, meals, refueling, etc., people in an annular area around the stop point are exposed. The population dose is again obtained by integrating a form of Equation (D-1) that includes an annular differential element, $2\pi r dr$:

$$\text{Dose} = K_o(TI)(\Delta T)(PD)\int_x^d (2\pi r)\left(\frac{e^{-\mu r}B(r)}{r^2}\right)dr \tag{D-9}$$

where Dose = integrated population dose per shipment (person-mrem)

ΔT = total stop time per shipment (hr)

Numerical evaluation of the integral for various values of x and d yields:

x(ft)	d(ft)	integral
5	400	26.104
5	1000	29.827
5	2600	31.613
10	2600	27.275

By accounting for the fraction of stops that occur in various population density zones and by making appropriate unit conversions, the integrated population dose in person-rem per year resulting from stops for a given shipment type is given by:

$$\text{Dose} = Q_1\, K_o(TI)(PPS)(SPY)\left[\Delta T_r(PD_r) + \Delta T_s(PD_s) + \Delta T_u PD_u\right] \tag{D-10}$$

where T_r = total stop time in rural population density zones (hours)

T = total stop time in suburban population density zones (hours)

T_u = total stop time in urban population density zones (hours)

Q_1 = 2.54×10^{-9}(rem-km^2/mrem-ft^2) (for x = 10 feet and d = 2600 feet)

D.3 DOSE TO WAREHOUSE PERSONNEL WHILE PACKAGE IS IN STORAGE

The dose to warehouse personnel is computed the same way as the dose received by persons while the shipment is stopped. The result is:

$$(\text{Dose})_{stor} = Q_2 K_o(TI)(PPS)(SPY)(\Delta T_{stor})(PD_{stor}) \tag{D-11}$$

where Dose_{stor} = integrated population exposure (person-rem/year)

T_{stor} = total storage time per shipment (hours)

PD_{stor} = population density in warehouse area

Q_2 = 2.77×10^{-9}(rem-km^2/mrem-ft^2) (for x = 5 feet and d = 1,000 feet)

D.4 DOSE TO CREWMEN

The annual dose to crewman is obtained directly from Equation (D-1) by using an average source-to-crew characteristic distance (d) for each transport mode:

$$(\text{Dose})_{crew} = Q_3(K_o)(TI)(PPS)(SPY)(N_c)\,\frac{e^{-\mu d}\,B(d)}{d^2}\,\Delta T_{ship} \qquad \text{(D-12)}$$

where N_c = number of crewman aboard

d = average distance to crew compartment (ft)

$Q3$ = 10^{-3} (rem/mrem)

ΔT_{ship} = average time required for a shipment $= \left[\frac{f_r}{V_r} + \frac{f_s}{V_s} + \frac{f_u}{V_u}\right]$ FMPS

FMPS = average distance (miles) per shipment

The values of $\frac{e^{-\mu d}\,B(d)}{d^2}$ for the assumed values of d for the various modes are shown below:

Mode	d(feet)	$\frac{e^{-\mu d}\,B(d)}{d^2}$
Van	7	2.03×10^{-2}
Truck	10	9.94×10^{-3}
Pass. Aircraft	50	3.88×10^{-4}
Cargo Aircraft	20	2.47×10^{-3}
Rail	500	2.88×10^{-6}
Ship	200	2.21×10^{-5}
Barge	150	4.06×10^{-5}

Because of regulatory limits for dose rate in the crew compartment, 2 mrem/hr is used as an upper limit for dose rate in this assessment. If the TI carried would cause this limit to be exceeded, it is assumed that shielding would be introduced to reduce the dose rate to this level.

D.5 DOSE TO PERSONS IN VEHICLES SHARING THE TRANSPORT LINK WITH THE SHIPMENT

Figure D-3 shows a truck carrying radioactive material. The truck is traveling at a speed V along with other vehicles in the same lane. Occasionally vehicles traveling in the opposite direction pass the truck in the other lane. There are two separate doses to be computed:

1. The dose to persons traveling in the opposite direction from the shipment and

2. The dose to persons traveling in the same direction as the shipment.

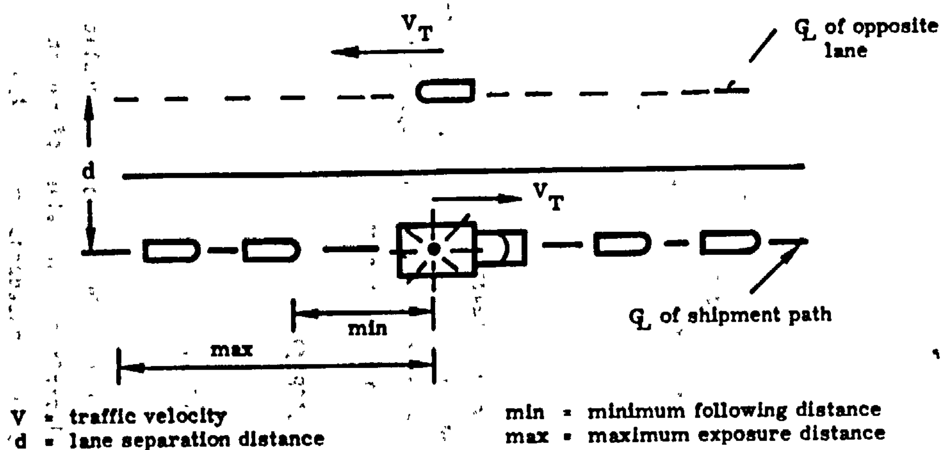


FIGURE D-3. DOSE TO PERSONS IN VEHICLES SHARING THE TRANSPORTATION LINK WITH THE SHIPMENT

D.5.1 DOSE TO PERSONS TRAVELING IN THE OPPOSITE DIRECTION

Assume that both the shipment and the oncoming traffic are moving at speed V(km/hr). The dose received by an individual in an oncoming vehicle may be computed by assuming that this vehicle is at rest and he is passed by the shipment at a speed of 2V. An expression for the integrated dose from a moving source was given in Equation (D-2).

Thus, the average integrated dose received by a person in an oncoming vehicle passing the truck at a distance x is:

$$D = \frac{2K}{(2V_T)} I(x) \qquad \text{(D-13)}$$

The average number N of oncoming vehicles per mile is

$$N_c = \frac{N'}{V_T} \qquad \text{(D-14)}$$

where N' is the traffic count (average number of cars per hour traveling in one direction). Let P be the average number of persons per vehicle. Thus the average number N of persons who travel in the opposite direction to the shipment and who are exposed per kilometer traveled by the truck is

$$N_{avg} = N_c P = \frac{N'F}{V_T} \qquad \text{(D-15)}$$

The average annual population dose to persons traveling in the opposite direction to the shipment is given by $D \times N_{avg} \times FMPS$, where FMPS is the average distance per shipment. Multiplication of this number by SPY, the annual number of shipments of the type being considered, results in the annual population dose for the given shipment scenario:

$$\text{Dose} = \frac{K}{V_T} I(x) \frac{N'}{V_T} P(FMPS)(SPY)$$

$$= KI(x) \frac{N'}{V_T^2} P(FMPS)(SPY) \qquad \text{(D-16)}$$

The traffic count N' and the average velocity V depend upon the population density zone and the time of day (i.e., rush hour or normal traffic). The value of the integral I(x) depends on the distance x of closest approach, which in turn depends on the type of road. The assumptions made for the various values for x and the corresponding values for I(x) are tabulated below:

Type of Road	x(ft)	$I(x)(ft^{-1})$
Freeway	50	2.9×10^{-2}
Four-Lane	30	4.8×10^{-2}
City Streets	10	1.5×10^{-1}

The following additional assumptions are made:

1. All rural and suburban truck travel is on freeways.

2. The traffic count doubles during the commuter rush periods (applicable in urban and suburban population zones).

3. The average speeds decrease by a factor of 2 during commuter rush periods (applicable in urban and suburban population zones).

4. Urban travel may be on freeways, four-lane roads, or city streets. Suburban and rural travel is all on freeways.

5. Urban travel on freeways and four-lane roads during rush hour is at half the average suburban velocity.

6. Urban travel on freeways during non-rush hours is at the average rural velocity. Urban travel on four-lane roads during non-rush hours is at the average suburban velocity.

Under these assumptions the following expression is obtained for the annual population dose in person-rem/year to persons traveling in a direction opposite to the shipment for a given shipment type:

$$(\text{Dose})_{opp} = Q(K_o)(TI)(PPS)(SPY)(FMPS)(P)(F) \qquad \text{(D-17)}$$

where

$$F = f_r \frac{N'_r I_{fwy}}{V_{Tr}^2} + f_s\left(\frac{f_{rh} 2N'_s I_{fwy}}{(V_{Ts}/2)^2} + \frac{f_n N'_s I_{fwy}}{(V_{Ts})^2}\right)$$

$$+ f_u\left[f_{fwy}\left(\frac{f_{rh} 2N'_u I_{fwy}}{(V_{Ts}/2)^2} + \frac{f_n N'_u I_{fwy}}{(V_{Tr})^2}\right)\right.$$

$$+ f_{4\ell}\left(\frac{f_{rh} 2N'_u I_{4\ell}}{(V_{Ts}/2)^2} + \frac{f_n N'_u I_{4\ell}}{(V_{Ts})^2}\right)$$

$$\left. + f_{cs}\left(\frac{f_{rh} 2N'_u I_{cs}}{(V_{Tu}/2)^2} + \frac{f_n N'_u I_{cs}}{(V_{Tu})^2}\right)\right]$$

In deriving this expression, the substitution $K = K_0 \times TI \times PPS$ has been made, where TI = TI/package, and PPS = number of packages/shipment. Other symbols in this equation are as follows:

f_r, f_s, f_u = fractions of distance traveled in rural, suburban, and urban zones, respectively

f_{rh} = fraction of distance traveled in rush hour traffic

f_n = fraction of distance traveled in normal traffic

f_{fwy} = fraction of travel on freeways or interstates

$f_{4\ell}$ = fraction of travel on four-lane roads

f_{cs} = fraction of travel on city streets

V_{Tr} = average velocity on freeways (miles/hour)

V_{Ts} = average velocity on freeways in suburban population density zones and on all four-lane roads (miles/hour)

V_{Tu} = average velocity on city streets (miles/hour)

I_{fwy} = $I\ (50\ ft) = 2.9 \times 10^{-2} ft^{-1}$

$I_{4\ell}$ = $I\ (30\ ft) = 4.8 \times 10^{-2} ft^{-1}$

I_{cs} = $I\ (10\ ft) = 1.5 \times 10^{-1} ft^{-1}$

$$Q = \left(10^{-3} \frac{\text{rem}}{\text{mrem}}\right)\left(\frac{1 \text{ mile}}{5280 \text{ ft}}\right) = 1.89 \times 10^{-7}$$

The annual dose is computed for each shipment scenario using Equation (D-17), and the results are summed over all the standard shipments to obtain the total annual dose to persons traveling in a direction opposite to that of the shipment.

D.5.2 DOSE TO PERSONS TRAVELING IN THE SAME DIRECTION AS THE SHIPMENT

On the average, vehicles carrying radioactive material move at the same speed as the rest of the traffic. Thus, vehicles traveling in the same direction as the shipment can be modeled as a static set of vehicles at fixed distances from the shipment. The dose in millirem received by a person located at distance x from the radioactive material may be computed by multiplying the dose rate from Equation (D-2) by the duration ΔT of the exposure:

$$D = \frac{K e^{-\mu x} B(x)}{x^2} \Delta T \qquad \text{(D-18)}$$

For a given scenario, the total annual exposure time is given by the quotient of total miles per year (miles per shipment x shipments per year) and average velocity:

$$\Delta T_{ann} = \frac{(FMPS)(SPY)}{V_T} \qquad \text{(D-19)}$$

It is assumed that people are distributed uniformly along the shipment path with a linear density given by

$$\text{Linear Density (persons/mile)} = \frac{N'P}{V_T} \qquad \text{(D-20)}$$

The annual dose to persons traveling in the same direction as the shipment for a given scenario is determined by multiplying the expression for the dose given in Equation (D-18) by the linear density given in Equation (D-20), using Equation (D-19) for ΔT_{ann}, and integrating over x from some minimum distance d out to a maximum distance "max":

$$(\text{Dose})_{\text{same dir.}} = 2 \left(\frac{N'P}{V_T}\right)\left(\frac{(FMPS)(SPY)}{V_T}\right) K \int_d^{max} \frac{e^{-\mu x} B(x)}{x^2} dx \qquad \text{(D-21)}$$

The factor of 2 takes into account vehicles ahead of and behind the shipment.

As in the case of persons traveling in the opposite direction, N' and V_T depend on the population density zone and the time of day (rush hour or normal traffic). Also the distance d of closest approach depends on the type of road. The average values selected for d are 100 ft for freeways and interstates, 30 ft for four-lane roads, and 10 ft for city streets. Using the same traffic assumptions as made for the calculation of the dose to persons traveling in the direction opposite to that of the shipment, the following expression is obtained for the annual dose (for a given shipment scenario) received by persons traveling in the same directions as the shipment:

$$(\text{Dose})_{\text{same dir.}} = Q'(K_o)(TI)(PPS)(FMPS)(SPY)(P)F \qquad \text{(D-22)}$$

where the traffic factor F is the same as that given in Equation (D-17), except that:

$$I_{fwy} = I_1 \text{ (100 ft)} = .008$$

$$I_4 = I_1 \text{ (30 ft)} = .031$$

$$I_{cs} = I_1 \text{ (10 ft)} = .097$$

$$\text{and } I_1 \text{ (d)} = \int_d^{2600 \text{ ft}} \frac{e^{-\mu x} B(x)}{x^2}$$

The constant Q' is:

$$Q' = 2 \times 10^{-3} \ \frac{\text{rem}}{\text{mrem}} \times \frac{1 \text{ mile}}{5280 \text{ ft}} = 3.79 \times 10^{-7}$$

The annual dose is computed for each shipment scenario using Equation (D-22), and the results are summed over all the standard shipments to obtain the total annual dose to persons traveling along the route in the same direction as the shipment.

REFERENCE

D.1. U. S. Atomic Energy Agency, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants," WASH-1238, December 1972.

APPENDIX E
DEMOGRAPHIC MODEL

E.1 INTRODUCTION

The analyses of both the normal and accident transport risks depend on the population density, i.e., the average number of people per unit area. Because population densities vary greatly, three different population density zones corresponding roughly to urban, suburban, and rural areas were considered. The average population densities assigned to each were determined from 1970 census data (Ref. E-1).

According to the 1970 census definition, urban population comprises all persons in places of 2,500 or more inhabitants, but not those living in rural portions of extended cities. Urban areas contain 73.5 percent of the total population.

E.2 URBANIZED AREAS

The Census Bureau has delineated so-called "urbanized areas" to provide a better separation of urban and rural population in the vicinities of the larger cities. An urbanized area consists of a central city with 50,000 or more inhabitants and surrounding closely-settled territory. Areas of large non-residential tracts devoted to such urban land uses as railroad yards, airports, factories, parks, golf courses, and cemeteries are excluded in computing the population density. The average population density in urbanized areas is 1,303/km^2 (3,375/mi^2); 31.5 percent of the total population live within the central cities of urbanized areas, and 26.8 percent live in the urban fringe, for a total of 58.3 percent living inside urbanized areas.

Urbanized areas such as Columbus, Ohio; Memphis, Tennessee; New Haven, Connecticut; San Antonio, Texas; and Wilmington, Delaware, have population densities higher than the average, while Atlanta, Georgia; Dallas, Texas; Des Moines, Iowa; and Bridgeport, Connecticut, have population densities lower than the average.

The average urban housing area consists of four to five housing units per acre or about 3,861 persons/km^2 (10,000 persons/mi^2). If this value for urban population density is assumed and 54 percent of the urbanized area population live in the central city, 18.2 percent of the urbanized area is occupied by the central city. This assumption forces an assumed density of 719 persons/km^2 for the so-called urban fringe. These two densities were selected to represent the urban and suburban population densities throughout the country.

E.3 OTHER URBAN AREAS

About 15.2 percent of the total population live in areas that are classified as urban, but that are outside the urbanized areas in and around the larger cities. The average population density in these areas is taken to be 719 persons/km^2, as in suburban population density zones.

E.4 RURAL AREAS

Rural areas, which contain 98.5 percent of the land area (approximately 3.5 million square miles) and 26.5 percent of the total population (approximately 50 million people), have an average population density of 6 persons/km^2. This figure was selected to represent rural areas.

E.5 EXTREME-DENSITY URBAN AREAS

Certain cities have population densities far in excess of the average value for urbanized areas. An analysis of population densities of cities, each having a total population of more than 100,000 persons, indicated that there were:

1. 98 cities with a population density less than 1,930/km^2 (5,000/mi^2);
2. 37 cities with a population density between 1,930 and 3,861/km^2 (5,000 - 10,000/mi^2);
3. 10 cities with a population density between 3,861 and 5,792/km^2 (10,000 - 15,000/mi^2);
4. 7 cities with a population density between 5,792 and 7,722/km^2 (15,000 - 20,000/mi^2);
5. 0 cities with a population density between 7,722 and 9,653/km^2 (20,000 - 25,000/mi^2); and
6. 1 city (New York City) with a population density greater than 9,653/km^2.

In each of these cases, the population density was determined by dividing the total population in the city by the land area enclosed by the city limits. Two additional points were noted:

1. New York City is clearly in a class by itself. The most densely populated borough is Manhattan, with a population density of 26,188 persons/km^2 (67,808/mi^2).

2. Cities with the larger population densities are not always the cities with the larger total populations. For example, Los Angeles, California, with a total population of 2,816,000, has a population density of 2,345/km^2, while Paterson, New Jersey, with a total population of 145,000, has a population density of 6,657/km^2, almost three times as great as that of Los Angeles.

The risks associated with the transportation of radioactive material through areas of very high population density are currently being evaluated in a follow-on study. In the current report, the consequences of a severe accident within such an area are evaluated for certain worst-case isotopes and are presented along with an estimate of the probability of occurrence. The annual risk estimates for all radioactive material transport, however, are made using the average values of 3,861, 719, and 6 persons/km^2.

E.6 SUMMARY AND CONCLUSIONS

For the purposes of this assessment, the 1970 census data were reduced to a nationwide model that specified three population zones - urban, suburban, and rural. The fraction of total land area, fraction of total population, and associated population densities for each of the population zones are shown in Table E-1. A population density of 15,444 persons/km^2 was used to represent an extremely dense urban area in the worst-case accident analysis in Chapter 5.

[illegible]

TABLE E-1

TABULAR SUMMARY OF DEMOGRAPHIC MODEL

Population Zone	Fraction of Land Area	Fraction of Population	Population Density (persons/km^2)
A. Urbanized Area	.0098	.583	1303
1. Central city	.0018	.315	3861
2. Urban fringe	.008	.268	719
B. Other Urban Areas	.0053	.152	719
C. Rural Areas	.985	.265	6
D. Demographic Model Used in This Assessment			
1. Urban (A.1)	.0018	.315	3861
2. Suburban (A.2+B)	.013	.42	719
3. Rural (C)	.985	.265	6
4. Extreme density urban	-	-	15444

REFERENCE

E-1. "Statistical Abstracts of the United States 1974" (95th Edition), U.S. Department of Commerce Social and Economic Statistics Division; U.S. Bureau of the Census.

APPENDIX F

INCIDENTS REPORTED TO DOT INVOLVING RADIOACTIVE MATERIAL FROM 1971 THROUGH 1974

This Appendix contains a list of the 98 incidents involving radioactive materials that were reported to the U.S. Department of Transportation (DOT) from 1971 through 1974. The data, tabulated in Table F-1, were obtained from the DOT Hazardous Materials Incident Reports. A sample of the DOT reoort form is presented as Figure F-1.

Columns 1 and 2 of Table F-1 describe the material involved for each incident (e.g., R.A.M.N.O.S. - Radioactive Material - Not Otherwise Specified) and give the 5-digit code for that material. Columns 3 and 4 describe the packaging in which the material was shipped, as obtained from Item G on Figure F-1. Columns 5 and 6 list the nature of the packaging failure from the 15 possibilities listed on Item F of Figure F-1. Columns 7 and 8 show the number of failed containers and the total number of containers in the shipment. Column 9 shows the special permit number obtained from Item G.30 on Figure F-1. Column 9 shows the special permit number obtained from Item G.30 on Figure F-1. Column 10 gives the incident report number: the first digit is the last digit of the year in which the incident occurred (e.g., 4... refers to 1974), and the second and third digits refer to the month of the incident. The remaining five digits codify the report within the month.

TABLE F-1

INCIDENTS REPORTED TO DOT INVOLVING RADIOACTIVE MATERIALS (SORTED BY REPORT NUMBERS)

COMMODITY	CODE	CONT 1	CONT 2	FAILURE 1	FAILURE 2	# FAIL	# SHIP	SP NO.	REPORT NO.
RADIOACTIVE MATERIA	08930	DRUM MTL		EXT PUNCT	OTHER	0	2	SP6000	1020027A
ZIRCONIUM SCRAP(BOR	11050			BODY-SIDE	OTHER	1	1		1030104A
UNKN	00000	TANK CAR		##########	##########	1	1		1050096A
QUES	00000			##########	##########	0	1		1080013A
UNKN	00000	DRUM MTL		OTHER	##########	1	44		1090113A
RADIOACTIVE DEVICES	08910			LOOSE FVC	##########	1	1		1100376A
RADIOACTIVE DEVICES	08910	BOX WOOD		EXT PUNCT	OTHER	1	4	SP5248	1110102A
RADIOACTIVE MATERIA	08930	CONT LD		##########	##########	0	1		1120173A
RADIOACTIVE MATERIA	08930			OTHER	##########	0	2		2010124A
RADIOACTIVE MATERIA	08930	CYL MTL	BOX WOOD	LOOSE FVC	##########	1	1		2010137A
RADIOACTIVE MTATERI	08920	CONT PLS	6D	##########	##########	1	29		2010193A
RADIOACTIVE MATERIA	08930	CONT LD	BOX FBR	DROPPED	##########	1	1		2020138A
RADIOACTIVE MATERIA	08940			##########	##########	0	0		2030227A
FISSILE RADIOACTIVE	05110	DRUM MTL		EXT PUNCT	##########	1	6		2040118A
RADIOACTIVE MATERIA	08930	BOX WOOD		OTHER	##########	1	1		2040329A
RADIOACTIVE MATERIA	08930	TUBE GLS	TUBE FBR	DROPPED	##########	2	2		2050044A
RADIOACTIVE MTATERI	08920	TANK TRK		EXT PUNCT	FREEZING	1	1		2070120A
RADIOACTIVE MATERIA	08930	LINR PLS	DRUM MTL	INT PRESS	CORR-RUST	1	4		2070331A
RADIOACTIVE MATERIA	08930	CYL MTL	7A	OTHER	##########	1	5		2070390A
RADIOACTIVE MATERIA	08930		BOX WOOD	OTHER FRT	##########	1	1		2080001A
RADIOACTIVE MATERIA	08930	17E		INNER REC	BOTTOM	1	9		2090377A
RADIOACTIVE MATERIA	08930	CYL MTL		LOOSE FVC	##########	1	1		2100389A
RADIOACTIVE MTATERI	08920	BOX MTL	BOX WOOD	EXT HEAT	##########	4	74		2100393A
RADIOACTIVE MTATERI	08920	17E		WELD	##########	1	57		2120196A
RADIOACTIVE MATERIA	08930	DRUM MTL		OTHER FRT	LOOSE FVC	0	10		2120264A
RADIOACTIVE MATERIA	08930	DRUM MTL		OTHER FRT	LOOSE FVC	4	10		3010116A
RADIOACTIVE MATERIA	08930	PAIL MTL		DEF FVC	LOOSE FVC	2	22		3010262A
RADIOACTIVE MTATERI	08920	BAG PPR		EXT PUNCT	##########	1	1K		3030098A
R.A.M. N.O.S.	08930	CAN MTL	BOX FBR	DROPPED		1	1		3070241A
R.A.M. N.O.S.	08930	21C		EXT PUNCT	BOTTOM	1	1		3070270A
R.A.M. SMALL QUANTY	08940	BOTL GLS	21C	OTHER FRT		1	4		3080530A
R.A.M. LOW SPEC ACT	08920	DRUM MTL		CORR-RUST		1	21		3100029A
R.A.M. N.O.S.	08930	CYL MTL	12B	DROPPED	BOTTOM	1	1		3100274A
R.A.M. LOW SPEC ACT	08920	17H		DROPPED		1	53		3110050A
RADIOACTIVE DEVICES	08910	BOX FBR		OTHER LIQ		1	1		3110179A
R.A.M. LOW SPEC ACT	08920	17H		EXT PUNCT		2	79		3120045A
R.A.M. LOW SPEC ACT	08920	DRUM MTL		CORR-RUST	BODY-SIDE	1	62		4020081A
RADIOACTIVE DEVICES	08910	BOX WOOD		OTHER FRT	OTHER	1	1		4020263A
R.A.M. N.O.S.	08930	CAN MTL	21C	OTHER		1	1		4020394A
R.A.M. N.O.S.	08930	BLANK		BOTTOM	BODY-SIDE	1	1		4030098A
R.A.M. N.O.S.	08930	7A		DROPPED	OTHER	1	1		4030170A
R.A.M. N.O.S.	08930	BOX FBR		WATER		0	6		4030232A
R.A.M. N.O.S.	08930	BLANK		OTHER		0	1		4030399A
R.A.M. N.O.S.	08930	DRUM MTL		EXT PUNCT	OTHER	2	0		4030476A
R.A.M. LOW SPEC ACT	08920	TANK PRT		OTHER		0	13		4040129A
R.A.M. N.O.S.	08930	CAN MTL		OTHER		1	1		4040132A
R.A.M. N.O.S.	08930	CAN MTL		OTHER		1	1		4040132B
R.A.M. N.O.S.	08930	55		OTHER		1	1		4040403A
R.A.M. N.O.S.	08930	12B		DROPPED	EXT PUNCT	0	12		4040404A
R.A.M. N.O.S.	08930	7A		DROPPED		1	2		4050132A

TABLE F-1 (continued)

COMMODITY	CODE	CONT 1	CONT 2	FAILURE 1	FAILURE 2	# FAIL	# SHIP	SP NO.	REPORT NO.
R.A.M. N.O.S.	C8930	BLANK		OTHER		1	1	SP5874	4050139A
R.A.M. N.O.S.	08930	BLANK		OTHER		1	1	SP5874	4050140A
P.A.M. N.O.S.	09930	BLANK		OTHER		1	1	SP5874	4050141A
R.A.M. N.O.S.	08930	7A		DROPPED	OTHER FRT	0	1		4050229A
R.A.M. N.O.S.	08930	CONT STY	12B	OTHER		1	1		4050255A
R.A.M. N.O.S.	08930	BOTL GLS	TUBE FBR	DROPPED	FXT PUNCT	1	2		4050486A
R.A.M. SPEC. FORM	08950	DRUM MTL		BOTTOM		0	1		4060104A
R.A.M. N.O.S.	09930	7A		OTHER		1	1		4060105A
R.A.M. N.O.S.	09930	BOX FBR		EXT PUNCT		0	1		4060274A
R.A.M. N.O.S.	C8930	17E		CHIME		1	11		4060680A
R.A.M. N.O.S.	C8930			WATER		0	2		4060698A
R.A.M. N.O.S.	09930	12B		DROPPED		0	1		4070266A
R.A.M. N.O.S.	08930	CONT PLS	BOX FBR	DROPPED		1	19		4070349A
R.A.M. N.O.S.	08930	TANK PRT		OTHER		1	1	SP5660	4070362A
FISSILE R.A.M.	05110	DRUM MTL		EXT PUNCT	OTHER	0	70		4070628A
R.A.M. N.O.S.	08930	BLANK		OTHER		0	2		4070739A
R.A.M. N.O.S.	08930	CAN MTL	BOX FBR	DROPPED		0	1		4070805A
R.A.M. SMALL QUANTY	08940	BOX FBR		BODY-SIDE		3	3		4070846A
R.A.M. N.O.S.	08930	BLANK	12B	OTHER		1	2		4080265A
R.A.M. N.O.S.	08930	BOX MTL	BOX WOOD	OTHER FRT		0	6		4080493A
R.A.M. N.O.S.	08930	BOX MTL	BOX FBR	WATER	BODY-SIDE	1	4		4080497A
R.A.M. N.O.S.	08930	BOX MTL	BOX FBR	OTHER FRT		1	1		4080630A
R.A.M. LOW SPEC ACT	03920	TYPE B		DROPPED		0	1		4080679A
P.A.M. N.O.S.	08930	LINR PLS	BOX FBR	OTHER		0	3		4080698A
R.A.M. N.O.S.	08930	BLANK	BOX FBR	DROPPED		1	1		4080789A
R.A.M. LOW SPEC ACT	03920	TANK PRT		OTHER		0	1		4080947A
R.A.M. N.O.S.	03930	BOTL GLS	BOX FBR	EXT PUNCT		1	1		4090093A
R.A.M. N.O.S.	08930	DRUM MTL		EXT PUNCT		0	1		4090112A
R.A.M. N.O.S.	08930	BOTL PLS	7A	OTHER		1	1		4090307A
THORIUM NITRATE SOL	13270	21C		DROPPED		1	24		4090323A
R.A.M. SPEC. FORM	08950	55		OTHER		1	1		4090359A
R.A.M. N.O.S.	08930	CAN MTL	DRUM MTL	LOOSE FVC		1	1		4090528A
R.A.M. N.O.S.	C8930	PAIL MTL		LOOSE FVC		1	2		4090721A
R.A.M. N.O.S.	08930	BLANK	12B	OTHER FRT		0	1		4090845A
R.A.M. SPEC. FORM	08950	BLANK	CAN MTL	CORR-RUST	BOTTOM	1	1		4100206A
R.A.M. SPEC. FORM	08950	55	BOX WOOD	OTHER FRT		1	1		4100433A
R.A.M. N.O.S.	08930	CAN MTL		EXT PUNCT	BODY-SIDE	1	3		4100585A
R.A.M. N.O.S.	08930	BLANK		DROPPED		0	0		4100655A
R.A.M. N.O.S.	08920	BOX MTL	BOX FBR	WATER		0	1		4110247A
R.A.M. N.O.S.	C8930	15A	7A	LOOSE FVC	BOTTOM	1	2		4120197A
R.A.M. N.O.S.	C8930	15A	7A	LOOSE FVC	BOTTOM	1	21		4120197B
R.A.M. N.O.S.	08930	BOTL	7A	EXT PUNCT	OTHER FRT	0	3		4120235A
R.A.M. N.O.S.	08930	BOTL	7A	EXT PUNCT	OTHER FRT	0	2		4120235B
R.A.M. N.O.S.	08930	TYPE B				0	1	SP5874	4120390A
R.A.M. N.O.S.	08930	7A		OTHER		1	1		4120628A
R.A.M. SPEC. FORM	08950	CAN MTL	BOX FBR	DEF FVC		0	2		4120638A
R.A.M. N.O.S.	08930	BLANK		OTHER		0	1		4120646A

DEPARTMENT OF TRANSPORTATION

Form Approved OMB No. 04-5613

HAZARDOUS MATERIALS INCIDENT REPORT

INSTRUCTIONS: Submit this report in duplicate to the Secretary, Hazardous Materials Regulations Board, Department of Transportation, Washington, D.C. 20590, (ATTN: Op. Div.). If space provided for any item is inadequate, complete that item under Section H, "Remarks", keying to the entry number being completed. Copies of this form, in limited quantities, may be obtained from the Secretary, Hazardous Materials Regulations Board. Additional copies in this prescribed format may be reproduced and used, if on the same size and kind of paper.

A INCIDENT

1. TYPE OF OPERATION
   1 ☐ AIR 2 ☐ HIGHWAY 3 ☐ RAIL 4 ☐ WATER 5 ☐ FREIGHT FORWARDER 6 ☐ OTHER *(Identify)* ______

2. DATE AND TIME OF INCIDENT *(Month - Day - Year)* ______ a.m. ______ p.m.

3. LOCATION OF INCIDENT

B REPORTING CARRIER, COMPANY OR INDIVIDUAL

4. FULL NAME

5. ADDRESS *(Number, Street, City, State and Zip Code)*

6. TYPE OF VEHICLE OR FACILITY

C SHIPMENT INFORMATION

7. NAME AND ADDRESS OF SHIPPER *(Origin address)*

8. NAME AND ADDRESS OF CONSIGNEE *(Destination address)*

9. SHIPPING PAPER IDENTIFICATION NO.

10. SHIPPING PAPERS ISSUED BY
    ☐ CARRIER ☐ SHIPPER
    ☐ OTHER *(Identify)* ______

D DEATHS, INJURIES, LOSS AND DAMAGE

DUE TO HAZARDOUS MATERIALS INVOLVED

11. NUMBER PERSONS INJURED

12. NUMBER PERSONS KILLED

13. ESTIMATED AMOUNT OF LOSS AND/OR PROPERTY DAMAGE INCLUDING COST OF DECONTAMINATION *(Round off in dollars)* $

14. ESTIMATED TOTAL QUANTITY OF HAZARDOUS MATERIALS RELEASED

E HAZARDOUS MATERIALS INVOLVED

15. CLASSIFICATION (Sec. 172.4)	16. SHIPPING NAME (Sec. 172.5)	17. TRADE NAME

F NATURE OF PACKAGING FAILURE

18. *(Check all applicable boxes)*

☐ (1) DROPPED IN HANDLING	☐ (2) EXTERNAL PUNCTURE	☐ (3) DAMAGE BY OTHER FREIGHT
☐ (4) WATER DAMAGE	☐ (5) DAMAGE FROM OTHER LIQUID	☐ (6) FREEZING
☐ (7) EXTERNAL HEAT	☐ (8) INTERNAL PRESSURE	☐ (9) CORROSION OR RUST
☐ (10) DEFECTIVE FITTINGS, VALVES, OR CLOSURES	☐ (11) LOOSE FITTINGS, VALVES OR CLOSURES	☐ (12) FAILURE OF INNER RECEPTACLES
☐ (13) BOTTOM FAILURE	☐ (14) BODY OR SIDE FAILURE	☐ (15) WELD FAILURE
☐ (16) CHIME FAILURE	☐ (17) OTHER CONDITIONS *(Identify)*	19. SPACE FOR DOT USE ONLY

Form DOT F 5800.1 (10-70)

FIGURE F-1. HAZARDOUS MATERIALS INCIDENT REPORT

G	PACKAGING INFORMATION - *If more than one size or type packaging is involved in loss of material show packaging information separately for each. If more space is needed, use Section H "Remarks" below keying to the item number.*					
	ITEM			#1	#2	#3
20	TYPE OF PACKAGING INCLUDING INNER RECEPTACLES *(Steel drums, wooden box, cylinder, etc.)*					
21	CAPACITY OR WEIGHT PER UNIT *(55 gallons, 65 lbs., etc.)*					
22	NUMBER OF PACKAGES FROM WHICH MATERIAL ESCAPED					
23	NUMBER OF PACKAGES OF SAME TYPE IN SHIPMENT					
24	DOT SPECIFICATION NUMBER(S) ON PACKAGES *(21P, 17E, 3AA, etc., or none)*					
25	SHOW ALL OTHER DOT PACKAGING MARKINGS *(Part 178)*					
26	NAME, SYMBOL, OR REGISTRATION NUMBER OF PACKAGING MANUFACTURER					
27	SHOW SERIAL NUMBER OF CYLINDERS, CARGO TANKS, TANK CARS, PORTABLE TANKS					
28	TYPE DOT LABEL(S) APPLIED					
29	IF RECONDITIONED OR REQUALIFIED, SHOW	A	REGISTRATION NO. OR SYMBOL			
		B	DATE OF LAST TEST OF INSPECTION			
30	IF SHIPMENT IS UNDER DOT OR USCG SPECIAL PERMIT, ENTER PERMIT NO.					

H REMARKS - Describe essential facts of incident including but not limited to defects, damage, probable cause, stowage, action taken at the time discovered, and action taken to prevent future incidents. Include any recommendations to improve packaging, handling, or transportation of hazardous materials. Photographs and diagrams should be submitted when necessary for clarification.

31. NAME OF PERSON PREPARING REPORT *(Type or print)*	32. SIGNATURE
33. TELEPHONE NO. *(Include Area Code)*	34. DATE REPORT PREPARED

Reverse of Form DOT F 5800.1 (10-70) GPO 1970 O - 406 376

FIGURE F-1 (continued)

APPENDIX G
CALCULATION METHODOLOGY FOR ACCIDENT ANALYSIS

The methodology used to compute annual early fatalities and latent cancer fatalities resulting from accidents involving shipments of radioactive material is presented in detail in Reference G-1. The procedures are outlined in this Appendix.

G.1. COMPUTATION OF ANNUAL EARLY FATALITY PROBABILITY

The technique for computing annual early fatality probability is illustrated in Figure G-1. Initially, the average dose received by individuals within a given isodose area is computed for each radionuclide in each accident severity category:

$$\phi_{i,j,k} = (n_i)(RF_{j,k})(AER_i)(RESP_i)(E_i)(RPC_i)(DF) \qquad \text{(G-1)}$$

where
- ϕ = average dose received in the area (rem)
- i = index over radionuclides
- j = index over the accident severity categories
- k = index over the package types
- n = curies per shipment (Ci)
- RF = release fraction
- AER = aerosolized fraction
- RESP = fraction of aerosolized material of respirable dimension in reference mixture
- E = particle size distribution factor*
- RPC = dose per curie inhaled (rem/Ci)
- DF = dilution factor (This value includes the effects of a 0.01 m/sec deposition velocity.)

The appropriate dose-response relationship (see Chapter 3) is then used to determine the probability of early fatality for each exposed individual. This is shown as block 6 on Figure G-1. Once the individual probability per exposure has been computed, a combination of binomial and Poisson statistics is used to compute the probability of a given number of early fatalities within a given isodose area:

$$P(k) = \sum_{i=k}^{\infty} \binom{i}{k} P_I^{\,k} (1 - P_I)^{i-k} \left(\frac{\lambda^i e^{-\lambda}}{i!} \right) \qquad \text{(G-2)}$$

*This factor accounts for potential variation in particle size between the aerosol used for reference for the rem-per-curie value and the actual aerosol being shipped. In the analysis in Chapter 5, a respirability of 0.24 is used for rem-per-curie reference and a value of 0.11 was obtained from an industry survey. Hence, E = 0.46.

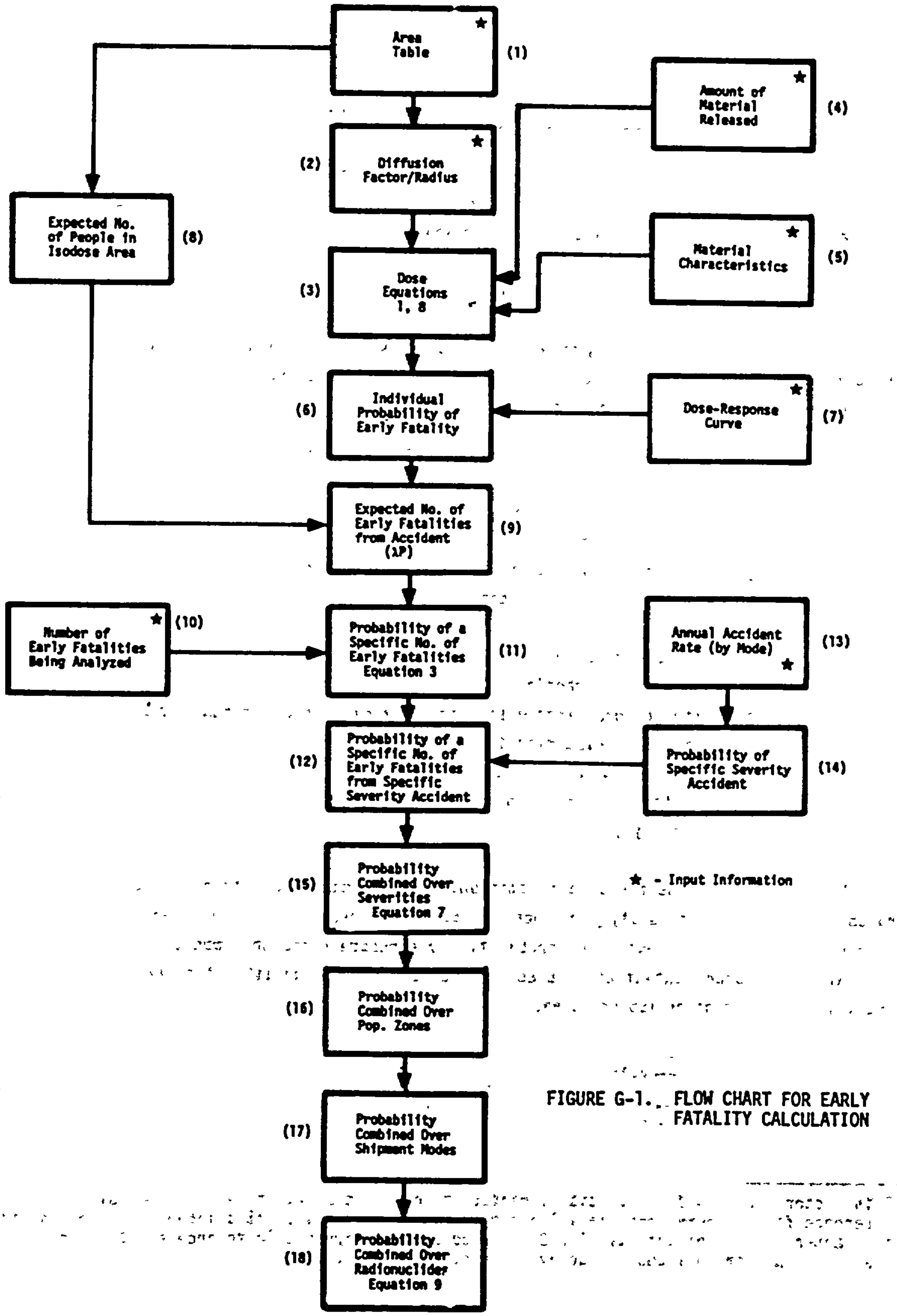


FIGURE G-1. FLOW CHART FOR EARLY FATALITY CALCULATION

$P(k)$ = probability of k early fatalities

i = predicted number of people in specific isodose area

P_1 = individual probability of early fatality when exposed to a given dose

λ = expected number of people in isodose area (product of area and average population density)

Using a Taylor expansion, Equation (G-2) can be reduced to

$$P(k) = \frac{(\lambda P_1)^k (e^{-\lambda P_1})}{k!} \qquad \text{(G-3)}$$

which is in the form of a Poisson distribution with parameter $\lambda P1$* where P(k) is the probability of k early fatalities assuming that an accident does occur. This value must now be combined with the annual probability of an accident of specific severity in the specific population density zone involving a specific mode of transport:

$$P(k)_{i,j,k,l} = \left(P(k)_{i,k}\right)\left(P(acc)_{i,j,l}\right) \qquad \text{(G-4)}$$

where

P(acc)i,j,k,l = annual probability of ith severity accident in jth population density zone involving kth radionuclide being shipped by the lth mode combination

$P(k)_{i,k}$ = P(k) from Equation (G-3)

The annual accident rate for accidents of a given severity is computed as follows:

$$\gamma_{i,j,k,l} = \left[\left(APM_{l,p}\right)\left(\eta_{i,l,p}\right)\left(\delta_{i,j,l,p}\right)\left(SPY_{k,l}\right)\left(FMPS_{k,l,p}\right)\right] + \left[\left(APM_{l,s}\right)\left(\eta_{i,l,s}\right)\left(\delta_{i,j,l,s}\right)\left(SPY_{k,l}\right)\left(FMPS_{k,l,s}\right)\right] \qquad \text{(G-5)}$$

where

$\gamma_{i,j,k,l}$ = accidents per year of ith severity in jth population density zone for kth radionuclide transported by lth mode combination

p = contribution from primary mode

s = contribution from secondary mode

$APM_{l,p}$ = overall accident rate for lth mode primary vehicle

$\eta_{i,l}$ = fraction of lth mode combination accidents that are of severity i

$\delta_{i,j,l}$ = fraction of ith severity accidents with lth mode combination in jth population density zone

$SPY_{k,l}$ = shipments per year of kth radionuclide by lth mode combination

$FMPS_{k,l}$ = distance per shipment for kth radionuclide by lth mode combination

P(acc) is obtained by using the Poisson distribution on $\gamma i,j,k,l$ from Equation (G-5).

The assumption is now made that fatality-producing transportation accidents involving radioactive material shipments are statistically independent on an annual basis. This allows the use of the Boolean identity

---

*It should be noted that the Poisson approximation for the probability of a given number of people in an isodose area combined with the binomial dose-effect relationship over predicts fatality probability for small values of λ.

$$P(A \cup B \cup C) = 1 - P(\bar{A})P(\bar{B})P(\bar{C}) \qquad \text{(G-6)}$$

where $P(\bar{A})$ = the Boolean complement of P(A),

to combine fatality probabilities over all severity categories, population density zones, mode combinations, and materials.

Thus, the annual probability of a specific number of early fatalities from a given radionuclide, shipped by a given mode combination in a given population density zone, over all accident severity categories is given by:

$$P_{j,k,l} = 1.0 - \prod_{i=1}^{8} (1 - P_i) \qquad \text{(G-7)}$$

where i = index over accident severity categories

$P_i = P(k)_{i,j,k,l}$ computed in Equation (G-4)

j = index over the population density zones

k = index over the radionuclides

l = index over the mode combinations for specific radionuclide

This technique is used to combine results for the population density zones and mode combinations for each atmospherically dispersed radionuclide that can produce a sufficient dose to cause an early fatality.

Some sources of whole-body external penetrating radiation also have the potential for providing sufficient dose to cause early fatalities. The number of these fatalities can be computed using the following formula for the dose rate at a distance r from this type of source:

$$DR(r) = \frac{(5597.2)(n)(E)(e^{-\mu r})(B(r))}{r^2} \qquad \text{(G-8)}$$

where DR(r) = dose rate at r (rem/hr)

n = curies of material (Ci)

E = energy of photons (MeV)

μ = energy attenuation coefficient (0.00393 m^{-1} (0.00118 ft^{-1}))

r = distance to source (m)

B(r) = Berger buildup factor (0.00018r + 1) (dimensionless, r in meters)

This result is most accurate for photon energies between approximately 0.25 MeV and 4.5 MeV. Outside those ranges, the values for μ, B(r) and the numerical constant would need to be adjusted (Refs. G-2 and G-3). The method of computing results for this type of source is very similar to that used for atmospherically dispersed sources and is illustrated in Figure G-2.

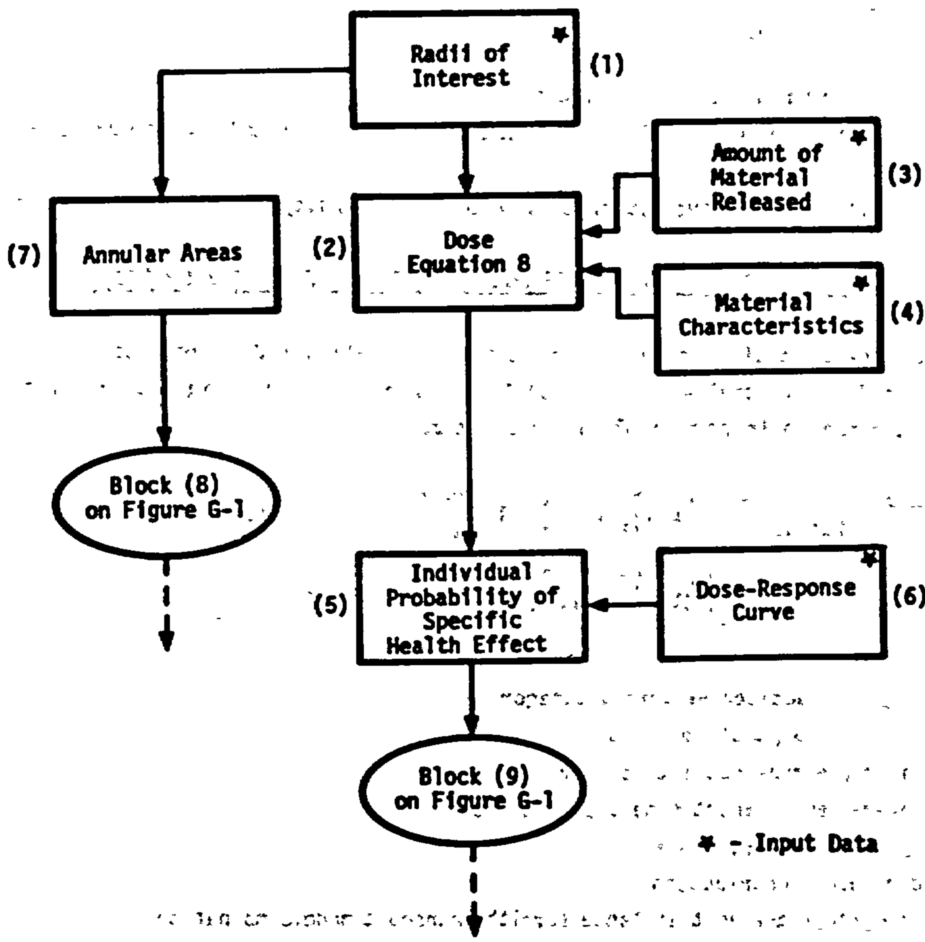


FIGURE G-2. EARLY FATALITY COMPUTATION FLOW DIAGRAM FOR EXTERNAL PENETRATING RADIATION SOURCES

The results of computation for all potentially fatal exposure sources and for all potentially fatal atmospherically dispersed sources can now be combined to give the annual probability of a specific number of early fatalities from transportation accidents involving all radionuclides shipped. This is given by:

$$P = 1.0 - \prod_{l=1}^{n} (1 - P_l) \qquad \text{(G-9)}$$

where l = index over the radionuclides shipped

n = number of radionuclides shipped that can produce a sufficient dose to cause early fatalities

P_l = probability combined over severities, population density zones, and mode combinations

G.2 COMPUTATION OF LATENT CANCER FATALITIES DUE TO AIRBORNE RELEASES FROM ACCIDENTS

The method for computing annual latent cancer fatalities (LCF) from accidents is illustrated in Figure G-3. Initially, the accident rate for each of the eight severity categories for each mode combination in each population zone is computed:

$$\left(\frac{\text{class h accidents}}{\text{year}}\right)_{i,j,k,l} = \left[\left(\lambda_{l,p}\right)\left(\delta_{j,l,p}\right)\left(\gamma_{l,p}\right)\left(SPY_{k,l,p}\right)\left(FMPS_{k,l,p}\right)\right] + \left[\left(\lambda_{l,s}\right)\left(\delta_{j,l,s}\right)\left(\gamma_{l,s}\right)\left(SPY_{k,l,s}\right)\left(FMPS_{k,l,s}\right)\right] \qquad \text{(G-10)}$$

where i = index over the accident severity categories

j = index over the population zones

k = index over the radionuclides shipped

l = index over the transport mode combinations

p = primary mode contribution

s = secondary mode contribution

λ_l = total accidents per unit distance for lth transport mode combination

$\delta_{j,l}$ = fraction of class i accidents in jth population density zone for lth mode

λ_l = class h accident fraction for lth transport mode

$SPY_{k,l}$ = shipments per year for kth radionuclide by lth mode

$FMPS_{k,l}$ = distance per shipment for kth radionuclide by lth mode

The number determined using Equation (G-10) is the annual accident rate for a specific severity accident, occurring in a specific population density zone, involving a specific radionuclide, shipped by a specific mode combination.

This must now be combined with the integrated organ dose resulting from a given atmospheric release of material. This dose is computed for a single exposure to the nth organ from the kth radionuclide involved in a category h accident in the jth population density zone.

$$\phi_{j,k,n} = \left(ci_k\right)\left(PPS_k\right)\left(RF_k\right)\left(AER_k\right)\left(RESP_k\right)\left(RPC_{n,k}\right)\left(IF\right)\left(DF\right)\left(PD_j\right)\left(RDF_i\right) \qquad \text{(G-11)}$$

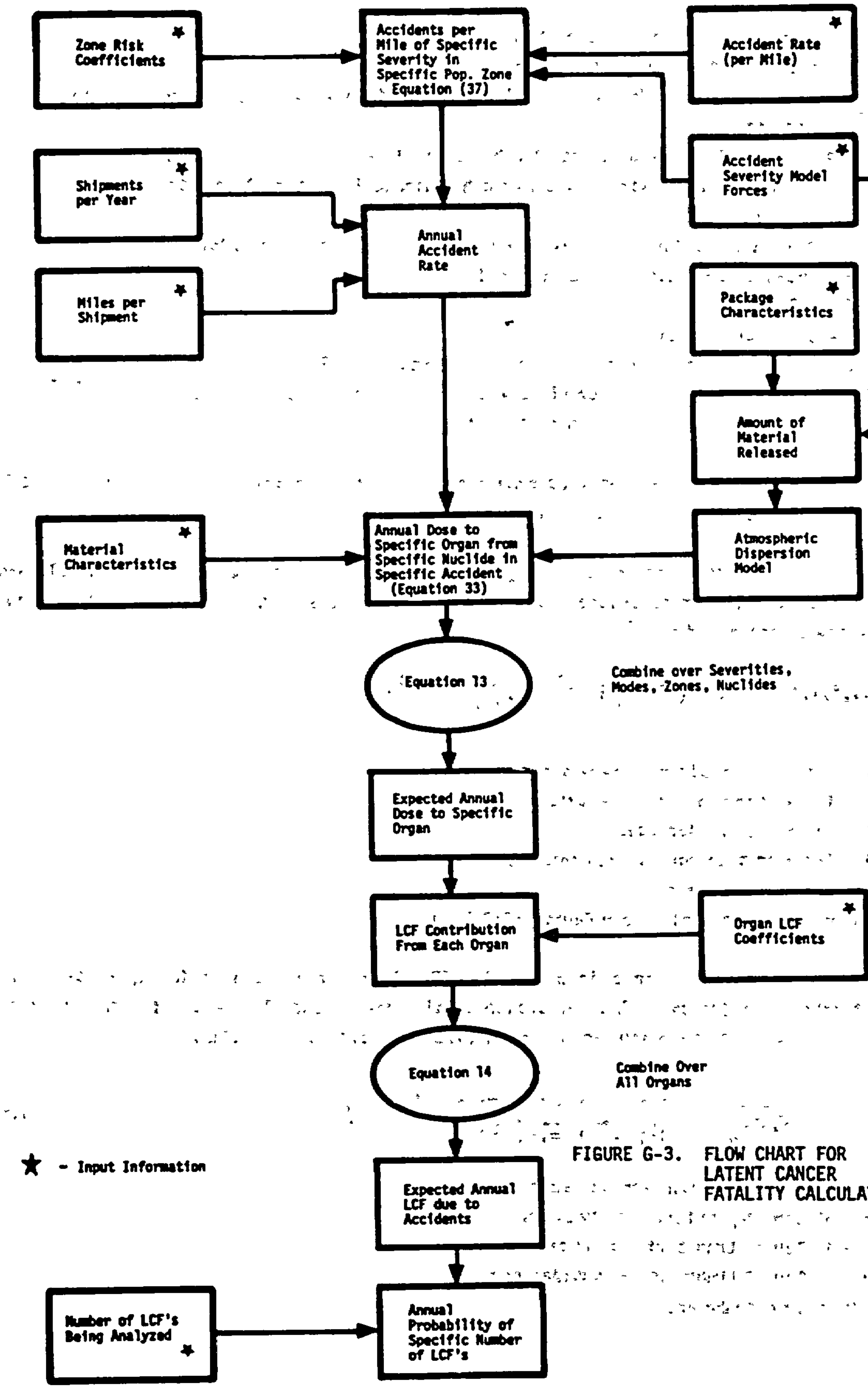


FIGURE G-3. FLOW CHART FOR LATENT CANCER FATALITY CALCULATION where Ci_k = curies per package for the kth radionuclide

PPS_k = packages of the kth radionuclide per shipment

$RF_{k,h}$ = release fraction for an h severity accident involving a package used to ship the kth radionuclide

AER_k = percent of released amount of kth radionuclide that is aerosolized

$RESP_k$ = percent of aerosolized amount of kth radionuclide material that is of a respirable size

$RPC_{k,n}$ = rem per curie (inhaled) delivered to nth organ by kth radionuclide

IF = integration factor over designated area

DF = dilution factor

PD = population density

E = particle size distribution factor (see Equation (G-1))

RDF_i = resuspension dose factor (This value includes a resuspension factor of 10^{-5} m^{-1} and is evaluated for each isotope.)

The IF and DF values are obtained from appropriate meteorological data, and the E and RPC values are obtained from appropriate dosimetric data.

The total integrated organ dose per year to the nth organ from the ith severity class of accidents for the lth transport mode with the kth radionuclide in the jth population density zone can now be specified by:

$$\text{Dose/yr}_{i,j,k,l,n} = \left(\lambda_l\right)\left(\gamma_{i,l}\right)\left(\delta_{i,j}\right)\left(SPY_{k,l}\right)\left(FMPS_{k,l}\right)\left(\phi_{j,l,n}\right) \quad \text{(G-12)}$$

where i = index over accident severity categories

j = index over population density zones

k = index over radionuclides

l = index over transport mode combinations

n = index over organs

(λ, γ, δ, are variables from Equation (G-10))

By summing the values determined in Equation (G-12) over all modes of transportation, all accident severity categories, all population density zones, and all transported radionuclides, the total annual dose to the nth organ for all classes of accident is obtained.

$$\frac{\text{Dose}}{\text{Year}_n} = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{t} \sum_{l=1}^{u} \left(\text{Dose/yr}_{i,j,k,l,n}\right) \quad \text{(G-13)}$$

where r = number of accident severity categories

s = number of population density zones

t = number of transported radionuclides

u = number of transport mode combinations

n = index over organs

Once the total annual organ doses are computed, they are converted to expected latent cancer fatalities using the LCF coefficients discussed in Chapter 3.

$$LCF = \sum_{n=1}^{v} K_n \,(\text{Dose/year})_n \qquad \text{(G-14)}$$

where LCF = expected latent cancer fatalities
K_n = latent cancer fatality coefficient for nth organ
n = index over organs
v = number of organs

G.3 COMPUTATION OF LATENT CANCER FATALITIES FROM EXTERNAL EXPOSURE SOURCE

Certain transported radioactive materials are not readily dispersible by virtue of their packagings (e.g., special form packages) or their chemical or physical form (e.g., nonvolatile components of spent reactor fuel or radiography source capsules). These materials may, however, provide a significant point source of external penetrating radiation. The integrated dose from shipments of this type (based on a 1-hour exposure) is given by:

$$ID = C\,K\,n\,E\,T\,PD\left(\int_{x}^{d} \frac{(2\pi r)}{r^2}\, e^{-\mu r}\, B(r)dr\right) \qquad \text{(G-15)}$$

where ID = integrated population exposure (person-rem)
C = units conversion constant (rem/mrem x $km^2/ft^2 = 9.3 \times 10^{-11}$)
K = 5597.2 (see Equation G-8)
n = curies per package (Ci)
E = photon energy (MeV)
T = exposure time (assumed to be 1 hour)
PD = population density (persons/km^2)
x = minimum distance from source to populated zone (assumed to be 3 meters)
d = maximum distance over which exposure is assumed to occur (assumed to be 780 meters)

The similarity between this and the "Dose while stopped" in Appendix D is intentional. When the integral is evaluated for the given limits and the expression is simplified, the result is:

$$ID = 1.4183 \times 10^{-5}\,(n)(E)(PD) \qquad \text{(G-16)}$$

Once the integrated dose is determined, the LCF coefficient of 121.6 per 10^6 person-rem is applied to predict the latent cancer fatalities. This value is then combined with the LCF for dispersion calculations to give a total expected annual LCF.

REFERENCES

G-1. J. M. Taylor and S. L. Daniel, "RADTRAN: A computer code to analyze transportation of radioactive material," SAND-76-0243, Sandia Laboratories, Albuquerque, NM, April 1977.

G-2. S. Glasstone and A. Sesonske, Nuclear Reactor Engineering, Van Nostrand Reinhold Company, New York, 1967.

G-3. U.S. Atomic Energy Commission, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants," WASH-1238, December 1972.

APPENDIX H

METHOD FOR DERATING ACCIDENT SEVERITY CATEGORIES

The accident severity categories for aircraft presented in Chapter 5 are based on an equivalent drop height mpact onto an unyielding surface as a measure of energy available for container deformation. This can be expressed in terms of impact velocity as shown on Figure 5-2. The actual damage mechanism, however, is the abrupt deceleration that results in package deformation.

One "unyielding" surface that has been used in shipping container tests at Sandia Laboratories (Ref. H-1) is a 10-centimeter-thick sheet of steel over a 4.5-meter-thick slab of reinforced concrete. However, a very small fraction of the earth's surface approaches this criterion for being unyielding.

To evaluate and quantify the extent to which surfaces are unyielding, an analysis was performed to relate the impact velocities on real elastic surfaces to those experienced onto an unyielding surface in terms of Poisson's ratio and Young's modulus of elasticity.

Consider an infinitely rigid sphere ($E = \infty$) being dropped onto an elastic half plane ($E < \infty$). The maximum displacement of the half plane is given in Reference H-2 as:

$$\alpha = \left[\frac{15\pi(\frac{1-\nu}{\pi E})(mv^2)}{16\sqrt{R}}\right]^{2/5} \quad \text{(H-1)}$$

where
- α = displacement of half plane
- m = mass of sphere
- R = radius of sphere
- E = Young's modulus of half plane
- ν = Poisson ratio for half plane
- v = impact velocity of sphere

If sinusodial behavior of the half plane is assumed, the maximum value of deceleration can be derived:

$$A_{max} = 0.1157\pi^2\, v^{6/5} \left[\frac{16\sqrt{R}}{15\pi\,\frac{1-\nu}{\pi E}\,m}\right]^{2/5} \quad \text{(H-2)}$$

If steel is used as an "unyielding" target, the equivalent velocity for a given value of deceleration can be found by solving Equation (H-2) for velocity for both the unyielding target and the real target at the same value of deceleration. If this is done, the following relationship is obtained:

$$\frac{V_{yielding}}{V_{steel}} = \left[\frac{1 - \nu_y^2}{1 - \nu_s^2}\right]\left[\frac{E_s}{E_y}\right]^{1/3} \qquad \text{(H-3)}$$

Table H-1 shows a breakdown of actual surface occurrence probabilities in the United States (based on air carrier routes) together with surface properties. Values computed for V/V_s are shown for each surface type.

The ratio of velocities shown in Table H-1 was used to evaluate the joint probability of experiencing an accident of a given severity and having it occur on a surface of given hardness. The result is a "derating system" that shifts accidents that have velocities typical of a Class VIII accident, for example, to a lower severity class typical of an impact velocity given by

$$V = V_{observed}/(V/V_s) \qquad \text{(H-4)}$$

For example, a hard rock impact (V/Vs = 2.21) has a probability of 0.05. Applying the 2.21 factor to a velocity typical of a Class VIII accident gives an effective velocity of 507 km/hr (1127/2.21), which is in the Class VII accident severity category. As a result, 5% of the Class VIII accidents are reassigned to Class VII due to impacts on hard rocks. A similar procedure is used for all other surfaces. The procedure is shown explicitly in Table H-2.

TABLE H-1

CALCULATED PROBABILITIES AND CHARACTERISTICS OF SURFACES UNDER FLIGHT PATHS BETWEEN MAJOR U.S. AIR HUBS (Ref. H-3)

Surface Type	Example	Probability	Young's Modulus-E (pascal)	Poisson's Ratio	V/Vs
Water	Water, marsh	0.18	1.5×10^{9}	0.5	4.48
Soft Soil	Sand, cultivated soil	0.28	6.9×10^{8}	0.2	7.05
Hard Soil	Partially consolidated clay	0.39	5.52×10^{9}	0.3	3.37
Soft Rock	Tuff, alluvium sandstone	0.09	1.38×10^{10}	0.2	2.53
Hard Rock	Granite, gneiss	0.05	2.07×10^{10}	0.2	2.21
Unyielding*	Abutments, steel	0.01	2.07×10^{11}	0.33	1.0

*A 1-percent unyielding surface has been added to the information in Reference 3 to add conservatism.

TABLE H-2

DETAILED DERATING SCHEME

I Accident Severity Category	II Fraction of accidents with damage in given severity category (based upon drop height onto an unyielding surface)	III Equivalent impact velocity onto an unyielding surface (for fire < 0.5 hr) kilometer/hr	IV Fraction deleted from category as a result of derating	V Fraction of category due to unyielding surface	Fraction added to category as a result of derating (shown by source category	Impact Surface Contribution to Fraction Added: hard rock	soft rock	hard soil	soft soil	water	Fraction of accidents with damage in given severity category (based upon real surfaces)
VIII	0.03	604-1127	0.0297	0.0003	0	0	0	0	0	0	0.0003
VII	0.04	306-604	0.0396	0.0004	VIII - .0042	0.0015	.0027	0	0	0	0.0046
VI	0.03	225-306	0.0297	0.0003	VIII - 0.0171	0	0	0.0117	0	0.0054	0.0194
					VII - 0.002	0.002	0	0	0	0	
V	0.03	129-225	0.0297	0.0003	VIII - 0.0084	0	0	0	0.0084	0	0.0279
					VII - 0.0192	0	0.0036	0.0156	0	0	
					VI - 0.0	0	0	0	0	0	
IV	0.05	89-129	0.0495	0.0005	VIII - 0.0	0	0	0	0	0	0.0107
					VII - 0.0072	0	0	0	0	0.0072	
					VI - 0.0015	0.0015	0	0	0	0	
					V - 0.0015	0.0015	0	0	0	0	
III	0.09	48-89	0.0891	0.0009	VIII - 0.0	0	0	0	0	0	0.0434
					VII - 0.0112	0	0	0	0.0112	0	
					VI - 0.0144	0	0.0027	0.0117	0	0	
					V - 0.0144	0	0.0027	0.0117	0	0	
					IV - 0.0025	.0025	0	0	0	0	
I, II	0.73	0-48	0	NA - categories I, II not derated	VIII - 0.0	0	0	0	0	0	0.8937
					VII - 0.0	0	0	0	0	0	
					VI - 0.0138	0	0	0	0.0084	0.0054	
					V - 0.0138	0	0	0	0.0084	0.0054	
					IV - 0.0470	0	0.0045	0.0195	0.014	0.009	
					III - 0.0891	0.0045	0.0081	0.0351	0.0252	0.0162	

REFERENCES

H-1. L. L. Bonzon, M. McWhirter, "Special Tests of Plutonium Shipping Containers," IAEA-SR-10/21, International Atomic Energy Seminar on Radioactive Material Packaging and Transportation, Vienna, Austria, August 1976.

H-2. S. P. Timoshenko, J. N. Goodien; Elasticity Theory, McGraw-Hill, 1970.

H-3. D. W. Larson, R. K. Clarke, J. T. Foley, and W. F. Hartman, "Severities of Transportation Accidents - Volume II - Aircraft (SLA74-0001)," Sandia Laboratories, Albuquerque, NM, September 1975.

APPENDIX I
SENSITIVITY ANALYSIS

I.1 INTRODUCTION

This appendix contains an analysis of the sensitivity of the risk assessment presented in this document to some of the parameters used in the calculation. It should be noted from the outset that this is neither an error analysis nor a full parametric study. The purpose of this analysis is simply to determine how sensitive the calculation is to some of the more important parameters. Since values chosen for many of these parameters were based on certain assumptions, the results of this parameter study should help to indicate the sensitivity of this assessment to those assumptions. The parameters considered are divided into three categories: fundamental parameters, general parameters, and shipment parameters. The fundamental parameters are those included in both the normal and accident calculations or used throughout one of these two calculations. The fundamental parameters include the population densities and the meteorological parameters. General parameters are those parameters included in part of either of the two calculations. Examples are release fractions for a specific package type and average velocities. Shipment parameters are those determined from the 1975 survey data. They include the average curies per package, distance per shipment, and TI per package. In the following sections, the sensitivity of the calculation to each of these three parameter types is discussed.

I.2 SENSITIVITY OF ANALYSIS TO FUNDAMENTAL PARAMETERS

The sensitivity of the assessment to fundamental parameters is measured by the change in the annual risk (either the normal or accident components) when the value of the parameter is changed by a fixed amount. In the two following sections, the changes in annual risks (expressed as a percent) are presented for a fixed (10 percent) change in one parameter with all other parameters held constant.

I.2.1 CHANGES IN POPULATION DENSITY

Using the parameters in the 1975 Baseline model, an incremental increase of 10 percent was made (independently) in each of the three population densities. The results are shown in Table I-1.

TABLE I-1

PERCENT CHANGES IN NORMAL AND ACCIDENT RISKS FOR A 10 PERCENT INCREASE IN POPULATION DENSITY

Parameter	Change in Annual Risk	
	Normal	Accident
Urban Population Density	0.7%	8.5%
Suburban Population Density	0.4%	2.1%
Rural Population Density	0	0

It is evident from the table that the accident risk component is much more sensitive to the value chosen for the urban population density than is normal risk. Normal risk is relatively insensitive to population density changes. Changes in rural density are unimportant in all cases.

I.2.2 CHANGES IN THE METEOROLOGICAL PARAMETERS

The atmospheric dispersion model used in the accident risk analysis is a Gaussian plume model using turbulent diffusion coefficients. An initial release height of 10 meters is assumed, and cloud depletion by dry deposition is allowed. Rather than investigate the sensitivity of the atmospheric dispersion model to these parameters, a 10 percent increase in the diffusion factors was assumed (see Figure 5-7). The result was a 9 percent change in the annual accident radiological risk. The annual normal risk value is, of course, unaffected by this change.

I.3 SENSITIVITY OF THE ACCIDENT ANALYSIS TO GENERAL PARAMETERS

In this section, the sensitivity of the calculation of the annual radiological risk resulting from potential transportation accidents is examined. Because of the different nature of the normal transport risk calculation, its sensitivity to both general and shipment parameters is discussed in Section I.5.

The accident risk depends on, among other things, the product of the annual accident rate, the package release fraction, the fraction of all accidents estimated to occur in a given population zone, and the population density of that zone. Each component of this product (and thus the product itself) is a function of both the transport mode and the accident severity category. Table I-2 is a tabulation of these products by severity category for each population zone for type A packages (or drums) transported by the truck mode. The last column in Table I-2 shows the percent contribution of each product to the total (sum of all the products). The table shows that for transport of any given type A package by truck under all the assumptions inherent in the calculation, 84 percent of the accident risk is from accidents that occur in urban zones, and most of this results from class II, III, and IV accidents. Thus, an error in estimating the urban population density or the fraction of distance traveled in urban areas has a much greater effect on the risk estimate (for type A packages by truck) than corresponding errors for suburban and rural zones. Abbreviated tabulations were made for each transport mode, package type, and population zone calculation and are presented in Tables I-3 to I-7.

The values shown in these tables are independent of the standard shipment model; they apply individually to each package transported. By the same token, a comparison of the relative risks of two transported packages can be made directly from these tables only if they contain the same quantities of the same material and are transported the same distance. Different materials may still be compared by recalling that the risk is proportional to the quantity of material transported, to the distance traveled, and to material characteristics such as fraction aerosolized, fraction respirable, and the rem-per-curie value.

TABLE I-2

PRODUCT OF ACCIDENT RATE, RELEASE-FRACTION, FRACTION OF ACCIDENTS IN GIVEN POPULATION ZONE, AND POPULATION DENSITY FOR TYPE A PACKAGES BY TRUCK

Severity Category	Population Zone	Product	Fraction Of Total	
I	R	0	0	
II	R	.23	4.5×10^{-5}	
III	R	1.3	2.6×10^{-4}	Total Rural 0.1%
IV	R	3.1	6.0×10^{-4}	
V	R	.89	1.7×10^{-4}	
VI	R	.49	9.6×10^{-5}	
VII	R	.043	8.5×10^{-6}	
VIII	R	.0086	1.7×10^{-6}	
I	S	0	0	
II	S	28	5.4×10^{-3}	
III	S	214	4.2×10^{-2}	Total Suburban 16%
IV	S	489	9.6×10^{-2}	
V	S	64	1.3×10^{-2}	
VI	S	17	3.3×10^{-3}	
VII	S	.65	1.3×10^{-4}	
VIII	S	.057	1.1×10^{-5}	
I	U	0	0	
II	U	1180	2.3×10^{-1}	
III	U	861	1.7×10^{-1}	Total Urban 84%
IV	U	1970	3.9×10^{-1}	
V	U	230	4.5×10^{-2}	
VI	U	45	8.8×10^{-3}	
VII	U	3.5	6.8×10^{-4}	
VIII	U	.31	6.0×10^{-5}	

TABLE I-3

PRINCIPAL CONTRIBUTORS TO ACCIDENT RISK FOR TRUCKS

Package Type	Accident Severity	Population Zone		Percent of Risk
A, Drum	IV	Urban		38.5
	II	Urban		23.1
	III	Urban		16.9
	IV	Suburban		9.6
	V	Urban		4.5
	III	Suburban		4.2
	V	Suburban		1.3
			TOTAL	98.1
B, Cask-2	V	Urban		32.1
	IV	Urban		27.5
	III	Urban		12.0
	V	Suburban		9.0
	IV	Suburban		6.8
	VI	Urban		6.3
	III	Suburban		3.0
	VI	Suburban		2.3
			TOTAL	99.0
B-Pu	VI	Urban		51.8
	VII	Urban		20.0
	VI	Suburban		19.3
	VII	Suburban		3.7
	VIII	Urban		3.5
			TOTAL	98.3
Cask-1 (exposure)	VIII	Urban		72.8
	VIII	Suburban		15.5
	VII	Urban		8.4
	VII	Suburban		1.6
	VI	Urban		1.1
			TOTAL	99.4

TABLE I-4

PRINCIPAL CONTRIBUTORS TO ACCIDENT RISK FOR AIRCRAFT

Package Type	Accident Severity	Population Zone		Percent of Risk
A, Drum	V	Suburban		21.0
	V	Urban		18.8
	VI	Suburban		14.6
	VI	Urban		13.1
	IV	Suburban		10.8
	IV	Urban		7.2
	II	Suburban		5.1
	III	Suburban		4.4
	III	Urban		2.9
	II	Urban		1.5
			TOTAL	99.4
B, Cask-2	V	Suburban		29.8
	V	Urban		26.6
	VI	Suburban		20.7
	VI	Urban		18.5
	IV	Suburban		1.5
	IV	Urban		1.0
			TOTAL	98.1
B-Pu	VI	Suburban		48.6
	VI	Urban		43.5
	VII	Urban		5.2
			TOTAL	97.3
Cask-1 (exposure)	VIII	Urban		59.3
	VIII	Suburban		11.0
	VII	Urban		9.3
	VIII	Rural		9.0
	VI	Suburban		4.4
	VI	Urban		3.9
	VII	Suburban		1.7
	VII	Rural		1.4
			TOTAL	100.0

TABLE I-5

PRINCIPAL CONTRIBUTORS TO ACCIDENT RISK FOR RAIL

Package Type	Accident Severity	Population Zone		Percent of Risk
A, Drum	III, IV	Urban		32.8
	II	Urban		14.6
	III, IV	Suburban		8.2
	V	Urban		2.2
			TOTAL	98.8
B, Cask-2	III, IV	Urban		29.4
	V	Urban		19.6
	III, IV	Suburban		7.3
	V	Suburban		5.5
			TOTAL	98.5
B-Pu	VII	Urban		50.0
	VI	Urban		21.7
	VII	Suburban		9.3
	VIII	Urban		8.3
	VI	Suburban		8.1
	VIII	Suburban		1.6
			TOTAL	99.0
Cask-1	VIII	Urban		73.3
	VIII	Suburban		13.7
	VII	Urban		9.0
	VIII	Rural		2.1
	VII	Suburban		1.7
			TOTAL	99.8

TABLE I-6

PRINCIPAL CONTRIBUTORS TO ACCIDENT RISK
FOR WATERBORNE MODES AND VARIOUS PACKAGE TYPES

Package Type	Accident Severity	Population Zone		Percent of Risk
A	IV	Suburban		56.4
	IV	Urban		33.6
	II	Urban		7.2
	II	Suburban		1.3
			TOTAL	98.5
B, Cask-2	IV	Suburban		57.0
	IV	Urban		34.0
	VII	Suburban		5.7
	VI	Suburban		2.2
			TOTAL	98.9
BPu	VII	Suburban		81.7
	VIII	Suburban		11.8
	VI	Suburban		6.4
			TOTAL	99.9
Cask-1 (exposure)	VIII	Suburban		87.5
	VII	Suburban		12.4
			TOTAL	99.9

TABLE I-7

PRINCIPAL CONTRIBUTORS TO ACCIDENT RISK FOR SECONDARY MODES AND VARIOUS PACKAGE TYPES

Package Type	Accident Severity	Population Zone		Percent of Risk
A, Drum	IV	Urban		41.7
	III	Urban		22.4
	II	Urban		11.5
	IV	Suburban		7.9
	V	Urban		7.3
	VI	Urban		2.9
	III	Suburban		2.7
	II	Suburban		1.4
			TOTAL	97.8
B, Cask-2	V	Urban		36.8
	IV	Urban		21.0
	VI	Urban		14.5
	III	Urban		11.3
	V	Suburban		7.0
	IV	Suburban		4.0
	VI	Suburban		2.7
			TOTAL	97.3
B-Pu	VI	Urban		58.0
	VII	Urban		17.8
	VI	Suburan		11.0
	VIII	Urban		6.3
	VII	Suburban		5.1
	VIII	Suburban		1.8
			TOTAL	100.0
Cask-1 (exposure)	VIII	Urban		72.9
	VIII	Suburban		20.9
	VII	Urban		4.2
	VII	Suburban		1.2
			TOTAL	99.2

I.4 SENSITIVITY OF THE ACCIDENT ANALYSIS TO THE SHIPMENT PARAMETERS

In this section the sensitivity of the accident risk analysis to the particular set of standard shipments is considered in a general way. Then the various combinations of mode, package type, accident severity, and population zone that make major contributions to the annual risk are tabulated using the 1975 standard shipments model.

In addition to the four-factor product discussed in Section I-3, the accident risk calculation also depends on the product of a number of factors that are characteristic of the material shipped and other shipment parameters. For purposes of comparing the relative hazards of different shipments, it is useful to define a new parameter called the "hazard factor."

Hazard Factor = (curies per package) x (packages per shipment) x (rem per curie inhaled) x (average distance per shipment) x (LCF coefficient for organ associated with rem per curie value) x (fraction aerosolized) x (fraction respirable) x (resuspension dose factor).

When comparing nondispersible materials, the gamma ray energy E is substituted for the rem per curie inhaled.

Table I-8 lists hazard factor sums for the various transport mode and package type combinations. Each entry represents the sum of all hazard factors for that package type and transport mode using the 1975 standard shipments model. These sums, which contain the standard shipments information, are then combined with the information contained in Tables I-3 through I-7 to obtain a ranking of the relative risk contributions by package type, transport mode, population zone, and accident severity category for the 1975 standard shipments. The results are shown in Table I-9. The first part of the table lists, in order of decreasing importance, the combinations that are the major contributors to the annual risk. Note the number of truck mode shipments that are major contributors. This does not necessarily mean that truck shipments are more hazardous. It simply reflects the predominance of truck shipments of the standard shipments model. The second table lists the percent contributions to the annual accident risk for each transport mode, summed over package types. The remaining three tables show the relative contributions of each package type, each of the eight accident severity categories, and each population zone to the accident risk. The major contribution made by type A packages is in part due to the relatively large number of packages of this type.

It is interesting to note that the most severe accidents do not contribute the greatest amounts to the annual accident risk under the assumptions used in this assessment. Over 80 percent of the risk comes from accidents of severities III, IV, and V. This results in part from the very low probability of category VII and VIII accidents and in part from the conservative set of release fractions for type A and B packages.

TABLE I-8

HAZARD FACTOR SUMS

Package Type/Mode	Truck	Van(Pa)*	Pass. Air	Cargo Air	Rail
A	1.1×10^{9}	6.8×10^{5}	1.2×10^{8}	4.4×10^{6}	1.3×10^{8}
B	4.9×10^{9}	2.0×10^{8}	5.7×10^{9}	5.1×10^{8}	5.0×10^{8}
BPu	4.3×10^{12}	1.9×10^{10}	6.5×10^{11}	9.8×10^{10}	0
Cask-1	1.6×10^{7}	0	0	0	3.2×10^{6}
Cask-2	1.1×10^{8}	0	0	0	2.4×10^{7}
Drum	1.2×10^{8}	7.2×10^{5}	8.6×10^{6}	5.2×10^{5}	0

Package Type/Mode	Ship	Barge	Van (T)*	Van (R)*	Van (Ca)*
A	1.0×10^{7}	0	1.9×10^{7}	1.1×10^{7}	5.1×10^{5}
B	1.0×10^{7}	0	1.4×10^{8}	1.7×10^{7}	3.5×10^{7}
BPu	0	0	1.4×10^{11}	0	6.1×10^{9}
Cask-1	0	0	0	2.1×10^{5}	0
Cask-2	0	0	0	1.6×10^{6}	0
Drum	0	0	8.1×10^{6}	0	8.8×10^{4}

*Pa - passenger air; T - truck; R - rail; Ca - cargo air.

TABLE I-9

OVERALL RISK CONTRIBUTION FROM ACCIDENTS FOR 1975 STANDARD SHIPMENTS

Mode	Package Type	Accident Severity	Population Zone	Percentage of Total Accident Risk
Truck	A, Drum	IV	Urban	14.5
Truck	BPu	VI	Urban	11.2
Truck	A, Drum	II	Urban	8.7
Truck	B, Cask-2	V	Urban	6.7
Truck	A, Drum	III	Urban	6.4
Truck	B, Cask-2	IV	Urban	5.7
Truck	BPu	VII	Urban	4.3
Truck	BPu	VI	Suburban	4.2
Truck	A, Drum	IV	Suburban	3.6
Truck	B, Cask-2	III	Urban	2.5
Sec. Modes	BPu	VI	Urban	2.1
Truck	B, Cask-2	V	Suburban	1.9
Truck	A, Drum	V	Urban	1.7
Truck	A, Drum	III	Suburban	1.6
Rail	A, Drum	IV	Urban	1.5
Rail	A, Drum	III	Urban	1.5
Truck	B, Cask-2	IV	Suburban	1.4
Truck	B, Cask-2	VI	Urban	1.3
Sec. Modes	B, Cask-2	V	Urban	1.3
			TOTAL	82.1%

TOTALS

Mode	Percentage of Accident Risk
Truck	79.3
Pass. Air	2.7
Cargo Air	0.2
Rail	8.8
Ship	1.1
Sec. Modes	7.9

Package Type	Percentage of Accident Risk
A, Drum	45.0
B, Cask-2	28.0
BPu	26.0

Accident Severity	Percentage of Accident Risk
1	0
2	10.0
3	15.0
4	31.0
5	14.0
6	23.0
7	6.0
8	1.0

Population Zone	Percentage of Accident Risk
Urban	80.2
Suburban	18.3
Rural	1.5

Although for most shipment scenarios the largest fractions of accidents were expected to occur in rural and suburban population zones, the urban zone contributes over 80 percent of the annual accident risk. The large population density of urban areas outweighs the relatively low fraction of accidents expected to occur in these areas.

I.5 SENSITIVITY OF THE NORMAL DOSE CALCULATION TO VARIOUS PARAMETERS

The annual normal population dose resulting from any one of the standard shipments is proportional to the total TI transported per year and the total distance. A 10 percent error, for example, in the average TI per package, the total packages per year, or the average distance per shipment would result in a 10 percent error in the annual normal dose.

Table I-10 contains tabulations of the percent of contributions to the annual normal risk by certain package types, population subgroups, transport modes, package type-population subgroup combinations, and transport mode-population subgroup combinations. The data for the table were obtained from the normal dose analysis using the 1975 standard shipment data. The dominant contribution of type A packages to the normal dose, as in the accident case, results from the comparatively large number of such packages in the standard shipments model. Type A packages make a larger contribution in the normal case because of the large fraction of the total TI that they represent. The truck mode is also the greatest contributor to the normal risk, again due in part to the comparatively large number of truck shipments. It is interesting to note that 65 percent of the normal risk results from doses to passengers, crew, attendants, handlers, and warehouse personnel. These dose calculations are independent of the population densities estimated for each of the three population zones.

TABLE I-10

PRINCIPAL CONTRIBUTORS TO THE NORMAL RISK

Package Type

Package	Percent of Normal Risk
A, Drum	88.0
B, B-Pu,	11.0
Cask	1.0

Population Subgroup

Subgroup	Percent of Normal Risk
Passengers	24
Crew	32
Attendants	1
Handlers	18
Off-Link	4
On-Link	4
Stops	11
Storage	6

Mode

Mode	Percent of Normal Risk
Truck	45.0
Pass. Air	29.7
Cargo Air	0.2
Rail	1.0
Ship	0.1
Sec. Modes	24.0

Package Type/Subgroup

Package Type	Subgroup	Percentage
A, Drum	Crew	27
A, Drum	Passengers	21
A, Drum	Handlers	16
A, Drum	Stops	11
A, Drum	Storage	6
B, B-Pu	Crew	5
A, Drum	Off-Link	4
A, Drum	On-Link	4
B, B-Pu	Passengers	3
B, B-Pu	Handlers	1

Model/Subgroup

Mode	Subgroup	Percentage
Truck	Crew	26
Pass. Air	Passengers	24
Sec. Modes	Handlers	12
Truck	Stops	10
Sec. Modes	Crew	5
Truck	On-Link	2
Pass. Air	Attendants	1
Pass. Air	Handlers	4
Truck	Off-Link	4
Truck	Storage	3
Sec. Modes	On-Link	2

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
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U.S. MAIL