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VOL. 1

FINAL ENVIRONMENTAL STATEMENT ON THE TRANSPORTATION OF RADIOACTIVE MATERIAL BY AIR AND OTHER MODES

Docket No. PR-71, 73 (40 FR 23768)

December 1977

Office of Standards Development
U. S. Nuclear Regulatory Commission

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

December 1977

Docket No. PR-71, 73 (40FR23768)

TO RECIPIENTS OF THE TRANSPORTATION
FINAL ENVIRONMENTAL STATEMENT (NUREG-0170)

Enclosed for your information is a final environmental statement dealing with the transportation of radioactive material by air and other modes. The document has been prepared in support of the Nuclear Regulatory Commission's advanced notice of rule making proceeding published in the Federal Register on June 2, 1975 (40FR23768), a copy of which is enclosed for your use.

Pursuant to the National Environmental Policy Act of 1969 and the Commission's regulations in 10 CFR Part 51 "Licensing and Regulatory Policy and Procedures for Environmental Protection," the Commission's Office of Standards Development issued a draft environmental statement on Transportation in March, 1976. After consideration of the 28 letters of comment received from the public and from Federal, State and local agencies, a final environmental statement on the Transportation of Radioactive Material by Air and Other Modes has been issued and designated NUREG-0170.

Taking into account the conclusions of the final environmental statement, public comments received on the proceeding, and other information, the Nuclear Regulatory Commission will consider the disposition of the rule making proceeding announced on June 2, 1975. Persons with views on the content or conclusions of the final environmental statement which may be helpful to the Commission in its deliberation should file such comments by March 15, 1978, with the U. S. Nuclear Regulatory Commission, Washington, D. C. 20555, Attention: Director, Office of Standards Development. If sufficient need for clarification of the final environmental statement becomes apparent, the Office of Standards Development will consider holding one or more public meetings for this purpose.

Robert B. Minogue

Robert B. Minogue, Director
Office of Standards Development

Enclosures:
1. Advanced Notice of Rule Making Proceeding
2. Final Environmental Statement

NUCLEAR REGULATORY COMMISSION

[10 CFR Parts 71 and 73]

RADIOACTIVE MATERIAL

Packaging and Transportation by Air

Following its organization under the Energy Reorganization Act of 1974 (Public Law 93-438), the Nuclear Regulatory Commission (NRC) has stated its intention of reviewing those of its regulations and procedures pertaining to the licensing and regulation of nuclear facilities and materials which were originally promulgated by the Atomic Energy Commission, with a view to considering what changes should be made. As part of that effort, the NRC is initiating a rule making proceeding concerning the air transportation of radioactive materials, including packaging, with a view to the possible amendment of its regulations in 10 CFR Parts 71 and 73, adopted pursuant to the Atomic Energy Act of 1954, as amended. The NRC considers the reevaluation of these particular regulations to be especially timely in view of concerns that have been recently expressed by public officials and others as to the safety and security of air shipment of plutonium and other special nuclear materials through highly populated metropolitan areas.

The Department of Transportation (DOT) has overlapping jurisdiction over safety in packaging and transportation by air of radioactive materials under the Transportation of Explosives and Other Dangerous Materials Act (18 U.S.C. 831-835) and the Transportation Safety Act of 1974 (Pub. L. 93-633, 88 Stat. 2156), and the Federal Aviation Administration has similar overlapping jurisdiction under the Federal Aviation Act of 1958 (49 U.S.C. 1421-1430, 1472(b)). It is expected that the expertise of these agencies will be utilized in the subject rule making proceeding.

Background of present regulations. Following a prohibition against shipment of radioactive material by mail in 1936 to protect unexposed film, safety regulations for shipping radioactive material were adopted by the Interstate Commerce Commission in 1948. Those regulations were based on a report of a National Academy of Sciences-National Research Council Subcommittee on Transportation of Radioactive Material. The basic principles reflected in those regulations were reviewed and adopted, with minor modifications and some elaboration, by the International Atomic Energy Agency (IAEA) in 1961 and reflected in recommended International Standards for the Safe Transport of Radioactive Material. In 1964, on the basis of shipping experience up to that date and an analysis of transportation accidents prepared by the United Kingdom Atomic Energy Authority, the IAEA issued revised transport regulations incorporating specific accident damage test standards which were incorporated into the NRC (then AEC) and DOT (then within the jurisdiction of the ICC) regulations by 1968. Except for changes in the regulations to deal with specific problems (e.g., leak testing of packages containing liquids, prompt pickup and monitoring of packages, restrictions on shipments of plutonium on passenger aircraft, opening and closing procedures), the safety regulations have remained essentially the same since that time.

The safety standards for transportation, as set forth in NRC's regulation in 10 CFR Part 71 and DOT regulations in 49 CFR Parts 170-178, are based on two main considerations: (1) Protection of the public from external radiation and (2) assurance that the contents are unlikely to be released during either normal or accident conditions of transport or, if the container is not designed to withstand accidents, that its contents are so limited in quantity as to preclude a significant radiation safety problem if released. These safety standards are applicable to packages used in all models of transport and were developed with the objective of providing an acceptable level of safety for transport of radioactive material by any mode.[1] With respect to air shipments, it was considered that, taking into account the high integrity of the packaging[2] and the low accident probability for air transportation (no more than one accident per 100 million miles, the risk of an air accident resulting in a release of radioactive material from a package was small.

NRC packaging standards are applicable to shipments by NRC licensees, while DOT regulations are applicable to transportation of radioactive material by land in interstate and foreign commerce, on civil aircraft, and on water. DOT regulations in Title 49 of the Code of Federal Regulations and FAA regulations in 14 CFR Part 103 cover labeling and conditions for shipment and carriage as well as certain packaging. NRC regulations exempt carriers from their application in view of the controls exercised over carriers by DOT and its component parts, including FAA.

For the purpose of developing and implementing consistent, comprehensive and effective regulations for the safe transport of radioactive material and to avoid duplication, the DOT (then ICC) and the AEC (NRC's predecessor) entered into a Memorandum of Understanding in 1966 which was superseded by a revised Memorandum of Understanding signed on March 22, 1973. Under the revised memorandum, the AEC (now NRC) develops performance standards for package designs and reviews package designs for Type B[3] fissile and large quantity packages. The DOT develops safety standards governing handling and storage of all radioactive material packages while in possession of a common, contract or private carrier, as well as standards for Type A packages.[4] DOT requires AEC (now NRC) approval prior to use of all Type B, fissile and large quantity package designs. DOT is the National Competent Authority with respect to foreign shipments under the IAEA transport standards. IAEA Certificates of Competent Authority are issued by DOT with technical assistance provided by NRC as requested.

Re-evaluation of present regulations. Consistent with the considerations expressed in the first paragraph of this notice, the NRC has decided that its regulations governing air transportation of radioactive material, including packaging, should be re-evaluated from the standpoint of radiological health safety and prevention of diversion and sabotage as well. In connection with this re-evaluation, the NRC has instructed its staff to commence preparation of a generic environmental impact statement on the air transportation of radioactive materials, including packaging and related ground transportation. The statement will be directed at air transportation. However other transportation modes—land and water transport—will be considered in light of the requirement of the National Environmental Policy Act of 1969 (NEPA) that the relative costs and benefits of alternatives to certain proposed Federal actions be fully considered. It is anticipated that the draft generic environmental impact statement will be available by the time that any proposed changes to the regulations eventuating from this rule making proceeding are published for comment in the FEDERAL REGISTER. While the generic impact statement is in preparation, impact statements or impact appraisals for individual NRC licensing actions related to the transportation of radioactive materials, such as import licenses for significant quantities of plutonium and other special nuclear material, will be prepared as required by NEPA and 10 CFR Part 51.

In order to aid the NRC in this re-evaluation of existing regulations pertaining to radioactive material transported by air, interested persons are invited to submit information, comments and suggestions with respect to those aspects of the above-referenced NRC regulations. The NRC is particularly interested in receiving views on the following:

1. Whether radioactive materials should continue to be transported by air, considering the need for, and the benefits derived from such transportation, the risks to public health and safety and the common defense and security associated with such transportation, and the relative risks and benefits of other modes of transport.

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[1] In contrast to the safety standards described above, NRC's requirements for the physical protection (security) of strategic quantities of special nuclear material, including plutonium, in 10 CFR Part 73, are specific as to the mode of transport.

[2] Container designs required to meet accident conditions are evaluated under current regulations against the following accident test conditions in sequence: 30-foot free drop of the container in the most damaging position onto a flat, essentially unyielding surface, 40-inch drop onto a steel bar to test the ability to withstand puncture, 30-minute fire test at 1475° F and 3-foot water immersion test for eight hours. The puncture test and the drop test are engineering qualification tests. The test conditions were chosen to provide reproducible laboratory conditions representative of severe transportation accident environments. For example, a 30-foot drop onto an unyielding surface produces impact or shock loads which are more severe than drops of several thousand feet onto targets such as land, water, or even city streets which would tend to yield when struck by the package. Because of the conservatism of most designs, packages, when subjected to tests involving free fall from much greater heights than 30-feet, have either remained undamaged or continued to contain their contents. For example, a number of packages which pass the NRC qualification tests have also been tested under extra severe conditions such as a 250-foot free fall onto an essentially unyielding surface. Packages currently approved for bulk shipment of plutonium oxide and nitrate will survive such test conditions. These extra severe tests provide added assurance that containers in much the same manner as aircraft flight recorders, could survive severe air accidents. A description of these tests is set forth in SC-DR-72 0597 (Sept. 1972), "Special Tests for Plutonium Shipping Containers 6M, SP5795, and L-10", a copy of which is available for public inspection at the Commission's Public Document Room, 1717 H Street NW., Washington, D.C.

[3] A Type B package is required for quantities in excess of a few millicuries and up to 20,000-50,000 curies, depending upon the radionuclide. Such packages are required to be designed to withstand accident conditions as well as normal conditions of transport.

[4] A Type A package is required for less than Type B quantities of radioactive material and is required to be designed to withstand normal conditions of transport only.

2. Assuming a justifiable need for air transportation of radioactive materials, to what extent should safety requirements be based on:

(a) Accident probabilities;
(b) Packaging;
(c) Procedural controls;
(d) Combinations of the above?

3. What is the relative risk of transport of radioactive material by air compared to other modes of transport, and to other hazards faced by the public which may or may not be the subject of regulation?

4. Are improvements in applicable regulations necessary, and if so, what improvements should be considered?

Documentation supporting the views expressed by interested persons would be helpful to the NRC in re-evaluation of its regulations relating to air transportation of radioactive materials and consideration of possible changes to such regulations

It should be noted that there are some related issues which will be, or are presently, the subject of consideration in other rule making proceedings and, therefore, will not be included in this proceeding They are:

1. Physical security protection requirements for strategic quantities of special nuclear material that would apply to all modes of transport (39 FR 40036).

2. Requirements for advance notice of shipments of strategic quantities of special nuclear material (40 FR 15098).

3 Quality assurance requirements for packages for all special nuclear material (38 FR 35190).

4 Radiation levels from radioactive material transported in passenger aircraft.

If it subsequently appears that additional issues should more properly be treated in a separate proceeding, or proceedings, appropriate notices to that effect will be published in the FEDERAL REGISTER.

Interested persons should send comments and suggestions, with supporting documentation, to the Secretary of the Commission, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, Attention: Docketing and Service Section by August 1, 1975. Copies of comments received may be examined in the NRC Public Document Room at 1717 H Street NW., Washington, D.C.

After comments have been received and considered, the NRC will publish its views as to NRC rules pertaining to air transportation of radioactive material in the FEDERAL REGISTER. When the aforementioned draft environmental impact statement is prepared, notice of its availability will be published in the FEDERAL REGISTER and opportunity for public comment afforded pursuant to NRC regulations implementing the National Environmental Policy Act of 1969 (10 CFR Part 51). In addition, background information on the subject of regulation of transportation of radioactive materials has been placed in the NRC Public Document Room at 1717 H Street NW., and at its local public document rooms throughout the nation. Copies of such background information are available upon request in writing to the Office of Standards Development, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

Interim evaluation. Recently there have been several requests that air shipments of plutonium and other special nuclear materials (and related ground transportation of special nuclear materials incidental thereto) be suspended pending reexamination of presently applicable regulations In assessing the appropriateness of such action at this time, the NRC has considered the following:

1. In more than 25 years of shipping special nuclear material, including plutonium, in civilian aircraft, there have been no air accidents involving the material

2 The experience in shipping thousands of packages per year of all forms of radioactive materials by all modes of transport under existing NRC, DOT, and FAA regulations has been very favorable.

3 The requests that have been received do not set forth any significant new information which would indicate that present package or security requirements are inadequate.

4. In view of the physical security measures now required by 10 CFR Part 73, the protection provided against severe accidents by the high integrity packaging required by NRC, DOT, and FAA regulations (summarized supra), the consistency of these requirements with international standards, the low accident probability (supra), and the favorable experience to date, the risk involved in the transportation of radioactive material under currently effective regulations is believed to be small.

Accordingly, it is presently the view of the NRC, subject to consideration of comments to be received, that its currently effective regulations can continue to be applicable during the period in which this rule making proceeding is in progress. More particularly, in light of present information as to the safety and security of air shipments of radioactive material, the Commission finds no sound basis, for the reasons stated above, for requiring the suspension of such shipments.

Notwithstanding the foregoing, in view of the concerns expressed and the fact that requests have been received for the suspension of air shipments of plutonium and other special nuclear materials, comments are specifically invited on the matter of whether suspension or other limitations on the air transportation of plutonium and other special nuclear materials are justified during the period that the subject rule making proceeding is being conducted. Views on this particular matter, together with the supporting basis for these views, should be submitted to the Secretary of the Commission, U.S. Regulatory Commission, Washington, D.C. 20555, Attention: Docketing and Service Section by July 2, 1975. The NRC will decide, after evaluating the views and comments received, whether a different course should be pursued during the pendency of this rule making proceeding and publish its conclusions in the FEDERAL REGISTER. Currently effective regulations will continue to be applied until a decision on this matter is made.

As indicated above, related specific issues will be, or are presently, the subject of consideration in other rule making proceedings, and the NRC will continue to take appropriate action, as justified by the circumstances, to assure that the risk associated with the transportation of radioactive materials remains small

Dated at Washington, D.C. this 29th day of May 1975.

For the Nuclear Regulatory Commission.

SAMUEL J CHILK,
Secretary of the Commission

[FR Doc 75-14519 Filed 5-30-75,8:45 am]

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Docket No. PR 71, 73 (40 FR 23768)

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Office of Standards Development
U. S. Nuclear Regulatory Commission

SUMMARY AND CONCLUSIONS

This Final Environmental Statement was prepared by the staff of the Office of Standards Development of the U. S. Nuclear Regulatory Commission (NRC), Washington, D.C. 20555. Mr. Donald R. Hopkins is the NRC Task Leader for this statement (telephone: 301-443-6910).

1. This action is administrative.

2. This Final Environmental Statement has been prepared in connection with NRC reevaluation of its present regulations governing air transportation of radioactive materials in order to provide sufficient analysis for determining the effectiveness of the present rules and of possible alternatives to these rules. This statement is not associated with any specific rule change at this time but will be used as a partial basis for determining the adequacy of the present transportation regulations. If a rule change results from consideration of this statement, a separate or supplementary environmental statement will be issued with respect to that action.

When NRC was beginning work on this environmental statement, consideration was given to covering all aspects of the environmental impact resulting from the transport of radioactive material by air. At the Federal level, both the NRC and the Department of Transportation, particularly the Federal Aviation Administration (FAA), are involved in regulating the safety of such transport. Therefore, NRC proposed to the FAA that the statement be cosponsored by both agencies and that both the shipper-packaging aspects and the carrier-transport aspects be covered. In a meeting in early 1975, the FAA declined to actively support the development of such a statement. As a result, the scope of the statement was limited to the shipper-packaging aspects. The statement deals with the carrier-transport area only to the extent necessary to determine the influence of the conditions of transport on the shipper-packaging area, e.g., exposures of personnel from packages of radioactive materials under normal and accident conditions.

Development of the statement began with consideration of transport of radioactive materials by air. However, in order to examine the environmental impact of alternatives, other modes of transport were examined, again primarily from the standpoint of the effect such transport would have on packaging as related to exposure of people under both normal and accident conditions. During the development of the statement, special interest arose in the alternative of transporting irradiated nuclear fuel by special trains. Some detail was added in the section on special trains but the statement scope was not sufficiently broad to deal thoroughly with this subject. A separate statement on the use of special trains for transporting irradiated nuclear fuel has been issued by the Interstate Commerce Commission (ICC) with NRC cooperation. Some of the same methodology used in this generic statement is used in the ICC study.

As a result of the limitations on the scope of this generic statement, only limited study of the conditions of transport, carrier controls, and routing has been undertaken. For example, no evaluation has been made of safety aspects of the vehicles or of items related to carrier controls other than those directly affecting the shipper-packaging area.

Except as noted, this statement does not specifically consider facets unique to the urban environment such as high population densities, diurnal variation in population, convergence of transportation routes, shielding effects of buildings, or the effect of local meteorology on accident consequences. A separate study specific to such considerations is being conducted and will result in a separate environmental statement specific to such an urban environment.

This statement was started in May 1975 and was completed prior to President Carter's April 7, 1977, message on nuclear power policy regarding deferral of commercial reprocessing and recycling of plutonium. Therefore, the 1985 projection of numbers and types of nuclear fuel cycle shipments and their environmental impact that has been used in this study reflects the potential development of plutonium recycle to the extent described in the NRC's generic environmental statement on mixed oxide fuel (GESMO). Since the analysis on non-fuel-cycle shipments remains valid, as does the analysis of all 1975 radioactive material shipments, this statement is issued with the caveat that it does not reflect changes in national energy policy originating with the President's April 7, 1977, message.

Although this statement has not been modified to reflect the President's policy message, it is the NRC staff's judgment, based on related analyses, that the results presented as realistic in this statement would continue to be realistic and the conclusions reached would be essentially the same if changes were made in accordance with the President's message.

3. The environmental impact of radioactive material shipments in all modes of transport under the regulations in effect as of June 30, 1975, is summarized as follows:

a. Radiation exposure of transport workers and of members of the general public along the transportation route occurs from the normal permissible radiation emitted from packages in transport. More than half of the 9800 person-rem exposure resulting from 1975 shipments was received by transport workers associated with the shipments. The remaining 4200 person-rems was divided among approximately ten percent of the U.S. population. None of these exposures would produce short-term fatalities. On a statistical basis, expected values for health effects that may result from this exposure are 1.7 genetic effects per year and 1.2 latent cancer fatalities distributed over the 30 years following each year of transporting radioactive material in the United States at 1975 levels (Chapter 4, Section 4.9). More than half of this effect results from the shipment of medical-use radioactive materials where the corresponding benefit is generally accepted (Chapter 1, Table 1-2).

b. Transportation accidents involving packages of radioactive material present potential for radiological exposure to transport workers and to members of the general public. The expected values of the annual radiological impact from such potential exposure are very small, estimated to be about one latent cancer fatality and one genetic effect for two hundred years of shipping at 1975 rates (Chapter 5, Section 5.9). More than two-thirds of that impact is attributable to nuclear fuel cycle and other industrial shipments (Chapter 1, Table 1-2).

c. Radiological impacts from export and import shipments were evaluated separately and were determined to be negligible compared to impacts from domestic shipments (Chapter 5, Section 5.7).

d. The principal nonradiological impacts from the use of resources for packaging materials and from the use of, and accidents involving, a relatively small number of dedicated transport vehicles were found to be two injuries per year and less than one accidental death per four years (Chapter 5, Section 5.8).

e. Examination of the consequences of a major accident and assumed subsequent release of radioactive material indicates that the potential consequences are not severe for most shipments of radioactive material (Chapter 5, Section 5.6). The consequences are limited by one or more parameters: short half-life, nondispersible form, low radiotoxicity. However, in the unlikely event of a major release of plutonium or polonium in a densely populated area, a few individuals could suffer severe radiological consequences. One early fatality would be expected, and as many as 60 persons would be exposed to radiation dose levels sufficient to produce cardiopulmonary insufficiency and fatalities in some cases. The latent cancer fatalities associated statistically with such a major release are estimated to be as many as 150 over a 30-year period (Chapter 5, Section 5.6). Costs for land reclamation associated with such an unlikely accident could range from 250 million to 800 million dollars for 1975 shipments and up to 1.2 billion dollars for 1985 shipments. The probability of such an event is estimated to be no greater than 3×10^{-9} per year for 1975 shipping rates (Chapter 5, Section 5.6). It should be noted that, to obtain the above result, all of the following conditions would have to occur:

(1) A low-probability, extra severe accident would have to involve a vehicle carrying a bulk shipment of plutonium or polonium in an extreme-population-density urban area. There are presently about 20 large-quantity shipments of polonium per year and one of plutonium (Chapter 5, Section 5.2.2);

(2) One or more of the packages of plutonium or polonium that are designed to withstand severe accident conditions would have to be subjected to the highest of the forces developed in the accident so as to cause gross failure of the package and subsequent release of a significant fraction of the radioactive contents from the package (Chapter 5, Section 5.2.3);

(3) The accident would have to create conditions in which plutonium or polonium released from the package would escape from the vehicle in which it was being transported, and a significant amount of material would have to become airborne in respirable form (Appendix A, Section A.4);

(4) The meteorological conditions at the time would have to be such that the plutonium or polonium remains airborne and is dispersed in a way that significant numbers of people would breathe the air containing the material in high concentrations (Chapter 5, Section 5.3); and

(5) Mitigating actions such as evacuation of persons from the area are not taken.

4. Principal alternatives considered are the following:

   a. Transportation mode shifts for various components of the industry (Chapter 6, Section 6.2).

   b. Operational constraints on transport vehicles to minimize accidents (Chapter 6, Section 6.3).

   c. Changes in packaging requirements to minimize release of radioactive materials in an accident (Chapter 6, Section 6.4).

   d. Changes in the physical properties of radioactive materials to minimize consequences in the event of a release (Chapter 6, Section 6.4.1).

Preliminary analyses were made of a number of alternatives to the present regulations and methods of transport. A few of the alternatives examined were found to be cost effective. However, the cost-effective alternatives dealing with changes in mode of transport did not significantly reduce the radiological impact; the others must be analyzed further to determine whether their adoption would reduce the radiological impact and achieve an impact level as low as is reasonably achievable (Chapter 6).

The alternative of reducing the amount of radioactive material transported, either generally or selectively, was not considered on the assumption that the benefits associated with the use of presently transported materials outweigh the small risk of their transportation.

While future rulemaking may depend in part for its justification on the analysis and conclusions of this statement, no rulemaking is proposed with its present issuance. The primary function of this statement is to establish the NRC staff view of the environmental impact of present transportation of radioactive material and of the projected impact in 1985. This statement provides an overview of a number of alternatives to present transportation requirements and of the changes in impact produced by those alternatives. While this overview serves to limit the number of alternatives worthy of further consideration, any detailed study of alternatives in support of rulemaking activities will be considered separately.

The alternatives considered in this statement are limited to those possible with existing transportation systems. While it might be possible to conceptualize new transportation systems that might reduce environmental impact, it is considered unlikely that any could be justified on a cost-benefit basis because of the present low risk.

5. The following Federal, State, and local agencies commented on the Draft Environmental Statement (NUREG-0034) made available in March 1976. Their comments, along with those from other parties, are in Appendix J.

a. Tennessee Valley Authority
b. Department of Health, Education, and Welfare
c. Environmental Protection Agency
d. Department of the Interior
e. Federal Energy Administration
f. Energy Research and Development Administration
g. Department of Transportation
h. State of New Mexico
i. State of New York
j. State of Georgia
k. City of New York

6. A draft of this Final Environmental Statement was made available to the public in February 1977 at the NRC Public Document Room in Washington, D.C., and at NRC's field offices in King of Prussia, Pennsylvania; Atlanta, Georgia; Glen Ellyn, Illinois; Arlington, Texas; and Walnut Creek, California. Public comments received on that draft are contained in Appendix K.

7. This Final Environmental Statement was made available to the public, to the Council on Environmental Quality, and to the above specified agencies in December 1977.

8. On the basis of the analysis and evaluation set forth in this statement and after weighing the small adverse environmental impact resulting from transportation of radioactive materials and the costs and benefits of the alternatives available for reducing or avoiding the adverse environmental effects, the staff concludes that:

a. Maximum radiation exposure of individuals from normal transportation is generally within recommended limits for members of the general public (Chapter 3, Section 3.5). There are transportation operations at a few locations where some transport workers receive radiation exposures in excess of the recommended limits established for members of the general public. In most cases, these operations employ radiation safety personnel to establish safe procedures and to train and monitor transport workers as though they were radiation workers.

b. The average radiation dose to the population at risk from normal transportation is a small fraction of the limits recommended for members of the general public from all sources of radiation other than natural and medical sources (Chapter 3, Section 3.5) and is a small fraction of natural background dose (Chapter 3, Section 3.3).

c. The radiological risk from accidents in transportation is small, amounting to about one-half percent of the normal transportation risk on an annual basis (Chapter 4, Section 4.9).

d. For the types and numbers of radioactive material shipments now being made or projected for 1985, there is no substantial difference in environmental impact from air transport as opposed to that of other transport modes (Chapter 4, Tables 4-15 and 4-17 and Appendix I, Table I-9).

e. Based on the above conclusions, the NRC staff has determined that the environmental impacts of normal transportation of radioactive material and the risks attendant to accidents involving radioactive material shipments are sufficiently small to allow continued shipments by all modes. Because transportation conducted under present regulations provides adequate safety to the public, the staff concludes that no immediate changes to the regulations are needed at this time. The staff has already upgraded its regulations on transportation quality assurance while this environmental statement was being prepared and has begun studies of transportation through urban areas and of emergency response to transportation accidents and incidents. In addition, the staff is continuing to study other aspects of transportation, such as the accident resistance of packages and the physical/chemical form of the radioactive contents, to maintain the present high level of safety and to determine the cost-effectiveness of changes that could further reduce transportation risk.

9. Based on considerations related to security and safeguards for strategic special nuclear materials (uranium enriched to 20% or more in the U-235 isotope, U-233, and plutonium), spent fuel, and other radioactive materials in transit, the staff concludes that:

a. Existing physical security requirements are adequate to protect at a minimum against theft or sabotage of significant quantities of strategic special nuclear materials 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.

b. 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 forthcoming 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.

c. The use of the ERDA (now the Department of Energy (DOE)) transport system is not, at this time, considered to be necessary for the protection of significant quantities 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.

d. Shipments of radioactive materials not now covered by NRC physical protection requirements, such as spent fuel (containing fission products and irradiated special nuclear materials) 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 that preclude direct handling) or because of the protection afforded by safety provisions, e.g., shipping containers.

Based on the above conclusions, the NRC staff has determined that the risks of successful theft of a significant quantity of strategic special nuclear material or sabotage of radioactive materials in transit resulting in a significant radiological release are sufficiently small to constitute no major adverse impact on the environment.

10. The validity of the risk assessment has been seriously challenged within the NRC staff. The challenge is with respect to the assessment of the overall level of accident risk and the relative levels of risk of the various types of shipments on which the total accident risk is based. The challenge results from the acknowledged conservative assumptions used in the accident assessment where valid data are not available to support more realistic values for certain parameters. Principal among these are package release fractions (Chapter 5, Table 5-8), particle size (Appendix A, Table A-7), fraction of released materials becoming airborne (Appendix A, Table A-7), and areas contained within dose isopleths (Chapter 5, Figure 5-7). These assumptions are not applied uniformly in the accident analysis over the various types of shipments (e.g., more data is available on plutonium shipment behavior in an accident situation than is available for polonium shipments; therefore, more conservative assumptions were applied to the polonium accident assessment). The resulting challenge is that the assessment is excessively conservative and shows the total accident risk to be greater than a more realistic assessment would show and that the values of risk assessed for different types of shipments may incorrectly show that certain types of shipments are more hazardous than others. However, since the conclusion drawn from the accident assessment is simply that the total accident risk is small compared to the normal transportation risk, the assessment is considered to support that limited conclusion and therefore to be adequate for that purpose, at this time. Nonetheless, further studies to develop additional data and refine the assessments are planned for the future; some are already underway in connection with the generic study on Transport of Radionuclides in Urban Environs and other detailed accident studies. Furthermore, rulemaking actions to reduce the risk in specific areas will not be taken until a more realistic risk assessment has been completed and the specific costs and the benefits have been evaluated.

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DETAILED SUMMARY

INTRODUCTION

This document is an assessment of the environmental impact from transportation of shipments of radioactive material into, within, and out of the United States. It is intended to serve as background material for a review by the United States Nuclear Regulatory Commission (NRC) of regulations dealing with transportation of radioactive materials. The impetus for such a review results not only from a general need to examine regulations to ensure their continuing consistency with the goal of limiting radiological impact to a level that is as low as reasonably achievable, but also from a need to respond to current national discussions of the safety and security aspects of nuclear fuel cycle materials.

The report consists of eight chapters and related appendices. The structure of the report and its content are indicated in the following outline of its chapters:

1. Introduction - The background of the study, uses of radioactive materials, and shipping activities in various major segments of the nuclear industry are discussed.

2. The Regulations Governing the Transportation of Radioactive Materials - The regulations are reviewed together with supporting information indicating the intent and basis for many of the transportation safety regulations.

3. Radiological Effects - The mechanism for radiological impact, the appropriate protection guidelines, and the health effects model used in this assessment are discussed.

4. Transport Impacts Under Normal Conditions - The environmental impacts, both radiological and nonradiological, that result from normal transportation are assessed in terms of a standard shipments model designed to represent current transport conditions.

5. Impacts of Transportation Accidents - The radiological and nonradiological impacts that result from accidents involving vehicles carrying radioactive material shipments are discussed.

6. Alternatives - Assessment is made of differences in radiological impact that would result from modifying the transport mode of certain shipments, adding operational constraints, changing form and quantity restrictions, and raising packaging standards. Cost-benefit tradeoffs are discussed.

7. Security and Safeguards - The need for security of certain radioactive material shipments is discussed together with an assessment of the present physical security requirements applied to various modes of transport.

8. Comments on NUREG-0034 and Major Changes That Have Occurred Since NUREG-0034 was Issued - Major changes from the draft assessment (NUREG-0034) are identified.

DESCRIPTION OF THE ENVIRONMENTAL IMPACT OF EXISTING ACTIVITIES

The environmental impact of radioactive material transport can be described in three distinct parts: the radiological impact from normal transport, the risk of radiological effects from accidents involving vehicles carrying radioactive material shipments, and all nonradiological impacts.

Radiological impacts in normal transport occur continuously as a result of radiation emitted from packages both aboard vehicles in transport and in associated storage. The radiation exposure of specific population groups such as crew, passengers, flight attendants, and bystanders is calculated in the report using a computer model that considers, for the principal radionuclides shipped, radiation exposure rates, shipment information, traffic data, and transport mode splits. Using this computer model, it was estimated that the total annual population exposure resulting from normal transport is about 9790 person-rem. The largest percentage of this population exposure (some 52%) results from the shipment of medical-use radionuclides. The remaining portion results from industrial shipments (about 24%), nuclear fuel cycle shipments (8%), and waste shipments (15%). Shipments by truck produce the largest population exposure, resulting from relatively long exposure times at low radiation levels of truck crew and large numbers of people surrounding transport links.

The individual radiation exposures in all modes are generally at low radiation levels and in most cases take on the character of a slight increase in background radiation. The analysis shows that radiation exposure from normal transportation, averaged over the persons exposed, amounts to 0.5 millirem per year compared to the average natural background exposure of about 100 millirem per year. Based on the conservative linear radiation dose hypothesis, this would result in a total of 1.2 latent cancers distributed statistically over the 30 years following each year of transporting radioactive material in the United States at 1975 levels. This can be compared to the existing rate of more than 300,000 cancer fatalities per year from all causes.

In the accident case, risk to the population from accidents involving vehicles carrying radioactive materials was estimated in terms of the number of latent cancer fatalities and early deaths that might occur on annual and single-accident bases. The analysis resulted in estimates of annual societal risk of 5.4×10^{-3} latent cancer fatalities and 5×10^{-4} early fatalities for each year of shipments at 1975 levels. These values can be compared to the 1100 (in 1969) early fatalities from electrocution each year. The latent cancer fatalities from transport accidents are related principally to industrial and fuel cycle shipments rather than to medical shipments, which are the dominant causes of latent cancer fatalities related to normal transport. This results principally from the larger quantities of more toxic materials associated with industrial and fuel cycle shipments.

In spite of their low annual risk, specific accidents occurring in very-high-density urban population zones can produce as many as one early fatality, 150 latent cancer fatalities, and decontamination costs estimated to range from 250 million to 800 million dollars for 1975 shipments and from 250 million to 1.2 billion dollars for 1985 shipments (1975 dollars). Although such accidents are possible, their probability of occurrence is very small (estimated to be no greater than 3×10^{-9} per year based on 1975 shipping rates).

Nonradiological impacts on safety were estimated to be two injuries per year and one fatality every five years from accidents involving vehicles used for the exclusive-use transport of nuclear materials. Accidents involving vehicles carrying radioactive materials in conjunction with carriage of other goods are not considered to be chargeable as radioactive material shipments since the total number of radioactive material packages transported annually is less than 10^{-5} of all goods transported annually in this manner.

RELATIONSHIP OF PROPOSED ACTIVITIES TO OTHER GOVERNMENT ACTIVITIES

Safety and safeguarding of radioactive material shipping is regulated by the NRC and the Department of Transportation in conjunction with cooperating State agencies. The interaction of these agencies is governed by either an agreement or a Memorandum of Understanding that defines the coordination of their activities.

PROBABLE IMPACT OF PROPOSED ACTIONS ON THE ENVIRONMENT

Any rule changes proposed as a result of this environmental assessment will be proposed in a future action. The impact on the environment of those rule changes will be considered separately with that action.

ALTERNATIVES TO EXISTING ACTIVITIES

Alternatives to the existing practices in the shipment of radioactive material are discussed in Chapter 6. Mode shifts, operational constraints, and package standards revisions were found to produce only small changes in the population exposure associated with normal transportation. Although large percentage decreases in the existing risk from transportation accidents result from some of these alternatives, the significance of these decreases is lessened by the following considerations:

1. Because the existing risk (annual early deaths plus latent cancer fatalities) from transportation accidents is a small percentage of the risk from normal transportation, large decreases in accident risk result in insignificant changes in the total (accident plus normal) risk; and

2. Because the existing risk from transportation accidents is so small, large relative decreases are actually small absolute decreases in effects (e.g., reduction in numbers of deaths or illnesses).

Where the cost-benefit ratio for an alternative is adverse, i.e., where the social and economic costs outweigh the decreases in environmental impact, better alternatives should be sought. It has been found, for example, that risk from an accident involving plutonium or polonium-210 is reduced by changing the physical form of these materials. This technique may be capable of producing a decrease in accident risk of 0.005 latent cancer fatalities per year (a 30% reduction) for large shipments of highly toxic materials. Detailed information on the feasibility of this alternative is not yet adequate to permit the determination of its associated costs.

UNAVOIDABLE ADVERSE ENVIRONMENTAL EFFECTS

The principal unavoidable environmental effect was found to be the population exposure resulting from normal transport of radioactive materials. Since the electromagnetic radiation emitted from a package cannot be reduced to zero by any finite quantity of shielding, the transport of radioactive materials will always result in some population exposure.

The much smaller unavoidable risk from accidents that have the potential for releasing radioactive material from packages will always be present but such accidents have a very small probability of occurrence.

The unavoidable nonradiological impact resulting from transport of radioactive material in exclusive-use vehicles amounts to about two injuries and one fatality every five years, mostly from accidents involving transportation of fuel and waste to and from nuclear power plants. This is because exclusive-use vehicles are predominantly used for such shipments. Other nonradiological impacts such as the use of vehicle fuel and other resources were found to be insignificant.

SHORT-TERM USE OF THE ENVIRONMENT VERSUS LONG-TERM POSITIVE EFFECTS

The most obvious and important short-term effect is the population radiation exposure from normal transport, which statistically amounts to 1.2 latent cancer fatalities per year. An additional short-term effect is the small annual accident risk.

Balanced against these risks are long-term positive results from the shipment of radioactive material in such areas as:

1. National Health - The use of radiopharmaceuticals in the diagnosis and treatment of illnesses provides a benefit in lives saved.

2. Oil Exploration - The use of radioactive material in well logging and flow tracing provides technology for intelligent exploitation of our oil resources and aids in optimizing the use of this valuable national energy resource.

3. Quality Control - The use of radionuclides for gauging the thicknesses of metal and paper, measuring product density, and locating levels of contents in small packages and in large holding tanks provides a capability to minimize waste of resources and optimize quality in finished goods.

4. Electricity Generation - The use of nuclear fuels in reactors allows production of electricity for society with lower fuel costs and lower levels of chemical pollutants to the environment than is possible by more conventional methods of generating electricity.

5. Industry - Radionuclides are used in many manufactured devices and consumer products ranging from home smoke detectors to antistatic devices.

IRREVERSIBLE COMMITMENT OF RESOURCES

The only irreversible commitment of resources determined in this assessment was that resulting from use of fuels to operate the transportation network. To the extent that the resources are committed to the transportation of radioactive materials alone, the quantity of fuels used is an infinitesimal quantity, since transportation of radioactive material normally occurs incidental to the movement of general goods in commerce. Only those portions of the fuel and other resources attributable to sole-use shipments are committed directly, and that activity is less than 10^{-5} of the nation's total transportation activity, making this irreversible commitment of resources negligibly small.

CHAPTER 1
INTRODUCTION

1.1 PURPOSE AND SCOPE OF THIS ENVIRONMENTAL STATEMENT

The purpose of this environmental statement is to assess the impact upon the environment resulting from the transportation of radioactive materials within the United States and from export and import shipments of such materials. The radiological impacts of transportation accidents involving radioactive materials are evaluated from a risk point of view, although the consequences of certain "worst-case" accidents are also evaluated. The data base for this assessment is the 1975 Survey (Ref. 1-1) of radioactive material shipments in the United States. All shipments exclusive of weapons, weapon components, and shipments in military vehicles are considered. Fuel cycle shipments, shipments of medical- and industrial-use isotopes, and waste shipments are specifically included. The expected radiological impacts in 1985 are also evaluated in terms of projections of the 1975 shipment data under certain growth assumptions.

1.2 BACKGROUND

Chapters 1 through 6 of this document are the result of a study begun in May 1975 by Sandia Laboratories under contract with the Nuclear Regulatory Commission (NRC). NRC, organized under the Energy Reorganization Act of 1974, has the responsibility of ensuring the safe use of radioactive materials through licensing and regulation. Soon after its inception, NRC stated that it intended to review those regulations and procedures originally set up by the Atomic Energy Commission (AEC) pertaining to the licensing and regulation of nuclear facilities and materials to determine what changes, if any, should be made. This environmental statement is, in part, an attempt to provide the technical data necessary for NRC to reevaluate the rules governing the transportation of radioactive materials.

In addition, there has been some expression of concern by members of Congress and the public about the safety and security of air shipments of plutonium and other special nuclear material (SNM) in the vicinity of populated areas. For example, the NRC authorization bill enacted into law on August 9, 1975, includes an amendment by Congressman Scheuer that states:

> The Nuclear Regulatory Commission shall not license any shipments by air transport of plutonium in any form, whether exports, imports or domestic shipments; <u>provided</u>, <u>however</u>, that any plutonium in any form contained in a medical device designed for individual human application is not subject to this restriction. This restriction shall be in force until the Nuclear Regulatory Commission has certified to the Joint Committee on Atomic Energy of the Congress that a safe container has been developed and tested which will not rupture under crash and blast-testing equivalent to the crash and explosion of a high-flying aircraft.

Pending satisfaction of this Congressional restriction, NRC has ordered the cessation of plutonium air shipments by its licensees.

The NRC announced its initiation of a rule-making proceeding concerning the air transportation of radioactive materials, including packaging, and invited comments by the public on the existing regulations (Ref. 1-2). Of particular interest were views and comments on:

1. Whether or not radioactive materials should continue to be transported by air;
2. The extent to which safety requirements should be based on accident probabilities, packaging, procedural controls, or combinations of these;
3. The relative risk of transport of radioactive materials by air compared to other modes of transport; and
4. What improvements, if any, in the applicable regulations should be considered.

In order to determine the quantities and types of shipments of radioactive materials currently being transported, NRC contracted with Battelle Pacific Northwest Laboratories in Richland, Washington, to conduct a survey (Ref. 1-1) of the transportation of radioactive materials. Questionnaires requesting data on the numbers and characteristics (e.g., quantity and external radiation level per package) of radioactive materials shipments were sent to about 2,300 of the approximately 18,000 licensees. Detailed questionnaires were mailed to special nuclear material (SNM) licensees who shipped 1 gram or more of SNM between March 1, 1974, and February 28, 1975, and to approximately 150 "major shippers," i.e., licensees who were known to have shipped large numbers of packages or large quantities of radioactive material. Questionnaires requesting only summary information were sent to a sampling of the licensees selected from lists supplied by NRC and by the agreement states (listed in Chapter 2). Data derived from that survey were used for this assessment, as explained in Appendix A.

Section 1.3 of this chapter contains a brief discussion of accident experience in the transportation of radioactive materials. Section 1.4 is an overview of the current industrial and medical uses of radioisotopes and their respective transportation requirements. Section 1.5 identifies the standard-shipments model on which the environmental assessment is based. Section 1.6 is a general discussion of the approach taken in the impact assessment. Finally, Section 1.7 contains an outline of the contents of each of the remaining chapters.

1.3 ACCIDENT EXPERIENCE IN THE TRANSPORTATION OF RADIOACTIVE MATERIALS (Ref. 1-3)

There are approximately 500 billion packages of all commodities shipped each year in the United States. About 100 million of these involve hazardous materials, including flammables, explosives, poisons, corrosives, and radioactive materials. There were over two million packages of radioactive materials transported in 1975. Thus, about 2 percent of hazardous material shipments involve radioactive materials.

Radioactive materials transportation has an excellent record of safety. Of the more than 32,000 hazardous materials transport incidents reported to the DOT during 1971-1975, only 144, or 0 45 percent, were noted to involve radioactive materials. Incidents involving flammable liquids, on the other hand, resulted in over 16,000 reports to the DOT. In only 36 of the 144 reported radioactive materials incidents was there any indication of release of contents or excessive radiation levels. In most cases, the releases involved only minor contamination from packages containing only small quantities of radioactive material.

Seventy-four of the 144 reported* radioactive materials transportation incidents involved air carriers and forwarders, 65 involved highway carriers, and 5 involved rail carriers. About 40 percent of the reported aircraft incidents occurred during handling and typically involved a package falling from a cargo-handling cart and then being run over and crushed by a vehicle.

About 13 percent of the highway incident reports resulted from vehicular accidents in which packages were burned, thrown from moving vehicles, or rolled on by vehicles. Only one of these reports indicated a release of contents. Five reports were submitted by rail carriers in the same five-year period. Two of these involved derailments of flat cars carrying large packagings, but neither incident involved a release.

1.4 AN OVERVIEW OF RADIOISOTOPE USES

Radionuclides used in the practice of nuclear medicine constitute the largest fraction of the packages of radioactive material transported annually in the United States. Other radioisotopes are finding extensive applications in well-logging, in industrial radiography, as large-curie teletherapy and irradiator sources, in some consumer products, and in the manufacture of certain types of gauges. Some fissile materials, such as U-235, are used as nuclear reactor fuel; others, such as Pu-239, are produced as byproduct material in nuclear reactors. These, together with relatively small amounts of radioactive material used in research, constitute the primary applications of radioisotopes.

1.4.1 MEDICAL APPLICATIONS

During the past 25 years, clinical applications of radioactive materials have become a major branch of medicine (Ref. 1-4). In particular, gamma-ray-emitting isotopes are now commonly used for the purpose of imaging specific areas or organs in the body. The normal technique used in a scanning procedure is to give the patient an injection of the isotope in the appropriate chemical form to localize it in the desired organ or system, and collect the emitted gamma radiation on an imaging device.

In 1972, some 6,355,000 procedures were performed in 3,300 hospitals in 1,500 cities in the United States using radiopharmaceuticals (Refs. 1-5 and 1-6). Radioisotopes of iodine were among the first such materials used. Their use in the study of thyroid physiology and in the diagnosis and treatment of thyroid disorders (300,000 to 540,000 administrations/year (Ref. 1-6)) still make them an important part of the current practice of nuclear medicine.

An example of the rapid growth of the use of organ-imaging techniques is the increased application of Tc-99m, an unstable daughter of Mo-99. Tc-99m is not, in itself, a natural

*Radioactive material incident reports are required by Title 49 of the Code of Federal Regulations (see Section 2.1 of Chapter 2 of this environmental statement).

component of any biological system, but its desirable properties (a six-hour half-life and 140-kev gamma ray which is well-matched to existing monitoring instruments) make it ideal for imaging. Because of these properties, relatively large amounts of Tc-99m can be administered with little radiation dose. As a result, there has been extensive research to incorporate this isotope into medically useful forms that provide the necessary imaging and then are excreted. It is estimated that nearly 5.5 million examinations were performed in 1972 using technetium. At present, one of the most useful forms is a pertechnetate used for brain scanning (1,000,000 administrations/year in 1972 (Ref. 1-6)).

A major source for hospital administration of Tc-99m is the Mo-99 generator or "cow," which consists of an alumina column on which the Mo-99 is adsorbed. The daughter product, Tc-99m, may be eluted, i.e., "milked," by flushing the column with a sterile saline solution (Ref. 1-4).

Many other isotopes are now used in scanning procedures: Au-198 or I-131 for the liver (380,000 administrations/year in 1972 (Ref. 1-6)), I-131 for the lungs (246,000 administrations/year in 1972 (Ref. 1-6)), Hg-203 for the kidneys (67,000 in 1972 (Ref. 1-6)), etc.

Isotopes with more energetic emissions, such as Co-60 and Cs-137, are used in therapeutic situations where the radiation is used to destroy localized malignancies.

Because the Tc-99m generators last about a week and because of the way physicians who practice nuclear medicine schedule their patients, hospitals and pharmacies prefer to receive a fresh generator on Monday mornings. Thus, significantly more radiopharmaceutical shipments tend to occur over the weekend than during the week. Radiopharmaceutical packages are frequently picked up at the airport and delivered to the hospital by taxi, personal automobile, or courier service. In some cases, a freight forwarder is used.

Radiopharmaceutical packages shipped to hospitals or nuclear pharmacies contain at most a few curies of the radioactive material and usually much less. The packaging usually consists of several cardboard boxes, one inside another, with a "pig," i.e., lead-shielded enclosure, inside the innermost box. The radiopharmaceutical, usually a liquid, is contained in a glass or plastic vial inside the pig. The vial is surrounded by absorbent material to contain the liquid if the vial should break.

Radiopharmaceutical companies receive the raw materials used to produce radiopharmaceuticals. These materials are often shipped by cargo aircraft in large containers approved for up to thousands of curies. Some companies have plants at more than one location and require transport of large curie quantities of materials between locations.

Most radiopharmaceuticals are produced in New Brunswick, St. Louis, Boston, Chicago, and San Francisco. Because of their short half-lives, they are often flown to their destination on regularly scheduled passenger flights, although one large manufacturer now ships more than 50 percent of his packages by a courier service, using fixed-bed trucks. Because of new applications that are being discovered and because of the increased use of established techniques, the number of packages shipped is growing at a rate of approximately 10 percent per year (Ref. 1-7).

1.4.2 THE WELL-LOGGING INDUSTRY

Well-logging firms use radioisotopes in down-hole measurements to provide information on the underground strata and to assess a well's capability for secondary and tertiary recovery. In a typical logging operation, a neutron source and a gamma source are placed in an instrumentation package and lowered by means of a cable to the bottom of the bore hole. The package is then withdrawn slowly while the instrumentation detects the neutrons and gamma-rays backscattered from the surrounding strata, and the detected signals are displayed on a chart recorder. The results yield information about the properties of rock formations as a function of depth.

Typically, an americium-beryllium neutron source of 5 to 20 curies and a Cs-137 gamma-ray source of several curies are used. Each source is enclosed inside two small, stainless-steel cylinders, one inside the other, with welded end caps. Sources are fabricated in a hot cell by a service company, which purchases the radioisotopes from a company having access to a production reactor. Well-logging firms transport the sources to remote well sites (and often to off-shore locations) both in the United States and in foreign countries, including, for example, Canada, England (North Sea), Germany, Brazil, Venezuela, and Iran.

Many well-logging sources were shipped by passenger aircraft prior to the Federal Aviation Administration (FAA) rule change implementing provisions of the Transportation Safety Act of 1974. That Act prohibited the shipment on passenger aircraft of any radioactive materials other than those intended for research or medical use. Deliveries of sources to sites within approximately a 1000-mile radius of the logging firm are generally made by truck, while deliveries to off-shore well locations are frequently made by helicopter. Exports of sources to foreign countries, as well as long-distance shipments within the United States (e.g., to Alaska), are sent by ship or cargo aircraft.

Some logging firms and some oil companies also use radioactive tracers, usually I-131, Kr-85, or tritiated water, that are injected into a well to monitor its flow properties. These materials are typically shipped in a glass serum vial carefully packaged in a metal can inside a lead-shielded container. Surrounding this container is enough absorbent material to absorb the liquid contents in case of breakage.

1.4.3 THE RADIOGRAPHY INDUSTRY

Radiography sources are made primarily from one of two isotopes, Ir-192 or Co-60, both of which emit relatively high energy gamma-rays. The radiation is used to examine the structural integrity of welded joints, principally in large pipes, frames, and pressure vessels, or to determine the thickness of a material. The source is enclosed by two small, welded, stainless-steel capsules and is positioned at the end of a short flexible steel cable to facilitate handling in the radiography "camera." The gamma rays emitted by the source pass through the welded joint and expose a piece of photographic film. Voids show up as dark spots on the developed negative.

Only a few companies manufacture these sources (obtaining the raw materials from production reactors), but there are numerous radiographers who use them. Unlike the radiopharmaceutical industry, the radiography industry requires individual shipments of sizeable quantities of radioisotopes in both directions between manufacturer and user. A fresh source, typically 100 curies, is sent to a radiographer for use in his camera. When it has decayed to about 30 curies, the source is returned to the manufacturer in exchange for a replacement. The new source is returned in the same shielded container in which it is shipped and stored.

Radiography cameras are also used for field work (e.g., at pipeline installations), which results in the need for transport from field offices to remote sites. The units are fairly portable and are usually transported by small truck or van. However, the majority of radiography is done at fabrication plants and requires no transport except to and from the supplier.

1.4.4 LARGE CURIE SOURCES

Teletherapy sources containing large quantities of Co-60 (up to 10,000 curies) are fabricated and shipped to cancer treatment centers both in the United States and abroad. Overseas exports are transported by ship, while domestic shipments go by truck or rail. Irradiator sources, usually Co-60 or Cs-137, are used for research or in large-scale food sterilization operations and contain hundreds of thousands of curies. These sources are returned to the manufacturer after decaying to about 30 percent of their initial activity. They are shipped in large casks which, because of their weight, are transported by surface modes.

1.4.5 RADIOACTIVE GAUGING SOURCES

A number of different gauging techniques use radioactive materials fabricated in sealed-source form. Material thickness is measured by detecting the variation in beta or gamma radiation that is transmitted through the material. Examples are thickness measurements of paper, rubber, plastic sheet, metal foil, and pipe wall. The material level of solids or liquids is measured by detecting a change in transmitted radiation through tanks, bins, boxes, bottles, cans, or other containers. Fluid densities and bulk densities of solids are measured by detecting transmitted radiation. Coating thicknesses of adhesives, paints, or anticorrosives are measured by detecting transmitted or backscattered radiation. Moisture content is measured by detecting the degree of neutron thermalization.

A number of different isotopes, usually in sealed source form and including Ra-226, Cs-137, Co-60, Kr-85, Sr-90, Am-241, Pm-147, and Th-204, are used in the individual sources, which contain from a few millicuries up to several curies of activity. The radioactive materials used by the source manufacturers are obtained from suppliers of byproduct material. Bulk shipments (up to several hundred curies per shipment) are generally transported in shielded packages by motor freight. The gauging equipment may be shipped with the source intact, or the source may be shipped separately and installed at the site.

1.4.6 THE NUCLEAR POWER INDUSTRY

The basic nuclear fuel cycle associated with the production of electrical energy from fission is shown schematically in Figure 1-1. The part of the cycle that supplies new fuel for power production is referred to as the "front end" and involves U-233, U-235, U-238, Th-232, and Pu-239. The majority of currently operational power reactors are of the light-water reactor (LWR) variety, which has two principal types: pressurized water reactors (PWR) and boiling water reactors (BWR). Both types use slightly enriched uranium (approximately 97 percent U-238, 3 percent U-235) as fuel.

The material flow in the front end of the fuel cycle is approximately as follows: Ores containing 0.1 to 0.5 percent uranium (which has an isotopic content of 99.29 percent U-238 and 0.71 percent U-235) are concentrated as U_3O_8 (yellowcake) near the mine and shipped to a conversion plant. At the conversion plant, the U_3O_8 is converted to UF_6, which is shipped to a uranium enrichment plant to be enriched in the fissile isotope U-235. The enriched UF_6 is sent to a fuel fabrication facility, where it is converted to UO_2 and pressed into pellets. The pellets are fabricated into fuel rod assemblies, and completed fuel assemblies are sent to reactors.

After a fraction of the U-235 fuel has been consumed by fission, the reactor is shut down, and the irradiated fuel elements are removed and sent to a reprocessing plant. This procedure is part of the "back end" of the fuel cycle. At the reprocessing plant, the irradiated fuel is separated from the cladding and is processed in a bath of hot nitric acid. The principal components of irradiated fuel are long-lived fission products (such as Cs-137 and Sr-90), unfissioned fuel (U-233, U-235), and transuranic isotopes (Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Cm-244, etc.). After non-fuel materials are chemically separated, the recovered uranium is converted to UF_6 and returned to the enrichment plant, while the transuranic wastes are stored in liquid form. The high-level fission product wastes are required to be solidified within five years of generation (Ref. 1-9) and subsequently buried in a federal waste repository. Recovered plutonium is converted to PuO_2 and stored or shipped to fuel fabrication plants as required.

No commercial reprocessing plants were in operation in 1975, although at least one was under construction. In the interim, irradiated fuel assemblies were stored on site at the various power reactors. Several plans for disposal of intermediate and high-level wastes are currently being evaluated, but the final selection of the method of disposal and the repository site has not yet been made.

The high-temperature gas-cooled reactor (HTGR) uses the Th-232/U-233 portion of the fuel cycle shown in Figure 1-1. The unique aspect of the front end of the HTGR fuel cycle is the fuel element construction. The UO_2 and ThO_2 are converted to carbides, coated with graphite, blended, formed into cylinders, and inserted into graphite blocks. The mixed fuel is then sent to the HTGR, which uses helium gas as a heat transfer medium. During operation of the reactor, some of the thorium is converted to U-233. The spent fuel, after at least a 90-day cooling-off period at the reactor site, is sent to a reprocessing plant. The recovered U-235, now at reduced enrichment level, is returned for re-enrichment to 93 percent. The U-233 is shipped to a conversion plant,

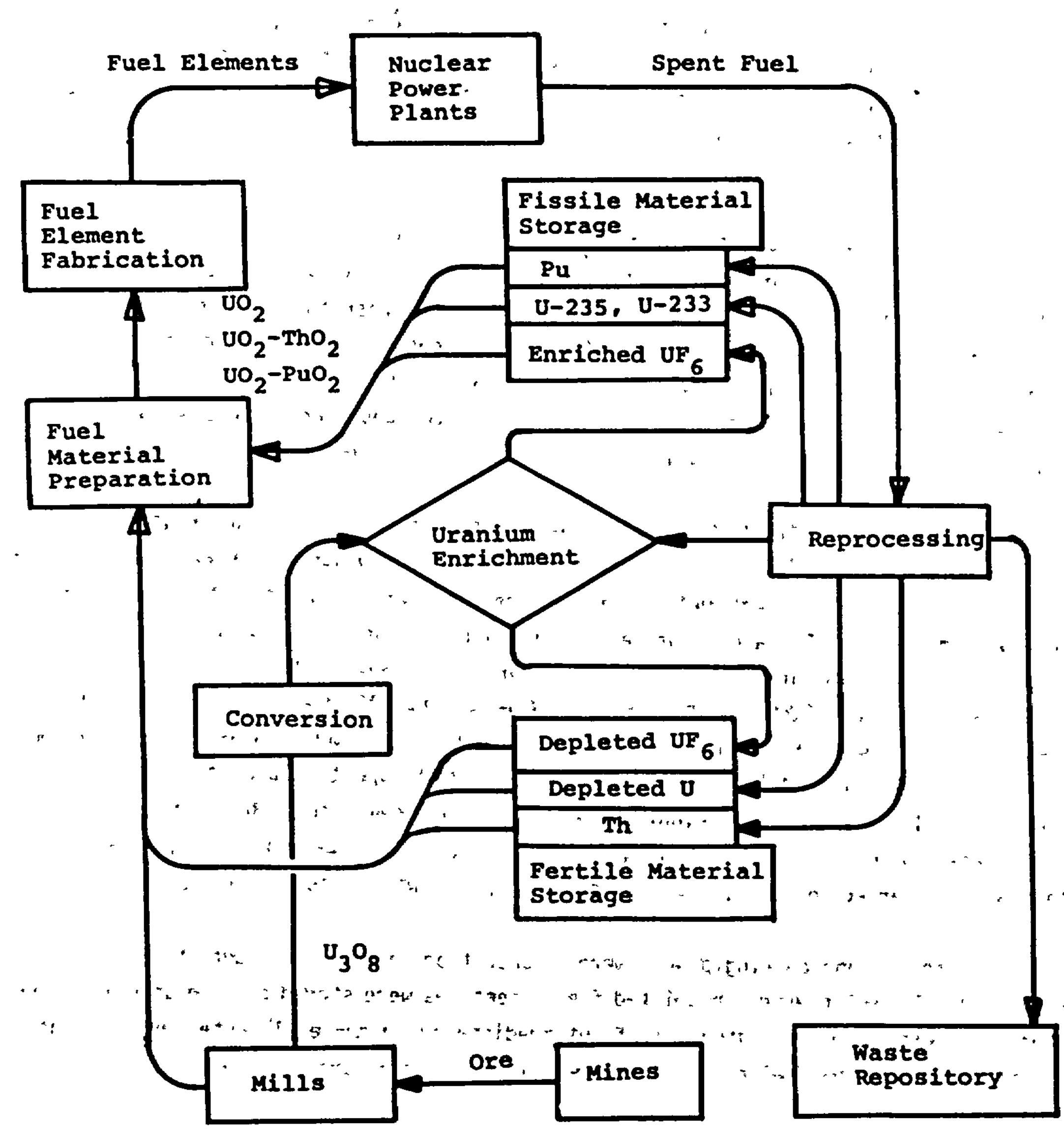

FIGURE 1-1. NUCLEAR FUEL CYCLE (Ref. 1-8).

where it is converted to a carbide to be used as a replacement fuel for U-235 in the reactor. Currently only one HTGR is licensed in the United States.

To conserve uranium resources and utilize the plutonium produced in the reactors, an alternative procedure has been evaluated in which plutonium oxide is mixed with uranium oxide. This oxide mixture is then "burned" in the reactor. Although an environmental impact assessment for mixed oxide fuels has been issued (Ref. 1-10), there is currently no recycling of plutonium except in a few experimental reactors.

Another reactor type is the liquid metal fast breeder reactor (LMFBR) (Ref. 1-11), in which plutonium is produced in the reactor from U-238 and subsequently used to fuel other reactors. This reactor can, in principle, produce more plutonium fuel than the U-235 fuel it consumes, thus conserving uranium resources.

The Naval Nuclear Propulsion Program uses highly enriched uranium (>90 percent U-235) in a PWR system. Like other reactor types, uranium is enriched as UF_6 by gaseous diffusion for fabrication into fuel elements. Because very ttle U-238 is present in the fuel, only very small quantities of plutonium are produced by neutron irradiation in the reactor. The recovered U-235 is re-enriched for reapplication to the fuel cycle.

Because of the large size of virtually all fuel cycle shipments, they are normally shipped in large containers that preclude modes of transport other than truck, rail, barge, or ship.

Certain quantities of "special nuclear materials" (SNM), such as plutonium, U-233, and U-235, or uranium enriched in these isotopes to a level of 20 percent or more, require physical protection against theft and sabotage during transport because it is conceivable that they could be made into a nuclear explosive device. The regulations that prescribe the safeguards for these materials are given in 10 CFR 70 and 10 CFR 73 and will be discussed in Chapter 2. The types of shipments requiring safeguarding include most plutonium shipments and all shipments of highly enriched uranium such as those involved in the HTGR and Naval Reactor Programs. Spent LWR fuel contains sizeable quantities of plutonium; however, the plutonium is not readily separable from the other radioactive material, and the radioactivity of the irradiated fuel material is sufficiently high that it is exempted from transportation safeguards requirements.

Much unirradiated SNM is transported in cargo aircraft and, prior to the previously mentioned DOT restrictions, some was transported by passenger aircraft. The other principal mode of transport is truck.

1.5 STANDARD SHIPMENTS

An assessment of the environmental impact of radioactive materials transportation requires a detailed knowledge of the package types, the principal transport modes, the number of packages transported per year, the average quantity of material per package, the average "transport index" or "TI" (a measure of the external radiation level), and the average distance traveled per shipment, for each type of radioactive material being shipped. To make this problem tractable, a list of "standard shipments" was compiled from the data obtained in the 1975 Survey (Ref. 1-1). This list is shown in Table 1-1, in which the total number of packages shipped per year in 1975 and the 1985 extrapolations are given for various isotope, package type, and transport mode combinations. The list is by no means complete, but the materials listed account for the vast majority of packages, curies, and TI reported in the 1975 Survey. A detailed discussion of the methods used to generate this list from the survey data is given in Appendix A.

Table 1-2 is a summary of radioactive material shipping activity both in 1975 and projected to 1985, listed by isotope use categories. The table lists the annual number of packages and curies, as well as the total TIs and shipment distances, for each category, as determined from the 1975 Survey data. Also shown are the contributions of each category to the annual expected latent cancer fatalities (LCF) resulting from normal transport and from transportation accidents. Detailed discussions of the methods used to obtain these results are presented in Chapters 4 and 5 and in related appendices.

1.6 METHOD USED TO DETERMINE THE IMPACT

Three circumstances under which impacts may be produced were considered: (1) normal transport conditions, (2) accidents involving the transport vehicle, and (3) theft or sabotage. The radiological impacts produced under each of these circumstances relate directly to the radiation emitted by the material. However, economic, legal, or social impacts may also occur. These impacts are more difficult to quantify than the radiological impacts.

1.6.1 NORMAL TRANSPORT CONDITIONS

Under normal transport conditions the radiological impact arises from routine exposure to freight handlers, aircraft passengers and crew, truck drivers, on-route bystanders, etc., resulting from the radiation emitted by the contained material or radioactive contamination of the package surface. Package shielding reduces but never completely eliminates this impact.

The radiological impacts are evaluated in terms of annual expected additional latent cancer fatalities, assuming a proportionality between population dose and numbers of additional latent cancer fatalities (see Chapter 3). The dose resulting from a given shipment is proportional to the total "transport index," or "TI" (see Chapter 2, Section 2.4) of all packages included in the shipment. Estimates of the total population dose are made by modeling the path of each package from the time it is presented for transport until it arrives at its ultimate destination. The population dose is computed for each standard shipment in Table 1-1 bv using the average TI, the average distance traveled, and the total packages per year. The methods of computing the dose depend on the transport mode. The total expected annual dose due to normal transport is given by the sum of the doses resulting from each standard shipment.

1.6.2 ACCIDENTS INVOLVING TRANSPORT VEHICLE

In the accident case, one considers the additional impact that could result from an accident involving a vehicle transporting one or more packages of radioactive material. Three possible

TABLE 1-1

STANDARD SHIPMENTS LIST - 1975 AND 1985 PROJECTIONS

Isotope	Package Type*	Transport Mode**	Packages per Year (1975)	Packages per Year (1985)
Various+	Limited++	AF	1.72×10^4	4.47×10^4
		P A/C	2.95×10^5	7.67×10^5
		T	3.91×10^5	1.02×10^6
Am-241	A	AF	521	1.22×10^4
		P A/C	4170	0
		T	2.04×10^4	5.3×10^4
	B	AF	7	161
		P A/C	55	0
		T	116	302
Au-198	A	AF	25	25
		P A/C	1820	1820
		T	2410	2410
Co-57	A	AF	267	694
		P A/C	9860	2.56×10^4
		T	6180	1.61×10^4
Co-60	A	T	1.77×10^4	4.6×10^4
	B	T	1460	3800

*For details of package terminology, see Chapter 2.

**AF - all-cargo aircraft; P A/C - passenger aircraft; T - truck; R - rail; S - ship; ICV - Integrated Container Vehicle.

+Modeled as I-131.

++Terminology recently applied by DOT to packages formerly referred to as "exempt."

TABLE 1-1 (continued)

Isotope	Package Type	Transport Mode	Packages per Year (1975)	Packages per Year (1985)
Co-60	LQ1	T	101	262
	LQ2	T	4	10
	LSA	AF	45	1440
		P A/C	509	0
		T	5540	1.44×10^4
C-14	A	AF	1080	2810
		P A/C	1.94×10^4	4.97×10^4
		T	6660	1.73×10^4
Cs-137	A	AF	41	2920
		P A/C	1080	0
		T	3.1×10^4	8.06×10^4
	B	AF	5	13
		T	69	179
Ga-67	A	AF	175	455
		P A/C	7030	5.18×10^4
		T	1.29×10^4	0
H-3	A	AF	1300	3380
		P A/C	2.6×10^4	6.76×10^4
		T	1.1×10^4	2.86×10^4

TABLE 1-1 (continued)

Isotope	Package Type	Transport Mode	Packages per Year (1975)	Packages Per Year (1985)
H-3	B	AF	18	47
		P A/C	364	946
		T	151	393
	LSA	AF	2	5
		P A/C	45	117
		T	18	47
Ir-192	A	AF	346	7500
		P A/C	2540	0
		T	1920	4990
	B	AF	1590	3.45×10^4
		P A/C	1.17×10^4	0
		T	1.37×10^4	3.56×10^4
I-131	A	AF	4720	4720
		P A/C	2.93×10^5	2.93×10^5
		T	1.08×10^5	1.08×10^5
	B	AF	13	13
		P A/C	310	310
		T	292	292
Kr-85	A	AF	136	354
		P A/C	1530	3980

TABLE 1-1 (continued)

Isotope	Package Type	Transport Mode	Packages per Year (1975)	Packages per Year (1985)
Po-210	LQ	AF	1	32
		P A/C	11	0
		T	7	18
		R	1	3
P-32	A	AF	268	697
		P A/C	7940	2.06×10^4
		T	3820	9930
Ra-226	A	T	2.6×10^4	2.6×10^4
	B	AF	39	440
		P A/C	401	0
		T	2620	2620
Tc-99m	A	AF	1280	3330
		P A/C	3.01×10^4	7.83×10^4
		T	2.09×10^5	5.43×10^5
Tl-201	A	P A/C	0	7500
		T	0	4.25×10^4
Waste	A	T	1.31×10^5	3.41×10^5
	B	T	821	2130
	LSA	T	2.03×10^4	5.28×10^4
Xe-133	A	AF	875	2280
		P A/C	1.22×10^4	3.17×10^4
		T	1.29×10^4	3.35×10^4

TABLE 1-1 (continued)

Isotope	Package Type	Transport Mode	Packages per Year (1975)	Packages per Year (1985)
Kr-85	A	T	3500	9100
		S	297	772
	B	AF	30	78
		P A/C	336	874
		T	634	1650
MF+MC*	A	T	2.15×10^4	8.9×10^4
	B	T	5000	2.07×10^4
	LQ	T	12	50
	LSA	T	3.33×10^4	1.38×10^5
Mo-99	A	AF	3200	8320
		P A/C	7.97×10^4	2.07×10^5
		T	5.49×10^4	1.43×10^5
	B	AF	109	283
		P A/C	2720	7070
		S	1880	4890
Po-210	A	AF	16	336
		P A/C	113	0
		T	81	211
		R	10	260

*Mixed corrosion products and mixed fission products.

TABLE 1-1 (continued)

Isotope	Package Type	Transport Mode	Packages per Year (1975)	Packages per Year (1985)
Mixed*	A	AF	115	299
		P A/C	2260	5880
		T	2.7×10^4	7.02×10^4
	B	P A/C	8	21
		T	101	263
	LSA	AF	26	68
		P A/C	513	1330
		T	5830	1.52×10^4
Pu-238	A	AF	34	88
		P A/C	1980	5150
		T	3250	8450
	B	AF	2	288
		P A/C	109	0
		T	179	465
Pu-239	B	AF	17	182
		P A/C	165	0
		T	4030	4030
	LQ	AF	1	1
U-Pu Mixture	B	AF	8	33
		P A/C	58	240

*Treated as I-131 for purposes of radiobiological modeling.

TABLE 1-1 (continued)

Isotope	Package Type	Transport Mode	Packages per Year (1975)	Packages per Year (1985)
U-Pu Mixture	B	T	330	1370
Spent fuel	Cask	T	254	1530
		R	17	652
U_3O_8	LSA	T	5.4×10^4	2.24×10^5
		R	6.6×10^4	2.73×10^5
UF_6 (natural)	A	T	2050	8440
		R	2500	1.04×10^4
UF_6 (enriched)	B	T	485	2000
		S	106	439
UO_2 (enriched)	B	T	9690	4.01×10^4
		S	2130	8820
UO_2 fuel	B	T	1280	5300
		S	282	1170
Recycle Plutonium	B	ICV	0	41

TABLE 1-2

SUMMARY OF RADIOACTIVE MATERIAL SHIPPING AND ITS MAJOR RADIOLOGICAL IMPACTS

Shipment Type	Packages per Year	Curies per Year	TI per Year	Kilometers per Year	LCF (normal) per Year	Percent	LCF (acc) per Year	Percent
1975								
Limited	7.03×10^{5}	2.11×10^{3}	7.74×10^{3}	1.19×10^{9}	0.0077	0.6	5.78×10^{-5}	1
Medical	9.10×10^{5}	5.78×10^{6}	6.43×10^{5}	1.12×10^{9}	0.616	52	6.11×10^{-4}	13
Industrial	2.15×10^{5}	9.39×10^{6}	3.43×10^{5}	3.01×10^{8}	0.281	24	1.60×10^{-3}	34
Fuel cycle	2.04×10^{5}	5.32×10^{8}	5.69×10^{5}	2.09×10^{7}	0.104	9	1.85×10^{-3}	39
Waste	1.52×10^{5}	2.68×10^{5}	2.98×10^{6}	3.22×10^{6}	0.182	15	6.17×10^{-4}	13
TOTAL	2.19×10^{6}	5.48×10^{8}	4.54×10^{6}	2.64×10^{9}	1.19	100	4.73×10^{-3}	100
1985								
Limited	1.83×10^{6}	5.50×10^{3}	2.02×10^{4}	3.11×10^{9}	0.020	0.7	1.51×10^{-4}	1
Medical	1.71×10^{6}	1.50×10^{7}	1.20×10^{6}	1.92×10^{9}	1.17	38	1.51×10^{-3}	9
Industrial	5.63×10^{5}	2.47×10^{7}	8.79×10^{5}	8.84×10^{8}	0.676	22	4.49×10^{-3}	27
Fuel cycle	8.36×10^{6}	8.41×10^{9}	2.46×10^{6}	7.16×10^{7}	0.469	15	7.88×10^{-3}	48
Waste	6.27×10^{5}	1.11×10^{6}	1.23×10^{7}	1.33×10^{7}	0.752	24	2.54×10^{-3}	15
TOTAL	5.57×10^{6}	8.45×10^{9}	1.68×10^{7}	5.97×10^{9}	3.08	100	1.66×10^{-2}	100

hazardous conditions may arise in such an accident:

1. A loss of shielding efficiency of the package,
2. A loss of containment and subsequent dispersal of the radioactive material, and
3. Accidental assembly of a critical mass (in fissile material shipments).

The first condition could result in persons near the accident being directly exposed to radiation. The second could ultimately result in direct exposure and intake of the radioactive material into humans by inhalation or ingestion of the dispersed material. The third case could result in neutron irradiation of persons in the vicinity of the accident at the time it occurs.

Accident risk is defined as the product of the probability of an accident and its consequences. The risk calculations incorporate accident rates and package release fraction estimates, both of which are functions of accident severity. Dispersible materials are assumed to be aerosolized in severe accidents, and the aerosol cloud is assumed to drift downwind according to a Gaussian diffusion model. Inhalation of the aerosolized debris by persons downwind from the accident produces doses to various internal organs. Nondispersible materials are assumed to undergo a partial loss of shielding and create a direct exposure hazard. The contributions of each standard shipment to the accident risk are summed to obtain the total risk. Radiological accident risks are expressed in terms of annual expected latent cancer fatalities and early fatality probabilities.

The consequences of postulated accidents involving certain large quantity shipments are also evaluated. The results are presented in terms of the number of persons receiving greater than specific doses of interest and in terms of the area that is contaminated to greater than a given level.

1.6.3 THEFT OR SABOTAGE

Certain quantities of SNM, such as plutonium or highly enriched uranium, are possible targets for theft, since they might be used to make a nuclear explosive device. Other radionuclides in large quantities may also become targets for theft or sabotage. The need for security of certain radioactive material shipments is discussed in Chapter 7, together with an assessment of the present physical security requirements applied to various modes of transport.

1.7 THE CONTENTS OF OTHER CHAPTERS OF THIS DOCUMENT

Chapter 2 discusses the federal regulations that apply to the transport of radioactive materials and the safeguarding of SNM. It is the environmental impact resulting from the transportation of radioactive materials under these regulations that is the subject of this report. Chapter 3 is a general discussion of the biological effects of radiation exposure. It includes a summary of the health effects model used in this assessment. The case of normal transport of radioisotopes and the associated environmental impact is discussed in Chapter 4. In Chapter 5 the impact due to accidents is discussed. Chapter 6 includes a discussion of alternatives to present shipping practice, including transport mode shifts, and their effect on the environmental impact.

The diversion of SNM and an evaluation of the steps taken to avoid such diversion are discussed in Chapter 7. Chapter 8 contains responses to comments received concerning the draft versions of this document. Specific subjects such as the standard shipments model, plutonium, etc., are addressed in the appendices.

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1-10. U.S. Nuclear Regulatory Commission, Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Reactors, NUREG-0002, August 1976.

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CHAPTER 2

REGULATIONS GOVERNING THE TRANSPORTATION OF RADIOACTIVE MATERIALS

2.1 INTRODUCTION

The objective of this chapter is to summarize the federal regulations pertaining to the transportation of radioactive materials. For complete details of transportation regulations, the interested reader is referred to the appropriate sections in the Code of Federal Regulations (some of which are provided in Appendix B to this document).

Three basic safety requirements that must be met when transporting radioactive materials are:

1. Adequate containment of the radioactive material;
2. Adequate control of the radiation emitted by the material; and
3. Prevention of nuclear criticality, i.e., prevention of the accumulation of enough fissile material in one location under conditions that could result in a nuclear chain reaction.

In addition, certain strategic quantities and types of special nuclear material (SNM) require physical protection against theft and sabotage during transit.

The purpose of the regulations is to ensure that these requirements are met. In the subsequent sections of this chapter, the regulations relating to each of these safety requirements are discussed.

NRC regulations provide the standards that must be met rather than attempting to specify how they are to be met. An example of the application of this basic concept is the fact that the regulations do not prohibit the shipment of any specific radioisotope,* as long as the basic safety standards are met.

Section 2.2 of this chapter is a discussion of the various regulatory agencies and their respective regulations. Section 2.3 discusses the regulations and standards designed to ensure the containment of radioactive material during transport, including the classification of radioactive materials for shipment, Type A packaging standards, Type B packaging standards, and packaging for large quantities, limited items, limited quantities, and low specific activity (LSA) materials. Section 2.4 discusses the standards for radiation control during transport and introduces the concept of the transport index.

The special regulations applicable to fissile materials for criticality control are discussed in Section 2.5. Section 2.6 outlines the responsibilities of a licensee who receives a shipment of radioactive material and discusses procedures for picking up, receiving, and opening

*Plutonium air shipments are presently prohibited by NRC order in compliance with Public Law 94-79 (Scheuer Amendment).

packages. The labeling requirements for packages are covered in Section 2.7. In Section 2.8 the responsibilities of the carrier, including vehicle placarding and stowage, are discussed. Section 2.9 covers the requirements for the reporting of incidents and decontamination procedures. Finally, in Section 2.10 the requirements for the safeguarding of special nuclear material in transit are discussed.

2.2 REGULATORY AGENCIES

The transportation of radioactive byproduct, source, and special nuclear materials within the United States is regulated by the Nuclear Regulatory Commission (NRC). The Department of Transportation (DOT) regulates all radioactive materials in interstate commerce. International shipments, in most cases, are consistent with the standards of the International Atomic Energy Agency (IAEA), with the DOT serving as the USA "competent authority." Certain "limited" (formerly called "exempt") quantities may be shipped by mail, and such shipments are regulated by the U.S. Postal Service. Shipments that are neither in interstate or foreign commerce nor in air transportation, as defined in the Federal Aviation Act of 1958, are controlled by NRC and by various state agencies.

The Nuclear Regulatory Commission was established by the Energy Reorganization Act of 1974, which went into effect on January 19, 1975. This act also created the Energy Research and Development Administration (ERDA) and abolished the Atomic Energy Commission (AEC). The licensing and related regulatory authority held by the AEC under the Atomic Energy Act of 1954, as amended, was transferred to the NRC. The authority of the AEC operating divisions to approve the use of radioactive material packages by their prime contractors was assumed by ERDA in this reorganization. Later, Section 301(a) of Public Law 95-91, enacted August 4, 1977, transferred all functions of ERDA to the Secretary of Energy. The special package approval authority is being phased out as NRC is able to review the large number of packages in use by prime contractors, and it is expected to expire in 1978. Approvals were issued only in accordance with the same package standards used by the AEC regulatory staff, and now by NRC.

Chapter I of Title 10 of the Code of Federal Regulations contains the rules and regulations of the NRC, including rules and definitions relating to the issuance of general and specific licenses for receiving, acquiring, owning, possessing, using, and transferring byproduct material, source material, and special nuclear material. A transfer of a nonlimited quantity of these materials can take place only between persons who are licensed either by the NRC or by certain "agreement states," a term to be explained later in this section.

The parts of Title 10, Chapter I that most directly pertain to radioactive material transportation are Parts 20, 70, 71, and 73, which deal with "Standards for Protection Against Radiation," "Special Nuclear Material," "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material under Certain Conditions," and "Physical Protection of Plants and Materials," respectively. In referring to these and other regulations in the Code of Federal Regulations, an abbreviated form will be used: "10 CFR 71.35(a)," meaning "Paragraph (a) of Section 71.35 of Part 71 of Title 10 in the Code of Federal Regulations."

The AEC, through formal agreements with certain "agreement states," transferred to those states the regulatory authority over byproduct material, source material, and subcritical quantities of special nuclear material. These agreement states are Alabama, Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Carolina, North Dakota, Oregon, South Carolina, Tennessee, Texas, and Washington. These states have adopted a uniform set of rules requiring an intrastate shipper of radioactive materials to conform to the DOT requirements for packaging, labeling, and marking.

DOT, under the Department of Transportation Act of 1966, the Transportation of Explosives Act, the Dangerous Cargo Act, the Federal Aviation Act of 1958, and the Transportation Safety Act of 1974, has regulatory responsibility for safety in transportation. The organizational unit of DOT concerned specifically with safety in the transport of radioactive and other hazardous materials is the Office of Hazardous Materials Operations within the Materials Transportation Bureau.

The DOT regulations governing carriage of radioactive materials by rail and by common, contract, or private carriers by public highway (e.g., truck) are found in 49 CFR 171-179, which make up Subchapter C, "Hazardous Materials Regulations." The DOT regulations regarding packaging of radioactive materials are found in 49 CFR 173, "Shippers -- General Requirements for Shipments and Packagings," and 178, "Shipping Container Specifications"; they are consistent with the NRC guidelines in 10 CFR 71. The DOT regulations governing the carriage of radioactive materials by air are in 49 CFR 175, "Carriage by Aircraft." The DOT regulations in 49 CFR 176, "Carriage by Vessel," apply to the carriage of radioactive and other hazardous materials by barge or ship.

Certain "limited" quantities of radioactive material may be shipped through the mail. The regulations of the U.S. Postal Service, found in 39 CFR 123-125, pertain to such shipments. The criteria used to determine how much radioactive material can qualify as "limited" are discussed later in this chapter.

In order to carry out their respective regulatory functions for the safe transport of radioactive materials with as little duplication of effort as possible, the Interstate Commerce Commission (ICC) and the AEC (now the NRC) signed a "memorandum of understanding" in 1966. It has been superseded by a revised memorandum of understanding between DOT and AEC signed on March 22, 1973.

According to the memorandum, the DOT regulations (49 CFR 171-179)* concerning packaging, marking, and labeling apply to shippers, and the regulations concerning vehicle placarding, loading, storage, monitoring, and accident reporting apply to carriers. All packagings for shipment of fissile material or for Type B or large quantities of radioactive material require approval by the NRC. In case of a transportation accident, incident, or suspected leakage from a package of radioactive material discovered while in transit, the DOT investigates the occurrence and prepares an investigation report. If, however, an accident or incident occurs, or

*As of April 15, 1976, the DOT Regulations for Transport of Hazardous Materials, formerly located in 49 CFR 170-189, 14 CFR 103 (air shipments), and 46 CFR 146 (water shipments) were consolidated into 49 CFR.

suspected leakage is discovered other than during transit, the occurrence is investigated by the NRC. The DOT is recognized as the "national competent authority" with respect to the administrative requirements of the International Atomic Energy Agency (IAEA) for the safe transport of radioactive materials. The two agencies (NRC and DOT) have agreed to cooperate via exchange of information in the development and enforcement of the regulations.

2.3 REGULATIONS DESIGNED TO ENSURE ADEQUATE CONTAINMENT

The regulations to be discussed in this section provide standards for packaging and define limits for the package contents. The terms "package" and "packaging" are defined in 10 CFR 71.4, "Definitions," as follows:

> (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, nonfissible neutron absorbers, and other supplementary equipment.

In defining the packaging standards and the package content limits, the consequences of loss of containment must be considered. In the event that some of the radioactive contents escape from the package, a potential hazard to transport workers and to the general public exists resulting from the external radiation emitted from the exposed radionuclide and from the often more serious problem of intake into the body, particularly through inhalation.

Since the radiotoxicity of radionuclides varies over eight orders of magnitude (Ref. 2-1), a realistic set of standards should take into account which isotope is being transported. For this reason each radioisotope is classified, for transport purposes, into one of seven transport groups, labeled by Roman numerals I through VII according to their relative toxicity and potential hazard. A list of the radionuclides and their respective transport groups may be found in Appendix C, "Transport Grouping of Radionuclides," to 10 CFR 71 (shown in Appendix B to this environmental statement) and in 49 CFR 173.390, "Transport Groups of Radionuclides."

Another approach is used in the 1973 revised regulations of the International Atomic Energy Agency, in which each radionuclide is assigned a value according to its individual radiotoxicity. In this approach the transport groups become unnecessary.

Radioisotope quantities in each transport group are classified in order of increasing quantity, as "limited," "Type A," "Type B," and "large" quantity. The reason for this classification will become apparent in the next section. The limits for these quantity groupings are shown in Table 2-1.

Certain physical forms of a radioactive material of any of the seven transport groups are classified as "special form" and are subject to the quantity limits shown in the line in Table 2-1 entitled "Special Form." A special-form material is essentially nondispersible in water,

TABLE 2-1

QUANTITY LIMITS FOR THE SEVEN TRANSPORT GROUPS AND SPECIAL FORM

Transport Group	Limited Quantity* (Curies)	Type A Quantity** (Curies)	Type B Quantity** (Curies)	Large Quantity** (Curies)
I	$\leq 10^{-5}$	10^{-5} to 10^{-3}	10^{-3} to 20	>20
II	$\leq 10^{-4}$	10^{-4} to 5×10^{-2}	5×10^{-2} to 20	>20
III	$\leq 10^{-3}$	10^{-3} to 3	3 to 200	>200
IV	$\leq 10^{-3}$	10^{-3} to 20	20 to 200	>200
V	$\leq 10^{-3}$	10^{-3} to 20	20 to 5×10^{3}	$>5 \times 10^{3}$
VI	$\leq 10^{-3}$	10^{-3} to 10^{3}	10^{3} to 5×10^{4}	$>5 \times 10^{4}$
VII	≤ 25	25 to 10^{3}	10^{3} to 5×10^{4}	$>5 \times 10^{4}$
Special Form	$\leq 10^{-3}$	10^{-3} to 20	20 to 5×10^{3}	$>5 \times 10^{3}$

*49 CFR 173.391.
**10 CFR 71.4 and 49 CFR 173.389.
Note: The regulations actually prescribe only the upper limits for Limited, Type A, and Type B quantities. The symbol ≤ means "less than or equal to," and > means "greater than."

in a fire, or under severe impact conditions. The complete definition is found in 10 CFR 71.4(o) (Appendix B to this document) and in 49 CFR 173.389, "Radioactive Materials; Definitions." The usefulness of the special-form concept is that more radioactive material may be shipped in a Type A package (one that does not resist severe accidents) because of the greatly reduced dispersibility of special-form material.

Any radioactive material that does not qualify as a special-form material is considered "normal form" and is categorized according to its transport group. While a special-form material could, in the event of a severe accident, present an external radiation exposure hazard, it is apparent from its definition that the chance of any significant amount of the contents being released into the air, groundwater, etc., and being ingested by a human is extremely remote. Examples of special-form materials are sealed radiography and teletherapy sources and, in some cases, unirradiated reactor fuel rods.

2.3.1 TYPE A PACKAGE

To be qualified for transport, any packaging used to contain radioactive material must meet the general requirements of 49 CFR 173.393, "General Packaging and Shipment Requirements" (Appendix B to this document). These requirements state, among other things, that the packaging must be adequate to prevent loss of dispersal of the radioactive contents and maintain the radiation shielding properties for the normal conditions encountered during transport. Tests to simulate normal transport conditions are outlined in 49 CFR 173.398(b), "Standards for Type A Packaging," and in Appendix A, "Normal Conditions of Transport," to 10 CFR 71 (see Appendix B to this document).

The seven transport groupings and the Type A quantity limits have their origin in the IAEA regulations. The Type A limits were determined in the following way (Ref. 2-2): It was recognized that the chance of a rail accident of such severity as to cause loss of the package contents was very small. Experimental work had indicated that a release of 0.1 percent of the package contents would be a reasonable assumption for the vast majority of possible accidents. Furthermore, on the basis of general handling experience, it was assumed that the actual intake of radioactive material into the body by a person coming into contact with air or surfaces contaminated by such a release was unlikely to exceed 0.1 percent of the amount released from the package. Thus, it would be unlikely that any one person would ingest more than one-millionth of the actual package contents in the event of an accidental release. Therefore, the Type A package limits were established on the basis that neither:

1. An intake of 10^{-6} of the maximum allowed package contents would result in a radiation dose to any organ in the body exceeding internationally accepted limits, assuming a 50-year life expectancy after the intake; nor

2. The external radiation from the unshielded contents would exceed 1 rem/hour at 10 feet (3 meters).

In 49 CFR 178 there are descriptions of various DOT-approved containers for Type A packaging, including carboys, fiberboard boxes, steel drums, etc., that may be used without specific regulatory approval. However, in a recent rulemaking (Ref. 2-3) DOT eliminated the various "hardware-oriented" specifications for the Type A package containers listed in 49 CFR 173.394, "Radioactive Material in Special Form," and 49 CFR 173.395, "Radioactive Material in Normal Form," and ruled that each Type A package presented for shipment must be certified according to the Type A "Specification 7A" design with a supporting safety analysis. The requirements for this design are specified in 49 CFR 178.350, "Specification 7A; General Packaging, Type A." The use of existing Specification 55 (as described in the former 49 CFR 178.250) containers is also authorized for Type A shipments, but the construction of additional Specification 55 containers after March 31, 1975, has been prohibited. Foreign-made packagings, properly labeled as "Type A," are also acceptable by DOT for use in domestic transport (see 49 CFR 173.394(a)(4) and 173.395(a)(4)).

2.3.2 TYPE B AND LARGE QUANTITY PACKAGING

Quantities of radioactive material greater than the Type A limits can be transported only in Type B packaging. A Type B packaging is designed to more stringent standards and hence is considerably more accident resistant than a Type A packaging. In addition to meeting the standards for a Type A package, a Type B package must also be able to survive certain hypothetical accident conditions with essentially no loss of containment and limited loss of shielding capability. The NRC packaging standards are given in Subpart C, "Package Standards," of 10 CFR 71, and the tests to simulate accident conditions are found in Appendix B, "Hypothetical Accident Conditions," to 10 CFR 71. A Type B packaging design requires the approval of the NRC before it can be used for shipping radioactive material.

The Type B quantity limits are somewhat artificial in that the regulations permit shipments of quantities greater than these limits as "large quantity" shipments in Type B containers. Like the Type A limits, Type B limits have their origin in the earlier IAEA regulations. In the 1973 revision of the IAEA regulations, the upper Type B limits were discontinued.

The types of packaging acceptable to DOT for Type B quantities, listed in 49 CFR 173.394 and 49 CFR 173.395, are summarized in Table 2-2, which includes the recent HM-111 rule changes (Ref. 2-3).

Certain types of sources, particularly irradiated reactor fuel elements, irradiator and teletherapy sources, and most plutonium shipments contain quantities of radioactive materials in excess of the Type B limits. Packaging for large sources is subject to the requirements for Type B packaging plus additional requirements related primarily to decay heat dissipation (49 CFR 173.393(e)). The DOT packaging requirements for large quantities of normal-form material are stated in the following exerpt from 49 CFR 173.395(c):

> Large quantities of radioactive materials in normal form must be packaged as follows: (1) Specification 6M (§178.104 of this chapter) metal packaging. Authorized only for solid or gaseous radioactive materials which will not decompose at temperatures up to 250°F. Radioactive thermal decay energy must not exceed 10 watts. (2) Any other Type B packaging for large quantities of radioactive materials which meets the pertinent requirements in the regulations of the U.S. Atomic Energy Commission (10 CFR 71) and is approved by the U.S.

TABLE 2-2

TYPE B PACKAGINGS PERMITTED BY DOT

FOR TRANSPORT BY 49 CFR 173.394 AND 49 CFR 173.395

Special Form	Normal Form
1. Spec 55 (300 Ci Max.) (49 CFR 178.250)	1. Spec 6M (for solid or gas only which does not decompose up to 250° F).
2. Spec 6M (49 CFR 178.104)	2. NRC (AEC) approved per 10 CFR 71.
3. NRC (AEC) approved per 10 CFR 71.	3. Type B packaging meeting 1967 IAEA regulations for which foreign competent authority certificate has been revalidated by DOT.
4. Type B packaging meeting 1967 IAEA regulations for which foreign competent authority certificate has been revalidated by DOT.	4. Spec 20WC jacket with snug-fitting inner Spec 2R or existing Spec 55 inner package. For liquid, 173.393(g) must also be met for the inner package.
5. Spec 20WC (49 CFR 178.194) outer jacket with snug-fitting Spec 7A (49 CFR 178.350) or existing Spec 55 inner container.	
6. Spec 21WC overpack with single inner Spec 2R (49 CFR 178.34) or existing Spec 55 inner package securely positioned and centered.	

> Atomic Energy Commission. (3) Any other Type B packaging which meets the pertinent requirements for large quantities of radioactive materials in the 1967 regulations of the International Atomic Energy Agency, and for which the foreign competent authority certificate has been revalidated by the Department.

The packaging requirements for large quantities of special-form material are located in 49 CFR 173.394(c) and are substantially the same as for normal form except that, for special form, provision is also made for the use of existing Specification 55 containers with a 20WC overpack; that is:

> Specification 20WC (§178.194 of this subchapter) wooden outer protective jacket, with a single, snug-fitting specification 55 inner packaging. Only use of existing specification 55 container authorized; construction not authorized after March 31, 1975. Radioactive thermal decay energy must not exceed 100 watts.

2.3.3 RADIOACTIVE DEVICES AND LIMITED QUANTITIES

Certain small quantities of radioactive materials are exempt from specification packaging, marking, and labeling requirements and from the general packaging requirements of 49 CFR 173.393, as are certain manufactured articles, such as clocks and electronic tubes, that contain radioactive materials in a nondispersible form. These exemptions are covered in 49 CFR 173.391, "Limited Quantities of Radioactive Materials and Radioactive Devices" (Appendix B to this document).

The "limited" quantity limits and the maximum allowable radioactivity content for exempt manufactured articles for the seven transport groups and for special form are given in Table 2-3. The limited quantity limits are also given in Table 2-1. These limits were chosen in such a way that the release of up to 100 percent of the contents in an accident would still represent a very low potential radiological hazard (Ref. 2-2).

2.3.4 LOW SPECIFIC ACTIVITY MATERIALS

To meet the need for bulk transportation of radioactive ores, slag, or residues from processing, the DOT regulations in 49 CFR 173.392, "Low Specific Activity Radioactive Material," provide exemptions from the requirements of 49 CFR 173.393(a) through (e) and (g) in the case of "low specific activity" (LSA) materials. However, LSA materials must be packed in accordance with the requirements of 49 CFR 173.395 and must be marked and labeled as required in 49 CFR 172.300, "General Marking Requirements," and 172.400, "General Labeling Requirements." LSA materials are defined in 10 CFR 71.4(g) (Appendix B to this document) and include uranium and thorium ores, ore concentrates, materials not exceeding the specific activity limits in Table 2-3, certain contaminated nonradioactive materials, certain solutions of tritium oxide, unirradiated natural or depleted uranium, and unirradiated natural thorium.

In defining the activity limits for LSA materials, the IAEA introduced the concept that, from a radiotoxicity point of view, LSA materials should be "inherently safe"; i.e., it is inconceivable that, under any circumstances arising in transport, a person could ingest enough

TABLE 2-3

LIMITS FOR LIMITED QUANTITIES, LSA MATERIALS, AND MANUFACTURED ARTICLES

Transport Group	Small or Limited Quantity Limit (mCi)*	LSA Materials Limits (mCi/gm)**	Maximum Radioactivity Content for Manufactured Articles (Curies)*	
			Per Device	Per Package
I	.01	.0001	.0001	.001
II	.1	.005	.001	.05
III	.1	0.3	.01	3
IV	1	0.3	.05	3
V	1		1	1
VI	1		1	1
VII	25000		25	200
Special Form	1		.05	20

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* 49 CFR 173.391 - exempt from specification packaging, marking, and labeling requirements and from the general packaging requirements of 49 CFR 173.393.

** 10 CFR 71.4(g) and 49 CFR 173.392 - for material in which activity is uniformly distributed; exempt from 49 CFR 173.393(a) though (e) and (g), but must be packed in accordance with the requirements of 49 CFR 173.395 and must be marked and labeled as required in 49 CFR 173.401 and 173.402. LSA limits are not defined for transport groups V, VI, VII, and special form.

material to give rise to a significant radiation hazard (Ref. 2-2). Thus, for LSA materials, it is the limited activity within each segment of the material itself rather than the packaging that permits shipments to meet the basic safety requirements. Nevertheless, both NRC and DOT place packaging requirements on shipments of LSA materials that are not transported on exclusive-use vehicles. NRC also has packaging requirements for Type B quantities of radioactive material transported on exclusive-use vehicles.

2.4 RADIATION CONTROL -- THE TRANSPORT INDEX

The second safety requirement that must be met when transporting radioactive material is the provision for adequate control of the radiation emitted from the material. This radiation is only partially absorbed by the containment and shielding systems. Some passes through the packaging and exposes freight handlers and others who come into close proximity with the package. In order to meet the radiation control limits, the shipper must provide the necessary shielding to reduce the radiation level outside the package to within the allowable limits. The regulations prescribe limits that are chosen to protect not only persons but also animals and film. In fact, the radiation control surface dose rate limit of 0.5 mrem/hour for packages requiring no control was chosen to prevent fogging of sensitive x-ray film that might be transported over a 24-hour period in close proximity to the package containing the radioactive material (Ref. 2-2).

For purposes of radiation control, packages of radioactive material are placed in one of three categories. Packages designated as "Category I - White" (which display a white label) may be transported with no special handling or segregation from other packages and must be within the 0.5 mrem/hour surface dose rate limit. If a transport worker were to handle such packages close to his body for 30 minutes per week, he would receive an average dose rate of 10 mrem/year, which is a factor of 10 less than the average dose rate (100 mrem/year) received by an individual from natural background radiation (Ref. 2-2). The regulations (in 49 CFR 173.393(c)) also prescribe a minimum package dimension of 10 cm (4 inches) so that a person cannot put the package in his or her pocket. The 0.5 mrem/hour surface dose rate limit also applies to "limited" packages, although the minimum package dimension requirement does not.

Except when carried on exclusive-use vehicles, where packages are handled only by shipper and receiver, packages designated as "Category III - Yellow" can have a surface dose rate no greater than 200 mrem/hour <u>and</u> a dose rate at 3 feet from any external surface no greater than 10 mrem/hour (the latter criterion is controlling for larger packages). This limit was chosen to prevent fogging of undeveloped x-ray film during a 24-hour period with a 5 meters (15 feet) separation, 5 meters being chosen as the U.S. Railway Express Company's 1947 conventional separation distance between parcels containing radium and parcels containing undeveloped x-ray film. A package giving out 10 mrem/hour at 1 meter produces 11.5 mrem in 24 hours at 5 meters (Ref. 2-2).

The 200 mrem/hour surface dose rate limit was chosen on the basis that a transport worker carrying such packages held against his or her body for 30 minutes per day would not receive a dose exceeding 100 mrem per 8-hour working day, which was considered acceptable in 1947. Based on current national radiological exposure guidelines, the 200 mrem/hour surface dose rate limit is acceptable as long as the associated handling time is such that individual doses of handlers not treated as "occupationally exposed" are less than the currently accepted limit of 500 mrem/year (Ref.2-4).

An intermediate package category, "Category II - Yellow," includes packages with a surface dose rate not exceeding 50 mrem/hour and a dose rate at 3 feet from any external surface not exceeding 1.0 mrem/hour. Such packages require special handling but do not present the potential hazard of a Category III package. If a highway or rail vehicle carries a Category III package, it must placarded. A summary of the dose rate limits for each package category is given in Table 2-4.

TABLE 2-4

PACKAGE DOSE RATE LIMITS:
MAXIMUM ALLOWED DOSE RATE (MREM/HR)*

Category	Package Surface	3 Feet from Surface (TI)
I - White	0.5	-
II - Yellow	50	1.0
III - Yellow	200	10

*49 CFR 173.393(i)

Since a number of packages of radioactive material are often loaded onto a single transport vehicle that may also carry passengers (e.g., a passenger aircraft), a simple system had to be devised to enable transport workers to determine quickly how many packages could be loaded and how to segregate the packages from passengers and film. For this purpose, the radiation transport index (TI) was devised. This index was defined as the highest radiation dose rate in mrem/hour at 3 feet from any accessible external surface of the package, rounded up to the next highest tenth (see 49 CFR 173.389(i)(1)). For example, if the highest measured dose rate at 1 meter were 2.61 mrem/hour, the TI for that package would be 2.7. From Table 2-4 it would appear that no package with a TI greater than 10 may be transported.

However, the regulations (see 49 CFR 173.393(j)) do provide for transport of packages with dose rates exceeding those in Table 2-4 in a transport vehicle (except aircraft) that has been consigned as exclusive use, provided the following dose limits are not exceeded:

(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) 10 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.

When more than one package of radioactive material is loaded onto a transport vehicle, a total index for the shipment is obtained by summing the TIs for each individual package, a process requiring only the simple addition of numbers. The total TI for packages loaded onto a single transport vehicle may not exceed 50 (see 49 CFR 174.700(b), 49 CFR 175.75(a)(3), and 49 CFR 177.842(a)). There are two exceptions to this rule. One is for vehicles (other than aircraft) consigned for exclusive use (49 CFR 173.393(j)). The other is for transport by ship; in this case a total TI of 200 is permitted with the packages in single groups each having a total TI not greater than 50, and each such group located at least 20 feet (6.1 meters) from any other group (49 CFR 176.700). At least two cargo airlines are presently operating under special DOT permit to carry up to 200 TI, but all other aircraft are limited to 50 TI.

The regulations also provide tables of safe separation distances that must be maintained between stowed packages of radioactive material and persons or undeveloped film for various types of transport (see 49 CFR 174.700, "Special Handling Requirements for Radioactive Materials," for rail freight; 49 CFR 175.700, "Special Requirements for Radioactive Materials," for aircraft; 49 CFR 176.700, "General Stowage Requirements," for ships; and 49 CFR 177.842(b) for truck and other common, contract, or private carriers by public highway). It will be noticed from Table 2-4 that these requirements apply only to Categories II- and III-Yellow packages. Category I packages are not assigned a transport index.

All packages are expected to retain their shielding effectiveness during normal transport conditions. The external dose rate, or TI, measured by the shipper and written on the package label must not increase during transport, e.g., as a result of faulty shielding. After being subjected to the hypothetical accident conditions listed in Appendix B to 10 CFR Part 71, any reduction of shielding caused by damage to a Type B package must not increase the external dose rate to more than 1000 mrem per hour at 3 feet from the external surface of the package (see 10 CFR 71.36(a)(1)).

2.5 SPECIAL CONSIDERATION FOR FISSILE MATERIAL

The third basic safety requirement for transporting radioactive materials is the prevention of nuclear criticality for fissile materials. These are defined in 10 CFR 71.4(e) as U-233, U-235, Pu-238, Pu-239, and Pu-241.

The criticality standards for fissile material packages are found in 10 CFR 71.33, which states, in effect, that a package used to ship fissile material is to be so designed and constructed and the contents so limited that the package would be subcritical if water were to leak into the package or if any liquid contents of the package were to leak out. However, a sufficient number of certain types of packages of fissile material, even though each package is subcritical, could conceivably be grouped in such a way that the assembly becomes critical. The number of such packages that may be transported together is limited and depends on the package design and contents.

There are, however, some quantities, forms, or concentrations of fissile nuclides that cannot be made critical under any credible transport conditions. These are specified in 10 CFR

71.9, "Exemption for Fissile Material," and are exempted from the special requirements for fissile material shipments. They include, for example, packages containing natural thorium or natural uranium or less than 15 grams of fissile material.

The regulations prescribe three package classes called Fissile Class I, II, and III for shipments of fissile materials that do not qualify for exemption as defined above. Fissile Class I packages are considered safe from nuclear criticality by virtue of the package design and contents and may therefore be transported in unlimited numbers and in any arrangement so long as the total radiation TI limit is not exceeded. Each such packaging must be so designed that it is a net absorber of neutrons in both normal and accident environments. The specific standards for Fissile Class I packages are given in 10 CFR 71.38.

If a limited number of packages would be subcritical in any arrangement and in any foreseeable transport circumstances, they are in Fissile Class II. For purposes of nuclear criticality safety control, a special fissile transport index is assigned to such packages as follows:

$$\text{fissile TI} = 50/N \qquad (2\text{-}1)$$

where N is the number of similar packages that may be transported together as determined under the limitations of 10 CFR 71.39(a). This transport index cannot be less than 0.1 nor more than 10. Thus, a shipment of N packages would not result in an aggregate fissile transport index greater than 50. The actual transport index assigned to any fissile material package is always the greater of the fissile TI or the previously defined radiation TI (see 49 CFR 173.389(i)). Aside from the limit on the number of packages per shipment, Fissile Class II packages (like Fissile Class I) require no nuclear criticality safety control by the shipper.

Fissile Class III includes all packages of nonlimited fissile material that do not comply with the requirements of either Class I or Class II packages. Fissile Class III packages are those considered to be precluded from criticality under all foreseeable circumstances of transport by reason of special precautions or special administrative or operational controls imposed on the transport of the consignment (Ref. 2-2). Special arrangements between the shipper and the carrier are required to provide nuclear criticality safety. The specific standards for such shipments are given in 10 CFR 71.40. International shipments of Fissile Class III packages require multilateral competent authority approval (Ref. 2-2).

Because of plutonium's toxicity, special additional requirements are imposed on its shipments. There is currently a ban on shipments of plutonium by aircraft (Ref. 2-5). The requirements of 10 CFR 71.42 apply to plutonium shipments after June 17, 1978, and stipulate that plutonium in excess of 20 curies per package must be shipped as a solid and must be packaged in a separate inner container. Exempted from this requirement is solid plutonium in the form of reactor fuel elements, metal, and metal alloy.

DOT packaging requirements for the shipment of fissile materials are given in 49 CFR 173.396, "Fissile Radioactive Material." This section specifies certain existing approved packagings for fissile materials and the authorized contents for each. Any other packaging design that is approved by NRC is accepted by DOT for fissile material shipments (see 49 CFR

173.396(b)(4) and 49 CFR 173.396(c)(3)). Since fissile material quantities are usually given in grams or kilograms, one cannot use Table 2-1 directly to determine which quantity classification applies to a given amount of a particular fissile isotope. The quantity limits in grams for Type A and Type B packages of some of the more important fissile materials are listed in Table 2-5. These were calculated from the data in Table 2-1 and the respective specific activities, taking into account the transport group assigned to each isotope. It is apparent from the table that a package containing, for example, only 2 grams of Pu-238 would be classified as a "large quantity," i.e., greater than the Type B limit, whereas a package containing 100 kg of 3 percent enriched uranium would be classified as a Type A quantity, because of the amount of radioactivity in each case.

2.6 PROCEDURES TO BE FOLLOWED BY THE RECEIVER

The standards discussed so far have been applicable to the shipper of radioisotopes and pertain primarily to packaging of the material in such a way that the transport occurs safely. The NRC standards of 10 CFR 20.205, "Procedures for Picking Up, Receiving, and Opening Packages" (Appendix B to this document), outline the procedures for picking up, receiving, and opening the packages and apply to the licensee who is to receive the package. These standards point out the responsibility of the receiver to:

1. Make arrangements with the carrier to receive the package or to receive notification of the arrival of the package at the carrier's terminal (in the latter case, the receiver is to pick up the package expeditiously from the terminal).

2. Monitor the external surfaces of the package for radioactive contamination caused by possible leakage of the radioactive contents and monitor the radiation levels on and at 3 feet from the external package surfaces. This monitoring must be performed no later than three hours after receipt of the package if received during normal working hours, or in any case, within eighteen hours.

3. Notify, by telephone and telegraph, both the final delivering carrier and the appropriate NRC Inspection and Enforcement Regional Office if the monitoring reveals:

   a. Removable radioactive contamination in excess of 0.01 microcuries per 100 square centimeters of package surface;

   b. Radiation levels on the external package surface in excess of 200 millirems per hour; or

   c. Radiation levels at 3 feet from an external package surface in excess of 10 millirems per hour.

4. Establish and maintain procedures for safely opening packages in which licensed material is received, and ensure that those procedures are followed, giving due consideration to special instructions for the type of package being opened. Exemptions from the requirements for monitoring external surfaces for contamination are provided in 10 CFR 20.205(b) for special-

TABLE 2-5

TYPE A AND TYPE B QUANTITY LIMITS IN GRAMS FOR CERTAIN FISSILE MATERIALS

Element	Specific Activity (Ci/gm [6])	Transport Group	Maximum Content (grams)* Type A	Type B
U-235	2.1×10^{-6}	III	1.4×10^{6}	9.5×10^{7}
U-238 (or depleted uranium)	3.3×10^{-7}	III	9.1×10^{6}	6.1×10^{8}
Uranium (average enrichment - 3% U-235)	3.86×10^{-7}	III	7.8×10^{6}	5.2×10^{8}
Uranium (natural - .711% U-235)	3.45×10^{-7}	III	8.7×10^{6}	5.8×10^{8}
U-233	9.5×10^{-3}	II	5.3	2100
Pu-238	17.4	I	5.7×10^{-5}	1.1
Pu-239	6.1×10^{-2}	I	1.6×10^{-2}	326
Pu-240	.23	I	4.3×10^{-3}	86
Pu-241 (+ daughters)	112	I	8.9×10^{-6}	0.18
Pu-242	3.9×10^{-3}	I	0.26	5200
Am-241 (+ Np-237)	3.24	I	3.1×10^{-4}	6.2
Am-243 (+ daughters)	.19	I	5.3×10^{-3}	106
Cf-252	536	I	1.9×10^{-6}	.038

*Greater quantities must be shipped in packages approved for large quantities.

form materials and gases, Type A packages containing only radioactive material in other than liquid form, packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries, all packages containing only limited quantities, and packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, C-14, S-35, or I-125.

2.7 LABELING OF PACKAGES

Each package containing more than limited quantities of radioactive material must be labeled on two opposite sides with one of three warning labels as described in 49 CFR 172.436, "Radioactive White - I Label"; 172.438, "Radioactive Yellow - II Labels"; and 172.440, "Radioactive Yellow - III Label." The labeling requirements are given in 49 CFR 172.403, "Radioactive Material."

All three label types contain the distinctive trefoil symbol and either one, two, or three vertical stripes. The one-striped label has a white background and is placed on a Category I - White package. A label with a bright yellow upper half and a white lower half is marked with either two or three vertical stripes and indicates a significant radiation level outside the package. The two-stripe label is placed on a Category II - Yellow package, and the three-stripe label is placed on a Category III - Yellow package. The radioactive White - I label may not be used for Fissile Class II packages (49 CFR 172.403(b)(1)). Each Fissile Class III package, each package containing a "large quantity" of radioactive material, and certain other types of packages must bear a Radioactive - Yellow III label (49 CFR 172.403(d)). The label must show the isotope contained in the package, the number of curies, and the transport index (except for the White - I label). In addition, each package weighing more than 50 kg (110 pounds) must have its gross weight marked on the outside of the package (49 CFR 172.310(a)(1)). Type A or Type B packaging must be plainly marked with the words "Type A" or "Type B," respectively. Packages destined for export shipment must also be marked "USA" (49 CFR 172.310(a)(3)).

2.8 REQUIREMENTS PERTAINING TO THE CARRIER - VEHICLE PLACARDING AND STOWAGE

DOT imposes certain regulations on the carrier for radioactive materials transport. These include vehicle placarding, examination of shipper certification papers and packages for proper marking and labeling, and proper loading and stowage of the packages aboard the transport vehicle. Appropriate placards must be displayed on the front and rear and on each side of rail or highway vehicles carrying packages bearing the Radioactive - Yellow - III label. The regulations regarding placarding are given in 49 CFR 172.504, "General Placarding Requirements."

In addition to placarding his vehicle as required, the carrier has the responsibility of ensuring that the articles offered for transport have been certified by the shipper to be properly classified, described, packaged, marked, labeled, and in proper condition for transportation.

For normal-form materials, the shipping papers must include the transport group or groups of the radionuclides, the names of the radionuclides in the material, and a description of their physical and chemical form. For all radioactive material, the activity of the material in curies and the type of radioactive label applied must also be listed. In addition, for fissile materials, the fissile class must be given with an additional warning statement as described in 49 CFR 172.203(d).

For shipments by aircraft, the operator of the aircraft (e.g., an airline official) must inform the pilot-in-command of the name, classification, and location of the radioactive material on the aircraft per 49 CFR 175.33, "Notification of Pilot-in-Command." In addition, for passenger-carrying aircraft there must be a clear and visible statement accompanying the shipment, signed or stamped by the shipper or his agent, stating that the shipment contains radioactive materials intended for use in, or incident to, research, medical diagnosis, or medical treatment (49 CFR 172.204(c)(4)).

The carrier is also required to make sure that the maximum allowable TI is not exceeded and that the packages are not transported or stored in groups having a total TI greater than 50. He must also ensure that such groups of yellow-labeled packages are separated by the required distances from areas continually occupied by persons, from film, and from shipments of animals. Further, he must ensure that a Fissile Class III shipment is not transported on the same vehicle with other fissile material and is segregated by at least 20 feet (6.1 meters) from other radioactive material packages in storage. The pertinent regulations are found in 49 CFR 174.700(d), 175.710, 176.700(d), and 177.842(f).

There are special requirements for stowage of packages of radioactive material bearing Radioactive - Yellow - II or Yellow - III labels aboard vehicles. For a vehicle loaded with the maximum allowable radioactive package load of 50 TI, a minimum distance of 2.1 meters must be maintained between the package and a space continuously occupied by people. In practice, radioactive packages are usually placed as far to the rear of the aft cargo hold as possible in passenger aircraft.

2.9 REPORTING OF INCIDENTS AND SUSPECTED CONTAMINATION

If death, injury, fire, breakage, spillage, or suspected radioactive contamination occurs as a direct result of hazardous materials transportation, the regulations (49 CFR 171.15, "Immediate Notice of Certain Hazardous Materials Incidents") require immediate notification to DOT and the shipper. The carrier must submit within 15 days of the date of discovery of such an occurrence a "detailed hazardous materials incident report" (49 CFR 171.16, "Detailed Hazardous Materials Incident Reports"). The vehicles, buildings, areas, or equipment in which a spillage of radioactive materials has occurred may not be used again until the radiation dose rate at any accessible surface is less than 0.5 mrem/hour and there is no significant removable surface contamination. The carrier can obtain technical assistance in radiation monitoring following an incident or accident by calling one of the ERDA or NRC Regional Offices for radiological assistance.

The level above which removable radioactive contamination is considered "significant" depends on the contaminating nuclide and is specified in 49 CFR 173.397(a). This section also prescribes a method for assessing the surface contamination of a package. For radioactive material packages consigned for shipment on exclusive-use vehicles (49 CFR 173.389(o)), the "significant" levels of surface contamination are 10 times as great as for packages transported on non-exclusive-use vehicles (49 CFR 173.397(b)). Exclusive-use transport vehicles must be surveyed with appropriate radiation detection instruments after each use and may not be returned to service until the radiation dose rate at any accessible surface is 0.5 mrem/hour or less and there is no significant removable radioactive surface contamination (49 CFR 173.397(c)).

2.10 REQUIREMENTS FOR SAFEGUARDING OF CERTAIN SPECIAL NUCLEAR MATERIAL

Certain strategic quantities and types of special nuclear material (SNM) require physical protection against theft and sabotage both at fixed sites and during transit because of their potential for use in a nuclear explosive device. The NRC standards for physical protection of materials while in transit are found in 10 CFR 73.30 - 10 CFR 73.36, which make up a subchapter entitled, "Physical Protection of Special Nuclear Material in Transit." They apply to any person licensed pursuant to the regulations in 10 CFR 70 who imports, exports, transports, delivers to a carrier for transport in a single shipment, or takes delivery of a single shipment free on board (f.o.b.) at the point where it is delivered to a carrier, any one of the following:

1. 5000 grams or more of U-235 contained in uranium enriched in the U-235 isotope to 20 percent of more,

2. 2000 grams or more of U-233,

3. 2000 grams or more of plutonium, or

4. Any combination of these materials in the amount of 5000 grams or more computed by the formula:

$$\text{grams} = (\text{grams contained U-235}) + 2.5\,(\text{grams U-233} + \text{grams plutonium}).$$

The standards also apply to air shipments of SNM in quantities exceeding:

1. 20 grams or 20 curies (whichever is less) of plutonium or U-233 or

2. 350 grams of U-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope).

Quantities and types of SNM that require safeguarding are often referred to as "strategic special nuclear material," or "SSNM." A licensee is exempt from these requirements for shipments of (see 10 CFR 73.6, "Exemptions for Certain Quantities and Kinds of Special Nuclear Material"):

1. Uranium enriched to less than 20 percent in the U-235 isotope,

2. SNM that is not readily separable from other radioactive material and that has a total external radiation dose rate in excess of 100 rems per hour at a distance of 3 feet from any accessible surface without intervening shielding (e.g., irradiated fuel), and

3. SNM in a quantity not exceeding 350 grams of U-235, U-233, plutonium, or a combination thereof, possessed in any analytical research, quality control, metallurgical, or electronic laboratory.

The general requirements for physical protection of SSNM while in transit are found in 10 CFR 73.30, "General Requirements" (Appendix B to this document), and are concerned with the following:

1. The necessity for the shipper to make prior arrangements with the carrier for physical protection of the SSNM, including exchange of hand-to-hand receipts at origin, destination, and transfer points.

2. The minimizing of transit time and avoidance of areas of natural disaster or civil disorder (does not apply to the air shipments described earlier).

3. The required use of tamper-indicating type seals and locking of containers for specified contents. No container weighing 500 pounds or less can be shipped in open trucks, railroad flat cars, or box cars and ships.

4. The use and qualification of guards.

5. The outlining of procedures to be followed by the licensee.

6. The provision for approval of special procedures not found in the standards.

Specific standards for safeguarding shipments of SSNM by road are given in 10 CFR 73.31, "Shipment by Road." The basic requirements of this paragraph are as follows:

1. No scheduled intermediate stops are allowed.

2. Vehicles used to transport SSNM are to be equipped with radiotelephones, and contact with the licensee or agent is to be made, in most cases, every two hours.

3. Two people are to accompany the shipment in the vehicle containing the shipment. In addition, either an armed escort consisting of at least two guards in a separate vehicle shall accompany the shipment (in this case only one driver is required in the vehicle containing the SSNM for shipments lasting less than one hour) or a specially designed truck or trailer that reduces the vulnerability to diversion shall be used.

4. The vehicles are to be marked on top with identifying letters, to permit identification in daylight and clear weather at 1000 feet above ground level, and also on the sides and rear of the vehicle.

Standards for safeguarding shipments of SSNM by <u>air</u> are discussed in 10 CFR 73.32, "Shipment by Air":

1. Shipments by passenger aircraft* of plutonium or U-233 in quantities exceeding 20 curies or 20 grams (whichever is less) or 350 grams of U-235 contained in uranium enriched to 20 percent or more in the U-235 isotope must be specifically approved by the NRC.

2. Transfers are to be minimized.

3. Export shipments are to be escorted by an unarmed authorized individual from the last terminal in the United States until the shipment is unloaded at a foreign terminal.

The regulations of 10 CFR 73.33, "Shipment by Rail," provide that, for safeguarding shipments by <u>rail</u>, an escort by two guards is required (guards are, by definition, uniformed and armed - see 10 CFR 73.2(c)). The guards ride either in the shipment car or in an escort car from which they can keep the shipment car under observation. Radiotelephone contact with the licensee or his agent is to be made at specific intervals.

The regulations for safeguarding shipments of SSNM by <u>sea</u>, given in 10 CFR 73.34, "Shipment by Sea," provide that:

1. Shipments shall be made on vessels making minimum ports of call and with no scheduled transfers to other ships.

2. The shipment is to be placed in a secure compartment that is locked and sealed.

3. Export shipments shall be escorted by an unarmed authorized individual from the last port in the United States until the shipment is unloaded at a foreign port.

4. Ship-to-shore contact is to be made every 24 hours, and the information regarding position and status of the shipment is to be sent to the licensee or his agent who arranges for the protection of the shipment.

The necessary <u>transfers</u> of SSNM during a shipment must be monitored by a guard. These monitoring procedures are outlined in 10 CFR 73.35, "Transfer of Special Nuclear Material":

1. At a scheduled intermediate stop where the SSNM is not to be unloaded, the guard is to observe the opening of the cargo compartment, maintaining continuous visual surveillance of it until the vehicle departs. Then the guard must immediately notify the licensee or his agent of the latest status.

2. At points where SSNM transfers occur, the guard is to keep the shipment under continuous visual surveillance, observe the opening of the cargo compartment for an incoming vehicle,

*Note that 49 CFR 175 prohibits these shipments unless the materials are intended for medical or research use, and Public Law 94-79 prohibits NRC approval of shipments by air in uncertified packages of any licensed plutonium other than that contained in specified medical devices.

and ensure that the shipment is complete by checking locks and/or seals. Continuous visual surveillance is also to be maintained when the shipment is in the terminal or in storage. Immediately after a vehicle carrying SSNM has departed, the guard must notify the licensee or his agent of the latest status.

3. The guard is to report immediately to the carrier and the licensee who arranged for the protection of the SSNM any deviations or attempted interference.

Finally, 10 CFR 73.36, "Miscellaneous Requirements," contains miscellaneous safeguarding requirements for licensees who ship, receive, export, or import SSNM. The basic features of these requirements are as follows:

1. If a licensee agrees to take delivery of an f.o.b. shipment of SSNM, the licensee, rather than the shipper, arranges for the protection of the shipment while it is in transit.

2. A licensee who imports SSNM must ensure that the shipment is not diverted in transit between the first point of arrival in the United States and delivery to the licensee.

3. The licensee who delivers SSNM to a carrier for transport must, at the time of departure of the shipment, notify the consignee of the methods of transportation, the names of the carriers, and the estimated arrival time. The licensee must also arrange to be notified by the consignee immediately upon arrival of the shipment.

4. The licensee who exports SSNM must comply with this regulation for transport to the first point outside the United States at which the shipment is removed from the vehicle.

5. A licensee who receives a shipment of SSNM is to notify the shipper immediately upon arrival of the shipment at its destination.

6. If a shipment of SSNM is lost or unaccounted for after the estimated arrival time, the licensee who arranged for safeguarding the shipment shall immediately conduct a trace investigation and file a report with the NRC as specified in 10 CFR 73.71, "Reports of Unaccounted For Shipments, Suspected Theft, Unlawful Diversion, or Industrial Sabotage."

The application of the above requirements and additional measures required as license conditions (10 CFR 70.32(b)) are discussed in Chapter 7.

REFERENCES

2-1. International Atomic Energy Agency, A Basic Toxicity Classification of Radionuclides, Technical Report Series No. 15, IAEA, Vienna, 1963.

2-2. A. Fairbairn, The Development of the IAEA Regulations for the Safe Transport of Radioactive Materials, Atomic Energy Review, Vol. 11, No. 4, IAEA, Vienna, 1973.

2-3. Docket No. HM-111, Federal Register, Vol. 39, No. 252, December 31, 1974.

2-4. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection," ICRP Publication 9, Pergammon Press, Oxford, 1966.

2-5. Public Law 94-79 (S.1716).

CHAPTER 3
RADIOLOGICAL EFFECTS

3.1 RADIATION

Radiation is emitted as a result of radioactive nuclides undergoing spontaneous decay. During the decay process, these nuclides emit characteristic particles or electromagnetic radiation and are thereby transformed into either completely different nuclei or more stable forms of the same nuclei. The nuclide that results from this emission may also be radioactive, depending on the relative stability achieved by the nucleus via decay (Ref. 3-1). From a radiological health viewpoint, three of the most important types of radiation are charged particles, neutrons, and electromagnetic radiation.

3.1.1 CHARGED PARTICLES

Charged particles such as beta and alpha particles undergo strong Coulomb interactions with matter. These interactions rapidly diminish the energy of the charged particles and therefore limit their travel to short distances. An alpha particle with 5 million electron volts (MeV) of energy, for example, will travel about 3.1 cm in dry air and 0.004 cm in tissue (Refs. 3-2 and 3-3).

3.1.2 NEUTRONS

Radiation dose from neutrons is a strong function of particle energy. Fast neutrons interact with matter primarily through scattering collisions with nuclei. About one-half the neutrons with energies near 1 MeV are absorbed after passage through 9.25 cm of water (Ref. 3-3). "Thermal" or low-energy neutrons have a higher probability of absorption by matter. They are captured by some nuclei in a process that is often accompanied by subsequent radiation or fission.

3.1.3 ELECTROMAGNETIC RADIATION

X-rays and gamma rays lose energy as a result of the photoelectric effect, Compton scattering, and pair production. Since these processes are less probable than the Coulomb interactions characteristic of charged particles, the range of electromagnetic radiation is much greater than that of alpha or beta particles of comparable energy. One-MeV gamma radiation will travel about 7 cm in water before half of the initial incident photons are absorbed (Ref. 3-3).

3.2 DOSE

Radiation exposure may be measured in terms of its ionizing effect or in terms of the energy absorbed per unit mass of exposed material. Historically, radiation exposure for x- and gamma radiation was measured in units of roentgens (the amount of radiation required to produce one electrostatic unit (esu) of charge from either part of an ion pair in 1 cm^3 of dry air). It can be shown that 1 roentgen is equivalent to energy deposition of 88 ergs in 1 gram of dry air (Ref. 3-4). A modern and more useful method for quantifying radiation interaction is in terms of the energy absorbed per unit mass. One radiation absorbed dose (rad) unit equals 100 ergs per gram of absorbing material.

Since biological effects of radiation have been found to depend on both the energy deposited and the spatial distribution of the deposition, it was found convenient to define the relative biological effectiveness (RBE) as

$$\text{RBE} = \frac{\text{Dose of 220-250 keV x-rays for a given effect}}{\text{Dose of the radiation in question for the same effect}} \tag{3-1}$$

where a particular biological effect is considered (Ref. 3-5). In an attempt to devise a unit that would provide a better criterion of biological injury when applied to different radiations, a biological dose unit, the Roentgen Equivalent Man (rem), is defined by

$$\text{Dose equivalent in rem} = \text{RBE} \times \text{absorbed dose in rad} \tag{3-2}$$

Since RBE will depend on effect studied, dose, dose rate, physiological condition, and other factors, the quality factor (QF) is defined to be the upper limit for the most important effect due to the radiation in question. The biological effect of 1 rem of radiation will be equivalent for all types and energies of radiations; radiation doses in rem are thus additive, independent of radiation nature. Table 3-1 lists QFs for various types of radiation.

TABLE 3-1

QUALITY FACTORS FOR VARIOUS TYPES OF RADIATION
(Refs. 3-6, 3-7, and 3-8)

Radiation	Range of Quality Factor	Typical Value
x-ray, γ-ray	1.0	1
Beta particles, electrons	1.0 - 1.7	1
Fast neutrons	5.0 - 11.0	10
Slow (thermal) neutrons	2.0 - 5.0	3
Alpha particles	1.0 - 20.0	10
Protons	1.0 - 10.0	10
Heavy ions, fission fragments	20.0	20

Radiation from sources external to the body is usually only harmful to humans when in the form of neutrons, x-rays, or gamma rays, since alpha and beta particles are typically stopped by the skin.* However, any source of radiation incorporated into the body is potentially hazardous. The large QF assigned to alpha particles, for example, indicates that they may be especially

*Extremely energetic beta radiation can penetrate the outer layers of skin and damage the more sensitive inner layers.

hazardous internally where they can deposit a large quantity of energy in a small amount of potentially more sensitive internal body tissue.

The radiosensitivities of different life forms differ considerably. In general, higher life forms are more sensitive to radiation than lower forms, although in some specific cases this is not true (Ref. 3-5). Table 3-2 shows the dose response for a range of life forms. Throughout this report, the radiological impact to man will be the only one quantitatively evaluated. This perspective is taken because of the generally higher sensitivity of man to radiation and because the societal impacts of doses to human beings are generally considered to be more significant than the impact due to irradiation of lower life forms.

3.3 BACKGROUND SOURCES OF EXPOSURE

Natural background radiation, originating primarily from cosmic rays and terrestrial gamma emitters, constitutes the most significant source of radiation exposure to the general population. The dose from background sources will vary with altitude, latitude, and differences in the radioactive material content of the soil, building materials, etc. The variation in cosmic radiation with altitude, for example, is shown in Figure 3-1. At low altitudes, the charged particle component (both solar and galactic) is essentially constant with latitude. However, depending on the altitude of the recipient, the neutron component varies as much as a factor of 3 from 41°N to 90°N (Ref. 3-9). Consequently, the individual dose from these sources will vary considerably with location. For example, a person in Louisiana or Texas will receive about one-half the annual dose received by a person in Colorado or Wyoming (Ref. 3-10).

Both internal and external exposure to all persons results from the presence of naturally occurring radioactive material in the soil, air, water, vegetation, and even the human body. The doses received by various organs from these sources can differ widely depending on the type of soil, house construction material, diet, etc. An average annual individual whole-body equivalent dose* of 102 mrem is received from natural background exposure (cosmic rays and internal and external terrestrial sources) (Ref. 3-10). Since the U.S. population was about 220 x 10^6 persons in 1975, the total annual natural background population dose is 22.4 x 10^6 person-rem.

Radiation exposure to the public also occurs in medical and dental applications of radiation sources. A large component of this dose results from diagnostic use of medical and dental x-rays (15.8 person-rem). A smaller, but increasing, population dose results from the use of radiopharmaceuticals (0.2 person-rem).

Fallout from atmospheric weapon testing by the U.S., U.S.S.R., U.K., China, and France is estimated to result in an average annual individual dose of 4 mrem (Ref. 3-10), contributing 9 x 10^5 person-rem in 1975.

Nuclear power, including fuel reprocessing and power reactor operation, is expected to result in an average annual dose of approximately 0.4 mrem to individuals in the general population in the year 2000 (Ref. 3-11), corresponding to an annual population dose of 9 x 10^4 person-rem.

*Whole-body dose is defined in paragraph 20.101(b)(3) of 10 CFR Part 20, "Standards for Protection Against Radiation," as dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of the eye.

TABLE 3-2

APPROXIMATE RADIOSENSITIVITY OF VARIOUS LIFE FORMS TO EXTERNAL RADIATION (Ref. 3-5)

Life Form	Biological Effects	Necessary Dose
Plant Life	Growth Impairments	2,000 - 70,000 R
Arthropods	Death	1,000 - 100,000 R
Insect Pupae and Larvae	Death	200 - 2,000 R
Fish, Amphibia, Reptiles	Death	1,000 - 2,000 R
Mammals (general)	Death (LD 50/30)*	300 - 800 R
Hamsters	Death (LD 50/30)*	800 R
Mouse	Death (LD 50/30)*	600 R
Man	Death (LD 50/30)*	300 - 600 R

*Lethal dose to 50 percent of the exposed population within 30 days.

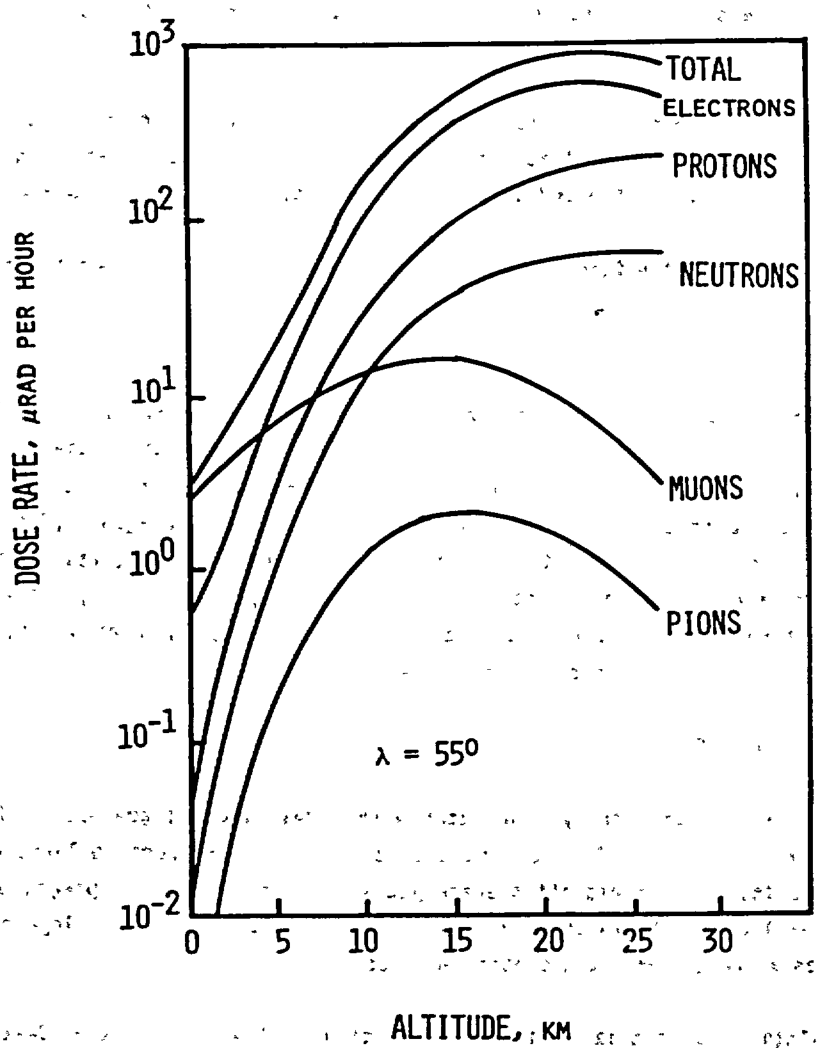


FIGURE 3-1. VARIATION OF GALACTIC RADIATION* DOSE RATES WITH ALTITUDE AT GEOMAGNETIC LATITUDE (λ) OF 55° (Ref. 3-9).

*Galactic radiation is primarily energetic alpha particles, protons, and some heavy nuclei derived from sources other than the sun. Solar radiation consists mainly of protons and heavier nuclei emitted from solar flares and also associated with sunspots (Ref. 3-9).

The occupational dose received by Federal radiation workers, naval nuclear propulsion program personnel, power reactor employees, nuclear fuel cycle service personnel, etc., accounts for an accumulated annual dose of 2×10^5 person-rem, for an average per capita dose of 0.8 mrem (Ref. 3-10).

Additional exposure results from color television sets, commercial air travel, and various consumer products using radium or other radioactive materials. The estimated annual individual dose from these causes is approximately 2 mrem for an accumulated dose of 4×10^5 person-rem.

Background radiation doses and the integrated population doses are summarized in Table 3-3.

3.4 HAZARDS FROM RADIATION

The effects of radiation upon the body are a manifestation of the localized deposition of electromagnetic or kinetic energy in the atoms along the path traveled by the radiation. The ionizations and excitations caused by this deposition can directly or indirectly alter both the chemical composition and the chemical equilibrium within the cells along the path (Ref. 3-5). The effects of the radiation may be undetectable, or they may manifest themselves as acute physiological changes, carcinogenesis, or genetic effects, depending on the amount and type of incident radiation, the type of cells irradiated, and the time span over which irradiation occurs. Each of these effects will be discussed briefly below.

3.4.1 ACUTE PHYSIOLOGICAL CHANGES

Acute physiological changes are normally associated with relatively large absorbed doses received over a short period of time. Data on these effects in man are derived largely from Japanese atomic bomb casualties, some radiation therapy patients, and a few recipients of high acute doses from industrial accidents in the early days of the nuclear weapon development programs. Table 3-4 summarizes acute whole-body radiation effects in man.

If the acute irradiation is localized in a specific region of the body, the effects can vary widely because of variations in cell sensitivity to radiation. The reproductive organs are among the more sensitive. Radiation doses to males beginning above 10 rads and extending to 600 rads produce a decrease in, or absence of, sperm beginning 6 to 7 weeks after exposure and continuing for a few months to several years, after which time there is full recovery. The extent of sperm count decrease and the rate of recovery are related to the magnitude of the dose (Ref. 3-13). On the other hand, organs such as kidneys, lungs, stomach, bladder, and rectum may be able to withstand acute doses of several thousand rads before substantial damage occurs (Ref. 3-7).

3.4.2 CARCINOGENESIS

Fatal cancers account for approximately 20 percent of all deaths in the U.S. (Ref. 3-14). These cancers are divided into three broad groups: carcinomas, sarcomas, and leukemias or lymphomas. Within these groups, there are 100 or so distinct varieties of disease based on the

TABLE 3-3

ESTIMATES OF ANNUAL WHOLE-BODY DOSES
IN THE UNITED STATES
(Refs. 3-10, 3-11, and 3-12)

Source	Average Annual Dose* (mrem)	Integrated Annual Population Dose** (10^6 person-rem)
Cosmic rays	44	9.7
Terrestrial Radiation		
External	40	8.8
Internal	18	4.0
Fallout	4	0.9
Nuclear Power	0.4***	.09
Medical/Dental		
Diagnostic x-rays	72†	15.8
Radiopharmaceuticals	1	0.2
Occupational	0.8	0.2
Miscellaneous	2	0.4
Total		40

*The numbers shown are average values only. For given segments of the population, doses considerably greater than these may be experienced.

**Based on U.S. population of 220 x 10^6.

***Estimate for the year 2000.

†Based on the abdominal dose.

TABLE 3-4

DOSE-EFFECT RELATIONSHIPS IN MAN FOR
ACUTE WHOLE-BODY GAMMA IRRADIATION
(Refs. 3-7 and 3-13)

Dose (rads)	Nature of Effect
5-25	Minimum detectable dose by chromosome analysis or other specialized tests.
50-75	Minimum acute dose readily detectable in a specific individual.
75-125	Minimum acute dose likely to produce vomiting in about 10 percent of people so exposed.
150-200	Acute dose likely to produce transient disability and obvious blood changes in a majority of people exposed.
~340	Median lethal dose for single short exposure with no medical treatment (Ref. 3-13).
~510	Median lethal dose for single short exposure with supportive medical treatment (barrier nursing, antibiotics, transfusions) (Ref. 3-13).
~1050	Median lethal dose for single short exposure with heroic medical treatment (bone marrow transplants, etc.) (Ref. 3-13).

original site of the malignancy. The specific fatality and man-year losses in the United States due to the principal types of cancer are shown in Table 3-5.

There are many theories of carcinogenesis, but most researchers acknowledge that a statistical correlation can be established between certain environmental factors and cancer induction. Examples of these correlations include the correlation of smoking to lung cancer and that of radiation dose to leukemia among atomic bomb survivors. The correlation between exposure to radiation and cancer induction has been qualitatively established for animal exposures and is widely accepted for human exposures (Ref. 3-15), although the physiological mechanisms involved are not well understood. Statistical analysis of large numbers of exposed persons such as Japanese atomic bomb survivors, uranium miners, fluorspar miners, radium dial painters (Ref. 3-11) permits rough predictions of latent cancer fatalities per million person-rem of population dose. These values, modified to account for the distribution of ages within the general population (Ref. 3-13), are used in the health-effects model for this assessment (discussed in Section 3.7 of this chapter).

3.4.3 GENETIC EFFECTS

The genetic material (DNA) is organized into linear sequences (chromosomes) of large numbers of protein groupings (genes). Changing the chemical nature or location of one or more of the protein molecules within a gene will change the genetic information carried by the chromosome and, hence, the genetic information used to "construct" cells in any offspring. Changes that result from such modifications of the genetic coding are called gene mutations. In extreme cases where there are gross changes in the number or overall composition of entire chromosomes, the mutations are called chromosomal aberrations (Ref. 3-13).

Whatever their origin, mutations are frequently detrimental, and every individual appears to carry a "load" of defective genes which collectively tends to reduce his overall fitness to some degree (Ref. 3-7). During the evolutionary past, an equilibrium between mutation rates and natural selection against detrimental genes and in favor of favorable genes has been established for each species (Ref. 3-7). Concern has arisen because of the laboratory work that has shown radiation to be mutagenic in lower life forms such as Drosophila (fruit flies) and various species of mice. These data have been extrapolated to dose-effect relationships (Refs. 3-3, 3-7, and 3-11) in man, although this extrapolation is a tenuous and possibly inaccurate procedure. There is positive evidence of induction of chromosomal aberrations by radiation in human lymphocytes. However, several detailed investigations of children of Japanese atomic bomb survivors have not shown significant increase in mutation incidence (Ref. 3-17).

3.5 RADIATION STANDARDS

As a result of early injuries and deaths from exposure to various sources of radiation, international efforts were organized during the early 1920's to establish standards for radiation protection. In 1928, the International Committee (now Commission) on Radiation Protection (ICRP) was created. In the United States, the Advisory Committee on X-ray and Radium Protection, later to become the National Council on Radiation Protection and Measurements (NCRP), was organized in 1929. More recently the Federal Government entered the field of radiation protection

TABLE 3-5

EFFECTS OF CANCERS IN THE UNITED STATES

(Refs. 3-14 and 3-16)

Type of Cancer	Annual Deaths	(%)	Annual Man-years of working life lost	(%)
lung	65,000	19	287,000	16
large intestine	46,000	14	141,000	8
breast	30,000	9	208,000	12
pancreas	18,000	5	unknown	—
prostate	17,000	5	unknown	—
stomach	16,000	5	unknown	—
leukemia	14,000	4	176,000	10
brain	6,000	2	117,000	7
lymphoma	11,000	3	114,000	7
other cancers	113,000	34	701,000	40
TOTAL	336,000	100	1,744.000	100

through the Federal Radiation Council (FRC), whose functions were transferred to the Environmental Protection Agency (EPA) in 1970. The dose limits proposed by NCRP, recommended as guidance for Federal agencies by FRC, and adopted for that purpose by the President of the United States on May 13, 1960, are tabulated in Table 3-6. It can be noted from this table that the recommended population dose limitation, for example, is 0.17 rem average whole-body dose per person per year. This value represents exposure from all sources except natural background radiation and medical procedures. In addition, the EPA in the Federal Register has proposed standards for exposure during normal uranium fuel cycle operations (see 40 FR 23420).

A maximum permissible concentration (MPC) in air or water may often be stated for a given radionuclide. This is the maximum concentration in air or drinking water to which a person might be chronically exposed internally without exceeding the recommended dose limitations to a specified critical organ. It should be noted that the levels in Table 3-6 were suggested as upper limits, with the understanding that radiation exposure is to be kept as low as is reasonably achievable. The recommended limiting levels (given in 10 CFR Part 20 and 40 FR 23420) are substantially below the level where harmful effects have been observed in humans.

3.6 COST-BENEFIT

There is a certain amount of statistical risk involved with any level of exposure to radiation. In line with other activities and needs of society, one must compare the benefits gained from the use of radioactive substances with the possible risks entailed. For example, people continue to use medical x-rays and radiopharmaceuticals that may help discover a developing tumor in spite of the potential for other cell damage produced by the radiation (Ref. 3-18). Similarly, few people are likely to change their location to reduce background dose, although this background can differ between certain states by as much as 100 mrem per year. In short, benefits outweighing the prospective costs are usually expected from certain uses of radioactive substances, just as from many other hazardous materials. In Table 3-7, the risk of fatal cancer or life-span shortening from radiation is compared to estimates of other risks commonly accepted in our society.

3.7 HEALTH-EFFECTS MODEL

The health-effects model used in this assessment is based on the more detailed model developed in Appendix VI to WASH-1400 (Ref. 3-13), although the complete methodology was not used. The simplifications discussed below were used to make the more detailed reactor accident analysis applicable to the transportation situation.

Potential dosage sources were first subdivided into external penetrating radiation sources (principally from normal transport as discussed in Chapter 4) and internal radiation sources (principally from inhalation following accidents as discussed in Chapter 5).

External penetrating radiation presents a whole-body exposure problem from photons and neutrons with each organ receiving similar dosages. Internal dose effects are dependent on the biological pathway taken by the specific radionuclide in the body. In order to specify this pathway, the chemical nature of the material, in particular whether it is soluble or insoluble,

TABLE 3-6

NCRP DOSE-LIMITING RECOMMENDATIONS

(Ref. 3-7)

Combined Whole-Body Occupational Exposure	
Prospective annual limit	5 rem in any one year (3/quarter)
Retrospective annual limit	10-15 rem in any one year
Long-term accumulation to age N years	(N-18) x 5 rem
Skin	15 rem in any one year
Forearms	30 rem in any one year (10/quarter)
Other organs, tissues, and organ systems	15 rem in any one year (5/quarter)
Pregnant women (with respect to fetus)	0.5 rem in gestation period
Dose Limits for the Public or Occasionally Exposed Individuals	0.5 rem in any one year
Population Dose Limits	
Genetic	0.17 rem average/year
Somatic	0.17 rem average/year
Emergency Dose Limits - Life Saving	
Individual (older than 45 yrs., if possible)	100 rem
Hands and forearms	200 rem, additional (300 rem, total)
Emergency Dose Limits - Less Urgent	
Individual	25 rem
Hands and forearms	100 rem, total

TABLE 3-7

COST IN DAYS OF LIFE ASSOCIATED WITH VARIOUS ACTIVITIES (Ref. 3-19)

Activity	Cost in Days of Life
Living in city (rather than in country)	1800
Remaining unmarried	1800
Smoking 1 pack of cigarettes per day	3000
Being 4.5 kg overweight	500
Using automobiles	240
170 mrem/year of radiation dose	10
Transportation of radioactive material*	0.030

*Calculation based on an average of 0.5 mrem per year to an average exposed individual (see Chapter 4).

must be specified. Additionally, for insoluble materials, the mechanism by which the material enters the body (i.e., ingestion or inhalation) must be specified. Ingestion is considered a pathway only for long-term low-level activity present in the diet (Ref. 3-13). An examination of the materials in the transportation analysis eliminates this pathway because the types and amounts of materials involved in accidents preclude significant food-chain buildup. Inhalation is therefore left as the only significant internal dose mechanism. Solubility or insolubility is determined from chemical forms suggested in Reference 3-13. Dosimetric parameters for each of the standard shipments evaluated are discussed in Appendix A.

In order to compare annual risk resulting from exposure during accidents involving various materials with annual risk from exposure to external penetrating radiation resulting from normal transportation of radioactive materials, a common basis for comparison must be established. For the purpose of this assessment, the expected number of additional latent cancer fatalities (LCFs) occurring during the lifetime of exposed individuals was chosen. Values for LCFs reflecting the consequences of exposure to various organs are tabulated in Table 3-8, which assumes a linear dose-effect relationship. Also from Table 3-8, the LCF coefficient of 121.6 deaths per million person-rem (less thyroid), for whole-body exposures, is used in the model. Neither of these values reflects the possible mitigation of effect due to low dose rates, as reflected in the calculations performed in Reference 3-13.

In addition to LCFs, the question of early fatalities due to large acute doses must be addressed. The two organs of particular interest for early fatalities in this analysis are the bone marrow (the fatality probability versus dose curve used is shown in Figure 3-2, curve B) and the lungs (the fatality probability versus dose curve is shown in Figure 3-3). The only incidences of early bone marrow fatalities (within the constraints of this model) would occur from large dosages from external penetrating radiation sources. Isotopes capable of causing early lung fatalities would include any inhaled material providing a sufficient dose to the lungs such as plutonium dioxide. The LD 50/365 (lethal dose to 50 percent of exposed people

TABLE 3-8

EXPECTED LATENT CANCER FATALITIES PER 10^6 PERSON-REM DOSE TO THE POPULATION* (Ref. 3-13)

Organ Exposed	Expected Deaths** per 10^6 Person-Rem
Blood Forming Organs (leukemia)	28.4
Lung	22.2
Stomach	10.2
Alimentary Canal	3.4
Pancreas	3.4
Breast	25.6
Bone	6.9
All Others	21.6
Whole Body	121.6
Thyroid***	13.4

*Adjusted for age distribution within the population.

**BEIR coefficients (Ref. 3-13) for a 75-year lifetime of potential cancer development are used.

***For assumed average individual doses of greater than 1500 rem.

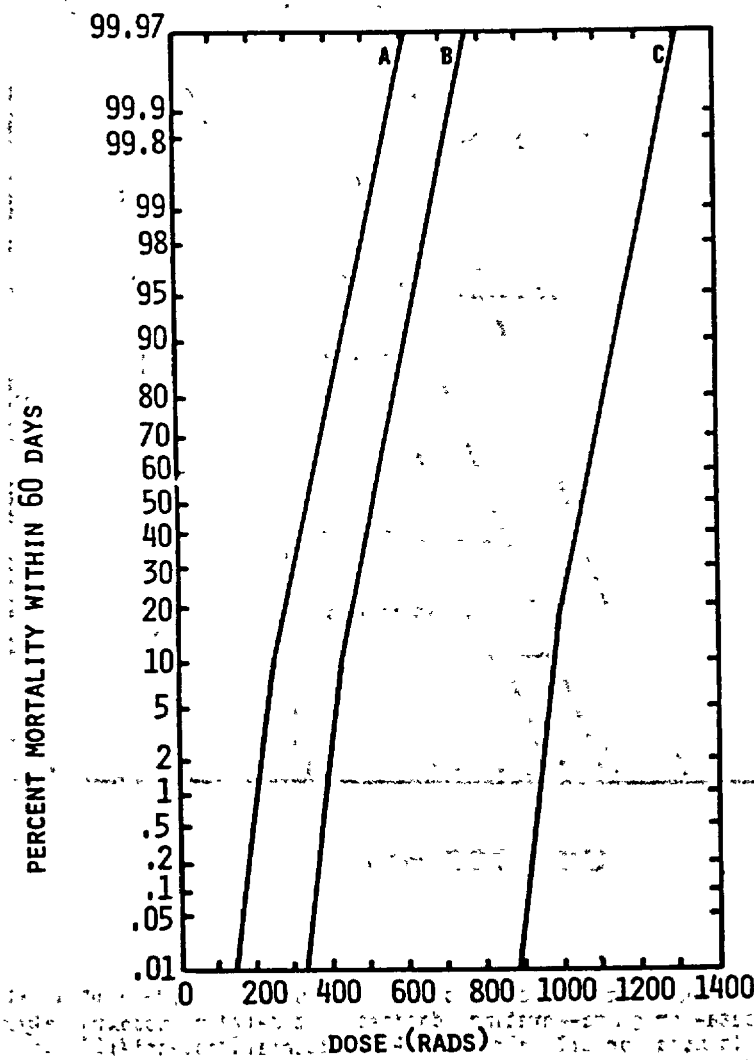
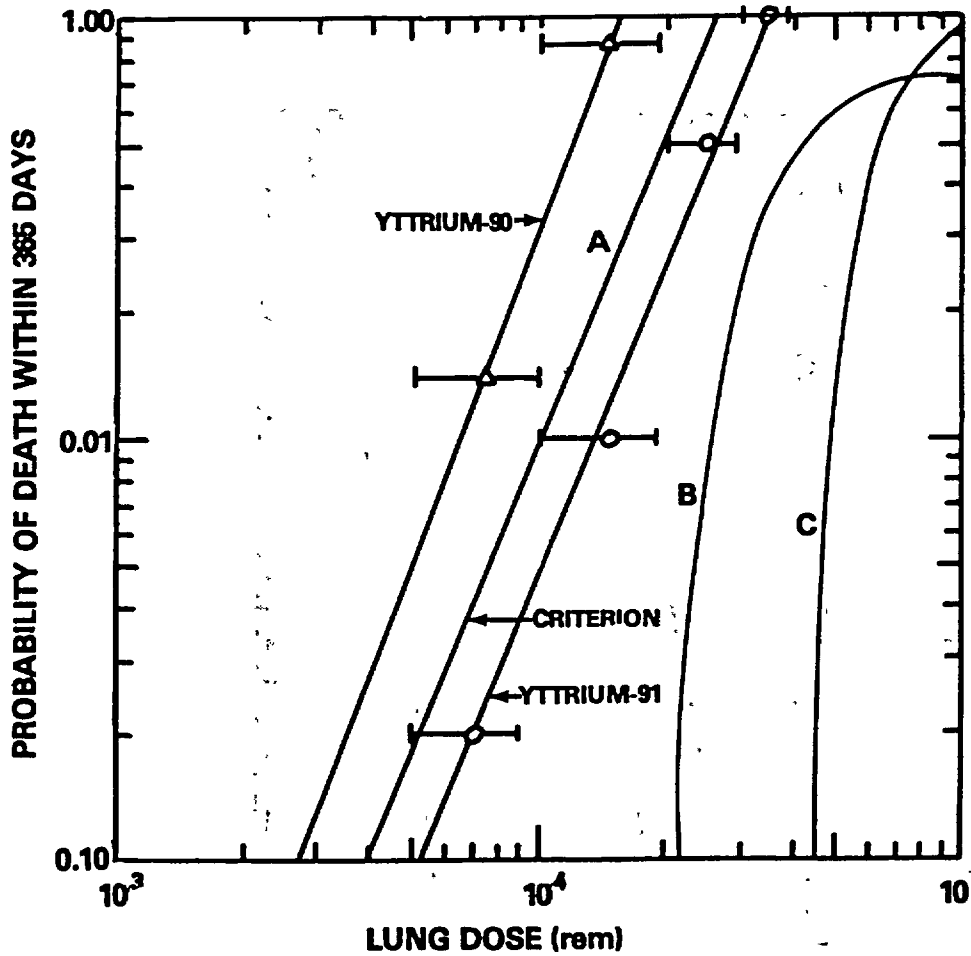


FIGURE 3-2. ESTIMATED DOSE-RESPONSE CURVES FOR MORTALITY WITHIN 60 DAYS FROM WHOLE-BODY EXPOSURE TO EXTERNAL PENETRATING RADIATION: WITH MINIMAL TREATMENT (CURVE A), SUPPORTIVE TREATMENT (CURVE B), AND HEROIC TREATMENT (CURVE C). CURVE B REPRESENTS THE MOST LIKELY LEVEL OF TREATMENT AVAILABLE FOR MOST ACCIDENT VICTIMS (Ref. 3-13); IT IS THEREFORE USED IN THIS ASSESSMENT TO ESTIMATE EARLY FATALITIES FROM WHOLE-BODY EXPOSURE TO EXTERNAL PENETRATING RADIATION.



A - Yttrium-90 and -91 were the isotopes used to obtain this curve. It is equally valid for other short-half-life beta- or gamma-emitting isotopes that deliver approximately the same dose rate. This curve is used for all short-half-life materials potentially encountered in transportation accidents (Source: Ref. 3-13).

B - This curve is based on data from Sr-90/Y-90 inhalation by beagles and is used for long-half-life, low-linear-energy-transfer radiation (Source: Ref. 3-20).

C - This curve is based on data from Pu-239 inhalation by beagles and is used for long-half-life, high-linear-energy-transfer radiation (Source: Ref. 3-20).

FIGURE 3-3. DOSE-RESPONSE CURVES FOR MORTALITY DUE TO ACUTE PULMONARY EFFECTS FROM RADIATION.

within 365 days) for long-lived alpha emitters is the basis for the curve identified as line C plotted on Figure 3-3 (Ref. 3-20). This aspect of the radioactive material shipment hazard is addressed in Chapter 5 of this assessment.

The number of genetic effects is based on the radiation dose received by the gonads. If the integrated gonadal dose is known, estimates can be made of the number of various types of genetic effects that might be expected to occur in all subsequent generations as a result of that dose. Values for the four types of genetic effects considered are shown on Table 3-9 (Ref. 3-13).

For the most part, the radioactive materials transported are relatively short half-life species. However, there are a few exceptions such as Pu-239 (discussed in Appendix C), Cs-137, and Co-60. Because these isotopes have the potential for a long residence time in the body, two doses must be considered. The early dose is based on the rem/curie value for a 60-day exposure for bone marrow or a 1-year period for lung. This early dose is used to compute early fatalities by using probabilities from Figures 3-2 and 3-3. The long-lived dose is based on the rem/curie value for a 50-year period. This long-term dose is used to predict LCFs for long half-life species.

TABLE 3-9

GENETIC EFFECTS COEFFICIENTS PER 10^6 PERSON-REM GONADAL DOSE

(Ref. 3-13)

Genetic Effect	Expected Genetic Effects Per 10^6 Person-Rem
Single-gene disorders	42
Multifactorial disorders	84*
Congenital disorders	6.4
Spontaneous abortions	42
Total Genetic Effects	174.4

*Upper range of 8.4-84.

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CHAPTER 4
TRANSPORT IMPACTS UNDER NORMAL CONDITIONS

4.1 INTRODUCTION

Normal transport of a radioactive material involves a wide range of events that can have environmental consequences. To make the source of these consequences clear, the sequence of events in a radioactive material shipment must be considered. First, for most shipments, the material is placed in a package meeting regulatory standards, the radiation exposure levels are noted, the package is labeled with the appropriate information, a shipping bill is prepared, and the package is put aside until the transportation process begins. Once the package begins moving toward its destination, it becomes a part of the subject of this assessment.

As shown schematically in Figure 4-1, the transportation process may take one of several paths. The package might be loaded onto a vehicle that will take it directly to its ultimate destination. However, most packages undergo a secondary mode of transport, e.g., a truck or light duty vehicle, which takes the package to a terminal where it is assigned to a primary vehicle along with other parcels. The primary vehicle takes it to a terminal near its destination where it is again loaded onto a secondary-mode vehicle that takes it to its ultimate destination.

In some other instances packages are picked up by or delivered to a freight forwarder and are consolidated with other packages into a single shipment. This shipment may consist of a large number of packages obtained from a number of different shippers. When the shipment arrives at its destination, it is separated into individual packages that are delivered to the consignees.

When transport occurs without unusual delay, loss of or damage to the package, or an accident involving the transporting vehicle, it is called "normal" transport. Radiological impacts occurring during this phase of transport are considered in Sections 4.2, 4.3, and 4.4 of this chapter. Cases do occur, although infrequently, in which the shipment is not timely, the package is damaged, or the contents are lost or destroyed without being involved in a vehicular accident. These abnormal occurrences are considered in Section 4.6.

4.2 RADIOLOGICAL IMPACTS OTHER THAN THOSE DIRECTLY ON MAN

The principal emphasis of this study is the direct impact on man and his environment from the transport of radioactive material. However, there are impacts on flora and fauna and on inanimate objects, as well as indirect impacts on man that also must be considered. As concluded in Chapter 3, these effects are judged to be very small in comparison to the direct radiological impact to man in the normal transport case. Indirect radiological impacts on man are negligible by comparison to the direct radiological impacts, since no credible mechanism

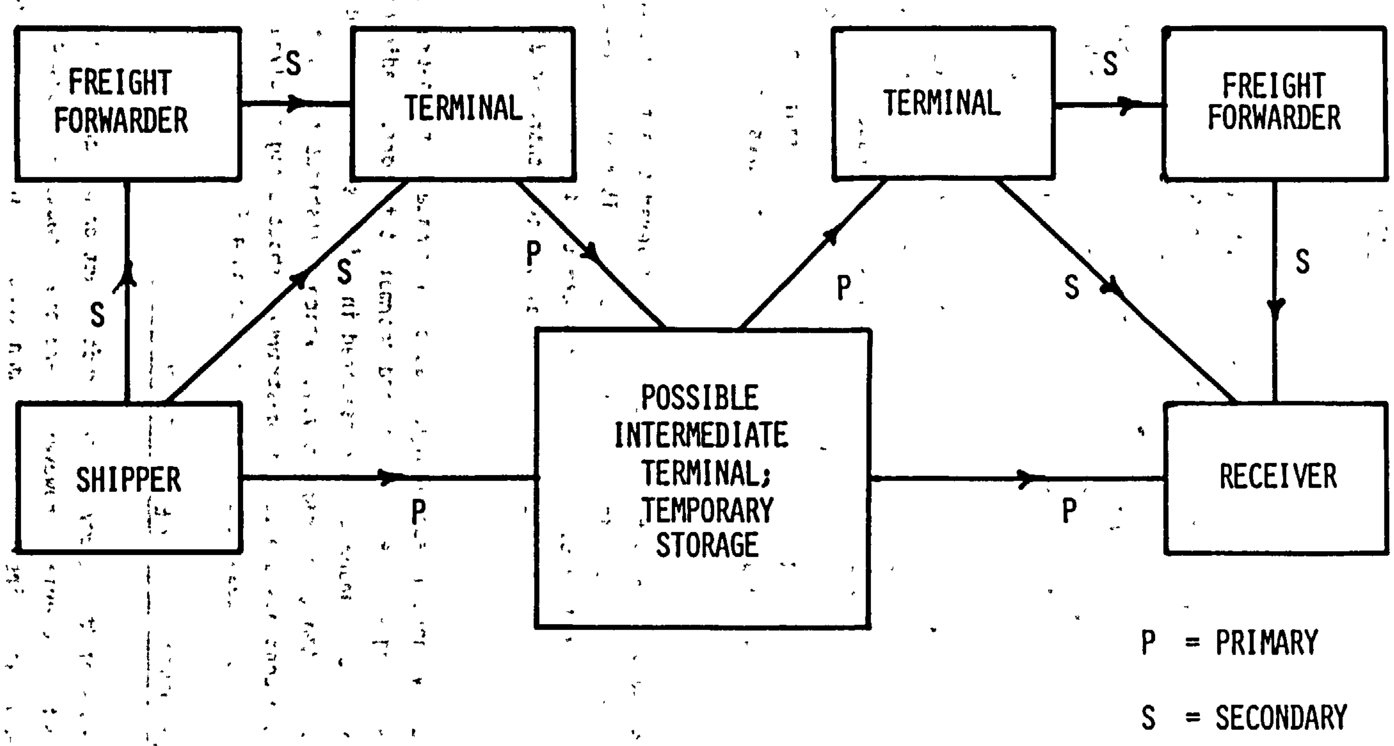

FIGURE 4-1. POSSIBLE TRANSPORT PATHS

exists for an indirect radiological effect, except through the food chain and by activation mechanisms. However, the food chain avenue is foreclosed in the normal case by package containment, and radiation outside packages is sufficiently low and of such type that activation of structures surrounding man is negligible. Exposures to casually exposed life forms are equal to or less than those to man and therefore present no significant impact. In addition, packaging and transport regulations are, in part, designed to minimize dosage to animals shipped in the same vehicle as radioactive material packages (see Chapter 2).

The principal radiological impact on objects is to undeveloped photographic film. The regulations for spacing between radioactive material packages and film are designed to minimize this problem (see Chapter 2).

4.3 DIRECT RADIOLOGICAL IMPACT ON MAN

The principal environmental impact during normal transport is direct radiation exposure to nearby persons from the radioactive material in the package. The impact is quantified in terms of annual population dose in person-rem and in terms of the annual latent cancer fatalities expected from this population dose. The radiological effects from normal transport result from radiation that escapes from the unbreached package. Shielding from buildings, terrain, or vehicles is not considered in this report. However, the maximum distance over which the average population dose is computed is limited as discussed in Appendix D.

Radiation dose rates decrease rapidly with distance from the package. Thus people who handle the package directly (such as loaders, dock workers, and baggage handlers) are exposed to the highest dose rates, although these exposures are usually for very short periods of time. The dose to handlers in all transport modes is addressed in Section 4.4 of this chapter.

Those who work in the vicinity of the package (but do not actually handle it) or who are transported with it (e.g., aircraft passengers) are subjected to lower dose rates than handlers but generally for longer periods of time. Bystanders and persons living along a travel route generally are subjected to even lower dose rates, but the small doses delivered to so many people make the total population dose comparable to other group population doses.

For the purposes of computing the direct radiological impact in the normal case, the most important characteristic of a package containing radioactive material is the transport index (TI), defined in Chapter 2 as the radiation dose rate in mrem per hour at a distance of one meter from the package surface. The radionuclide and the characteristics of the packaging are of little importance in evaluating the impact in the normal case. However, these factors may govern whether the material can be shipped by a given transport mode and may limit the total number of packages on a given vehicle.

The evaluation of the radiological impact of normal transport makes use of the standard shipments model developed in Appendix A. Various tables in that appendix list the package type, average TI per package, primary and secondary transport modes, and average distances for each standard shipment. The methodology for the normal transport annual population dose calculation is presented in detail in Appendix D. This appendix shows the factors considered in each calculation and the specific relationships used to compute the population dose.

Different transport modes have different characteristics such as mean velocity, location of bystanders, and carriage of passengers, all of which affect population dose. For that reason, each primary mode is considered separately when assessing environmental impact. As previously mentioned, a secondary transport mode is frequently used to transport the package from the shipper to the primary mode terminal and from the end point terminal to the receiver. The radiological impacts associated with secondary mode transport are considered explicitly in Section 4.3.2.2. For each primary and secondary mode analyzed, both the accumulated annual person-rem and the maximum individual dose received by persons as a result of transport by that mode are evaluated. These results are summarized in the tables at the end of the chapter.

4.3.1 TRANSPORT BY AIR

The radiological impacts of normal transport of radioactive materials by aircraft are the direct radiation doses to passengers, attendants, crew, cargo handlers, and persons in the vicinity of the aircraft while it is stopped. Doses to persons on the ground below the flight path are considered negligible because of the large separation distances and high velocities. The discussion of the environmental impact of transport of radioactive material by air is divided into three sections according to the principal transport mode: commercial air passenger service, commercial air cargo service, and other air modes (including air taxi and corporate aircraft, helicopter, and lighter-than-air craft).

4.3.1.1 Transport by Passenger Aircraft

4.3.1.1.1 Passenger Dose

The materials shipped by passenger aircraft are included in Appendix A. Other shipment parameters used in the calculation of passenger dose are shown in Table 4-1. The annual population dose received by passengers aboard aircraft carrying radioactive material is computed as follows:

$$\begin{pmatrix}\text{Annual}\\ \text{Population}\\ \text{Dose}\end{pmatrix} = \begin{pmatrix}\text{Total Passenger}\\ \text{Aircraft Flights per}\\ \text{Year Carrying RAM}\end{pmatrix}\begin{pmatrix}\text{Average}\\ \text{Dose}\\ \text{Rate}\end{pmatrix}\begin{pmatrix}\text{Average}\\ \text{Flight}\\ \text{Duration}\end{pmatrix}\begin{pmatrix}\text{Average Number}\\ \text{of Passengers}\\ \text{per Flight}\end{pmatrix} \quad (4\text{-}1)$$

The average dose rate is given by the average TI per flight (TI per package x number of packages per flight) times the TI-dose rate conversion factor $K_{D/TI}$ (for passengers, $K_{D/TI}$ = 0.03 mrem/hour/TI, Ref. 4-3). The average flight duration is the average distance per flight divided by the mean speed. This calculation is performed for each standard shipment. The sum of the doses computed for each standard shipment results in a total annual population dose to passengers of 2330 person-rem.

The average annual dose received by an individual airline passenger depends on the number of flights taken, the fraction of those flights carrying radioactive material (radioactive

TABLE 4-1

SHIPMENT PARAMETERS FOR CALCULATION OF POPULATION AND INDIVIDUAL DOSE FOR THE PASSENGER AIR SHIPMENT MODE

Transport Parameters:			
Mean Speed (km/hr)		682	(Ref. 4-1)
Passengers/Flight		78	(Ref. 4-2)
Cabin Attendants/Flight		4	
Crew/Flight		3	
$K_{D/TI}$ (mrem/hr/TI) (passengers)	=	0.030	(Ref. 4-3)
$K_{D/TI}$ (mrem/hr/TI) (cabin attendants)	=	0.028	(Ref. 4-3)
Average Flight Duration (hours)	=	2	
Average Distance from Cockpit to Radiation Source (m)	=	15.2	
Stop Time (hr)	=	1	
Population Density at Stops (people/km^2)	=	720	
Passenger Flights per Year	=	2.68×10^6	(Ref. 4-2)
Passenger Flights per Year that Carry Radioactive Material (RTF = 1/30)	=	8.95×10^4	

Total TI shipped/year = 4.33×10^5

Average TI per radioactive material (RAM) flight = 4.8

(4.33×10^5 TI/8.95×10^4 RAM flights/year) traffic factor - RTF), the number of TI on the flight, and the duration of those flights. According to the Civil Aeronautics Board there were about 210 million revenue passengers enplaned on scheduled domestic and international flights between March 1975 and March 1976. Using an average RTF of 1/30, the total number of passengers enplaned on flights carrying radioactive material should have been about 7 million. Each passenger makes, on the average, about 5 flights per year (Refs. 4-3, 4-4), but it is unlikely that any individual would fly on more than one radioactive material flight per year. Distributing the 2330 person-rem among 7 million exposed passengers results in an annual average individual dose of 0.34 mrem. The cosmic radiation background dose rate to which these same passengers are exposed is 0.23 mrem/per hour at an altitude of 9 km.

Assuming that 75 percent of the flight time is spent at 9 km, for 5 flights per year and an average of 2 hours per flight, the annual average cosmic radiation background dose per individual was 1.7 mrem (Refs. 4-5, 4-6). Multiplying this average individual dose by 7×10^6 passengers results in an annual population dose of 1.2×10^4 person-rem to these passengers from cosmic radiation. Thus the average individual dose from radioactive materials on board is considerably less than the cosmic-ray background dose received by the same individuals. Passengers who receive a greater radiation dose from the cargo because they travel more than the average also receive a proportionally higher cosmic radiation dose.

It has been pointed out in another study (Ref. 4-4) that a select group of individuals flying 500 hours per year between airports with RTF's of 1/4 and 1/10 (e.g., Knoxville, Tennessee, and St. Louis, Missouri) would each receive, on the average, 108 mrem per year, assuming an average dose rate at seat level of 1.3 mrem/per hour (fully loaded conditions). These same individuals would receive 86 mrem per year from cosmic radiation (500 hours per year x 0.23 mrem per hour x 0.75).

4.3.1.1.2 Dose to Cabin Attendants

The dose to cabin attendants was calculated in the same manner as the dose to passengers. The average number of attendants per flight was estimated to be four, and the dose conversion factor used was 0.028 mrem per hour per TI (Ref. 4-3). The latter factor is an average over the cabin length and acknowledges the fact that the attendant moves throughout the cabin during the flight. The total population dose to attendants in 1975 was calculated to be 112 person-rem. Assuming that this dose was delivered to 20,000 attendants [one-half of the total attendant population (Ref. 4-4)], the average dose received by each would have been about 6 mrem.

Experiments in Oklahoma City and Boston indicate that the maximum dose rate to an attendant in the tourist section of an aircraft carrying the maximum allowable load of radioactive material is between 0.6 and 0.8 mrem per hour (Refs. 4-3, 4-4), while the dose to an attendant in the first class section is essentially zero (under current practice, radioactive packages are usually carried in the aft cargo hold). If 1000 hours per year of flight time is assumed with an RTF of 1/10 (corresponding to an attendant who works only out of airports serving major radiopharmaceutical centers) and the average load is assumed to be 4.8 TI, the tourist class attendant may receive up to 13 mrem per year (1000 hours per year x 1/10 x 0.028 mrem per hour per TI x 4.8 TI). This compares with a dose of 173 mrem per year (1000 hours per year x 0.23 mrem per hour x 0.75) from cosmic radiation assuming that three quarters of the flying time is spent at 9 km altitude. Multiplying this average individual dose by the 20,000 attendants results in an annual population dose to these attendants of 3500 person-rem.

4.3.1.1.3 Dose to Crew

Crew members on passenger aircraft are usually located away from radioactive materials packages. The common practice of storing packages in the rear baggage holds results in a cockpit dose rate that is very small. The positive effects of this practice are pointed out by Barker, et al. (Ref. 4-3) based on measurements of radiation exposure to flight crews. In most cases radiation was undetectable in the cockpit when radioactive materials were stowed in the aft baggage compartment some 15 meters away.

The annual population dose to crew members is computed in the same way as the doses to passengers and attendants just discussed except that, instead of determining the dose rate by an empirical TI-Dose rate conversion factor, the dose rate is computed analytically using the dose-rate formula given in Appendix D, Equation (D-1). The dose-rate factor K is proportional to the TI, as discussed in Section D.1 of Appendix D. Using an average source-to-cockpit distance of 15 meters together with the assumption of three crew members per flight, an estimate of 16 person-rem to the crew is obtained by summing the contributions of all standard shipments. Distributed over approximately 30,000 flight crew members, this amounts to an annual average individual dose of 0.53 mrem.

In a survey at Boston's Logan Airport (Refs. 4-3, 4-4), only 2 of 42 flights known to be carrying radioactive material had detectable radiation levels in the cockpit area and in both cases the level was only 0.1 mrem per hour. A similar survey in Chicago found none of the 100 flights surveyed had detectable radiation levels in the cockpit. Assuming an RTF of 1/10, the maximum annual dose received by a flight crew member flying 1000 hours per year would be 2.5 mrem, for an average load of 4.8 TI. These same crew members would receive about 173 mrem per year from cosmic radiation, assuming that three-quarters of their 1000 hours per year are spent at an altitude of 9 km, for a total annual population dose from cosmic radiation of 5200 person-rem.

4.3.1.1.4 Dose to Bystanders During Stops

During aircraft stops, the population surrounding the aircraft both within and outside the terminal building is exposed to radiation from any radioactive cargo carried by the aircraft. A general expression for the integrated population dose received during shipment stops is derived in Section D.2 of Appendix D. All stops are assumed to occur in areas with an average population density of about 720 per km^2. A total stop time of 1 hour is assumed for each shipment. The total annual population dose to bystanders during stops, summing over all standard shipments, is 11 person-rem.

The maximum annual dose to an individual during aircraft stops is likely to be received by a member of the ground crew who is refueling, loading, or unloading the plane. If this individual spends 10 minutes per flight 4 times an hour at a distance of 3 meters from an average cargo, his annual dose is estimated to be 85 mrem, using the dose rate formula given in Appendix D, Equation (D-1), and assuming the RTF = 1/10, the average TI = 4.8 (Type A packages), a 40-hour work week, and 50 work weeks per year.

4.3.1.1.5 Summary

The radiation doses resulting from passenger aircraft transport of radioactive materials in 1975 (exclusive of secondary-mode contributions and doses received by freight handlers) are summarized in Table 4-2. The total annual population dose of 2470 person-rem resulting from radioactive material on board passenger aircraft is considerably less than that received by the same individuals from cosmic radiation.

4.3.1.2 Transport by All-Cargo Aircraft

There were 31,400 all-cargo aircraft departures in 1975 (Ref. 4-7). Because of the relatively small number of all-cargo flights and because of the limited number of airports served by all-cargo aircraft, most of the radioactive materials transported by air go by passenger aircraft.

The principal radiological impact from normal transport of radioactive materials by all-cargo aircraft is the dose to the crew and to bystanders. Radioactive materials in cargo aircraft are usually stowed as far from the crew compartment as possible. A 6-meter distance between crew and radioactive cargo was assumed for this assessment.

At the time of this report, two cargo carriers were operating under a Federal Aviation Administration (FAA) waiver that permitted carriage of up to 200 TI per aircraft on specific routes and for a specific time period. This increase in the allowable TI has the potential for increasing the radiation exposure to individual members of the crew, but precautions are required by the FAA to minimize these exposures.

4.3.1.2.1 Dose to Crew

Table 4-3 lists the shipment parameters for the air cargo mode used to compute the doses. The crew dose was computed in the same way as the dose to passenger aircraft crew using Equation (D-1) in Appendix D. An average of three crew members per flight was assumed. The annual dose obtained by summing over all shipments by all-cargo aircraft is 4.1 person-rem. The total crew population exposed to this population dose is estimated to be approximately 350 by applying the ratio of the cargo to passenger air flights to the total number of passenger aircraft crew. As a result, the average annual individual dose is estimated to be 12 mrem. The average annual individual cosmic ray dose would be similar to that for crews on passenger aircraft (173 mrem), for an annual population dose of 60 person-rem.

TABLE 4-2

ANNUAL DOSES FROM TRANSPORT OF RADIOACTIVE MATERIAL (RAM) IN PASSENGER AIRCRAFT AND CORRESPONDING COSMIC RADIATION DOSES - 1975

Population Subgroup	Total Exposed Persons	Annual Population Dose (person-rem)		Annual Individual Dose (mrem)	
		RAM	Cosmic Radiation	RAM	Cosmic Radiation[a]
Passengers	7×10^6	2330	1.2×10^4	0.34 (avg) 108 (max)	1.7 (avg) 86 (max)
Attendants	2×10^4	112	3500	6 (avg) 13 (max)	173
Crew	3×10^4	16	5200	0.53 (avg) 2.5 (max)	173
Ground Crew (including bystanders)	($720/km^2$)	11	not evaluated	85 (max)[b]	44[c]
TOTALS		2470	2.1×10^4		

[a] Dose is in addition to an average annual individual dose of 102 mrem received by persons on the ground from natural background exposure.

[b] Applies only to the most exposed member of ground crew.

[c] See Table 3-3.

TABLE 4-3

SHIPMENT PARAMETERS FOR CALCULATION OF POPULATION DOSE FOR THE AIR CARGO SHIPMENT MODE

Transport Parameters:

Mean speed (km/hr)	682	
Crew per flight	3	
Average distance from cockpit to radiation source (m)	6	
Stop time (hr)	1	
Population density at stops (people/km^2)	720	
Estimated total all-cargo flights per year	31,400	(Ref. 4-7)
All-cargo flights per year carrying radioactive material (RTF = .042 (Ref. 4-8)	1,320	
Flight duration (hr)	2	

Total TI shipped/yr = 1.61×10^4

Average TI per RAM flight = 12

The maximum annual dose likely to be received by an individual crew member was estimated by assuming 1000 hours total flight time, with one-eighth of the time spent on flights carrying radioactive material. If each of those flights carried the average (12 TI) amount of radioactive material at a separation distance of 6 meters, the annual individual dose received, computed by using the dose-rate formula in Appendix D, Equation (D-1), would be 61 mrem.

Measurements conducted on typical flights of the two carriers licensed for up to 200 TI per flight indicated that the crew received an average of 0.41 mrem per TI carried with an average load of 44.7 TI and an average annual dose of 364 mrem (Ref. 4-9). Crew exposure for these flights are monitored carefully according to restrictions in the FAA waiver which requires, among other things, that a health physicist supervise the handling and stowage of radioactive material to ensure that radiation exposures are as low as reasonably achievable.

4.3.1.2.2 Dose to Bystanders During Stops

Bystanders are exposed to radioactive material packages during the time required to unload or add cargo to the freighter aircraft. Because freight operations usually occur in areas away from the main terminals the population density may be lower than that for the passenger air case; nevertheless, the same population density (720 persons per km^2) was assumed. Using the same computational technique, the annual dose to bystanders was estimated to be 0.4 person-rem.

The maximum dose delivered to a ground crew member is estimated using the same values as for passenger aircraft, except that the average RTF is 1/24 and the average TI is 12. This gives a maximum anticipated annual individual dose of 106 mrem.

4.3.1.2.3 Summary

The annual population doses resulting from all-cargo aircraft transport of radioactive material in 1975 are summarized in Table 4-4. The total annual population dose is about 5 person-rem.

4.3.1.3 Transport by Other Air Modes

4.3.1.3.1 Transport by Other Fixed-Wing Modes

The assessment of radiological impact from transport of radioactive materials by other fixed-wing modes such as corporate aircraft was performed in a way similar to that for all-cargo aircraft. An informal survey suggests that some radioactive materials are transported by this mode, particularly in the oil-well logging industry. The radiological impacts are determined in essentially the same way as in the all-cargo mode except that the aircraft are usually physically smaller than the typical cargo aircraft and therefore do not permit as much spacing between the crew and radioactive packages.

The total TI transported by other fixed-wing modes is estimated to be no more than one percent of that transported by all-cargo aircraft, i.e., 160 TI per year maximum. The dose rates experienced by the two crew members are estimated using Equation (D-1) in Appendix D,

TABLE 4-4

ANNUAL DOSES FROM TRANSPORT OF RADIOACTIVE MATERIAL IN CARGO AIRCRAFT AND CORRESPONDING COSMIC RADIATION DOSES - 1975

Population Subgroup	Total Exposed Persons	Annual Population Dose (person-rem)		Annual Individual Dose (mrem)	
		RAM	Cosmic Radiation	RAM	Cosmic Radiation
Crew	350	4.1	61	12 (avg) 61 (max)	173
Bystanders/ Ground Crew	$720/km^2$	0.4	not evaluated	106 (max)	44[a]

[a]See Table 3-3.

assuming a separation distance of 3 meters. The estimated total annual population dose from this mode is 0.04 person-rem, assuming an average flight time of 1 hour. This dose is negligible by comparison to the values calculated for transport by passenger and all-cargo aircraft.

4.3.1.3.2 Transport by Helicopters

Helicopters are not widely used for transporting radioactive material. They are used to transfer well-logging sources to off-shore drilling rigs. The actual extent of such transfers is not known, but a thousand such transfers per year is estimated. For a two-man crew, a 1-hour flight time, a separation distance of 3 meters, and a load of 2 TI, the possible dose is about 0.5 person-rem. This result is obtained using Equation (D-1) in Appendix D for the dose rate with d = 3 meters and taking K_0 typical of Type-A packages. A population exposure of 0.5 person-rem is a negligible fraction of the total population dose for air transport.

4.3.1.3.3 Transport by Lighter-Than-Air Vehicles

There is no known current use of lighter-than-air vehicles (LTAV) in radioactive material transport. But contemplated use for special nuclear material shipments with a flight crew of three and a separation distance of 15 meters would result in a population dose of 0.04 person-rem, assuming 1000 such shipments per year of plutonium in Type-B packages, and an average of 2 hours per flight. The average dose rate was determined using Equation (D-1) in Appendix D, with d = 15 meters.

4.3.1.3.4 Bystander Doses from Other Air Modes

The total annual TI transported by air modes other than passenger and cargo aircraft considered in the preceeding calculations is 3140 TI per year. A total of 16,000 TI per year was transported by all-cargo aircraft. Since the doses received by persons while stopped is proportional to the total TI, the doses while stopped for all air modes other than passenger and all-cargo aircraft should be that for all-cargo aircraft times 3140 TI per 16,000 TI or 0.08 person-rem.

Individual doses to ground crew (including bystanders) were computed assuming that a single individual will service a maximum of one-third of the flights per year at a distance of 1.5 meters for a helicopter or corporate aircraft. The exposure time was estimated to be 10 minutes per flight for the individual. The results are presented in Table 4-5.

4.3.1.3.5 Summary

The integrated and individual doses estimated for shipments by other air modes are summarized in Table 4-5. Because flight altitudes for these air modes are generally lower than for commercial air modes, the cosmic ray dose rate is substantially lower (approximately 0.01 mrem per hour at 3 km). Based on the numbers of crewmen listed, the cosmic ray dose rate is estimated to be 0.05 person-rem. This was computed by summing the contributions of each "other-air" mode, assuming 0.75 of the flight time is spent at an altitude of 3 km using the appropriate flight time, numbers of crewmen, and flights per year.

TABLE 4-5

DOSE RESULTING FROM RADIOACTIVE MATERIAL SHIPMENT BY HELICOPTERS AND CORPORATE AIRCRAFT - 1975

Mode	Population Subgroup	Annual Individual Dose (mrem)*	Annual Population Dose (person-rem)
Helicopter	Flight crew	5	5
	Bystanders/ Ground crew	60	see all-modes dose
Corporate Aircraft	Flight crew	4	0.04
	Bystanders/ Ground crew	0.6	see all-modes dose
All Modes Shown Above	Bystanders/ Ground crew		0.08
TOTAL			0.62

*Flight crew doses are computed assuming 20 one-hour flights per year by the same individual. 2 TI per flight is assumed for helicopter and 1.6 TI per flight is assumed for corporate aircraft.

4.3.1.4 Storage Associated with the Air Transport Mode

The radioactive material package may be considered to be in storage between the time it is offered for shipment and the time it is placed aboard an aircraft and again after removal from the aircraft but before transfer to a secondary-mode vehicle for delivery to its final destination. Storage areas are typically on or near the airport grounds and are part of the airline freight handling facilities. Terminals visited during the course of this study had a specific location set aside for radioactive material packages, but the area was not isolated from the general work area. If a storage area occupies approximately 11,000 m^2 (120,000 ft^2) and has 10 employees per shift, the average population density is approximately 900 persons per km^2. In the case of aircraft transport, this dose is charged to the secondary mode vehicles and hence is discussed in Section 4.3.2.2.

4.3.2 SURFACE TRANSPORT BY MOTOR VEHICLE

An estimated 1.2 million radioactive material shipments are transported each year by truck. In addition, most land and air shipments involve a secondary ground link that is also by truck or light duty vehicle. While a number of truck shipments are radiopharmaceuticals, a substantial fraction of those radioactive materials requiring massive shielding are also shipped by truck because of the capability to carry heavy cargo. These latter shipments are relatively few in number and are associated with large fuel-cycle shipments, irradiator sources, and other large-quantity sources.

4.3.2.1 Transport in Trucks

The principal radiological impacts from truck transport of radioactive materials are the direct radiation dose to handlers, crew, and bystanders. In contrast to the passenger aircraft case, there are no passengers exposed to radiation; however, persons along the transport route are exposed during passage of the vehicle. In most cases, exposures are for a relatively short duration, but the number of persons who can be exposed may become very large during a trip of considerable distance. Additional doses result from stops for meals, crew rest, repair, and refueling. Because access to the area around the vehicle during stops is not limited as in the case of air shipment, the potential for exposure is higher. The parameters used to evaluate the normal dose resulting from truck transport are summarized in Table 4-6.

4.3.2.1.1 Dose to Truck Crew

The calculation of the annual population dose received by truck crew is similar to that for the dose to aircraft crew. The average dose rate in the cab is computed using Equation (D-1) in Appendix D with d = 3 meters and with $K = K_0 \times TI$. If the computed dose rate exceeds 2.0 mrem per hour, it is assumed that shielding is introduced to limit the dose to 2 mrem per hour as required by the regulations for exclusive-use vehicles and as a practical limit for all shipments. Two crew members per vehicle are assumed. The crew is assumed to be in the cab only during periods of actual travel. Thus, the duration of exposure to the crew is approximately the same as the distance traveled divided by the average speed while moving. The total annual crew dose summed over all standard shipments is computed to be about 2580 person-rem.

TABLE 4-6

SHIPMENT PARAMETERS FOR CALCULATION OF POPULATION DOSE FOR THE TRUCK TRANSPORT MODE

Transport Parameters	High-Population Areas	Medium-Population Areas	Low-Population Areas
Average Speed (km/hr)	24	40	88
Fraction of Travel Distance	0.05	0.05	0.9
Population Density (persons/km^2)	3,861	719	6
Duration of Stops (hr)	1	5	2
Traffic Distribution			
Fraction in Rush Hour	0.08	0	0
Fraction in Non-Rush Hour	0.92	1	1
Truck Traffic Distribution			
Fraction on City Streets	0.05	0	0
Fraction on 4 Lane	0.10	0	0
Fraction on Freeway	0.85	1	1
One-Way Traffic Count per Hour (normal traffic)*	2,800	780	470

Total TI shipped = 3.8×10^6 (3.36×10^6 in exclusive-use trucks)

*Based upon a recent traffic survey in Albuquerque, New Mexico.

The maximum individual dose is likely to be received by a crew member transporting irradiated fuel. Although the maximum allowable radiation dose rate in the cab of an exclusive-use truck carrying radioactive material is 2 mrem per hour, experience indicates that dose rates are usually less than 0.2 mrem per hour (Ref. 4-10) because of the distance from the cask and shielding by intervening material. Dose rates at 2 meters from an irradiated fuel cask are at most 10 mrem per hour (about 33 mrem per hour at 1 meter) but are more likely to be about 25 mrem/hour at 1 meter from the vehicle surface (Ref. 4-10). Assuming that a crew member spends 20 hours per trip in the cab and a total of one hour at a distance of 1 meter from the cask, his maximum possible dose per trip is 73 mrem (2 mrem per hour x 20 hours + 33 mrem per hour x 1 hour). If the same crew member made 30 such trips a year, his annual dose would be 2.2 rem. In practice, however, a 0.2-mrem-per-hour radiation level in the cab and a 25-mrem-per-hour level at 1 meter are more likely, and the accumulated dose is about 29 mrem per trip for a maximum annual individual dose of about 870 mrem.

4.3.2.1.1 Dose to Population Surrounding the Moving Vehicle

The population dose received while the vehicle is in motion is composed of two principal components: that resulting from the exposure of persons in other vehicles occupying the transport link (on-link) and that received by persons along the transport link (off-link).

The off-link population dose calculation is discussed in detail in Section D.1 of Appendix D. Equation (D-1) in Appendix D was used to compute this dose for each standard shipment involving truck transport, and the results were summed to obtain the total annual off-link dose. The transport parameters used in the calculation are listed in Table 4-6. The resulting total annual off-link population dose is 348 person-rem.

The on-link population dose calculation is discussed in Appendix D, Section D.5 and is composed of two components:

1. The dose to persons traveling in the direction opposite to the shipment and

2. The dose to persons traveling in the same direction as the shipment.

The "opposite direction" dose is obtained using Equation (D-17) of Appendix D; the "same direction" dose, Equation (D-22). Both calculations are made for each standard shipment using the transport parameters listed in Table 4-6, and the results are summed over all standard shipments. The resulting total annual on-link population dose is about 172 person-rem.

The maximum dose to an individual sharing the transport link with the vehicle would probably be received by a person in a vehicle following the shipment from its point of origin to its destination. If a truck driver followed an irradiated fuel shipment at a distance of 30 meters during a 20-hour trip once per week, 50 weeks per year, he would receive 94 mrem per year (Equation (D-1), Appendix D, with d = 30 meters). However, it is highly unlikely that this particular set of circumstances would occur for the same driver each week. A more reasonable assumption might be that a specific driver's annual accumulated time at 30 meters behind irradiated fuel shipments might be equivalent to one 20-hour trip. Under these circumstances, that driver would receive an annual dose of 1.9 mrem.

The maximum dose received by a person living along a transport route would probably be received by an individual living adjacent to a highway where radioactive material was frequently shipped. Using Equation (D-2) in Appendix D, the annual dose received by a person living 30 meters from a roadway on which standard irradiated fuel shipments (K = 1000 mrem-ft^2 per hour) pass 250 times per year at an average speed of 48 km per hour is 0.009 mrem.

Neither the off-link nor the on-link calculations explicitly take into account the effects of shielding outside the packaging that might act to absorb radiation and therefore mitigate the population dose. This is likely to be most effective in cities where buildings are constructed from relatively good radiation absorbers such as concrete and steel and in hilly terrain where topographic features may provide shielding.

4.3.2.1.3 Dose to Population While Vehicle is Stopped

The computation of the population dose that occurs as a result of shipment stops is discussed in Section D.2 of Appendix D. Equation (D-10) in Appendix D was used to compute this dose for each standard shipment using the stop duration and population density values listed in Table 4-6. The assumptions shown in Table 4-6 regarding the length of stops in each of the three population zones were made from the observation that fuel stops and rest areas are more often located in suburban areas or in areas that have population densities higher than the rural average. When the results are summed over all standard shipments involving truck transport, a total annual dose of 1000 person-rem is obtained. Again, the effects of shielding by buildings and terrain would probably reduce this value.

Although vehicles carrying large amounts of radioactive material are placarded, bystanders may get close enough to receive a small dose from a shipment. If a bystander spends 3 minutes in an area 1 meter from an irradiated fuel cask, he would receive a dose of 1.3 mrem, assuming a 25 mrem per hour radiation level at that distance (Ref. 4-10). Unless the same person "investigated" several such shipments per year, this is expected to be the maximum annual dose received by an individual while the shipment is stopped.

4.3.2.1.4 Dose Resulting from Intransit Storage

At the beginning and end of the transport cycle and at intermediate terminals, radioactive material packages may be stored temporarily while awaiting a truck that is proceeding to the final destination. The potential therefore exists for irradiation of truck terminal employees and surrounding population during these periods of temporary storage. The calculation is identical to that for storage involved with air transport, and the same average population density (900 persons per km^2) in the warehouse is assumed. The resulting annual population dose for an average intransit storage time of 2 hours per shipment is computed to be 261 person-rem.

4.3.2.2 Truck, Light Truck, and Delivery Vehicles

This transport mode includes all secondary transport. All radioactive materials that are shipped by air and almost all that are transported by truck, rail, ship, or barge are taken from the shipper to the shipping terminal and from the receiving terminal to the receiver by trucks, vans, or automobiles. Freight terminals are usually located in or near cities; thus the population densities are relatively high, and the speeds are relatively low.

Using the same calculation procedure as used for the truck mode with the material and transport parameters shown in Table 4-7, the following estimates of population dose to the indicated groups are predicted:

1. Annual dose to crew (1 person per shipment) = 53 person-rem.

2. Annual dose to surrounding population (on-link) = 216 person-rem.

3. Annual dose to surrounding population (off-link) = 51 person-rem.

4. Annual dose to surrounding population (stopped) = 79 person-rem.

5. Annual dose to surrounding population (intransit storage) = 310 person-rem.

The annual total population dose from secondary modes is 709 person-rem.

Assuming that a van driver carries a shipment with the maximum TI carried by van noted in the standard shipments (3.8 TI - "mixed" - Type B) once per working day (250 working days per year) over a distance of 40 km at a speed of 40 km per hour, he would receive 352 mrem per year (using the same computational procedure as in other crew dose calculations and a separation distance of 2 meters). Recent studies by a number of State health agencies in cooperation with NRC and DOT revealed few instances where these assumptions might be valid. A more likely scenario would be a courier-service driver who makes a single radiopharmaceutical pickup and delivery per week (50 weeks per year). Assuming a total of 3.8 TI (2 Mo-99 generators), the driver would receive 70 mrem per year (1/5 x 352).

The likelihood of the same person following or investigating a van loaded with radioactive material in a city on a regular basis is considered remote. Hence, the maximum annual on-link and bystanders doses are considered negligible. The annual maximum off-link dose is assumed to be the same as that for truck, namely 0.009 mrem.

4.3.2.3 Summary of Truck Transport

The annual doses resulting from truck and van transportation of radioactive material (exclusive of freight handler dose) are summarized in Table 4-8; the total is 5070 person-rem.

TABLE 4-7

SHIPMENT PARAMETERS FOR CALCULATION OF POPULATION DOSE FOR THE DELIVERY VEHICLE TRANSPORT MODE

	High-Population Areas	Medium-Population Areas
Transport Parameters		
Average Speed (km/hr)	24	40
Distribution of Travel Distance	0.4	0.6
Population Density (persons/km^2)	3,861	719
Stop Duration (hr)	0.5	0
Traffic Distribution		
Fraction in Non-Rush Hour	0.92	0.92
Fraction in Rush Hour	0.08	0.08
Roadway Distribution		
Fraction on City Streets	0.65	0.65
Fraction on 2-Lane	0.05	0.05
Fraction on 4-Lane	0.05	0.05
Fraction on Freeway	0.25	0.25

Total TI Shipped = 1.18×10^6

TABLE 4-8

DOSES RESULTING FROM TRUCK AND VAN TRANSPORT OF RADIOACTIVE MATERIALS - 1975 (EXCLUSIVE OF FREIGHT HANDLERS)*

Mode	Population Subgroup	Annual Population Dose (person-rem)	Maximum Annual Individual Dose (mrem)
Truck	Crew	2580	870
	On-link	172	1.9
	Off-link	348	0.009
	While stopped	1000	1.3
	Storage	261	500*
Van	Crew	53	70
	On-link	216	negligible
	Off-link	51	0.009
	While stopped	79	negligible
	Storage	310	500*
	TOTAL	5070	

*See discussion of freight handlers in Section 4.4.

4.3.3 RAIL TRANSPORT

The methods used for calculating the impact of transport by rail are similar to those used for truck transport because of similarities in route structure and service areas. The major differences between truck and train are in the speed of transport (train is generally slower) and the proximity of population exposed on the rail link. Although the speed of a freight train while moving through the countryside is reasonably fast, the need to enter sidings occasionally to allow faster trains to pass and to pick up and drop off cars reduces the mean speed considerably. This results in a longer time for exposure of the public to radiation. Where passenger trains pass or are passed, a population dose is incurred in a manner analogous to that received by other vehicles using the highway in the truck mode. Shipment parameters used to compute population dose for rail transport are shown in Table 4-9.

4.3.3.1 Transport by Freight Trains

Because of the length of time required for a shipment and special capability for handling massive loads, the principal radioactive materials shipped by rail are those with long half-lives or those that require special shielding. An example of a shipment of this sort would be a large irradiated fuel cask. The only material shipped by passenger train is a negligible amount of "limited" postal shipments.

4.3.3.1.1 Exposure of Train Crew

An average freight train is composed of approximately 70 cars. As a result, the proximity of the train crew to a car carrying radioactive material is difficult to quantify except on a statistical basis. While the train is in motion, the brakeman or conductor in the caboose may be as close as 3 meters or as far as a few thousand meters from a radioactive shipment. If the latter condition occurs, a great deal of intervening cargo acts to shield the crew car. Similar arguments can be made for the engine crew so long as there is only one shipment per train. If there is only a single cargo car making up the train, the engine crew and caboose crew experience similar dose rates.

The dose received by the crew is calculated in a manner similar to that for trucks. The dose-rate formula (Equation (D-1), Appendix D) is used with d = 152 meters, and the average exposure time is given by the average shipment distance divided by the average speed. A total of five crew members is assumed. The computation is performed for each standard shipment involving rail transport, and the results are summed to obtain an annual population dose to crew members of 0.9 person-rem.

The maximum annual individual dose to a member of a train crew is estimated for 50 irradiated fuel shipments per year, an average separation distance of 152 meters, and an average crew time of 8 hours. This combination gives a maximum annual dose of 1.2 mrem.

4.3.3.1.2 Exposure of On-link and Off-link Population

Those persons exposed on the transport link are passengers on trains or freight train crews who pass or who are passed by a train carrying radioactive materials. This calculation

TABLE 4-9

SHIPMENT PARAMETERS FOR CALCULATION OF POPULATION DOSE FOR THE RAIL MODE

Transport Parameters	High-Population Areas	Medium-Population Areas	Low-Population Areas
Average Speed (km/hr)	24	40	64
Distribution of Travel Distance	0.05	0.05	0.9
Population Density (people/km^2)	3,861	719	6
Stop Duration (hr)	0	0	24
Passenger Trains (trains/day)	5	5	1
Number of Crew (engineer, fireman, conductor, and 2 brakemen)	5	5	5
Average Separation Distance Between Crew and Radioactive Material (m)	152	152	152

Total TI shipped = 1.8×10^5*

*A TI of 111 is assigned to spent fuel shipments to correspond to the regulatory limit of 10 mrem/hr at a distance of 6 feet from the surface of the vehicle.

is similar to that for truck transport, assuming one freight train per hour and a 10-foot mimimum separation between passing trains. Because of the very small number of passenger trains and the small number of freight train crew members, the on-link annual dose is only 0.012 person-rem. The maximum annual individual on-link dose is negligible owing to the small number of passing trains.

Using the data given in Table 4-9, and summing over the population zones, an annual value of 23 person-rem to the surrounding off-link population is obtained. The maximum off-link dose is similar to that received by a railway station employee who works at a railway station near a spent fuel reprocessing site. If 17 trains per year carrying irradiated fuel pass that station at an average distance of 30 meters and an average speed of 8 km per hour, and if that same station employee is working when each of them pass, he will receive 0.017 mrem according to Equation (D-2) in Appendix D, with K = 1000 mrem-ft^2 per hour.

4.3.3.1.3 Exposure to Population During Stops

As indicated earlier, freight trains frequently stop at rail sidings in order to let other trains pass or to pick up additional cars. In addition, crew change and fuel stops occur at 4-to-6-hour intervals throughout the trip. If it is assumed that the train is stopped a total of 24 hours per trip and those stops occur predominately in low population density zones, a total annual population dose while stopped of 0.9 person-rem is computed using the general expression for population dose during shipment stops derived in Section D.2 of Appendix D for each standard shipment and summing the results.

An example of the maximum dose to an individual while the train is stopped is that received by a railroad employee who serviced the train while it was stopped. If it is postulated that the employee works at a station near an irradiated fuel reprocessing center that handles 100 percent of the annual rail shipments and that this employee spends an average of 15 minutes at an average distance of 15 meters from each shipment, his annual dose would be 1.65 mrem. This value was obtained using the dose-rate formula in Appendix D, Equation (D-1) with d = 15 meters and assuming 17 shipments per year and a K of 1000 mrem-ft^2 per hour.

4.3.3.2 Storage Associated with Rail Transport

Very little storage is likely to be associated with rail transport of radioactive materials. A spent fuel shipment that occupies a single car might spend 24 hours in rail yards waiting to be included in a train to take it toward its destination. In such a location, the average exposable population density is estimated to be 25 people per km^2, corresponding to 20 employees in a railyard 1.6 kilometers long and 0.5 kilometer wide. Again, using the formula for dose while stopped, given in Section D.2 of Appendix D, an annual population dose of 0.7 person-rem is obtained.

An example of the maximum individual dose during rail shipment storage is that delivered to a railroad employee assigned to service or check the railcars carrying irradiated fuel in the yard prior to final coupling to the parent train. If such a person checks 17 such trains per year at an average distance of 8 meters, and if such a check takes 1 hour, he would receive an annual dose of 25 mrem. This number was obtained by using Equation (D-1) of Appendix D for the dose rate and assuming a K value of 1000 $mrem\text{-}ft^2$ per hour for each shipment, as in the standard shipment model.

4.3.3.3 Summary

The annual doses resulting from rail transport of radioactive material are summarized in Table 4-10; the total is 26 person-rem (exclusive of freight handler dosage).

4.3.4 TRANSPORT BY WATER

Historically, water transport modes have been used for shipments of material that are massive or bulky or that do not require exceptionally fast travel. Shipments of irradiated fuel and fresh fuel would therefore qualify for water transport. A considerable number of export shipments of enriched uranium and long-half-life isotopes by ship were reported to have occurred in 1975 (see Appendix A).

4.3.4.1 Transport by Barge

It is anticipated that barge may be a feasible method for transporting fresh fuel to reactors and irradiated fuel to reprocessors located on appropriate waterways. No such shipments were reported in the 1975 shipper survey. However, at least one shipment occurred in early 1976. With relatively few people exposed during movement and a few exposed at each terminal, population exposure is expected to be negligible. The transport of irradiated fuel by barge is considered as an alternative in Chapter 6 of this report.

4.3.4.2 Transport by Ship

For the overseas export-import trade in radioactive materials, there are only two transport modes available: air and ship. Generally, relatively light-weight packages (less than a few tonnes) of short-half-life materials are transported by aircraft. The 1975 survey revealed a total of 3747 TI transported by ship, principally enriched uranium, fresh reactor fuel, and Kr-85. The total annual population dose from these shipments was calculated to be 8.1 person-rem using the transport parameters in Table 4-11 and the same computational techniques as used for other transport modes. The results are summarized in Table 4-12.

An example of the maximum dose is that received by a crewman whose assigned watch station includes the cargo area in which an enriched uranium shipment is stowed. If that person stands 8 hours of watch every day and makes normal hourly rounds, he probably spends 5 minutes per hour at an average distance of 3 meters from the shipment. If his vessel carries a single shipment per year and the trip lasts 10 days, his annual dose would be 3.7 mrem. Individual exposures of the other population subgroups were not evaluated because the actual numbers of people and their yearly exposures were not known.

TABLE 4-10

DOSES FROM RAIL TRANSPORT OF RADIOACTIVE MATERIAL - 1975

Population Subgroup	Annual Population Dose (person-rem)	Maximum Annual Individual Dose (mrem)
Crew	0.9	1.2
Surrounding population		
On-link	0.012	not evaluated
Off-link	23	0.017
Bystanders/Railway Workers	0.9	1.65
Storage	0.7	25
TOTAL	26	

TABLE 4-11

SHIPMENT PARAMETERS FOR CALCULATION OF POPULATION DOSE FOR WATERBORNE TRANSPORT MODES

	Ship	Barge
Number of Crewmen	10	5
Mean Velocity (km/hr)	14	5
Distance from Source to Crew (m)	61	46
Fraction of Travel		
High population zones	0.001	0.01
Medium population zones	0.009	0.09
Low population zones	0.99	0.90
Total Stop Time (hr)		
(Medium population zone)	10	10

Total TI Shipped = 3747

TABLE 4-12

DOSE RESULTING FROM SHIP TRANSPORT OF RADIOACTIVE MATERIAL - 1975

Population Subgroup	Annual Population Dose (person-rem)	Maximum Annual Individual Dose (mrem)
Crew	5.7	3.7
Bystanders/stevedores during stops	1.1	not evaluated
Persons in port area (off-link)	0.9	not evaluated
Persons in vicinity of storage area	0.4	not evaluated
TOTAL	8.1	

4.4 EXPOSURE OF HANDLERS

Handlers of radioactive material packages are generally exposed to the highest dose rates of any population group; however, because they handle the packages for relatively short times, relatively small doses are received. Handling, as defined in this report, occurs whenever a package is transferred from one mode to another, irrespective of the number of people and physical movements that take place. A recent study (Ref. 4-11) indicated that the average population dose received by handlers at airports was 2.5×10^{-4} person-rem per TI for small packages. This population dose conversion factor was used for each handling considered in this report. Thus the dose computed for handlers is likely to be conservative because the number of people involved in airport handling is likely to be the largest and the time spent in handling the most prolonged throughout the shipping industry.

In this document, the handler dose is computed by multiplying this average dose conversion factor by the average TI per package, the number of packages per shipment, the number of shipments per year, and an estimated number of handlings per package. This calculation is repeated for each standard shipment, and the total handler dose is obtained by summing all standard shipments. The total annual handler dose was calculated to be 1740 person-rem.

Irradiated fuel casks and irradiator sources, because of their large sizes, are not handled in the same ways as smaller packages. Two handlers are assumed to spend 15 minutes at both the shipping end and the receiving end attaching and detaching rigging equipment for loading and unloading the cask in an average radiation field of 200 mrem per hour (1 meter from the cask) (Ref. 4-10). This results in a population dose of 0.1 person-rem (2 persons x 200 mrem per hour x 1/4 hour) at each end, for a total of 0.2 person-rem per shipment. Multiplication by the number of shipments per year gives the annual population dose in person-rem. A total of 54 person-rem to handlers may result from the handling of large casks. Much of this exposure is not expected to be within the transport industry but rather to employees of the shippers and consignees.

Individual doses to handlers have been evaluated for those employed in airport terminals (Ref. 4-11). Results of those studies indicate that no workers would receive annual doses in excess of 500 mrem and most workers who participated in the survey would have received annual doses smaller than 100 mrem as a result of handling radioactive material shipments. It is expected that the individual doses to airport handlers are the largest of any similar group.

4.5 NONRADIOLOGICAL IMPACTS ON THE ENVIRONMENT

The two principal nonradiological impacts that may arise from the normal transport of radioactive material are area denial and resource use.

4.5.1 AREA DENIAL

There is no significant area denial resulting from normal transport of radioactive material packages. Most packages are shipped along with other freight and are stored in the same terminals as other freight awaiting shipment. Although radioactive material packages are usually isolated in designated areas of freight terminals, it is doubtful that significantly smaller total floor areas would be required if there were no transport of radioactive materials. Exclusive-use shipments require no storage, since they proceed directly from shipper to consignee.

4.5.2 RESOURCE USE

The primary resource uses associated with radioactive material transport include the commitment of shielding material for construction of packages and the use of energy to move the transport vehicles. The shipment of radioactive material requires shielding of individual packages to reduce exposure to people and photographic materials during transport. Construction of these packages requires commitment of natural resources in a manner that may or may not permit recycling and reuse. The principal materials used for shielding are lead and depleted uranium. Quantities committed at any one time to use as shielding in transportation packaging are only a small percentage of the total amounts of these materials used for all other purposes.

Reuse of lead shielding material by return of used packages to the shipper is accomplished (according to an interview with a major radiopharmaceutical shipper) about 50 percent of the time. In the remaining cases, the disposition of the material is unknown, but it is assumed that a significant recycling effort takes place. This assumption is based largely on the fact that the radioactive material packages are received by people who are licensed to possess radioactive materials and who appreciate the value of reusing the shielding material either directly or by recasting it into a usable form. In addition, industrial and commercial users often have an active salvage operation for metals of all kinds. Thus, one might well expect no more than 20 percent loss in lead shielding material per year. A significant fraction of this material is sent to refuse disposal areas. The environmental impacts of this loss are the energy and resources necessary to replace the unreturned material and the presence of lead in an uncontrolled environment.

Depleted uranium is typically used as shielding in large casks such as those used to ship irradiated fuel or large irradiator sources. Since these casks are quite costly, the uranium resources involved are carefully controlled and fully recycled. Depleted uranium used to construct shields is obtained from enrichment tailings and, at present, has few alternative uses.

Other materials such as wood, steel, fiberboard, and plastic are also used in the construction of packaging used to transport radioactive materials. Since radioactive materials constitute only a very small percentage of the total amount of goods transported in similar packages, the use of these resources for their transport is considered negligible.

The second area of resource use is in the operation of the transportation industry itself. The transport of material requires the commitment of personnel, money, and resources. Since radioactive material packages account for only 2×10^6 of the 500×10^9 packages transported annually, and since, for the most part, they are transported incidentally to other freight, virtually no savings in resources would be realized if they were removed from the transport process.

Certain radioactive material shipments, however, cannot be handled routinely along with other freight. Because of excessive bulk, radioactivity, or massive shielding, certain shipments are handled as the exclusive cargo for transport between two locations. Examples of these kinds of shipments are irradiated fuel from military and civilian reactors and large irradiator sources. Natural and enriched uranium are usually carried on exclusive-use vehicles because of their bulk rather than their radioactive properties. The resource use and environmental impact committed to such shipments can be identified with and charged to the transportation of radioactive materials. Such environmental impact items as fuel use, noise, pollution, and accidental injuries and deaths can be associated with such activities. A considerable amount of material is transported by exclusive-use vehicles, but only about 7,500 such shipments consisting of nuclear fuel, waste, large quantity source, and some radiopharmaceuticals are made per year. These shipments are a negligible fraction of the total number of shipments of all materials and therefore account for only a small fraction of these nonradiological transportation impacts.

4.6 ABNORMAL TRANSPORT OCCURRENCES

In each mode of transport there is a class of incidents that occur infrequently and that cause additional radiation exposure and radioactive contamination. These incidents are considered here as a component of normal transportation because they do not involve accidents that cause damage to the shipping vehicle. Included are such events as dropping of packages by material handlers, packages being run over and crushed by a vehicle, and skewering of packages by a fork lift, any of which may compromise package integrity. Other occurrences relate to packaging procedures and include failure to pack the radioactive materials properly, labeling packages with an incorrect TI rating (either too large or too small), failure to close seals properly, use of defective fittings, or failure to provide adequate shielding. Package loss is yet another in the class of abnormal occurrences, any of which may result in excess radiation exposure to handlers or to the general public.

The DOT received 144 hazardous material incident (HMI) reports involving radioactive materials during the 5-year period 1971-1975 (Ref. 4-12). Releases were indicated in only 36 of these reports. About half of these releases occurred in 1975 (20 incidents), indicating that fewer than one out of every 100,000 packages were involved in incidents leading to a release. Air carriers (including air freight forwarders) accounted for about half the total number of reports submitted. Highway carriers accounted for about 45 percent, and the remainder were filed by rail carriers. Over 60 percent of the releases were noted by highway carriers. Most of the air shipment incidents involved Type A or limited packages of radiopharmaceuticals. Appendix F includes 98 of these incidents in a list of hazardous material incident reports obtained from DOT.

Five of the twelve reported releases in the air mode involved packages dropped in handling, typically falling off a cargo handling cart and then being run over and crushed by a vehicle. Other releases for the air mode resulted from damage by other freight, external puncture, loose fittings or closures, or other improper packaging.

The reported highway incidents included Type A radiopharmaceutical packages, drummed low-specific-activity wastes, large casks, and radiography sources. Twelve of the reported incidents (only one of which involved a release of radioactivity) were caused by vehicular accidents and are therefore the subject of Chapter 5. Defective or improper packaging was responsible for over half the incidents that involved a release.

A principal impact produced by a damaged package is radiation exposure of individuals handling the package and others who are near the package for a period of time, especially before the damage is detected. Other impacts are associated with the resulting radioactive contamination, including the doses received by cleanup crews and the cleanup costs. For most packages (e.g., radiopharmaceuticals or small industrial sources), this is a small effect.

As an example of the radiation levels to which persons might be exposed, a 30-curie Ir-192 source with complete loss of shielding resulting from a packaging error could produce a dose rate of as much as 25 rem per hour at 1 meter from the center of the package. A single incident in which shielding was lost on one side of such a package is known to have occurred. Although the exposed individuals exhibited no detectable acute health effects (indicating a dose of less than 25-50 rem), it is clear that the potential exists for large individual doses under these circumstances.

Most radioactive materials are shipped in Type A packages, which are designed to withstand only normal conditions of transportation. The quantities of material released in package-damaging incidents are expected to be on the order of 10^{-3} of the package content. With this release fraction for Type A quantities of a radionuclide and assuming that 10^{-3} of the material released is inhaled, ingested, or absorbed, an average individual dose rate about 0.5 rem per year is expected. (This dose rate and release fraction are derived from the basis of the IAEA Type A quantity specification for each material.) Since most handling accidents are likely to occur in terminal areas, fewer than 10 people are likely to be exposed and the population exposure received per incident is unlikely to be greater than 5 person-rem. For the current 20 incidents involving a release per year, the expected annual population dose rate is expected to be less than 100 person-rem from this source.

4.6.1 IMPROPER LABELING OF PACKAGES

Estimates of the annual radiological impacts resulting from abnormal occurrences are difficult at best, since incidents involving release or partial loss of shielding are so diverse, and the numbers of persons exposed are usually not known. Some of the shipments reported in the 1975 Survey (Ref. 4-13, described in Chapter 1) may have included packages with incorrectly assigned transport indexes. If the total reported TI were too low, the annual normal dose is higher than that calculated in this chapter. On the other hand, if the total reported TI were too high, the annual dose would be lower than anticipated. However, assigning a TI higher than that warranted by the radiation level could cause shipments to be unnecessarily delayed because of restrictions on the maximum TI allowed on a transport vehicle. Improper labeling of packages usually occurs for one of the following reasons: (a) premature release of the package for shipment or (b) an error in measuring the radiation level at 3 feet from the package surface to determine the TI.

Premature release of a package for shipment is a particular problem with short-half-life materials because the decay that occurs between labeling and actual commencement of shipping is factored into the labeling process. If the time lag is underestimated consistently, an extra hazard may be incurred by the public and the industry.

Measurements of package TIs in 1973 showed a significant number had more TIs than stated on the label (Ref. 4-14). To combat this problem and that resulting from improper shielding, FAA has proposed that every package offered to the airlines be monitored before it is accepted for shipment. This procedure might catch shipping errors before the consequences could affect a large number of people.

4.6.2 IMPACT RESULTING FROM LOSS OF CONTROL OF RADIOACTIVE MATERIAL PACKAGES

The principal impact resulting from loss of control of a package is irradiation of people in the vicinity of the package who are unaware of its presence or contents. Loss of control might result when a package is separated from its radioactive labels or if it is dropped during transport. Either scenario is potentially more serious if shielding or package integrity is lost, especially if a long-half-life nuclide is involved.

A typical population dose may be computed by using Equation (D-9) of Appendix D, where allowance is made for the change of the TI with time due to radioactive decay:

$$D(T) = \frac{K_o}{0.693} I(x,d) PD (TI)_o t_{\frac{1}{2}} \left(1 - e^{\frac{-0.693T}{t_{\frac{1}{2}}}}\right) \quad (4\text{-}2)$$

where $I(x,d) = 2\pi \int_x^d \frac{1}{r} e^{-\mu r} B(r) dr$

$t_{\frac{1}{2}}$ = half-life of isotope

$(TI)_o$ = initial package TI

PD = population density

T = time during which package is lost

K_o = TI to dose rate constant conversion factor

Assuming a suburban population density of 719 persons per km^2 (6.68×10^{-5} persons per ft^2) and a 1.0-TI Type-A package of I-131 with a half-life of 8 days, the population dose received is about 7×10^{-3} person-rem, assuming the package is lost indefinitely. The population dose associated with a lost package in an area of higher population density would be proportionally higher, but is unlikely to reach a significant level.

The average time to recover a lost package is approximately 14 days (based on incidents reported during 1976). A high dose rate makes a package easier to locate using radiation survey equipment. Using the 14-day value in the above calculation, the population dose for an I-131 package loss is of the order of 0.005 person-rem. Records indicate an average of 5 losses per year over the last 9 years. Assuming all lost packages to be like the I-131 package just considered, an average annual population dose of 0.025 person-rem might be expected.

4.7 SHIPMENT BY FREIGHT FORWARDERS

The previously mentioned State surveillance studies (Ref. 4-15) examined four freight forwarder locations where consolidation of radiopharmaceutical packages is carried out. The average annual population exposure associated with these operations was found to be 4 person-rem per location. It is estimated that there are no more than 10 such locations throughout the country, resulting in a maximum annual population exposure of 40 person-rem.

4.8 EXPORT AND IMPORT SHIPMENTS

Export risks are considered to occur from the time the material leaves the shipper until it enters the country of its destination. This includes the secondary mode link from the shipper to the U.S. port of departure and the primary mode link to the first port of entry into the destination country, but not the secondary mode link to the ultimate destination within the foreign country. Import risks are considered to occur from the time the shipment first arrives in the U.S. until it reaches its ultimate U.S. destination. Thus, import risks are associated primarily with the secondary mode transport of the material from the U.S. port of entry to its destination.

4.8.1 EXPORT SHIPMENTS

The export normal risks were evaluated in ways completely analogous to the total normal risk evaluation using the export standard shipments model discussed in Appendix A, Section A.6.1. Secondary mode mileages were half of their counterparts in the total risk calculation, since the secondary mode link on the receiving end was not considered and the number of handlings were adjusted accordingly. The results are given in Tables 4-13 and 4-14 by transport mode and material, respectively. The total annual normal population dose resulting from export shipments is 61 person-rem, or 0.6 percent of the total 1975 normal risk.

The maximum individual dose due to export shipments is unlikely to be greater than that delivered to an airline passenger who happens to fly on a number of passenger aircraft flights carrying radioactive materials. The data indicated about 600 TI were exported by passenger aircraft. If these 600 TI were transported on 50 flights each carrying 12 TI and if an individual happened to fly on one-fourth of all flights with radioactive materials and experience the average 0.36 mrem per hour dose rate (0.030 mrem per hour TI x 12 TI) for an average of 8 hours per flight, his total dose would be 36 mrem.

4.8.2 IMPORT SHIPMENTS

Since imports reported in the 1975 Survey accounted for only an estimated 40 TI and the total TI transported annually is 4.5×10^6, the contribution of these to the total normal dose is considered negligible.

TABLE 4-13

ENVIRONMENTAL IMPACT OF NORMAL EXPORT SHIPMENTS (BY MODE)

SUMMATION OF GROUP POPULATION EXPOSURE TO RADIATION IN PERSON REM AS A RESULT OF TRANSPORT OF VARIOUS RADIOACTIVE MATERIALS BY VARIOUS TRANSPORT MODES UNDER NORMAL CONDITIONS

	GROUPS				SURROUNDING POPULATION				
					WHILE MOVING				
MODE OF SHIPMENT	PASSENGERS	CREWMEN	ATTENDANTS	HANDLERS	OFF LINK	ON LINK	STOPS	STORAGE	TOTALS
PASS. AIR	1.002E+01	6.833E-02	4.794E-01	6.097E-01	0.	0.	1.512E-02	0.	1.119E+01
CARGO AIR	0.	5.320E+00	0.	3.610E+00	0.	0.	1.021E-01	0.	9.033E+00
TRUCK	0.	1.573E+00	0.	0.	4.627E-02	2.363E-02	1.723E-01	4.510E-02	1.863E+00
SEC. MODES	0.	7.055E+00	0.	6.156E+00	9.492E-01	4.006E+00	9.274E-01	3.739E+00	2.283E+01
RAIL	0.	0.	0.	0.	0.	0.	0.	0.	0.
OTHER	0.	7.669E+00	0.	3.855E+00	1.179E+00	0.	2.251E+00	8.193E-01	1.577E+01
TOTALS	1.002E+01	2.169E+01	4.794E-01	1.423E+01	2.177E+00	4.030E+00	3.467E+00	4.603E+00	6.869E+01

TABLE 4-14

ENVIRONMENTAL IMPACT OF NORMAL EXPORT SHIPMENTS (BY ISOTOPE)

SUMMATION OF GROUP POPULATION EXPOSURE TO RADIATION IN PERSON REM AS A
RESULT OF TRANSPORT OF VARIOUS RADIOACTIVE MATERIALS UNDER NORMAL CONDITIONS

	GROUPS				SURROUNDING POPULATION				
					WHILE MOVING				
ISOTOPE SHIPMENT	PASSENGERS	CREWMEN	ATTENDANTS	HANDLERS	OFF LINK	ON LINK	STOPS	STORAGE	TOTALS
AM241-A	6.743E-01	2.113E-01	3.227E-02	1.672E-01	6.277E-03	1.331E-02	2.098E-02	2.815E-02	1.154E+00
AM241-B	1.099E-02	4.994E-03	5.258E-04	4.200E-03	1.288E-04	5.438E-04	3.015E-04	4.448E-04	2.213E-02
AU198	0.	4.845E-03	0.	9.000E-03	2.499E-04	1.051E-03	5.411E-04	7.982E-04	1.648E-02
CO57	3.502E-02	3.274E-03	1.676E-03	1.500E-02	2.386E-04	1.007E-03	9.018E-04	1.330E-03	5.845E-02
CO60-A	0.	2.781E-03	0.	3.000E-03	8.301E-05	3.503E-04	1.804E-04	2.661E-04	6.661E-03
CO60-B	0.	1.272E-01	0.	1.950E-02	3.334E-03	2.846E-03	4.965E-03	6.195E-03	1.640E-01
C-14	2.725E+00	2.524E-01	1.304E-01	4.464E-01	8.234E-03	3.475E-02	2.684E-02	3.959E-02	3.663E+00
IR192-A	0.	1.204E-02	0.	1.500E-02	4.150E-04	1.752E-03	9.018E-04	1.330E-03	3.144E-02
IR192-B	0.	1.202E-01	0.	2.208E-01	7.295E-03	3.079E-02	1.585E-02	2.338E-02	4.183E-01
MF+MCA	0.	1.190E-01	0.	1.674E-01	4.632E-03	1.955E-02	1.006E-02	1.485E-02	3.355E-01
I131-A	9.624E-01	3.041E-02	4.606E-02	1.152E-01	1.733E-03	7.315E-03	6.926E-03	1.022E-02	1.180E+00
MIXED-A	5.713E-03	4.222E-04	2.734E-04	2.100E-03	3.113E-05	1.314E-04	1.262E-04	1.862E-04	8.983E-03
MO99-A	4.124E+00	6.959E-01	1.974E-01	1.074E+00	2.191E-02	9.249E-02	8.125E-02	1.146E-01	6.401E+00
MO99-B	8.520E-01	7.176E-02	4.078E-02	8.100E-02	1.858E-03	7.843E-03	5.814E-03	8.578E-03	1.070E+00
P32-R	1.042E-01	6.856E-03	4.986E-03	1.806E-02	3.123E-04	1.318E-03	1.086E-03	1.602E-03	1.384E-01
XE133-A	1.004E-01	3.963E-03	4.806E-03	1.176E-02	1.743E-04	7.357E-04	7.713E-04	1.117E-03	1.237E-01
RA226-A	0.	1.702E-02	0.	2.408E-02	6.641E-04	2.803E-03	1.443E-03	2.128E-03	4.806E-02
KR85-A	1.252E-01	8.369E-02	5.992E-03	5.082E-02	5.297E-03	8.374E-03	6.256E-03	8.721E-03	2.943E-01
PU238-B	1.892E-02	1.716E-02	9.055E-04	1.512E-02	4.371E-04	1.845E-03	1.316E-03	1.868E-03	5.756E-02
U238	0.	7.413E-02	0.	2.673E-02	9.111E-03	8.062E-03	7.639E-03	1.030E-02	1.360E-01
UF6-E-LG	0.	7.362E+00	0.	7.420E+00	6.575E-01	2.291E+00	1.998E+00	2.586E+00	2.232E+01
UO2-E-LG	2.785E-01	1.113E+01	1.333E-02	3.251E+00	1.411E+00	1.353E+00	1.198E+00	1.628E+00	2.026E+01
UO2-RX	0.	1.339E+00	0.	1.071E+00	3.538E-02	1.493E-01	7.688E-02	1.134E-01	2.785E+00
TOTALS	1.882E+01	2.169E+01	4.794E-01	1.423E+01	2.177E+00	4.030E+00	3.467E+00	4.603E+00	6.069E+01

4.9 SUMMARY OF ENVIRONMENTAL IMPACTS FOR NORMAL TRANSPORT

In this summary only the radiological impacts from normal transport of radioactive materials are discussed in detail, since they are the predominant ones. Other impacts, e.g., area denial and resource use, are secondary. Because radioactive materials are carried most often on vehicles whose prime purpose is to carry passengers or other freight, these secondary impacts would occur regardless of the presence of the radioactive material package. The impacts predicted for 1985 are based on the scaled-up standard shipments model presented in Appendix A.

The radiological impact in terms of annual population doses is given in Table 4-15 for various population subgroups and modes of shipment. Table 4-16 shows similar information classified by isotope shipment rather than by mode of shipment. Tables 4-17 and 4-18 show the projected values for 1985. Table 4-19 summarizes the maximum individual annual dose values. From the data contained in these five tables, the following observations can be made:

1. Shipments of waste material account for 15 percent of the 1975 dose and 24 percent of the 1985 dose. These shipments are numerous and have large TI values. Shipment of isotopes for medical use accounts for approximately 52 percent of the total 1975 dose and 38 percent of the 1985 dose. While each such shipment emits radiation at relatively low intensity, the number of such shipments is very large. Shipments of isotopes for industrial use account for 24 percent of the 1975 dose and 22 percent of the 1985 dose. Nuclear fuel cycle shipments account for 9 percent of the 1975 dose and 15 percent of the 1985 dose. Limited shipments contribute 0.6 percent of the 1975 dose and 0.7 percent of the 1985 dose.

2. The highway transport modes (truck and delivery van) contribute 69 percent of the total 1975 dose. Passenger air transport accounts for 30 percent of the total 1975 dose.

3. On the basis of person-rem per TI carried, the passenger air mode causes the largest radiological effect for the material carried. Values for each mode are shown below:

Mode	Person-rem per TI carried
Passenger air	0.0067
Ship	0.00265
Secondary modes	0.00198
All-cargo air	0.00128
Truck	0.00116
Rail	0.00065

When the mean person-rem per TI for secondary transport modes is added o that for each primary transport mode, the ranking is as follows:

TABLE 4-15

ANNUAL NORMAL POPULATION DOSES (PERSON-REM) FOR 1975

SHIPMENTS BY POPULATION GROUP AND TRANSPORT MODE

Transport Mode	Population Group								Totals	% of Total
					Surrounding Population					
	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage		
Passenger Aircraft	2330.0	16.000	111	433.00	0	0	10.800	0	2902.00	30
Cargo Aircraft	0	4.090	0	16.10	0	0	0.413	0	20.60	-
Truck	0	2580.000	0	51.60	347.000	172.000	999.000	261.000	4406.00	45
Rail	0	0.893	0	92.50	22.500	0.012	0.879	0.666	117.00	1
Other	0	5.710	0	1.87	0.878	0	1.080	0.392	9.93	-
Secondary Modes	0	534.000	0	1143.00	51.200	216.000	79.200	310.000	2333.00	24
TOTALS	2330.0	3140.000	112	1740.00	422.000	388.000	1090.000	572.000	9790.00	
% OF TOTAL	24	32	1	18	4	4	11	6		

TABLE 4-16

ANNUAL NORMAL POPULATION DOSES (PERSON-REM) FOR 1975
SHIPMENTS BY POPULATION GROUP AND MATERIAL

Material		Passengers	Crew	Attendants	Handlers	Surrounding Population Off-Link	On-Link	Stops	Storage	Totals	% of Total
Am-241	A	18.900	115.000	0.905	79.000	4.380	10.500	14.600	18.400	262.000	3.0
Am-241	B	.413	1.100	0.020	0.240	0.032	0.047	0.046	0.059	1.950	-
Au-198		15.500	25.200	0.740	16.600	0.938	2.180	2.440	3.140	66.700	1.0
C-14		2.790	1.230	0.134	0.805	0.046	0.109	0.079	0.107	5.300	-
Co-57		6.500	4.590	0.311	1.960	0.150	0.279	0.231	0.305	14.300	-
Co-60	LSA	7.490	110.000	0.358	43.900	3.720	7.280	10.400	13.100	197.000	2.0
Co-60	A	0	433.000	0	122.000	13.000	19.000	26.100	32.500	645.000	7.0
Co-60	B	0	10.900	0	3.290	0.265	0.131	0.864	1.04	16.400	-
Co-60	LQ_1	0	0.110	0	0	0.003	0.001	0.004	0.001	0.120	-
Co-60	LQ_2	0	0.627	0	0.800	0.075	0.038	0.076	0.020	1.640	-
Cs-137	A	3.440	138.000	0.165	130.000	5.300	16.300	27.100	33.800	355.000	4.0
Cs-137	B	0	0.605	0	0.222	0.02	0.039	0.054	0.067	1.010	-
Ga-67		3.360	7.940	0.161	6.030	0.312	0.781	0.955	1.22	20.800	-
H-3	LSA	0.321	0.213	0.015	0.253	0.010	0.032	0.026	0.035	0.906	-
H-3	A	0.314	0.169	0.015	0.115	0.006	0.015	0.012	0.016	0.663	-

TABLE 4-16 (continued)

Material	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage	Totals	% of Total
I-131 A	1000.000	504.000	48.000	426.00	20.500	54.600	43.000	57.900	2160.000	22.0
I-131 B	0.848	1.140	0.041	0.554	0.041	0.090	0.088	0.114	2.420	-
Ir-192 A	20.500	18.400	0.981	9.370	0.638	1.350	1.140	1.500	53.800	-
Ir-192 B	170.000	265.000	8.140	85.000	8.500	15.300	14.000	18.100	584.000	6.0
Kr-85 A	10.100	25.100	0.483	6.440	0.816	1.170	1.090	1.400	46.600	-
Kr-85 B	0.092	0.224	0.004	0.060	0.007	.011	0.011	0.014	0.424	-
Limited	17.800	26.600	0.853	11.600	0.878	1.660	1.690	2.170	63.300	1.0
MF+MC LSA	0	22.500	0	0	3.470	1.710	16.100	4.210	47.900	-
MF+MC A	0	18.600	0	0	8.940	4.410	32.200	8.440	72.700	1.0
MF+MC B	0	1.080	0	0	0.026	0.013	0.106	0.028	1.250	-
MF+MC LQ	0	0.326	0	0	0.008	0.004	0.011	0.003	0.351	-
Mixed LSA	1.250	19.000	0.060	6.970	0.626	1.170	1.670	2.090	32.800	-
Mixed A	1.680	25.000	0.080	17.600	0.956	2.300	3.540	4.440	55.700	1.0
Mixed B	0	1.500	0	0.576	0.050	0.096	0.147	0.183	2.550	-
Mo-99 A	873.000	715.000	41.800	393.000	25.100	53.800	47.600	62.600	2210.000	23.0
Mo-99 B	144.000	127.000	6.890	31.100	3.810	5.800	4.500	5.920	329.000	3.0
P-32	10.900	6.630	0.522	4.510	0.250	0.599	0.491	0.654	24.600	-
Po-210 A	0.019	0.018	0.0009	0.013	0.0007	0.002	0.002	0.002	0.056	-

TABLE 4-16 (continued)

Material	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage	Totals	% of Total
Po-210 LQ	0.171	0.150	0.008	0.058	0.005	0.010	0.008	0.011	0.421	-
Pu-238 A	0.080	0.179	0.004	0.158	0.007	0.020	0.024	0.031	0.505	-
Pu-238 B	0.589	1.250	0.028	0.357	0.038	0.063	0.066	0.084	2.480	-
Pu-239 B	0.915	27.900	0.044	6.190	0.825	1.170	1.530	1.910	40.500	-
Pu-239 LQ	0	0.003	0	0.003	0.0002	0.0008	0.0002	0.0003	0.008	-
Ra-226 A	0	58.700	0	27.300	1.97	3.790	5.820	7.260	105.000	1.0
Ra-226 B	0.104	1.330	0.005	1.380	0.065	0.204	0.314	0.396	3.800	-
Spent fuel - rail	0	0.068	0	6.800	0.175	0.222	0.089	0.427	7.780	-
Spent fuel - truck	0	31.300	0	50.800	3.8	1.880	4.820	1.260	93.800	1.0
Tc-99	3.440	42.200	0.165	57.700	2.160	7.050	11.200	14.000	138.000	1.0
UF6-nat	0	17.200	0	6.500	1.030	1.310	1.810	2.540	30.400	-
UF6-enr	0	3.140	0	0.147	0.118	0.135	0.218	0.107	3.870	-
U02-enr	0	19.500	0	2.970	2.830	3.250	5.210	2.570	36.300	-
U02-Rx	0	12.500	0	0.395	0.443	0.465	0.689	0.341	15.000	-
U308	0	113.000	0	172.000	47.000	38.900	47.800	67.100	485.000	5.0
U-Pu	1.840	12.700	0.088	1.960	0.356	0.422	0.439	0.553	18.400	-
Waste LSA	0	17.400	0	0	3.450	1.700	12.600	3.290	38.400	-

TABLE 4-16 (continued)

Materials	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage	Totals	% of Total
Waste A	0	139.000	0	0	254.000	125.000	746.000	195.000	1460.000	15.0
Waste B	0	0.565	0	0	0.357	0.176	1.580	0.413	3.090	-
Xe-133	10.8	12.800	0.516	5.460	0.421	0.789	0.743	0.964	32.500	-
TOTAL	2330,000	3140.000	112.000	1740.000	422.000	388.000	1090.000	572.000	9790.000	
PERCENT	24	32	1	18	4	4	11	6		

TABLE 4-17

ANNUAL NORMAL POPULATION DOSES (PERSON-REM) FOR 1985 SHIPMENTS BY POPULATION GROUP AND TRANSPORT MODE

Transport Mode	Population Group: Passengers	Crew	Attendants	Handlers	Surrounding Population: Off-Link	On-Link	Stops	Storage	Totals	% of Total
Passenger Aircraft	4010	27.30	192	702.00	0	0	17.30	0	4948.0	19
Cargo Aircraft	0	37.80	0	146.00	0	0	3.96	0	188.0	1
Truck	0	6649.00	0	308.00	1340.00	662.000	3870.00	1010.00	13840.0	54
Rail	0	3.86	0	499.00	97.40	0.052	3.85	2.92	607.0	2
Other	0	29.60	0	7.60	3.86	0	4.37	1.59	47.0	-
Secondary Modes	0	1220.00	0	2820.00	132.00	557.000	195.00	814.00	5732.0	23
TOTALS	4010	7970.00	192	4480.00	1580.00	1220.000	4090.00	1830.00	25400.0	
% OF TOTAL	16	31	1	18	6	5	16	7		

TABLE 4-18

ANNUAL NORMAL POPULATION DOSES (PERSON-REM) FOR 1985
SHIPMENTS BY POPULATION GROUP AND MATERIAL

Material	Passengers	Crew	Attendants	Handlers	Surrounding Population Off-Link	Surrounding Population On-Link	Surrounding Population Stops	Surrounding Population Storage	Totals	% of Total
Am-241 A	0	313.000	0	205.000	12.300	31.200	37.900	47.800	648.000	3.0
Am-241 B	0	2.980	0	0.625	0.908	0.149	0.119	0.152	4.110	-
Au-198	15.500	25.200	0.740	16.600	0.938	2.180	2.44	3.14	66.700	-
C-14	7.260	3.200	0.348	2.090	0.119	.283	0.205	0.278	13.800	-
Co-57	16.900	11.300	0.808	3.160	0.336	.500	0.517	0.366	33.900	-
Co-60 LSA	0	292.000	0	114.000	9.990	20.200	27.100	34.000	497.000	2.0
Co-60 A	0	1130.000	0	317.000	33.700	49.400	67.700	84.400	1680.000	7.0
Co-60 B	0	28.300	0	4.550	0.691	.341	2.180	2.720	42.700	-
Co-60 LQ_1	0	.286	0	0	0.007	.003	0.011	0.003	0.311	-
Co-60 CQ_2	0	1.570	0	2.000	0.131	.094	0.190	0.050	4.090	-
Cs-137 A	0	363.000	0	338.000	15.700	43.800	70.300	87.900	918.000	4.0
Cs-137 B	0	1.570	0	0.576	0.063	.102	0.140	0.175	2.610	-
Ga-67	24.800	5.490	1.180	15.700	0.438	1.850	0.942	1.390	51.700	-
H-3 LSA	0.836	.555	0.04	0.659	0.027	.083	0.068	0.091	2.360	-
H-3 A	0.817	.440	0.039	0.299	0.017	.040	0.031	0.042	1.720	-

TABLE 4-18 (continued)

Material	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage	Totals	% of Total
I-131 A	1000.000	504.000	48.000	426.000	20.500	54.600	43.000	57.900	2160.000	9.0
I-131 B	0.848	1.140	0.041	0.553	0.041	0.090	0.088	0.114	2.920	-
Ir-192 A	0	54.000	0	24.400	2.010	5.010	2.950	3.890	92.200	-
Ir-192 B	0	745.000	0	221.000	25.200	53.000	36.400	47.100	1130.000	4.0
Kr-85 A	26.200	65.200	1.260	16.700	2.120	3.050	2.830	3.630	121.000	1.0
Kr-85 B	0.240	0.582	0.011	0.156	0.018	0.029	0.029	0.038	1.100	-
Limited	46.300	69.400	2.220	30.200	2.290	4.320	4.390	5.670	165.000	1.0
MF+MC LSA	0	93.100	0	0	14.400	7.100	66.700	17.400	199.000	1.0
MF+MC A	0	77.100	0	0	37.000	18.300	134.000	34.900	301.000	1.0
MF+MC B	0	4.460	0	0	0.109	0.054	0.440	0.115	5.170	-
MF+MC LQ	0	1.360	0	0	0.033	0.016	0.046	0.012	1.460	-
Mixed LSA	3.250	49.500	0.156	18.200	1.630	3.050	4.350	5.450	85.600	-
Mixed A	4.370	65.100	0.209	45.800	2.480	5.970	9.210	11.500	145.000	1.0
Mixed B	0	3.890	0	1.500	.130	0.249	0.382	0.476	6.630	-
Mo-99 A	2270.000	1860.000	109.000	1020.000	65.300	140.000	124.000	163.000	5750.000	23.0
Mo-99 B	374.000	331.000	17.900	80.800	9.910	15.100	11.700	15.400	856.000	3.0
P-32	28.300	17.200	1.350	11.700	0.648	1.550	1.270	1.700	63.700	-
Po-210 A	0	0.059	0	0.043	0.004	.008	0.005	0.009	0.127	-

TABLE 4-18 (continued)

Material	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage	Totals	% of Total
Po-210 LQ	0	0.443	0	0.152	0.017	0.039	0.021	0.029	0.700	-
Pu-238 A	0.209	0.466	0.010	0.411	0.019	0.052	0.063	0.081	1.310	-
Pu-238 B	0	3.450	0	0.926	0.112	0.213	0.171	0.219	5.090	-
Pu-239 B	0	28.000	0	6.190	0.833	1.210	1.530	1.910	39.700	-
Pu-239 LQ	0	0.003	0	0.003	0.0002	0.0008	0.0002	0.0003	0.007	-
Pu-recycle	0	6.650	0	0.041	0.333	0	0.006	0	7.030	-
Ra-226 A	0	58.700	0	27.300	1.970	3.790	5.820	7.260	105.000	-
Ra-226 B	0	1.410	0	1.380	0.071	0.229	0.314	0.396	3.800	-
Spent fuel - rail	0	2.600	0	261.000	6.690	8.530	3.440	16.400	298.000	1.0
Spent fuel - truck	0	188.000	0	306.000	22.900	11.300	29.000	7.600	565.000	2.0
Tc-99	8.950	110.000	0.426	150.000	5.610	18.300	29.000	36.400	358.000	1.0
Tl-201	144.000	34.500	6.900	27.800	1.360	3.530	2.310	3.200	224.000	1.0
U308	0	467.000	0	710.000	195.000	161.000	198.000	278.000	2010.000	8.0
UF6-nat	0	71.000	0	26.900	4.240	5.410	7.480	10.500	126.000	-
UF6-enr	0	13.000	0	0.609	0.489	.560	0.904	0.444	16.000	-
U02-enr	0	80.700	0	12.300	11.700	13.400	21.500	10.600	150.000	1.0
U02-Rx	0	51.600	0	1.640	1.840	1.930	2.860	1.410	61.300	-

TABLE 4-18 (continued)

Material		Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage	Totals	% of Total
U-Pu		7.610	52.800	0.364	8.130	1.480	1.750	1.820	2.300	76.300	-
Waste	LSA	0	71.900	0	0	14.300	7.040	52.000	13.600	159.000	1.0
Waste	A	0	574.000	0	0	1050.000	516.000	3080.000	805.000	6010.000	24.0
Waste	B	0	2.330	0	0	1.470	0.726	6.510	1.700	12.700	-
Xe-133		28.000	33.400	1.340	14.200	1.090	2.050	1.930	2.510	84.500	-
TOTALS		4010.000	7970.000	192.000	4480.000	1580.000	1220.000	4090.000	1830.000	25400.000	
% OF TOTAL		16	31	1	18	6	5	16	7		

TABLE 4-19

SUMMARY OF MAXIMUM ANNUAL INDIVIDUAL DOSES FROM RADIOACTIVE MATERIAL TRANSPORT

Population Subgroup	1975 Max. (Avg.) Probable Dose (mrem)	
Airline Passengers	108	(0.34)
Cabin Attendants	13	(2.9)
Passenger Aircraft Flight Crew	2.5	(0.53)
All-Cargo Aircraft Flight Crew	61	(12)
Air Crew (other air modes)	5	
Truck Crew	870	
Van Crew	70	
Train Crew	1.2	
Ship Crew	3.7	
Freight Handlers	500	
Bystanders (pass. air)	85	
Bystanders (cargo air)	106	
Bystanders (other air modes)	60	
Bystanders (truck)	1.3	
Bystanders (rail)	1.65	
Off-link (truck/van)	0.009	
Off-link (rail)	0.017	
On-link (truck/van)	1.9	
Storage (rail)	25	

Mode (including secondary link)	Person-rem per TI carried
Nonexclusive trucks	0.00889
Passenger air	0.00814
Ship	0.00524
All-cargo air	0.0035
Rail	0.00183
Exclusive-use trucks (no secondary link)	0.00058

4. The estimated total annual population dose is 9,790 person-rem in 1975 and 25,400 person-rem in 1985. This dose has the same general characteristics as other chronic exposures to radiation such as natural background. The predicted result of public exposure to this radiation is approximately 1.19 latent cancer fatalities and 1.7 genetic effects in 1975 and 3.08 latent cancer fatalities and 4.4 genetic defects in 1985. While the value of 9,790 person-rem may seem large, it is small when compared with the 4×10^7 person-rem received by the total U.S. population in the form of natural background radiation (see Chapter 3). The total population at risk for radioactive material transport is estimated to be about 20×10^6 people (1975), based on estimates of numbers of aircraft passengers, persons in air terminals, and persons living within 0.5 mile of truck and van routes. Thus, the average annual individual dose is approximately 0.5 mrem, which is a factor of 300 below the average individual dose from background radiation. These results are shown in Table 4-20.

5. Exports and imports of radioactive materials make only a very small contribution to the overall normal risk.

TABLE 4-20
RESULTS - NORMAL TRANSPORT OF RADIOACTIVE MATERIALS

	1975	1985
Total Annual Population Dose (Person-rem)	9,790	25,400
Expected Annual LCF's	1.2	3.1
Expected Annual Genetic Effects	1.7	4.4

$$\text{1975 Average Individual Dose} = \frac{9790}{20 \times 10^6} = 0.5 \text{ Mrem}$$

Annual Normal Dose Attributable to Export and Import Shipments in 1975 = 61 Person-Rem

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CHAPTER 5

IMPACTS OF TRANSPORTATION ACCIDENTS

5.1 INTRODUCTION

Two factors are considered in evaluating the impact of accidents that involve vehicles carrying radioactive shipments: probability and consequence. The probability that an accident releasing radioactive material will occur can be described in terms of the expected number of accidents (of given severity) per year for each transport mode, together with the package response to those accidents and the dispersal that is expected. The consequence of an accident is expressed in terms of the potential effects of the release of a specified quantity of dispersible radioactive material to the environment or the exposure resulting from damaged package shielding.

The product of probability and consequence is called the "annual radiological risk" and is expressed in terms of the expected radiological consequences per year. This risk can be quantified for each shipment type. Summing the risks over all shipments gives the total annual risk resulting from all shipments. Since this method does not distinguish high probability-low consequence risks from low-probability/large-consequence risks, shipments with potentially severe consequences are, in addition, considered separately from the risk calculations.

The actual method by which risk is calculated is outlined in Appendix G and detailed in Reference 5-1. Figure 5-1 outlines the informational flow used in the calculation of impacts due to transportation accidents. It also shows the additional impacts that add to the annual risk discussed above.

This chapter is divided into eight additional sections. Section 5.2, which follows this introduction, includes discussions of accident rates for various transport modes and severities and of package release fractions. Section 5.3 discusses the dispersion/exposure model and the inherent assumptions used in the meteorological calculation. The results of the risk calculations using the 1975 standard shipments and their 1985 projections (see Appendix A) are presented in Section 5.4. Section 5.5 discusses the potential effects and cleanup costs of the radioactive contamination from a transportation accident. In Section 5.6 the "worst-case" shipment scenarios are considered, i.e., those that have the potential for very severe consequences but have a very low occurrence probability. Section 5.7 discusses the impact due to export/import shipments. Section 5.8 discusses the nonradiological impacts of transportation accidents, and Section 5.9 summarizes the results of the accident risk and consequence calculations. A sensitivity analysis for the risk computation is performed in Appendix I.

5.2 DETAILED ANALYSIS

Direct radiological impacts on man are considered to be the most important component of the environmental impact. Direct impact to man may result from transportation by any mode or

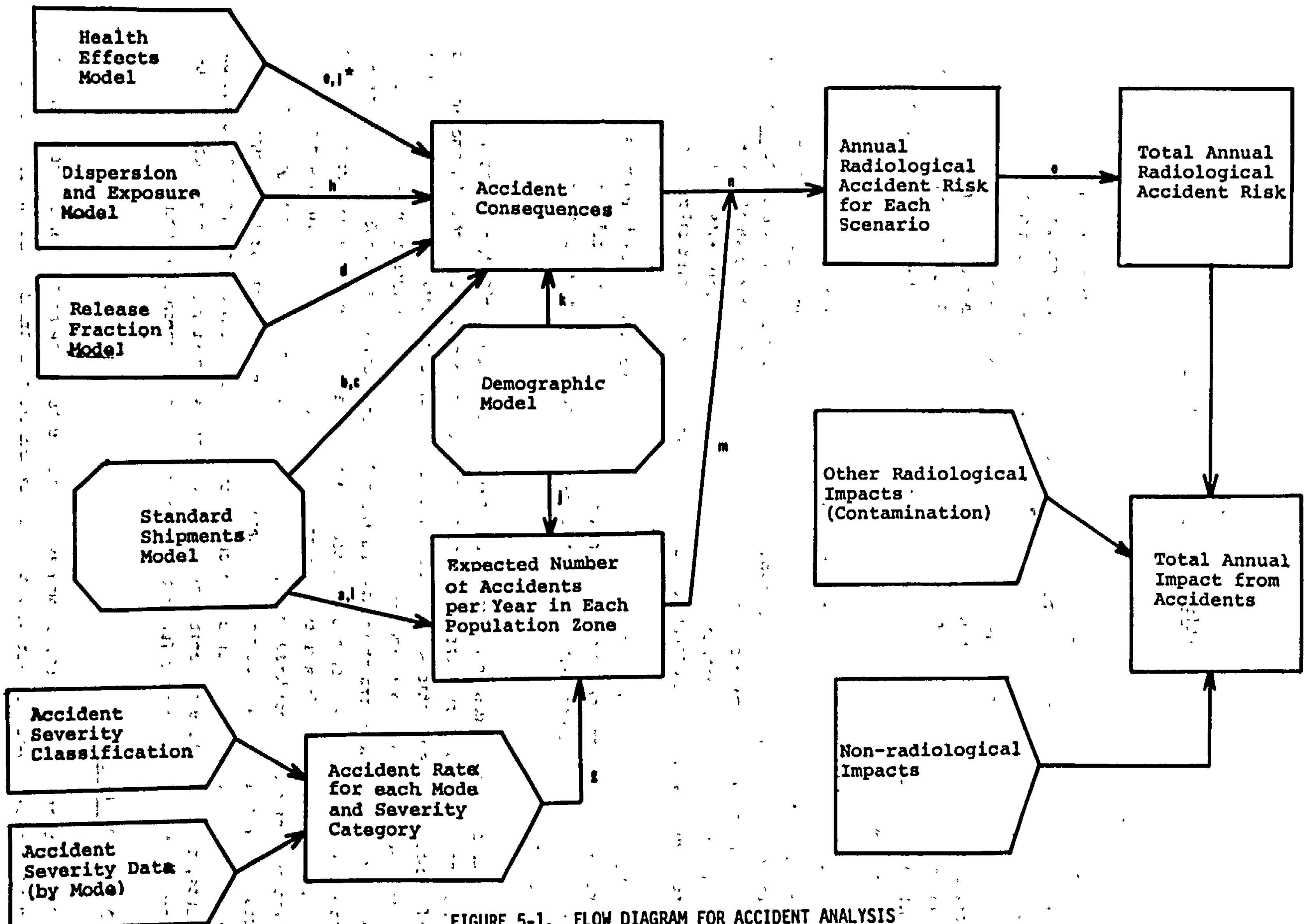


FIGURE 5-1. FLOW DIAGRAM FOR ACCIDENT ANALYSIS

*See notes on following page.

FIGURE 5-1 (continued)

Notes:

a. Shipment mode.

b. Type of packaging.

c. Type of radionuclide; chemical and physical form.

d. Amount of dispersible material released or amount of unshielded material.

e. Dosimetric data for radionuclide.

f. Overall accident rate for each mode.

g. Accident rate for each mode-severity combination.

h. Amount of dispersible material inhaled or external exposure from unshielded material.

i. Number of shipments per year; average distance per shipment.

j. Fractions of accidents expected in each population zone.

k. Population densities.

l. Biological effects of exposure.

m. Average number of accidents per year of each severity.

n. Summation over all severities.

o. Summation over all scenarios.

submode. The probability that a transport vehicle of a particular mode will be involved in an accident of a specific severity depends on the accident rate per vehicle-kilometer, the number of shipments per year by that mode, and the distance traveled by each shipment transported by that mode. The "consequences" of an accident involving a specific mode depend on the quantity and type of radioactive material carried, the fraction of the material that is released in the accident, the population density in the area where the release occurs, the local meteorology at the time of the accident, and the biological effect of the material on the environment.

5.2.1 ACCIDENT RATES

In order to compute the probability of an accident, it is first necessary to know the accident rate for the mode under consideration. The accident rates used in this assessment are specified per vehicle-kilometer and are summarized in Table 5-1, which also lists the sources for the information.

5.2.2 ACCIDENT ENVIRONMENTAL SEVERITY CLASSIFICATION

The amount of radioactive material released to the environment in an accident depends upon the severity of the accident and the package capabilities. Very severe accidents might be expected to release a considerable amount of the radioactive material carried, while minor accidents are unlikely to cause any release. Thus, in addition to the overall accident rate for each mode, the distributions of accidents according to severity must be determined. In this section, the accident severity classification scheme used in this assessment is discussed, and the distributions of accidents according to severity are determined for air, truck, rail, and waterborne transport modes. In addition, estimates of the relative occurrences of accidents of each severity, in each population zone, and for each transport mode are discussed.

5.2.2.1 Aircraft Accidents

The classification scheme devised for aircraft accidents follows that of Clarke, et al. (Ref. 5-2) and is illustrated in Figure 5-2. The ordinate is the speed of impact onto an unyielding surface, and the abscissa is the duration of a 1300°K fire. The results of Clarke et al. indicate that impact speed and fire duration are the most significant parameters with which to categorize aircraft accidents and that crush, puncture, and immersion are lower-order effects (Ref. 5-3). Unyielding surface rather than real surface impacts were chosen in order to make use of the data of Clarke et al. and to facilitate comparison with the regulatory standards. A derating model is introduced into the analysis later to account for the probability of impact on real surfaces rather than on unyielding targets.

The first two scale divisions for impact speed were chosen to correspond to standards for Type A and Type B packagings, respectively. Thus, Category I accidents (with no fire), equivalent to a drop from 4 feet (1.2 m) or less onto an unyielding surface, should not produce a loss of containment or shielding in a Type A package. A 30 foot (9.1 m) equivalent drop was chosen as the division between Category II and Category III impact accidents, corresponding to the Type B container test specification. The remaining impact category divisions were

TABLE 5-1

ACCIDENT RATES

Mode	Accident Rate (per vehicle-kilometer)	Reference
Aircraft	1.44×10^{-8}	5-2*
Truck, Delivery van	1.06×10^{-6}	5-2, 5-5
ICV	$.46 \times 10^{-6}$	5-5, 5-7
Train	$.93 \times 10^{-6}$**	5-2, 5-7, 5-8
Helicopter	$.63 \times 10^{-6}$	5-9
Ship, Barge	6.06×10^{-6}	5-10

*Also see K. A. Soloman, "Estimate of the Probability that an Aircraft Will Impact the PVNGS," NUS-1416, June 1975.

**Rail accidents are given as railcar accidents per railcar-kilometer.

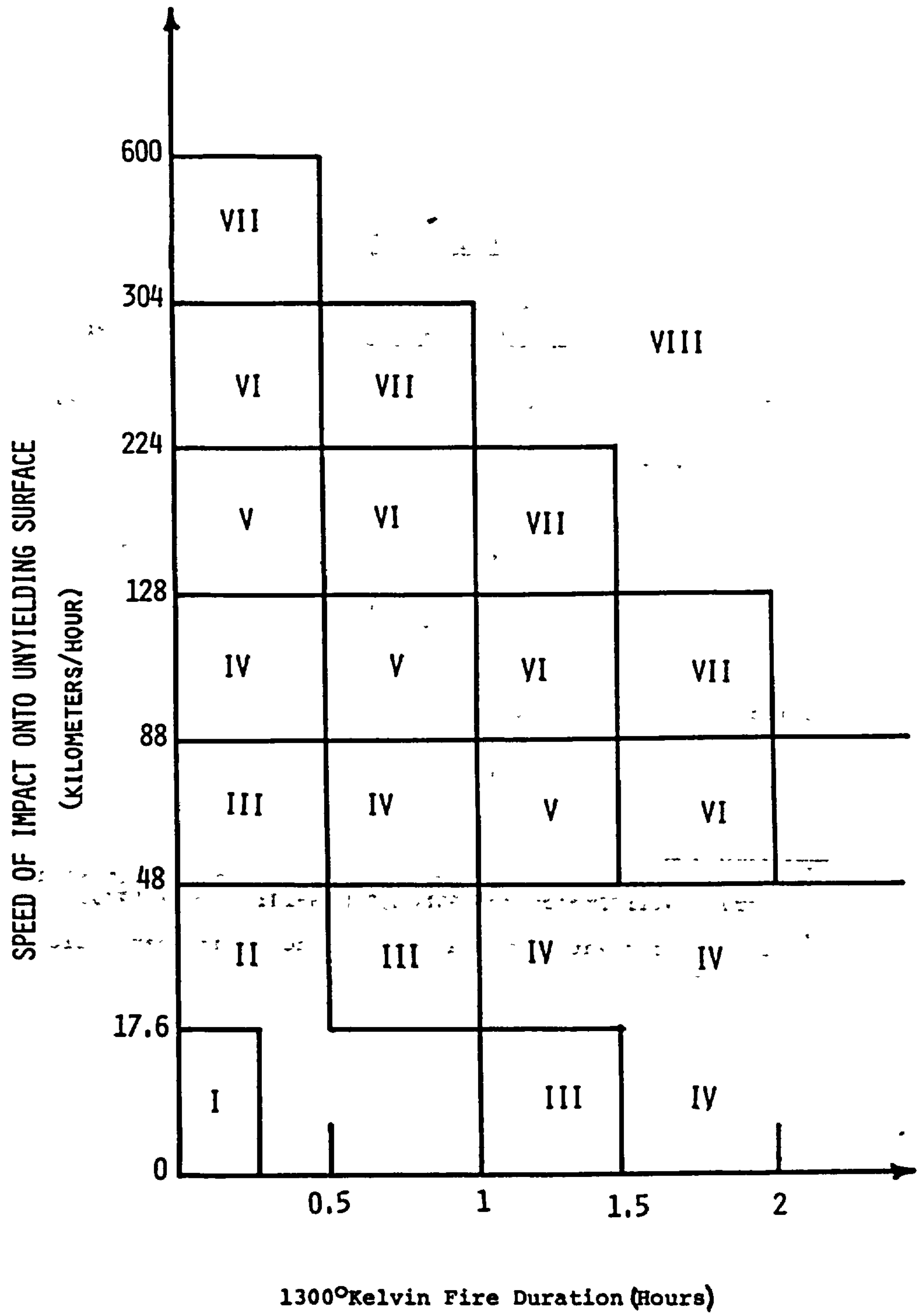


FIGURE 5-2. ACCIDENT SEVERITY CATEGORY CLASSIFICATION SCHEME - AIRCRAFT

chosen more or less arbitrarily from the aircraft accident data compiled by Clarke et al. (Ref. 5-3) in such a way that

1. 95% of the accidents involving impact are severity Category VII or less,
2. 85% of the accidents involving impact are severity Category VI or less,
3. 80% of the accidents involving impact are severity Category V or less,
4. 70% of the accidents involving impact are severity Category IV or less, and
5. 60% of the accidents involving impact are severity Category III or less.

The fire duration category divisions were chosen in such a way that, with the exception of certain Category IV accidents, increasing the fire duration by 30 minutes is equivalent to increasing the impact to the next higher level. Impacts at less than 48 kilometers per hour would not be sufficient to   en accident of severity Category V or greater regardless of how long the fire burned. The fire temperature was chosen as 1300°K to facilitate comparison with previous data (Ref. 5-2) and to correspond roughly to the temperature of a jet fuel fire.

Note that Category I accidents can involve a fire of as much as 15 minutes' duration. A Type A package involved in a Category I accident in which a fire occurs would not be required by the regulations to survive the accident without loss of shielding or containment.

The fractions of aircraft accidents expected in each of the eight aircraft accident severity categories are given in Table 5-2. The numbers under the column heading "Unyielding Surface" were taken from the accident severity data of Clarke et al. (Ref. 5-3) and were adapted to the accident severity classification scheme used in this study.

The fractional occurrences listed under the heading "Real Surfaces" account for the fact that most aircraft accidents involve impact onto surfaces that yield or deform to provide at least some cushioning effect and result in impact forces that are less severe than would occur on an unyielding surface. These fractional occurrences are obtained by derating those for unyielding surfaces, based upon occurrence statistics for surfaces of varying hardness. The details and rationale for this procedure are discussed in Appendix H. The derating of accident severities was made beginning with Category VIII and working back as far as Category III. No real surface derating is expected for Categories I and II, since these low-severity accidents are expected to occur while the aircraft is on the ground at the airport.

A subclassification within each severity category was made to estimate the fraction of those accidents that occur in a given population density zone. Three zones were used in this assessment: low, medium, and high, characterized by average population densities of 6, 719, and 3861 persons/km^2, respectively (the derivation of these values is discussed in Appendix E). Since accident reports do not generally include the population density of the surrounding areas, the data to determine the accident occurrence fractions in various population zones do

TABLE 5-2

FRACTIONAL OCCURRENCES* FOR AIRCRAFT ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences f_i		Fractional Occurrences According to Population Density Zones		
	Unyielding Surface	Real Surface	Low	Medium	High
I	.57	.447	.05	.9	.05
II	.16	.447	.05	.9	.05
III	.09	.0434	.1	.8	.1
IV	.05	.0107	.1	.8	.1
V	.03	.0279	.3	.6	.1
VI	.03	.0194	.3	.6	.1
VII	.04	.0046	.98	.01	.01
VIII	.03	.0003	.98	.01	.01
TOTAL	1.00	1.00			

*Overall Acident Rate = 1.44×10^{-8} accidents/kilometer for commercial aircraft (K. A. Soloman, "Estimate of the Probability that an Aircraft Will Impact the PVNGS," NUS-1416, June 1975.)

not exist. Thus, estimates were based on the following assumptions relating severity to accident locations:

1. Accidents of severities I and II are assumed to occur at airports. Since most airports are in suburban (or medium) population density zones, 90% of all class I and II accidents were estimated to occur in medium density zones, with 5% each in low- and high-density zones.

2. Accident Categories III-VI were expected to be mainly takeoff and landing accidents and thus were expected to occur near airports.

3. The fractional occurrence of accidents in low-population-density zones was assumed to increase somewhat with accident severity, since a greater percentage of Categories V and VI accidents occur at higher speeds, which implies greater distance from the airport.

4. Accidents of severity Categories VII or VIII are mainly in-flight accidents and are expected to occur at random along the flight path. They are very strongly weighted toward the rural, or low density, areas since about 98% of the land area of the United States is considered rural (Ref. 5-4). The remainder is estimated to be split between medium population density (1.9% of the total land area) and high population density (0.1% of the total land area).

The accident rate for U.S. certified route carriers used in this assessment is 1.44×10^{-8} per kilometer. This accident rate represents an average over all aircraft types for the years 1967-1972, but within those years the range was 1.13×10^{-8} to 2.0×10^{-8} per kilometer. The accident rate for each severity level was obtained by multiplying the overall accident rate by the fractional occurrence for real surfaces for that severity class. For each scenario in the standard shipments model, three risks are computed, assuming the shipments occur entirely in a low-, medium-, or high-population density zone. The actual risk is obtained by forming the sum of these three risk values, weighted by the fractional accident occurrence in each population density zone for that scenario. This same computational technique is used for all transport modes.

5.2.2.2 Truck Accidents

The severity classification scheme for truck accidents is shown in Figure 5-3. In this case the ordinate is crush force rather than impact. Foley et al. (Ref. 5-5) have shown that, in the case of accidents involving motor carriers, the dominant factors in the determination of accident severity are crush force, fire duration, and puncture. The crush force may result from either an inertial load (e.g., container crushed upon impact by other containers in load) or static load (e.g., container crushed beneath vehicle).

The fractional occurrences of truck accidents in each of the eight severity categories are listed in Table 5-3. Since the dominant effect is crush rather than impact, no real-surface derating is involved. The fractional occurrences were taken from the data of Foley et al. (Ref. 5-5). Note that the values for Categories VII and VIII are much lower than for

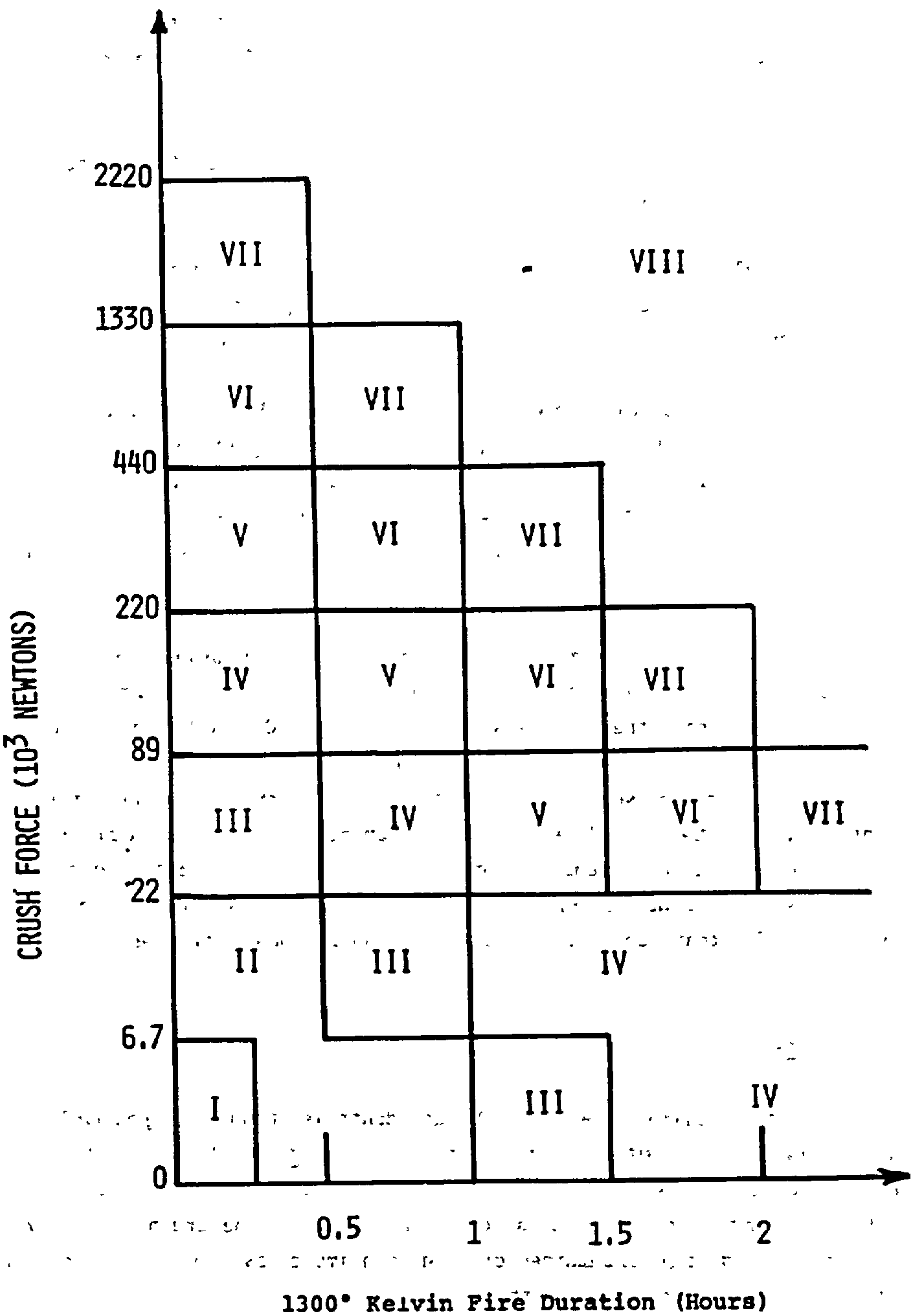


FIGURE 5-3. ACCIDENT SEVERITY CATEGORY CLASSIFICATION SCHEME - MOTOR TRUCKS

TABLE 5-3

FRACTIONAL OCCURRENCES* FOR TRUCK ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences f	Fractional Occurrences According to Population Density Zones		
		Low	Medium	High
I	.55	.1	.1	.8
II	.36	.1	.1	.8
III	.07	.3	.4	.3
IV	.016	.3	.4	.3
V	.0028	.5	.3	.2
VI	.0011	.7	.2	.1
VII	8.5×10^{-5}	.8	.1	.1
VIII	1.5×10^{-5}	.9	.05	.05

*Overall Accident Rate (Ref. 5-5) = 1.06×10^{-6} accidents/kilometer
(0.46×10^{-6} accidents/kilometer for ICV's)

aircraft accidents. The overall accident rate for motor carriers transporting hazardous materials used for this assessment is 1.06×10^{-6} accidents/kilometer.

The estimated fractions of truck accidents in each severity category occurring in each population density zone are also shown in Table 5-3. The very low severity accidents are expected to occur mainly in urban areas. The table reflects a gradual shift of accidents to rural areas with increasing severity as average velocity increases.

Current plans are to require shipment of plutonium in 1985 by Integrated Container Vehicles (ICV) (Ref. 5-6). These are trucks with large vault-like cylinders designed to withstand accident forces and attempted penetration by thieves or saboteurs. Using ERDA nuclear weapons shipment data, the accident rate (which includes the effects of a reduced speed limit, freeway travel, no weekend driving, etc.) is expected to be 0.46×10^{-6} accidents/kilometer (Ref. 5-7). The fraction of accidents within each severity category and the fraction of accidents in each population zone are expected to be the same for ICVs as for other trucks.

5.2.2.3 Delivery Van Accidents

The accident severity classification scheme for delivery vans is the same as that for trucks, as shown in Figure 5-3. Fractional occurrences by severity and the overall accident rate are shown in Table 5-4 and were taken to be the same as for trucks. The fractional occurrences in the three population zones, however, are different. In the standard shipments model, delivery vans are used only as a secondary transport mode. There is practically no rural travel since most of the radioactive materials transport in delivery vans is to and from airports, truck terminals, and railroad depots. There are expected to be more low-severity accidents in high-population-density zones and more severe accidents on freeways in medium-population density zones as a result of the higher freeway speeds.

5.2.2.4 Train Accidents

Figure 5-4 illustrates the accident severity classification scheme used for train accidents. The ordinate in this case is impact velocity, taking into account the effects of puncture. In their analysis of train accidents, Larson et al. (Ref. 5-8) considered crush to be an important factor. However, they were concerned with containers shipped in carload lots and with the crush forces resulting from interaction with other cargo in the rail car. Since the principal rail shipment considered is spent fuel, which is not shipped on the same car as other cargo, crush as a severity criterion is not of prime importance.

Table 5-5 lists the fractional occurrences for train accidents by severity class and by population density zone. The f_i-values were taken from the data of Larson et al. (Ref. 5-8). As with truck accidents, no real-surface derating of the fractional occurrences is required, since the predominant mode of damage in severe accidents is puncture. The overall accident rate is 0.93×10^{-6} railcar accidents/railcar-kilometer, assuming an average train length of 70 cars and an average of 10 cars involved in each accident (Refs. 5-7 and 5-8). As in the case of motor trucks, the more severe accidents are assumed to occur in lower-population-density zones where velocities are higher.

TABLE 5-4

FRACTIONAL OCCURRENCES* FOR DELIVERY VAN ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences f	Fractional Occurrences According to Population Density Zones: Low	Medium	High
I	.55	.01	.39	.60
II	.36	.01	.39	.60
III	.07	.01	.39	.60
IV	.016	.01	.50	.49
V	.0028	.01	.50	.48
VI	.0011	.01	.50	.49
VII	8.5×10^{-5}	.01	.60	.39
VIII	1.5×10^{-5}	.01	.60	.39

*Overall Accident Rate = 1.06×10^{-6} accidents/kilometer

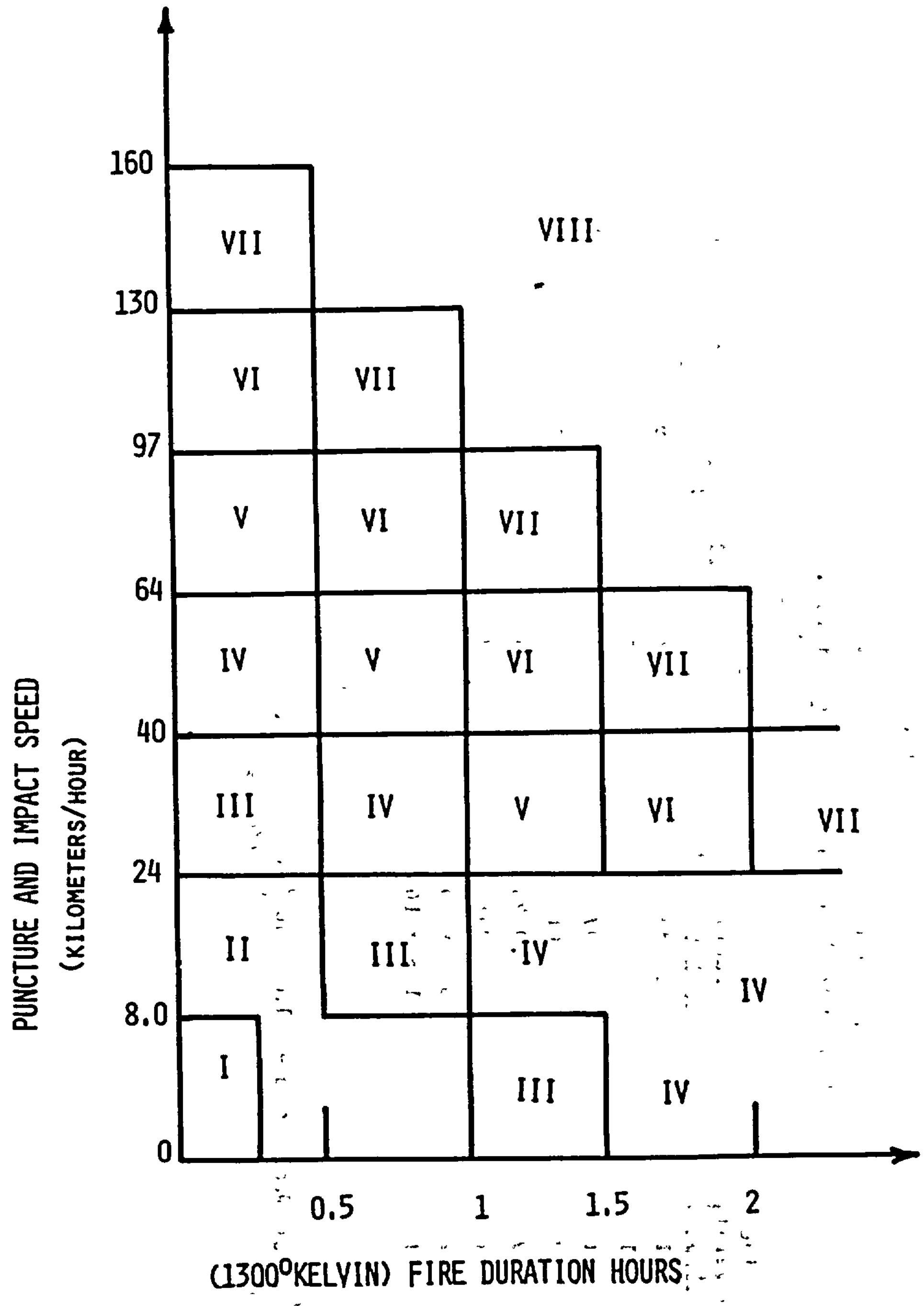


FIGURE 5-4. ACCIDENT SEVERITY CATEGORY CLASSIFICATION SCHEME - TRAIN

TABLE 5-5

FRACTIONAL OCCURRENCES* FOR TRAIN ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences	Fractional Occurrences According to Population Density Zones: Low	Medium	High
I	.50	.1	.1	.8
II	.30	.1	.1	.8
III	.18	.3	.4	.3
IV	.018	.3	.4	.3
V	.0018	.5	.3	.2
VI	1.3×10^{-4}	.7	.2	.1
VII	6.0×10^{-5}	.8	.1	.1
VIII	1.0×10^{-5}	.9	.05	.05

*Overall Accident Rate = 0.93×10^{-6} railcar accidents/railcar-kilometer.

5.2.2.5 Helicopter Accidents

Helicopter accidents are classified in a manner similar to aircraft accidents (Figure 5-2). The overall accident rate is 0.63×10^{-6} accidents/kilometer (Ref. 5-9), and the fractional occurrences, shown in Table 5-6, are taken to be the same as for aircraft impacting on real surfaces. However, the fractional occurrences in the three population density zones are different since helicopters are used principally as a secondary transport mode to and from airports.

Accidents represented by the first two severity categories occur while the helicopter is on the ground either at the airport or at a pickup or delivery point, all of which would be located primarily in medium- and low-population density zones. It is anticipated that helicopter flights, particularly those carrying extremely hazardous material, would be routed to avoid flying over high-population-density zones whenever possible. Thus, the takeoff and landing accidents (severity Categories III-VI), as well as the in-flight accidents (Categories VII-VIII), are expected to be concentrated in the medium- and low-population-density zones. Category VII and VIII accidents involving helicopters are considered to be midair collisions and would be expected to occur mainly in the immediate vicinity of an airport; thus most of these accidents should occur in medium-population-density zones.

5.2.2.6 Ship And Barge Accidents (Ref. 5-10)

Records for calendar year 1973 for domestic waterborne traffic show a total of 6.67×10^{11} ton-miles. Precise data are not available to indicate what fraction of those ton-miles was barge traffic; however, a reasonable estimate seems to be 1.73×10^{11} ton-miles of barge traffic. According to the Coast Guard's annual statistics of casualties, there were an estimated 1395 barge accidents in 1973, of which about 60% involved cargo barges.

The available data cannot be analyzed in the same way as the data for rail or truck transport. On the basis of discussions with the U.S. Coast Guard, it is estimated that the average net cargo weight of a typical barge is about 1200 tons. The total number of barge miles would then be about 1.44×10^{8}. This yields an accident rate of about 6.0 accidents per million barge kilometers.

Very little data are available on the severity of accidents involving barges. Since barges travel only a few miles per hour, the velocity of impacts in accidents is small. However, because of the large mass of the vehicle and cargo, large forces could be encountered by packages, for instance, spent fuel casks aboard barges. A forward barge could impact on a bridge pier and suffer crushing forces as other barges are pushed into it. A coastal or river ship could knife into a barge. Fires could result in either case. An extreme accident, i.e., an extreme impact plus a long fire, is considered to be of such low probability that it is not considered a design-basis accident. The likelihood of a long fire in barge accidents is small because of the availability of water at all times. Also, since casks could be kept cool by sprays or submergence in water, there is compensation for loss of mechanical cooling.

TABLE 5-6

FRACTIONAL OCCURRENCES* FOR HELICOPTER ACCIDENTS BY ACCIDENT SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category	Fractional Occurrences (Real Surfaces)	Fractional Occurrences According to Population Density Zones: Low	Medium	High
I	.447	.35	.60	.05
II	.447	.35	.60	.05
III	.0434	.45	.45	.10
IV	.0107	.45	.45	.10
V	.0279	.45	.45	.10
VI	.0194	.45	.45	.10
VII	.0046	.19	.80	.01
VIII	.0003	.19	.80	.01

*Overall Accident Rate = 0.63×10^{-6} accidents/kilometer

The likelihood of cargo damage occurring in barge accidents is much less than in the case of rail accidents. The accident severity breakdown for ship and barge is shown in Table 5-7.

If a cask were accidentally dropped into water during barge transport, it is unlikely that it would be adversely affected unless the water was very deep. Most fuel is loaded into casks under water, so immersion would have no immediate effects. The water would remove the heat, so overheating would not occur. Each cask is required by NRC regulations (10 CFR § 71.32(b)) to be designed to withstand an external pressure equal to the water pressure at a depth of 15 m (50 ft), and most designs will withstand external pressure at much greater depths. If a cask seal were to fail due to excessive pressure in deep water, only the small amount of radioactivity in the cask coolant and gases from perforated elements in the cask cavity would be likely to be released. Even if the cask shielding were ruptured as a result of excessive pressure, the direct radiation would be shielded by the water. About 10 m of water, which is the depth of most storage pools, would be ample shielding for radiation, even from fully exposed fuel elements.

In a recent study (Ref. 5-11) it was concluded that the pressure seals on a spent fuel cask that is dropped into the ocean might begin to fail at a depth of 200 meters, a typical depth at the edge of the continental shelf, and release contaminated coolant. The fuel elements, which contain most of the radioactive material, provide excellent containment. In an operating reactor, the fuel elements are under water at elevated temperatures and at pressures on the order of 1000 to 2000 psi. Thus exposure to water pressures at depths of 600 to 1200 m should have no substantial effect on the fuel elements themselves. The study concluded that they would not fail until they reached a depth of approximately 3000 meters. Once they failed, the fuel pins would release fission products into the ocean, but these would be dispersed into such a large volume of the ocean that the concentrations would be very small. Certain nuclides such as cesium and plutonium could be reconcentrated through the food chain to fish and invertebrates that could be eaten by man; but, as pointed out in the study, the possibilities of a single person consuming large quantities of seafood, all of which was harvested from the immediate vicinity of the release, is very remote, especially since most seafood is harvested in areas over the continental shelves.

In virtually all cases, except those in which the cask was submerged to extreme depths, recovery would be possible with normal salvage equipment. If the cask and elements could not be recovered, corrosion could open limited numbers of weld areas within about 2000 years (Ref. 5-11), with possible localized failures occurring sooner. However, by that time most of the radioactivity would have decayed. Subsequent release would be gradual, and the total amount of radioactivity released at any one time and over the total period would be relatively small. Considering the extremely low probability of occurrence, the major reduction in radioactivity due to radioactive decay, and the dilution that would be available, there would be little environmental impact from single events of this kind.

Should a shipment be accidentally dropped during transfer to a barge, the main effect will likely be limited to that of rather severe damage to the barge. It is possible that a fuel cask could penetrate the barge decks and fall into the relatively shallow water of the breakwater basin. As previously discussed, there would be at most only minor radiological

TABLE 5-7

FRACTIONAL OCCURRENCES* FOR SHIP AND BARGE ACCIDENTS BY SEVERITY CATEGORY AND POPULATION DENSITY ZONE

Accident Severity Category**	Fractional Occurrences**	Accident Severity Category	Fractional Occurrences (this assessment)	Fractional Occurrences According to population density zone: Low	Medium	High
minor-2	.897	I	.897	0	.5	.5
minor-3	.0794	II	.0798	0	.5	.5
moderate-2	.00044					
moderate-3	.00113	III	.00113	0	.9	.1
moderate-4	.0186	IV	.0186	0	.9	.1
severe-2	.0000052	V	.0000052	.1	.9	0
severe-3	.000072	VI	.000072	.1	.9	0
severe-4	.000195	VII	.000195	.1	.9	0
extra severe-1	.000013	VIII	.000013	.1	.9	0

*Overall accident rate = 6.06×10^{-6} accidents/kilometer

**From Ref. 5-10.

consequences, since the cask (or drums) could be recovered easily and rather quickly. The environmental impact resulting from damage to the barge (including its sinking) would also be minor, since salvage could readily be started. The most significant effect would be the economic loss from recovery operations.

Waterborne traffic spends a very small fraction of its travel in high-population-density regions. The highest traffic density will probably occur in the port areas and, as a result, be associated with lower speed. Categories VI, VII, and VIII accidents probably require relatively large forces, a long-term fire, or an explosion, which are more likely to occur in open water. Categories III through V are more likely to be the result of a lower speed collision in a dock area, either with another vessel or a pier. The population density of dock areas of most cities was considered to be representative of a medium-population zone. Hence, Class III-V accidents are assumed to occur in a medium-population zone. Categories I and II accidents are not likely to involve another vessel, since they are very minor in nature. Hence, they are considered to occur either in open waters or while securely moored. These assumptions are reflected in Table 5-7.

5.2.3 RELEASE FRACTIONS

In order to assess the risk of a transportation accident, one must be able to predict the package response to an accident of given severity. In particular, one needs to know the fraction of the total package contents that would be released for an accident of given severity. The actual releases for a given package type would not necessarily be the same for a number of accidents of the same severity class. In some cases there may be no release, while in others there may be, for example, a 10% release. Indeed, in a given accident involving a number of radioactive material packages transported together, some of the packages may release part of their contents while others have no release at all. The approach taken in this assessment is to derive a point estimate for the average release fraction for each severity category and package type and assume <u>all</u> such packages, including each package in a multipackage shipment, respond to such an accident in the same way without regard to the type or form of the contents.

The paucity of data on package responses to severe accidents makes it difficult to predict even the average release fraction, much less a distribution. Since the packaging standards do not require tests to failure there has been, until recently, little information relating the response of packages to accident environments.

Recently, a series of severe impact tests was carried out at Sandia Laboratories using several types of containers commonly used to ship plutonium (Refs. 5-12 and 5-13). All container types survived tests with no structural damage to the inner container after impacts onto unyielding targets occurred at speeds up to those typical of a Category V impact accident. Several containers exhibited some minor structural damages and cracking in Category VI impacts, but no verified release occurred. Tests of containers typical of those in commerce resulted in failure of a nonspecification cast iron plug and allowed material loss and also compromised the overall integrity of the inner containers. In one test a container lost 6% of its contents (magnesium oxide powder) in a Category VII impact; others survived Category VIII impacts with no loss of contents. Although none of the containers in this test series was subjected to fire, others of the same type survived less severe impacts followed by a 1300°K environment lasting for a half-hour with no release. Using this test information or assuming that packagings begin to fail at severities just above those that they are required to survive, the responses of packages are estimated by the methods detailed below. The release fraction estimates for all packagings evaluated are shown in Table 5-8.

Two specific release fraction models are considered. Model I specifies total release of package contents for all accident severities exceeding that specified by Federal regulations. This somewhat unrealistic model assumes that zero release occurs up to the regulatory test level and that the packaging fails catastrophically in all environments that exceed that level. Clearly, packagings do not behave in this fashion, but this approach does present a simplistic evaluation of present regulations. Model II is considered to be a more realistic model, although it too has inherent conservatism as is discussed later. Models I and II are used for the 1975 and 1985 risk assessment, and Model II is used for consideration of transportation alternatives in Chapter 6.

5.2.3.1 Release Fractions For Plutonium Shipping Containers

Two sets of release fractions for Type B plutonium shipping containers are listed for Model II; both are derived from the container impact test data described earlier (Refs. 5-12 and 5-13). Those release fractions listed under the heading 1975 Pu show a small release (1%) in a Category VI accident. This accounts for the possibility that small amounts of material might be forced through the cracks observed in the inner container. The 5% release in Category VII reflects the results of the one test in which a measurable amount of material escaped. The Category VIII release fraction of 10% is an estimate of the upper limit to the release fraction based upon analysis of all test data.

The 1985 Pu release fractions acknowledge that in the interim period from 1975 to 1985, package development programs currently underway are likely to produce packages that will have higher integrity. As a result only a 1% release is expected in Category VII and 10% in Category VIII. Even lower release fractions are likely to be justifiable for containers currently under development, but no lower values were shown without complete test data and assurance that older containers will be out of use.

The Integrated Container Vehicle (ICV) is currently being discussed as the principal transport vehicle for plutonium shipments in 1985 and is expected to change the release fractions associated with plutonium shipments appreciably. The massive vault-like containers will be highly accident resistant. The release fractions assumed for these containers are also shown in Table 5-8.

5.2.3.2. Other Type B Containers

Federal regulations require that Type B packagings be able to withstand tests designed to simulate certain accident conditions (Ref. 5-14). In the absence of test data on safety margins for Type B packages, the assumption is made that most containers begin to fail just beyond the accident conditions at which they were tested, although not in the catastrophic

TABLE 5-8

RELEASE FRACTIONS

Model I

Severity Category	LSA Drums	Type A	Type B	Cask (Exposure)	Cask (Release)
I	0	0	0	0	0
II	1.0	1.0	0	0	0
III	1.0	1.0	1.0	1.0	1.0
IV	1.0	1.0	1.0	1.0	1.0
V	1.0	1.0	1.0	1.0	1.0
VI	1.0	1.0	1.0	1.0	1.0
VII	1.0	1.0	1.0	1.0	1.0
VIII	1.0	1.0	1.0	1.0	1.0

TABLE 5-8 (continued)

RELEASE FRACTIONS

Model II

Severity Category	LSA Drum	Type A	Type B No Pu	Type B 1975 Pu	Type B 1985 Pu	Cask (exposure)	Cask (release)	ICV
I	0	0	0	0	0	0	0	0
II	.01	.01	0	0	0	0	0	0
III	.1	.1	.01	0	0	0	.01	0
IV	1.0	1.0	.1	0	0	0	.1	0
V	1.0	1.0	1.0	0	0	0	1.0	0
VI	1.0	1.0	1.0	.01	0	3.18×10^{-7}	1.0	0
VII	1.0	1.0	1.0	.05	.01	3.18×10^{-5}	1.0	0
VIII	1.0	1.0	1.0	.1	.1	3.12×10^{-3}	1.0	.1

manner assumed with Model I. Above the threshold test at which release occurs, the release fractions are assumed to increase with increasing accident severity as assumed for plutonium containers. Note that catastrophic failure (i.e., complete release) is assumed for accident severity categories above IV. This is a conservative assumption in the absence of tests to failure.

5.2.3.3. Type A And Low Specific Activity Containers

The same rationale used for Type B containers is used for Type A containers. A small release is assumed for Category II with progressively greater releases with increasing severity in the same way as for Type B containers. An independent test carried out at Sandia Laboratories on a single Type A (Mo-99 generator) container under Category IV impact conditions resulted in extensive packaging damage but zero release. Thus, the release fractions assumed for this type of packaging are believed to be conservative.

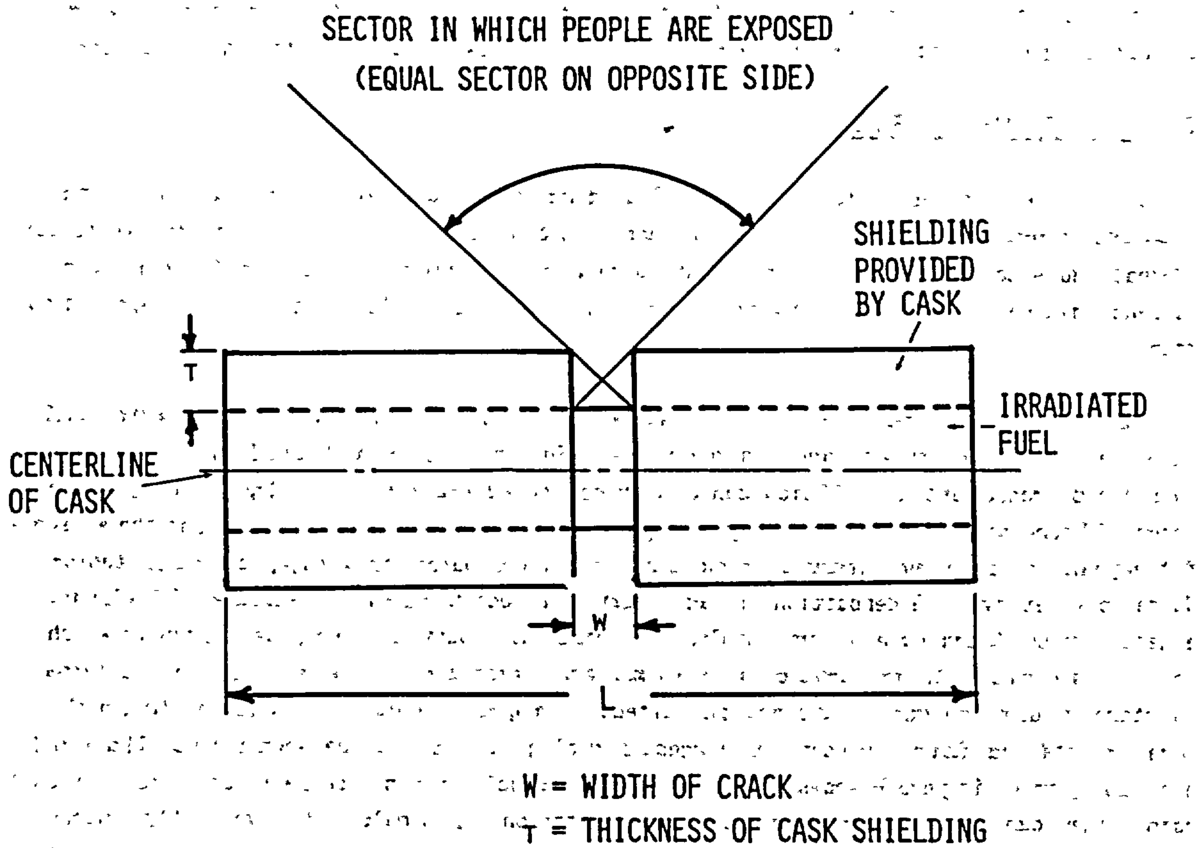
5.2.3.4 Casks

Large casks are used for shipments of large irradiator or teletherapy sources, irradiated fuel, and high-level fuel cycle waste. In analyzing release fractions, therefore, two types of releases must be considered: direct release of contents to the environment and exposure of the surrounding environment to neutron or gamma radiation through a breach in shielding. These two problems must be addressed separately.

Spent fuel can be thought of as a combination of two components: gaseous and volatile materials in the coolant, plenums, and void spaces in fuel rods and non-volatile fission products and activated material held in the matrix of the fuel pellets. Since packagings for large-quantity shipments such as spent fuel must meet Type B standards, the Type B packaging release fractions discussed previously are used to evaluate the release of available gaseous and volatile materials (Ref. 5-14). Drop tests using spent fuel shipping containers were conducted at Sandia Laboratories (Ref. 5-15). There were no releases at impact velocities up to 394 kilometers per hour onto hard soil.

The effect of loss of shielding is modeled by assuming that a circumferential crack is produced in the cask by the accident forces (see Figure 5-5). Using probabilities and descriptions of breaches suggested in Reference 5-16, a Category VI accident was considered the minimum accident with forces sufficient to cause a crack through the entire cask. This was modeled as a circumferential crack 0.1 cm wide around the entire cask. In a Category VII accident this crack is assumed to be 1 cm in width; in a Category VIII accident, it is assumed to be 10 cm in width.

The "release fraction" for the loss of shielding case is not really a release fraction at all, but is the product of the fraction (W/L) of the source length that is exposing the surrounding population and the fraction $[1 - 2/\pi \tan^{-1}(T/W)]$ of the surrounding area that lies within the sector being exposed (see Figure 5-5). The computation of the integrated population dose is then carried out assuming a fictitious point source whose strength is the total



$$\text{FRACTION OF SURROUNDING POPULATION EXPOSED} = 1 - \frac{2}{\pi} \text{TAN}^{-1}\left(\frac{T}{W}\right)$$

FIGURE 5-5. RELEASE FRACTION MODEL FOR EXPOSURE-TYPE SOURCES SHIPPED IN CASKS

number of curies contained multiplied by the "release fraction," with the integration extending over the entire area. The values in Table 5-8 were determined for a cask length, L, of 2.54 meters and a shielding thickness, T, of 0.4 meter.

5.2.4 SHIPMENT PARAMETERS

The shipment parameters that contribute to the accident impact calculation include the number of curies per package, the number of packages per shipment, the physical/chemical form of the material, the dosimetric aspects of the material, the number of shipments per year by each mode, and the distance traveled by each shipment. These data are presented in Appendix A.

5.3 DISPERSION/EXPOSURE MODEL

Once a release has occurred, the released material is assumed to drift downwind and disperse according to a Gaussian diffusion model and can produce such environmental effects as internal and external radiation doses, contamination, or buildup in the food chain. If the accident involves a material in special form, only external radiation exposure is assumed to occur.

Environmental impacts result both from a release to the atmosphere and from external radiation exposure from a large source whose shielding has been damaged in an accident. Atmospheric transport and diffusion can disperse released material over large areas, but the degree of dispersion is determined by atmospheric turbulence, which is a function of the season of the year, time of day, amount of cloud cover, surface characteristics, and other meteorological parameters. The deposition of radionuclides associated with the passage of a cloud of released material can have a very complex environmental impact. Some possible ways in which the dispersed material can produce a dose to man are summarized in Figure 5-6. Direct external or internal dose to man is the principal effect from gamma emitters. Material that emits alpha or beta radiation produces the largest radiological consequence when aerosolized and inhaled by man. Figure 5-6 shows that deposited radionuclides can also be taken into the food chain. They can be transferred from soil to vegetation to animals and eventually to man. However, radiation doses to man through the food-chain pathway are usually more significant (relative to doses through inhalation, for example) if there exists a continuous source of release to the environment.

5.3.1 ATMOSPHERIC DISPERSION MODEL

The dispersion model is based on Gaussian diffusion, a technique widely used in analysis of atmospheric transport and diffusion. Accidents that involve a release of dispersible material are assumed to produce a cloud of aerosolized debris instantaneously at the accident site. The initial distribution of aerosol mass with height is assumed to be a line source extending from the ground to a height of 10 meters. The initial concentration increases with height in a manner consistent with data obtained in experimental detonations of simulated weapons (Ref. 5-17). The use of such an initial distribution is justified for accidents in which fires or residual energy provide an aerosol cloud to be released from the accident site. Since the dose from a 10-meter-high line source is indistinguishable from that of a point

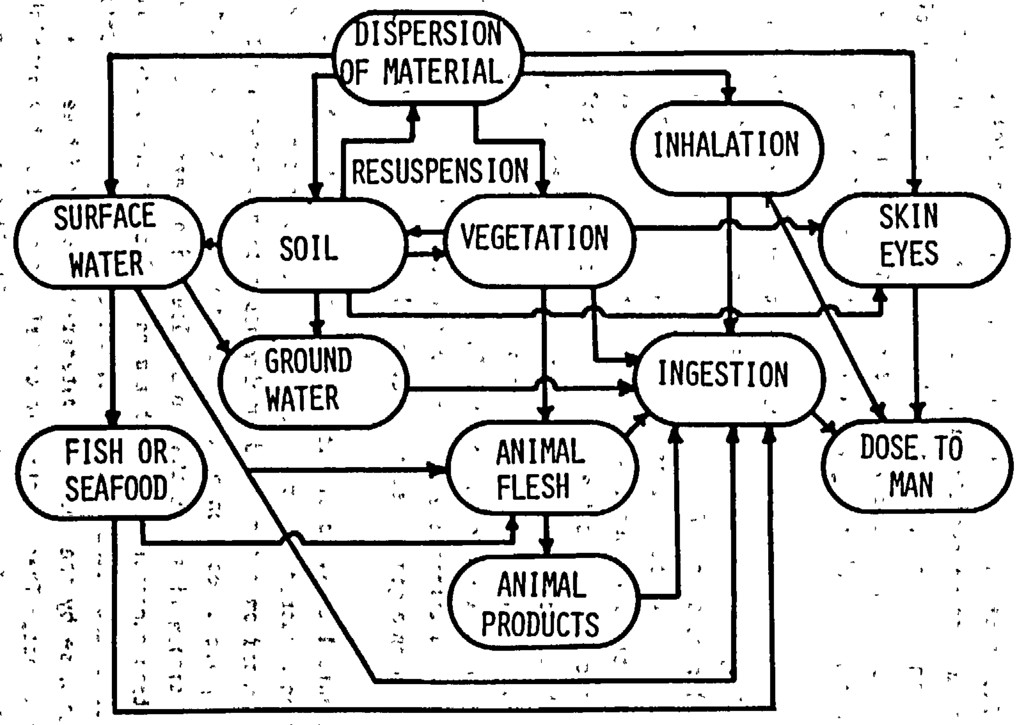


FIGURE 5-6. POSSIBLE ROUTES TO MAN FROM RADIONUCLIDE RELEASE

source at downwind distances greater than about 100 meters, the initial distribution with height is unimportant. Doses calculated using this model are conservative, since most potential accidents involve energy releases that may carry aerosolized materials to heights greater than 10 meters. The degree of conservatism increases as the height of release increases and is especially conservative for elevated sources such as a release that might result from midair aircraft collisons.

Transport and diffusion of the aerosol cloud (composed of particles so small that gravitational settling is minimal) occur symmetrically about the mean wind velocity vector. This process is described using climatological distributions of horizontal and vertical components of turbulence intensities and wind speed. The aerosolized material is allowed to diffuse horizontally without constraint and vertically to an altitude of 1400 meters (Ref. 5-18).

A year or more of meteorological data recorded at sites near White Sands, New Mexico, and Aiken, South Carolina, is used in the model. These data are used to generate values for the lateral and vertical dimensions of the aerosol cloud, which are expressed in terms of the measured lateral and vertical turbulence intensities (Ref. 5-19). These values are calculated for various downwind locations to provide estimates of the dilution that has occurred as a function of the downwind distance and the amount of aerosolized material involved. The results obtained for each of the meteorological data sets are examined to determine the area within which a given dilution factor is not exceeded (this is an area in which a given concentration is exceeded). A curve of area exceeded in only 5% of all meterological conditions versus dilution factor not exceeded within the area is shown in Figure 5-7. This area is taken as a credible upper limit in which a given dilution factor will not be exceeded.

In order to make a full analysis of actual inhalation hazard, the phenomena of deposition and resuspension must be considered. As the cloud of aerosolized material is transported by the wind, material is scavenged from the cloud by dry deposition processes and deposited on the ground. Wet deposition, i.e., deposition by rain and snowfall, is not considered in this model; the neglect of wet deposition will mean that this calculation overestimates the population dose in areas where precipitation can interact with the aerosol cloud. Dry deposition occurs continuously, and its effect is estimated by depleting the total quantity of material that would contribute to inhalation dose by the amount of material deposited between the source release point and a point of interest. The amount of material deposited at any point is calculated using a deposition velocity, V_d (m/sec), which, when multiplied by the time-integrated concentration (Ci-sec/m^3), yields the amount deposited, D (Ci/m^2). A value of 0.01 m/sec is used for V_d based on a previous analysis (Ref. 5-20) and for consistency with the resuspension model used in this document. Dry deposition removes material from the cloud and reduces the downwind concentration, as shown in the lower curve on Figure 5-7.

Resuspension occurs when deposited particle material on a surface is made airborne as a result of mechanical forces (walking, vehicle traffic, plowing, etc.) and wind stress on the deposition surface (as in sandstorms or blowing snow). The resuspended material becomes available for inhalation by people in the contaminated area and can cause an additional component of body burden and radiation dose accumulating with time. Methods used to calculate

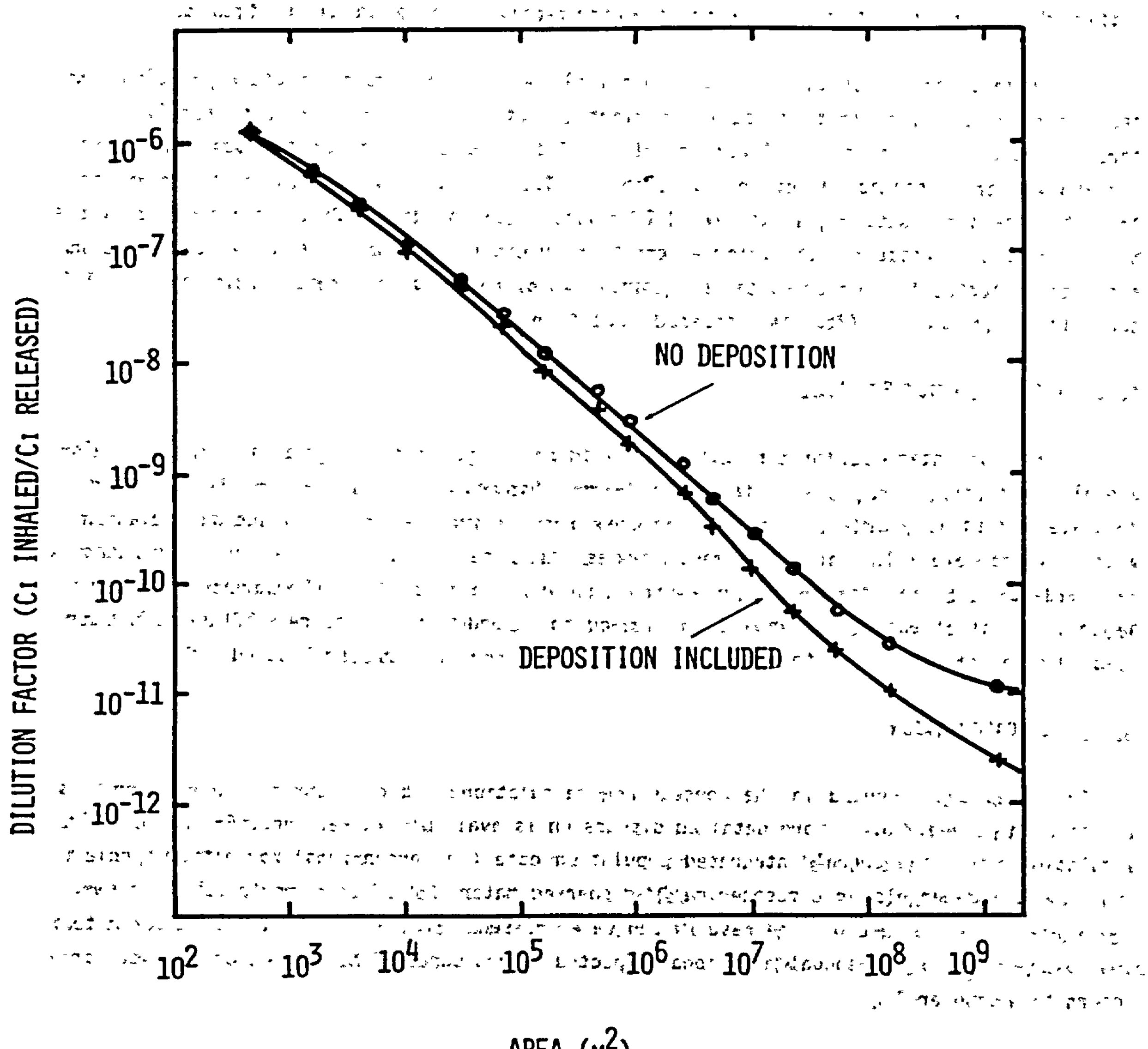


FIGURE 5-7. DOWNWIND DILUTION FACTOR AS A FUNCTION OF AREA

resuspension involve an empirical "resuspension factor," K/m, which is the ratio of the air concentration at a point to the surface concentration just below that point in the contaminated area. An initial value of 10^{-5}/m decreasing exponentially with a 50-day half-life to a constant value of 10^{-9}/m is used in this study to evaluate the dose contributed by resuspension (Ref. 5-20). Because of radioactive decay, short-half-life materials such as Tc-99m provide little resuspension dose, whereas long-half-life nuclides such as Pu-239 increase the initial dose by a factor of up to 1.6 over the dose received during actual cloud passage.

Two effects can be calculated once the actual downwind concentration and deposition patterns are known. The first and most important effect is the inhalation dose received by persons in the downwind area. The calculation of this dose is discussed in Appendix G, and the results are presented later in this chapter. The second effect, which can be determined from the deposition pattern, is the level of surface contamination. Contamination on surfaces has two principal effects: the material can be resuspended and inhaled (as previously discussed), and affected land or crops can be quarantined or condemned if the contamination level is sufficient. The latter effect is discussed in Section 5.5.

5.3.2 EXTERNAL EXPOSURE MODEL

If the postulated accident results in shielding damage to a package containing a nondispersible material, e.g., one of the special-form shipments such as Co-60 or Ir-192, or an irradiated fuel cask, direct external exposure results from the gamma or neutron radiation emitted by the material. This assessment assumes that after an accident the source remains at the accident site for 1 hour with no evacuation and no introduction of temporary shielding The area in which people are exposed is assumed to extend for a distance of 0.8 kilometer radially from the location of the source. This calculation is discussed in Appendix G.

5.3.3 DOSE CALCULATION

Two doses are computed in the consequence calculation, and the computation of each is discussed in Appendix G. A more detailed discussion is available in Reference 5-1. The first calculation is of the annual integrated population dose (in person-rems) for either special form exposure materials or atmospherically dispersed materials. This computation is shown schematically in Figure 5-8. The results can be expressed either as person-rems delivered to particular organs or as annual additional expected latent cancer fatalities using conversion factors from Chapter 3.

The second calculation is annual early fatality probability. If an isotope can give a sufficient dose to cause an early fatality, either from external exposure or excessive pulmonary exposure, the annual probability of this occurrence is computed as shown in Figure 5-9.

5.4 APPLICATION OF THE MODEL TO 1975 AND 1985 STANDARD SHIPMENTS

The annual population dose calculations were carried out for the standard shipment scenarios discussed in Appendix A using the methods discussed previously. The results are presented

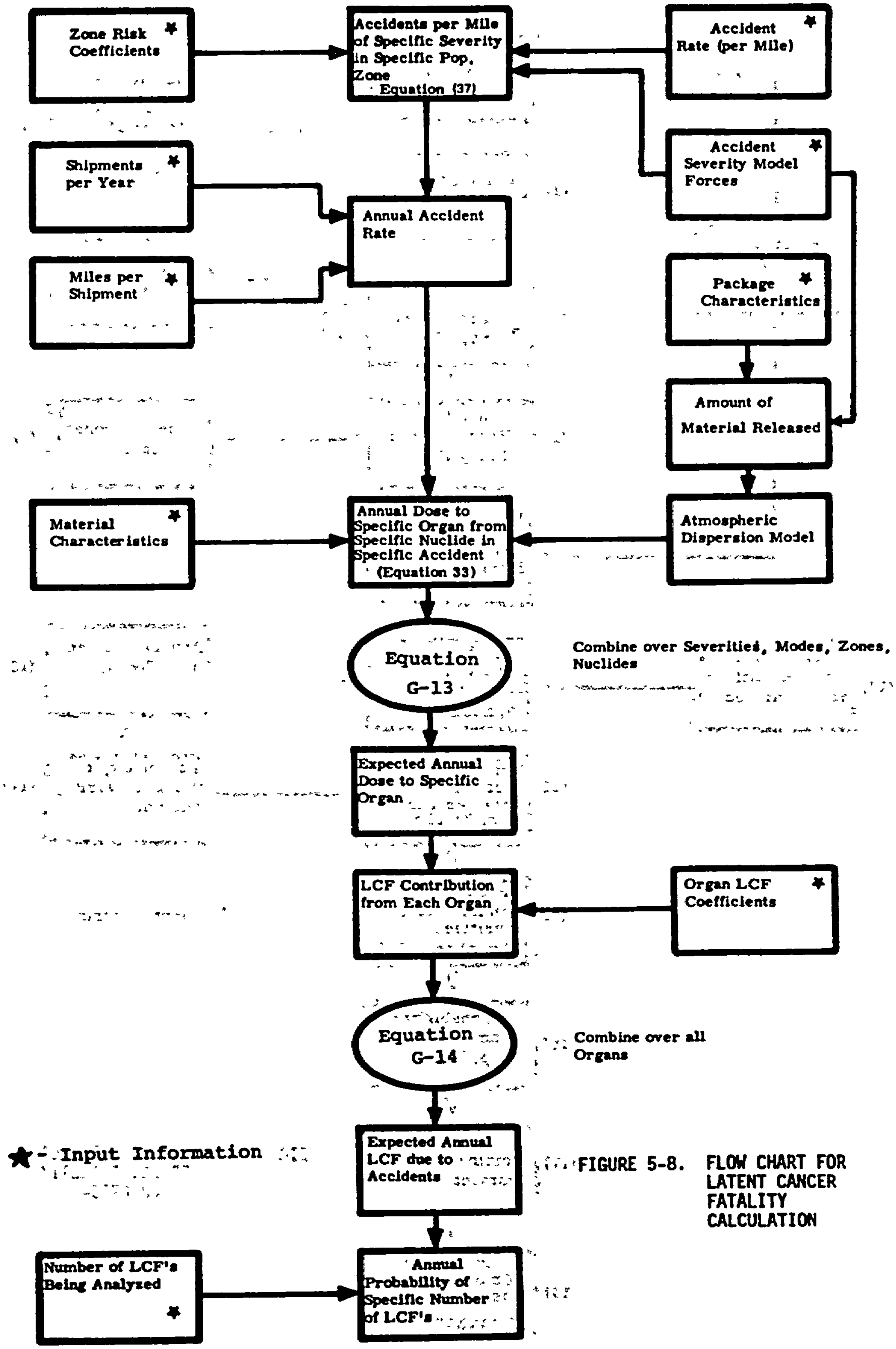


FIGURE 5-8. FLOW CHART FOR LATENT CANCER FATALITY CALCULATION

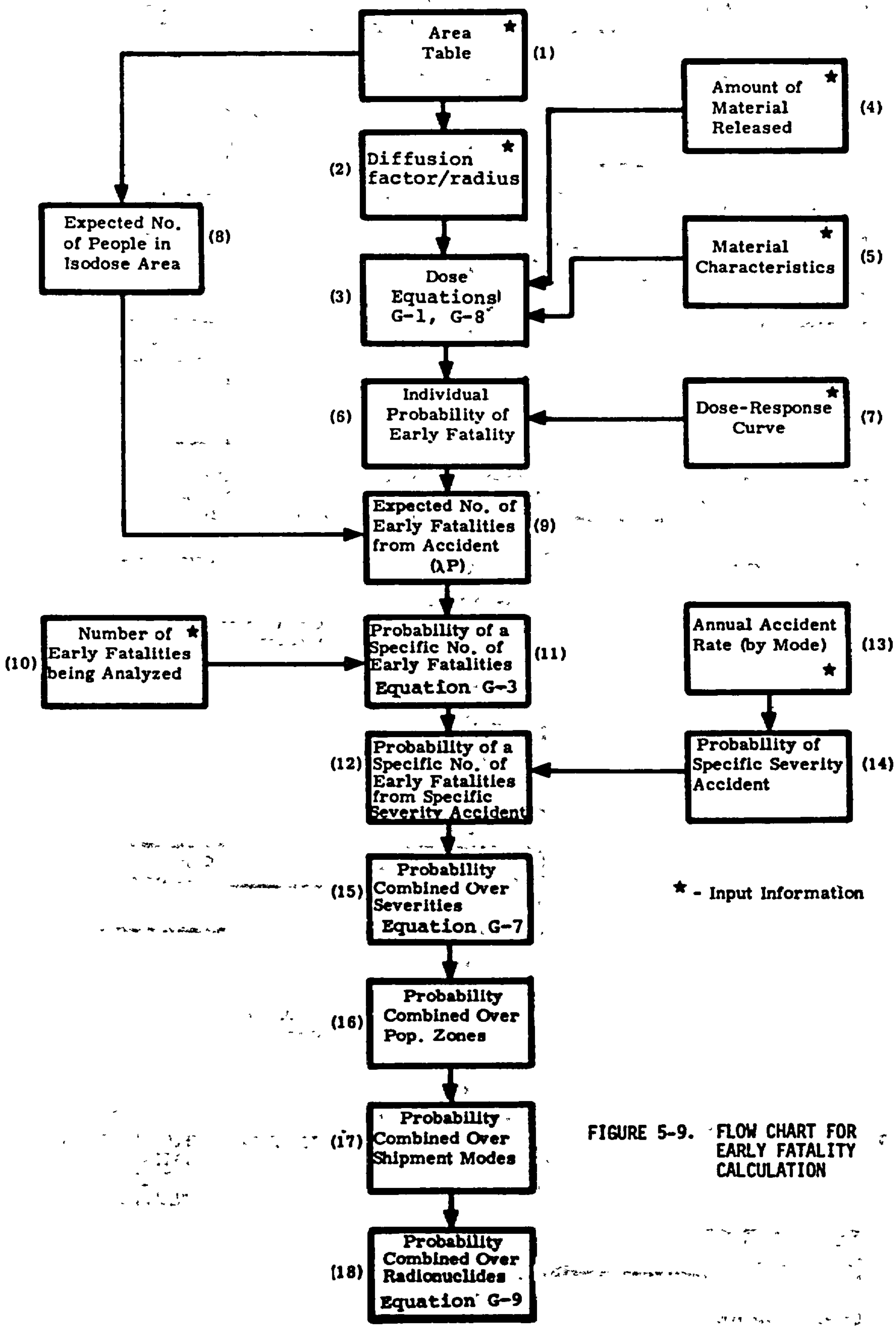


FIGURE 5-9. FLOW CHART FOR EARLY FATALITY CALCULATION

in Table 5-9 for both 1975 and 1985 standard shipments. The annual probability of more than a given number of early fatalities is plotted on Figure 5-10 for 1975 and 1985. Note that a total of 5.37 x 10^{-3} latent cancer fatalities were expected to result in 1975 from all radioactive material shipments, with the principal contributor being the 144-curie Po-210 shipment scenario with 24% of the 1975 LCFs.* The mixed fission product/corrosion product shipments taken together are of similar importance to Po-210, and the shipments of uranium-plutonium mixtures are third, representing 10.7% of the total LCFs in 1975.

The picture in 1985 is similar, except that the plutonium shipments become much less important. This results from the expected improvement in packaging release fractions in plutonium containers.

The data plotted in Figure 5-10 indicate an annual probability of one or more early fatalities (within 1 year of an accident) of approximately 3.5 x 10^{-4}, while the probability of 10 or more is 2.5 x 10^{-6}. This implies that an accident serious enough to kill one person from acute radiological effects would occur only once in 2000 years at 1975 shipping levels.

Results using Model I release fractions for 1975 and 1985 data are presented in Table 5-10 and Figure 5-11. The results shown in Table 5-10 show clearly the impact of the Model I release fractions, which imply that the containment capability of the containers is no better than the regulations require. The most important shipments in this analysis are those with the large quantities of very hazardous materials. The expected LCFs in this case are 9.8 per year in 1975, more than 1000 times that for Model II. The data plotted in Figure 5-11 for the probability of early fatalities using Model I release fractions are also very different from the Model II results. They indicate a probability of less than 0.1 of having one or more early fatalities per year for 1975 using this unrealistic, but legally possible, release fraction model.

5.5 CONSEQUENCES OF CONTAMINATION FROM ACCIDENTS

In addition to direct radiological impacts to man, an accident involving radioactive material may result in environmental contamination leading to loss of crops or contamination of buildings and necessitating evacuation of residents. Analysis of these impacts has been addressed in some detail for the case of a reactor accident in Reference 5-20, and a similar methodology has been adopted for this report.

The potential contamination consequences of a transportation accident involving radioactive materials are, in general, several orders of magnitude smaller than those for a reactor accident. The potential for ingestion of radioactive materials is reduced considerably by the

*There are many factors that can modify the risks identified in Table 5-9. One of these factors is the accident resistance of the package used to ship particular radionuclides. Not included in this analytical model, and thus not reflected in the results, is the fact that all large-quantity shipments of polonium were made in the same accident-resistant packages used to ship plutonium. If considered, this would result in much smaller releases in many of the accident severity categories, and in a smaller total risk attributed to polonium.

TABLE 5-9

ACCIDENT RISK ANALYSIS RESULTS - EXPECTED LATENT CANCER FATALITIES

1975 AND 1985 - MODEL II RELEASE FRACTIONS

Standard Shipment	Expected Latent Cancer Fatalities 1975	Percent of Total Risk	Expected Latent Cancer Fatalities 1985	Percent of Total Risk
Po-210 (144 ci)	.00131	24.4	.00373	22.4
MF+MC (LSA)	.000709	13.2	.00294	17.7
U-Pu Mix	.000514	10.7	.00022	1.3
MF+MC (A)	.000478	8.9	.00198	11.9
Waste (A)	.000388	7.2	.00160	9.6
UF_6 (natural)	.000328	6.1	.00135	8.2
Waste (B)	.000182	3.4	.000752	4.5
Co-60 (40,000 ci)	.00013	2.4	.000336	2.0
Pu-239 (B)	.000129	2.4	.0000122	0.0
Mixed (A)	.00011	2.1	.000286	1.7
U_3O_8	.0000817	1.5	.000338	2.0
MF+MC (392 ci)	.0000800	1.5	.000334	2.0
Mo-99 (A)	.0000708	1.3	.000184	1.1
UF_6 (enriched)	.0000594	1.1	.000246	1.5
Limited	.0000579	1.1	.000151	0.9
Mo-99 (B)	.0000573	1.1	.000149	0.9
Co-60 (LSA)	.0000478	0.9	.000126	0.8
I-131 (A)	.0000384	0.7	.0000384	0.2
Mixed (B)	.0000383	0.7	.0000997	0.6
Spent fuel	.0000356	0.7	.000422	2.5
All others	.000482	9.0	.00136	8.2
TOTAL	.00537		.0166	

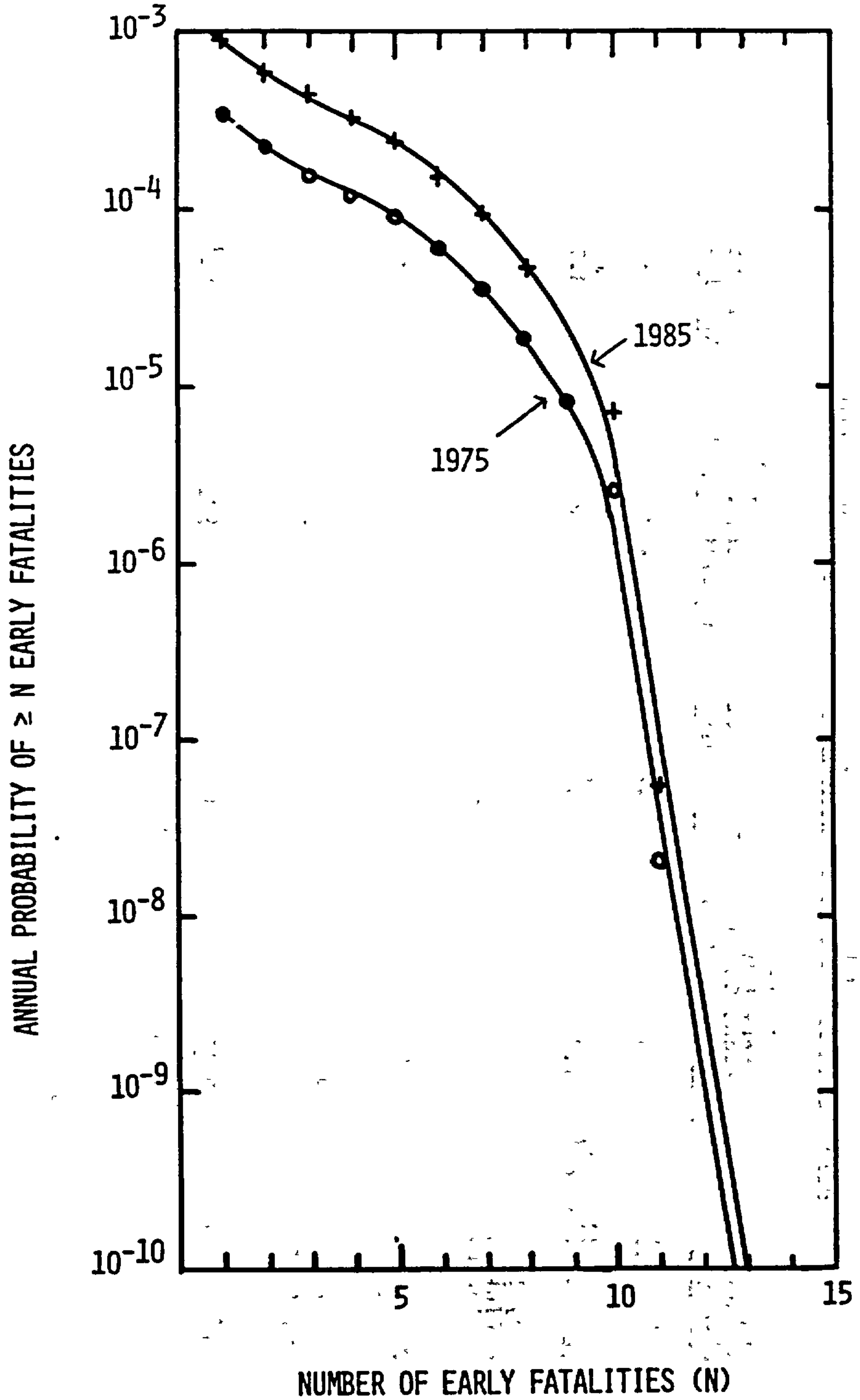


FIGURE 5-10. CUMULATIVE ANNUAL EARLY FATALITY PROBABILITY - 1975, 1985 - MODEL II

TABLE 5-10

ACCIDENT RISK ANALYSIS RESULTS - 1975, 1985 - MODEL I RELEASE FRACTIONS

Standard Shipment	Expected Latent Cancer Fatalities -1975	Percent of Total Risk	Expected Latent Cancer Fatalities - 1985	Percent of Total Risk
U-Pu Mixture	7.9	80.2	32.8	86.6
Pu-239 (1169 ci)	1.78	18.0	1.78	4.7
Recycle plutonium	-	-	1.83	4.8
Spent fuel (rail)	0.021	0.2	0.8	2.1
Spent fuel (truck)	0.047	0.5	0.29	0.8
All others	0.11	1.1	0.038	0.1
	9.86	100	37.9	100

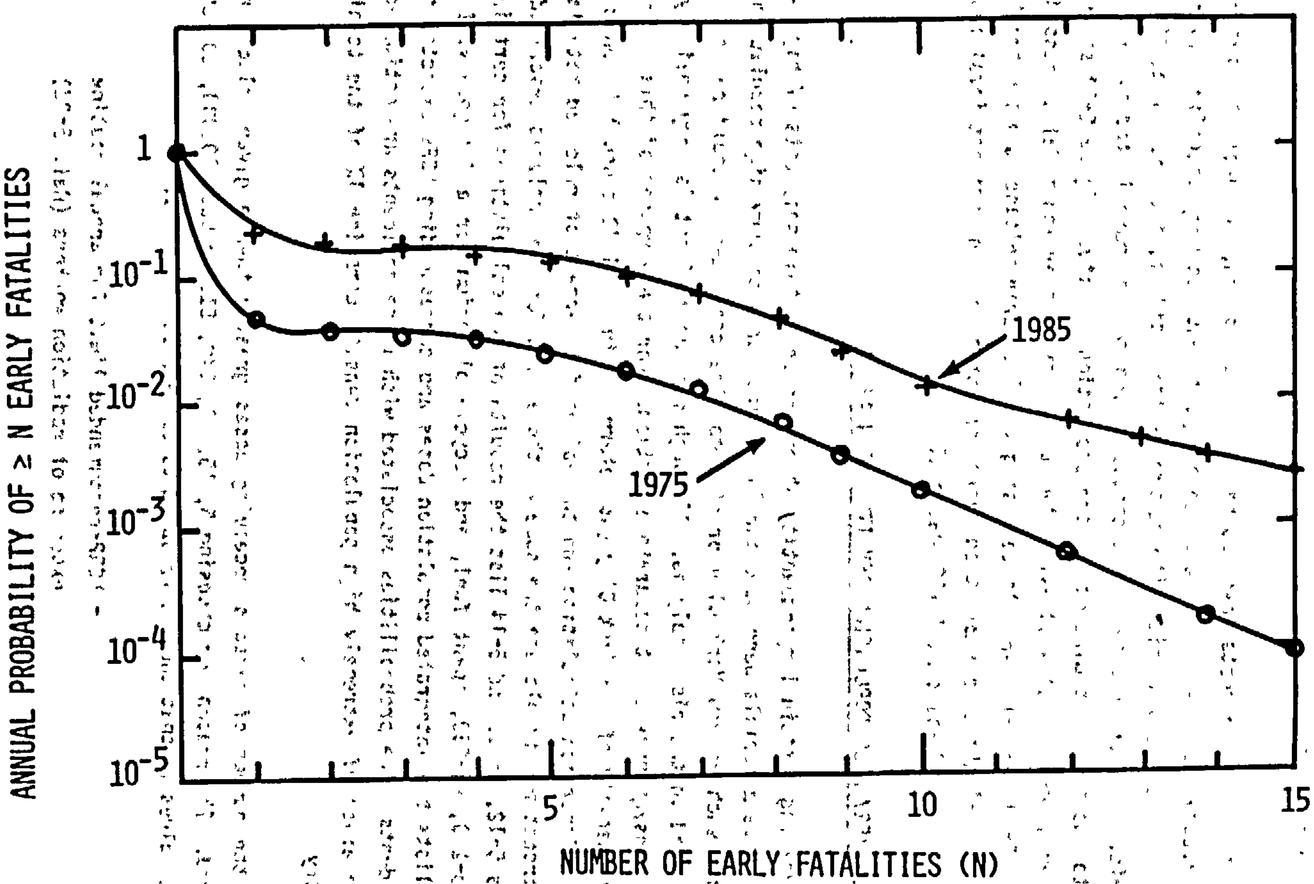


FIGURE 5-11. CUMULATIVE ANNUAL EARLY FATALITY PROBABILITY - 1975, 1985 - MODEL I

fact that contaminated areas are smaller and could be cordoned off. Contaminated crops, milk, and possibly even animals might have to be condemned and destroyed.

A detailed analysis of decontamination costs for four land-use situations for contamination by both a long-lived and a short-lived isotope is presented in this Section. A cleanup level of 0.65 $\mu Ci/m^2$ was used, based on the Palomares, Spain, nuclear weapons incident (Ref. 5-21). The assumptions and results are shown in Table 5-11. Values associated with Table 5-11 were extracted from Reference 5-20.

The analysis of decontamination costs involves many assumptions and, of necessity, represents only order-of-magnitude accuracy. More accurate analysis requires very specific information about land use near the accident site, the nature of the accident, the weather at the time of the accident, etc. However, the cost of decontamination may be approximated as being directly proportional to the area contaminated and the population density. Figure 5-12 shows the area contaminated versus curies released using the atmospheric dispersion model discussed in Section 5.3. Figures 5-13 and 5-14 were plotted using the 600-curie release as a benchmark. These figures show the approximate decontamination costs resulting from an accident involving a given size shipment of long- and short-half-life material.

5.6 SEVERE ACCIDENTS IN VERY HIGH POPULATION DENSITY URBAN AREAS

If an accident involving certain large-quantity shipments or certain shipments of highly toxic or highly radioactive materials were to occur in an urban area of very high population density (i.e., $>10^4/km^2$) such as New York City or Chicago, the consequences could be more serious than any considered in the risk analysis. Although such an accident is very unlikely, its potentially severe consequences merit separate attention. For the purposes of this analysis, the average urban density of New York City (as determined in the 1970 census) is used: 15,444 people/km^2. The dispersion calculation and the values for percent of released material aerosolized and the percent respirable are the same as those used for the analysis described in Section 5.3. Tables 5-12, 5-13, and 5-14 list the results of the calculations for certain shipments of Co-60, Po-210, Pu-239, spent fuel, and recycle plutonium for a Category VIII accident. Table 5-12 lists the integrated population doses and corresponding LCFs expected to result from these accidents. The probabilities associated with these accidents are estimated by assuming that urban areas of extremely high population density comprise 1% of the total urban area in the country.

Table 5-13 shows the number of persons receiving doses greater than a given value for each accident considered. The reason for choosing 5, 15, 50, 340, 510, 3,000, 10,000, 20,000 and 70,000 rems as dose values is that these correspond to certain benchmark values:

15 rems to lungs	- NCRP-recommended limit for annual routine exposure of radiation workers (Ref. 5-22)
3000 rems to lungs	- threshold for pulmonary morbidity from short-lived gamma and beta emitters (Ref. 5-20)

TABLE 5-11

ESTIMATED DECONTAMINATION COST FOR 600 CURIE RELEASE OF VARIOUS MATERIALS [a]*

Population Zone	Land Use	Long-Lived Contaminant: Decont. Technique	Long-Lived Contaminant: Estimated Cost ($)	Short-Lived Contaminant [b]: Decont. Technique	Short-Lived Contaminant [b]: Estimated Cost ($)
Rural (6 person/km^2)	undeveloped/ uninhabited	(1) DF<20- bury by deep plowing [c]	$7.8x10^5$	(1) cordon off for 60 days [e]	$29,000
		(2) DF ≥ 20- scrape and bury [d]	$3.04x10^5$		
			Total = $$1.08x10^6$		Total = $29,000
	farmland/ dairyland	(1) DF < 20 bury by deep plowing	$7.8x10^5$	(1) cordon off for 60 days	$29,000
		(2) DF ≥ 20 scrape and bury	$3.04x10^5$	(2) 270 evacuees for 60 days	$3.65x10^4$
		(3) decon. homes/barns a. DF<20 [f]	$6.22x10^5$	(3) purchase & dispose of crops, forage, milk [k]	$9.77x10^5$
		b. DF≥20 [g]	$7.42x10^4$		
		(4) 270 evacuees [h]	$3.65x10^4$		
		(5) purchase & dispose of crops, forage, and milk [i]	$1.15x10^6$ [j]		
			Total = $$2.97x10^6$		Total = $1.04x10^6$

*See notes at end of table.

TABLE 5-11 (continued)

Population Zone	Land Use	Long-Lived Contaminant		Short-Lived Contaminant [b]	
		Decont. Technique	Estimated Cost ($)	Decont. Technique	Estimated Cost ($)
Suburban (719 persons/km^2)	98.5% single family dwellings	(1) Decon. homes a. DF < 20 [l] b. DF ≥ 20 [m]	 56.1x10^6 12.1x10^6	(1) cordon off all residential areas with DF ≥ 20 [t]	7.2x10^4
	0.8% public areas (schools, etc.)	(2) 3.24x10^4 evacuees	4.4x10^6	(2) Decon. homes DF>20	12.3x10^6
	0.4% commercial & industrial areas	(3) Decon. public areas a. DF < 20 [n] b. DF ≥ 20 [o]	 1.83x10^5 1.0x10^5	(3) cordon off all parks [u]	2.84x10^5
	0.3% parks, cemeteries, etc.	(4) Decon. commercial & industrial areas a. DF < 20 [p] b. DF ≥ 20 [q]	 9.15x10^4 9.77x10^4	(4) Decon. public areas	2.84x10^5
		(5) Decon. parks by replacing lawn [r]	1.12x10^6	(5) Decon. commercial & industrial areas	1.89x10^5
		(6) indiv. and corporate income loss [s]	7.33x10^6	(6) 2035 evacuees for 60 days. 30,320 evacuees for 10 days	5.74x10^6
				(7) income loss	9.64x10^6
			Total = $82x10^6		Total = $28.5x10^6

TABLE 5-11 (continued)

Population Zone	Land Use [w]	Long-Lived Contaminant: Decont. Technique	Long-Lived Contaminant: Estimated Cost ($)	Short-Lived Contaminant: Decont. Technique	Short-Lived Contaminant: Estimated Cost ($)
Urban (3861 persons/km^2)	20% high density resid. (6 story apts) [cc]	(1) Decon. apartment buildings a. DF<20[x] b. DF≥20[y]	a. $1.7x10^6$ b. $1.06x10^6$	(1) cordon off resid. areas with DF≥20 [t]	$7.2x10^4$
	20% single fam. resid[cc]	(2) Decon. single fam. residences a. DF<20[l] b. DF≥20[m]	a. $11.4x10^6$ b. $2.45x10^6$	(2) cordon off all parks and vacant areas	$3.2x10^6$
	20% public land	(3) Decon. public land a. DF<20 b. DF≥20	a. $4.6x10^6$ b. $2.5x10^6$	(3) Decon. resid. with DF ≥ 20	$3.5x10^6$
	20% Ind. & commercial	(4) Decon. commercial & industrial area a. DF<20 b. DF≥20	a. $4.6x10^6$ b. $4.9x10^6$	(4) Decon. commercial & industrial areas	$9.5x10^6$
	10% parks	(5) Decon parks	$5.67x10^6$	(5) 10,900 evacuees for 60 days; $1.63x10^5$ for 10 days	$30.8x10^6$
	10% undevel. or vacant land	(6) Decon vacant areas (scrape and bury)	$4.83x10^5$	(6) Decon. public areas	$7.1x10^6$
		(7) $1.64x10^5$ evacuees	$22x10^6$	(7) income loss	$51.8x10^6$
		(8) income loss	$37.2x10^6$		
			Total = $\$98.6x10^6$		Total = $\$106x10^6$ [aa,v]

Notes for Table 5-11

a. $4.5 \times 10^7 m^2$ (1.11×10^4 acres) require decontamination; 2.82×10^6 m^2 (698 acres) require a DF $\geq$ 20. 400 cpm/m^2 (.65 μci/m^2).
b. I-131 is used as an example/$t_{1/2}$ = 8 days/7 x $t_{1/2}$ = 60 days.
c. $75 per acre.
d. $435 per acre - includes costs of reburial.
e. $5 per hour per guard/4 guards per shift (based on conversations with private security agencies). This could be reduced if National Guard or active duty military were used.
f. $4915 per building/2 buildings per 4-person family (home and barn).
g. $8725 per building/2 buildings per 4-person family (home and barn).
h. $13.5 per day per evacuee; 10 day evacuation required.
i. $104 per acre (based on 48-state average - less Alaska and Hawaii).
j. If orchards are involved, the cost could be considerably higher (up to $5000 per acre) to account for the loss of crops in subsequent years.
k. The entire year's crops are purchased/60-days of milk products are purchased/the average dairy yield per acre is $16 per year.
l. 5 houses per acre/$1095 per house (includes street cleanup).
m. 5 houses per acre/$3510 per house (includes street cleanup).
n. $2200 per acre.
o. $18,000 per acre.
p. $2200 per acre.
q. $35,000 per acre.
r. $0.13 per ft^2 to replace lawns/0.61 acres of parks per 100 persons.
s. $1100 per capita per quarter - individual/$940 per capita per quarter - corporate/10 days of lost income.
t. 10 guards on patrol per shift.
u. 1 guard per 5 acre park per shift.
v. If total evacuation for 60 days with no decontamination were used, the approximate cost would be $261 $\times 10^6$ for suburban and $1.4 $\times 10^9$ for urban. However, this approach would probably not be socially acceptable.
w. Based on approximate values for an average U.S. city (New York City Planning Commission, "Plan for New York City - Volume 1 (initial issue)," 1969)- streets are included with appropriate categories.
x. $15 per occupant for 6-story apartment building } all residents assumed to live in multi-story buildings
y. $140 per occupant for 6-story apartment building }
z. 20 guards on patrol per shift.
aa. Clearly, the method used to deal with a spill of this sort would be the least expensive method - probably outright cleanup rather than long-term evacuation.
bb. Single family units.
cc. The single family units are assumed to have 4 persons per unit, 5 units per acre. The remaining people are assumed to live in multi-story buildings.

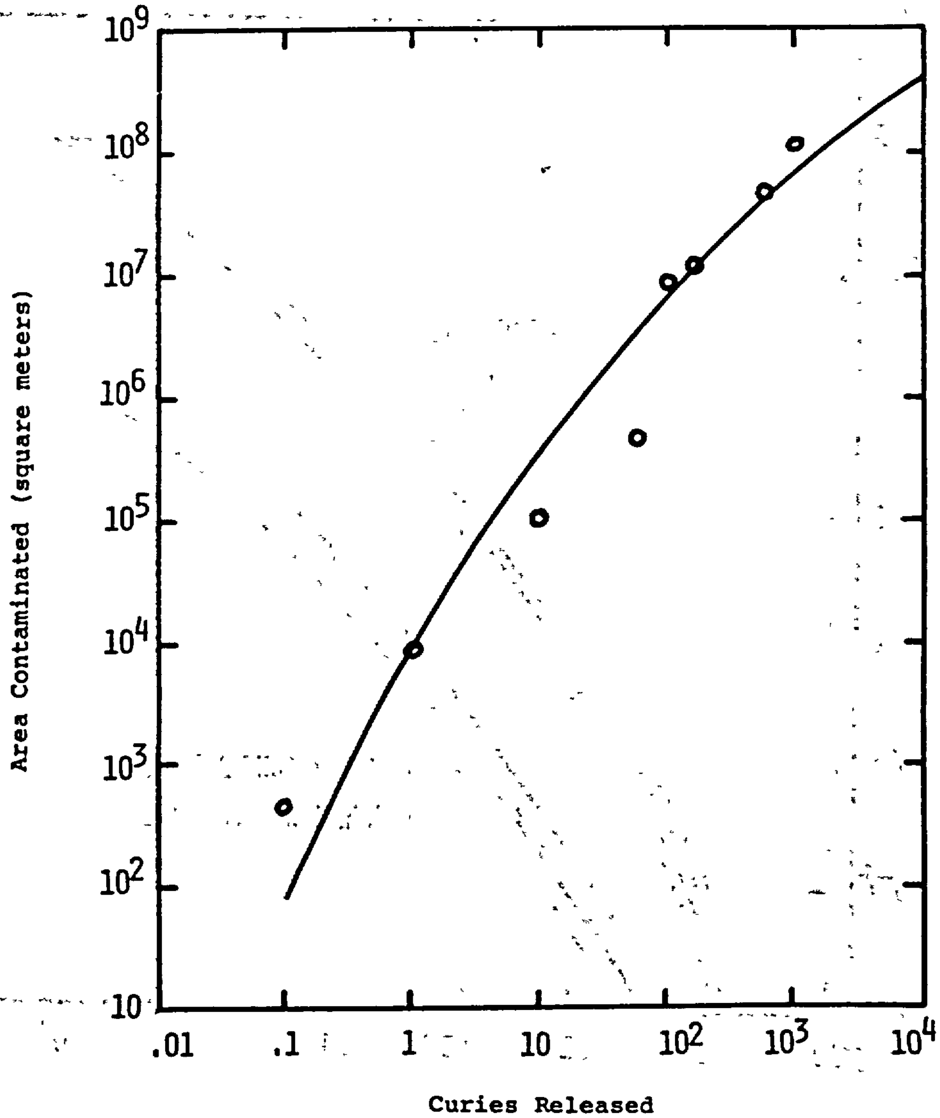


FIGURE 5-12. AREA CONTAMINATED TO A LEVEL OF 0.65 $\mu Ci/m^2$ FOR A GIVEN RELEASE

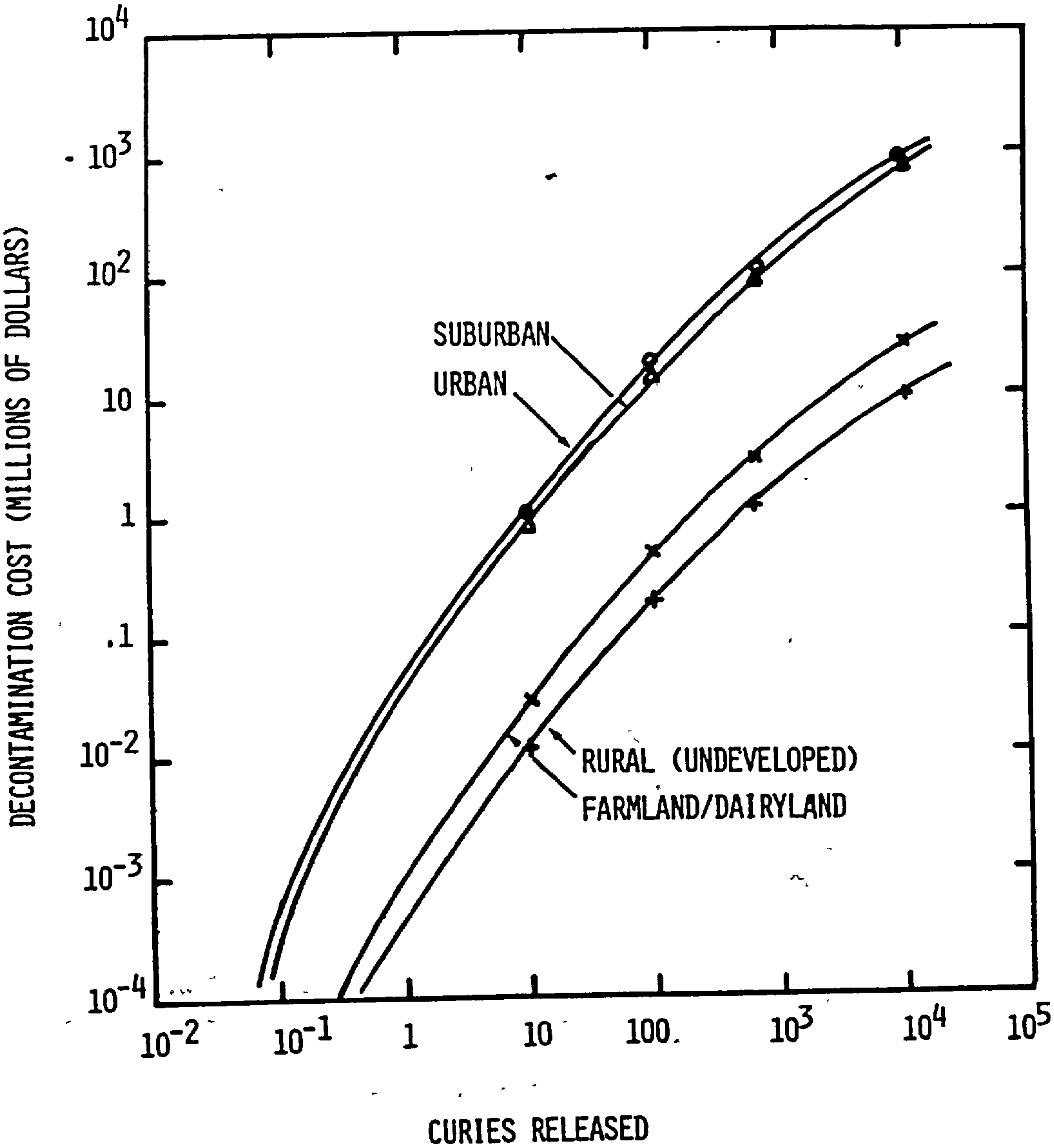


FIGURE 5-13. DECONTAMINATION COSTS FOR RELEASES OF LONG-LIVED ISOTOPES

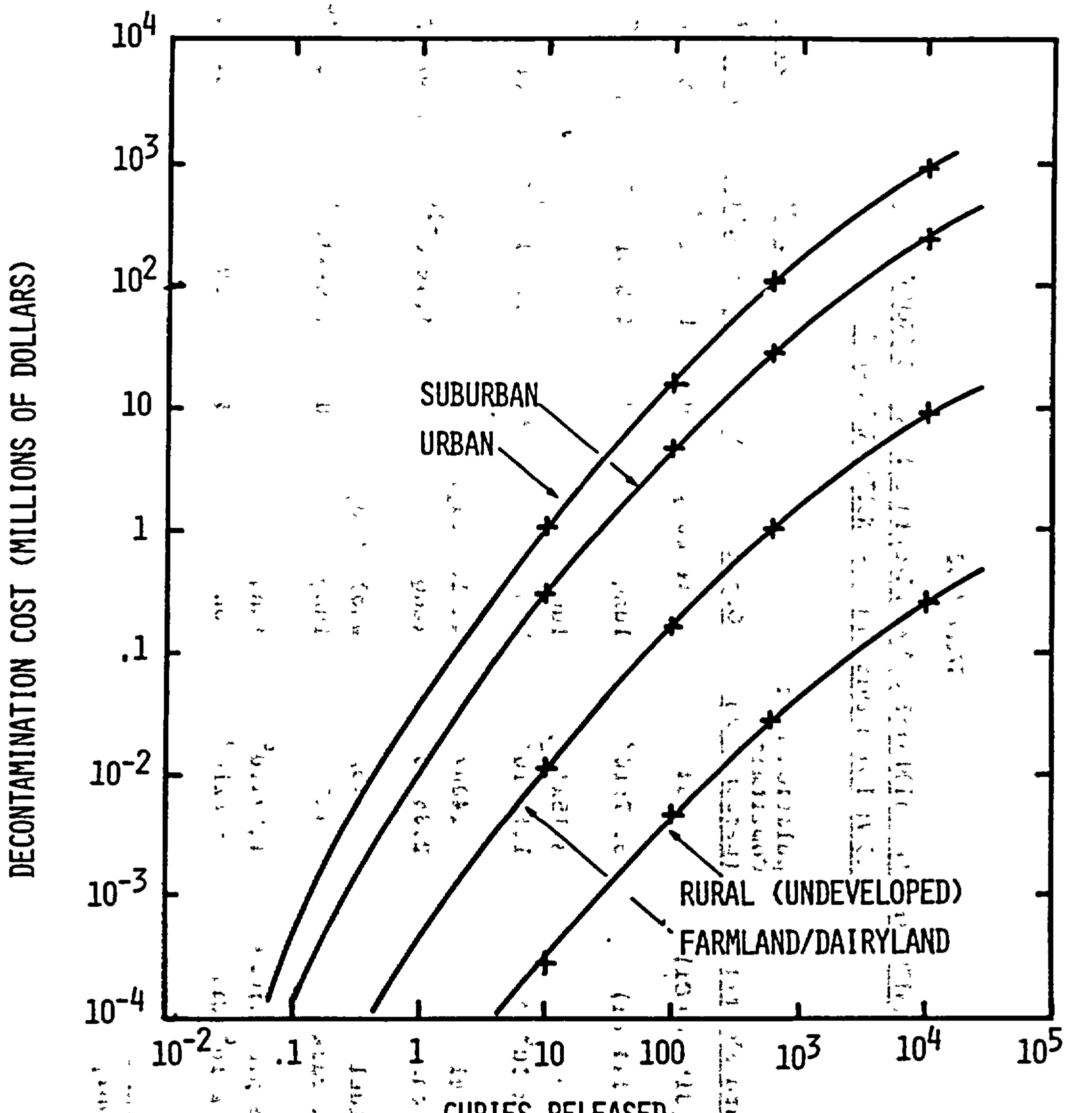


FIGURE 5-14. DECONTAMINATION COSTS FOR RELEASES OF SHORT-LIVED ISOTOPES

TABLE 5-12

INTEGRATED POPULATION DOSE AND EXPECTED LATENT CANCERS FROM CERTAIN CLASS VIII ACCIDENTS IN HIGH-DENSITY URBAN AREAS

Standard Shipment	Population Dose Commitment (person-rem)	Organ	LCF	1975 Probability	1985 Probability
Co-60 (315,000 Ci)	284	whole body	0	$1.02x10^{-10}$	$2.55x10^{-10}$
Po-210 (144 Ci)	$5.27x10^{6}$	lung	117	$2.57x10^{-10}$	$8.2x10^{-10}$
Plutonium (1.23×10^{6} Ci)	$3.15x10^{6}$/ $1.11x10^{7}$	lung/ bone	147	$1.06x11^{-11}$	$1.06x10^{-11}$
Spent fuel (rail cask)	1400/ $2.85x10^{4}$	whole body/ lung	1	$1.8x10^{-10}$	$6.91x10^{-9}$
Spent fuel (truck cask)	215/ 4450	whole body/ lung	0	$2.99x10^{-9}$	$1.8x10^{-8}$
Recycle plutonium* (6.19×10^{6} Ci)	$1.59x10^{6}$/ $5.6x10^{6}$	lung/ bone	74*	0.0	$2.24x10^{-10}$

*1985 only.

TABLE 5-13

NUMBER OF PEOPLE RECEIVING DOSES GREATER THAN OR EQUAL TO VARIOUS SPECIFIED ACUTE DOSES (IN REMS) OF INTEREST IN CERTAIN CLASS VIII ACCIDENTS IN HIGH-DENSITY URBAN AREAS

Shipment	Organ	Time Period for Dose	5	15	50	340	510	3000	10,000	20,000	70,000
Co-60 (315,000 Ci)	Whole Body	1 hr	75	-	12	0	0	-	-	-	-
Po-210 (144 Ci)	Lung	1 yr	-	3.42×10^4	-	-	-	59	-	2	-
Plutonium (1.23×10^6 Ci)	Lung	1 yr	-	2337	-	-	-	-	0	-	0
Spent Fuel (truck cask)	Whole Body	1 hr	61	-	8	0	0	-	-	-	-
	Lung	1 yr	-	0	-	-	-	0	-	0	-
Spent Fuel (rail cask)	Whole Body	1 hr	440	-	40	7	0	-	-	-	-
	Lung	1 yr	-	48	-	-	-	0	-	0	-
Recycle Pu (6.19×10^6 Ci)	Lung	1 yr	-	2475	-	-	-	-	0	-	0

TABLE 5-14

EARLY FATALITIES AND DECONTAMINATION COSTS

CLASS VIII ACCIDENTS - EXTREME DENSITY URBAN AREAS

Isotope	Total Curies	Percent Released	Percent Aerosolized	Early Fatalities	Decontamination Cost*
Co-60	315,000	0	0	0	NA
Po-210	144	100	100	1	$\$300 \times 10^6$
Plutonium	1.2×10^6	10	5	0	$\$800 \times 10^6$
Recycle Pu (1985 only)	6.2×10^6	10	5	0	$\$1200 \times 10^6$
Spent fuel	9.1×10^6	100**	100**	0	$\$400 \times 10^6$
Spent fuel	1.4×10^6	100**	100**	0	$\$200 \times 10^6$

*Adjusted for increased evacuation and income loss costs resulting from higher population density.

**Of available gaseous and volatile fission products only.

10,000 rems to lungs	- threshold for pulmonary morbidity from long-lived alpha emitters when received as an acute dose (Refs. 5-20 and 5-23)
20,000 rems to lungs*	- produces early fatality from pulmonary morbidity resulting from short-lived beta-gamma emitters when received as an acute dose (Ref. 5-23)
70,000 rems to lungs*	- produces early fatality from pulmonary morbidity resulting from long-lived alpha emitters when received as an acute dose (Ref. 5-23)
5 rems to whole body	- NCRP-recommended limit for annual whole-body radiation for radiation workers (Ref. 5-22)
50 rems to whole body	- threshold for noticeable physiological effects from acute exposure to whole-body radiation (Ref. 5-22)
340 rems to whole body**	- produces early fatality from bone marrow destruction from acute exposure with minimal medical treatment (Ref. 5-20)
510 rems to whole body**	- produces early fatality from bone marrow destruction from acute exposure with supportive medical treatment (Ref. 5-20)

5.7 EXPORT AND IMPORT SHIPMENTS

The annual radiological risk calculation for accidents involving import and export shipments was done in the same way as for the 1975 and 1985 standard shipments models. A separate standard shipments model was devised for 1975 export shipments only and is discussed in Appendix A.

The total annual radiological risk computed for export shipments in 1975 is 1.57×10^{-5} LCF per year, or 0.3% of the total accident risk. Table 5-15 shows a breakdown of the annual accident risk by material and major transport modes. Over half of the risk results from enriched uranium shipments because this is the dominant exported material. Since most exported enriched uranium shipments are transported by ship, these dominate the risk; shipments by aircraft and truck are of lesser importance. It is not anticipated that export shipments would contribute a significantly greater percentage of the annual risk in 1985 than they did in 1975. A detailed analysis of the environmental effects of U.S. nuclear power export activities is given in Reference 5-24.

*LD 50/360 value (lethal dose within 360 days for 50% of a population so exposed).

**LD 50/30 value (lethal dose within 30 days for 50% of a population so exposed).

TABLE 5-15

ANNUAL EXPECTED LATENT CANCER FATALITIES RESULTING FROM ACCIDENTS INVOLVING EXPORT SHIPMENTS OF RADIOACTIVE MATERIALS - 1975 EXPORT SHIPMENTS MODEL

Material	Major Transport Mode(s)	Annual Expected Latent Cancer Fatalities	Percent of Total Export Shipment Risk
Enriched UO_2	Ship	5.5×10^{-6}	35.1%
Enriched UF_6	Ship	4.4×10^{-6}	28.1%
MF+MC - Type A	Cargo Air	3.3×10^{-6}	21.1%
Co-60 - Type B	Truck	1.4×10^{-6}	8.9%
Enriched UF_6	Cargo Air Truck	7.5×10^{-7}	4.6%
Mo-99 - Types A,B	Pass Air, Cargo Air	1.4×10^{-7}	0.9%
All Other Exports	Ship, Truck Pass. Air, Cargo Air	1.9×10^{-7}	1.3%
TOTAL		1.57×10^{-5}	100%

According to the 1975 Survey (see Appendix A), virtually all of the curies imported in 1975 were contained in four Type B Co-60 shipments, each containing only one package with an average of 1.8×10^5 curies per package. The average distance per shipment was 670 km, and the shipments were all transported by truck. One of the scenarios considered in the 1975 standard shipments model, Co-60-LQ2, involved four Co-60 shipments by truck, 3.2×10^5 curies per shipment and 3200 km per shipment. These four shipments result in an annual risk of 1.2×10^{-10} LCF per year. The risk for the four import shipments can be determined from this figure, reduced in proportion to the curies transported and the shipment distance. The result is 1.4×10^{-11} LCF per year.

5.8 NONRADIOLOGICAL RISKS IN TRANSPORTATION ACCIDENTS

Most radioactive materials are shipped incidental to other freight shipments, i.e., the shipment would take place whether or not the radioactive material were on board. For these shipments the only impacts chargeable to the radioactive material are the normal population dose discussed in Chapter 4 and the radiological accident risk discussed earlier in this chapter.

However, for exclusive-use shipments, i.e., those that require the exclusive use of the transport vehicle, there are certain nonradiological risks that must also be considered, e.g., the risk that the driver of a exclusive-use vehicle will be injured or killed in an accident, not from radiological causes, but from the accident itself. In addition to fatalities, nonradiological injuries and property damage must be considered as part of the environmental impact of radioactive materials transport along with the radiological effects.

It has been estimated (Ref. 5-25) that transport of cold fuel to nuclear power plants and shipments of irradiated fuel and solid wastes from the plants by exclusive-use vehicles could result in 0.03 injuries and 0.003 fatalities per reactor year if all fuel and solid waste transport were by truck and irradiated fuel transport were by rail or barge. For the approximately 60 power reactors in operation in 1975, this translates into 2 injuries and 0.2 fatalities per year.

Probably the greatest use of exclusive-use trucks for other than fuel cycle materials is in the transport of radiopharmaceuticals, primarily Mo-99/Tc-99m generators. If it is estimated that 10% of the generators that were transported by truck in the 1975 standard shipments model are transported by exclusive-use trucks in average aggregate quantities of 80 TI per shipment, about 130 such shipments per year would be expected. For an average shipment distance of 960 kilometers, the total distance traveled would be 1.25×10^5 kilometers per year. Utilizing the accident statistics and injury and fatality data that were used to estimate the nonradiological impact for shipments to and from power plants (Ref. 5-25), the transport of Mo-99/Tc-99m generators by exclusive-use trucks would produce about 0.07 injuries and about 0.004 fatalities per year.

Finally, certain all-cargo airlines make routine flights exclusively for shipment of radioactive materials, primarily Mo-99/Tc-99m generators. It is estimated that these flights cover 320,000 kilometers per year. Using the commercial aircraft accident rates of

1.44×10^{-8} accidents per kilometer, these flights would be expected to result in about 0.005 accidents per year. Assuming that a crew of two would be killed in each accident, an average of 0.01 fatalities per year would be expected.

Thus, the estimated nonradiological impacts resulting from transport in vehicles used exclusively for radioactive material shipments is 2.05 injuries and 0.213 fatalities per year. The major contribution is made by transport of cold and spent fuel to and from nuclear power plants.

5.9 SUMMARY OF RESULTS

The results of the calculations of the risk resulting from potential transportation accidents involving radioactive materials shipments may be summarized as follows:

1. The accident risk for the 1975 level of shipping activity, as determined from the 1975 shipping survey, is very small: roughly 0.005 additional LCF per year, or one additional LCF every 200 years, plus an equal number of genetic effects. This number of LCFs is only 0.3% of those resulting from normal transport population exposures.

2. Over 70% of the accident risk is attributable to shipments of Po-210, plutonium, waste, mixed fission and corrosion products, and UF_6 (Table 5-9).

3. The projected accident risk in 1985 is 0.0166 LCF per year, or about 3.5 times the 1975 risk, but is still very small in comparison to the LCFs resulting from normal transport. Even though the 1985 calculation takes into account a modest amount of plutonium recycle, the risk from plutonium (U-Pu mix) is 1.3% of the total risk.

4. Using Model II release fractions, the annual probability of one or more early fatalities from radiological causes in a transportation accident is about 5×10^{-4} in 1975 and about 10^{-3} in 1985.

5. Costs of decontamination following a transportation accident involving a 600-curie release can be as much as 100×10^{6} dollars in an urban population zone.

6. In spite of their low annual risk, specific accidents occurring in very-high-density urban population zones can produce as many as 1 early fatality, 150 LCFs, and large decontamination costs. Although such accidents are possible, their probability of occurrence is very small.

7. The contribution to the annual accident risk from export and import shipments is less than 0.01 times the domestic transport risk and is likely to remain so in 1985.

8. The principal nonradiological impacts are those injuries and fatalities resulting from accidents involving vehicles used exclusively for the transport of radioactive materials. The number of expected annual nonradiological fatalities is almost 50 times greater than the

expected number of additional LCFs resulting from radiological causes but is less than one fatality every five years.

The annual individual probability of an early (radiological) fatality resulting from a transportation accident involving a radioactive materials shipment is presented in Table 5-16 together with annual individual probabilities of an early fatality from other types of accidents. The numbers listed in the table are based on the assumptions that all accidents occur randomly throughout the population and that the number of persons at risk for early fatalities resulting from radiological causes following a transportation accident is 75×10^6 (estimating that approximately one-third of the population lives along major transport routes). The table shows, for example, that an individual is 10^5 times as likely to be killed as a result of being struck by lightning as he is to die from radiological causes within one year following a transportation accident involving a shipment of radioactive materials. The table shows that there are many commonly accepted accident risks that are very much greater than the accident risk of transporting radioactive materials.

TABLE 5-16

INDIVIDUAL RISK OF EARLY FATALITY BY VARIOUS CAUSES (Ref. 5-20)

Accident Type	Number per Year	Individual Risk per Year
Motor Vehicle	5.5×10^4	1 in 4,000
Falls	1.8×10^4	1 in 10,000
Fires	7.5×10^3	1 in 25,000
Drowning	6.2×10^3	1 in 30,000
Air Travel	1.8×10^3	1 in 100,000
Falling Objects	1.3×10^3	1 in 160,000
Electrocution	1.1×10^3	1 in 160,000
Lightning	160	1 in 2,000,000
Tornadoes	91	1 in 2,500,000
Hurricanes	93	1 in 2,500,000
100 Nuclear Reactors	3×10^{-3}*	1 in 5,000,000,000
Transportation of Radioactive Material (from Radioactive causes)	3.5×10^{-4}**	1 in 200,000,000,000***

*Statistical estimate.
**Statistical estimate for 1975.
***Using a population at risk of 75 million people.

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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 (1.2×10^6 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 (1.2×10^6 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	9.08×10^{-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	9.25×10^{-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	9.12×10^{-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 x 10^6 in cask leasing charges, and the 5,768 total shipments would cost an additional \$13 x 10^6 for shipping. When these costs are combined with the equivalent of \$9 x 10^5 additional radiological costs, the alternative of shipping all irradiated fuel by truck is not cost effective to the extent of \$28 x 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 x 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 x 10^6 in cask leasing charges, \$5 x 10^6 in shipping charges, and \$5 x 10^5 in equivalent radiological costs. This alternative would therefore be cost effective by about \$11 x 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 2.5×10^{-4} LCFs per year. Thus, under the assumption of no accidents with special trains, the total accident risk would be reduced by 2.5×10^{-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 1.86×10^{-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 $\$6.6 \times 10^5$ 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 $\$1 \times 10^6$ 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 $(\$79,360 - \$49,920) \times 652 = \$19.2 \times 10^6$

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 x 10^5
IV	76 years	128	20	$2.63 x 10^5
V,VI,VII,VIII	700 years	1280	150	$2.14 x 10^5
TOTAL				$6.22 x 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.

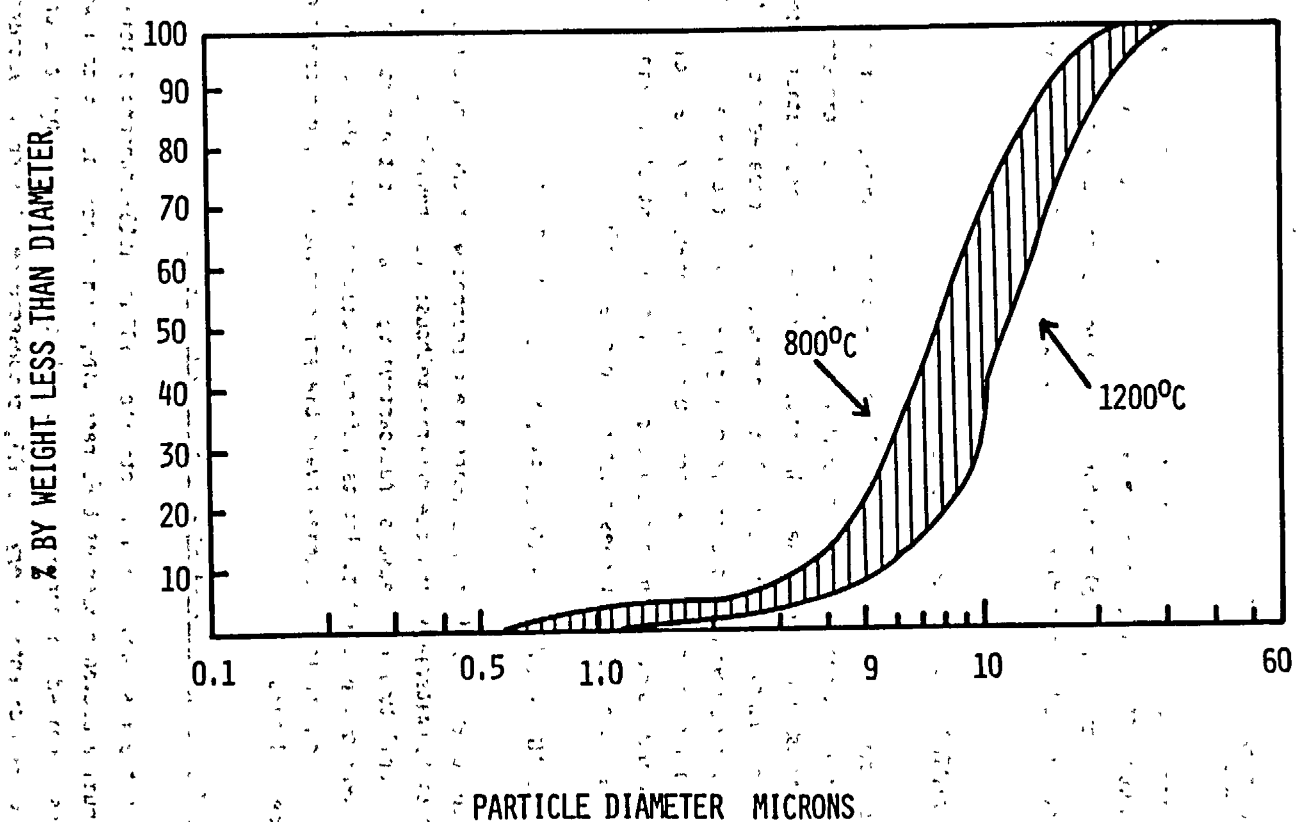

FIGURE 6-1. VARIATION IN PLUTONIUM DIOXIDE PARTICLE SIZE DISTRIBUTION FOR A RANGE OF CALCINING TEMPERATURE BETWEEN 800°C AND 1200°C (Ref. 6-16).

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 or 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

- 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.

- 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.

- 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.[a] 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	3.2×10^5	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	1.23×10^6	2.0	1600	1
Spent Fuel	Cask	1.4×10^6 [4]	1.0 [2]	2530 [5]	1
	Cask	9.1×10^6 [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:

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

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

TABLE A-8 (continued)

Material	Package Type	AF	P A/C	Truck	Rail	Ship
Mo-99	A	8320	2.07×10^5	1.43×10^5	-	-
	B	283	7070	4890	-	-
Po-210	A	336	-	211	260	-
	LQ	32	-	18	3	-
P-32	A	697	2.06×10^4	9930	-	-
Ra-226	A	-	-	2.6×10^4	-	-
	B	440	-	2620	-	-
Tc-99m	A	3330	7.83×10^4	5.43×10^5	-	-
Tl-201	A	-	7500	4.25×10^4	-	-
Waste	A	-	-	5.4×10^5	-	-
	B	-	-	3300	-	-
	LSA	-	-	8.4×10^4	-	-
Xe-133	A	2280	3.17×10^4	3.35×10^4	-	-
Mixed	A	299	5880	7.02×10^4	-	-
	B	-	21	263	-	-
	LSA	68	1330	1.52×10^4	-	-
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	-	-	2.24×10^5	2.73×10^5	-
UF_6 Nat.	A	-	-	8440	1.04×10^4	-
UF_6 Enr.	B	-	-	2010	-	439
UO_2 Enr	B	-	-	4.01×10^4	-	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	6×10^{-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	1.24×10^{4}	14000	18	7580	-1.25x10
UF_6 (enr)	B	0.34	3.4	DS	117	9660	-	-	261	760	27	869	405
UO_2-Rx	B	1.48×10^{-6}	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.

(p) "Transport group" means any one of seven groups into which radionuclides is 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:

	Radioactive half-life		
Radionuclide	0 to 1000 days	1000 days to 10^4 years	Over 10^4 years
Atomic number 1-81.	Group III	Group II	Group III.
Atomic number 82 and over	Group I	Group I	Group III.

33 FR 17621

(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.

33 FR 17821

(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.

31 FR 9941

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

38 FR 10437

(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	20[1]	5,000

37 FR 3985

§ 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.

37 FR 3985

(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

31 FR 9941

§ 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.

37 FR 3985

§ 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

38 FR 10437

(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_4, UF_6, or uranium oxide 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

33 FR 10437

(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.

37 FR 3985

§ 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.

38 FR 10437

§ 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_4, UF_6, or uranium oxide

[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

[38 FR 10437] (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.

[31 FR 9941] ***§ 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:

[38 FR 10437] (1) No single package contains more than a type A quantity of radioactive material, as defined in § 71.4(q); and

[31 FR 9941] (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:

[38 FR 10437] (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.

[39 FR 22131] **§ 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.**

[35 FR 6271] 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:

[38 FR 10437] (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

[39 FR 32320] (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.

[38 FR 10437] (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:

38 FR 10437

(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

40 FR 8774

§ 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.

31 FR 9941

*§ 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.

37 FR 3985

***§ 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.

37 FR 3585

(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).

38 FR 10437

(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)

*Redesignated by FR 10437.

***Amended 37 FR 3985

**Effective date of this amendment.

31 FR 9941

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

§ 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.

37 FR 3985

§ 71.24 Procedural controls.

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

39 FR 22131

§ 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.

31 FR 9941

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

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.

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.

38 FR 10437

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.

31 FR 9941

(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.

(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.

31 FR 9941

(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.

(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.

31 FR 9941

(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.

(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:

38 FR 10437

(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.

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 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.

31 FR 9941

(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.

(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

(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.

31 FR 9941

§ 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:

(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. 39 FR 20960

(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.

31 FR 9941 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:

(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:

(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.

34 FR 9941

§ 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.

40 FR 8774

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

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

33 FR 17821

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.

33 FR 17621

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
	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
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

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 226	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)	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

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.

[31 FR 9941; 33 FR 17621]

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.

[31 FR 9941]

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.

[33 FR 17621]

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.

[31 FR 9941]

B.1.2 10 CFR §§73.30-36, PHYSICAL PROTECTION OF SPECIAL NUCLEAR MATERIAL IN TRANSIT

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.

§ 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	0.05
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	Quantity in curies: 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:

$$_{92}U^{238} + {}_{1}H^{2} \longrightarrow {}_{93}Np^{238} + 2n$$

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

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:

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

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).

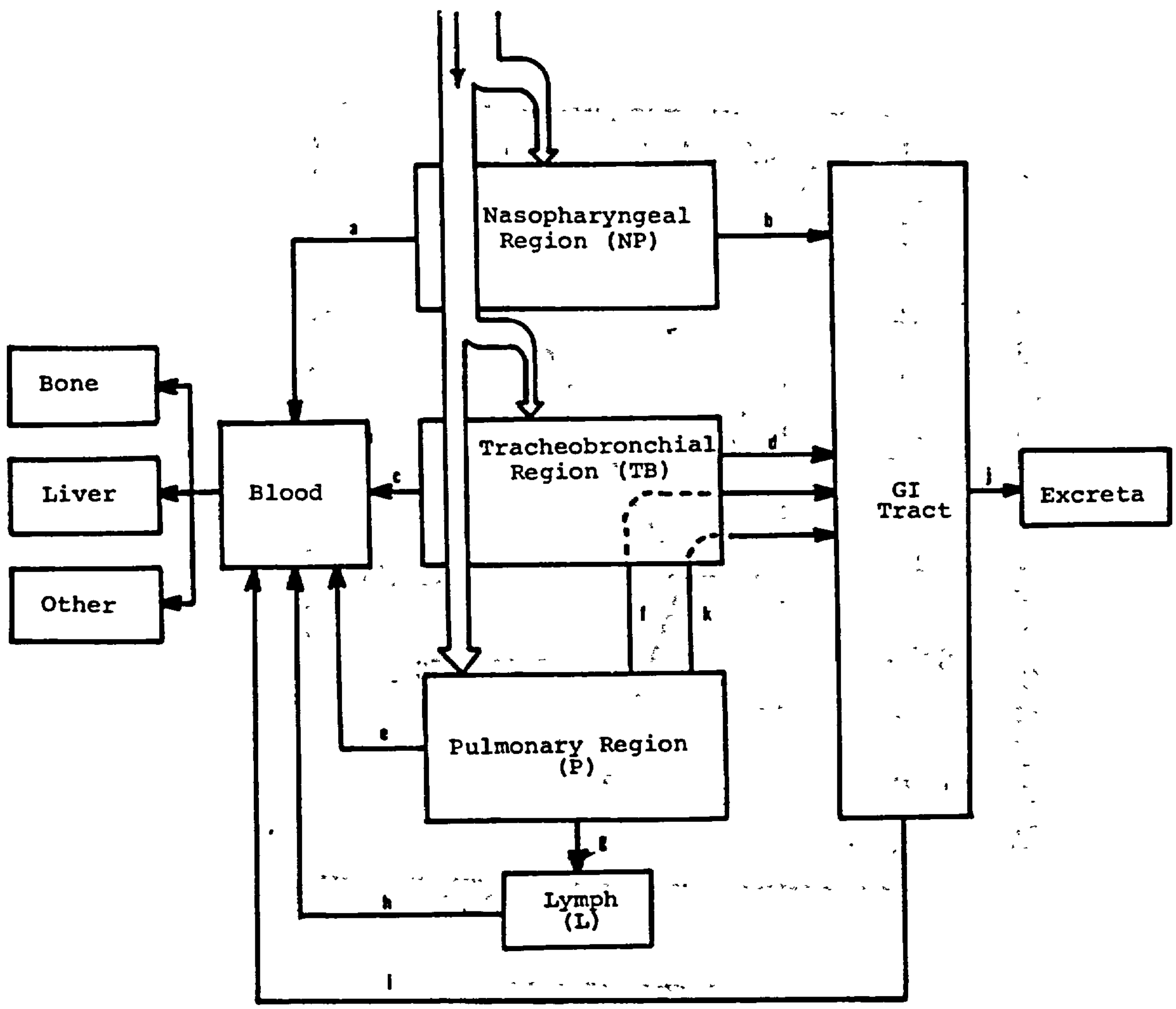

FIGURE C-1. BIOLOGICAL PATHWAYS FOR INHALED MATERIAL (Refs. C-3, C-7, C-19, C-20)

(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

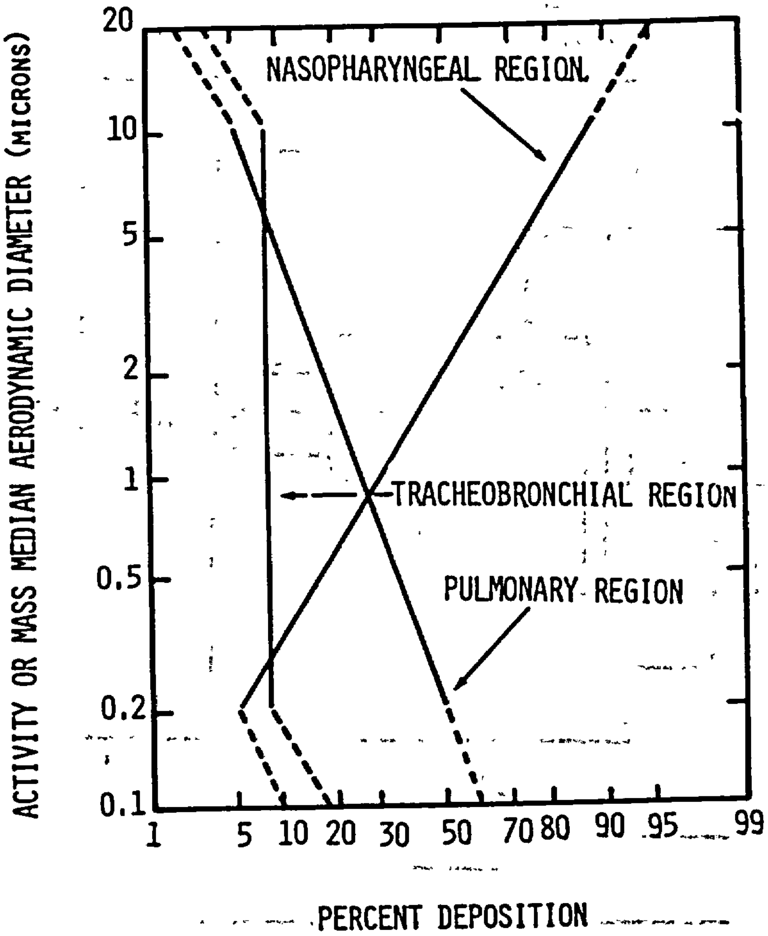

FIGURE C-2. DEPOSITION MODEL (Ref. C-7).

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.

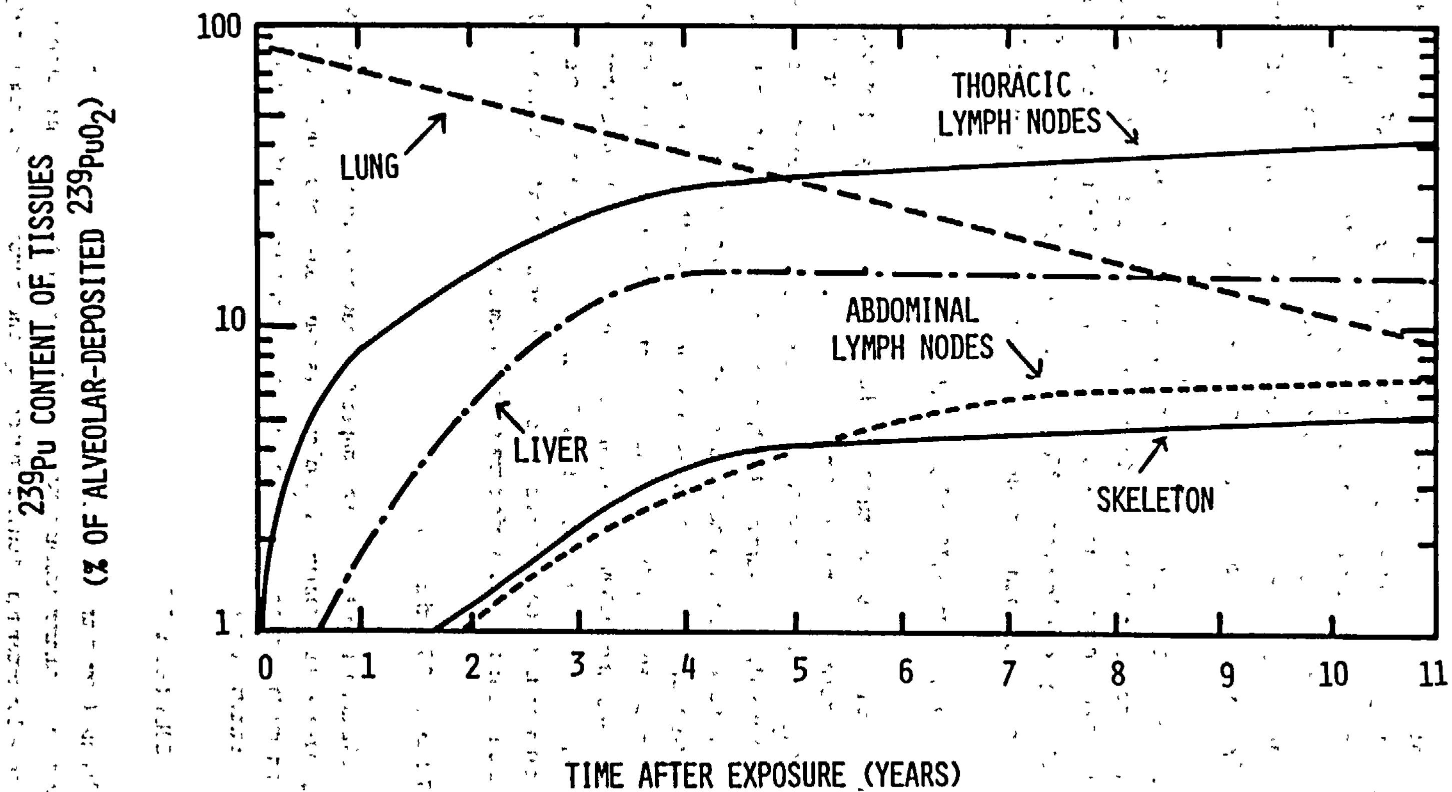

FIGURE C-3. TRANSLOCATION OF PULMONARY-DEPOSITED Pu-239 IN BEAGLE DOGS (Ref. C-16).

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 hazard 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:

$$D(d) = \frac{Ke^{-\mu d}\ B(d)}{d^2} \qquad \text{(D-1)}$$

where
- $D(d)$ = 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

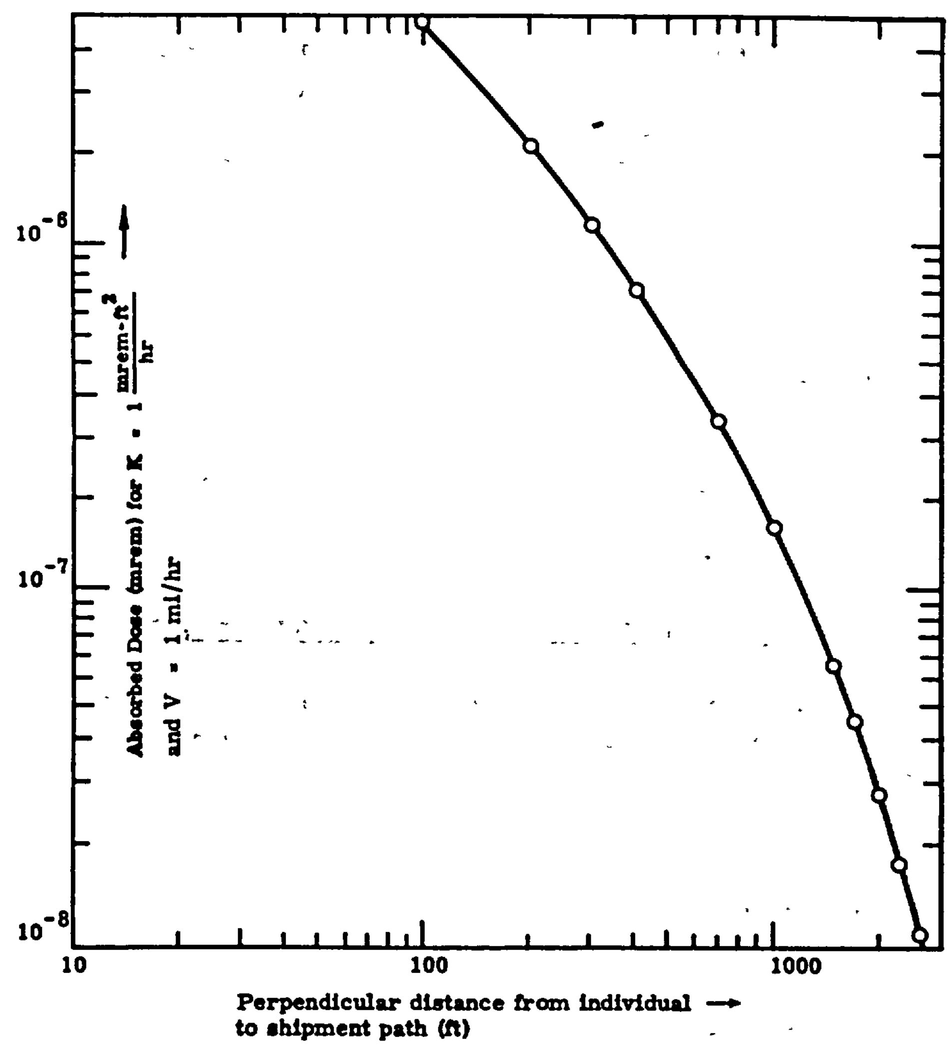
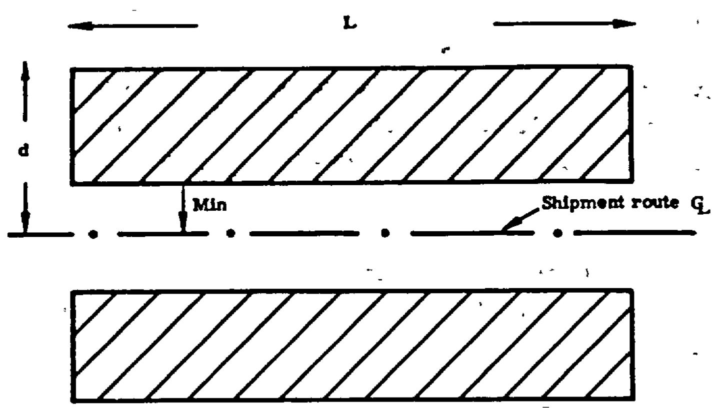


FIGURE D-1: DOSE RECEIVED BY AN INDIVIDUAL AS A SHIPMENT PASSES



- 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:

$$Dose_u = \frac{4K(f_u)(PD_u)(L)}{V_u} I_u(f_o + K'f_1) \qquad (D\text{-}5)$$

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:

$$Dose = 4KL(2.42)\left[\frac{f_r PD_r}{V_r} + \frac{f_s PD_s}{V_s} + \frac{f_u PD_u}{V_u}(f_o + 1.636f_1)\right] \qquad (D\text{-}6)$$

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, $2\pi r dr$:

$$\text{Dose} = K_o(TI)(\Delta T)(PD)\int_x^d (2\pi r)\left(\frac{e^{-\mu r}B(r)}{r^2}\right)dr \quad \text{(D-9)}$$

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:

$$\text{Dose} = Q_1\ K_o(TI)(PPS)(SPY)\left[\Delta T_r(PD_r) + \Delta T_s(PD_s) + \Delta T_u PD_u\right] \quad \text{(D-:0)}$$

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:

$$(\text{Dose})_{stor} = Q_2 K_o(TI)(PPS)(SPY)(\Delta T_{stor})(PD_{stor}) \quad \text{(D-11)}$$

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:

$$(Dose)_{crew} = Q_3(K_o)(TI)(PPS)(SPY)(N_c) \frac{e^{-\mu d} B(d)}{d^2} \Delta T_{ship} \quad \text{(D-12)}$$

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}

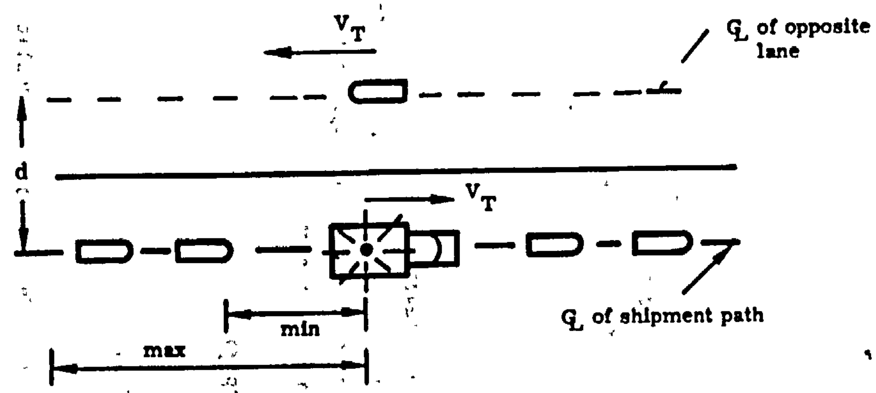
Because of regulatory limits for dose rate in the crew compartment, 2 mrem/hr is used as an upper limit for dose rate in this assessment. If the TI carried would cause this limit to be exceeded, it is assumed that shielding would be introduced to reduce the dose rate to this level.

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.



V = traffic velocity
d = lane separation distance
min = minimum following distance
max = maximum exposure distance

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:

$$\text{Dose} = \frac{K}{V_T} I(x) \frac{N'}{V_T} P(FMPS)(SPY) \qquad \text{(D-16)}$$

$$= KI(x) \frac{N'}{V_T^2} P(FMPS)(SPY)$$

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:

$$(\text{Dose})_{opp} = Q(K_0)(TI)(PPS)(SPY)(FMPS)(P)(F) \qquad (D\text{-}17)$$

where

$$\begin{aligned} F = {} & f_r \frac{N_r' I_{fwy}}{V_{Tr}^2} + f_s\left(\frac{f_{rh} 2N_s' I_{fwy}}{(V_{Ts}/2)^2} + \frac{f_n N_s' I_{fwy}}{(V_{Ts})^2}\right) \\ & + f_u \left[f_{fwy}\left(\frac{f_{rh} 2N_u' I_{fwy}}{(V_{Ts}/2)^2} + \frac{f_n N_u' I_{fwy}}{(V_{Tr})^2}\right) \right. \\ & + f_{4\ell}\left(\frac{f_{rh} 2N_u' I_{4\ell}}{(V_{Ts}/2)^2} + \frac{f_n N_u' I_{4\ell}}{(V_{Ts})^2}\right) \\ & \left. + f_{cs}\left(\frac{f_{rh} 2N_u' I_{cs}}{(V_{Tu}/2)^2} + \frac{f_n N_u' I_{cs}}{(V_{Tu})^2}\right) \right] \end{aligned}$$

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) = $1.5 \times 10^{-1} ft^{-1}$

$$Q = \left(10^{-3} \frac{rem}{mrem}\right)\left(\frac{1 \text{ mile}}{5280 \text{ ft}}\right) = 1.89 \times 10^{-7}$$

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:

$$D = \frac{Ke^{-\mu x}B(x)}{x^2} \Delta T \qquad \text{(D-18)}$$

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:

$$I_{fwy} = I_1\ (100\ \text{ft}) = .008$$

$$I_4 = I_1\ (30\ \text{ft}) = .031$$

$$I_{cs} = I_1\ (10\ \text{ft}) = .097$$

$$\text{and } I_1\ (d) = \int_d^{2600\ \text{ft}} \frac{e^{-\mu x} B(x)}{x^2}$$

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

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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.

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		1100076A
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		2040229A
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	EXT 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		4060234A
R.A.M. N.O.S.	C8930	17E		CHIME		1	11		4060680A
R.A.M. N.O.S.	C9930			WATER		0	2		4060688A
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.	09930	TANK PRT		OTHER		1	1	SP5660	4070362A
FISSILE R.A.M.	05110	DRUM MTL		EXT PUNCT	OTHER	0	70		4070629A
R.A.M. N.O.S.	08930	BLANK		OTHER		0	2		4070739A
R.A.M. N.O.S.	09930	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	08920	TYPE B		DROPPED		0	1		4080679A
R.A.M. N.O.S.	08930	LINR PLS	BOX FBR	OTHER		0	3		4080698A
R.A.M. N.O.S.	09930	BLANK	BOX FBR	DROPPED		1	1		4080789A
R.A.M. LOW SPEC ACT	08920	TANK PRT		OTHER		0	1		4080947A
R.A.M. N.O.S.	08930	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	10270	21C		DROPPED		1	24		4090323A
R.A.M. SPEC. FOPM	08950	55		OTHER		1	1		4090359A
R.A.M. N.O.S.	08930	CAN MTL	DPUM MTL	LOOSE FVC		1	1		4090529A
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.	08930	BOX MTL	BOX FBR	WATER		0	1		4110247A
R.A.M. N.O.S.	08930	15A	7A	LOOSE FVC	BOTTOM	1	2		4120197A
R.A.M. N.O.S.	08930	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 - 408 378

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.

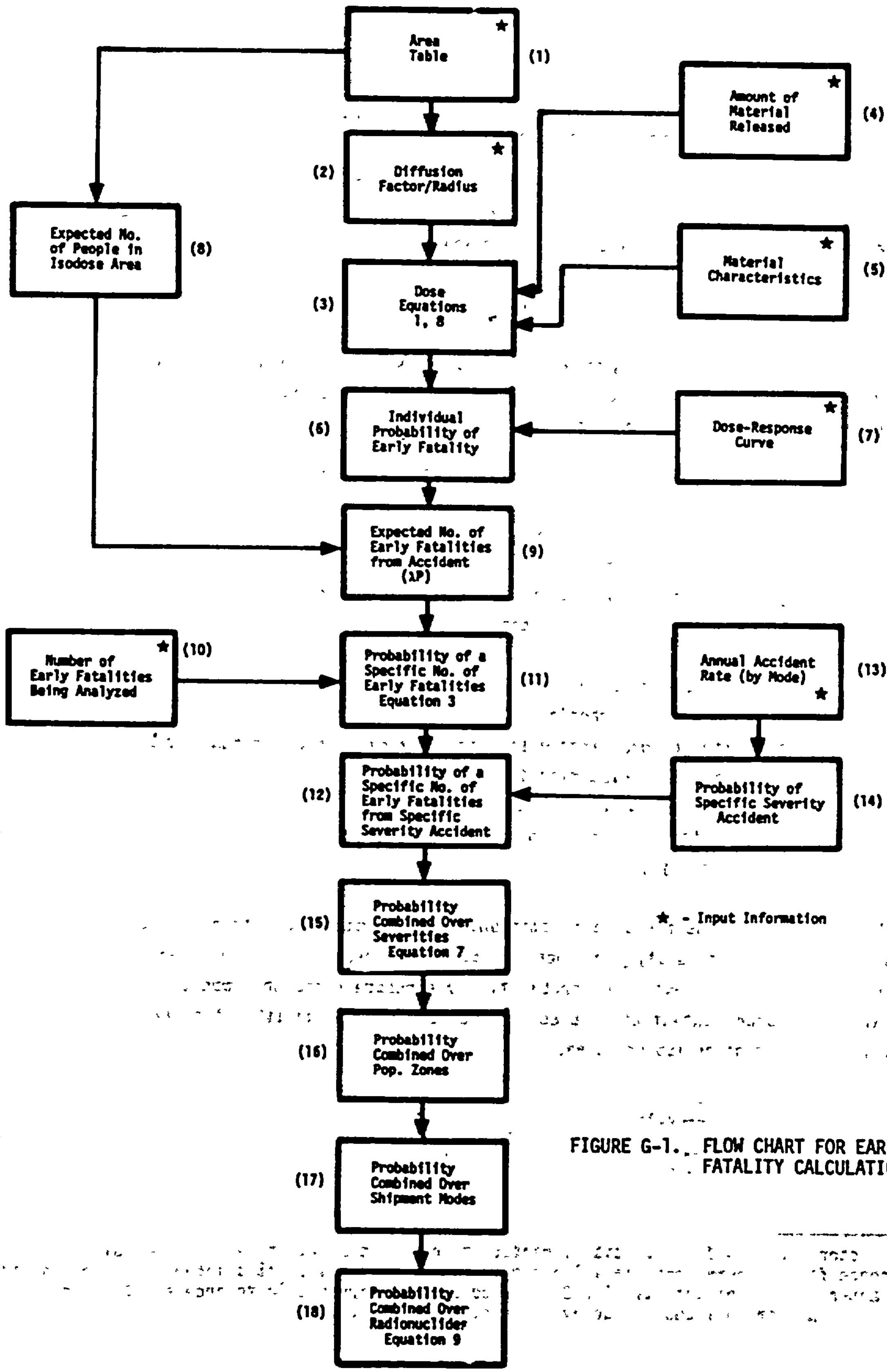

FIGURE G-1. FLOW CHART FOR EARLY FATALITY CALCULATION

$P(k)$ = 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

$$P(k) = \frac{(\lambda P_1)^k (e^{-\lambda P_1})}{k!} \quad \text{(G-3)}$$

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:

$$P(k)_{i,j,k,l} = \left(P(k)_{i,k}\right)\left(P(acc)_{i,j,l}\right) \quad \text{(G-4)}$$

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:

$$\gamma_{i,j,k,l} = \left[\left(APM_{l,p}\right)\left(\eta_{i,l,p}\right)\left(\delta_{i,j,l,p}\right)\left(SPY_{k,l}\right)\left(FMPS_{k,l,p}\right)\right] + \left[\left(APM_{l,s}\right)\left(\eta_{i,l,s}\right)\left(\delta_{i,j,l,s}\right)\left(SPY_{k,l}\right)\left(FMPS_{k,l,s}\right)\right] \quad \text{(G-5)}$$

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.

$$P(A \cup B \cup C) = 1 - P(\bar{A})P(\bar{B})P(\bar{C}) \quad \text{(G-6)}$$

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:

$$P_{j,k,l} = 1.0 - \prod_{i=1}^{8} (1 - P_i) \quad \text{(G-7)}$$

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:

$$DR(r) = \frac{(5597.2)(n)(E)(e^{-\mu r})(B(r))}{r^2} \quad \text{(G-8)}$$

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.

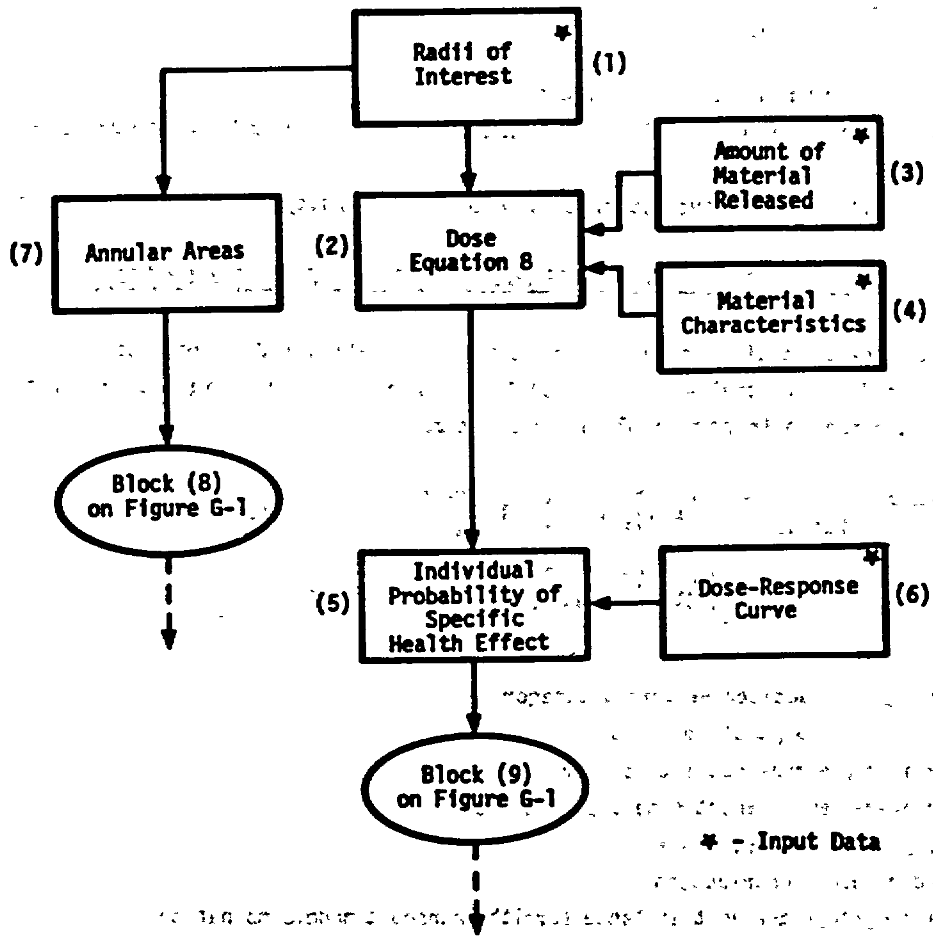

FIGURE G-2. EARLY FATALITY COMPUTATION FLOW DIAGRAM FOR EXTERNAL PENETRATING RADIATION SOURCES

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:

$$\frac{\text{class h accidents}}{\text{year}}_{i,j,k,l} = \left[\left(\lambda_{l,p}\right)\left(\delta_{j,l,p}\right)\left(\gamma_{l,p}\right)\left(SPY_{k,l,p}\right)\left(FMPS_{k,l,p}\right)\right] + \left[\left(\lambda_{l,s}\right)\left(\delta_{j,l,s}\right)\left(\gamma_{l,s}\right)\left(SPY_{k,l,s}\right)\left(FMPS_{k,l,s}\right)\right] \qquad \text{(G-10)}$$

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.

$$\phi_{j,k,n} = \left(ci_k\right)\left(PPS_k\right)\left(RF_k\right)\left(AER_k\right)\left(RESP_k\right)\left(RPC_{n,k}\right)\left(IF\right)\left(DF\right)\left(PD_j\right)\left(RDF_i\right) \qquad \text{(G-11)}$$

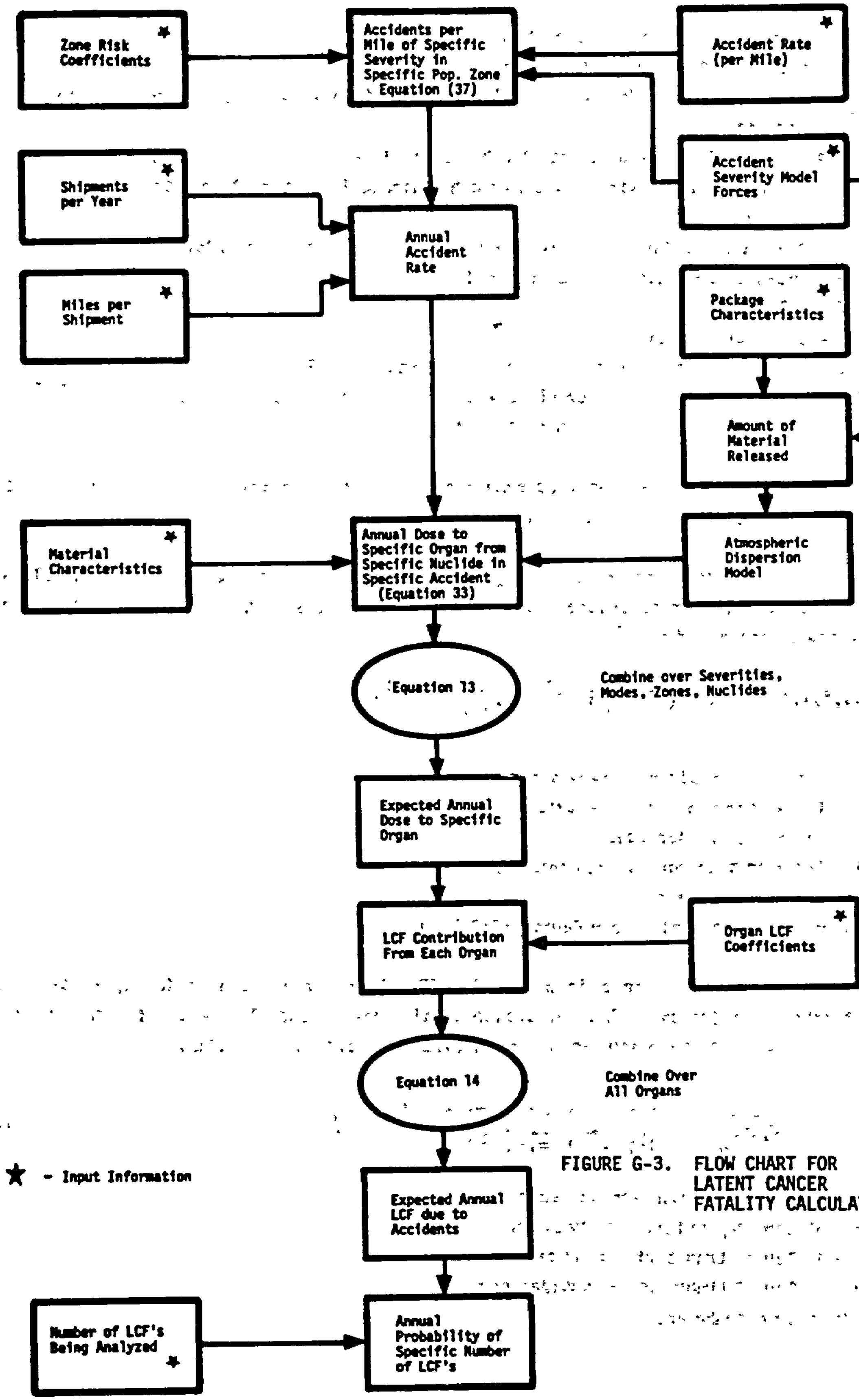

FIGURE G-3. FLOW CHART FOR LATENT CANCER FATALITY CALCULATION where Ci_k = curies per package for the kth radionuclide

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 <u>COMPUTATION OF LATENT CANCER FATALITIES FROM EXTERNAL EXPOSURE SOURCE</u>

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

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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 impact 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:

$$\alpha = \left[\frac{15\pi\left(\frac{1-\nu}{\pi E}\right)(mv^2)}{16\sqrt{R}}\right]^{2/5} \qquad \text{(H-1)}$$

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:

$$A_{max} = 0.1157\pi^2\, v^{6/5} \left[\frac{16\sqrt{R}}{15\pi\frac{1-\nu}{\pi E}\, m}\right]^{2/5} \qquad \text{(H-2)}$$

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:

$$\frac{V_{yielding}}{V_{steel}} = \left[\frac{1 - \nu_y^2}{1 - \nu_s^2}\right]\left[\frac{E_s}{E_y}\right]^{1/3} \quad \text{(H-3)}$$

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

$$V = V_{observed}/(V/V_s) \quad \text{(H-4)}$$

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}	
IV	R	3.1	6.0×10^{-4}	Total Rural 0.1%
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}	
IV	S	489	9.6×10^{-2}	Total Suburban 16%
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}	
IV	U	1970	3.9×10^{-1}	Total Urban 84%
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	Package Type	Percentage of Accident Risk
Truck	79.3	A, Drum	45.0
Pass. Air	2.7	B, Cask-2	28.0
Cargo Air	0.2	BPu	26.0
Rail	8.8		
Ship	1.1		
Sec. Modes	7.9		

Accident Severity	Percentage of Accident Risk	Population Zone	Percentage of Accident Risk
1	0	Urban	80.2
2	10.0	Suburban	18.3
3	15.0	Rural	1.5
4	31.0		
5	14.0		
6	23.0		
7	6.0		
8	1.0		

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

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