10-15-75

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Assessment of the Environmental Impact of the FAA Proposed Rule Making Affecting the Conditions of Transport of Radioactive Materials on Aircraft

September 10, 1975

Prepared for the U.S. Energy
Research and Development Administration
under Contract E(45-1):1830

Battelle
Pacific Northwest Laboratories

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Under Contract AT(45-1)-1830

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $7.60; Microfiche $2.25

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ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF THE FAA PROPOSED RULE MAKING AFFECTING THE CONDITIONS OF TRANSPORT OF RADIOACTIVE MATERIALS ON AIRCRAFT

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September 10, 1975

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I. INTRODUCTION

Radioactive materials are used at tens of thousands of locations throughout the United States for medical, research, and industrial purposes. To supply the needs of these users about three quarters of a million packages of radioactive material are shipped annually in the country. The majority of these packages are shipped by passenger and cargo-only aircraft.

Several federal and state agencies ensure the safety of radioactive material transportation through regulation of the packaging and the conditions of transport. The Federal Aviation Administration (FAA) regulates the transport of radioactive material by commercial aircraft.

The FAA has issued a Notice of Proposed Rule Making which includes changes in the conditions of transporting radioactive material on commercial aircraft. These proposed amendments are reproduced as Appendix A herein. This draft environmental impact statement examines the potential effects of enacting those portions of the Notice of Proposed Rule Making (NPRM) which affect the carriage of radioactive materials on commercial aircraft.

The statement is presented in 10 sections and 5 appendices of this document. A glossary of terms and a list of acronyms follow the appendices. Sections IV and IX are of necessity somewhat detailed and lengthy. For ease of reference, summaries are given at the beginning of these two sections.

II. BACKGROUND FOR PROPOSED RULEMAKING

A. THE EXTENT AND NATURE OF RADIOACTIVE MATERIAL SHIPMENTS

A large and increasing quantity of radioactive material is shipped normally by common carriers in the United States. Estimates of the quantity shipped in 1974 range from 600,000 to 1,000,000 packages.[1, 2] Recent information from manufacturers tends to support an estimate of 600,000 packages of radioactive material shipped by all modes of transportation in 1974. Estimates of the annual growth in the number of packages shipped range from 10 to 25%.[1, 2]

The U.S. Atomic Energy Commission (AEC) estimated that in 1973, 75% of the radioactive material packages shipped were transported by aircraft.[3] However, our recent analysis indicates that this percentage has since decreased to an estimated 60% of all packages in 1975.

About 95%[4] of the radioactive material packages shipped by air are used in the medical profession.[a] Most medical shipments are radiopharmaceuticals which are used to diagnose abnormalities and disease in the heart, lung, liver, spleen, kidneys, central nervous system, skeleton, and other organ and tissue systems within the body. They are also utilized to determine physiologic functions including: cardiac output measurements, thyroid function, and determination of total blood or plasma volume.[5]

Most radiopharmaceuticals used in the practice of nuclear medicine require rapid delivery to hospitals and clinics because of their short half life, chemical instability, and/or the immediate needs of the medical profession. The majority of radiopharmaceuticals

(a) Only radioactive materials which are to be used for medical diagnosis or treatment or for research are permitted to be carried on passenger aircraft by Section 108 of the Hazardous Materials Transportation Act of 1974.

are prepared in five cities: New York, Boston, Chicago, St. Louis and San Francisco.[6] There are approximately 3300 hospitals in the United States using radioactive diagnostics.

Because of the large distances between radiopharmaceutical producers and users and the need for rapid delivery, air shipment has been used extensively. Several studies have indicated that the great majority of the packages shipped by air are shipped on passenger aircraft.[1, 4] The Society of Nuclear Medicine[5] and the American College of Radiology[7] have taken the position that nuclear medicine procedures can be provided satisfactorily in all geographic regions of the country only if radiopharmaceuticals are transported on scheduled commercial passenger aircraft. The panel appointed by the Joint Committee on Atomic Energy to study radioactive material transport reported that they consider "that there is an overall benefit and requirement that radioactive material particularly for medical purposes be permitted to be shipped by passenger aircraft and that there is no reasonable alternative method of shipping."[4]

More recent information from radiopharmaceutical suppliers indicates a trend toward greater utilization of cargo aircraft rather than passenger aircraft for their shipments. However, because of the limited number of flights and airports serviced by scheduled cargo aircraft, it is expected that use of passenger aircraft will continue to be required for a large percentage of the shipments.

There are nearly 5 million aircraft departures annually in the United States.[1] An airlines survey, conducted by the AEC,[3] indicated that on the average less than 1 out of 30 passenger flights from 20 major airports in the United States carried packages of radioactive material. This radioactive material traffic factor (RTF), the ratio of flights carrying radioactive material to total flights, varied among the different airports surveyed. The highest RTF, 1 out of 4 passenger flights, was found at the Knoxville, Tennessee airport.

B. RESPONSIBILITY FOR SAFE TRANSPORT OF RADIOACTIVE MATERIAL

The Nuclear Regulatory Commission (NRC) and the Department of Transportation (DOT) are the Federal regulatory agencies that are primarily responsible for assuring the safe transportation of radioactive material.[a] The Federal Aviation Administration (FAA) is part of the DOT.

The discussion which follows divides the regulatory process into the categories of licensing, packaging standards and criteria, radiation level limitations, and exposure standards. Under each category the responsibilities of the various Federal agencies are discussed.

1. Licensing

Subject to certain specified exemptions, most shippers and recipients of radioactive material are licensed by the Nuclear Regulatory Commission, The applicable regulations are in 10 CFR Parts 30-36/40/50/70/71/73. Common carriers are exempt from the regulations.

2. Packaging Standards and Requirements

The radioactive material packaging standards and criteria are found in the regulations of the DOT (49 CFR Parts 170-179) and the regulations of the NRC (10 CFR Part 71). The detailed packaging and labeling requirements established by the DOT are incorporated by reference into the FAA regulations for air transportation of dangerous articles found in 14 CFR Part 103. A discussion of the packaging standards and requirements is included in Section II.C.

(a) A detailed description of their respective responsibilities is included in a statement by Dr. Dixie Lee Ray in Hearings on the Transportation of Hazardous Materials before the Senate Commerce Committee, June 12, 1974.

3. Radiation Level Limitations

Radiation levels during transportation are limited by regulations on the radiation emitted from packages and by stowage and segregation provisions. Radiation level limitations for individual packages are found in the DOT regulations in 49 CFR Part 173. Stowage and segregation of packages containing radioactive material aboard aircraft is regulated by the FAA. The current minimum separation distances and other stowage criteria are given in 14 CFR Part 103. A discussion of the package radiation level requirements is included in Section II.C.

4. Radiation Exposure Standards

The FAA has the final authority for determining an acceptable radiation level in civil aircraft flying in air commerce. In arriving at a determination, FAA has utilized input from several governmental and quasi-government agencies.

The current radiation standards used by the Federal Government including the FAA are consistent with recommendations made by the Federal Radiation Council (FRC). The FRC recommended(8) that the "yearly radiation exposure to the whole body of individuals in the general population (exclusive of natural background and the deliberate exposure of patients by practitioners of the healing arts) should not exceed 500 mrem." The FRC also recommended that average annual individual whole body exposure over an unmonitored population group should not exceed 170 mrem. Both recommendations are in essential agreement with the current recommendations of the National Council on Radiation Protection and Measurements (NCRP).(9)

The responsibilities of the FRC were transferred to the Environmental Protection Agency (EPA) under Reorganization Plan No. 3 in 1970. EPA is charged with providing advice and recommendations to all Federal agencies for the formulation of radiation standards.(10) Its recommendation for this proposed rulemaking was issued as a report[11] in December 1974. The recommendations of the report[11] are discussed in Section IX of this impact assessment.

Acting under the authority of the Atomic Energy Act of 1954, as amended, the NRC has set permissible levels of radiation exposure in unrestricted areas resulting from a licensee's possession or use of radioactive materials. The limit is 0.5 rem in one calendar year for an individual.[12] Within this limitation, the regulation also provides that no licensee shall cause an individual to receive in excess of two millirems in any one hour or 100 millirems in any seven consecutive days.

C. SAFETY LIMITATIONS ON RADIOACTIVE MATERIAL PACKAGING AND STOWAGE

Two techniques are employed to provide protection from radioactive material during transportation. Protection from the release of radioactive materials during transportation is provided by limitations on the characteristics of the packaging. Protection against penetrating radiation is provided through limitations on the radiation levels on the outside of packages, and on stowage and segregation provisions. These techniques are discussed in the following two sections.

1. Safety Limitations - Packaging

The type of packaging required is specified in the DOT regulations (49 CFR Part 173) according to the type and quantity of radioactive material to be shipped.

Small quantities of radioactive materials, small quantities of radioactive materials in manufactured goods, and low specific activity materials may be shipped in strong industrial packages and are exempt from specification packaging, marking and labeling with the radioactive material labeling.

Type A quantities of radioactive materials (49 CFR §173.389(ℓ)) must be shipped in packaging, identified as Type A packaging, which will prevent loss or dispersal of the radioactive contents and retain shielding efficiency and effectiveness of other safety features under normal conditions of transport. The standards for evaluation and testing of package adequacy are specified in the DOT and the NRC regulations.

Quantities exceeding Type A quantities must be shipped in Type B packaging. Type B packaging must be designed to withstand normal transport conditions without loss of contents or shielding efficiency if subjected to a sequence of accident damage tests specified in the NRC and the DOT regulations.

2. Safety Limitations - External Radiation Levels

Protection from penetrating radiation is provided by limitations on the radiation levels on the outside of packages of radioactive materials and on stowage and segregation provisions. The number of packages in a single aircraft or area is limited to control the aggregate radiation level and to provide nuclear criticality safety for fissile materials. Minimum separation distances from people and undeveloped film are specified for loading and storing packages of radioactive materials to keep the exposure of persons and film to within acceptable limits.

The radiation emitted from individual packages of radioactive material is limited by DOT regulations (49 CFR §173.393) to control the radiation level to which persons and property in the vicinity of the package would be exposed. Packages of radioactive material are categorized and labeled according to the amount of radiation they emit. Maximum exposure rate limits for the three categories of packages are given in Table II-1.

TABLE II-1. Maximum Exposure Rates Versus Package Category

Package Label Category	Exposure Rate on Accessible Surface of Package (mrem/hr)	Exposure Rate 3 ft from External Surface of Package (mrem/hr)
Radioactive - White I	0.5	0
Radioactive - Yellow II	10	0.5
Radioactive - Yellow III	200	10

February 1, 1975 the Air Line Pilots Association (ALPA) embargoed the carriage on passenger aircraft of packages containing radioactive material with a TI greater than 3. This embargo resulted from an agreement between ALPA, the Society of Nuclear Medicine, and the American College of Radiologists. It was not sanctioned by any governmental agency.

As a simple indicator of the radiation dose rate from an individual package, DOT regulations define one "transport index" (TI) as being equal to 1 mrem/hr at 3 ft from the surface of the package. Title 14 CFR Part 103 specifies limits for aggregations of packages in terms of the sum of the transport indices. Currently the number of packages stowed in one group or area, or loaded on one aircraft, must be so limited that the sum of their transport indices does not exceed 50. This prevents a large aggregation of packages, each with a significant radiation level, from producing a much higher radiation level than desirable because of the additive effect of the radiation levels from all of the packages.

A table of minimum separation distances from people, animals, and unexposed film is specified for packages of radioactive material on aircraft in terms of the sum of the transport indices of the packages. Due to the limited distances from the cargo hold to the passenger section and between cargo compartment walls, the separation table requirements (14 CFR Part 103) limit the aggregate TI to a total of less than 50 for current passenger aircraft. Wide-bodied aircraft such as the B-747 and DC-10 are capable of carrying more total TI than smaller aircraft.

Whether there is one package or a large number of packages in an aircraft or a location, the transport worker or carrier is required to read the TI recorded on the label of each package, add the total number of TIs present, determine from the tables in the regulations the distance those packages must be kept from undeveloped film (so marked), animals and persons aboard the aircraft, and assure that those distances are provided.

The transport index system has also been adapted for limiting aggregations of packages containing fissile radioactive materials (primarily uranium and plutonium) to assure nuclear criticality safety. The shipper determines in accordance with specific criteria,[13] a transport index figure which is to be assigned to the fissile material package. For shipping, the shipper assigns to each package of fissile material the nuclear safety TI as calculated or the radiation level TI (as described earlier), whichever is the higher. The transport worker, as is the case for radiation levels, adds the TIs and by complying with the limitations on the number of TIs in any one aircraft or location, limits the amount of fissile material in all types of packages to safe limits.

Mixing nuclear safety TIs with radiation level TIs in the course of transport increases the margin of safety for both since they are not synergistic.

D. RADIATION EXPOSURE UNDER EXISTING REGULATIONS

The radiation levels to which aircraft passengers, cabin attendants, and flight crews are exposed depend on the amount of radiation emanating from each package, the number and location of packages on the aircraft, and the shielding provided by intervening cargo or aircraft structure. The cargo hold areas on essentially all passenger aircraft operated by U.S. carriers are located below the passenger compartments. Under current regulations, assuming that the aircraft floor structure does not absorb any radiation, the radiation level at the floor of the passenger compartment could be as high as 10 mrem/hr in an aircraft with the maximum permitted loading of radioactive material packages. The corresponding radiation level at seat height (40 cm above the floor) would be about 4.8 mrem/hr. The feet and lower legs are considerably less sensitive to radiation than the gonads and blood forming sites at seat level. Therefore, in evaluating radiation exposure the dose rate at seat level is more pertinent than the dose rate at floor level. Measurements of radiation levels on two commonly used passenger aircraft, a DC-9 and a B-727,[14] demonstrated that the floor structure does absorb radiation and that the actual maximum radiation level at seat height is about 3.4 mrem/hr, rather than the 4.8 mrem/hr possible under current regulations.

The radiation dose that a passenger actually does receive on a flight depends on: 1) whether the flight is carrying radioactive material, 2) whether the radiation level from the packages carried on the flight is less than or equal to the maximum permitted level, 3) where he sits, and 4) the duration of the flight. In order to compute a particular individual's annual radiation dose from the carriage of radioactive materials on passenger aircraft, this information would be required for every flight he takes during the year.

The annual collective doses to passengers, pilots, and cabin attendants can be determined statistically from knowledge of the radioactive material shipments. Annual collective doses from the transport of radioactive material in 1973 are given in Table II-2.

The information given in the table was developed by the AEC from a detailed evaluation of shipping conditions. To provide perspective for interpreting the collective doses from the carriage of radioactive material packages on passenger aircraft, the dose that each group receives from cosmic radiation during flight is also included in the table.

TABLE II-2. Annual Collective Doses

Population Groups	No. of Persons	Annual Collective Doses (Man-Rem/Year) Radioactive Packages	Cosmic Radiation
Persons Exposed To Radiation From Packages:[a]			
Passengers	6×10^6 [c]	1,400	2,000
Flight Crew	1.5×10^4	1	3,000
Cabin Attendants	2×10^4	70	4,000
All Persons:[b]			
Passengers	175×10^6 [c]	1,400	70,000
Flight Crew	3×10^4	1	6,000
Cabin Attendants	4×10^4	70	8,000

(a) All persons on flights carrying radioactive material.
(b) All persons who flew on passenger aircraft during the year.
(c) An individual is counted once for each flight he makes.

Barker, et al.,[15] developed hypothetical population groups who, because of flying habits, might have unusual exposures to radiation due to flying on passenger aircraft. They estimated that the average radiation dose from the carriage of radioactive materials to individuals in the most highly exposed groups was about 50 mrem/year. This value is approximately one-half of the annual radiation dose a person receives from background radiation[16] and is well within the FRC guidelines on exposure. The dose to the individual receiving maximum exposure in the select groups was estimated to be 340 mrem/year, which also is within the FRC guideline of 500 mrem/year exposure for an individual.

No comparable information exists for exposures to crews of cargo-only aircraft.

E. INCIDENTS IN THE TRANSPORT OF RADIOACTIVE MATERIAL BY AIR

The preceding paragraphs discussed radiation levels and doses that would occur when shipment of radioactive material is in compliance with the stowage regulations. Several investigations have indicated that there has been noncompliance with regulations in the past[17] which has led to higher exposures on particular passenger flights. Most of these resulted in radiation levels that were higher than permitted under the current regulations but which in themselves presented no significant threat to the occupants of the aircraft.

In the past five years there have been two potentially serious incidents which resulted in increased exposure or contamination of the aircraft in flight. There has been no indication of any deleterious health effect in any individual exposed on the two flights; however, the incidents were cause for concern. The first occurred in December 1971 and involved the leakage of a radioactive solution (^{99}Mo) which contaminated the cargo hold of a passenger aircraft.[18] The second occurred in April 1974 and involved an improperly loaded ^{192}Ir source.

F. STUDIES OF AIR TRANSPORT OF RADIOACTIVE MATERIAL

There have been several recent studies of the transport of radioactive material. In 1972 the National Transportation Safety Board issued a "Special Study of the Carriage of Radioactive Material by Air."[18] The principal conclusions of the study were that, at that time, the radioactive materials carried by air did not normally constitute any unusual risk of life to the public; however, vigilance should be maintained to ensure that the rapid growth of the nuclear industry did not in the future increase the minimal risk to the public. Recommendations for improving the operation of the radioactive material shipment system were presented.

In July 1974 the AEC transmitted to the FAA Recommendations for Revising Regulations Governing the Transportation of Radioactive Material in Passenger Aircraft.[3] These recommendations were developed from a series of special studies and surveys[14, 19, 20, 21] funded by the AEC to evaluate the radiation doses received by passengers and crew members aboard passenger aircraft. The AEC report concluded that although radiation doses were low, they were not as low as practicable. The report presented specific recommendations for changes to the FAA regulations which would result in lowering the doses to exposed individuals.

In September 1974 a special panel appointed by the Joint Committee on Atomic Energy (JCAE) issued a report on the Transportation of Radioactive Material by Passenger Aircraft.[4] A report entitled Considerations for Control of Radiation Exposures to Personnel from Shipments of Radioactive Materials on Passenger Aircraft[11] was released by the EPA in December 1974. These reports also concluded that radiation exposures under current regulations were not as low as practicable and made recommendations for changes.

The AEC, JCAE panel, and EPA reports were in agreement that exposures which could occur under present regulations were not "as low as practicable;" however, they did not agree on what changes were needed.

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2. Transcript of the Public Conference on Transportation of Hazardous Materials in Air Commerce, held at the U.S. Department of Transportation Departmental Auditorium, Washington, D.C., p. 170, October 23, 1974.

3. USAEC, Recommendations for Revising Regulations Governing the Transportation of Radioactive Material in Passenger Aircraft, submitted to FAA, July 1974 (hereinafter cited as the AEC report).

4. Transportation of Radioactive Material by Aircraft, Report No. 1 of the Special Panel to Study Transportation of Nuclear Material for the Joint Committee on Atomic Energy, September 17, 1974 (hereinafter cited as the JCAE report).

5. Statement of Capt. William H. Briner at Hearings on the Transportation of Hazardous Materials before the Senate Commerce Committee, June 13, 1974.

6. Address by Dr. J. Calvin Brantley, Vice President, New England Nuclear Corp., before the annual meeting of the Society of Nuclear Medicine, June 12, 1974.

7. Statement of Dr. James L. Quinn III, at Hearings on FAA Regulations Concerning Hazardous Air Cargo, before the Special Subcommittee on Investigations of the House Interstate and Foreign Commerce Committee, April 25, 1974.

8. Federal Radiation Council Report No. 1, May 1960.

9. National Council on Radiation Protection and Measurements, Report No. 39, January 1971.

10. 42 U.S.C. §2021(h).

11. U.S. Environmental Protection Agency Office of Radiation Programs, Considerations for Control of Radiation Exposures to Personnel from Shipments of Radioactive Materials on Passenger Aircraft, December 1974 (hereinafter cited as the EPA report).

12. 10 CFR §20.105.

13. Title 10, CFR 71.

14. Joint Study of Radiation Levels in Aircraft, conducted by DOT and FAA.

15. R.F. Barker, D.R. Hopkins, A.N. Tse (all of NRC), "Adequacy and Effectiveness of Federal Aviation Administration Regulations in Controlling Radiation Dose to Passengers and Crew in Passenger Carrying Aircraft", presented at the Fourth International Symposium on Packaging and Transportation of Radioactive Materials, Miami Beach, Florida, September 22-27, 1974.

16. Hearings on the Transportation of Hazardous Materials before the Senate Commerce Committee, June 1974, p. 115.

17. U.S. General Accounting Office, The Need for Improved Inspection and Enforcement in Regulating Transportation of Hazardous Materials, B-164497, May 1973.

18. National Transportation Safety Board, Special Study of the Carriage of Radioactive Materials by Air, NTSB-AAS-72-4, April 1972.

19. R.M. Johnson, E.R. Hermann, "Survey to Establish Radiation Dose Rates Received by Airline Passengers and Crew", Northwestern University, July 1973.

20. Jacob Shapiro, "Determination of Exposure Rates to Occupants of Passenger Aircraft Used to Transport Radioactive Materials", Harvard University, April 1974.

21. Gordon L. Brownell, "Impact on the Cost of Shipping Radiopharmaceuticals of Varying the Package External Radiation Levels", Massachusetts Institute of Technology, July 1974 (hereinafter cited as the Brownell report).

III. PROPOSED RULE MAKING

A. MEANS OF CONTROLLING RADIATION EXPOSURE ABOARD AIRCRAFT

Currently exposure from radioactive material aboard aircraft is controlled by regulations which limit the radiation dose rate outside each package and the number and position of the packages when loaded on the aircraft. Allowable radiation levels in areas occupied by individuals, animals and unexposed film are not specified in the regulations or measured by the carriers. The TI of the package (a measure of the radiation level outside the package) is specified on the package label for purposes of carrier control. A table in the regulations limits the sum of the TI's of the packages that can be loaded into a single aircraft. The maximum value of the aggregate TI depends on the available separation between the surface of the packages and portions of the aircraft occupied by individuals, animals and unexposed film (so marked). Compliance with the TI and separation restrictions assures that the radiation levels in the occupied areas of the aircraft are within predetermined levels.

This general means of radiation exposure control with the modifications discussed in Section III.C, would be continued under the proposed rule making.

B. OBJECTIVES OF THE PROPOSED RULE MAKING

There are two elements to consider in setting objectives for the regulation of radioactive material on aircraft: 1) total population (or collective) dose and 2) the maximum exposure to individuals in higher exposure groups.

The overall objective for this rule making is to reduce radiation exposure to "as low a level as practicable." By itself, however, this objective is too vague to provide guidance in setting regulation standards. Within the context of the overall objective, bearing in mind the two elements noted above, two specific objectives for the proposed rule making were formulated.

The first objective is to reduce the total collective dose, resulting from carrying radioactive material on aircraft, to an acceptable level. There are three guidelines utilized to determine what is an acceptable level:

1. There should be no unnecessary exposure,
2. Reducing small risks from exposure should not be required, according to the BEIR Report, if the funds that would be used could clearly produce greater benefits when spent otherwise.
3. The benefit/cost ratio for exposure reductions must be acceptable.

The second objective of the proposed rule making is to limit exposure to all flyers (passengers and crew) to only a fraction of the FRC recommended limit of 500 mrem/year. For this objective, the first two guidelines also apply. The third guideline does not apply because a benefit/cost calculation cannot be made for reduction in an individual's dose. The reason is that mortality probability estimates for an individual are not available for such low level radiation exposure.

These objectives will be accomplished through four types of changes in the current regulations:

1. Changes which reduce the maximum radiation level at locations occupied by passengers and crews
2. Changes which prohibit the unnecessary shipment of certain radioactive materials on passenger aircraft
3. Changes which reduce the likelihood of improper storage of radioactive material aboard aircraft.
4. Changes which encourage shipment on cargo-only aircraft rather than on passenger aircraft.

C. COMPARISON OF EXISTING AND PROPOSED REGULATIONS

The existing regulations (14 CFR Part 103) are given in Appendix B. The complete text of the proposed amendments to 14 CFR Part 103 is in Appendix A. The proposed rule making will affect the carriage of packages bearing the "Radioactive - Yellow II" label and the "Radioactive - Yellow III" label on both passenger and cargo-only aircraft. A summary comparison of the existing and proposed regulations is shown in Table III-1.

The proposed rules will add a new § 103.20 to 14 CFR. The new section, applicable only to passenger aircraft, will restrict the carriage of radioactive materials that bear a "Radioactive - Yellow III" label to those that have a transport index of 3.0 or less. Section 103.20 will also require each radioactive material package bearing a "Radioactive - Yellow II" or "Radioactive - Yellow III" label to be carried on the floor of the cargo compartment of the aircraft. It will permit a package bearing either of those labels to be carried on a passenger-carrying aircraft only if it contained a radioisotope with a radioactive half-life that does not exceed 30 days. (The radioactive half-life of any radioisotope is the time required to lose 50 percent of its activity by decay. Each radioisotope has a unique half-life.) Exceptions to the half-life restriction are made for radioactive materials that are susceptible to rapid chemical deterioration or that have a half-life exceeding 10^8 years, and for certain export/import shipments as specifically approved by the FAA Administrator.

A new § 103.21(a) is proposed that sets forth minimum spacing distances between people or animals and packages of radioactive materials carried aboard passenger-carrying aircraft. Proposed § 103.21(a) will take the place of current § 103.23 and the separation prescribed therein. A comparison of the separation prescribed in the existing and proposed regulations is shown in Table III-2.

The proposed new § 103.21(b) provides for the use of a spacing system of "predesignated areas" for the stowage of packages containing radioactive materials aboard passenger aircraft. The "spacing-out" system would have to be acceptable to the FAA. Under this proposal, a system of predesignated areas would be acceptable to the FAA when designed to insure that: 1) the packages of radioactive material are placed in each predesignated area in compliance with the minimum distance required by paragraph (a) of § 103.21; and 2) the predesignated areas are laterally separated from each other by at least four times the distance specified in paragraph (a) to limit radiation level "peaking" from the summation of radiation emitted from each predesignated area.

TABLE III-1. Existing and Proposed Regulations

Item	Existing Regulations	Proposed Regulations
Packaging		
Maximum package TI	10 (§ 173.393)(a)	3 (§ 103.20)
Surface	200 mrem/hr. (§ 173.393)	No change
Quantity Limits	Transport group packaging Limits (§ 173.390-391)	No change
Overpack Marking	Not covered	Label with TI (§ 103.24)
Stowage		
Total TI/Aircraft:		
Passenger	50[b] (§ 103.19)	No change
Cargo	Similar to passenger	200 (§ 103.19), Fissile Packages ≤ 50 (§ 103.22)
Configuration:		
Passenger	Separation table (§ 103.23)	Separation table or predesignated areas (§ 103.21) Packages with radioactive - yellow II and III labels on floor only (§ 103.20)
Cargo	Similar to passenger	Separation table for TI ≤ 50 (§ 103.22a). For TI > 50, 1) ≤ 50 TI per group of packages, 2) ≥ 20 ft separation between groups, 3) ≥ 30 ft separation from persons and animals (§ 103.22b).
Film Protection	Separation table (§ 103.23)	No change (§ 103.24)

(a) Regulations with the designation (§ 173.__) are published in 49 CFR Part 173; those with the designation (§ 103.___) are in 14 CFR Part 103.

(b) The effective total TI which can be carried is limited by the cargo compartment height of existing aircraft and in all cases is less than 50.

TABLE III-1. (Cont'd)

Item	Existing Regulations	Proposed Regulations
Overpack TI:		
Passenger	Not covered	3.0 maximum (§ 103.24)
Cargo	Not covered	10.0 maximum (§ 103.24)
Inspection and Monitoring		
Responsibility	- carrier (§ 103.3)	No change
Methods	- exterior package inspection (§ 103.4) - package monitoring (§ 103.23) - aircraft scan if leakage or damage indicated (§ 103.23)	
Half Life	No limit	Prohibit materials with half-life > 30 days and < 10^8 years in packages with radioactive - yellow II and III labels on passenger aircraft except: - compounds subject to rapid chemical deterioration - special export/import shipments (§ 103.20)

TABLE III-2. Separation Distances

Total Transport Index	Separation Distance, inches	
	Proposed Rule Making	Existing Regulations
0.1 to 1	12	12
1.1 to 2	20	24
2.1 to 3	28	
3.1 to 4	34	
4.1 to 5	40	
5.1 to 6	46	36
6.1 to 7	52	
7.1 to 8	57	
8.1 to 9	61	
9.1 to 10	65	
10.1 to 11	69	48
11.1 to 12	73	
12.1 to 13	77	
13.1 to 14	81	
14.1 to 15	85	
15.1 to 16	89	
16.1 to 17	93	
17.1 to 18	97	
18.1 to 20	102	
20.1 to 25	118	60
25.1 to 30	130	
30.1 to 35	142	72
35.1 to 40	154	
40.1 to 45	166	84
45.1 to 50	177	

The FAA also proposed to increase the amount of radioactive material that is permitted to be carried on cargo-only aircraft and to set forth requirements for the stowage of packages containing radioactive materials aboard cargo-only aircraft. Section 103.19 of the current regulations limits the quantity of radioactive materials that may be carried on cargo-only aircraft to an amount that represents a total transport index of 50. It is proposed to amend § 103.19(b) to permit the quantity of radioactive materials that may be carried aboard a cargo-only aircraft to be increased to a total transport index of 200. More specifically, under proposed § 103.22, when the total transport index of all the packages carried does not exceed 50, the distance required between the packages containing radioactive materials and a space occupied by a person or an animal will be the same distance required on a passenger-carrying aircraft. When the transportation index of all the packages exceeds 50, however, the proposal will require a minimum separation distance of at least 30 ft. (9m) between the packages carried and any space occupied by a person or an animal. In addition, when the total transport index exceeds 50, the proposal will require packages to be stowed in groups with the transport index for any group of packages limited to a maximum of 50. Each group of packages will be required to be separated from every other group by not less than 20 ft (6m). To assure nuclear criticality safety the total transport index for packages containing fissile material is limited to 50 (§ 103.22b).

An amendment to § 103.24 is proposed to incorporate the existing requirements for separating radioactive materials from undeveloped film that are currently incorporated in § 103.23; and to permit the transportation of packages containing radioactive materials in shipping unit overpacks when certain stated conditions are met (§ 103.24).

IV. PROBABLE EFFECT OF THE PROPOSED ACTION ON THE ENVIRONMENT

A. SUMMARY

Section IV presents a detailed evaluation of the probable effect of the notice of proposed rule making (NPRM) on the environment. It is concluded that the principal effect of the NPRM will be to change the radiation exposure from radioactive materials transported on commercial aircraft and the weight and number of radioactive material packages transported by air. Radioactive material packages do not represent a major portion of the total volume, weight or number of packages transported by air. The change in weight and number of packages of radioactive material transported by air resulting from the NPRM would have a safe and negligible effect on the use of aircraft cargo space. Section IV.B contains a brief discussion of radiation protection criteria. Expanded discussion appears in Appendices C and D. Analysis of the effects of the portions of the NPRM applicable to passenger aircraft is made in Section IV.C.2; those portions applicable to cargo-only aircraft are considered in Section IV.C.3. The findings for passenger and cargo-only aircraft are summarized separately below.

Passenger Aircraft

Analyses are made of both the collective annual radiation exposure and the average annual radiation exposure to individuals on passenger aircraft carrying radioactive material. It is concluded that the NPRM will reduce both the collective annual exposure (See Table IV-1) and the average annual exposure to individuals (See Table IV-2) and that these exposures are within applicable guidelines. The radiation exposures to various groups of individuals (e.g.,) passengers with particular flying habits, flight crew members, cabin attendants) are also examined. It is concluded that the NPRM will also reduce the radiation exposure to the select groups of passengers.

The NPRM will provide for a reduced maximum radiation dose rate to which flight crew members and cabin attendants could be exposed below the levels permitted by existing regulations. However, due to the pecularities of current loading practices flight crew members and cabin attendants are exposed to a dose rate significantly below that which would be permitted by existing regulations. Therefore, the NPRM in some instances could increase the radiation levels to which flight crew members and cabin attendants are exposed. Exposures will, however, remain within FRC guidelines.

Cargo-Only Aircraft

Analysis of the effects of the portions of the PRM pertaining to cargo-only aircraft is made in Section IV.D. The analysis indicates that the PRM will reduce the radiation dose rates to which flight crews are exposed. Radiation exposure to animals carried aboard the aircraft will likewise be reduced. However, radiation exposure of undeveloped film (so marked) carried aboard the aircraft will be unaffected by the NPRM.

The effect of the NPRM on the criticality safety of fissile material shipments is examined in Section IV.C.3.b.3. It is concluded that the NPRM will have no effect on criticality safety.

B. RADIATION EFFECTS AND RADIATION PROTECTION CRITERIA

Radiation affects the body by causing excitation or ionization of the atoms and molecules (See Appendix C). These events can lead to physical and chemical changes which may affect cellular, metabolic or organ structures and functions. The effects of radiation may be classified either as somatic--the effect (long-term or short-term) on the individual himself, or as genetic--the effect on future generations. In the past, radiation protection criteria and guidelines for individuals and the general public were primarily based on possible genetic effects. As our knowledge of radiation effects has grown, it has become evident that protection of individuals and the general public from somatic effects is also important and that criteria and guidelines must be based on both these considerations. It is generally felt that any exposure to ionizing radiation constitutes a risk. It is the intent of all radiation protection criteria to restrict radiation dosages to an acceptably small risk. Thus, radiation protection criteria depend not only on purely biomedical and physical considerations but also on value judgments of the acceptability of a risk. The concept that radiation exposure should be maintained "as low as practicable" arose from the desire to minimize the risk of radiation exposure and yet to permit attainment of the benefits gained through use of radiation. A discussion of the "as low as practicable" concept is given in Appendix C.

Radiation is a natural phenomenon that has always existed. (See Appendix C) The unit used to measure radiation dose is the rem or mrem (1/1000 of a rem). The average exposure of a person in the United States to background radiation from cosmic rays and natural radioactive materials in the earth is about 100 mrem per year. Other radiation exposures result from man's activities. It is estimated that the average annual exposure from the use of radiation in medical diagnosis and treatment is about 73 mrem per person. The average per capita nonbackground, nonmedical dose to the general public is currently about 6.6 mrem per year. Thus the average annual dose to individuals in the United States is currently about 180 mrem.

The Federal Radiation Council (FRC) and the National Council on Radiation Protection and Measurement recommend that the average whole body radiation dose (excluding medical and background exposures) to the population of the United States not exceed 170 mrem annually. However, since it cannot be demonstrated that exposure to any level of radiation does not constitute a risk, it is recommended that exposure be kept "as low as practicable."

The FRC guidelines recommend an upper limit of 500 mrem per year excluding medical and background exposures) as the nonoccupational dose to an individual. This is also the limit adopted by NRC for exposure in unrestricted areas. Again, since it is assumed that any exposure to ionizing radiation constitutes a risk, which is assumed to increase linearly with the amount of exposure, it is recommended that all exposures be kept "as low as practicable" within these guidelines. (Recent evidence suggests, however, that the risk may not increase linearly with exposure; see Appendix D.)

The risk of radiation induced cancer is considered to be the only somatic risk that needs to be taken into account in evaluating radiation protection. It has been estimated by conservative extrapolation from high dose rate experiments that the chances are about 1 in 10,000 that an individual exposed to 500 mrem will at some later date die from a radiation induced cancer. This risk is assumed herein to be directly proportional to the dose (e.g., the chances are only 1 in 50,000 that an individual exposed to 100 mrem will, at some later time, die of a radiation induced cancer). Similarly, the number of excess cancer deaths per year in a group of one million people exposed to an average radiation level of 100 mrem per year is estimated to be about 18. (See Appendices C and D.)

Synopsis of Radiation Considerations

- Current regulations and guidelines limit annual whole-body radiation dose (excluding medical and background exposures) to 170 mrem averaged over the population of the United States and 500 mrem to the individual.
- Radiation exposure should be kept "as low as practicable."
- The excess cancer deaths per year in a group of one million people each exposed to an average radiation dose rate of 100 mrem/year is estimated to be about 18.
- The number of cancer deaths attributable to radiation dose per year is assumed to be directly proportional to the population dose.

C. RADIATION EXPOSURES

1. General Considerations

The NPRM will affect both the individual and the collective ratiation exposures received from the transport of radioactive material by aircraft. The annual radiation dose to an individual resulting from the carriage of radioactive material by air can be determined by summing over all the flights he makes in a year, the product of the time he is aboard the flight and the radiation level at his location. Mathematically this is expressed as

$$D_j = \sum_{i=1}^{F} H_i R_i \qquad \text{(Eq. IV-1)}$$

where

D_j is the annual dose to individual j (expressed in mrem/yr)

i denotes his i^{th} flight

F is the total number of flights he makes in the year

H_i is the hours flown on flight i

R_i is the radiation level at his location on the i^{th} flight.

The annual collective dose (the total annual dose from exposure to radiation from radioactive material packages to all persons who fly on aircraft carrying radioactive material) can be obtained by adding the dose received by each individual who flies. Mathematically, the annual collective dose can be expressed by

$$P = \sum_{j=1}^{N} D_j \qquad \text{(Eq. IV-2)}$$

where

P is the annual collective dose (expressed in man-rem/yr)

N is the total number of people who flew on passenger aircraft in that year

D_j is defined as the annual dose to individual j.

Although the data to evaluate these equations are generally unavailable, consideration of the factors in the equations gives insight into the effect of the NPRM on the collective dose and the individual dose from radioactive material carried on aircraft. The dose received depends on the number of people who fly, the number of trips they make annually, the number of hours they fly, and the radiation level at their location on each of their flights. The first three factors will be unaffected by the NPRM. The NPRM will only affect the radiation level, R_i, which depends on:

- radiation emitted by each package of radioactive material on the flight,
- number of packages on the flight,
- relationship between radiation dose rate at location i and radiation emitted by packages of radioactive material.

The third item is a function of the energy and type of radiation emitted, the distance between location i and each package, the radiation absorption by the aircraft structure and intervening cargo, and the physical size and shape of the radiation source.

Thus the individual and collective radiation doses from radioactive material carried on aircraft depend on many factors, some of which cannot reasonably be controlled by rule making (e.g., the number of hours a person flies in a year, some package and aircraft characteristics). In order to evaluate the effect of the NPRM, it is necessary to assume conditions that the rule making will not affect. Therefore, there is always the possibility of unusual conditions that would violate an assumption and result in higher exposure values than obtained in the following analyses. However, it is considered likely that deviation from the values given would be in the direction of dose reduction.

2. Passenger Aircraft

a. Collective Dose

Barker et al.[1] have developed a relationship indicating that the collective dose is closely proportional to the total TI carried on passenger aircraft. The annual collective doses received in 1973 by passengers and crew members on flights carrying radioactive material were estimated by the AEC[2] using this relationship and a value for the total TI transported annually which was developed from an airlines survey.[3]

The results of the AEC evaluation indicate that in 1973 the collective doses from radiation emitted from packages of radioactive material transported by passenger aircraft was 1400 man-rem per year to a total of six million passengers; 70 man-rem per year to 20,000 exposed flight attendants; and less than 1 man-rem per year to 15,000 exposed flight crew members. In the evaluation, a person was considered to be exposed if he were aboard a flight carrying packages of radioactive material. The total collective dose was approximately 1500 man-rem per year.

As previously stated, the annual collective dose is heavily dependent upon the total TI shipped within a year but almost independent of the spreading out of packages into more passenger aircraft. It is also approximately independent of the lateral spacing of groups of packages or the total TI permitted on an individual aircraft. The only exception to this approximation is that for the same total TI shipped, spacing out would slightly increase the exposure of flight crews. The current practice (not required by regulation) is generally to load radioactive material packages in the rear cargo hold,[4] a long distance from the cockpit. Carriage of the maximum TI permitted under the proposed regulations would require that some packages be located closer to the cockpit than is currently the case. Since the dose rate increases as the distance between the packages and a person decreases, the flight crew's radiation dose would increase in theory. However, since currently the majority of passenger aircraft carry less than the maximum permitted TI[3] and since it is expected that custom will continue to favor loading in the rear cargo hold on flights not carrying a capacity load of TIs, the increase in the collective dose to flight crews should be minimal. For the same total TI shipped annually, the increase in the total collective dose that would result from the lateral spacing-out provision of the NPRM would be negligible. Therefore, under the NPRM the annual collective dose will be reduced nearly proportionately to the reduction in the total TI transported by passenger aircraft.

An extension of Barker's method was used in the current analysis to develop a numerical conversion factor for man-rem exposure per unit TI transported on passenger aircraft. Using the average dose rate per unit TI and the average number of persons per flight from Barker's paper[1] results in an average dose rate of 1.8×10^{-3} man-rem/hr per unit TI. Analysis of recent information on delivery patterns of radiopharmaceuticals indicate that currently the average duration of flights carrying packages with TI greater than 1 is approximately 3 hr. Therefore, the conversion factor of 5.4×10^{-3} man-rem per unit TI transported was used in the collective dose analysis which follows and in the cost-benefit analysis in Section IX.

Estimates are made in Sections IX and X of this report of the total TI transported annually by passenger aircraft under existing conditions (effective package TI limit of 3) and under various alternatives. A comparison of these estimates of TI shipped annually in 1973, at present and under the NPRM is provided in Table IV-1. Annual collective (population) doses corresponding to the various TI levels are also provided for comparison.

TABLE IV-1. Total TI Transported Annually on Passenger Aircraft and Corresponding Collective Dose

	Total TI	Collective Annual Dose (man-rem/yr)
1973(1)	400,000	1471
At Present(2)	190,000	1030
Proposed Rule Making(3)	180,000	970

1. Based on AEC analysis(2)
2. Currently the radiopharmaceutical industry limits the TI per package for radioactive material carried on passenger aircraft to a maximum of 3. This is also the limit under the NPRM. The main difference between the total TI shipped at present and that projected under the NPRM results from the half life restriction in the proposed amendments.
3. Effect of this proposed rule-making restricting the transport on passenger aircraft of radionuclides with half lives exceeding 30 days and less than 10^8 years was evaluated using data of the AEC survey of manufacturers. Total number of packages and total packages TI was determined for all radionuclides with half lives greater than 30 days and less than 10^8 years. Packages of 0 TI (Radioactive Units I) were excepted. Approximately 15% of total nontechnetium generator packages (see Section IX-B for definition of technetium generator packages) consisted of packages which would be prohibited from transport aboard passenger aircraft by the proposed half life restrictions. Average TI for those packages was approximately 0.22.

   If the package distribution of the AEC survey of suppliers is assumed to be typical, 15% of the 575,000 nongenerator packages projected for shipment in 1975 (Table IX-3) are potentially affected by the proposed rule-making.

   Of the approximately 85,000 potentially affected packages about 45% (40,000) will be transported by passenger aircraft (Table IX-4), and thus would be affected by the proposed rule-making. With an average package TI of 0.22, approximately 10,000 total TI would be diverted from passenger aircraft to other modes of transport. Subtracting 10,000 TI from the projections of total TI transported by passenger aircraft under the proposed rule-making and alternatives (Table IX-20) gives estimates of total TI transported and resulting collective dose with and without the proposed half life restrictions (Table IV-1).

The reduction in TI shipped from 1973 to the present was due to changes in the manufacturers' shipping methods. It should be noted that restriction on package TI does not mandate the estimated changes in total TIs transported. This is because reduction in individual package TI limits can be accomplished in two ways. One method is to decrease the amount of radioactive material contained in the package. Presumably the "left out" radioactive material must also be shipped, so it goes in additional packages. The effect of this method ("splitting") is to lower individual package TI but to increase the number of packages shipped--with no net effect on total TI transported. The alternative method of lowering individual package TI is to provide additional shielding for the package. With this method the same amount of radioactive material is shipped per package, but at a lower package TI. The number of packages shipped remains the same and total TI transported is decreased.

Since the proposed regulations do not specify acceptable methods of reducing package TI, it is necessary to assess probable manufacturer behavior when predicting the effect of the proposed regulations (and alternatives) on total TI transported and consequent collective dose. Various constraints will affect the methods chosen to reduce package TI including effects of additional shield weight, consumer preference and desirability for shield standardization. These are discussed in detail in Section IX. Based on information obtained from manufacturers and customers, it was determined that the most probable response in meeting a package TI limit of 3 would be an increase in shielding (although a certain amount of "splitting" would occur under particular alternatives). It is upon this assessment of manufacturer behavior that the estimates of Table IV-1 are made.

The BEIR report,[5] although cautioning that the relationship is conservative (overestimates the health effects), developed an expression which indicates 10,000 man-rem annual exposure to low level radiation could statistically result in 1.8 cancer deaths per year. Thus, the 1030 man-rem exposure which occurs under current regulations has the statistical potential to result in approximately 0.2 cancer deaths per year. Under the NPRM this would be reduced approximately 5%.

b. Individual Dose

1. Passengers. As can be seen from Equation IV-1, the annual dose received by an individual passenger depends on the number and duration of flights he takes during the year. The results of a recent Gallup Poll[6] indicate that approximately 34 million adults flew on passenger aircraft in 1974. Over 50% of these people made no more than 2 trips (1 round trip) during the year. Less than 5% made more than 12 trips. The average number of flights per person was less than 5. Barker et al.[1] determined that the average duration per flight was 2 hr. Therefore, less than 5% of the people who flew on passenger aircraft in 1974 flew more than 24 hr each.

The AEC airlines survey[3] results indicate that less than one in thirty passenger aircraft flights departing from the 20 largest airports in the United States carry radioactive material packages [the radioactive traffic factor (RTF) is less than 1/30]. For smaller airports the average is much less than one in thirty. Thus, the odds are greater than 29 to 1 that there will be no radioactive material packages on a passenger aircraft flight selected at random. The NPRM should reduce the radioactive traffic factor to some extent, since implementation of the "spacing-out" provision will increase the effective TI capacity of most aircraft (see Table X-3). However, no data is available to estimate the reduction. In the analysis of the radiation dose to select groups of individuals, given later in this section, it was conservatively assumed that the NPRM would not reduce the RTF.

Average Annual Radiation Dose for Exposed Air Passengers

If we assume that each person makes five flights during the year, then the 6 million passengers (see Table II-1) exposed to radiation from radioactive material carried aboard passenger aircraft[2] are actually only a little more than a million individuals. Assuming that a million individuals are exposed to the collective doses given in Table IV-1, then the average individual doses are as shown in Table IV-2. These radiation doses are well within the FRC guidelines on radiation exposure.

TABLE IV-2. Average Annual Exposure to Individuals on Flights Carrying Radioactive Materials

	Average Individual Dose (mrem/yr)
1973	1.5
At Present	1.03
Proposed Rule-Making	0.97

Radiation Exposures to Individuals

The probable effect of the NPRM on the annual radiation dose received by each individual is more difficult to assess than the probable effect on the annual collective radiation dose. In order to exactly determine the annual radiation dose one would have to evaluate Equation IV-1 about 34,000,000 times (once for each individual who flies during the year). This task is impossible in practice. It would require knowledge of the flying habits of each individual and a complete description of the number, radiation level, and location of radioactive material packages carried on each flight taken by each individual.

One approach to the analysis of the annual dose to individuals from the carriage of radioactive materials on passenger aircraft is to determine the maximum dose rate permitted under the regulations and multiply that by the number of hours an individual flies during the year. This would give a theoretical upper bound on his exposure. If we assume that a person flies 500 hr per year and that he always sits in a seat with the maximum permitted radiation dose rate under the regulations (2 mrem/hr), his maximum annual dose would be 1 rem, clearly outside the FRC guidelines.

It is pertinent, however, to consider the probability that an individual would receive such a dose. This is determined by: 1) the probability that an individual will fly that many hours in a year; and 2) that he will be exposed to the maximum permitted radiation level on each of his flights. As previously stated, it is estimated that less than 5% of the people who fly as passengers, fly more than 24 hr annually. Data to determine the percentage of people who fly 500 hr annually is not readily available; however, it is probably of the order of 0.1%.

Likewise the probability must be considered that on each of an individual's flights the dose rate at his location will be the maximum permitted under the regulations. Assuming that: 1) an individual flies 500 hr per year, taking 100 flights each of 5 hr duration, 2) all his flights are made from an airport that has an RTF of 1 in 4,[a] 3) on all flights carrying radioactive material the individual sits where the radiation level is 2 mrem/hr, and 4) either the distribution of flights carrying radioactive material is random or his selection of flights is random, then the likelihood that he will receive 1 rem exposure in the year is $(1/4)^{100}$. This means that if all of the people who fly more than 24 hr annually, flew 500 hr each under the above conditions, the chances that any one person would receive an annual dose of 1 rem would be about 1 in 10^{54} (i.e., 1 in a billion billion billion billion billion billion). Assuming 50,000 persons each fly 500 hr annually the likelihood that any individual would receive a dose in excess of 500 mrem is less than 1 in 300 (i.e., once in 300 years an individual would receive a dose in excess of 500 mrem annually).

Although the selection of an individual's flights and the distribution of flights from a particular airport which carries radioactive material are not random, which undoubtedly would result in higher likelihoods than given

a. The AEC airlines survey[3] results indicated that one airport had a RTF of 1 in 4, all others had a smaller RTF.

above, it is considered unlikely that an individual who flies 500 hr a year annually would receive an annual dose of 500 mrem or greater.

The above probability analysis took no credit for either the possibility that an individual might not sit in a location having the maximum dose rate (under the NPRM the average dose rate in any section of the aircraft would be about 1 mrem/hr) or the fact that about half of his flights would be from airports having a lower RTF and hence a lower probability of exposure. Although there is no conclusive data, it is felt that the risk of an individual receiving radiation exposure in excess of the FRC guidelines as a result of enactment of the NPRM is remote.

Radiation Exposure To Select Groups of Individuals

In lieu of exact information, another practice in evaluating dose to individuals is to postulate one or more select groups of people with particular flying habits which potentially could result in high exposure and the radiation field to which they would be exposed. The accuracy of this approach depends on how well the select groups are chosen (are they realistic?) and how well their radiation exposures are estimated. The select group approach will be used here with the knowledge of its limitations. Assumptions on radiation levels aboard passenger aircraft will be developed first.

The radiation levels in the passenger cabin vary with location. The maximum radiation level at seat height is about 4 mrem/hr under existing regulations and will be about 2 mrem/hr under the proposed regulations.

Under existing regulations all packages of radioactive material shipped on a passenger aircraft can be stowed in one tight group. Current practice usually is to stow the packages close together in the aft cargo hold. This results in a radiation level exceeding about 0.1 mrem/hr in only about 1/3 of the passenger compartment (usually the rear third) on planes the size of a B-727. According to the AEC airlines survey,[3] about half of the radioactive material packages and TI transported by passenger aircraft are carried on B-727 aircraft. For larger aircraft less than one-third of the passenger compartment is normally exposed to radiation levels about 0.1 mrem/hr under current regulations.

In general, airlines seat people in different parts of the passenger compartment based on their preferences or habits (e.g., first class at the front, tourist class nonsmoking in the middle, tourist class smoking at the rear of the aircraft). Therefore, passengers usually sit in specific portions of the aircraft rather than randomly throughout the entire aircraft. Since only about one-third of the aircraft is exposed to significant radiation levels and it is usually the same part on each flight, the AEC, in evaluating the average dose rate on a flight fully loaded with radioactive material, averaged over the portion (usually approximately 7 rows) having a significant radiation field. According to the AEC the average dose rate at seat level under current regulations is about 1.3 mrem/hr under fully loaded conditions. The NPRM with the lateral spacing out provision distributes the dose more evenly among the passengers on the aircraft. Under the proposed rule making the average dose in any section of the aircraft under fully loaded conditions would not exceed about 1 mrem/hr. Thus the dose rate to individuals seated in the most highly exposed portion of a fully loaded aircraft will be reduced by about 30% under the NPRM.

In summary, the radiation level assumptions used in the following evaluations are: 1) the maximum radiation level at seat height is 4 mrem/hr under existing regulations and 2 mrem/hr under the NPRM, and 2) the average radiation level at seat height is 1.3 mrem/hr in one section under existing regulations and about 1 mrem/hr in any section under the NPRM.

<u>Select Group of Passengers Who Fly 500 Hours Per Year</u>

The select group of passengers considered in this analysis consists of those individuals who fly 500 hr per year. Included in this group are: 1) frequent air travelers, such as salespersons, 2) people who commute by air to and from work on weekdays, and 3) individuals who commute by air to and from their homes on weekends and in addition do a significant amount of flying in the course of their work. The maximum annual dose that these individuals could receive under the NPRM is about 1 rem; however, as discussed above, such a dose is extremely unlikely. The maximum dose that they could receive under the existing regulations is about 2 rem.

Estimation of the annual dose to this select group requires evaluation of the radioactive traffic factor (RTF). The AEC airlines survey(3) indicates that the RTF varies for individual airports. The RTF and the exposure therefore depends on the origin of the individual's flights. The average RTF for flights departing from the 20 largest airports (which represent about half of all flight departures in the United States) is less than 1 in 30; that for the smaller airports is much less. The RTFs for flights departing major radioactive material shipping centers (New York, Boston, Chicago, St. Louis, San Francisco) range up to 1 in 10. The survey showed only one airport (Knoxville, Tennessee) that had an RTF for departing flights that was greater than 1/10. The Knoxville airport RTF is 1 in 4.

The average annual weighted exposure time for the select group is obtained by dividing the annual hours flown (500) by the average RTF (1/30). Therefore, the average number of hours per year that individuals in this group fly aboard aircraft carrying radioactive material is 17.

Within this select group, different subgroups can be identified whose members would have greater weighted exposure times because of the particular airports they fly between. Weighted exposure times for flights between airports with different RTFs are given in Table IV-3.

It is assumed that the radiation levels to which individuals in this select group will be exposed will be the previously stated averages (1.3 mrem/hr under existing regulations and 1 mrem/hr under the proposed regulations) although the distribution in the total TI per aircraft found

TABLE IV-3. Weighted Exposure Time as a Function of RTF

Group Designation	RTF Airport 1	RTF Airport 2	Mean RTF	Weighted Exposure Time (hr/yr)
Select Group	1/30	1/30	1/30	17
Subgroup A	1/30	1/10	1/15	34
Subgroup B	1/10	1/10	1/10	50
Subgroup C	1/4	1/30	1/7	71
Subgroup D	1/4	1/10	1/6	83

in the airlines survey indicates that most likely the radiation levels will be lower. Under these assumptions the average annual dose to the select group is 22 mrem under existing regulations and will be 17 mrem under the proposed regulations.

The average annual dose to the various subgroups that fly between particular airports is given in Table IV-4. The distribution of an individual's flights throughout the days of the week will cause some variation in exposure, but it will not significantly affect the results given in the table. It should be noted that only a few individuals would be in subgroup C and D because the airport with the RTF of 1/4 is relatively small with respect to passenger traffic.

TABLE IV-4. Average Annual Exposure--Select Subgroups[a]

Group Designation	Weighted Exposure Time (hr/yr)	Average Annual Dose (mrem) Proposed Regulations	Existing Regulations
Select Group	17	17 (Group Average)	22 (Group Average)
Subgroup A	34	34	44
Subgroup B	50	50	65
Subgroup C	71	71	92
Subgroup D	83	83	108

a. Select subgroups of individuals who fly 500 hr per year.

2. Flight Crew. Approximately 15,000 flight crew members are currently exposed to an annual collective dose of less than 1 man-rem from the carriage of radioactive material on passenger aircraft (an average individual dose of less than 0.1 mrem/year).[2] One reason for this very low exposure is the current practice of usually stowing radioactive material packages in the aft cargo hold, far from the cockpit. Since, as was discussed before, the radiation dose rate decreases as the distance between the packages and a person increases, flight crews receive a low dose. In 100 flights surveyed at Chicago's O'Hare Airport, all known to carry radioactive materials, no detectable radiation level was found in the cockpit.[4] At Boston Logan Airport, only 2 out of 42 flights surveyed, all known to carry radioactive material, were found to have any measurable radiation level in the cockpit and in both cases, the radiation level was only 0.1 mrem per hour.[7] Even the group of pilots who fly out of airports serving major radiopharmaceutical supply centers such that the RTF is about 1 out of 10 receive less than an estimated 5 mrem per year, based on 1,000 hr per year flying time. The maximum exposures of the flight crew members who fly for the airline with highest RTF (one in three)[2] is about 17 mrem per year.

Under unusual situations, the radiation dose to a flight crew member who flies the same outbound flight with 0.1 mrem per hour in the cockpit for the entire flight year would be 50 mrem per year. This estimate indicates an upper exposure limit under unlikely conditions.

If the current practice were to store the packages of radioactive material in the forward cargo hold, flight crews could be exposed to a higher dose rate. However, based on the Oklahoma City study,[8] the maximum dose rate at the flight crew's seats would still be less than 0.4 mrem/hr.

The NPRM reduces the maximum dose rate that a flight crew member can be exposed to. On fully loaded flights, the NPRM could result in an increase of his dose rate from the currently low value of approximately 0.1 mrem/hr which results from the practice of stowing radioactive material in the aft cargo holds. However, due to the more restrictive spacing table requirements of the NPRM the increased dose rate would certainly be less than 0.4 mrem/hr, most likely about 0.2 mrem/hr. If all of his flights which carried radioactive material, carried essentially a full load (a highly unlikely situation), his exposure under the NPRM would be about twice the values given above for each of the respective groups of flight crew members. Under the NPRM the flight crews' exposures would remain within the FRC guidelines.

3. Cabin Attendants. The AEC analysis (see Table II-2) indicated that approximately 20,000 cabin attendants (stewards and stewardesses) receive an annual collective exposure of 70 man-rem in 1973. Thus, the average annual radiation dose to cabin attendants from carriage of radioactive material on passenger aircraft was about 3.5 mrem per person in 1973. At the present reduced shipping level their average exposure is estimated to be 2.5 mrem/year per person. Under the proposed regulations their average radiation dose is expected to be reduced by about 5 percent to 2.4 mrem/year per person.

Select Groups of Cabin Attendants

Cabin attendants fly about 1000 hr per year. Since their job involves moving up and down the aisle of the aircraft serving the needs of passengers, the radiation level they are exposed to is the average level in the aisle area of the portion of the aircraft that they serve. For the purpose of this analysis, it is assumed that the first class area comprises about 1/3 of the cabin length and the tourist class section about 2/3 of the cabin length. Consistent with the evaluation of the dose to passengers and flight crews, the dose to cabin attendants was evaluated at gonad level, assumed to be 90 cm above the floor of the cabin.

Based on the Oklahoma City experiments[8] and the Boston Logan Airport data,[7] the dose rate to a cabin attendant working the tourist section on an aircraft carrying the maximum load of radioactive material packages is estimated to range up to about 0.6 to 0.8 mrem/hr under current regulations.

Under current loading practices (loading radioactive material in the aft cargo hold) a cabin attendant working the first class section receives essentially no exposure. If the current practice were to load the packages under the first class section, the dose rate to cabin attendants working this section could be nearly twice as high (~1.4 mrem/hr) as the above dose rate for cabin attendants in the tourist class section. This higher dose rate results from the shorter averaging distance in the first class section (half the length of the tourist class section).

Before discussing the effect of the PRM on the dose to select groups of cabin attendants, it is important to clarify the relationship between the total TI carried on the aircraft and the average dose rate in the passenger cabin. Since currently radioactive packages are generally loaded on the floor of the cargo hold and will be required to be loaded there under the NPRM, the vertical distance between the packages and occupants of the passenger cabin will not change. Moving packages to different locations on the floor of cargo holds or dividing them into groups placed in different parts of the cargo hold will have essentially no effect on the average dose rate in the passenger cabin. It will affect the maximum dose rate in the cabin and the dose rate distribution at different locations in the cabin (i.e., shift the area receiving the highest dose rate to a different portion of the cabin), but it will not significantly affect the average dose rate over the whole cabin. Thus, the average dose rate in the passenger cabin is nearly proportional to the number of TI carried on the aircraft. Since a cabin attendant is exposed to the average radiation level, her dose rate is nearly proportional to the total TI loaded under (or closely adjacent to) the section of the aircraft where she works. If the cabin attendant worked throughout the whole aircraft, her dose rate would be closely proportional to the total TI loaded in the cargo holds.

Under the NPRM the total TI in one location is decreased, but the total TI aboard an aircraft can be increased above the value currently permitted by the separation table. The effect of the change in total TI on the dose rate to a cabin attendant depends on whether the number of TI under, or close to, the section that she works is increased or decreased. Thus, the NPRM will in some instances increase and in other instances decrease the dose rate to cabin attendants.

Under the NPRM, the dose rate that any cabin attendant would be exposed to on an aircraft loaded to the maximum permissible TI is estimated to be 0.7 mrem/hr. The current dose rate is estimated to be in the range of 0.6 to 0.8 mrem/hr due to the practice of loading in the aft cargo holds (loading in the forward cargo hold could result in a dose rate of approximately 1.4 mrem/hr). Thus, the NPRM could result in a small change (increase or decrease) in the dose rate for a tourist class cabin attendant. However, the dose rate under the NPRM will be only about half of that which could result under existing regulations if the radioactive material were stowed in the forward cargo hold.

For a dose rate of 0.7 mrem/hr which could occur under the NPRM, the AEC has calculated the estimated annual doses that would be received by select groups of cabin attendants. These are given in the following paragraphs.

The select group of cabin attendants consists of those cabin attendants who fly out of airports serving major radiopharmaceutical supply centers where the RTF is about 1 out of 10. Assuming there is no radioactive material on board their return trips, the probable exposure time for cabin attendants in this select group would be approximately 50 hr/year. The average annual dose to individuals in the group would be about 35 mrem/year if the NPRM is adopted.

The largest RTF for flights of any airline departing from any airport is about one in three.(2) Cabin attendants who serve that airline from that airport as home base could receive about three times (ratio of 2 RTF: 1/3 to 1/10) as much dose as the average dose received by cabin attendants in the select group. The average dose to cabin attendants in this subgroup would then be 120 mrem per year under the NPRM. This analysis assumes that all the flights carrying radioactive material carry a near capacity load. Examination of the airlines survey(3) results suggests that this is not the case and therefore lower doses would be expected. Under very unusual circumstances, if a cabin attendant flies the same outbound flight for the entire flight year,[a] and, if that flight always carries the maximum number of packages, her annual radiation dose could approach 350 mrem per year under the recommended limits. Since this estimate is based on an improbable situation, it is believed that this radiation dose is not realistic but indicate an upper limit of annual radiation dose to cabin attendants.

c. <u>Exposure to Animals and Undeveloped Film</u>

The NPRM will reduce both the annual collective dose and the individual dose to animals from radioactive material carried on passenger aircraft. The decrease in the annual collective radiation exposure to animals carried in the cargo hold will be greater than the factor of decrease of TI of radioactive material packages carried on passenger aircraft.

Information on the annual collective dose received by animals carried in the cargo holds of passenger aircraft is not readily available; however, the NPRM will reduce the current exposure by greater than 5%. Considering individual animals, the maximum dose rate that an animal in the cargo hold could be exposed to under current regulations is about 10 mrem/hr. The dose rate under the NPRM would be reduced, the degree of reduction being a function of the TI of the radioactive material packages carried on the aircraft.

The annual radiation exposure to packages of undeveloped film (so marked) carried in the cargo hold of passenger aircraft will be decreased as the ratio of the TI shipped under the NPRM to the TI shipped at present. It is expected that the half-life restriction portion of the NPRM will decrease the TI transported by passenger aircraft by 5%; therefore, the

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a. This is unlikely to happen because cabin attendants normally "bid" for new routes every month. The bidding is based on an attendants seniority with the company.

annual radiation exposure of undeveloped film (so marked) due to the carriage of radioactive material packages on passenger aircraft will be decreased by at least 5%.

The maximum radiation level that a package of undeveloped film could be exposed to under existing and proposed regulations must also be considered. In all cases in which the undeveloped film is not stowed between two groups of radioactive material packages, the radiation exposure will be decreased by the NPRM. The radiation exposure will normally also be decreased when the film is stowed between two groups of packages of radioactive material; however, there are circumstances of stowage between two groups in which the exposure could be increased under the NPRM. If the film is stowed between two groups of radioactive material packages on an aircraft carrying the maximum permitted TI and the film package is so large that it is located at the minimum permitted spacing to both groups of packages, then the radiation exposure of the film under the NPRM could exceed that which could occur under present regulations. The increase is due to the additive effect of the radiation from the other radioactive material packages in the cargo hold. On only one commonly used passenger aircraft would the increase exceed about 5%. On the DC-9 under the above circumstances the exposure could be greater, but the increase would be less than 25%. It is felt that the combination of high TI loading of an aircraft, stowage of undeveloped film between two groups of radioactive material packages separated by the minimum separation distance, and loading of a package of film that fills, or nearly fills, the entire permitted space (4 times the separation distance given in part 103.21 minus 2 times the minimum separation distance given in part 103.24 of the proposed amendents) between the two groups is highly unlikely.

It is concluded that the proposed rule making will reduce the annual radiation exposure of undeveloped film (so marked) and will in almost all instances reduce the maximum radiation exposure to a package of undeveloped film. The increase in the maximum radiation level that could occur under a combination of unlikely circumstances is less than 25%.

d. Likelihood of Excessive Radiation Exposure Due to Improper Stowage

Under the NPRM there will still be the possibility, as there is under existing regulations, that packages of radioactive material will be improperly stowed in the cargo hold in violation of the separation table requirements. However, the NPRM, by simplifying the regulations, should decrease the likelihood of improper stowage. Specific changes which should decrease this likelihood are:

- The new requirement that overpacks must be labeled with the cumulative TI,
- The requirement that Radioactive-Yellow II and Radioactive-Yellow III packages be stowed on the floor of the cargo hold, and
- Reduction of the maximum package TI from 10 to 3 permitting all packages to be transferred freely among all the common commercial passenger aircraft.

Therefore, the PRM should reduce the likelihood of excessive radiation exposure due to improper stowage of radioactive material packages.

3. Cargo-Only Aircraft

On the basis of information provided by individual manufacturers of radiopharmaceuticals it is estimated that on a TI basis 15% of the radioactive material shipped annually is transported by cargo-only aircraft. For cargo-only aircraft, there is no readily available information on the distribution of TI per aircraft, radiation levels at crew locations or the probability that a cargo flight will carry radioactive materials. Therefore, the effect of the NPRM on the radiation exposure can best be evaluated in terms of the maximum radiation dose rate rather than radiation dose.

The evaluation is made in two parts: 1) the effect of the NPRM for a total transport index not exceeding 50, and 2) the effect of the NPRM for a total transport index exceeding 50 but not exceeding 200.

a. Total TI Not Exceeding 50

1. Exposure of Flight Crews

The maximum radiation dose rate that flight crews can receive under both existing and proposed regulations is controlled by spacing tables. Assuming the same structural attenuation in cargo aircraft as in passenger aircraft, and assuming that a flight crew member is seated 40 in. from the partition dividing the cargo area from the cockpit, then under current regulations he could be exposed to a maximum dose rate of approximately 4 mrem/hr from radioactive material packages. With the same assumptions, under the NPRM, the maximum dose rate would be about 2 mrem/hr. Thus the NPRM will reduce the maximum dose rate by about a factor of two.

2. Exposure of Animals and Undeveloped Film

The radiation exposure to animals on a flight carrying radioactive material will be reduced due to the larger spacing distances required by the proposed regulations. The spacing from radioactive material packages to undeveloped film will not be changed by the NPRM. The radiation exposure of undeveloped film (so marked) will be unaffected by the NPRM.

b. Total TI Exceeding 50 But Not Exceeding 200

1. Exposure of Flight Crews

The radiation exposure to flight crews under the proposed regulation is controlled by the requirements that packages be segregated in groups not exceeding 50 TI per group and that no group shall be closer than 30 ft from the cockpit and any space occupied by animals. (Current regulations do not permit greater than 50 TI on an aircraft.) Using the same assumptions as in Section IV C.3.a.i, and further assuming that the four groups are spaced out along the length of the aircraft, the maximum dose rate to a flight crew member under the NPRM will be slightly greater than 1 mrem/hr. Thus, the maximum dose rate to a flight crew member on a flight carrying 200 TI of radioactive material will be about 1/4 his maximum dose rate under current regulations and a little more than half of the dose rate that he could receive under the NPRM on a flight not carrying more than a total of 50 TI.

2. Exposure of Animals and Undeveloped Film

The maximum dose rate that an animal would receive on a cargo flight under the proposed regulations will be less than half that which could be received under existing regulations due to the greatly increased separation distances required.

The NPRM contains no provisions for the carriage of undeveloped film (so marked) on aircraft carrying more than 50 TI of radioactive material. It is expected that only a small percentage of the cargo flights will carry more than 50 TI of radioactive material, therefore, the impact of the NPRM on the carriage of undeveloped film on cargo-only aircraft should be negligible.

3. Fissile Material Shipments

The transport index (TI) assigned to a radioactive material package may either be in terms of radiation units or criticality units. To make this distinction, one must differentiate between nonfissile radioactive materials and fissile radioactive materials.

For nonfissile radioactive materials, which make up greater than 95% of the air shipments of radioactive material, the principal concern is radiation and the transport index is in terms of radiation units. The transport index is simply the radiation dose rate (mrem/hr) at 3 ft from an accessible external surface of the package.

For fissile radioactive material, principally uranium and plutonium, the concern can be either radiation or criticality. Consequently, the transport index is taken as the higher of the following:

- Radiation dose rate in mrem/hr at 3 ft; or
- A number calculated by dividing the number "50" by the number of similar packages which may be transported together according to criticality safety criteria.[9]

If the total TI of fissile material packages aboard the aircraft does not exceed 50, criticality considerations are minimal. Fifty TI based on criticality units was selected on the basis that:

a) Five times that number (or 250 TI) of such undamaged packages would be subcritical in any arrangement.

b) Twice that number (or 100 TI) of such packages would be subcritical in any arrangement if each package were subjected to the hypothetical accident conditions specified in NRC regulations.[10]

Since the proposed regulations would allow no more fissile material packages on aircraft than are allowed under the present rules, there is no change in the environmental impact of transporting such packages.

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V. ENVIRONMENTAL EFFECTS OF POTENTIAL ACCIDENTS

Radioactive material carried on passenger or cargo aircraft does not affect the expected frequency of airplane accidents. Neither does the carriage of radioactive material significantly increase the accident consequences, measured in terms of fatalities. However, since packages containing radioactive material are not designed to survive all airplane crashes, releases of radioactive material can be postulated and evaluated.

The radiological effects of accidents will be quantified in this section. The accident environment will be described first. This will be followed by a section which describes the characteristics of several radionuclide shipments and estimates their behavior in the accident environment. The final section will look at the probable radiological consequences of a release.

A. Aircraft Accident Environment

The accident environment for commercial aircraft has been evaluated at Sandia.[1] Statistical data are available in FAA annual reports.[2-5] The FAA statistics break the accidents down into accidents which occur during departure or landing and those which occur inflight. In the years 1969 to 1973 there were 59 accidents[a] during more than 22 million departures.[b] Thus the frequency of accidents per departure is once in 3.8×10^5 departures. During the same time period, there were 21 inflight accidents[c] in 9.4 billion miles of flight.[b] The average air shipment distance for radioactive material packages is estimated to be 1200 miles (see pg IX-25). Thus the frequency of inflight accidents for the 1200 mile trips is once in 370 thousand trips. Using the FAA aviation statistics, the average distance between stops was estimated to be 419 miles, thus an accident during departure and landing in a 1200 mile trip is once in 120,000 trips. Combining both classes of accidents results in an accident frequency of once in 91,000 shipments.

Not all accidents are expected to release radioactive material. Sandia estimates that severe damage to the fuselage occurs in 37% of all accidents. Fires occur in approximately 33% of all accidents. Contrary to intuition, the Sandia evaluation saw essentially no correlation between impact severity and the likelihood of fire.

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a. Accidents (not including inflight accidents) causing aircraft damage.
b. Domestic passenger flights in scheduled service of certificated route trunk and local service air carriers.
c. Inflight accidents involving substantial damage to the aircraft.

In this analysis, it is assumed that a release occurs only in accidents where extensive damage to the fuselage occurs. Thus a release is expected to occur once in 250,000 shipments. A large release is assumed to occur only if there is severe cargo damage and the occurrence of a fire. This is estimated to occur once in 750,000 shipments of radioactive material.

B. Magnitude of Releases Resulting from Air Transport Accidents

The spectrum of radioactive materials shipped by air is very broad. The consequences of releasing each radionuclide which might be present on an airplane is beyond the scope of this evaluation. Instead five isotopes were picked to represent a spectrum of the radioactive materials currently shipped.

Four of the radioisotopes considered in the evaluation were selected from the AEC Radiopharmaceutical Survey[6] tables. The survey results indicate that the four most frequently shipped radioisotopes are ^{99}Mo (which contains the decay product ^{99m}TC), ^{99m}Tc, ^{131}I and ^{125}I. The ^{99}Mo, ^{131}I and ^{125}I shipments were evaluated. Since the radiological effects calculation for the ^{99}Mo includes the dose from ^{99m}Tc, the ^{99m}Tc shipments were not evaluated. The fourth radioisotope selected from the table was ^{57}Co. The latter selection was on the combined bases of relatively long half-life, number of packages shipped, and hazard classification. The fifth isotope considered was ^{226}Ra, selected on the basis of high radiological hazard per curie released. Characteristics of the radioisotopes and the shipments which were used in the accident analysis are given in Table V-1.

TABLE V-1. Characteristics of Selected Radioactive Material Shipments

Isotope	Half-Life	Transport[a] Group	Packages Per Year	Curies/Package Max.	Curies/Package Avg.
^{99}Mo	66 hr	IV	110,000	1000	19.
^{125}I	60 days	III	33,000	20	0.062
^{131}I	8 days	III	150,000	1000	1.38
^{57}Co	271 days	IV	9,100	0.1	0.01
^{226}Ra	1600 yrs	I	1,800	0.12	0.09

a) Defined in 10 CFR 71, Appendix C.

The number of packages of the first four radioisotopes shipped per year was estimated from extension of the AEC Radiopharmaceutical Survey results. This survey covered only part of the industry shipments in 1973 and therefore the results had to be extended to the entire industry and the year 1975. The distribution of curies/package was obtained from the same survey for all but ^{226}Ra shipments. The radium data was based on communications with a radium shipper.(7) It is noted that the high average curies per package for ^{99}Mo results from shipment of a relatively small number of packages of bulk ^{99}Mo and from the large intervals, e.g., 20-1000 curies, used in reporting the survey results in reference 6. For lack of detailed information on the distribution within the interval it was conservatively assumed to be uniform.

When evaluating the radiological consequences of air transport accidents, the amount of material involved in the accident must be specified. Unfortunately, no definitive information is available on the frequency that a given amount of a radionuclide will be present on a flight. Although there are distributions of flights vs total TI present on the plane, this gives essentially no guidance to the amount of material present. In fact, the use of Radiopharmaceutical Survey results shows that many packages have TI's of about 3 yet differ in the activity of the material contained by four orders of magnitude. Very simply, when smaller amounts are shipped, they are shipped in lighter packages with shielding which is proportionally less effective. Since the TIs of these packages are about 3, which is the average TI per flight, determined from the Airlines survey,(8) usually only one package will be present per flight.

The number of flights annually which carry radioactive material has been estimated to be 100,000.(9) This means that an average of about 6 packages are present on a flight.

Table V-2 shows the estimates used in the analysis of the number of flights containing various curies of radionuclides. The distribution of curies per shipment was obtained using the maximum values of curies per package in an interval, as given in reference 6 together with estimates of the number of packages per shipment. The analysis is conservative in that it uses maximum values and considers all shipments of the radioisotopes are made by passenger aircraft.

Table V-2 gives the estimated frequency of air transport accidents involving various quantities of radioisotopes. To estimate the consequences of aircraft accidents, two more factors must be considered: the fraction of the radioactive material released in the accident, and the dose received by the population exposed to the release.

TABLE V-2. Estimated Number of Shipments of Selected Quantities of Radionuclides

	Curies/shipment*				
	.02	1	5	20	1000
Isotope	Number of Shipments/year				
^{99}Mo		60	26,000	3,400	3,800
^{125}I	900	1500	100	80	
^{131}I	2600	9400	800	150	400
^{57}Co	400	160			
^{226}Ra		1800			

The airborne release fraction estimates are shown in Table V-3 for the fire and no-fire environments. These release fractions are based on experiments which have been performed at Hanford during the past decade and have been summarized in various topical reports.

TABLE V-3. Estimated Release Fractions from Air Transport Accidents

		Fraction Released	
Nuclide	Form	Fire	Cargo Breach
^{99}Mo	Liquid	0.002	6×10^{-4}
^{125}I	Liquid	1.0	6×10^{-4}
^{131}I	Liquid	1.0	6×10^{-4}
^{57}Co	Liquid	0.002	6×10^{-4}
^{226}Ra	Solid	5×10^{-5}	0

* Maximum values used to assure that analysis is conservative.

In Table V-3 the ^{99}Mo is shown being shipped as a liquid. Actually in technetium generators the ^{99}Mo solution is adsorbed on a resin column and will not drain from the column if the outer container is breached. At the same time, in a fire, the liquid would boil off from the column. No experiments have been performed to estimate the fraction that would be released. In the absence of such numbers, liquid release fractions have been applied. The release fraction in a fire environment is based on the fraction released when a liquid solution is boiled to dryness.[10] The release in the no-fire case is based on experiments carried out on soils exposed to winds of various speeds. The estimate presented in Table V-3 is based on analyses summarized in BNWL-1846.[11] The estimates for the radium shipments were obtained from experiments carried out on plutonium metal buttons.[12]

The dose received resulting from an air transport accident is now calculated for the release of each radionuclide using the downwind population distribution presented in the ALAP document for the seashore reactor site.[13] Many other distributions could have been used, but it is felt that this population distribution indicates the level of radiological consequences which are likely from the crash of an aircraft carrying radioactive material.

For the downwind population distribution used, Table V-4 presents the inhalation doses received from a release of one curie of each of the selected radionuclides. The doses are given in terms of whole body dose and also dose to a critical organ.

TABLE V-4. Whole Body and Critical Organ Doses Received per Curie of Selected Radionuclides Released

Nuclide Released	Whole Body Dose (man-rems)	Critical Organ	Dose to Critical Organ (organ - rems)
^{99}Mo-^{99m}Tc	7.9×10^{-4}	Lungs	0.037
^{125}I	3.4×10^{-3}	Thyroid	1.6
^{131}I	5.0×10^{-3}	Thyroid	2.7
^{57}Co	5.2×10^{-4}	Lungs	0.057
^{226}Ra	460	Bone	640.

C. Spectrum of Radiological Consequences Resulting from Air Transport of Selected Radioisotopes

In any accident environment there is a spectrum of consequences resulting from accidental releases. When accident severity is plotted as a function of the probability that that accident or more severe accidents would occur, a curve called a risk spectrum curve is formed. The data in the previous section can be used to construct such a curve for the air cargo environment described in the previous subsection. It is then possible to construct a curve showing the anticipated effect of the NPRM. The major effect of the NPRM, from the standpoint of the accident environment, will result from the elimination of radioactive materials with half-lives greater than 30 days. However, it is noted that the number of packages that may be loaded on one aircraft is increased by the lateral "spacing out" provision of the proposed rule making. This decreases the number of flights required to transport a given amount of radioactive material. Thus it will tend to decrease the likelihood of radioactive material being aboard an aircraft which is involved in an accident but increase the consequences proportionately. This effect was not included in the evaluation. It would change the shape of the risk spectrum but would not affect the risk.

The risk spectrum curves are constructed by developing equations for the probability of a specific release and the estimated consequences of that release. The equation for the dose is:

$$D_{n,i,j} = A_{n,i} \, f_{n,j} \, k_n$$

where:

- n is the subscript denoting the nuclide being transported
- i is the index denoting the amount shipped per flight
- j is the index denoting the multiplicity of releases
- A is the amount shipped in curies
- f is the release fraction
- k is the dose conversion factor to relate a release of one curie to the population dose expressed in either man-rems or organ-rems
- D is the population dose.

The equation for the corresponding release frequency is:

$$P_{n,i,j} = P_a N_{n,i} P_{f_{n,j}}$$

where

- P_a is the probability of an accident during an air shipment of radioactive material, one accident/91,000 flights
- $N_{n,i}$ is the annual number of radioactive material shipments containing amount $A_{n,i}$
- $P_{f_{n,j}}$ is the estimated frequency of the j^{th} fractional release of the n^{th} nuclide initiated by an air transport accident.

The risk spectrum curves are constructed from the pairs of values $(D_{n,i,j}, P_{n,i,j})$. The procedure is to arrange the pairs of numbers in order of decreasing values of $D_{n,i,j}$ and then sum all the values of $P_{n,i,j}$ which are associated with the values of D which are greater than or equal to $D_{n,i,j}$.

Risk spectra for the case representing the existing shipping conditions and the case representing the NPRM with the 30-day half-life restriction are shown in Figure V-1. The NPRM case was generated by dropping ^{125}I (60-day half-life), ^{57}Co (271-day half-life) and ^{226}Ra (1600 year half-life) from the analysis. It can be seen that the anticipated influence of the NPRM on the accident risk spectrum is small. There is a slight decrease in the release frequency because fewer packages are transported. Elimination of the greater than 30-day half-life radioisotopes results in a small decrease in the potential dose to the population from more severe accidents. These conclusions are reinforced by the fact that some packages banned on passenger flights will undoubtedly be shipped on cargo flights. Therefore the reduction in air accident risk will be even less than indicated. With the uncertainties in the analyses caused by data inadequacies there is no evidence that the NPRM will significantly affect the accident risk in the transport of radioactive materials by air.

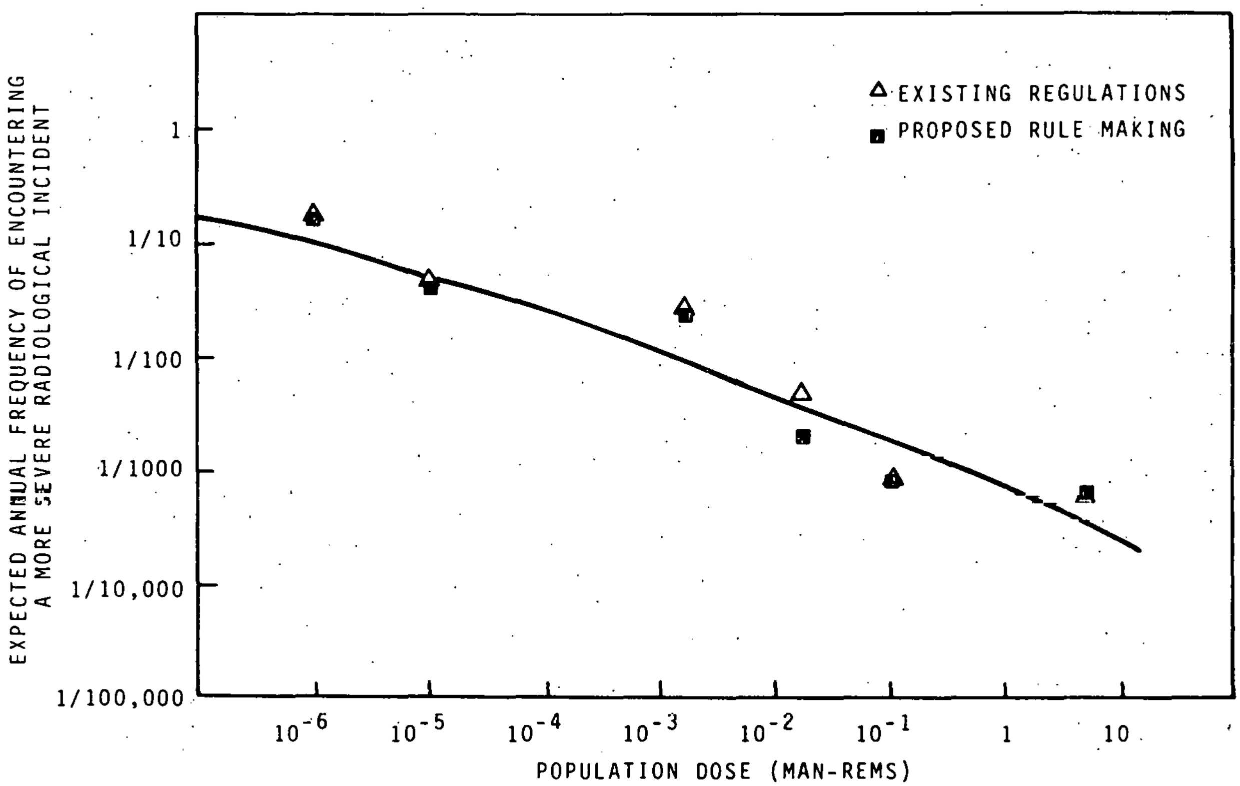

FIGURE V-1. Risk Spectrum Curve for Transport of Radioactive Materials on Passenger Aircraft

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VI. SHORT-TERM USES OF THE ENVIRONMENT VS. LONG-TERM ENVIRONMENTAL LOSSES

The principal long-term environmental impact resulting from the proposed activity is the potential accrual of genetic defects in the population as a whole, induced by radiation from the transport of radioactive packages. A certain number of genetic defects are normally present in the population as a result of the effects of natural background radiation and nonradiation mutagens. The inventory of genetic defects is maintained at an equilibrium level by the continual disappearance of defective genetic material by the reduced viability or fertility of bearers. The long-term effect of the proposed rulemaking will consequently be the upward or downward adjustment of the existing equilibrium level by the increase or decrease in radiation dose to the population.

The long-term impact may be quantified by applying the BEIR Committee estimated cost of future ill health resulting from radiation induced genetic damage. The BEIR report[1] estimated a cost of $12 to $120 in future ill health effects per man-rem increase in radiation exposure. Applying the most conservative value, $120/man-rem, to the annual collective doses to the flying population (Section IX Table IX-20), gives cost estimates of future ill health attributable to long-term genetic effects. Resulting costs range from approximately $80,000 annually for the alternative limiting package TI to 1, to approximately $230,000 annually for the alternative limiting package TI to 10. The 3 TI package limit (the proposed rulemaking) would result in estimated annual future costs of approximately $130,000. Prohibiting the transportation of radioactive packages on passenger aircraft would essentially eliminate these future costs.

Future costs in terms of genetically induced ill health also accrue from the occupational exposure of those who manufacture, distribute and administer radiopharmaceuticals. Since existing data are insufficient to permit estimates of the exposure of these personnel, assessment of the overall long-term impact of the nuclear medicine program is not possible at this time.

Principal benefactors of the proposed action are individuals whose health is maintained or restored by the use of nuclear medicines. This benefit can be considered as short-term if it is argued that future environments are essentially unaffected by the welfare of any one individual in the present. A counter-argument could be advanced, however, that certain individuals can be responsible for intellectual, cultural or physical achievements of lasting and singular importance which would be foregone by the premature death of these individuals. If this latter argument is accepted, the use of nuclear medicines can provide long-term benefits potentially compensating for associated long-term environmental impacts.

Foreclosure of Options

Adoption of the proposed regulations will not impose permanent commitments on society. The adopted regulations can be revised at any time to reflect the then-current needs and values of society. Revision is advisable if either transportation patterns or the number of packages being shipped changes significantly.

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VII. IRREVERSIBLE OR IRRETRIEVABLE COMMITMENTS OF RESOURCES

The proposed action is not expected to directly subject any natural or cultural environmental resources to irreversible damage or irretrievable loss. The only resource which will be significantly affected if an alternative to the proposed action is adopted is lead consumption. Lead is used as shielding material for radioactive packages.

The proposed maximum package TI of 3 will not alter lead consumption since the industry is already meeting this standard. Increased consumption of lead for shielding would result if a package TI limit of 1 were adopted. Conversely, adoption of package TI limits of either 5 or 10 would result in decreased consumption of lead for shielding purposes. The projected incremental changes in lead consumption are as follows for the package TI limits considered:

TI Max = 1 . . .	400 ton annual increase
TI Max = 3 . . .	No change
TI Max = 5 . . .	690 ton annual decrease
TI Max = 10 . .	910 ton annual decrease

Several manufacturers encourage voluntary return of depleted technetium generators by paying the return shipping cost of spent generators. Two manufacturers who were queried experienced recovery rates of 25% and 50% respectively. Assuming an average return rate of 35%, the differential annual consumption of lead becomes:

TI Max = 1 . . .	260 ton annual increase
TI Max = 3 . . .	No change
TI Max = 5 . . .	450 ton annual decrease
TI Max = 10 . .	590 ton annual decrease

The proposed alternative limiting package TI to 3 will produce no change in the current consumption of lead for shielding. The 5 TI and 10 TI alternatives would result in a net decrease in lead consumption. The 260 ton annual increase in consumption projected for the 1 TI alternative represents what is considered to be an insignificant proportion of the annual domestic consumption of lead (less than 0.02% of 1970 consumption).[1] Moreover, it is probable that a substantial proportion of depleted generator shields are recycled locally as scrap, although some are disposed of as essentially irretrievable solid waste. Continuing increases in the price of lead plus maintenance of return incentives by manufacturers should contribute to a reduction in the amount of shielding lead lost as solid waste.

REFERENCE

(1) Bureau of Mines, Minerals Yearbook, Vol. 1. U.S. Department of Interior, Washington, D.C., 1970.

VIII. ALTERNATIVES TO THE PROPOSED ACTIONS

The alternatives to the NPRM need to be consistent with the objectives discussed in Section III(B). As noted there, the two specific objectives for this rulemaking are to limit the collective dose to an acceptable level and to ensure that the probability of an individual receiving in excess of the FRC recommended limit of 500 mrem/year is remote. Four categories of changes in the existing regulations were identified in Section III:

1. Changes which reduce the radiation level at locations occupied by passengers and crews.
2. Changes which prohibit the unnecessary shipment of certain radioactive materials on passenger aircraft.
3. Changes which reduce the likelihood of improper storage of radioactive material aboard aircraft.
4. Changes which encourage shipment on freighter aircraft rather than on passenger aircraft.

Two broad groups of alternatives are analyzed: alternatives for passenger flights, and alternatives for cargo-only flights. Within each group, various alternatives in each of the four categories are analyzed. Table VIII-1 lists the alternatives to the NPRM which are discussed in this impact statement. The existing and proposed regulations were summarized in Table III-1. A detailed cost-benefit analysis of the maximum package TI alternatives is made in Section IX. A comparison of the package TI alternatives and other alternatives using both quantifiable and unquantifiable criterion is presented in Section X. An introductory discussion to the alternatives follows in the remainder of Section VIII.

A. PASSENGER AIRCRAFT

1. Radiation Level at Seat Height

The separation table in 14 CFR § 103.23 of the regulations determines the maximum radiation level at seat height. Under the existing regulations the maximum level is about 4 mrem/hour. Under the proposed regulations the maximum level will be approximately 2 mrem/hour. The alternative considered in Section X is 0.5 mrem/hour. This alternative was proposed in the EPA[1] report.

TABLE VIII-1: Alternatives to the Proposed Actions

	Alternatives Considered
Passenger Aircraft	
Radiation Level at Seat Height	• Status Quo (~ 4 mrem/hr) • 0.5 mrem/hr
Package TI Limit (Maximum)	• 10* • 5 • 1
Half-Life Restriction	• Status Quo (no restriction) • 7 days (maximum) • 60 days (maximum)
Lateral Spacing Out	• Status Quo (no provisions for) • With Limit on Maximum TI
Carriage of Radioactive Materials	• Prohibit
Method of Exposure Control	• Set Radiation Level Limit
Cargo Aircraft	
Maximum TI on Aircraft	• Status Quo
Radiation Level in Cockpit	• Status Quo • Reduced

*Existing regulation.

A change in the allowable radiation level at seat height will not necessarily affect collective population dose. The effect of the change could be to simply cause an increase in the RTF (i.e., cause more flights to carry radioactive material). A change will affect the maximum exposure to individuals in select exposure groups and the number of people in these groups. Potential effects are discussed in Section X.

2. Maximum Package TI

The alternatives to the proposed maximum package TI of 3 which are analyzed are 10 TI, 5 TI, and 1 TI. The 10 TI alternative would normally not be considered as an alternative because it is the existing regulation. However, because of the radiopharmaceutical industry's self imposed limit, possibly imposed in anticipation of the ALPA embargo, the current effective TI limit is 3. Three TI is thus the proposed TI limit, as well as status quo limit.

The package TI limit is highly related to the radiation level at seat height. On aircraft with relatively small cargo hold depth, it may only be possible to place one radioactive package on the floor of the cargo compartment and still meet the radiation level criterion at seat level. In order to avoid transportation disruptions, it is desirable to specify a maximum package TI such that any package can be carried on any commercial jet aircraft currently used in the U. S. This has been done for the proposed TI limit of three and was also done in the JCAE[(2)] and EPA reports. The proposed 3 TI limit corresponds to a maximum radiation level of approximately 2 mrem/hour for a DC-9, the aircraft with the smallest cargo depth.

The 1 TI alternative is based upon the JCAE and EPA reports. The JCAE report recommends a maximum package TI of one. This recommendation was apparently based upon another JCAE recommendation that the maximum radiation level anywhere in the passenger compartment should not exceed one. This level was recommended because the Panel felt it to be consistent with the NRC regulations for dose rate in unrestricted areas (10 CFR § 20.105) and because it was felt to be as low as practicable. The EPA report recommends that the maximum radiation level at seat height be limited to 0.5 mrem/hour. For a DC-9 this corresponds to a maximum package TI of one. The selection of the 0.5 mrem/hour exposure level was also based upon a curve relating incremental manufacturing and shipping cost per package to seat level dose rate. A 500 mCi technetium generator stowed on the cargo floor of a DC-9 aircraft was used as the basis of the curve. The incremental cost rapidly increased for radiation level limits below 0.5 mrem/hour.

The 5 TI alternative is based on a proposal made by a group of 21 producers of radioactive material who are members of the Atomic Industrial Forum.(3)

As discussed in Section IV, reduction in the maximum package TI will not necessarily reduce the annual collective exposure of passengers and flight crews, nor the maximum radiation level at seat height. The annual collective exposure is nearly directly proportional to the total TI transported annually on passenger aircraft. Manufacturers could meet a new TI limit simply by reducing the quantity of radioactive material shipped within a package and shipping more packages. In this case, the total TI transported annually, and hence the annual collective dose, would not change. However, if the manufacturers add shielding to meet the new standard, the annual collective exposure will be reduced. In Section IX it is assumed that in most cases shielding will be added and that packages will not be subdivided. There is strong evidence to support this assumption because the manufacturers have increased the shielding on packages in order to meet conditions which effectively reduced the maximum TI from 10 to 3.

Reducing maximum package TI will not necessarily reduce the maximum radiation level at seat height. Additional packages could be placed at one cargo floor location, maintaining the previous radiation level. In order to change the radiation level, separation requirements must be changed.

3. Half Life Restriction

Presently, there are no restrictions based on half life for shipment of radioactive material. The proposed rules will prohibit the shipment on passenger aircraft of Category II and III materials with half lives greater than 30 days and less than 10^8 years. The reason for this rule is to reduce the shipment of material on passenger aircraft which decays slowly enough to be feasibly shipped by other means. Effects of the rule will be reduction of both the collective dose to airline passengers and crew and the maximum exposure to individuals in the select exposure groups.

Alternatives to the prohibition of shipment of Category II and Category III packages of radioactive materials having a half life greater than 30 days that are considered are: 1) the status quo (i.e., no restriction on half life), 2) the proposed rule except with a half life limit of seven days, and 3) the proposed rule except with a half life limit of 60 days. The latter two choices were introduced to evaluate the sensitivity of the effect of a half life restriction on the half life limit selected.

4. Lateral Spacing of Packages on Passenger and Freighter Aircraft

The separation table in the existing regulations is interpreted as if all radioactive packages were located in one group on the cargo floor. Consequently, it is not currently possible to place the maximum allowable 50 TI on a passenger aircraft. The proposed rules provide for a system of lateral spacing of packages whereby it will be possible to place up to 50 TI on some aircraft. This proposed rule and the alternative of no lateral spacing out are discussed in Section X.

The effect of lateral spacing will be to leave collective dose unchanged. It will also decrease somewhat the maximum radiation exposure of more highly exposed passengers by spreading the radiation dose among more passengers.

5. Carriage of Radioactive Materials

Brief consideration is given in Section X to the implication of prohibiting the transportation of radioactive material by passenger aircraft.

6. Methods of Exposure Control

The existing and proposed regulatory framework leave little decision making to the airlines. An alternative method of regulation would be to set permissible aircraft cabin radiation levels and let the airlines decide how to locate packages to stay within the designated limit. The implications of this alternative are also discussed in Section X.

B. CARGO-ONLY AIRCRAFT

The proposed rules will increase the total TI which can be carried on freighter aircraft from 50 TI to 200 TI. This change is proposed to encourage more use of cargo-only flights to ship radioactive material.

One alternative to the rule limiting the maximum TI carried on a cargo aircraft to 200 is considered. This is the status quo (i.e., a maximum TI of 50).

The radiation level in the cockpit of cargo-only aircraft will be reduced under the proposed rules. The existing radiation level and a further reduction are considered as alternatives in Section X.

REFERENCES

1. U.S. Environmental Protection Agency Office of Radiation Programs, Considerations for Control of Radiation Exposures to Personnel from Shipments of Radioactive Materials on Passenger Aircraft, December 1974 (hereinafter referred to as the EPA report).

2. Transportation of Radioactive Material by Aircraft, Report No. 1 of the Special Panel to Study Transportation of Nuclear Material for the Joint Committee on Atomic Energy, September 17, 1974 (hereinafter cited as the JCAE report).

3. Statement of Dr. J. Calvin Brantley, Vice President, New England Nuclear Corporation, in the Transcript of the Public Conference on Transportation of Hazardous Materials in Air Commerce, p. 171. The conference, sponsored by the Department of Transportation, was held in Washington, D.C., on October 2-3, 1974.

IX. COST-BENEFIT ANALYSIS OF PASSENGER AIRCRAFT ALTERNATIVES

A. SUMMARY

A cost-benefit analysis of 10 TI, 5 TI, and 1 TI package limits is made on an incremental basis using the proposed rule (and the existing effective maximum TI) of 3 as a base case.

Costs are estimated by considering the charges in shielding, transportation, and handling costs resulting from adoption of each alternative TI. Benefits are estimated by first predicting the number of health effects for each TI limit, using data in the BEIR report. Estimated health effects are assigned values using information on the value of saving a statistical life. Benefits are derived by multiplying the number of lives saved times the value of saving a statistical life.

The analysis in Section IX is based on reduction of collective radiation dose to the flying population. Dose to select individual is also important and is considered in Section X.

Results of the cost-benefit analysis indicate that if collective dose is used as the principal criterion for selecting maximum package TI, the 10 TI limit is preferred. However, other considerations, discussed in Section X warrant the selection of a more stringent package TI limit than suggested by the benefit-cost analysis.

B. COMPUTATION OF BENEFITS

Quantifying the benefits to be achieved by reduced radiation exposure in the transport of radioactive material on passenger aircraft is the most difficult aspect of the cost-benefit analysis. Little precedent exists to provide guidance; consequently, the FAA has used what limited data are currently available.

In order to enable cost-benefit calculations, the reduction in exposure to the total passenger population is determined and converted to an approximate dollar value. FAA recognizes that a cost-benefit analysis based solely on population exposure should not be the sole criterion in selecting an appropriate standard. Other factors important to such a decision are the maximum plausible exposure to select groups of passengers and the fact that airline passengers do not necessarily derive any direct benefit from their exposure. These two issues are discussed in Section X.

As noted, very little work on quantifying the value of reduced radiation has been published. The approach used here is to combine information from several sources on the value of preventing a statistical death together with information from the BEIR report on the somatic and genetic health effects of low level radiation. This information enables computation of the dollar worth of eliminating a man-rem of exposure. For comparison, the recently announced (40 Federal Register 19442, May 5, 1975) NRC worth of $1000/man-rem is also utilized in the analysis.

1. Estimation of Benefits from Reduced Radiation Exposure

The principal benefit to be gained from a reduced radiation exposure level in aircraft passenger compartments is a potential reduction in radiation induced somatic and genetic health effects. The benefit derived by patients utilizing radiopharmaceuticals is not considered in the analysis because it is assumed that the radiopharmaceuticals will continue to reach hospitals, at higher cost, under reduced exposure levels as long as carriage on passenger aircraft is not absolutely prohibited.

Data on the values of saving a statistical life were compiled by Otway.[1] Table IX-1 is adapted from his paper. Several more recent sources have been added. The first four values in the table were converted to life value estimates using a rather high mortality probability of 10^{-3} per man-rem. A smaller probability, resulting in a smaller dollar value, would be justified by the BEIR report.

It is important to recognize that the values in Table IX-1 represent estimates of the value of saving a statistical life. Society may be willing to spend considerably more to save an identifiable life (e.g., a lost child) than to save a statistical life.

TABLE IX-1. Estimates of the Value of Saving a Statistical Life

Source	Estimate
Cohen[2]	$250,000
Hedgran and Lindell[3] (a)	$200,000
Dunster[4]	$ 10,000
Lederberg[5]	$100,000 - $600,000
Otway[1]	$200,000
Mean value of jury awards in wrongful death actions[6]	$ 50,000 - $400,000
Carlson[7]	$ 5,000 - $1,000,000
Fromm[8]	$373,000
Acton[9] (b)	$ 25,000 - $ 43,000
Rice and Cooper[10] (b)	$130,000
Thaler and Rosen[11] (b)	$200,000 (1967 dollars)

(a) Otway reported that the value of $100 per man-rem in the cited source was subsequently increased to $200 per man-rem.
(b) These sources are not in Otway's paper.

Four major approaches have been identified for quantifying the benefits of a program designed to reduce detrimental health effects: "1) explicit statements of politically designated persons; 2) evaluations implicit in past decisions; 3) livelihood--or human capital--measures; and 4) life-saving, or willingness to pay measures."[12] The methods in Table IX-1 appear to be variations of Approaches 2, 3 and 4.

Approach 1 is not likely to be useful because of the difficulty of finding an appropriate person or organization and because of the natural reluctance of such a person(s) to designate a value.

Approach 2 is based upon using the implicit judgments in past policy decisions by the government or by individuals as a basis for quantifying benefits. One difficulty with this approach is the very wide variations in the implicit value of life saved. Carlson's range in Table IX-1, for example, is based upon evaluations showing a value of several thousand dollars for governmental expenditures for highway improvements to approximately one million dollars for an ejection seat in a new fighter-bomber. Thaler and Rosen examined the relationship between wage rates and the risks of occupational deaths. Their research suggests a much smaller range of values than found by Carlson.

Approach 3 approximates the value of saving a statistical life by discounting future earning streams. Fromm and Rice and Cooper utilized this approach. Fromm assigned the present value of an individual's future earnings stream as a minimum value of life to the individual. He supplemented this number with estimates of value to the individual's family, friends, community, employer, the economy as a whole, the government, and air carriers. Rice and Cooper calculated that the present value of lifetime earnings discounted at 4% reaches a maximum of $131,000 for a male between 25 and 29.

Approach 4 was utilized by Acton. He queried several population samples for the amount they would be willing to pay for a program (e.g., ambulance service) which would reduce their probability of dying from a heart attack. The responses imply that large groups would be willing to pay from $28,000 to $43,000 for each life saved by the program.

All of the estimates in Table IX-1 suffer from the difficulty of quantifying such an elusive and metaphysical concept as the value of saving a statistical life. Nevertheless, the fact that most estimates are within an order of magnitude of each other suggests that estimation of an approximate value representing the amount society is willing to spend to save a statistical life is feasible. Unless such a value is selected, cost-benefit analysis of alternative exposure standards is not possible.

For this analysis the FAA has assumed that society should be willing to spend $500,000 to save a statistical life. This number is intentionally chosen to be conservative; it exceeds by a substantial margin most of the values in Table IX-1. A sensitivity analysis using values of $100,000 and $1,000,000 is made later in Section IX for comparison.

2. Quantification of the Health Risk of Radiation Exposure

The $500,000 figure developed in the preceding section, together with data in the BEIR report regarding the health risks of radiation exposure, enables quantification of the benefits associated with reduced radiation exposure. The BEIR report summarizes the known data on both the somatic health effects (i.e., effects on exposed individuals) and the genetic health effects resulting from exposure to low level radiation.

For somatic risk, the BEIR report concluded that cancer mortality is the only health effect which needs to be considered in setting radiation protection standards for the public. The report estimates excess cancer mortality per 0.17 rem per year for the entire U.S. population (assumed in the report to be 200 million persons) to range roughly from 3,000 to 15,000, with the most likely value falling in the range of 5,000 to 7,000.[13] For this analysis the highest (most conservative) figure, 15,000 deaths, will be utilized. The calculation below indicates how the somatic health cost can be computed in terms of dollars per man-rem:

$$\frac{(200{,}000{,}000 \text{ population})\ (0.17 \text{ rem})}{15{,}000 \text{ deaths}} = 2{,}267 \text{ man-rems/death}$$

$$\frac{\$500{,}000\text{/death prevented}}{2{,}267 \text{ man-rems/death}} = \$221\text{/man-rem}$$

The genetic effect of low level radiation is ill health in future generations. The BEIR report suggests that the future cost of ill health in present dollars caused by one man-rem is between $12 and $120.[14] For this analysis the most conservative figure, $120, is used.

The total health cost as a result of exposure to low level radiation is the sum of the genetic and somatic costs, or $221 + $120 = $341, or approximately $350 per man-rem per year. This number represents an amount which society should be willing to spend to prevent one man-rem per year of radiation exposure. For life saving values of $100,000 and $1,000,000, comparable estimates are $200 and $600 per man-rem, respectively. The NRC value is $1000 per man-rem. NRC has indicated that its value is an interim, conservative value and that the ultimately accepted value may well prove to be less (40 Federal Register 19441).

C. ESTIMATES OF THE COST OF THE PROPOSED ACTION AND ALTERNATIVES

1. Background of Cost Estimates

Principal costs affected by the proposed action and its alternatives are shielding and transportation costs of radioactive products transported by aircraft during some portion of their distribution cycle. Although a wide variety of radioactive products are currently being transported by aircraft, a few products are found to constitute the majority of shipments exceeding a package TI of 1. Two products, ^{99}Mo and ^{131}I, have been selected as the basis of the cost analysis which follows. Prior to the radiopharmaceutical industry's reduction of package TI to 3, technetium generators (the principal product containing molybdenum) were the major type of packages with a TI exceeding 3.(15) Iodine-131 contributed about 60% of the nongenerator TI and 75% of the nongenerator packages exceeding an average TI of 1 in the AEC survey of suppliers of radioactive materials.(16) Limiting the cost analysis to ^{99}Mo and ^{131}I products permits a reasonably valid assessment of costs for these two isotopes. Because these isotopes represent such a large portion of products affected by the proposed action and alternatives, it is believed that the resulting costs may be extrapolated to other affected products with reasonable confidence. Although shield attenuation varies considerably among isotopes presently in shipment, ^{131}I is assumed to be a representative isotope for nontechnetium generator packages.

Molybdenum-99

Molybdenum-99 is the parent isotope of the short-lived (6 hr half-life) isotope ^{99m}Tc. ^{99m}Tc is employed as a radioactive label in compounds used for diagnoses of abnormalities and diseases of the brain, bone, liver, spleen and other organs. It is also used in procedures measuring the rate of various bodily functions. Currently, over 90% of nuclear medicine examinations are reported to utilize ^{99}Tc labeled compounds.

Because of the short half-life of ^{99m}Tc, most technetium is supplied to users by means of technetium generators. Generators contain the parent isotope, ^{99}Mo, adsorbed on a column of alumina, which has a high absorbtion capacity for ^{99}Mo but a low affinity for the decay product ^{99m}Tc. Pure ^{99m}Tc is removed by periodic elution. Typical generator construction consists of the alumina column, enclosed in a two-part lead shield. The shield assembly is encased in an outer plastic sheath. The top of the generator assembly is pierced by two ports through which connections to the alumina column are installed. In use, a vial of eluent (sterile physiologic saline solution) is attached to one connection, and a second, evacuated vial is attached to the other connection. Elution proceeds automatically.

Generators are produced in calibrated sizes ranging from 50 to 500 mCi. Calibration is typically established for approximately a week following manufacture, necessitating an initial ^{99}Mo loading of approximately five times calibrated loading.

Generators are packed in shipping cartons equipped with styrofoam inserts. Absorbent material is not used since liquid is not present in the unit except during elution. Elution ports are sealed, however, to maintain sterile conditions. A set of eluent charged vials and evacuated collection vials is normally packed with the generator. Supplemental sheet lead shielding is occasionally employed with larger generator sizes.

Iodine-131

Iodine-131 compounds were extensively used for brain, lung and other scanning until about 1968 when use of ^{99}Tc labeled compounds became popular. Although ^{99}Tc compounds have been substituted for ^{131}I for many diagnostic procedures, ^{131}I is still used for thyroid uptake studies as well as hyperthyroidism and thyroid carcinoma therapy. Informal discussions with manufacturers and users have produced conflicting evidence as to the recent trend in ^{131}I usage. The continued substitution of "cold kits," employing technetium labeling, for ^{131}I compounds should contribute to a continuing decline in the use of ^{131}I. However, increases in numbers of patients using nuclear medicine services has evidently maintained a constant or increasing consumption of ^{131}I for some institutions.

Iodine-131 compounds are typically provided in liquid or solid (capsule) form in sealed vials or screw-cap bottles containing 1 to 200 mCi of activity. Vials are encased in lead shields ("safes") of appropriate wall thickness, typically varying from 1/8 to 1/2 inch. Safes are packed in sealed containers, equipped with absorbent material for liquid shipments. The sealed containers are then loaded into shipping containers equipped with cardboard dividers or styrofoam inserts capable of accommodating from one to several shielded vial assemblies. Loading of the shipping container depends on the customer's order and cumulative package radiation level. It is reported that most shipments contain a single vial.

2. Annual Shipments

Technetium Generators

A survey of the literature produced conflicting evidence for basing estimates of the number of technetium generators presently being shipped. A 1973 confidential survey of manufacturers conducted by the Society of Nuclear Medicine (SNM)[17] reported shipments of 60,949 units in 1970, 70,348 units in 1971, and 79,185 units in 1972. The AEC survey of suppliers, including all manufacturers of technetium generators, recorded the shipment of 1,302 packages containing from 0.1 to 3 Ci ^{99}Mo within a 7-day period in 1973. Assuming that all of these packages represent technetium generators and that shipments are the same from week-to-week, an annual total of approximately 70,000 units is indicated for 1973.

Estimates of the recent growth rate of the generator market are equally diverse. Those obtained during an informal telephone survey of manufacturers and users ranged from "stable" to 15% annual growth. A projection of the SNM figures for 1970-1972 gives approximately 11%, 9% and 7% annual growth rate for 1973, 1974 and 1975 respectively.

Technetium generator production through 1975 is projected in Figure IX-1 using both the SNM and AEC survey results for base values. Stable, 10% and 15% growth is projected, as well as the decreasing growth rate extrapolated from the SNM survey data. Based on these projections, a reasonable estimate for 1975 production is about 95,000 units.

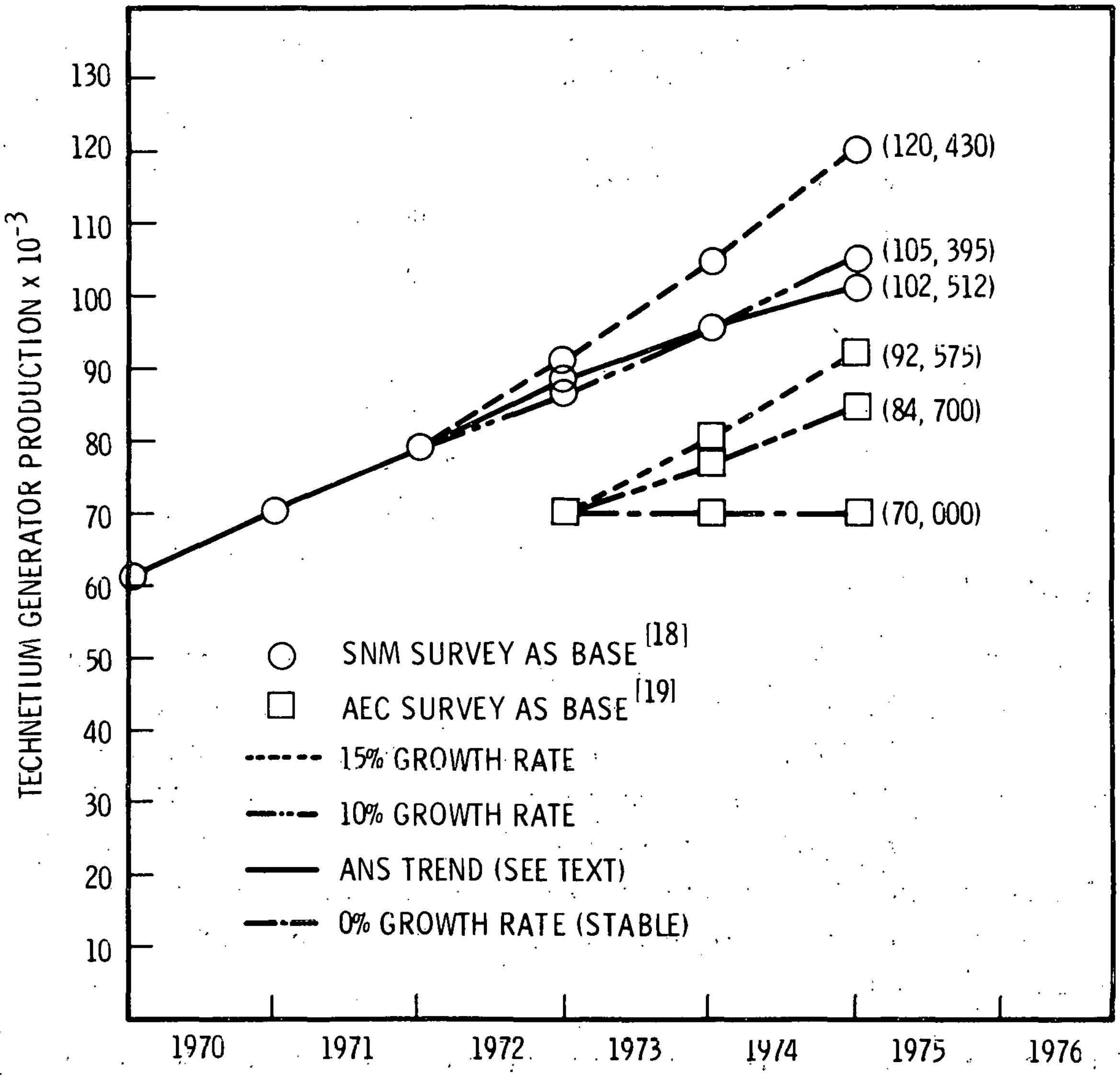

FIGURE IX-1. Projected Technetium Generator Production Through 1975

Technetium generators are produced in calibrated loadings of 50, 100, 150, 200, 300, 400 and 500 mCi. The 150 mCi units are produced by one manufacturer only and will be lumped with 100 mCi units in the ensuing discussion. Market share information for the various generator sizes was obtained from each manufacturer of generators. Using total generator market share of each manufacturer, as estimated by each manufacturer, estimates were made of annual generator production by calibrated loading. Estimates are tabulated in Table IX-2 based on annual production of 95,000 units.

TABLE IX-2. Estimates of 1975 Technetium Generator Production by Calibrated Loading

Calibrated Loading (mCi)	Estimated Market Share	Annual Production
50	21%	20,000
100	30%	28,000
200	25%	24,000
300	16%	15,000
400	5%	5,000
500	3%	3,000

Nongenerator Packages

Total annual shipments of radionuclides (generators and nongenerators) were estimated by the Atomic Industrial Forum[20] as 525,000 to 550,000 packages in 1973. A 10.5% annual growth rate in the number of packages shipped was observed during this same survey. Using a figure of 550,000 packages for 1973, and applying a 10% annual growth rate, an estimated 670,000 packages should be shipped in 1975. Subtracting the estimated 95,000 technetium generator shipments gives 575,000 shipments of nongenerator radionuclides.

The most restrictive alternative considered in this evaluation would limit maximum package TI to 1; consequently, nongenerator packages exceeding a TI of 1 are of particular interest for purposes of this assessment. An estimate of nongenerator packages exceeding 1 TI can be made using the AEC survey of suppliers. For this estimate ^{99}Mo packages between 0.1 and 3 Ci are assumed to represent generators and are thus excluded. It was also assumed that the survey, which included an estimated 75% of packages shipped during the 1 week survey period, was representative of all nongenerator packages shipped both during the week of survey and for the year. Employing these assumptions, nongenerator packages exceeding an average of 1 TI constituted approximately 25% of nongenerator packages shipped, including exempt shipments. (Nongenerator packages exceeding 1 TI are assumed not to exceed 3 TI since at this time of the survey it was reported that almost all packages exceeding 3 TI were technetium generators.[21]) This percentage was applied to the preceding estimate of nongenerator packages shipped to obtain estimated numbers of packages shipped, by package type, summarized in Table IX-3.

TABLE IX-3. Estimated Numbers of Radioactive Packages Shipped, by Package Type, for 1975

Package Type	Estimated Shipments, 1975
Nongenerators, TI 0-1	430,000
Nongenerators, TI 1-3	145,000
Technetium Generators	95,000
Total Packages	670,000

3. Patterns of Distribution

Radiopharmaceuticals comprise approximately 95% of the packages of radioactive material presently being shipped in the U.S.[22] These products are produced by a relatively small number of manufacturers and are distributed to thousands of users, primarily hospitals and independent clinical laboratories, throughout the country. Manufacturers customarily distribute to a national market.

Constraints on distribution include chemical instability of certain labeled compounds and short half-lives of certain radionuclides.

Temperature control of chemically unstable shipments is typically accomplished by packaging in dry ice with styrofoam insulation. Materials with a short half-life require rapid delivery, or alternatively, large initial loadings. Products exhibiting either of the foregoing characteristics require a reliable transportation system capable of rapid delivery of large numbers of packages to diverse destinations. Numerous users of radiopharmaceuticals are located in remote or isolated areas, necessitating intermodel transfers of packages. This increases the necessity for reliable well-controlled service.

Available transportation systems providing service of adequate speed and reliability for transport of radiopharmaceuticals include commercial air cargo service (via either passenger or freighter aircraft), "small package" airlines, and surface package delivery services. Air parcel post is employed for shipments meeting Postal Service regulations for radioactive materials.

Scheduled air cargo service using both passenger and freighter aircraft provides rapid, convenient and reliable delivery to approximately 500 airports throughout the U.S. Airport pickup and delivery is typically by local package delivery service. Most packages shipped as air cargo are transported on passenger aircraft apparently due to the greater frequency of service and larger number of airports served. It was reported by shippers that use of freighter aircraft is declining due to impact of the "energy crisis" and to the substitution of wide-bodied passenger aircraft.

"Small package" airlines, specializing in the transport of packages weighing less than 100 lb, are expanding service throughout the U.S. Certain flights are dedicated to radiopharmaceuticals and special permits allowing carriage of greater than 50 TI have been issued for flights transporting large quantities of radioactive materials. Small package airlines may offer local pickup and delivery using company-owned vehicles. Advantages of this service include rapid delivery to airports of all sizes as well as enhanced control and flexibility afforded by a single carrier and sole-use vehicles.

Delivery via all-surface transportation is generally employed for regional distribution within distances of 300 to 400 miles from point of manufacture or from intermediate destination airports. Surface delivery over distances exceeding 1,000 miles is routinely employed by at least one manufacturer of radiopharmaceuticals. Surface transportation services are generally supplied by common carriers. Sole-use vehicles are employed where carriage of a total TI in excess of 50 is desirable. Final delivery to users may be via local package delivery service or even taxicab. Surface transportation can provide the advantage of direct delivery to user without intermodal transfer. Sole-use vehicles enhance control and provide scheduling flexibility.

Packages shipped by U.S. Postal Service air parcel post are limited to quantities of 1 mCi or less for common radionuclides.[a] Air parcel post

(a) Applicable Postal Service regulations (from U.S. Postal Services Publication G, Radioactive Matter, April 1971):

B. Authorized mailable radioactive materials include only those which are classified as "small quantities" of radioactive materials or "radioactive devices", as prescribed in 49 Code of Federal Regulations 173.391. These authorized materials, the maximum quantities mailable, and the conditions under which they may be mailed are described below:

1. Small quantities (49 CFR 173.391(a)).

Transport Group (173.389(h)), (173.390)	Maximum quantity per package
I	0.01 millicuries
II	0.1 millicuries
III, IV, V, or VI	1.0 millicuries
VII	25.0 curies
Special form radioactive materials (173.389(g))	1.0 millicuries
Tritium oxide in aqueous solution	0.5 millicuries/milliter (3 curies/package limit)
Fissile radioactive materials (173.389(a))	15 grams*

*The total radioactivity may not exceed either the applicable activity limit for the appropriate transport group or the special form radioactive material limit.

(^{99}Mo and ^{99}Tc are in Transport Group IV; ^{131}I is in Transport Group III.)

is routinely employed for packages not exceeding 5 lb in weight. Service is fast and economical; however, packages are not traceable.

Estimates of the percentage of packages presently shipped by major transportation modes, compiled from information provided by individual manufacturers, are given in Table IX-4.

TABLE IX-4. Percent Radionuclide Packages Shipped by Major Transportation Modes

Transportation Mode	Percent
Passenger Aircraft	45
Freighter Aircraft	15
All Surface	40

Estimates in Table IX-4 represent a recent shift away from use of passenger carrying aircraft. Increased availability of alternative transport modes, enhanced control and scheduling flexibility of carriers offering delivery from point-of-origin to user, and the increased TI capacity of sole-use vehicles are among the reasons for this shift.

Traditional scheduling practice for technetium generators has been to ship generators, calibrated for the following Friday, late Friday evening, or early Saturday morning. Delivery is scheduled prior to the beginning of the Monday workday. This system minimizes initial radionuclide loading since generators calibrated for a post-loading period of 7 days remain in calibration throughout the subsequent work week. Calibration periods of 9 days, with consequently larger initial loadings, would be required if other than weekend delivery were employed. Twice-a-week delivery has been recently offered, with deliveries typically scheduled for Monday and Wednesday. This system can be advantageous for laboratories providing weekend diagnostic services and/or requiring substantial elution capacity for end-of-week workloads.

Most nongenerator packages are shipped daily. Distribution practice is similar to technetium generators with nongenerator packages being shipped in the same vehicles in many cases.

4. Calculation of Cost and Benefit Effects of the Proposed Rule-Making and Alternatives

Alternatives considered for cost benefit analysis include:

- Limiting the maximum package TI to 3 as proposed by the FAA and recommended by the AEC.
- Limiting the maximum package TI to 1 as recommended by the EPA and the JCAE Special Panel.
- Limiting the maximum package TI to 5 (voluntary industry limit prior to the ALPA embargo).
- Limiting the maximum package TI to 10 per present regulations.

Costs considered are those attributable to changes in shielding requirements and transportation costs associated with establishing maximum package TIs at the four limits considered. Adequate information was not available to permit evaluation of total production costs; consequently, costs will be expressed in terms of differential costs between alternatives. Differential annual population dose can likewise be estimated, permitting computation of incremental dollar/man-rem rates between alternatives. Costs and benefits treated in this section will be relative to the 3 TI alternative which is the effective status quo under the current radiopharmaceutical industry limits.

Although it might be desirable to perform cost-benefit analyses for other actions associated with the proposed rulemaking, including limitations on half-life, increases in allowable TI for all-cargo aircraft, spacing-out and revised separation distance requirements; information necessary for analysis of these actions is not readily available. Moreover, the effect of these actions on population exposure are not as potentially significant as the proposed limitations on package TI. Impacts of these actions are evaluated in Section X.

a) Maximum Package TI of 3 (Proposed Rule Making and Effective Status Quo)

Technetium Generators. Generators presently marketed have a package TI limit of 3 and are thus effectively meeting the conditions of the proposed FAA action. Shipping weights and package TIs for generators presently marketed were obtained by telephone survey of manufacturers. These values were weighted by the estimated market share of each manufacturer to obtain composite shipping weights and package TI values, listed in Table IX-5. Shield weights were assumed to be 5 lb less than shipping weights.[a]

TABLE IX-5. Estimated Composite Characteristics for Technetium Generators (TI Max = 3)

Calibrated Loading (mCi)	Package TI	Composite Shipping wt[a] (lb)	Estimated Shield wt (lb/kg)
50	0.9	35	30/13.6
100	1.5	35	30/13.6
200	1.5	45	40/18.2
300	2.4	50	45/20.5
400	2.7	55	50/22.7
500	2.9	55	50/22.7

(a) To nearest 5-lb increment.

Nongenerator Packages. Almost all packages inventoried in the 1973 AEC survey of suppliers which had a TI in excess of 3 were technetium generators. It was therefore assumed that characteristics of nongenerator packages observed in the AEC survey would be representative of conditions

(a) Both English and metric units are employed in the ensuing discussion. Metric units are commonly used in shielding design practice, whereas English units of weight are used by the U.S. transportation industry. Consequently, in this report, shield characteristics are expressed in metric units, which are subsequently converted to English weights for transportation and material cost analyses.

under the 3 TI alternative. Using the manufacturers survey data, average package TI was calculated for nongenerator packages having average TI in excess of 1. Calculations were limited to packages with contents in the categories of 1 to 100 and 100 to 1,000 mCi.[a] (Packages containing in excess of 1,000 mCi constituted a very small proportion of packages shipped; packages containing 1 mCi or less did not exceed an average package TI of 1.) Average curie loadings of 50 mCi and 200 mCi were assumed for the 1 to 100 mCi and 100 to 1,000 mCi classes, respectively. Theoretical shield thicknesses were estimated for 1 to 100 mCi and 100 to 1,000 mCi classes using the ^{131}I data of Brownell[23] for lead shielding. Estimated design thicknesses were obtained by rounding up theoretical thicknesses to the next 0.25 cm increment. Equivalent shield weights were taken from Brownell data to obtain the estimated shield weights shown in Table IX-6.[b]

b) Maximum Package TI of 1

Technetium Generators. Under this alternative it is assumed that generator package TI would be limited to 0.9, providing a 10% margin under the regulatory limit. Theoretical shield thicknesses for a TI of 0.9 were derived for standard generator loadings using Brownell data as were equivalent shield weights for the resulting shield thicknesses. Design weight was estimated as 110% of theoretical weight, rounded up to the next 5-lb increment. Five pounds were added to obtain estimated shipping weights (Table IX-7).

(a) As discussed in Section IX.B.2 nongenerator packages include a great diversity of isotopes and curie loadings. Sixty-six radionuclides were inventoried in quantities greater than exempt in the AEC survey of shippers. Curie loadings of packages in shipment range from fractions of millicuries to packages containing hundreds of curies and weighing 400 lb or more. Iodine-131 in loadings of 1 to 100 mCi and 100 to 1,000 mCi was selected as a typical isotope for this analysis because ^{131}I represents such a large proportion of nongenerator packages inventoried.

(b) Estimates of shield weight are derived using the Brownell conversions from shield wall thickness to theoretical shield weight (Brownell Figure 16 for Tc generators and Figure 19 for ^{131}I). These conversions are plotted using three generator shield configurations and two ^{131}I shield configurations resulting in three curves in Figure 16 and two curves in Figure 19. Shield weights derived in this evaluation are obtained by averaging the extreme (highest and lowest) weights obtained from Brownell Figures 16 or 19, as appropriate.

TABLE IX-6. Estimated Shield Characteristics for Nongenerator Packages Exceeding 1 TI (TI Max = 3)

Package Loading (mCi)	Assumed Average Loading (mCi)	Observed Averaged TI	Equivalent Shield Thickness (cm)	Design Shield Thickness (cm)	Equivalent Shield wt (lb/kg)
1-100	50	1.3	0.85	1.0	4.0/1.8
100-1000	200	2.5	1.25	1.5	7.0/3.2

TABLE IX-7. Estimated Technetium Generator Characteristics (TI Max - 1)

Calibrated Loading (mCi)	Package TI	Equivalent Shield Thickness (cm)	Shield wt (lb/kg)	Shipping wt (lb)
50	0.9	3.1	25/11	30
100	0.9	3.9	35/16	40
200	0.9	4.6	50/23	55
300	0.9	5.0	60/27	65
400	0.9	5.2	65/30	70
500	0.9	5.4	70/32	75

Contrary to present manufacturer practice of producing two or three standard shield sizes for six or more generator loadings, it is assumed that under this alternative that individual shields would be employed for each generator size. This strategy would minimize shipping weight although possibly aggravate assembly problems.

Discussions with customers and freight expediters indicated that 65 to 70 lb is about the maximum package weight which could be conveniently handled during shipment and in typical laboratories. Sixty-five pounds was therefore selected as a maximum practical package weight. This corresponds to the approximate shipping weight of the heaviest generators presently being shipped. Under this constraint the largest generator capable of being practically transported under the 1 TI alternative would be a 300 mCi generator.

A large user of technetium generators was asked whether elimination of 400 and 500 mCi units would present a problem. For this particular laboratory, substitution of two smaller units for a single large unit would present no difficulties. Since 400 mCi and 500 mCi units comprise a small percentage of the total generator market (estimated at 8%, see Table IX-2) it is believed that discontinuing these sizes would have slight impact.

Under the 1 TI alternative, the discontinued 400 and 500 mCi sizes are assumed to be replaced by equivalent numbers of 200 and 300 mCi generators, resulting in estimated annual production (1975 levels) given in Table IX-8.

TABLE IX-8. Estimated Annual Production of Technetium Generators by Calibrated Loading (TI Max = 1)

Calibrated Loading (mCi)	Estimated Annual Production
50	20,000
100	28,000
200	37,000
300	18,000
400	None
500	None

Nongenerator Packages. Under the 1 TI alternative, it is assumed that nongenerator packages presently exceeding a TI of 1 would be reduced to 0.9 TI by increased shielding. Using the average package loading assumed in the preceding section (Table IX-6) and a TI of 0.9, equivalent shield thicknesses were calculated for package loadings of 1 to 100 mCi and 100 to 1,000 mCi. Brownell data for ^{131}I and lead shielding was employed. Estimated design thicknesses were obtained by rounding up to the next 0.25 cm increment. Equivalent shield weights were calculated from Brownell data for ^{131}I lead shields (Table IX-9).

TABLE IX-9. Estimated Shield Characteristics for Nongenerator Packages Presently Exceeding 1 TI (TI Max = 1)

Package Loading (mCi)	Assumed Average Loading (mCi)	Assumed TI	Equivalent Shield Thickness (cm)	Design Shield Thickness (cm)	Equivalent Shield wt (lb/kg)
1-100	50	0.9	1.1	1.25	5.0/2.3
100-1000	200	0.9	1.9	2.0	11.0/5.0

c) Maximum Package TI of 5

Technetium Generators. It is assumed that under this alternative maximum package TI would be limited to 4.5. Theoretical shield weights for a TI of 4.5 were computed from the Brownell data. Design weights were assumed to be 110% of theoretical weight rounded up to the next 5-lb increment. Results are compiled in Table IX-10.

TABLE IX-10. Estimated Technetium Generator Characteristics (TI Max = 5)

Calibrated Loading (mCi)	Package TI	Equivalent Shield Thickness (cm)	Shield wt (lb/kg)	Shipping wt (lb)
50	4.5	1.3	10/4.5	15
100	4.5	2.1	15/6.8	20
200	4.5	2.8	20/9.1	25
300	4.5	3.3	25/11	30
400	4.5	3.6	30/14	35
500	4.5	3.8	35/16	40

As discussed previously, it has been manufacturer practice to use two or three shield weights for the entire line of generator sizes. For this alternative it is assumed that 20 lb design weight shields are employed for 50, 100 and 200 mCi generators, 25 lb shields for 300 mCi generators, and 35 lb shields for 400 and 500 mCi generators. Resulting package TIs were computed for all loadings using Brownell data and shield thicknesses of Table IX-10 for 20, 25 and 30 lb design weight generators. Resulting package TIs are given in Table IX-11.

TABLE IX-11. Estimated Technetium Generator Characteristics Assuming Shield Standardization (TI Max = 5)

Calibrated Loading (mCi)	Package TI	Equivalent Shield Thickness (cm)	Shield wt (lb/kg)	Shipping wt (lb)
50	1.2	2.8	20/9.1	25
100	2.5	2.8	20/9.1	25
200	4.5	2.8	20/9.1	25
300	4.5	3.3	25/11	30
400	3.6	3.8	35/16	40
500	4.5	3.8	35/16	40

Since all shield sizes would be transportable, estimated quantities produced would be similar to quantities of Table IX-2.

Nongenerator Packages. Under the 5 TI alternative it is assumed that nongenerator package characteristics would not differ substantially from conditions observed in the AEC survey of suppliers, summarized in Table IX-6.

d) Maximum Package TI of 10

Technetium Generators. It is assumed that under this alternative maximum package TI would be limited to 9. Theoretical, design and shipping weights for a package TI of 9 were computed from the Brownell data in the manner previously described for a TI of 4.5. Results are compiled in Table IX-12.

It was assumed that standard shield sizes of 15 and 25 lbs would be adopted under this alternative. Resulting package TIs were computed for

TABLE IX-12. Estimated Technetium Generator Characteristics (TI Max = 10)

Calibrated Loading (mCi)	Package TI	Equivalent Shield Thickness (cm)	Design wt (lb)	Shipping wt (lb)
50	9.0	0.6	5	10
100	9.0	1.3	10	15
200	9.0	2.1	15	20
300	9.0	2.6	20	25
400	9.0	2.8	20	25
500	9.0	3.1	25	30

the appropriate loadings, using the Brownell data and shield thicknesses of 3.1 and 2.1 cm for 25 and 15 lb design weight shields respectively. Resulting package TIs are given in Table IX-13.

TABLE IX-13. Estimated Technetium Generator Characteristics Assuming Shield Standardization (TI Max = 10)

Calibrated Loading (mCi)	Package TI	Equivalent Shield Thickness (cm)	Design wt (lb)	Shipping wt (lb)
50	2.3	2.1	15	20
100	4.5	2.1	15	20
200	9.0	2.1	15	20
300	5.4	3.1	25	30
400	7.2	3.1	25	30
500	9.0	3.1	25	30

Quantities produced would be similar to quantities of Table IX-2.

Nongenerator Packages. Under the 10 TI alternative it is assumed that nongenerator package characteristics would not differ substantially from conditions observed in the AEC survey of manufacturers, summarized in Table IX-6.

5. Cost Estimates

Cost estimates of differential manufacturing and shipping costs between alternatives are made in this section. Differential costs are based on the proposed package limit of 3 TI.

a) Manufacturing Costs

Manufacturing costs considered include:

- Cost of shielding material (lead)
- Design and toolup costs for new shields
- Cost of fabrication and handling procedures

Material (lead) costs can be estimated with reasonable accuracy. Other cost categories can only be approximated given available information.

Shielding Costs. An estimate of $0.35/lb for lead was obtained from results of a recent bid for a 2,000 lb lot of pig lead. Resulting costs for shielding material are presented in differential form for the various alternatives in Tables IX-14 (technetium generators) and IX-15 (nongenerator packages).

TABLE IX-14. Estimated Differential Costs for Technetium Generator Shielding Material Relative to 3 TI Limit

Calibrated Loading (mCi)	TI Max = 1			TI Max = 5			TI Max = 10		
	No. Pkgs[(b)]	Lbs Lead[(c)]	$ Cost[(d)]	No. Pkgs[(a)]	Lbs Lead[(c)]	$ Cost[(d)]	No. Pkgs[(a)]	Lbs. Lead[(c)]	$ Cost[(d)]
50	20,000	(5)	(35,000)	20,000	(10)	(70,000)	20,000	(15)	(105,000)
100	28,000	5	49,000	28,000	(10)	(98,000)	28,000	(15)	(147,000)
200	37,000	10	129,500	24,000	(20)	(168,000)	24,000	(25)	(210,000)
300	18,000	15	94,500	15,000	(20)	(105,000)	15,000	(20)	(105,000)
400	0	-	0	5,000	(15)	(26,250)	5,000	(25)	(43,750)
500	0	-	0	3,000	(15)	(15,750)	3,000	(25)	(26,250)
Total			$238,000			$(483,000)			$(637,000)

(a) From Table IX-2
(b) From Table IX-8
(c) Differential shield wt between identified alternative and 3 TI limit; parenthesis indicate load savings relative to the 3 TI limit.
(d) Lead @ 35¢/lb; parentheses () indicate cost savings relative to the 3 TI limit.

TABLE IX-15. Estimated Differential Costs for Nongenerator Shielding Material, 1 TI Alternative Versus 3 TI Limit[a]

Package Loading (mCi)	Packages[b]	Lead[c] (lb)	Cost[d] ($)
1-100	140,000	1	$49,000
100-1000	5,000	4	7,000
Total Cost			$56,000

(a) Conditions of 3 TI limit apply to 5 TI and 10 TI alternatives.
(b) Ratio between 1-100 mCi packages and 100-1000 mCi packages for ^{131}I (approximately 95% and 5% respectively) observed in AEC survey of suppliers is applied to estimated numbers of nongenerator packages exceeding 1 TI (Table IX-3).
(c) Differential weight of lead per package (Tables IX-6 and IX-9).
(d) Lead at 35¢/lb.

Design and Toolup Costs. Design and toolup costs were estimated to be $50,000 per new generator shield and $10,000 per vial shield, amortized over a period of 5 years. Three manufacturers of generators and ten manufacturers of other radiopharmaceuticals requiring changes in shielding were assumed. Resulting costs are presented in Table IX-16.

TABLE IX-16. Design and Toolup Costs for Technetium Generators and Nongenerator Package Shields[a]

Item	TI Max = 1 No. Shields	TI Max = 1 $ Cost	TI Max = 5 No. Shields	TI Max = 5 $ Cost	TI Max = 10 No. Shields	TI Max = 10 $ Cost
Generators	12[b]	120,000	9[d]	90,000	6[c]	60,000
Nongenerators	20[c]	40,000	0	-	0	-
Total Costs		160,000		90,000		60,000

(a) Costs relative to 3 TI alternative amortized over 5 years.
(b) 4 new shields, 3 manufacturers.
(c) 2 new shields, 10 manufacturers.
(d) 3 new shields, 3 manufacturers.
(e) 2 new shields, 3 manufacturers.

Fabrication and Handling Costs. Changes in shield fabrication and handling costs were assumed to approximate changes in cost of material (Tables IX-14 and IX-15).

b) Shipping Costs

Regional Delivery. Twenty percent of all packages were assumed to be delivered to regional users within 300 miles of the point of origin. Delivery was assumed to be by a single carrier. A pickup and delivery charge of $7.75 plus 19¢/lb in excess of 25 lbs was used. This rate is based on rates presently in effect within the State of Washington for delivery of products originating out-of-state. No mileage charge is assessed; rates are good for delivery throughout the state. Cumulative cost for regional delivery is plotted in Figure IX-2.

National Delivery. Eighty percent of all packages were assumed to be delivered to the national market. A delivery process believed to be typical was assumed, including a) pickup at point-of-origin for airport delivery; b) air freight to regional distribution airport; c) off-loading and monitoring (effective July 1, 1975); and d) airport pickup and delivery to users. Airline delivery distance was estimated to average approximately 1,200 miles.[a] Typical costs were estimated to be as follows:

Pickup and Delivery (to airport)	$7.75 + 19¢/lb over 25 lb
Air Freight (1,200 miles)	34¢/lb to 100 lb; $14 minimum
Hazardous Cargo Surcharge	$3/package
Transfer and Monitoring Fee	$5/package
Pickup and Delivery (to customer)	$7.75 + 19¢/lb over 25 lb

(a) The 1,200 mile figure was derived as follows: distances between each of the 4 major originating airports for radioactive shipments and each of the 20 largest U.S. airports (excluding the airport of origin and airports within 300 miles of the airport of origin) were weighted by the associated metropolitan population, and divided by the total metropolitan population served. The weighted distances were summed for each originating airport, and the sum weighted by the proportion of total radioactive shipments shipped from the associated originating airport. Summing the resulting distances gives approximately 1,200 miles.

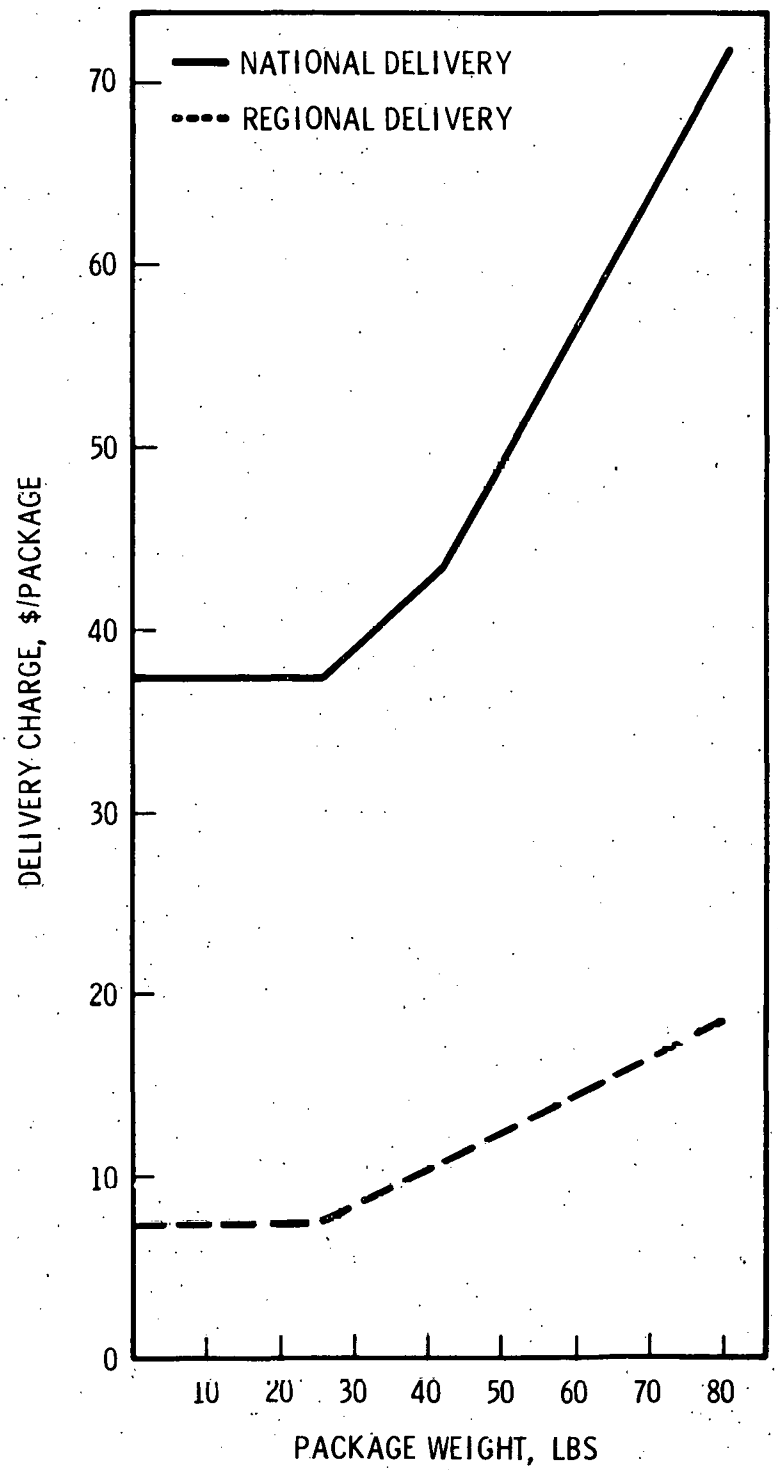

FIGURE IX-2. Estimated Package Delivery Costs

Similar costs were assumed to apply for national delivery of packages using long-distance surface transport. Cumulative national delivery costs are plotted in Figure IX-2.

Estimated Shipping Costs. Estimated annual shipping costs for technetium generators under the proposed rule making and various alternatives are presented in Table IX-17. For nongenerator packages, the projected increases in shield weight (Tables IX-5 and IX-8) are believed to have little effect on shipping costs. Assuming average consignment of two of the heaviest vial/safe assemblies (11 lb each) to a package, it is unlikely that the average package will exceed 25 lb in weight. Resulting effects on shipping costs appear to be minimal since flat rate charges are predicted below 25 lb (Figure IX-2).

TABLE IX-17. Estimated Annual Shipping Costs for Technetium Generators

Calibrated Loading (mCi)	Shipping Weight (Lbs.)	Regional Delivery			National Delivery		
		Packages (20%)	Charge	Total	Packages (80%)	Charge	Total
TI Max of 3							
50	35	4,000	9.65	38,600	16,000	41.30	660,800
100	35	5,600	9.65	54,040	22,400	41.30	925,120
200	45	4,800	11.55	55,440	19,200	46.40	890,880
300	50	3,000	12.50	37,500	12,000	50.00	600,000
400	55	1,000	13.45	13,450	4,000	53.60	214,400
500	55	600	13.45	8,070	2,400	53.60	128,640
Total				207,100			3,419,840
TI Max of 1							
50	30	4,000	8.70	34,800	16,000	39.40	630,400
100	40	5,600	10.60	59,360	22,400	43.20	967,680
200	55	7,400	13.45	99,530	29,600	53.60	1,586,560
300	65	3,600	15.35	55,260	14,400	60.80	875,520
400	-	-	-	-	-	-	-
500	-	-	-	-	-	-	-
Total				248,950			4,060,160

TABLE IX-17. (contd)

Calibrated Loading (mCi)	Shipping Weight (Lbs.)	Regional Delivery Packages (20%)	Charge	Total	National Delivery Packages (80%)	Charge	Total
TI Max of 5							
50	25	4,000	7.75	31,000	16,000	37.50	600,000
100	25	5,600	7.75	43,400	22,400	37.50	840,000
200	25	4,800	7.75	37,200	19,200	37.50	720,000
300	30	3,000	8.70	26,100	12,000	39.40	472,800
400	40	1,000	10.60	10,600	4,000	43.20	172,800
500	40	600	10.60	6,360	2,400	43.20	103,680
Total				154,660			2,909,280
TI Max of 10							
50	20	4,000	7.75	31,000	16,000	37.50	600,000
100	20	5,600	7.75	43,400	22,400	37.50	840,000
200	20	4,800	7.75	37,200	19,200	37.50	720,000
300	30	3,000	8.70	26,100	12,000	39.40	472,800
400	30	1,000	8.70	8,700	4,000	39.40	157,600
500	30	600	8.70	5,220	2,400	39.40	94,560
Total				151,620			2,884,960

Total annual shipping costs for the alternatives appear in Table IX-17. Costs of Table IX-17 are presented as differential costs in Table IX-18, bringing shipping costs into a form comparable to the manufacturing costs previously estimated.

TABLE IX-18. Annual Differential Shipping Costs for Technetium Generators (3 TI Limit as Base)[a]

Alternative	Regional Delivery	National Delivery	Total Shipping Costs
TI Max = 1	$40,000	$640,000	$680,000
TI Max = 5	(50,000)	(510,000)	(560,000)
TI Max = 10	(60,000)	(530,000)	(590,000)

(a) Costs rounded to nearest 10^4 dollars. Parentheses () indicate cost savings.

c) Total Costs

Total annual manufacturing and shipping costs are presented in Table IX-19. Costs are given relative to the 3 TI limit.

TABLE IX-19. Total Annual Differential Costs for All Packages, Relative to the 3 TI Limit[a]

Item	TI Max of 1	TI Max of 5	TI Max of 10
Generators:			
Material	240,000	(480,000)	(640,000)
Design	120,000	90,000	60,000
Fabrication	240,000	(480,000)	(640,000)
Shipping	680,000	(560,000)	(590,000)
Nongenerators:			
Material	60,000	-	-
Design	40,000	-	-
Fabrication	60,000	-	-
Shipping	-	-	-
Total[b]	1,400,000	(1,400,000)	(1,800,000)

(a) Costs rounded to nearest 10^4 dollar. Parentheses () indicate cost savings.
(b) Total costs rounded to nearest 10^5 dollars.

D. ESTIMATES OF THE BENEFIT OF THE PROPOSED ACTION AND ALTERNATIVES

The principal benefit accruing from package TI limitations is reduction of the collective radiation dose to the total flying population. As discussed in Section IV, package TI limitations would not be expected to produce a significant effect on radiation dose to select groups. Moreover, reduction of collective dose can be expected to occur only if package TI is limited by increased shielding. "Splitting" of single packages of large TI into multiple packages of smaller TI will have no effect on the total population dose. As discussed in Part B of this section, it is believed package TI limits would be achieved in practice by shielding modification, except for the alternative limiting package TI to 1. For the 1 TI alternative, the excessive weight of suitable shields for 400 and 500 mCi technetium generators would probably result in discontinuance of these sizes and substitution of equivalent numbers of 200 and 300 mCi units. The effect of this splitting is accounted for in the evaluation which follows:

TI Transported by Various Modes. Estimates of cumulative TI shipped by all transport modes are presented in Table IX-20. The present distribution of shipments among major transport modes was estimated in Section IX.B.3 to be 45% air passenger, 15% air freighter and 40% all-surface. Applying the 45% shipped by air passenger mode to the figures of Table IX-20 provides estimates of total TI shipped aboard passenger aircraft for the proposed rule making and each alternative (second column, Table IX-21).

Collective Dose. Collective radiation dose to the total flying population attributable to the four alternatives can be estimated using the following relationship, developed in Section IV of this report:

$$\text{Collective Dose to Flying Population} = 0.0054 \times \text{TI Transported by Passenger Aircraft}$$

TABLE IX-20. Total TI Transported by All Modes

A. Technetium Generators

Calibrated Loading (mCi)	TI Max = 3			TI Max = 1			TI Max = 5			TI Max = 10		
	Packages	TI	Total TI	Packages	TI	Total TI	Packages	TI	Total TI	Packages	TI	Total TI
50	20,000	0.9	18,000	20,000	0.9	18,000	20,000	1.2	24,000	20,000	2.3	46,000
100	28,000	1.5	42,000	28,000	0.9	25,200	28,000	2.5	70,000	28,000	4.5	126,000
200	24,000	1.5	36,000	37,000	0.9	33,300	24,000	4.5	108,000	24,000	9.0	216,000
300	15,000	2.4	36,000	18,000	0.9	16,300	15,000	4.5	67,500	15,000	5.4	81,000
400	5,000	2.7	13,500	-	-	-	5,000	3.6	18,000	5,000	7.2	36,000
500	3,000	2.9	8,700	-	-	-	3,000	4.5	13,500	3,000	9.0	27,000
Totals			154,200			92,700			301,000			532,000
B. Nongenerator Packages												
TI 0 - 1	430,000	0.16[a]	68,800	430,000	0.16	68,800	430,000	0.16	68,800	430,000	0.16	68,800
TI 1 - 3:[b]												
1-100 mCi	40,000	1.3	182,000	140,000	0.9	126,000	140,000	1.3	182,000	140,000	1.3	182,000
100-1000 Mci	5,000	2.5	12,500	5,000	0.9	4,500	5,000	2.5	12,500	5,000	2.5	12,500
Totals			263,300			199,300			263,300			263,300
Combined Totals			417,500			292,000			564,300			795,300

(a) Average TI for packages less than 1 TI from AEC Survey of Suppliers.

(b) See Table IX-14, note (b) for derivation of numbers of packages.

TABLE IX-21. Estimated Annual Collective Dose to Flying Population[a]

Alternative	Total TI Transported[b]	Annual Collective Dose (man-rem)	Differential Relative to 3 TI (man-rem)[c]
TI Max = 3	190,000	1030	-
TI Max = 1	130,000	700	(330)
TI Max = 5	250,000	1350	320
TI Max = 10	360,000	1950	920

(a) Collective dose estimates do not include potential reductions attributable to proposed limitations on half-life. Effect of the proposed half-life limitations on collective dose is discussed in Section IV.
(b) TI rounded to nearest 10^4.
(c) Parentheses ( ) indicate dose avoided.

E. COST-BENEFIT COMPARISONS

The differential collective doses derived in Section IX.D for the alternative package TI limits must be converted into dollar equivalents in order to compare benefits and costs of each alternative. Dollar values per man-rem avoided were developed in Section IX.A, based on summed somatic and genetic costs of radiation exposure. Statistical life-values of $100,000, $500,000, and $1,000,000 were considered, resulting in equivalent dollar costs per man-rem of $200, $350 and $600, respectively.

The three man-rem costs developed in Section IX.B, plus the $1000 per man-rem value adopted as an interim value by NRC were applied to each differential collective dose to determine the dollar benefits of each alternative. Resulting dollar benefits are presented for comparison in Table IX-22.

TABLE IX-22: Cost-Benefit Comparisons for all Alternatives, Relative to 3 TI Unit[a]

Alternative	Differential Cost (Dollars)	Differential Dose (rem)	Benefit (Dollars)[b] $200/man-rem	$350/man-rem	$600/man-rem	$1000/man-rem	Benefit: Cost Ratio[c]
TI Max = 1	1,400,000	(330)	(70,000)	(120,000)	(200,000)	(330,000)	1:4
TI Max = 5	(1,400,000)	320	60,000	110,000	190,000	320,000	4:1
TI Max = 10	(1,800,000)	920	180,000	320,000	550,000	920,000	2:1

(a) Parentheses ( ) indicate increased benefits or costs saved.
(b) Dollars rounded to nearest 10^4.
(c) For $1000/man-rem benefit.

Examination of Table IX-22 indicates that:

- Adoption of a package TI limit of 1 would result in costs exceeding benefits by $1.1 million annually for the most conservative (highest) estimate of life-value. The corresponding benefit-cost ratio is 0.25 indicating costs of four times benefits.
- Adoption of a package TI limit of 5 would result in a net savings of approximately $1.1 million, again using the most conservative estimate of life-value. The corresponding benefit-cost ratio (with increase in collective dose being considered as "cost" and cost savings considered as "benefit") is approximately 4 to 1.
- Adoption of a package TI limit of 10 would result in a net savings of approximately $0.9 million, using the most conservative estimate of life-value. The corresponding benefit-cost ratio (calculated as in the preceding paragraph) is approximately 2 to 1.

These benefit-cost comparisons suggest that the proposed regulations establishing a package TI limit of 3 exceed the "cost-effective" level by a substantial margin. The "cost-effective" package TI limit based on population dose may be greater than 10, however, as is discussed in Section X of this report, considerations other than cost effectiveness based on collective exposure to the flying population, warrant establishment of a package TI limit below that suggested by this cost analysis. The cost-benefit analyses demonstrate that the proposed rulemaking will operate well within the region where marginal cost increases exceed marginal increases in benefits, and thus can be construed as conservative with respect to minimization of health hazard.

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X. ANALYSIS OF ALTERNATIVE ACTIONS

The various elements of the proposed regulations for both passenger and cargo aircraft are discussed in this section. Separation of the various elements is made for clarity, but it is important to recognize that the impact of the regulations as a whole is the major concern (see Section IV). The population radiation exposure and the maximum select group exposure to passengers and airline crew is not solely dependent on any one of the elements, but rather on the elements in their entirety.

A. PASSENGER AIRCRAFT

The first two alternative categories from Table VIII-1, the radiation level at seat height and the maximum package TI, are analyzed together because they are closely interrelated.

1. Radiation Level at Seat Height and Maximum Package TI

The principal objectives of the NPRM are: 1) to reduce the collective dose to those traveling on aircraft to an acceptable level; and 2) to ensure that the probability of any one individual receiving a radiation dose exceeding the recommended level of 500 mrem/year is remote. These two aspects of the NPRM have the greatest impact on the fulfillment of these objectives.

a. Radiation Level at Seat Height

2 mrem/hr maximum

The proposed minimum spacing requirements between radioactive packages and passengers, crew members and animals (§ 103.21(A) are designed to limit the dose rate at seat level to a maximum of $\sim$2 mrem/hr and an average of 1 mrem/hr. This portion of the NPRM ensures a reduction in exposure rate to individual passengers or crew members, including individuals presently receiving the highest radiation dose. (As discussed in Section IV, effects on collective dose and on the number of individuals receiving the highest radiation dose are not determined by cabin radiation level limits, but by regulations affecting package radiation levels, stowage patterns and number of packages transported aboard passenger aircraft.) As noted earlier, the maximum dose rate possible under existing regulations is about 4 mrem/hr. For an individual occupying a seat with the maximum radiation level, exposure will be reduced by one-half under the NPRM.

For individuals occupying the rear third of the cabin (the portion of the occupied spaces normally experiencing the greatest ambient radiation level under current loading practice), the average dose rate will be reduced from 1.3 to 1 mrem/hr by the NPRM. It should be noted, however, that redistribution of packages to other cargo spaces or to other aircraft, resulting from the revised separation requirements, may increase the ambient radiation level in other occupied spaces, or may increase the RTF.

The maximum exposure conceivably received by a passenger flying 500 hr/year who always sits in the seat with the maximum allowable radiation level (2 mrem/hr) and who always patronizes flights carrying radioactive material (RTF = 1) would be 1 rem/yr. This level clearly exceeds the recommended limit of 500 mrem/year. However, as demonstrated in Section IV, the probability of any individual experiencing conditions leading to a dose greater than 500 mrem/year is exceedingly small.

0.5 mrem/hr Maximum

A 0.5 mrem/hr maximum exposure level is suggested in the EPA report. Adoption of this level would reduce the cumulative exposure of individuals receiving the greatest annual exposure. A person flying 500 hr could receive at most 250 mrem/year.

This alternative is not recommended for two reasons. First it would require a maximum package TI of 1 if packages are to be interchangeable among aircraft. A package TI of 1 was demonstrated in Section IX to have a very low benefit/cost ratio. Secondly, the reduction in risk to individual passengers is felt to be too small to warrant the required expenditure to shield packages to a maximum of 1 TI.

The BEIR report recommends that reduction of small risks should not be required if the funds necessary for reduction could produce greater benefits when spent otherwise. Costs for reducing the exposure level to 0.5 mrem/hr and package TI to 1 are greater than benefits gained.

b. Maximum Package TI

The maximum package TI is closely related to the maximum exposure level at seat height. For this rule making, a maximum package TI of 3 is proposed. A 3 TI package will result in a radiation level of approximately 2 mrem/hr on a DC-9 (see Table X-1). The DC-9 has the smallest vertical cargo clearance of all U.S. manufactured commercial jet passenger aircraft.

The maximum package TI principally influences collective rather than maximum dose to select groups and individuals. As noted in Section IX, an effect on collective dose is not guaranteed by a change in the maximum package TI. The recent experience under the radiopharmaceutical industry's self imposed limit of 3 TI per package strongly indicates, however, that manufacturers will respond to a lower TI limit by adding shielding, thus reducing total collective dose.

The analysis in Section IX suggests that on a benefit/cost basis the maximum package TI should not be reduced from the existing level of 10 TI. In spite of this analysis, the FAA has proposed a maximum TI limit of 3 for two reasons. The first reason relates to package interchangeability among aircraft. If a package TI standard greater than 3 was adopted, certain packages could not be carried on particular aircraft and still meet the 2 mrem/hr cabin radiation limit. For example, no package with a TI greater than 3 could be carried on a DC-9. As discussed later in this section, FAA has determined that a regulatory framework based on spacing distance and maximum package TI is the preferred way to control radiation exposure. In order for this system to function properly, it is necessary to be able to carry packages on any of the passenger aircraft in widespread use.

An additional reason for not selecting a higher maximum package TI standard is the resulting impact on radiation exposure for all of the individuals (e.g., employees of the manufacturers, package handlers, local delivery men, and hospital employees) other than airline passengers who come into contact with the packages. Many of these individuals are monitored for exposure to keep their cumulative exposures within the occupational

TABLE X-1. Maximum Allowable TI in One Location for Various Exposure Limits[a]

Aircraft	Available Separation Distance (cm)[b]	Existing Regulations	Max. Exposure at Seat Level (mrem/hr) 2	1	0.5
B-707	90	5	4	2	1
B-727	115[c]	10	6	3	1
B-737	97[c]	10	4	2	1
B-747	160	30	9	4	2
DC-8	107	10	5	2	1
DC-9	79	5	3	1	1
DC-10	158[c]	30	9	4	2

a. To nearest permitted TI, assumes a package height of 40 cm.
b. Cargo hold height plus passenger cabin floor thickness less 40 cm package height.
c. The forward and aft cargo holds on this aircraft differ in height, distance given is for the cargo hold with the greatest height.

limit. Others, such as airline baggage handlers and loaders, are not monitored.[a] In both cases it is desirable to keep exposures as low as practicable. A higher maximum permissible package TI would increase exposure to all of these individuals.

2. Lateral Spacing Out of Packages Into Predesignated Areas

As discussed in Section IV, there will be two principal effects of this portion of the NPRM. The first will be to spread the radiation dose more uniformly throughout the entire aircraft while maintaining the dose rate for seat height at about 2 mrem/hr maximum and 1 mrem/hr average. The second will be to increase the TI carrying capacity of each aircraft.

a. A recent survey conducted at the Portland, Oregon International Airport indicated that 43 freight handlers and inspectors employed by one airline wearing film badges for 1 month received radiation doses that were below measurable levels. Oregon State Health Division, Transport of Radioactive Materials in Oregon, January 1975.

Spreading the dose more uniformly throughout an aircraft will reduce the total dose of individuals sitting in the rear or smoking sections where most packages are currently placed. The radiation dose rate in the forward two-thirds of an aircraft will be raised somewhat. The total population dose will essentially be unchanged but the maximum annual dose for a frequent traveller will decrease because of reduction in the RTF.

The increased TI capacity of aircraft is shown in Table X-2. The effect of the increased TI capacity of aircraft will be to facilitate somewhat the distribution of radiopharmaceuticals and help insure adequate service to communities with relatively infrequent airline service. The package handling costs associated with the increased capacity are not likely to change significantly. There may be a tendency toward lower handling cost because fewer flights will carry packages. The effect may be offset, however, by the increased cost of placing and removing packages from more than one cargo hold.

TABLE X-2. Maximum Allowable TI Per Aircraft[(a)]

Aircraft	Existing Regulations	Proposed Regulations[(b)]
B-707-120B/320/320B/420	5	15
B-727-100	10	18
B-727-200	10	23
B-737-100	10	10
B-737-200	10	15
B-747/747B	30	42
DC-8-43/55	10	23
DC-8-61/63	10	39
DC-8-62	10	29
DC-9-10/20	5	15
DC-9-30	5	15
DC-9-40	5	21
DC-10-10/20/30/40 (with lower galley)	30	26
DC-10-30 (without lower galley)	30	35

a. Assumes packages are 40 cm on a side.
b. Maximum loading permitted with lateral spacing out.

The principal alternative to this portion of the NPRM is to prohibit lateral spacing of packages. There are several important considerations related to this alternative. First, it would not distribute the radiation dose throughout the aircraft. As a consequence, those passengers sitting in the rear of the aircraft will continue to receive most of the radiation dose. On most flights this means that those in the smoking sections will receive the bulk of the radiation dose. Because of the increased TI per aircraft, permitted by lateral spacing out, the dose rate for cabin attendants on a fully loaded flight could increase somewhat under the proposed rule making (see Section IV).

This alternative could disrupt the existing transportation network because the total number of TIs that could be carried on each flight would be less than currently permitted. For a DC-9 aircraft the allowable TI (at 2 mrem/hr maximum) would be reduced to 3, and for a DC-8, 707, and 727 reduced to 5, 4 and 6, respectively. These values are felt to be sufficiently low to cause some disruption of the distribution process of radiopharmaceuticals. The results of the AEC Airlines Survey(1) indicate that in 1973 26% of the flights carrying radioactive material carried a total of greater than 3 TI; 16% carried greater than 5 TI.

One advantage of not allowing lateral spacing out of packages is a reduced enforcement problem. Enforcement of the spacing out requirements will be difficult. The only feasible approach is to make occasional spot checks. Presumably airlines will mark the cargo holds with a suitable designation to indicate where packages are to be placed. Under the proposed rules these areas must be approved by the FAA Administrator.

The lateral spacing distances were derived to minimize radiation "peaking" due to radiation emitted from packages in different locations reinforcing each other. If the distances are not adhered to, the maximum dose rate at seat height could exceed 2 mrem/hr. The same problem could occur, however, without lateral spacing if more TIs than indicated in Table X-2 are loaded onto the plane in one location. On balance, the FAA believes that with appropriate explanation and spot checking, compliance with the lateral spacing requirements can be achieved and that it will distribute the radiation dose more uniformly in the passenger compartment.

3. Half Life Restriction Alternatives

a. Status Quo (No Restriction on Half Life)

The NPRM prohibits passenger aircraft from carrying any package of radioactive material that bears a "radioactive yellow II" or "radioactive yellow III" label with a specified radioisotope having a half life greater than 30 days, except for:

1. Radioactive materials that are susceptible to rapid chemical deterioration, as evidenced by a shipper's statement to that effect, which must appear with the shipper's certificate;
2. Export shipments as specifically approved by the Administrator; and
3. Radioactive materials having a radioactive half life exceeding 10^8 years.

The half life restriction will ban greater than 50% of the radionuclides inventoried in the AEC Radiopharmaceutical Suppliers Survey(2) tables. Consideration of the number and TI of packages containing radionuclides with greater than 30 day half lives but that could fall into exempt categories leads to the estimate that this portion of the NPRM will prohibit about 8% of all packages shipped and about 5% of the TI that are currently shipped on passenger aircraft. This analysis assumes that half life is currently not a consideration to shippers in selecting transport modes and that the Radiopharmaceutical Suppliers Survey(2) results are reasonably representative of the totality of air shipments.

Thus the status quo for the proposed half life restriction rule would result in the shipment of 8% more packages and 5% more TI on passenger aircraft. Since the 30 day maximum half life limit (with the exceptions given) is sufficiently long that alternate shipping methods can be used without serious deterioration of the product, the status quo results in unnecessary exposure to passengers, cabin attendants and flight crew members. There are, however, instances when product deterioration is not the primary concern. Rapid delivery of chemically stable, greater than 30 day half life radioactive materials may be required to meet urgent needs of the medical profession. The half life restriction would prohibit the use of passenger aircraft for such shipments. Although the NPRM will undoubtedly be an impediment to the rapid delivery of some of these types of shipments which are permitted under the status quo, it is felt that the impact will be small.

The half life restriction of the NPRM will ban the Category II and Category III shipments of some radionuclides (e.g., ^{60}Co, ^{137}Cs, ^{226}Ra, ^{239}Pu) which, on a per curie shipped basis, are among the more hazardous to man if released in an accident. However, the risk of an accident depends on other factors besides the hazard per curie released. These are: 1) the probability of an accident involving the material (this is proportional to the shipments per year) and 2) the number of curies of the material that can be released in an accident (this depends on the physical form of the material and the number of curies per package or per aircraft). The analysis presented in Section V shows no significant difference in the accident risk in the status quo and under the NPRM.

b. Half Life Restriction Other than 30 Days

The 30 day half life limit in the NPRM was selected on the bases that: 1) it would prevent unnecessary shipment of radioactive material on passenger aircraft, thus reducing unnecessary radiation exposure, yet 2) would have minimal impact on the rapid and reliable delivery of radioactive materials. The selection of the 30 day limit does not mean either that 29 day half life shipments on passenger aircraft are necessary or that 31 day half life shipments are unnecessary. It is likely that regardless of what half life restriction is applied, there, at some time, will arise an urgent need for a radioisotope where the delay in having to use an alternate method of transport will be costly in terms of timely diagnosis or treatment of an illness. The effects of selection of either a 7 day limit or a 60 day limit in place of the 30 day limit are considered below.

Using an expedited shipment method it is felt that 7 day delivery could be achieved with acceptable reliability. With a 7 day half life restriction, approximately 70% of the radioisotopes listed in the Radiopharmaceutical Suppliers Survey[2] table would be banned from shipment on passenger aircraft. The ban would affect about 35% of the packages and TI currently shipped. About 80% of the effect will be due to the elimination from shipment of the 8 day half life ^{131}I, a radioisotope commonly used in nuclear diagnostic techniques. Thus, a 7 day half life restriction would be an impediment to the rapid delivery of 35% of the packages currently shipped; including ^{131}I, the most frequently shipped radioisotope listed on the survey. Such a restriction would lead to a significant reduction in the population dose due to the transport of radioactive material by air and would reduce the likelihood of radioactive material being on an aircraft involved in an accident. This restriction, however, would significantly perturb current shipping practices and could result in the shipment of much greater quantities of radioactive material by other transport modes. (If delivery could be made in 1 day by passenger aircraft but would take 7 days via alternate means of transport, the activity shipped would have to be about 70% greater to result in equal strength on the delivery date.) Complete evaluation of this alternative would require detailed analysis of the effect of such a restriction on the overall risk of transporting radioactive materials and on the timely delivery of radioactive materials.

A 60 day half life restriction would affect shipment of about 50% of the radioisotopes listed in the Radiopharmaceutical Suppliers Survey.[2] This is only slightly less than the percentage affected by the 30 day half life restriction. The table contains only four radioisotopes having half lives between 30 and 60 days. However, since one of these is the frequently shipped radioisotope ^{125}I, a 60 day half life restriction would only affect about 1% of the packages and the TI shipped. Therefore, a 60 day half life limit would result in minimal reduction in unnecessary shipments by passenger aircraft, yet could impede the occasional urgent shipment of longer half life materials. The 60 day limit would eliminate Category II and Category III shipments of some of the more hazardous (on a per curie basis) radioisotopes; however, at current shipping levels this would have negligible effect on the accident risk.

Neither alternative half life limit is clearly superior to the 30 day half life limit.

4. Prohibit Shipment of Radioactive Material on Passenger Aircraft

This alternative has been considered and found to be unacceptable. The principal reason is that delivery of radiopharmaceuticals, which comprise the vast majority of the radioactive material shipped on passenger aircraft, to areas of the country not served by cargo-only aircraft would become prohibitively expensive. Much of the area within and adjacent to the Mountain Time Zone falls in this category. If air passenger service to these areas could not be utilized, long distance surface transportation or chartered air cargo flights would be the only means of shipment. Both would be costly, the latter particularly. Surface transportation would also be time consuming and would require short half life radiopharmaceuticals to be manufactured with a much higher activity level.

An additional related reason for not adopting this alternative is that it would interfere with package distribution reliability. Closing out passenger aircraft from the distribution system would eliminate an important and reliable transportation mode for package delivery. In an emergency situation, passenger aircraft may be the only alternative to ensure package delivery.

Even though the alternative of prohibiting shipment of radioactive material on passenger aircraft is not proposed in this rule making, it is recognized that shipment in passenger aircraft should not be encouraged. To discourage use of passenger aircraft the total TI carried on any one aircraft should be reduced as discussed in Subsection 3.

5. Let Airlines Devise Means to Meet Exposure Limits

An alternative to the existing and the proposed regulatory framework would be for the FAA to simply specify an acceptable exposure limit for the passenger compartment (e.g., 2 mrem/hr maximum and 1 mrem/hr average) and let the airlines adopt their own package stowage scheme to ensure compliance with the designated limits. This alternative was considered but is not recommended for several reasons.

The most important reason is the potentially significant disruption of the manufacturing and distribution systems if the airlines adopted different maximum package TI limits.

A second reason is that this alternative would probably result in duplication of effort. If this alternative were adopted, the airlines would likely adopt a spacing and package TI scheme comparable to that proposed herein, otherwise they would be forced to conduct their own analyses to develop alternative regulatory schemes.

One final reason for not adopting this alternative is the enforcement problem it would create for inspectors. Inspection of packages and loading under a variety of regulation schemes could lead to confusion in the enforcement process.

For all of these reasons, the proposed regulatory scheme is deemed preferable to this alternative.

B. CARGO-ONLY AIRCRAFT

1. Radiation Level in Cockpit

The NPRM will reduce the maximum radiation level in the cockpit to about one fourth of the level which could occur under existing regulations. Determination of an acceptable dose rate limit requires consideration of the annual exposure of flight crew members. The latter depends on the radioactive traffic factor (RTF) for cargo-only aircraft; whether or not only a few particular flights carry radioactive material; and the actual radiation level in the cockpit for the various types of all-cargo aircraft. Such information is not currently available. However, the NPRM should result in a radiation level in the cockpit of cargo-only aircraft that is close to the level that will exist in the cabin of passenger aircraft. No further reduction in the radiation level should be attempted prior to evaluation of all-cargo RTF and survey of cockpit radiation levels.

2. Maximum TI on Aircraft

a. Maintain Status Quo

Maintenance of the status quo (50 TI total per aircraft) will not increase incentive to use cargo-only aircraft in place of passenger aircraft for the transport of radioactive materials. By increasing the number of TI permitted aboard cargo-only aircraft to 200, the NPRM should encourage increased use of cargo-only aircraft which would decrease the collective annual dose from the transport of radioactive material by air while having minimal effect on the rapid delivery of the packages.

The maximum dose rate to which flight crews could be exposed is a factor of two higher under the existing regulations than it would be under the NPRM. The maximum dose rate to animals shipped aboard aircraft carrying radioactive material is also a factor of two higher. The maximum exposure of undeveloped film (so marked) would be the same under the status quo and the NPRM.

C. EXPOSURE TO NONBENEFICIARIES

One final factor that merits discussion relates to both collective exposure and the maximum exposure to select individuals and groups. This is the argument advanced in the EPA report: that it is inappropriate to expose nonbeneficiaries (i.e., airline passengers and crew) to the radiation from radiopharmaceuticals. Those advancing this argument suggest that shielding should be increased and that the cost of the shielding should be passed on to the patient, the ultimate beneficiary of the radiopharmaceutical. While the basic philosophy behind this argument is appealing and has been considered in this rulemaking, it does not justify lower exposure and package standards than proposed herein.

If this philosophy were followed to its ultimate, radiation exposure would have to be reduced to virtually nothing. This would require a very large expenditure, and no one, including EPA, has proposed a "zero discharge" standard for radioactive packages. The question then is what is an acceptable exposure level and package TI limit? The FAA is not in a position to give a definitive answer to this question and has relied on the exposure limits set and recommended by NRC and FRC. As Section IV has indicated, the probability that any passenger or crew member will exceed the maximum recommended dose limit, 500 mrem/year, is remote. Moreover, no detectable somatic health effects in humans have been observed at this exposure level.

It is also important to recognize that it is not possible to completely pass the cost of increased shielding on to the patient because of medical insurance. In 1972 it was estimated that 77% of the civilian population had private hospital insurance and 72% had coverage for in-hospital medical visits.(3) Thus in most cases the additional shielding cost will be spread throughout society via the insurance mechanism.

It is not entirely true that airline passengers are nonbeneficiaries from the radiopharmaceuticals. The number of patients benefiting from a nuclear medicine examination was estimated in one study at approximately 7.5 million(4) in 1973 and approximately 10 million in 1974 by another study.(5) These figures suggest that the probability that a passenger will benefit from a nuclear medicine examination at some point in his life is quite high. Thus, the airline passenger as well as the general public are indirect beneficiaries of air transportation of radiopharmaceuticals.

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APPENDIX A. PROPOSED CHANGES IN THE REGULATIONS FOR THE CARRIAGE OF RADIOACTIVE MATERIAL ON AIRCRAFT

The FAA proposes to amend Part 103 of 14 CFR as follows:

1. By amending paragraph (b) in § 103.19 to read as follows:

§ 103.19 Quantity Limitations.

* * * * *

(b) No person may carry a number of packages of radioactive materials that make the total transport index number (determined by adding together the transport index numbers shown on the labels of the individual packages) --

(1) Aboard passenger-carrying aircraft, more than 50.

(2) Aboard cargo-only aircraft, more than 200.

2. By adding a new § 103.20 to read as follows:

§ 103.20 Special limitations: radioactive materials packages on passenger-carrying aircraft.

No person may carry on a passenger-carrying aircraft any package containing radioactive materials that bears a "radioactive yellow II" or "radioactive yellow III" label unless --

(a) The package bears a transport index that does not exceed 0.5 in the case of a "radioactive yellow II" label, or 3.0 in the case of a "radioactive yellow III" label;

(b) The package is carried on the floor of the cargo compartment;

(c) The package is carried on the aircraft in accordance with §§ 103.21(a) or (b), 103.24(c), and 103.31(e); and

(d) The radioisotope specified on the label has a half-life not to exceed 30 days, except --

(1) Radioactive materials that are susceptible to rapid chemical deterioration, as evidenced by a shipper's statement to that effect, which must appear with the shipper's certificate;

(2) Export/import shipments as specifically approved by the Administration; and

(3) Radioactive materials having a radioactive half-life exceeding 10^8 years.

3. By adding a new § 103.21 to read as follows:

§ 103.21 Requirement for carriage of packages containing radioactive materials on passenger-carrying aircraft

(a) No person may carry on a passenger-carrying aircraft any package containing radioactive materials that bears a "radioactive yellow II" or "radioactive yellow III" label closer to a space that is occupied by a person or by an animal than the minimum distance prescribed in the following table. The distance is measured from the package surface nearest the compartment occupied by a person or an animal to the inside limiting surface of the compartment, that is, the surface nearest the space occupied by a person or an animal. If more than one package of radioactive materials is aboard an aircraft, the minimum separation distance for each individual package shall be determined from the following table on the basis of the sum of the transport index numbers shown on the labels of each of the individual packages in the aircraft. However, when packages of radioactive materials are placed in the aircraft in accordance with a system of predesignated areas specified in paragraph (b) of this section, the minimum separation distance for those packages within each area will be determined from the following table on the basis of the sum of the index numbers of those packages within the particular area.

Transport Index or Sum of The Transport Indexes of All Packages Aboard The Aircraft	Minimum Distances in Inches or Centimeters to Area Occupied By Persons or Animals	
	Inches	Centimeters
0.1 to 1	12	30
1.1 to 2	20	50
2.1 to 3	28	70
3.1 to 4	34	85
4.1 to 5	40	100
5.1 to 6	46	115
6.1 to 7	52	130
7.1 to 8	57	145
8.1 to 9	61	155
9.1 to 10	65	165
10.1 to 11	69	175
11.1 to 12	73	185
12.1 to 13	77	195
13.1 to 14	81	205
14.1 to 15	85	215
15.1 to 16	89	225
16.1 to 17	93	235
17.1 to 18	97	245
18.1 to 20	102	260
20.1 to 25	118	300
25.1 to 30	130	330
30.1 to 35	142	360
35.1 to 40	154	390
40.1 to 45	166	420
45.1 to 50	177	450

(b) Packages containing radioactive materials that bear "radioactive yellow II" or "radioactive yellow III" labels may be carried on aboard a passenger-carrying aircraft in accordance with a system of predesignated areas acceptable to the Administrator. A system of predesignated areas aboard an aircraft is acceptable to the Administrator when it is so designed as to assure that --

(1) The packages are placed in each predesignated area in accordance with the minimum separation distances required by paragraph (a) of this section; and

(2) The predesignated areas are laterally separated from each other by a minimum distance equal to at least four times the distance required by paragraph (a) of this section for the predesignated area containing packages with the largest sum of transport indexes.

4. By adding a new § 103.22 to read as follows:

§ 103.22 Requirements for carriage of radioactive materials on cargo-only aircraft.

No person may carry on a cargo-only aircraft any package of radioactive materials bearing either a "radioactive yellow II" or "radioactive yellow III" label unless the following conditions are met:

(a) When the total transport index for all of the packages does not exceed 50.0, no package is carried closer to a space aboard the aircraft that is occupied by a person or an animal than the minimum distance prescribed in § 103.21 (a).

(b) When the total transport index for all of the packages exceeds 50 --

(1) The separation distance between the inside limiting surface of any space aboard the aircraft that is occupied by a person or an animal and the radioactive materials package surface nearest to it is at least 30 feet (9 meters);

(2) The transport index for any group of packages does not exceed 50.0;

(3) Each group of packages is separated from every other group aboard the aircraft by not less than 20 feet (6 meters) from the outer surface of the group; and

(4) The total index number for fissile packages on the aircraft does not exceed 50 TI.

For the purposes of this paragraph, a group of packages consists of any packages that are not separated from each other in the aircraft by at least 20 feet (6 meters).

5. By deleting paragraph (a) in § 103.23 as follows:

§ 103.23 Special requirements for radioactive materials.

* * * * *

(a) (Deleted).

* * * * *

6. By revising the title and content of § 103.24 to read as follows:

§ 103.24 Other special requirements for the acceptance and carriage of radioactive materials

(a) No person may carry on any aircraft packages of radioactive materials bearing "radioactive yellow II" or "radioactive yellow III" labels closer than the distances shown in the following table to any package containing undeveloped film (if so marked).

Total Transport Index	Minimum Separation Distance in Feet To Nearest Undeveloped Film For Various Times of Transit				
	Up to 2 Hours	2-4 Hours	4-8 Hours	8-12 Hours	Over 12 Hours
None	0	0	0	0	0
0.1 to 1.0	1	2	3	4	5
1.1 to 5.0	3	4	6	8	11
5.1 to 10.1	4	6	9	11	15
10.1 to 20.0	5	8	12	16	22
20.1 to 30.0	7	10	15	20	29
30.1 to 40.0	8	11	17	22	33
40.1 to 50.0	9	12	19	24	36

(b) No person may accept for carriage aboard aircraft a shipment of radioactive materials in a shipping unit overpack unless --

(1) The packages of radioactive materials contained within the outer rigid (such as a fiberboard carton) or non-rigid (such as a plastic bag) overpack are each packaged, marked, and labeled in accordance with applicable regulations;

(2) The shipping unit overpack is labeled as prescribed in 49 CFR 173.399 and complies with the following requirements:

(i) If the radiation dose rate for the shipping unit overpack exceeds 0.5 millirem per hour at 3 feet from any surface, then the label shall be a "radioactive yellow III" label as described in § 173.416(c). The "contents" entry on that label shall state "mixed radioactive materials."

(ii) For non-rigid overpacks, a single label, together with other required markings, shall be affixed to the overpack by means of a securely attached, durable tag. The transport index shall be determined by adding together the transport indexes of each of the packages contained therein.

(iii) For rigid overpacks, a transport index shall be determined in one of two ways:

(A) By adding together the transport indexes of each of the packages contained in the overpack; or

(B) Except for fissile radioactive materials, by direct measurement as prescribed in 49 CFR 173.389(i). Such overpacks with the inner packages contained therein must be capable of withstanding the compression test as prescribed in 49 CFR 173.398(b)(v).

(iv) The overpack shall be marked with --

(A) The name and address of the shipper and consignee;

(B) The applicable proper shipping name or names as in 49 CFR 172.5; and

(C) The statement "inside packages comply with prescribed specification(s)."

(v) The overpack shall not have a transport index in excess of 3.0 for passenger aircraft shipments or 10.0 for cargo-only aircraft shipments.

(vi) The overpack shall be considered a single package for purposes of the shipping paper requirements of § 103.4.

(vii) The overpack may not contain inside packages from more than one consignor.

(c) No person may carry on any aircraft any package of fissile class III radioactive material (as defined in 49 CFR 173.389(a)(3)), except --

(1) On a cargo-only aircraft which has been assigned for the sole use of the consignor for the specific shipment of fissile radioactive material. Instructions for such sole use must be provided for in special arrangements between the consignor and carrier, with instructions to that effect issued with shipping papers; or

(2) On an aircraft on which there are no other packages of radioactive material required to bear one of the "radioactive" labels described in 49 CFR 173.414. Specific arrangements must be effected between the shipper and carrier, with instructions to that effect issued with the shipping papers; or

(3) In accordance with any other procedure specifically approved by the Administrator.

7. By amending § 103.25 to read as follows:

§ 103.25 Notification of pilot in command.

(a) When articles subject to the provisions of this Part are carried in an aircraft, the operator of the aircraft shall include in the cargo load manifest, and in a written notice given to the pilot in command before takeoff, the following information:

(1) The shipping name and the classification of each dangerous article as prescribed in 49 CFR 172.5;

(2) The quantity in terms of weight, volume or as otherwise appropriate;

(3) The location of the dangerous articles in the aircraft;

APPENDIX B. EXISTING FAA REGULATIONS ON RADIOACTIVE MATERIALS SHIPMENTS

The following pages have been reproduced from pages 185, 186 and 187 of 14 CFR and contain the FAA regulations for shipment of radioactive materials.

§ 103.15 **Containers for liquids.**

(a) Each shipper who packs liquids for shipment under this part shall pack the liquids in securely closed inside containers that are strong enough to prevent leakage or distortion of the containers from temperature or pressure change during shipment, and must have them filled in a manner that provides adequate outage.

(b) In the case of quantities of one quart or less in each inside container, the shipper must pack each inside container in a strong outside container with cushioning and absorbent material to prevent breakage or leakage. However, inside containers of a combined capacity of not more than one quart may be packed within one such outside container.

§ 103.17 **Quantity equivalents.**

Quantities measured by the metric system or the imperial system may be substituted on the basis of one liter or one imperial quart per quart specified, and 500 grams per pound specified, up to one gallon for liquids or 10 pounds for solids.

§ 103.19 **Quantity limitations.**

(a) No person may carry more than 150 pounds net weight of nonflammable compressed gas in any inaccessible cargo pit or bin on any aircraft.

(b) No person may carry aboard an aircraft a number of packages of radioactive materials that make the total transport index number (determined by adding together the transport index numbers shown on the labels of the individual packages) more than 50.

(c) No person may carry more than 50 pounds net weight of any article that is subject to this part (other than an article specified in paragraph (a) or (b) of this section and magnetized materials) in any inaccessible cargo pit or bin of any aircraft.

(d) No person may carry aboard a passenger-carrying aircraft any package of radioactive material which contains a large quantity (large radioactive source) of radioactivity (as defined in 49 CFR 173.389(b)), except as specifically approved by the Administrator.

(Sec. 9, 80 Stat. 931; 49 U.S.C. 1657, 1421-1430) [Doc. No. 1580, Amdt. 1-1, 28 F.R. 6722, June 29, 1963, as amended by Amdt. 103-2, 31 F.R. 9058, July 1, 1966; 33 F.R. 14936, Oct. 4, 1968; Amdt. 103-11, 36 F.R. 21879, Nov. 17, 1971; Amdt. 103-14, 38 FR 4389, Feb. 14, 1973]

§ 103.23 **Special requirements for radioactive materials.**

(a) No person may place packages of radioactive materials bearing "radioactive yellow-II" or "radioactive yellow-III" labels in aircraft closer than the distances shown in the following table to a space (or dividing partition between spaces) which may be continuously occupied by people, or shipments of animals, or closer than the distances shown in the following table to any package containing undeveloped film (if so marked). If more than one of these packages is present, the distance shall be computed from the following table on the basis of the total transport index numbers shown on the labels of the individual packages in the aircraft:

Total transport index	Minimum separation distances in feet to nearest undeveloped film for various times of transit					Minimum distance in feet to area of persons, or minimum distance in feet from dividing partition of cargo compartments
	Up to 2 hours	2-4 hours	4-8 hours	8-12 hours	Over 12 hours	
None	0	0	0	0	0	0
0.1 to 1.0	1	2	3	4	5	1
1.1 to 5.0	3	4	6	8	11	2
5.1 to 10.0	4	6	9	11	15	3
10.1 to 20.0	5	8	12	16	22	4
20.1 to 30.0	7	10	15	20	29	5
30.1 to 40.0	8	11	17	22	33	6
40.1 to 50.0	9	12	19	24	36	7

(b) In addition to the reporting requirements of § 103.28, the carrier must also notify the shipper at the earliest practicable moment following any incident in which there has been breakage, spillage, or suspected radioactive contamination involving radioactive materials shipments. Aircraft in which radioactive materials have been spilled may not be again placed in service or routinely occupied until the radiation dose rate at any accessible surface is less than 0.5 millirem per hour and there is no significant removable radioactive surface contamination (see 49 CFR 173.397). In these instances, the package or materials should be segregated as far as practicable from personnel contact. If radiological advice or assistance is needed, the U.S. Atomic Energy Commission should also be notified. In case of obvious leakage, or if it appears likely that the inside container may have been damaged care should be taken to avoid inhalation, ingestion, or contact with the radioactive materials. Any loose radioactive materials should be left in a segregated area pending disposal instructions from qualified persons.

(Sec. 9, 80 Stat. 931; 49 U.S.C. 1657, 1421–1430) [33 F.R. 14936, Oct. 4, 1968; Amdt. 103-9, 36 F.R. 21183, Nov. 4, 1971]

§ 103.24 Special requirements for fissile class III radioactive materials.

(a) No person may carry aboard any aircraft any package of fissile class III radioactive material (as defined in 49 CFR 173.389(a)(3)), except as follows:

(1) On a cargo-only aircraft which has been assigned for the sole use of the consignor for the specific shipment of fissile radioactive material. Instructions for such sole use must be provided for in special arrangements between the consignor and carrier, with instructions to that effect issued with shipping papers; or

(2) On any aircraft on which there are no other packages of radioactive material required to bear one of the "radioactive" labels described in 49 CFR 173.414. Specific arrangements must be effected between the shipper and carrier, with instructions to that effect issued with the shipping papers; or

(3) In accordance with any other procedure specifically approved by the Administrator.

(Sec. 902(h), (49 U.S.C. 1421–1430, 1472(h), 1655(c))) [Doc. No. 11558, Amdt. 103-14, 38 FR 4389, Feb. 14, 1973]

§ 103.25 Notification of pilot in command.

Whenever articles subject to the provisions of this part are carried in an aircraft, the operator of the aircraft shall inform the pilot in command, before takeoff, in writing, of the shipping name and the classification of each dangerous article as prescribed in 49 CFR 172.5, the quantity in terms of weight, volume or as otherwise appropriate, and the location of the dangerous articles in the aircraft. The person marking the cargo-load manifest shall mark it conspicuously to indicate the dangerous articles.

[Doc. No. 12124, Amdt. 103-1, 38 FR 14915, June 7, 1973]

§ 103.27 Damage to dangerous articles.

Except as provided in §103.23, the pilot in command or operator of the aircraft shall remove from the aircraft any package subject to this part that appears to be damaged or leaking and may not carry it in the aircraft until it has been determined that the damaged or leaking article meets the requirements of this part.

[Doc. No. 1580, Amdt. 1-1, 28 F.R. 6722, June 29, 1963, as amended by Amdt. 103-8, 35 F.R. 16829, Oct. 31, 1970]

§ 103.28 Reporting certain dangerous article incidents.

(a) Each carrier who transports dangerous articles shall report to the nearest ACDO, FSDO, GADO or other FAA facility by telephone at the earliest practicable moment after each incident that occurs during the course of transportation (including loading, unloading or temporary storage) in which as a direct result of any dangerous article—

(1) A person is killed;

(2) A person receives injuries requiring his hospitalization;

(3) Estimated carrier or other property damage, or both, exceeds $50,000; or

(4) Fire, breakage, or spillage or suspected radioactive contamination occurs involving shipment of radioactive materials (see also § 103.23(b)).

(5) Fire, breakage, spillage, or suspected contamination occurs involving shipment of etiologic agents. In place of the report required by paragraph (a) of this section, a report on an incident involving etiologic agents may be made by telephone directly to the Director, Center for Disease Control, U.S. Public Health, Atlanta, Ga., Area Code 404-633-5313.

(6) A situation exists of such a nature that, in the judgment of the carrier, it should be reported to the Department even though it does not meet the criteria of subparagraphs (1), (2), or (3) of this paragraph, e.g., a continuing danger to life exists at the scene of the incident.

(b) The following information shall be furnished in each report required by this section:

(1) Name of reporting person.

(2) Name and address of carrier represented by reporter.

(3) Phone number where reporter can be contacted.

(4) Date, time, and location of incident.

(5) The extent of the injuries, if any.

(6) Classification, name, and quantity of the dangerous article involvement and whether a continuing danger to life exists at the scene.

(c) Each carrier who transports hazardous materials shall report in writing in duplicate on DOT Form F 5800.1, within 15 days of the date of discovery, each incident that occurs during the course of transportation (including loading, unloading, or temporary storage) in which, as a direct result of the hazardous materials, any of the circumstances set forth in paragraph (a) of this section occurs or there has been an unintentional release of hazardous materials from a package (including a portable tank). Each carrier making a report under this section shall send that report to the Secretary, Hazardous Materials Regulations Board, Department of Transportation, Washington, D.C. 20590, with a separate copy to the FAA facility indicated in paragraph (a) of this section.

[Amdt. 103-8, 35 F.R. 16829, Oct. 31, 1970, as amended by Amdt. 103-9, 36 F.R. 21183, Nov. 4, 1971; Amdt. 103-15, 38 FR 8136, Mar. 29, 1973]

§ 103.29 Magnetized materials; packing and marking requirements.

Each shipper offering magnetized materials (which might cause an erroneous aircraft magnetic compass reading) for shipment by air shall—

(a) Plainly mark the outside of the package "Magnetized Materials";

(b) Pack magnets or magnetized devices such as magnetrons and light meters so that the polarities of each unit oppose one another; and

(c) Install keeper bars on permanent magnets or shield them to prevent the magnetic field from affecting that magnetic compass.

§ 103.31 Cargo location.

(a) No person may carry articles that are subject to the requirements of this part in a cabin of a passenger-carrying aircraft.

(b) Each person carrying articles acceptable only for cargo aircraft shall carry those articles in a location accessible to a crewmember in flight.

(c) No person may place a package of "yellow" label material (flammable solids or oxidizing materials) next to, or in a position to allow contact with, a package of "white" label material (corrosives) in any aircraft.

(d) No person may load magnetized material (which might cause an erroneous magnetic compass reading) on an aircraft in the vicinity of a magnetic compass or compass master unit that is a part of the instrument equipment of the aircraft in a manner that affects its operation. If this requirement cannot be met, a special aircraft swing and compass calibration may be made. No person loading magnetized materials may obscure the warning labels.

(e) No person may carry articles subject to the requirements of this part in an aircraft unless they are suitably safeguarded to prevent their becoming a hazard by shifting. For packages labeled "radioactive yellow II" or "radioactive yellow III", such safeguards must prevent movement that would permit the package to be closer to a space that is occupied by a person or an animal, or to other packages or groups of packages than is permitted by § 103.23.

(f) No person may carry an article subject to the requirements of this part that is acceptable for carriage in passenger-carrying aircraft, other than magnetized materials, unless it is located in the aircraft in a place that is inaccessible to persons other than crewmembers.

(Sec. 9, 80 Stat. 931; 49 U.S.C. 1657, 1421-1430) [Doc. No. 1580, Amdt. 1-1, 28 F.R. 6722, June 29, 1963, as amended at 33 F.R. 14936, Oct. 4, 1968; Amdt. 103-4, 33 F.R. 19823, Dec. 27, 1968; Amdt. 103-17, 38 FR 17833, July 5, 1973; Amdt. 103-19, 38 FR 30104, November 1, 1973]

§ 103.33 Transportation of gasoline, kerosene, or aviation fuel in small aircraft.

A small aircraft operated entirely within the State of Alaska or a small helicopter operated into a remote area in the United States may carry, in other than scheduled passenger-carrying operations, not more than 20 gallons of gasoline, kerosene, or aviation fuel, if—

(a) Transportation by air is the only practical means of providing suitable fuel;

APPENDIX C. CONSIDERATIONS IN THE EVALUATION OF THE EFFECTS OF LOW LEVEL IONIZING RADIATION

I. SOURCES AND EFFECTS OF LOW-LEVEL IONIZING RADIATION

A. Sources of Radiation

Naturally occurring radiation arises from cosmic and terrestrial sources. Typical dose rates from cosmic radiation to individuals at sea level in temperate zones range from 40 to 70 mrem/yr.[1] Dose rates increase to approximately 5000 mrem/yr at 40,000 ft elevation.[2] The average dose rate in the United States from cosmic radiation is 44 mrem/yr.[3]

Principal sources of natural terrestrial radiation are radionuclides present in soils and rocks, the atmosphere and hydrosphere. These radionuclides expose man directly or are transferred to man through food chains or inhalation. Typical dose rates to individuals from internal and external radiation sources of terrestrial origin are 50 and 20 mrem/yr, respectively.[4]

In addition to radiation from naturally occurring sources, individuals are exposed to several sources of radiation as a result of man's actions. These sources include development and testing of nuclear devices, power production,medical diagnosis and treatment, and other peaceful uses of radiation and radioactive materials. Average individual doses from these sources are: weapons development (fallout) - 4 mrem/yr; routine operation of nuclear power plants - 0.003 mrem/yr; medical - 73 mrem/yr; and others - 3 mrem/yr.[1]

The average dose rate to individuals averaged over all persons in the United States and from all of these sources is about 180 mrem/yr.[1]

B. Health Effects in Humans

Radiation produces health effects in living organisms primarily by causing excitation and ionization of molecules within cells. These events lead to physical and chemical changes which may affect cellular metabolic or organ structures and functions. These changes may be genetic (hereditary, involving germ cells) affecting the progeny of the exposed person or somatic (physical, involving body cells) affecting only the exposed person. Somatic effects may appear within a short time (hours) for very high doses and high dose rates or after a long time (decades) for moderate doses and moderate dose rates. It has been domonstrated that the body does repair damage due to radiation when doses and dose rates are low.(5)

Quantitative evidence regarding genetic effects are based mainly on experimental studies with mice and Drosophila and are supported by data from studies of human populations in Japan. Results of these studies indicate that genetic effects in a population are doubled when the individual average chronic radiation dose is in the range of 20,000 to 200,000 mrem.(1) The most tangible measure of genetic damage is probably "ill health". It is thought that about 20% of ill health is attributable to genetic effects. Assuming a doubling dose of 20,000 mrem, 5000 mrem per generation (individual dose for 30 years) would, at equilibrium, lead to an increase of 5% in the ill health of any population.(1)

Somatic effects have been observed in Japanese atomic bomb survivors, in various occupational groups and in groups exposed to therapeutic irradiation. This data has lead to the prediction that additional exposure of the U. S. population to 5000 mrem per person per 30 years could cause from about 3000 to 15,000 cancer deaths annually. The most likely estimate is about 6000 cancer deaths annually, an increase of about 2% in the spontaneous cancer death rate.(1) This rate indicates about 180 additional cancer deaths per year per 1,000,000 persons for 1 rem per person exposure. Actual records of Japanese atomic bomb survivors who were exposed to high doses and high dose rates indicate about 2.5 additional cancer deaths per 1,000,000 persons per year for 1 rem per person exposure. Calculations that estimate the additional cancer deaths in a population are based on linear extrapolation from high dose-high dose rate experimental results which are generally admitted to overestimate effects of low dose-low dose rates. Therefore, the risks presented herein are considered to be quite conservative, if at all indicative, of the actual induction of excess cancers due to radiation. Current positions on methods of predicting health effects from low level exposures to ionizing radiation are summarized in Appendix D.

As a comparison, a recent report by the U. S. Environmental Protection Agency (EPA) has estimated that the average per capita annual nonmedical, nonoccupational dose to the general public as a result of all of man's activities was 6.6 mrem in 1970 and that this will be only 6.4 mrem in the Year 2000.(6) These doses are about 30 times less than the maximum permissible dose (5000 mrem/in 30 yr) used in the above examples.

C. Health Effects in Animals

There is considerable literature relating to radiation effects on animals but few studies have been conducted to determine the effects from chronic low level external and internal radiation on aquatic and terrestrial animals. While the most recent studies have yet to preclude the existence of extremely radiosensitive animals, no animals have yet been found that show particular sensitivity to chronic, low-level radiation doses.(1, 7)

II. RADIATION DOSE LIMITS

A. Radiation Workers

Maximum permissible doses for radiation workers, (i.e., persons whose work is performed in a restricted area) do not include contributions from background radiation, man-made devices outside of the working environment nor radiation exposures in the healing arts.(8) General radiation dose limits have been set by the Nuclear Regulatory Commission (NRC) for its licensees and are followed by the Occupational Safety and Health Administration (OSHA) for other occupational workers. Other Federal agencies have adopted regulations for specific instances.

For example, the Department of Labor has issued radiation standards for uranium mining. Although some authority to regulate atomic energy related activities has been delegated to states, the states are not free to set exposure limits that differ from those set by NRC.[9]

The NRC maximum permissible exposures to individuals in restricted areas are shown in Table C-1.

TABLE C-1. Maximum Permissible Exposures to Individuals in Restricted Areas[a][10]

	Rems Per Calendar Quarter
1. Whole body; head and trunk; active Blood-forming organs; lens of eyes; or gonads	1-1/4
2. Hands and forearms; feet and ankles	18-3/4
3. Skin of whole body	7-1/2

a. Restricted areas are defined to be areas where access is controlled[11]

The annual dose limit can be obtained by taking four times the quarterly dose limit (e.g., 5 rem annual dose to the whole body). Two exceptions to the rule are given in the regulations. The first allows a greater whole body dose than shown in Table C-1 if the whole body dose does not exceed three rems during any calendar quarter. The second provides that the dose to the whole body when added to the accumulated occupational dose to the whole body shall not exceed 5(N-18) where N is the individual's age in years. These regulations have been followed by OSHA.[12] The OSHA regulations provide in addition that no employee under the age of 18 may receive exposure in excess of 10% of the limits shown in Table C-1.

B. Individual Members of the Public

At the present time, the only radiation dose limit applicable to members of the general public is one set by NRC.[13] This regulation requires applicants' for a license to limit exposure to individuals in unrestricted areas to a maximum of 0.5 rem per year. This limit is consistent with the recommendations of the FRC and NCRP[5], both of which specify a maximum individual exposure to the whole body (exclusive of medical exposure) of 0.5 rem per year.

C. Population Average

FRC and NCRP recommend that the dose to the whole body of the population of the United States from all other sources shall not exceed a yearly average of 170 mrem per person.[8] Since the genetically significant dose is the ruling criterion, the critical target is considered to be the gonads. The recommended dose limit for the general population does not include contributions from natural radiation or radiation from the healing arts.

D. Special Population Groups

Special population groups which may be more likely exposed to radiation from a given facility or activity than the general population are usually readily identifiable. People living close to a facility or who are exposed to a particular pathway (such as drinking water) or who have particular habits (such as fishing) make up most such special groups. Doses to these special groups usually determine the operational limitations of a facility or activity.

The practical application of the recommendations does, however, offer a dilemma regarding how large the group must be before concern for somatic injury to the individual is replaced by concern for genetic injury to population. NCRP[5] states that there exist in the U. S. "several genetic pools and that currently there is relatively little mixing across certain racial or ethnic lines". They advise that averaging to determine whether exposure is within 170 mrem/yr. should be done over these sub-populations where they can be clearly defined. In the unlikely event that these sub-populations travel always as a group, the guidelines pertaining to individuals would almost certainly apply to passenger aircraft. Annual dose limits to individuals of a group or the group as a whole are the same as those described in Sections II.B and II.C of this Appendix, i.e., 500 mrem and 170 mrem, respectively.[8]

E. "As Low As Practicable" Criterion

National and international recommending and regulating agencies have long stated that the fundamental principle for establishing radiation protection standards is that radiation doses should always be kept "as low as practicable".[1, 8, 14, 16] The recent proliferation of the use of radioactive materials in military, medical and industrial applications has caused these agencies to consider more closely the application of this principle.

The work "practicable" implies theoretical feasibility in contrast to the work "practical" which implies a more sensible and business-like approach. Nevertheless, the phase "as low as practicable" has been interpreted to include economic considerations.[a] The phrase is therefore quite close to the BEIR report[1] recommendation that no unnecessary exposure to radiation should be permitted but reducing small risks from exposure should not be required if the funds that would be used could clearly produce greater benefits when spent otherwise.

F. Animals

No dose limits have been specified for organisms other than man. However, radiation health effects observed in animals have also been observed in man and no unusual radiosensitivities have been identified. Therefore, limits set for humans are believed to be more than adequate for animals (See Sections II.C and II.D of this Appendix).

(a) See for example, the NRC design objectives for effluent from nuclear power reactors in 10 CFR § 50.34a (a).

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10. 29 CFR § 20.101.

11. 10 CFR § 20.3 (14[a]).

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APPENDIX D. CURRENT POSITIONS ON PREDICTING HEALTH EFFECTS OF LOW LEVEL EXPOSURE TO IONIZING RADIATION

I. CURRENT POSITIONS

The National Council on Radiation Protection and Measurements, (NCRP), after reviewing recent developments relating to radiation standards for the public,[1] particularly in regard to extrapolated estimates of cancer risk at low doses and low dose rates, has taken the position that no change is required at this time in the conclusions set out in NCRP Report No. 39 issued in 1971.[2]

The NCRP position is centered on the principle that the "lowest practicable" radiation level is the fundamental basis for establishing radiation standards, and on the assumption that the most important radiation health hazards do not have a dose threshold. On this basis, the setting of radiation protection standards require consideration of compensatory trade-offs between currently assumed hazards and benefits. In addition, the NCRP continues to hold the view that risk estimates for radiation induced cancers from low doses and low dose rates, derived on the basis of linear extrapolation from the rising portions of the dose effect curves from high doses and high dose rates, are not expected to be realistic. Such procedure has such a high probability of overestimating the actual risk as to be of only marginal value, if any, for purposes of realistic risk-benefit evaluation.[1]

However, the 1972 BEIR Report states that societal needs can be met with far lower average exposures and risks than permitted by the current Radiation Protection Guide of 170 mrems/yr. and that to this extent the current Guide is unnecessarily high.[3] As a result of this statement, the linear dose-effect hypothesis and linear extrapolation values from the BEIR Report have been coming into more frequent use to estimate cancer deaths from radiation. Confirmation of experimental indications of a dose rate influence on radiation effects would make this practice inappropriate since data are beginning to indicate that risks to the population from low doses and low dose rates should not be based on extrapolation of risk estimates derived from data at high doses and high dose rates.[1]

The application of the "lowest practicable" principle involves value judgments based upon perception of compensatory benefits commensurate with risks, preferably in the form of realistic numerical estimates of both benefits and risks from activities involving radiation and alternative means to the same benefits.

The NCRP has cautioned governmental policy-making agencies of the unreasonableness of interpreting or assuming "upper-limit" estimates of carcinogenic risks at low radiation levels, derived by linear extrapolation from data obtained at high doses and high dose rates, as actual risks, and of basing policies on such restrictive interpretation or assumption.[1]

II. DISCUSSION OF BASES

Attempts to make quantitative estimates of the carcinogenic risks to the public from exposure to radiation at the very low doses and low dose rates of importance in relation to radiation protection guides have utilized linear extrapolation from data points obtained at high doses and high dose rates.

All national and international groups which have studied the problems of quantitative carcinogenic risk estimates have regarded the practice of linear extrapolation as overestimating the risk when the extrapolation is made from the rising and fairly linear portion of the dose-effect relationship.

Ultimately, the dose-effect relationship reflects the distribution and variability of individual susceptibilities to the dose. In animal experiments on radiation induction of cancers, the radiation dose given to each group of animals at each dose point is usually deliberate controlled and known. The results of most animal experiments involving lifetime observation of cancer induction effects from low linear energy transfer (LET) radiation (e.g., x-rays and gamma rays), have shown an overall sigmoid ("S" shaped) dose-effect curve. The curve is composed of an unknown region below the lowest dose used ($\sim$ 10,000 mrem) followed by a fairly linear rising portion (sometimes preceded by a rising concave portion), followed in turn by a portion decreasing in rate of rise and leading to a plateau, and followed finally at the highest doses by a falling portion with negative slope. This data, and previous reviews of dose-effect relationships and influence of dose rate, have been extensively reviewed in the 1972 UNSCEAR Report(4) and are acknowledged and discussed to a considerable extent in the BEIR Report.(3) While there may indeed be a linear relationship between dose and effect at low doses and dose rates, the slope of the line is most likely considerably less than that derived from extrapolation between data points obtained at high doses and dose rates and the point of "natural" incidence of cancer at the level of natural background radiation (∿ 100 mrem/yr). Even in an overall sigmoid relationship, there may be fairly linear parts or fairly linear combinations of points with different slopes at low, intermediate and high dose ranges.

A wealth of data obtained on non-human organisms, including mammals, indicates that capability of recovery from radiation damage effects is widely shared if not universal. This implies that efforts vary with dose rate. Most of the existing data (also currently unpublished data)(5) on dose rate influence on carcinogenic effectiveness of radiation, indicate reduction of effectiveness of low LET radiation by fractionation of dose or reduction of dose rate for single doses in the rising portions of the dose-effect curves.

Both the UNSCEAR Report(4) and the BEIR Report(3) have employed a dose rate factor, derived from experiments on mice, which reduces the effect of low doses and dose rates in estimating human genetic risks from irradiation. Existing and forthcoming experimental data pertaining to the influence of dose rate in radiation carcinogenesis requires further consideration to evaluate the feasibility of applying dose rate effectiveness correction factors in estimating human risks of radiogenic cancer at low doses and low dose rates. Recent work, based on data of the A-bomb survivors and radiobiological studies on the dose-rate effect,(6) uses higher, preferred, and lower linear estimates, as well as a much lower dose-squared estimate. The results indicate that the dose response to gamma irradiation may be sigmoid rather than linear. Despite the differences between this approach and that of the BEIR Report, there is reasonable agreement between the two linear estimates for high dose rates. In addition, the former work presents radiobiological evidence of effectiveness reduction at lower dose rates of low LET radiation on the life shortening effect in dogs and mice, induction or leukemia and bone sarcomas in mice, and induction of mammary tumors and thyroid tumors in rats. On the basis of this evidence a tentative overall effectiveness factor of 0.2 (low vs high dose rates for low LET radiation) for the summed impact of delayed somatic effects in humans was derived. It was further indicated that individual effectiveness factors vary with biological effect and species and may vary with the dose level at which comparison is made.

The average exposure of the U. S. public to man-made radiation sources other than those used in medical procedures has consistently been only a very small fraction of background radiation or of specified dose limits. It is quite unlikely that any significant fraction of the general population approaches the maximum allowable individual exposure limit of 500 millirem in any one year, or the current Radiation Protection Guide of 170 millirems in any one year, population average. However, the benefits and costs to society of further reductions of dose limits still need to be judged in terms of "lowest practicable" principles.

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3. Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR), The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, National Academy of Sciences, National Research Council, Washington, D.C., November 1972.

4. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Ionizing Radiation: Levels and Effects, 2 volumes, United Nations, New York, 1972.

5. For example, the data of Drs. J. Storer, J. Yuhas, M. Holland, D. Grahn and G. Sacher, presented at the NAS-NRC-organized meeting, Snowmass, Colorado, July 21-31, 1973. An ad hoc panel of the National Academy of Sciences prepared an NAS publication (1974), based on reports submitted at the Snowmass meeting, entitled, Research Needs for Estimating the Biological Hazards of Low Doses of Ionizing Radiations.

6. Mays, L. W., Lloyd, R. D. and Marshall, J. H., Malignancy Risk to Humans from Total-Body Gamma-Ray Irradiation, Proc. 3rd International Congress, International Radiation Protection Association (in press).

APPENDIX E. EVALUATING PROPOSED CHANGES IN PACKAGE TRANSPORTATION INDEX LIMITS USING THE CONCEPT OF IMPLIED VALUE OF LIFE

An alternative method of evaluating the proposed alternatives is to examine the value of saving a statistical life implied by adoption of each package TI limit. "Marginal values" of statistical life can be calculated for incremental costs and benefits between selected package TI limits. If cost effectiveness was the sole criterion for selection of an optimal package TI limit, the selected package TI would be one producing an incremental value corresponding to the socially acceptable value of saving a statistical life.

In the following analysis the implied value for saving a statistical life is evaluated for alternative package TI limits of 5, 3 and 1. In contrast to the analysis of Section IX, the 10 TI alternative is used as a base. The implied value for saving a statistical life for a given TI limit is the "marginal" life-value computed from the incremental costs and benefits accruing as the TI limit is varied from a higher level down to the level of interest. Marginal life saving values are evaluated for 5 TI (10 TI-5 TI increment); 3 TI (5 TI-3 TI increment); and 1 TI (3 TI-1 TI increment).

This analysis utilizes the cost data of Section IX.C expressed in modified form. Costs are expressed as differential costs for the TI increments described in the preceding paragraph. For the 10 TI-5 TI increment, costs, except for design and toolup costs, are the difference between the respective differential costs (10 TI and 5 TI) relative to the 3 TI alternative (Table IX-19). Design and toolup costs will be similar to those of the 5 TI alternative relative to the 3 TI alternative (Table IX-19).

For the 5 TI-3 TI increment, costs, except for design and toolup costs, will be similar to differential costs previously calculated for the 5 TI alternative. Design and toolup costs for this increment are estimated to be $90,000 annually (three shields each for three manufacturers, $50,000 per design, amortized over five years).

For the 3 TI-1 TI increment, costs will be similar to those previously estimated for the 1 TI alternative.

Benefits for the three increments are derived as follows: 10 TI-5 TI increment - the difference between the 10 TI and 5 TI differential benefits relative to the 3 TI alternative; 5 TI-3 TI increment - the differential benefit of 5 TI relative to 3 TI; 3 TI-1 TI increment - the differential benefit of 1 TI relative to 3 TI.

Incremental costs and benefits for the selected TI increments are summarized in Table E-1.

TABLE E-1. Incremental Costs and Benefits

Item	10 TI-5 TI	5 TI-3 TI	3 TI-1 TI
Generators:			
Material	$ 160,000	$ 480,000	$ 240,000
Design	90,000	90,000	120,000
Fabrication	160,000	480,000	240,000
Shipping	30,000	560,000	680,000
Nongenerators:			
Material	-	-	60,000
Design	-	-	40,000
Fabrication	-	-	60,000
Shipping	-	-	-
Total Costs	$ 440,000	$1,610,000	$1,410,000
Benefit (Man-Rem Avoided)	600 Man-Rem	320 Man-Rem	330 Man-Rem

Implied life-value may be derived from the costs and benefits of Table IX-22 as follows:

(1) Determine the genetic value of man-rem saved (at $120/man-rem, Section IX.A) and subtracting this amount from the total costs of Table IX-22.

(2) Convert the man-rem avoided into excess mortality (at 1 death/ 2267 man-rem exposure, Section IX.A).

(3) Divide the amount remaining in Step (1) by the corresponding excess mortality. This gives the implied life-value.

These steps and resulting implied life-values are summarized in Table E-2 for the selected TI limits.

TABLE E-2. Implied Life-Values

Item	TI Max = 5 (10 TI-5 TI)	TI Max = 3 (5 TI-3 TI)	TI Max = 1 (3 TI-1 TI)
Benefit (Man-Rem Avoided)	600	320	330
Equivalent Genetic Value	$ 72,000	$ 38,000	$ 40,000
Remaining Cost	368,000	1,572,000	1,400,000
Excess Mortality	0.26	0.14	0.15
Implied Life-Value	$ 1.4×10^6	$ 11.2×10^6	$ 9.3×10^6

The implied life-values of Table E-2 exceed the maximum values accepted by society (Section IX.A) for every incremental decrease in package TI limits. It is clear that the "cost-effective" package TI, based on life-values currently accepted by society, is well above a 5 TI and probably above a 10 TI limit. (Subdividing the 10 TI-5 TI increment might show further decreases in the implied life-value near the 10 TI end of this increment.)

An expansion of this approach could be used to precisely locate the cost-effective package TI limit. Implied life saving values would be derived for additional package TI limits, e.g., between 10 TI and 5 TI and above 10 TI. Resulting implied life-values would be plotted in graphical form against corresponding package TI limits, creating a curve from which the "cost-effective" package TI corresponding to selected life saving values could readily be determined. This approach was not employed since it is evident that in this case considerations other than cost effectiveness will act to establish a package TI limit substantially more stringent than the "cost-effective" level.

APPENDIX F. GLOSSARY OF TERMS AND ACRONYMS

AEC	Atomic Energy Commission
ALPA	Air Line Pilots Association
BEIR	Report of the Advisory Committee on the Biological Effects of Ionizing Radiations
Category II Package	As used in this report, a package that bears a "radioactive yellow II" label
Category III Package	As used in this report, a package that bears a "radioactive yellow III" label.
Collective Dose	The summation of whole-body radiation doses to individuals in a population group, expressed in man-rem.
Cosmic Radiation	Highly penetrating ionizing radiation which originates outside the earth's atmosphere
Criticality Safety	Prevention of a criticality accident
Curie (Ci)	The basic unit to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. A curie is also a quantity of any nuclide having 1 curie of radioactivity.
DOT	Department of Transportation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
Fissile Material (also Fissile Radioactive Material)	Defined as ^{238}Pu, ^{239}Pu, ^{241}Pu, ^{233}U, or ^{235}U, or any material containing any of these materials (see 49 CFR § 173.396(a) for exclusions). A characteristic of fissile material is that when present in sufficient quantities and under certain conditions a neutron chain reaction can occur which would result in extremely high radiation levels. This event is termed a criticality accident.
Freighter Aircraft	Equivalent to cargo-only aircraft.
FRC	Federal Radiation Council
Genetic Effects of Radiation	Radiation effects that can be transferred from parent to offspring. Any radiation-caused changes in the genetic material of sex cells.

Isotope	One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. An equivalent statement is that the nuclei of isotopes have the same number of protons but different numbers of neutrons. Thus, ${}^{12}_{6}C$, ${}^{13}_{6}C$, and ${}^{14}_{6}C$ are isotopes of the element carbon, the subscripts denoting their common atomic numbers, the superscripts denoting the differing mass numbers, or approximate atomic weights. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.
JCAE	Joint Committee on Atomic Energy
Man-Rem	A unit of population dose. one man-rem of dose equals 100 mrem dose to 10 persons, 10 mrem dose to 100 persons, etc.
Maximum Dose Rate	The highest dose rate of radiation at any seat level in an aircraft.
Maximum Loading	The maximum number of packages of transport indices (TI) can be transported in a cargo compartment of an aircraft.
Millicurie (mCi) (see Curie)	1/1000 of a curie.
Mrem (see Rem)	Millirem, 1/1000 of a rem
Millirem Per Hour (Mrem/Hr)	A unit of radiation dose rate
NCRP	National Council on Radiation Protection and Measurements (see comment, Section II.C, pg. II-5)
NPRM	Notice of Proposed Rule Making
NRC	Nuclear Regulatory Commission
Radiation	The propagation of energy through matter or space in the forms of waves and fast-moving particles. Of particular concern is ionizing radiation which affects matter that it passes through.
Radiation Dose	The quantity of ionizing radiation absorbed by the body or any part of the human anatomy, expressed in rem or mrem (1/1000 rem).
Radiation Dose Rate	The quantity of radiation absorbed per unit time, expressed in mrem per hour or mrem per year.

Radiation Exposure — In this report, exposure has the same meaning as radiation dose.

Radiation Level — A condition of radiation exposure at a location expressed in mrem per hour. If a person occupied the location for a period of time, the radiation dose received by the person would be the product of the radiation level and the period of time.

Radioactive Half-Life — Time required for a radionuclide to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

Radioactive Labels — Labels bearing the unique trefoil radiation warning symbol which are required to be placed on two opposite sides of each package of radioactive material. Each radioactive label shows the contents, the amount of radioactivity in curies, and on radioactive yellow-II and radioactive yellow-III labels, the number of transport indexes. Labels are divided into:

1) radioactive white-I label -- for each package not exceeding 0.5 millirem per hour at any point on the external surface of the package, not authorized for Fissile Class II packages;

2) radioactive yellow-II label -- for each package exceeding limits of radioactive white-I label, but not exceeding 10 millirems per hour at surface and not exceeding TI of 0.5; and

3) radioactive yellow-III label -- for each package exceeding limits of radioactive yellow-II label, each Fissile Class III package, each large quantity package, and each package being transported under a DOT permit.

Radioactive Material — Any material or combination of materials which spontaneously emits ionizing radiation.

Radioactive Traffic Factor (RTF) — The ratio of the number of departures of commercial aircraft carrying packages of radioactive material to the total number of commercial departures from an airport.

Radionuclide — An unstable isotope of an element that decays or disintegrates spontaneously, emitting ionizing radiation.

Radiopharmaceutical	A pharmaceutical compound containing a radionuclide for use in medical diagnoses or therapy, e.g., radioactive ^{99m}Tc in saline solution which is used in imaging procedures.
Rem	(Acronym for roentgen equivalent man.) The unit of dose of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X-rays.
Roentgen	(Abbreviation r) A unit of exposure to ionizing radiation. It is that amount of gamma or X-rays required to produce ions carrying 1 electrostatic unit of electrical charge (either positive or negative) in 1 cubic centimeter of dry air under standard conditions.
Seat Height	Defined as 40 cm above the floor of the passenger compartment which is considered to be the height of a seat in an aircraft or any position in a passenger compartment at 40 centimeters above the floor.
Select Group	A subgroup of a defined population which might potentially receive higher radiation exposures than other members of the population.
Separation Distances	The distance between the passenger side of the floor or partition of the passenger compartment and the nearest surface of a package of radioactive material stowed in the cargo compartment.
Short-lived Radionuclide	A radioisotope which disintegrates rapidly. Its radioactivity diminishes in a short time.
SNM	Society of Nuclear Medicine
Somatic Effects of Radiation	Effects of radiation limited to the exposed individual, as distinguished from genetic effects.
Spacing-out	A configuration for loading packages of radioactive materials in the cargo compartment of an aircraft which allows an aircraft to carry several groups of packages simultaneously. The spacing-out configuration limits the number of packages in each group and specifies minimum separation distances and distances between groups of packages.
Statistical Life	As used in this report, an unidentifiable life.

Technetium Generator — A source of ^{99m}Tc, a short (6 hr) half-life radioisotope used extensively in medical diagnoses. Due to the short half-life, ^{99m}Tc is usually supplied in technetium generators which continually produce ^{99m}Tc through decay of 66 hr half-life ^{99}Mo. Technetium generators consist of a lead shielded ion exchange column containing adsorbed ^{99}Mo. ^{99m}Tc is eluted from the generator as needed. The useful life of a technetium generator is about 1 week.

Transmission Factor — The fraction of radiation passing through the aircraft structures between the radiation source and the dose point of interest.

Transport Index (TI) — The number placed on the label of a package of radioactive material to designate the degree of control to be exercised by the carrier during transportation. The transport index is equal to the larger of the following: the highest radiation dose rate, in millirem per hour at three feet from any accessible external surface of the package; or, for fissile material packages, the number 50 divided by the number of similar packages which may be transported together under NRC rules.

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