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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

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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, DC. 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, DC. 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; provided, however, 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

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*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,

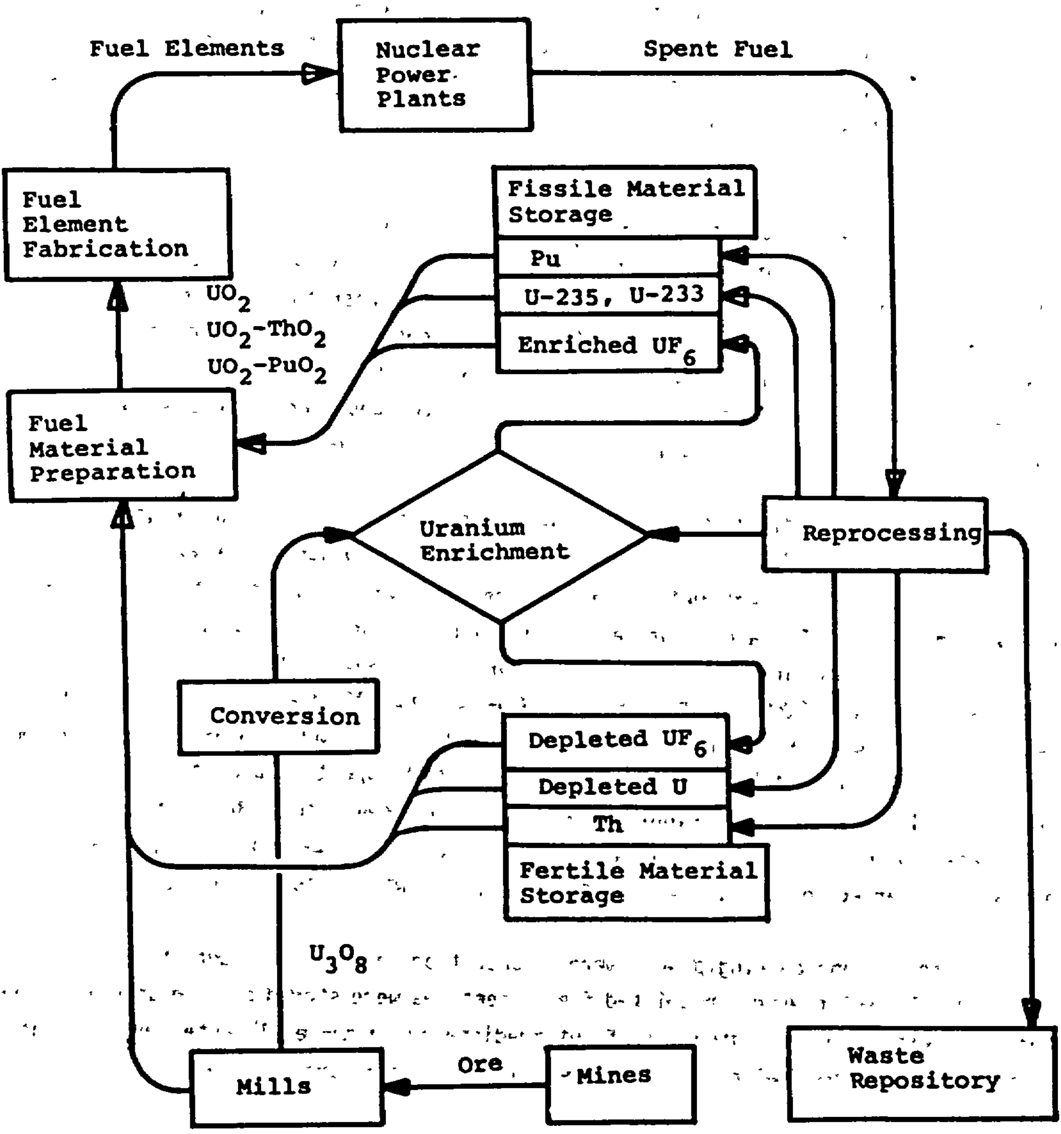

FIGURE 1-1. NUCLEAR FUEL CYCLE (Ref. 1-8).

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 little 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 by 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

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[*] 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

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*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

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*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

1975

Shipment Type	Packages per Year	Curies per Year	TI per Year	Kilometers per Year	LCF (normal) per Year	Percent	LCF (acc) per Year	Percent
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

Shipment Type	Packages per Year	Curies per Year	TI per Year	Kilometers per Year	LCF (normal) per Year	Percent	LCF (acc) per Year	Percent
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.

1-11. U.S. Atomic Energy Commission, Liquid Metal Fast Breeder Reactor Program, WASH-1535, December 1974.

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

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*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

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*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}	$>5 \times 10^{3}$

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*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

1. Spec 55 (300 Ci Max.) (49 CFR 178.250)
2. Spec 6M (49 CFR 178.104)
3. NRC (AEC) approved per 10 CFR 71.
4. Type B packaging meeting 1967 IAEA regulations for which foreign competent authority certificate has been revalidated by DOT.
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.

Normal Form

1. Spec 6M (for solid or gas only which does not decompose up to 250° F).
2. 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. 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.

> 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

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*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

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*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 air 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 rail, 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 sea, 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 transfers 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,

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*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.

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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

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*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.

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*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

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

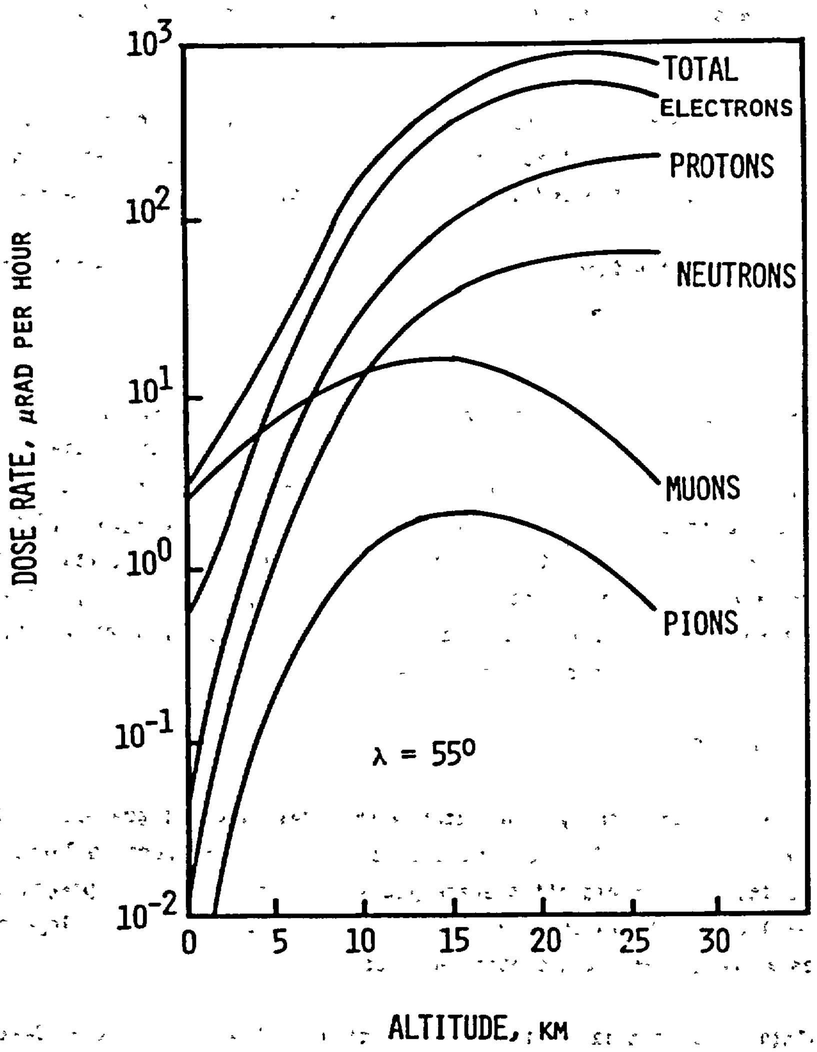

FIGURE 3-1. VARIATION OF GALACTIC RADIATION* DOSE RATES WITH ALTITUDE AT GEOMAGNETIC LATITUDE (λ) OF 55° (Ref. 3-9).

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*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

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*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

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*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

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*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.

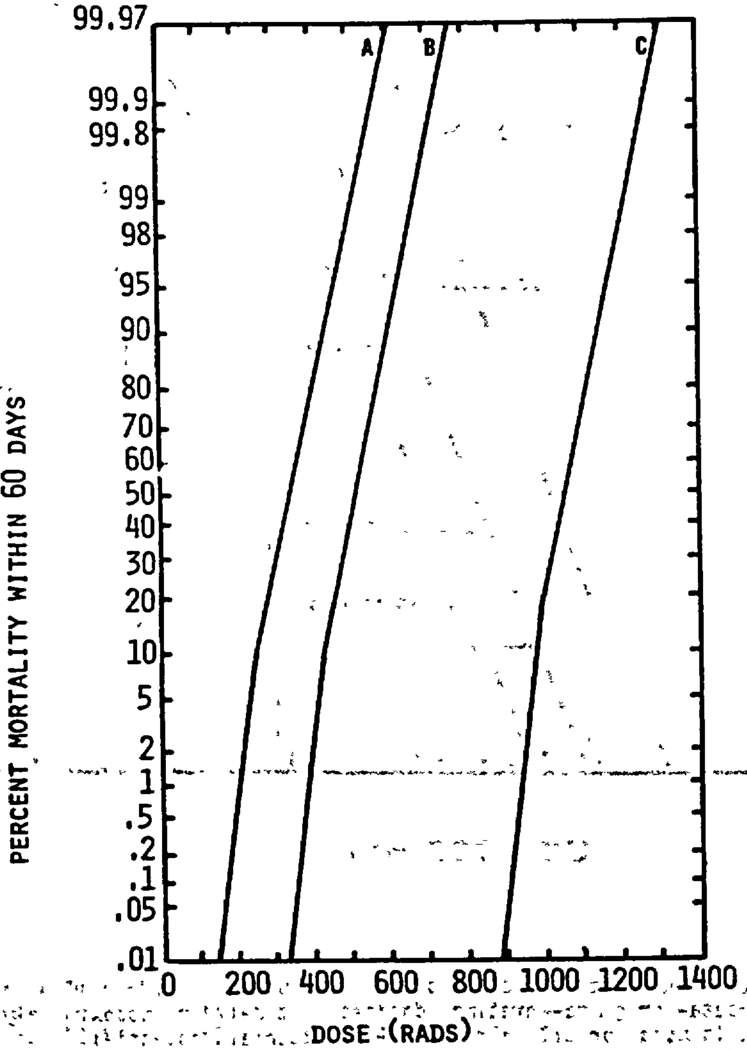
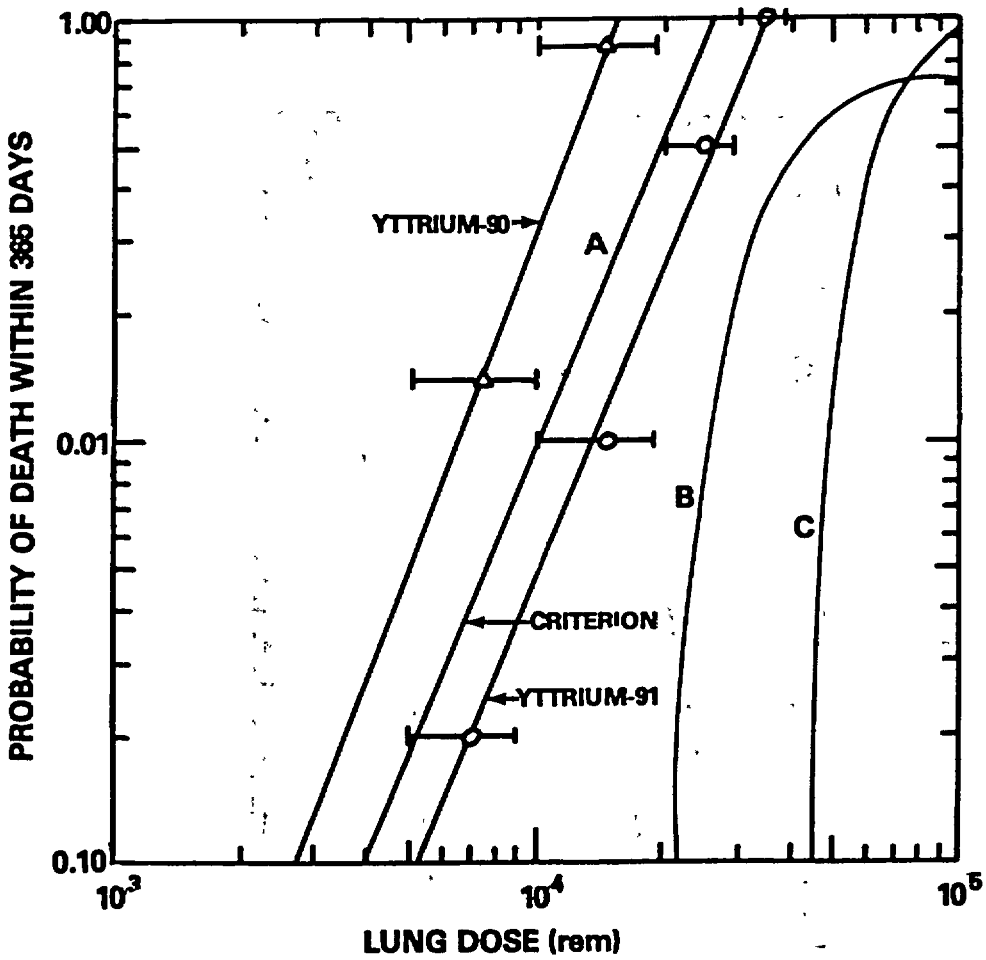


FIGURE 3-2. ESTIMATED DOSE-RESPONSE CURVES FOR MORTALITY WITHIN 60 DAYS FROM WHOLE-BODY EXPOSURE TO EXTERNAL PENETRATING RADIATION: WITH MINIMAL TREATMENT (CURVE A), SUPPORTIVE TREATMENT (CURVE B), AND HEROIC TREATMENT (CURVE C). CURVE B REPRESENTS THE MOST LIKELY LEVEL OF TREATMENT AVAILABLE FOR MOST 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

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*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

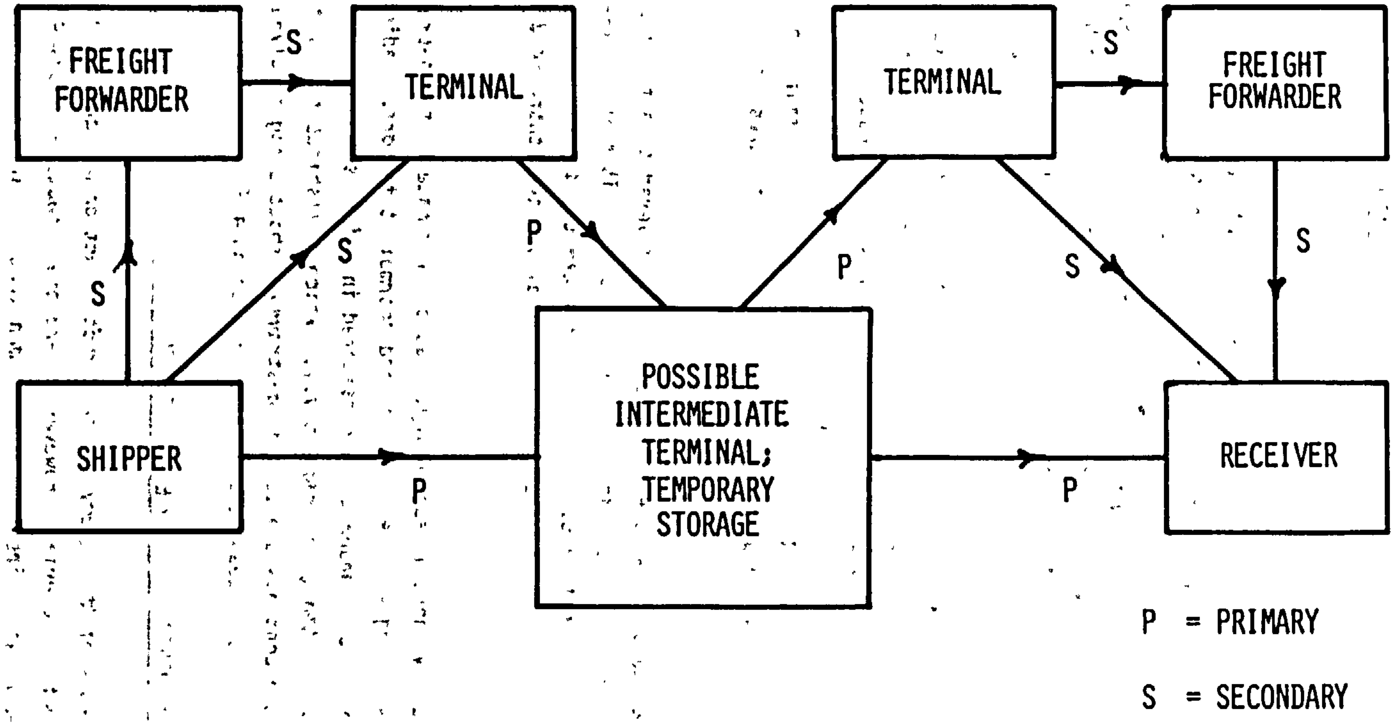

FIGURE 4-1. POSSIBLE TRANSPORT PATHS

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:

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

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 x 10^6 passengers results in an annual population dose of 1.2 x 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		

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[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]

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[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

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*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)

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*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	

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*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 x 10^5*

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*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-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 x 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:

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

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.	4.827E-02	2.707E-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	4.449E-04	2.213E-02
AU198	0.	4.845E-03	0.	9.000E-03	2.499E-04	1.051E-03	5.411E-04	7.987E-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-X	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	1.002E+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 to 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

	Population Group									
					Surrounding Population					
Transport Mode	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	Storage	Totals	% of Total
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

					Surrounding Population					
Material	Passengers	Crew	Attendants	Handlers	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	-
UO2-enr	0	19.500	0	2.970	2.830	3.250	5.210	2.570	36.300	-
UO2-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

	Population Group									
					Surrounding Population					
Transport Mode	Passengers	Crew	Attendants	Handlers	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

					Surrounding Population					
Material	Passengers	Crew	Attendants	Handlers	Off-Link	On-Link	Stops	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

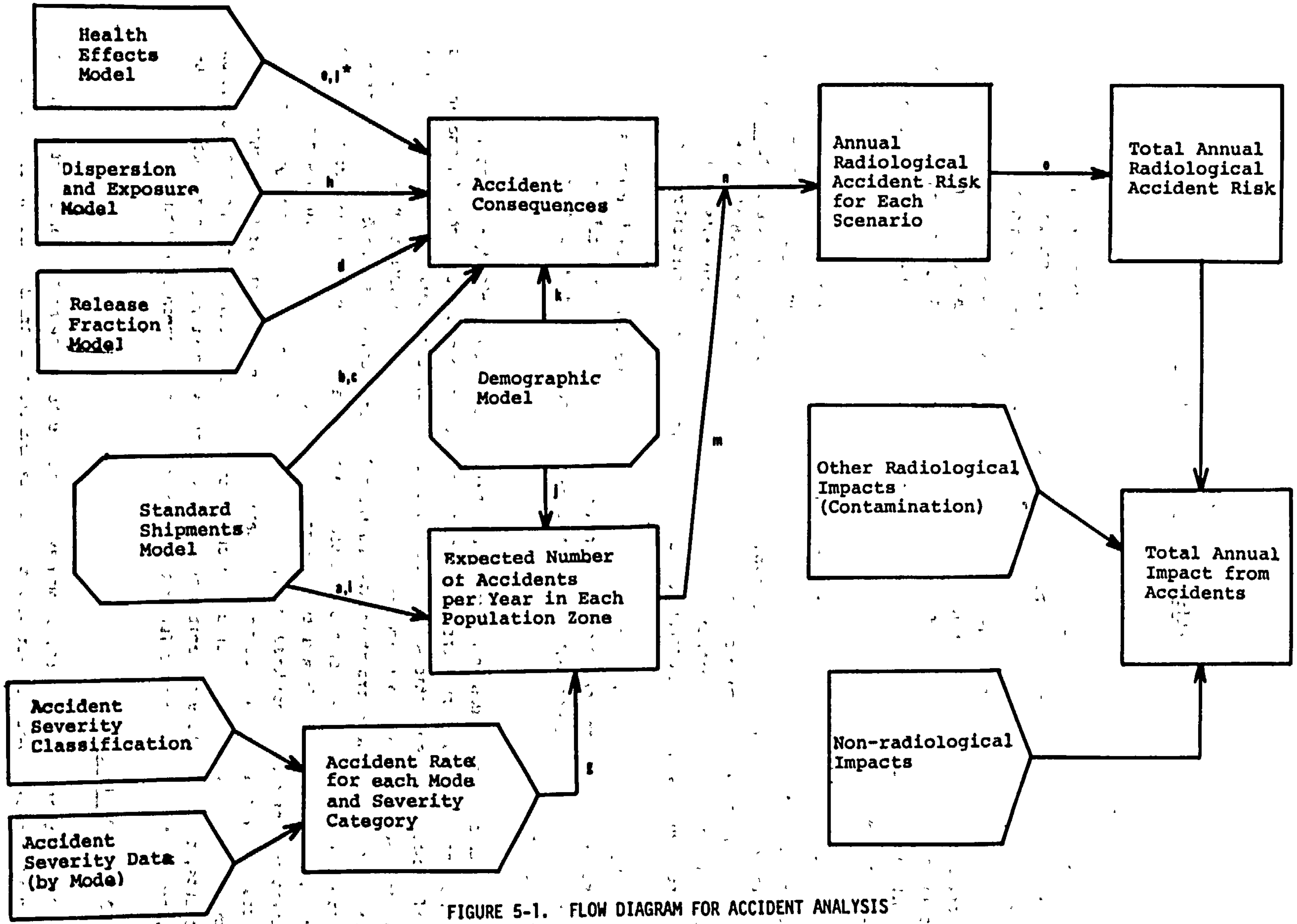

FIGURE 5-1. FLOW DIAGRAM FOR ACCIDENT ANALYSIS

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*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

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[*] 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.

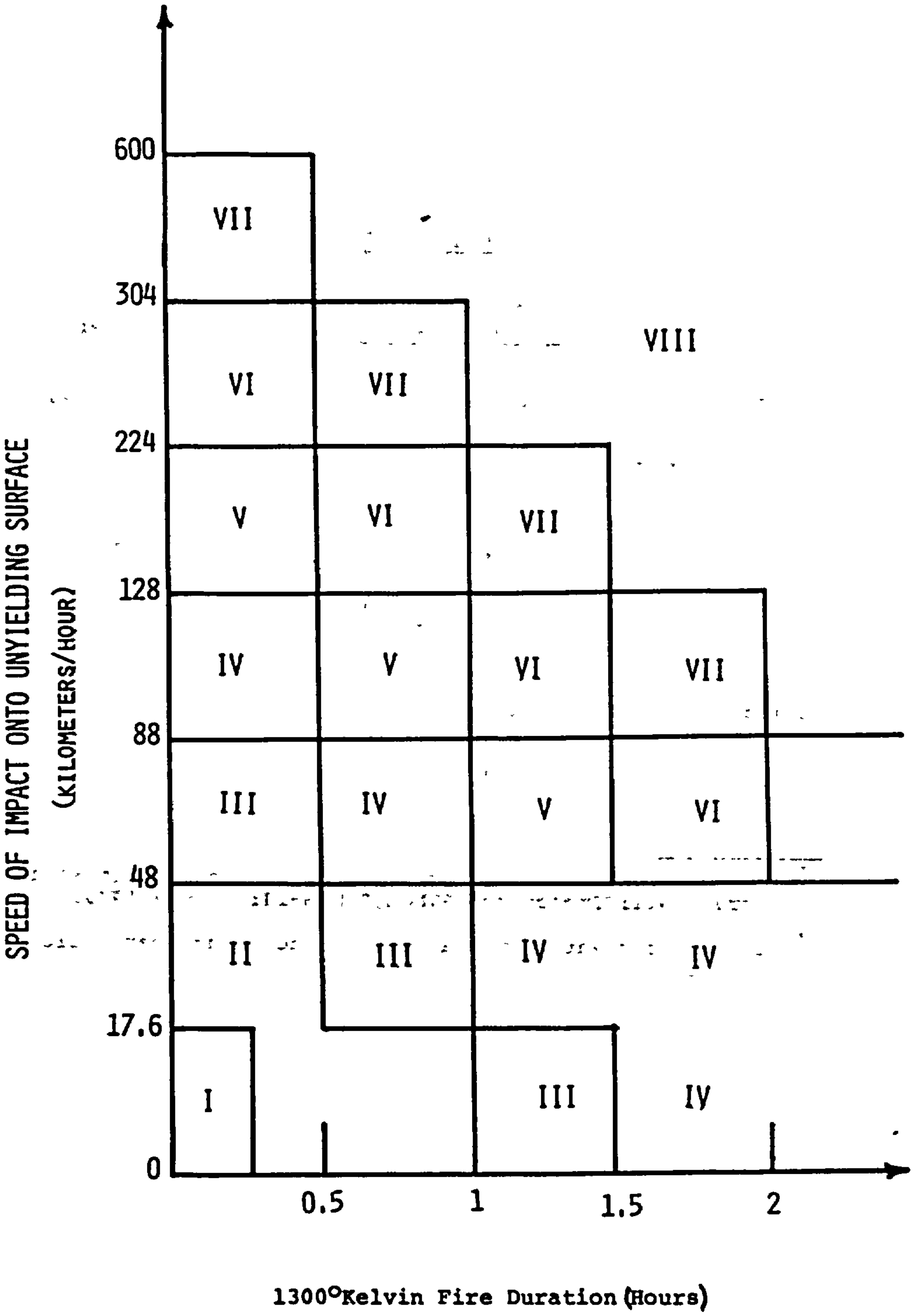

FIGURE 5-2. ACCIDENT SEVERITY CATEGORY CLASSIFICATION SCHEME - AIRCRAFT

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 [illegible] an 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			

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*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

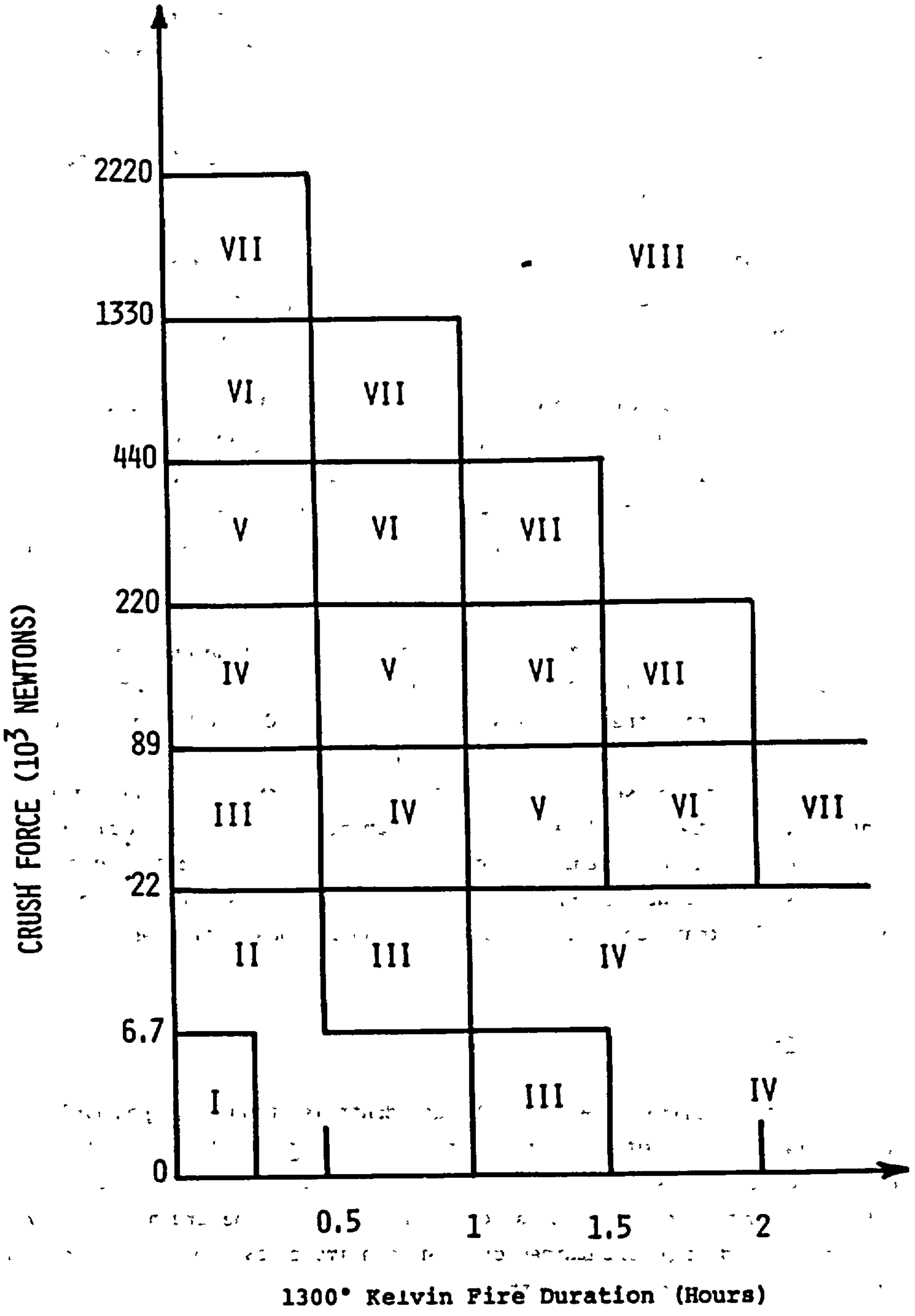

FIGURE 5-3. ACCIDENT SEVERITY CATEGORY CLASSIFICATION SCHEME - MOTOR TRUCKS

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

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[*] 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 x 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 x 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 x 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

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

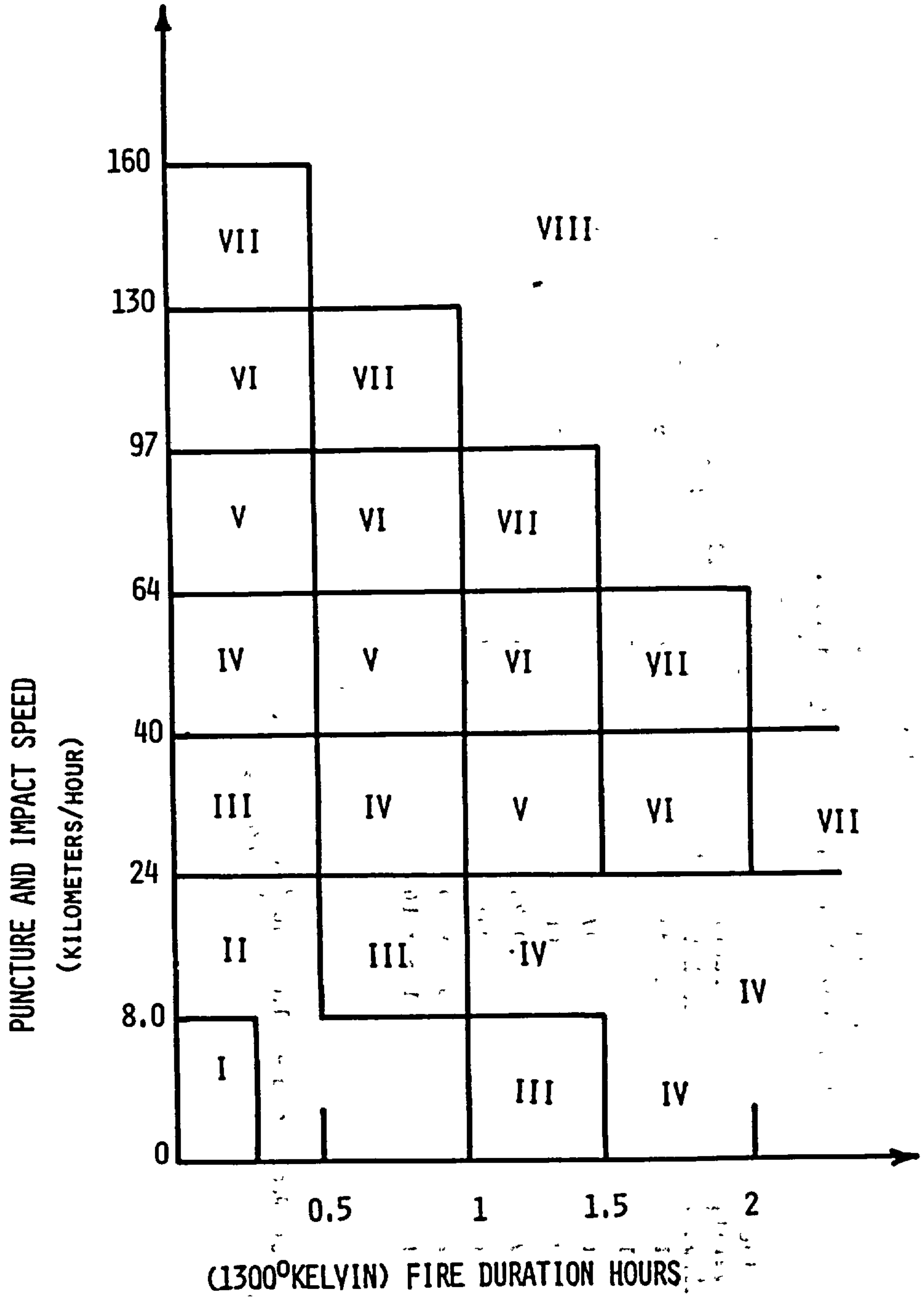

FIGURE 5-4. ACCIDENT SEVERITY CATEGORY CLASSIFICATION SCHEME - TRAIN

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

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*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.

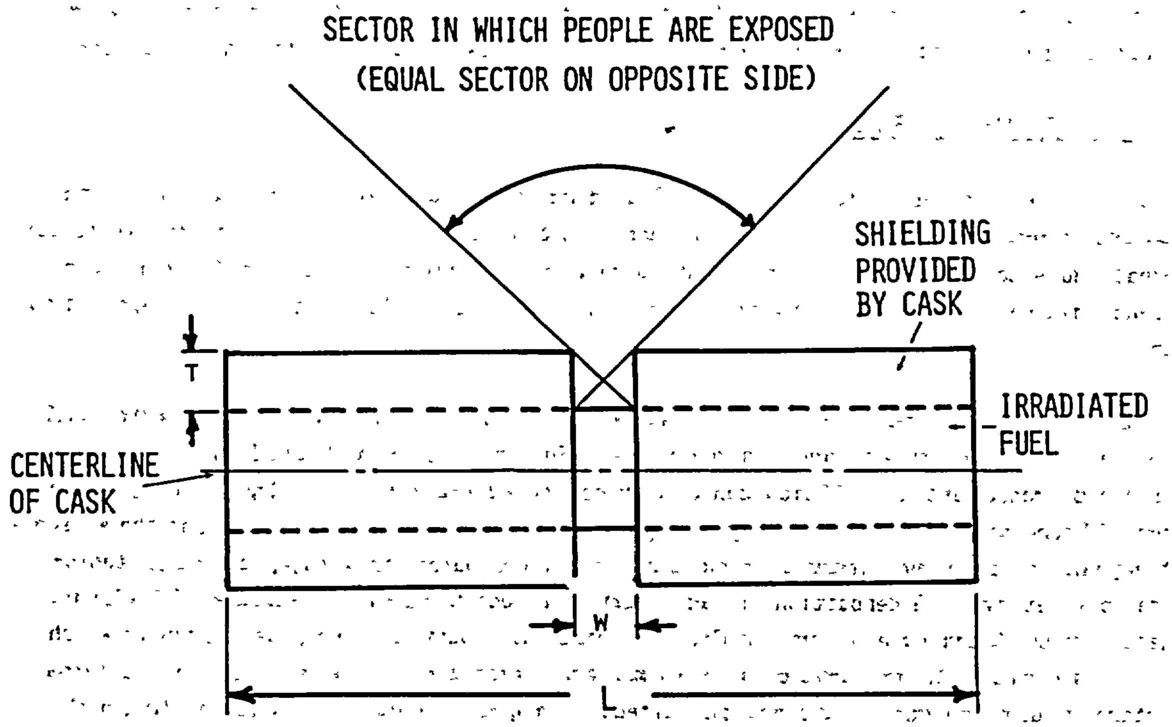
5.2.3.4 Casks

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



W = WIDTH OF CRACK

T = THICKNESS OF CASK SHIELDING

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

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

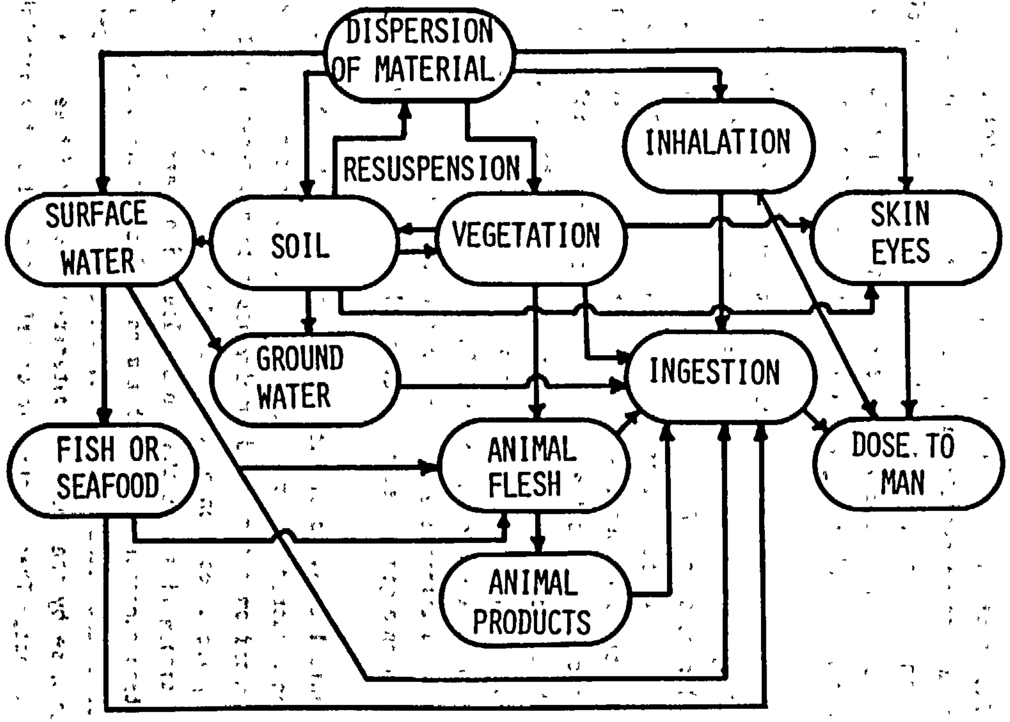


FIGURE 5-6. POSSIBLE ROUTES TO MAN FROM RADIONUCLIDE RELEASE

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

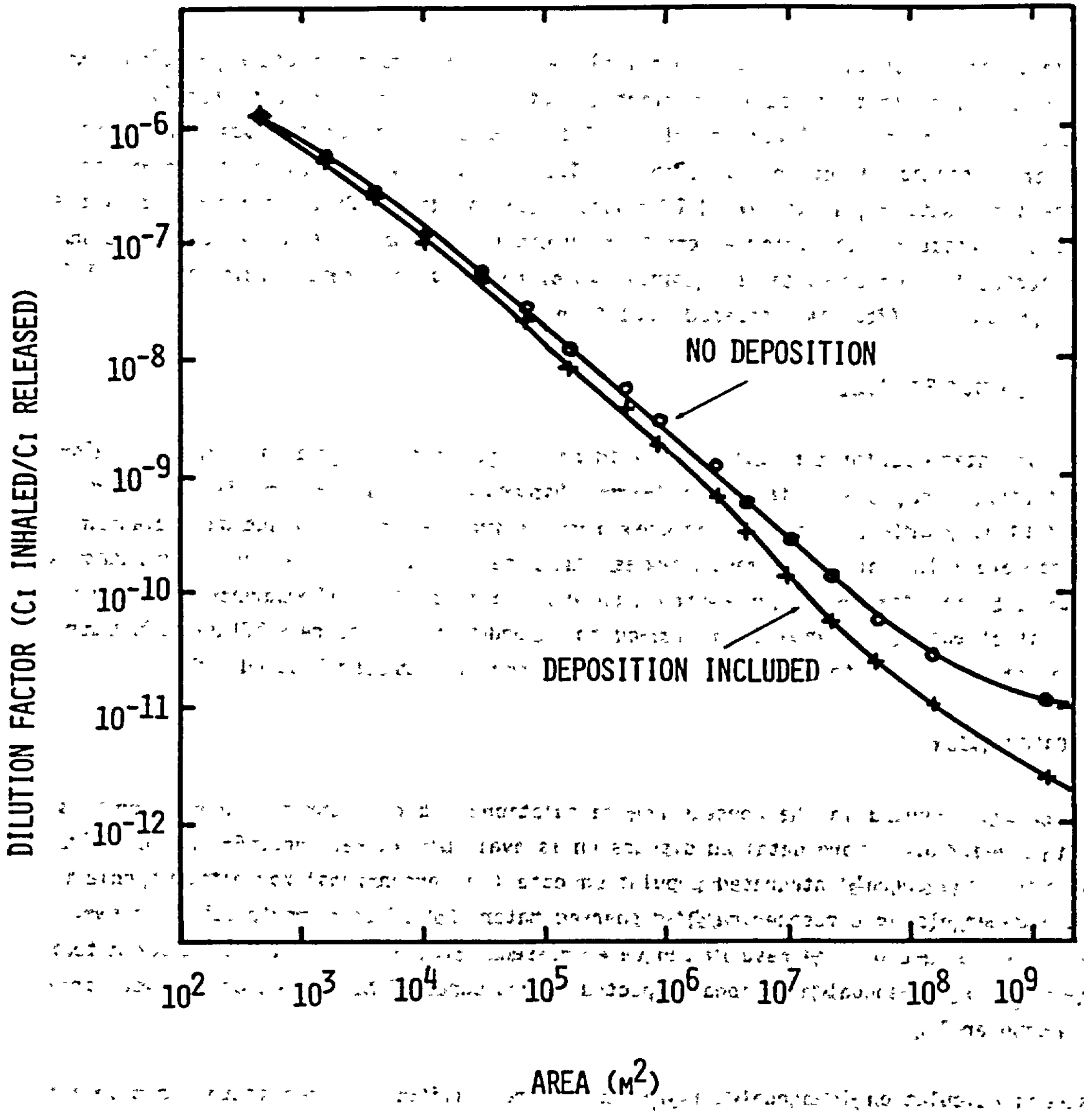


FIGURE 5-7. DOWNWIND DILUTION FACTOR AS A FUNCTION OF AREA

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

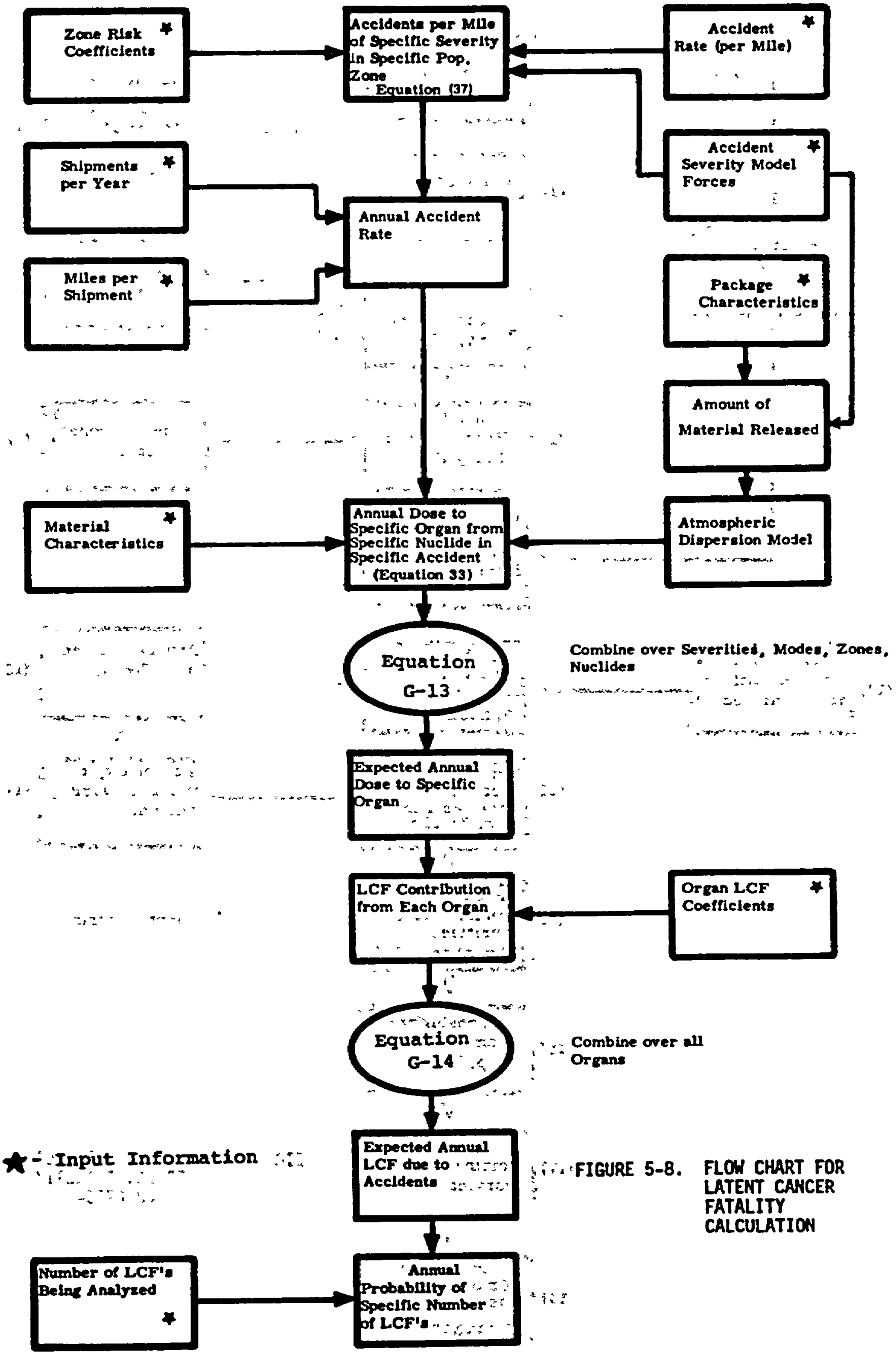


FIGURE 5-8. FLOW CHART FOR LATENT CANCER FATALITY CALCULATION

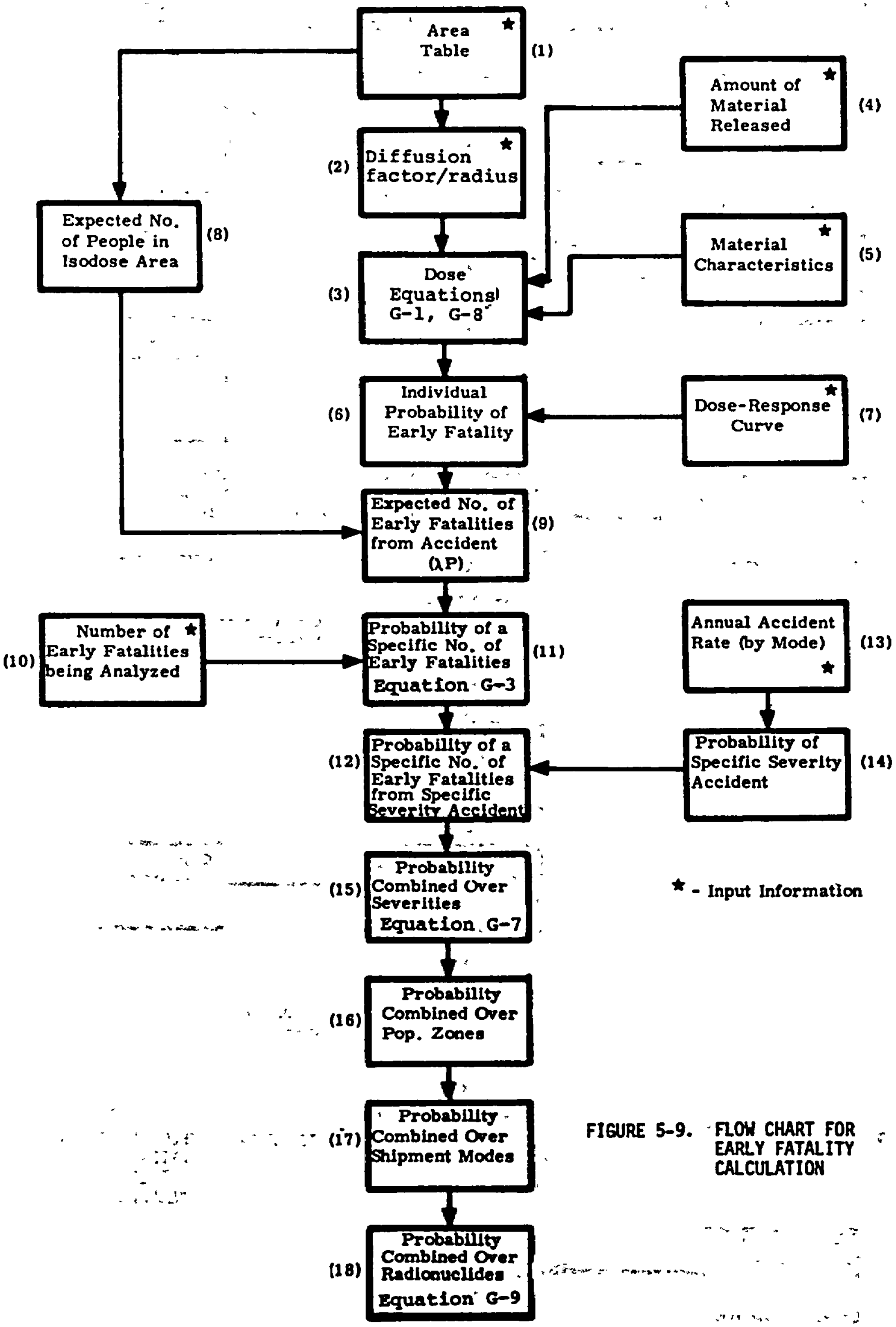


FIGURE 5-9. FLOW CHART FOR EARLY FATALITY CALCULATION

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 5.37×10^{-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 3.5×10^{-4}, while the probability of 10 or more is 2.5×10^{-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

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*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	

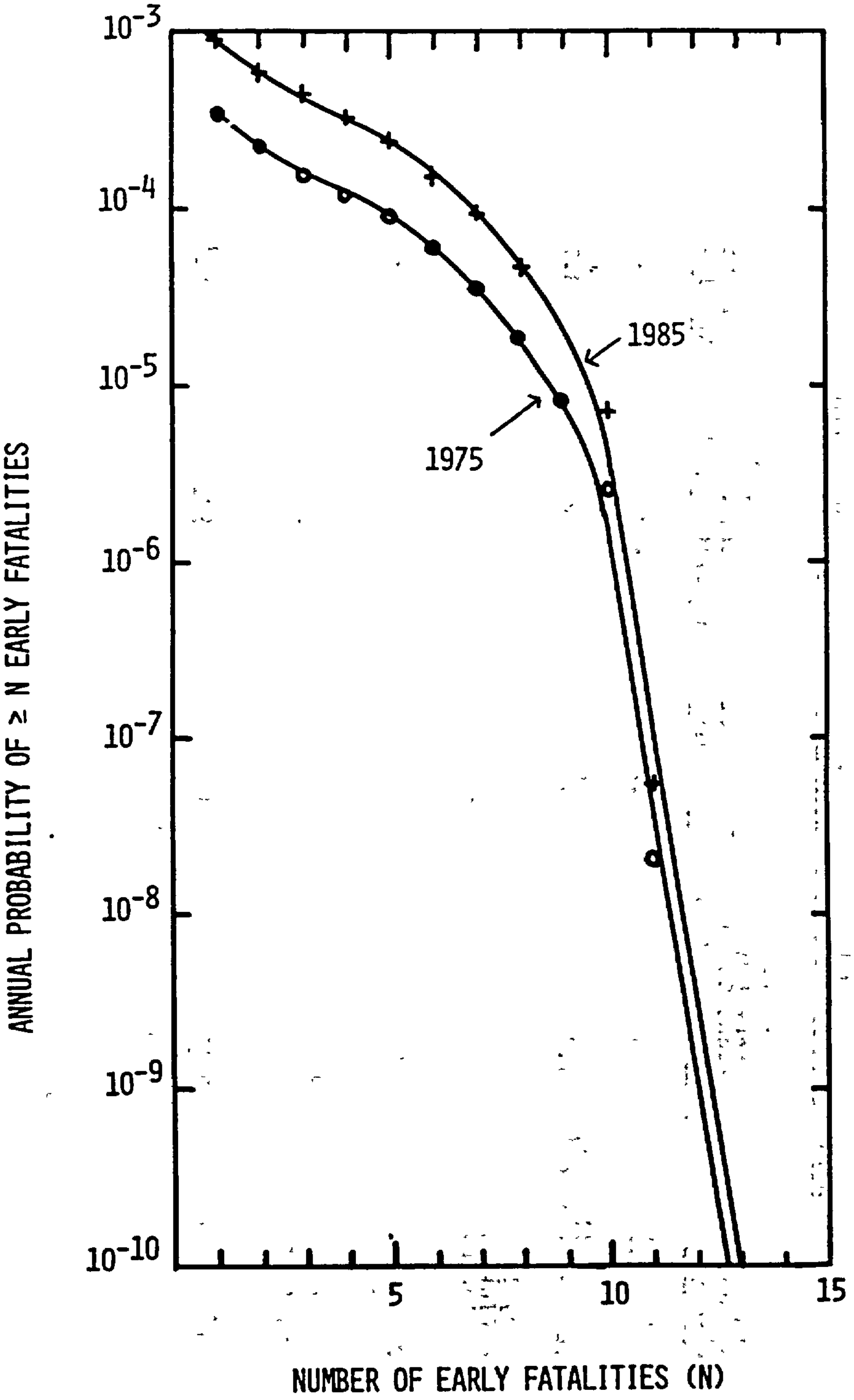

FIGURE 5-10. CUMULATIVE ANNUAL EARLY FATALITY PROBABILITY - 1975, 1985 - MODEL II

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

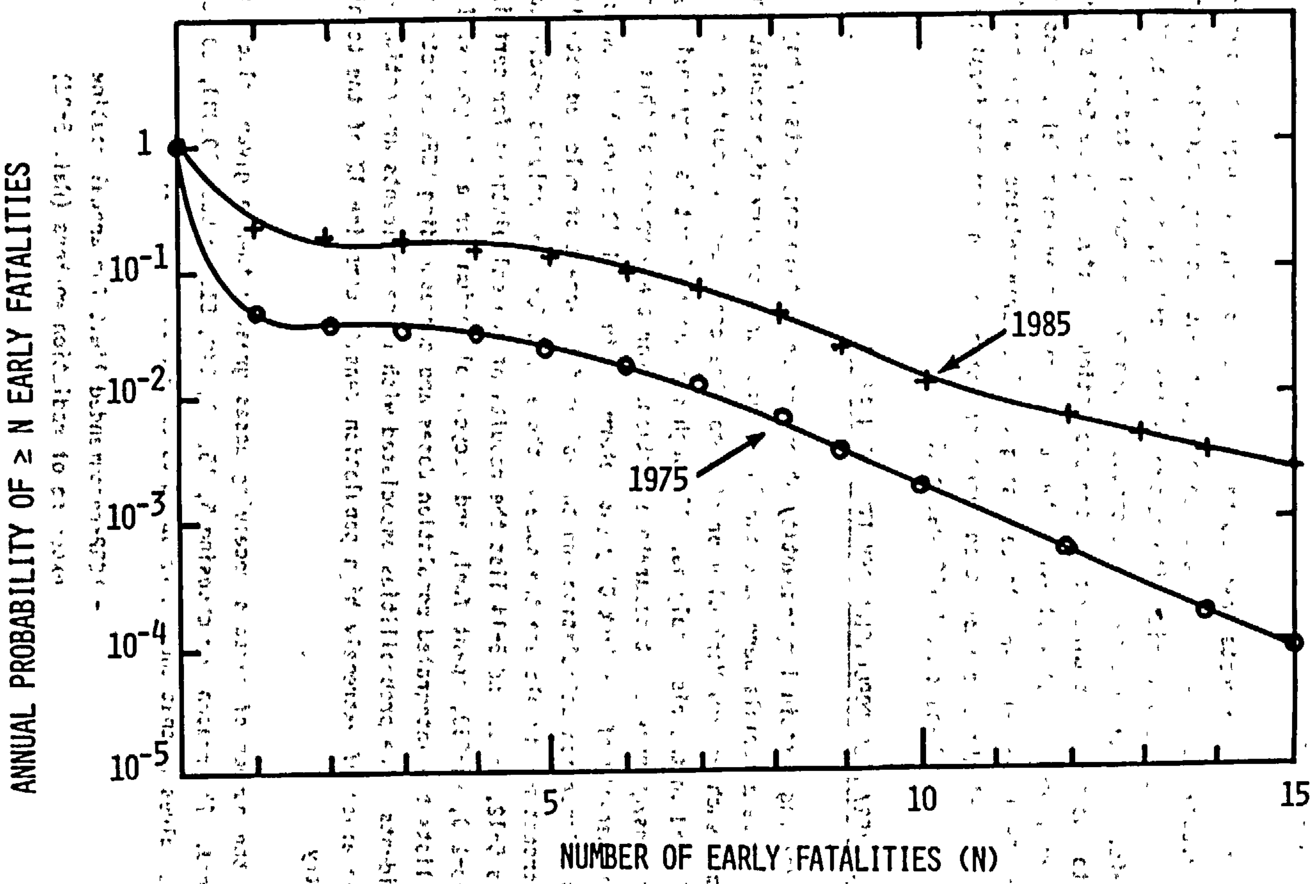

FIGURE 5-11. CUMULATIVE ANNUAL EARLY FATALITY PROBABILITY - 1975, 1985 - MODEL I

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]*

		Long-Lived Contaminant		Short-Lived Contaminant [b]	
Population Zone	Land Use	Decont. Technique	Estimated Cost ($)	Decont. Technique	Estimated Cost ($)
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 $\geq$ 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 $\geq$ 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$\geq$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

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*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]	 56.1×10^6 12.1×10^6	(1) cordon off all residential areas with DF ≥ 20 [t]	7.2×10^4
	0.8% public areas (schools, etc.)	(2) 3.24×10^4 evacuees	4.4×10^6	(2) Decon. homes DF>20	12.3×10^6
	0.4% commercial & industrial areas	(3) Decon. public areas a. DF < 20[n] b. DF ≥ 20[o]	 1.83×10^5 1.0×10^5	(3) cordon off all parks [u]	2.84×10^5
	0.3% parks, cemeteries, etc.	(4) Decon. commercial & industrial areas a. DF < 20[p] b. DF ≥ 20[q]	 9.15×10^4 9.77×10^4	(4) Decon. public areas	2.84×10^5
		(5) Decon. parks by replacing lawn [r]	1.12×10^6	(5) Decon. commercial & industrial areas	1.89×10^5
		(6) indiv. and corporate income loss[s]	7.33×10^6	(6) 2035 evacuees for 60 days. 30,320 evacuees for 10 days	5.74×10^6
				(7) income loss	9.64×10^6
			Total = 82×10^6		Total = 28.5×10^6

TABLE 5-11 (continued)

		Long-Lived Contaminant		Short-Lived Contaminant	
Population Zone	**Land Use [w]**	**Decont. Technique**	**Estimated Cost ($)**	**Decont. Technique**	**Estimated Cost ($)**
Urban (3861 persons/km^2)	20% high density resid. (6 story apts) [cc] 20% single fam. resid[cc] 20% public land 20% Ind. & commercial 10% parks 10% undevel. or vacant land	(1) Decon. apartment buildings		(1) cordon off resid. areas with DF≥20 [t]	$7.2x10^4$
		a. DF<20[x]	$1.7x10^6$		
		b. DF≥20[y]	$1.06x10^6$		
		(2) Decon. single fam. residences		(2) cordon off all parks and vacant areas	$3.2x10^6$
		a. DF<20[l]	$11.4x10^6$		
		b. DF≥20[m]	$2.45x10^6$		
		(3) Decon. public land		(3) Decon. resid. with DF ≥ 20	$3.5x10^6$
		a. DF<20	$4.6x10^6$		
		b. DF≥20	$2.5x10^6$		
		(4) Decon. commercial & industrial area		(4) Decon. commercial & industrial areas	$9.5x10^6$
		a. DF<20	$4.6x10^6$		
		b. DF≥20	$4.9x10^6$		
		(5) Decon parks	$5.67x10^6$	(5) 10,900 evacuees for 60 days; $1.63x10^5$ for 10 days	$30.8x10^6$
		(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; $2.82 \times 10^6 m^2$ (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 x 10^6 for suburban and $1.4 x 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
y. $140 per occupant for 6-story apartment building } live in multi-story buildings
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.

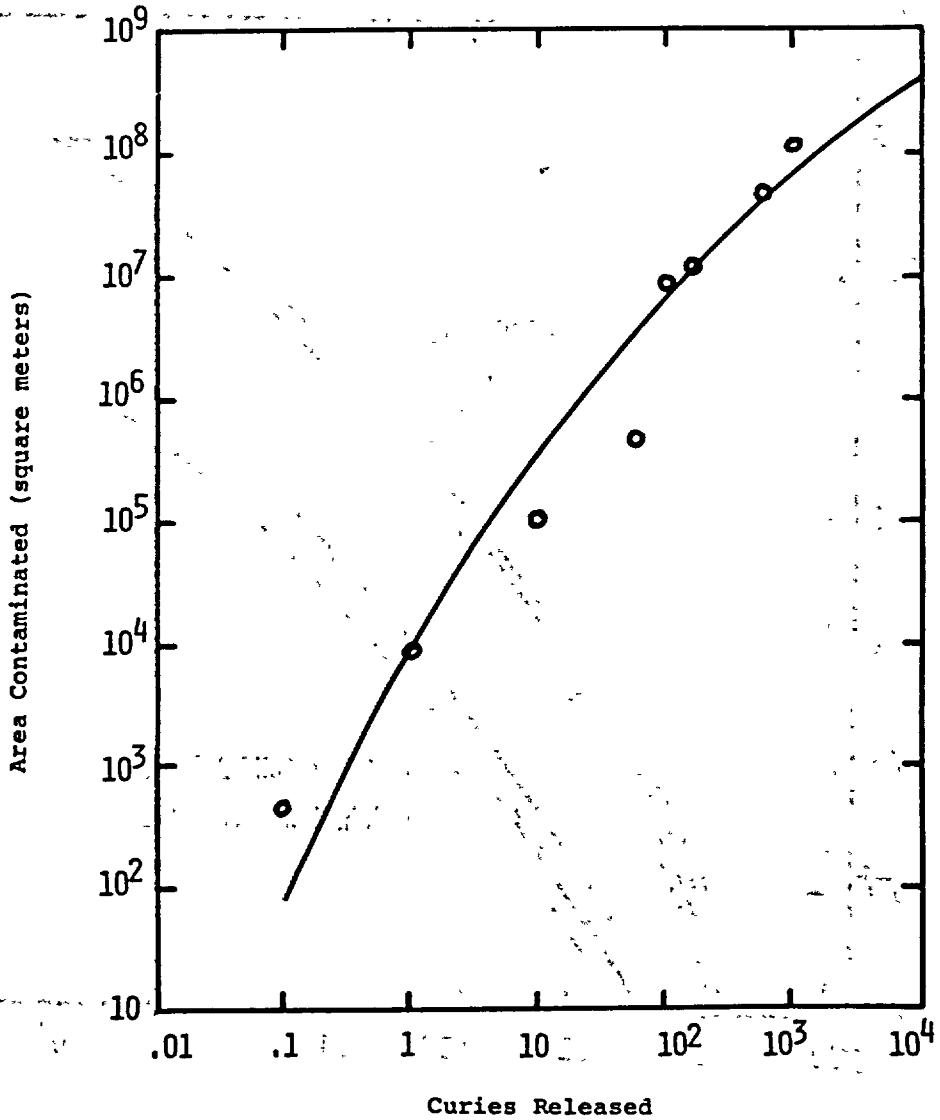

FIGURE 5-12. AREA CONTAMINATED TO A LEVEL OF 0.65 $\mu Ci/m^2$ FOR A GIVEN RELEASE

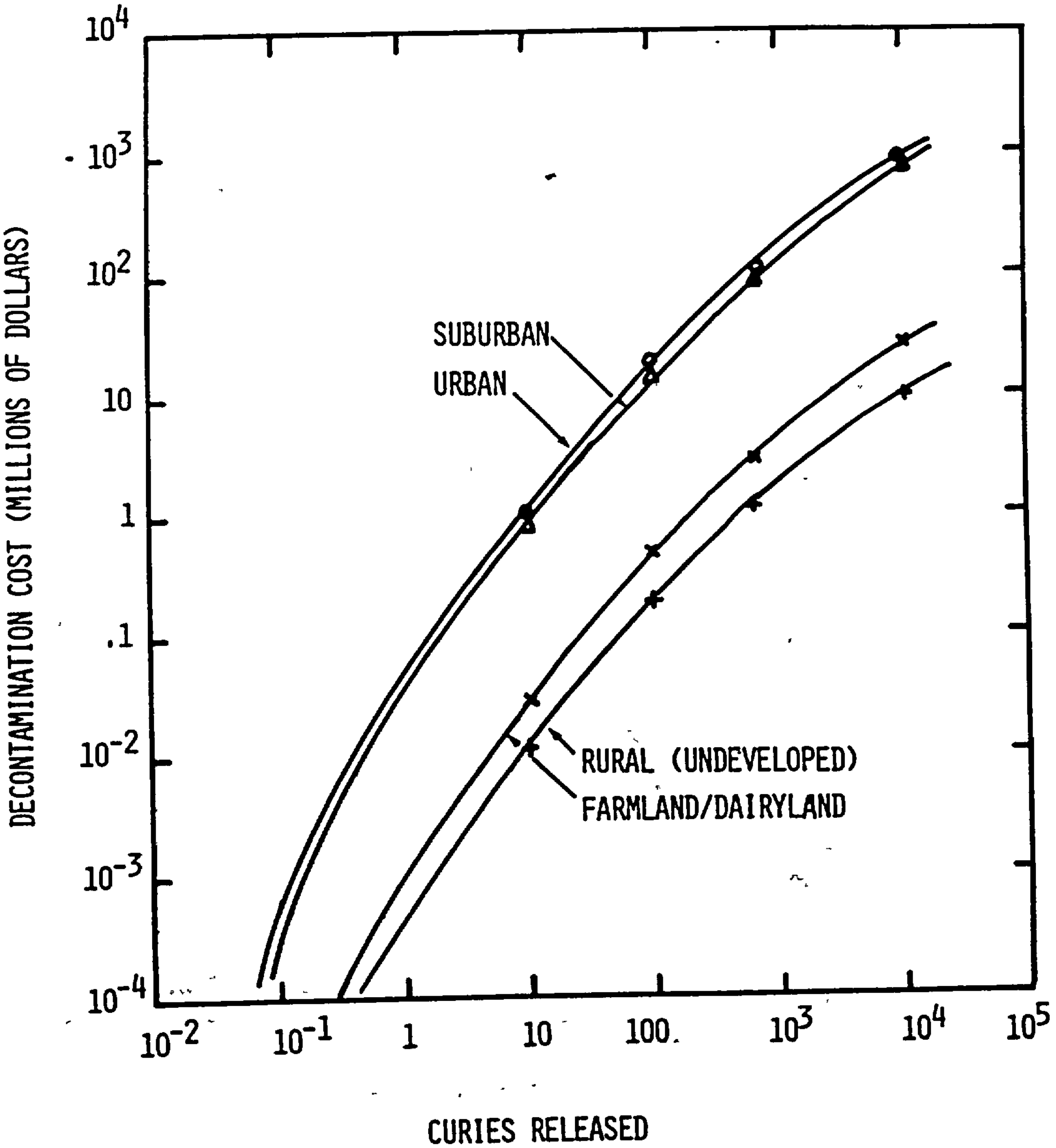

FIGURE 5-13. DECONTAMINATION COSTS FOR RELEASES OF LONG-LIVED ISOTOPES

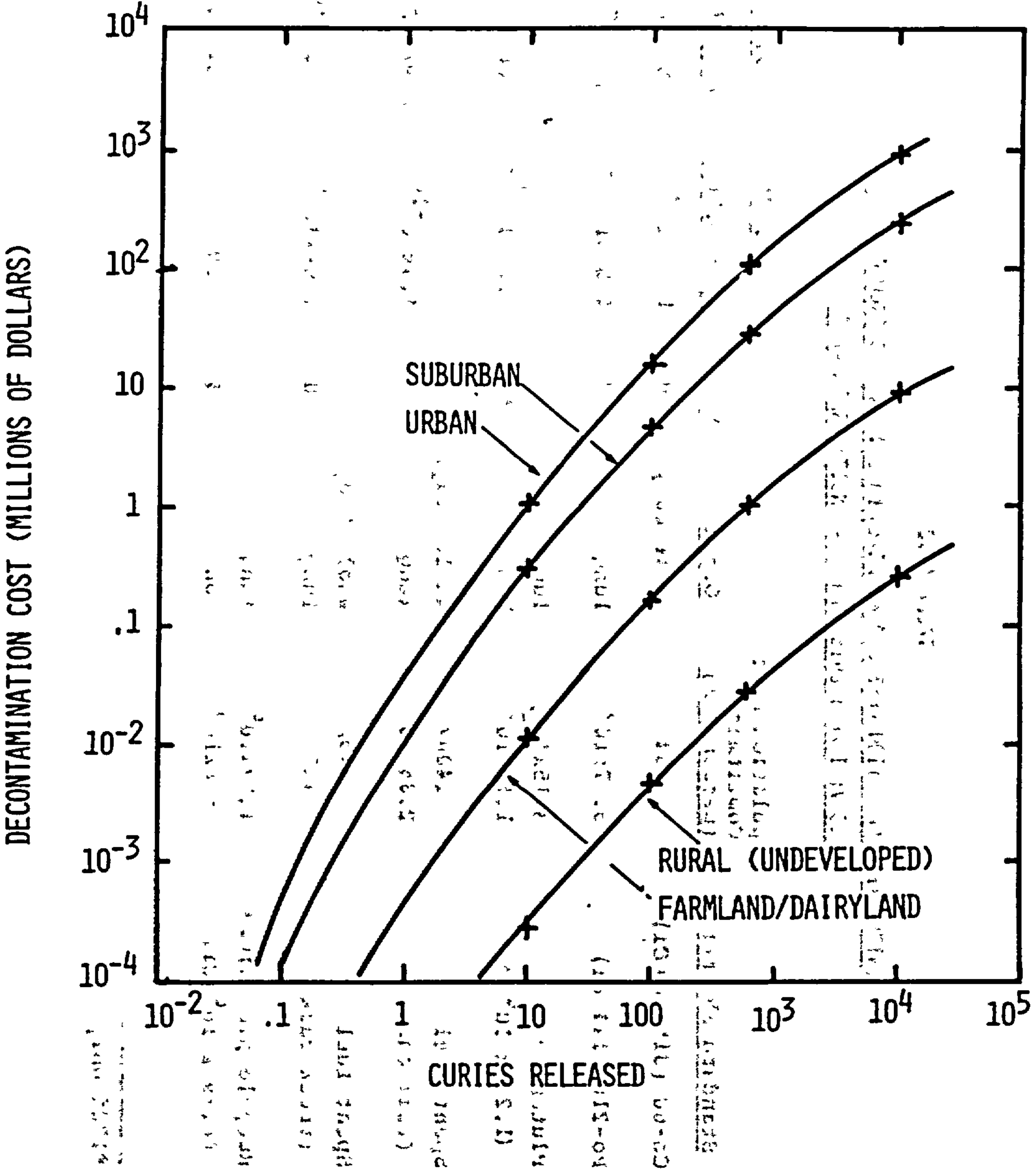

FIGURE 5-14. DECONTAMINATION COSTS FOR RELEASES OF SHORT-LIVED ISOTOPES

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	1.02×10^{-10}	2.55×10^{-10}
Po-210 (144 Ci)	5.27×10^{6}	lung	117	2.57×10^{-10}	8.2×10^{-10}
Plutonium (1.23×10^{6} Ci)	3.15×10^{6}/ 1.11×10^{7}	lung/ bone	147	1.06×11^{-11}	1.06×10^{-11}
Spent fuel (rail cask)	1400/ 2.85×10^{4}	whole body/ lung	1	1.8×10^{-10}	6.91×10^{-9}
Spent fuel (truck cask)	215/ 4450	whole body/ lung	0	2.99×10^{-9}	1.8×10^{-8}
Recycle plutonium* (6.19×10^{6} Ci)	1.59×10^{6}/ 5.6×10^{6}	lung/ bone	74*	0.0	2.24×10^{-10}

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*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	$\$200 \times 10^6$

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*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.

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*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 x 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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