Safety in the Transportation of Radioactive Materials by Passenger Aircraft

Lester Rogers

U.S. Atomic Energy Commission, Washington, D.C.

More than 6 million patients benefit each year from the use of radioactive materials for diagnostic and therapeutic purposes. Because of their fast decay rate, most radionuclides used in medicine must be transported by the fastest, most reliable means, which is by passenger aircraft. This paper discusses the responsibilities of various Federal regulatory agencies related to the transportation of radioactive materials, the method of controlling exposures to aircraft passengers, the surveys conducted to assess exposures, and the steps being taken to reduce unnecessary exposures. It concludes that radionuclides used in medicine can be delivered rapidly and safely by passenger aircraft.

I appreciate this opportunity to summarize the AEC's views on the air transportation of radioactive materials for medical use. Radioisotopes make a major contribution to the health of the people in this country through their widespread availability and use for diagnostic and therapeutic purposes. There are presently some 6,000 hospitals and physicians licensed by the AEC and Agreement States to possess and use radioactive materials for medical purposes. It is estimated that more than 6 million patients benefit each year through the administration of radioisotopes.

Radioisotopes used in medicine have a short half-life and lose their effectiveness rather rapidly by radioactive decay. The bulk of radiopharmaceuticals are prepared by a few suppliers that are located in cities such as Boston, Chicago, New Brunswick, N.J., San Francisco, and St. Louis. This means that they can be available to the thousands of hospitals and physicians located in small towns and large cities throughout the country where patients are actually treated only if there is a fast and reliable means of transportation throughout the country.

More than 25 years of experience have shown that the network of commercial passenger airlines is the only system available that can provide this service at reasonable cost. But, of course, since the day of the first shipment in the late 1940s, the necessity for packaging and handling these radioactive materials in a manner that would not be hazardous to airline staff or the traveling public was obvious. To achieve this protection, the AEC has worked with the Federal Aviation Administration (FAA) and the Department of Transportation (DOT) to develop and implement regulations.

Regulation of Shipments

The AEC, under the Atomic Energy Act, is authorized to license and regulate the receipt, possession, use, and transfer, including transportation, of "byproduct material," "source material," and "special nuclear material" (Table 1). AEC's

For reprints contact: Lester Rogers, Dept. of Regulatory Standards, U.S. Atomic Energy Commission, Washington, D.C. 20545.

Editor's note: This article was written before it was announced that the AEC will be dissolved.

Table 1. Transportation of Radioactive Materials: Regulatory Safety Authority

Type of material / Activity	Radium, accelerator products and other radioisotopes	Byproduct source and special nuclear material	Other hazardous materials
Possession, use		AEC	
Transportation in interstate and foreign commerce, on navigable waters, in civil aircraft	DOT	AEC DOT	DOT
Intrastate transportation	States	AEC	States

Table 2. AEC — DOT Memo of Understanding

1. Overlapping responsibilities.
2. DOT overall standards and carrier regulations.
3. AEC review and approve packages (Type B, large quantity, fissile material), develop standards and regulate where DOT does not.
4. Incidents — DOT lead agency for investigation if in carrier phase, AEC elsewhere. Enforcement according to jurisdictions.

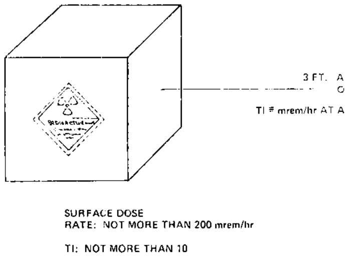

FIG. 1. Limitations on package radiation levels. A Transport Index (TI) is number of mrem/hr at 3 ft from package. Regulation limits package TI to 10 and surface dose to 200 mrem/hr.

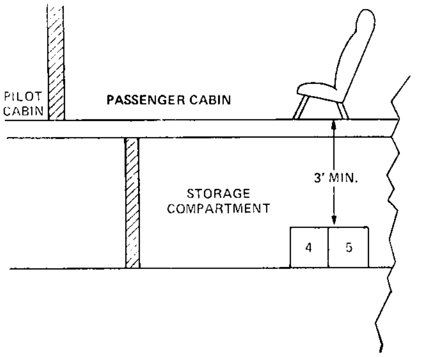

FIG. 2. Example of minimum separation distance. Packages containing radioactive materials must be placed in storage compartment in positions specified by Federal regulations.

broad authority covers all persons who possess or handle such materials, including shippers, carriers, and recipients.

The Department of Transportation has authority to regulate the transportation of all radioactive materials in interstate and foreign commerce, on civil aircraft, and on vessels on navigable waters.

This somewhat overlapping of responsibilities necessitated a Memorandum of Understanding (Table 2) between the two agencies under which DOT regulates packaging and labeling of all radioactive materials and conditions of carriage. The AEC has exempted from its regulations carriers regulated by DOT but does review and approve designs of packages for the larger quantities of radioactive material and regulates packaging and private carriage by its licensees.

Also, under the Memorandum of Understanding, DOT requires reports and investigates incidents that occur or are detected while in transit, and AEC requires reports and investigates incidents that occur or are detected before transport or after receipt.

In normal transportation, radiation exposures from packages of radioactive material are controlled by (A) limits on the external radiation levels on the outside of each package and by (B) provisions on storage, stowage, and handling exercised by the carrier based on the Transport Index (TI) which is the number of mrem/hr at 3 ft from the package (Fig. 1). While the regulations do not specify allowable radiation levels in occupied areas, they do specify that the sum of the TIs for packages in any single area or on any aircraft cannot exceed 50, and packages must be placed in the cargo compartment so that the distance between the passenger compartment (Fig. 2) and the nearest package surface is at least as great as that specified in the regulations for the total TI on the packages in the cargo compartment. Together these regulations limit radiation dose rates to persons on the plane to no more than 4 mrem/hr at seat level.

According to the radiotoxicity and the radiation and physical characteristics of the radioactive content, its half-life, and the quantity involved, packages of radioactive material are divided into three basic types: exempt, Type A, and Type B (Table 3). Small quantities of radioactive material may be shipped in exempt or Type A packaging in accordance with DOT requirements, which does not require AEC approval. Most of the radiopharmaceutical traffic falls in these categories — mostly in Type A.

The exempt category does not require specific labeling and requires only strong industrial packages while Type A quantities must be shipped in labeled packaging that will prevent loss or dispersal of the radioactive contents and retain shielding effectiveness under normal conditions of transport, including anticipated rough handling.

Quantities exceeding Type A limits must be shipped in Type B packaging which is designed to withstand accident conditions without loss of contents or shielding efficiency.

Table 3. Categories of Radioactive Shipments

Exempt quantities	Low specific activity very small amounts	(No appreciable hazards)
Small quantities	Type A packaging	(Withstand normal conditions of transport)
Intermediate quantities	Type B packaging	(Withstand accident)
Large quantities	Type B plus heat	
Fissile materials	Type B plus criticality considerations	

Table 4. Estimated Number of Shipments

Year	Mode of transport	Estimated No. of shipments
1961	Rail, truck, air	200,000
1973	Rail, truck, air	800,000
1973	Passenger aircraft*	600,000

*About 95% of shipments aboard passenger aircraft are small quantities of medical radioisotopes for hospitals and doctors.

Safety Precautions

Within the United States over the past 25 years, millions of packages of radioactive material have been transported but only about 350 reportable accidents or incidents in all modes of transportation have occurred. Only 30% of these involved any release of contents or increased radiation levels and none resulted in serious injury or death attributable to exposure to radiation.

There were two recent incidents involving Type B packages on passenger aircraft — none involving radiopharmaceuticals. In 1971 an aircraft was contaminated when an estimated 7 Ci of ^{99}Mo in liquid form leaked from a faulty container, and last April, 32 Ci of ^{191}Ir radiographic source was improperly loaded in a shielded container and thus caused radiation exposure to cargo handlers, passengers, and crew members. In response to this incident, the shipper has been notified of the AEC's intent to impose a civil penalty of $8,000 for failure to follow proper procedures for packaging. To further minimize the probabilities of incidents involving radiographic sources, we have stopped the use of the C-10 cask involved in the incident until modifications of the design of the cask, approved by AEC's regulatory staff, have been made by the manufacturer. After an investigation of other types of casks for radiography shipments, another design was found deficient and its use was stopped until approved modifications are made.

For other shipments, we are considering various means to require shippers and receivers to reduce the probabilities of occurrence of incidents and to minimize the exposure if incidents do occur. For example, a proposed amendment to AEC regulations published for comments in December 1973 would impose more comprehensive requirements for quality assurance in the design, fabrication, assembly, testing, use, and maintenance of Type B, large quantity, and fissile material packages. Already, subsequent to the first passenger aircraft incident in 1971 in which there was leakage of liquid from a Type B package, DOT has imposed precautionary requirements on shippers that provide for checks before each shipment on external radiation and contamination levels and on possible leakage at drastically reduced external pressure. The AEC amendment would further reduce the likelihood of improper packages being transported.

Another recent AEC amendment already requires prompt pickup and monitoring of certain packages on receipt and the immediate reporting of leakage or excessive levels to the carrier and to the AEC. However, on the basis that some packages have a very low probability of leakage and that other packages contain insufficient radioactive material to produce a significant hazard even if leakage occurs, we have exempted some categories of packages in which most of the radiopharmaceuticals are shipped. This is because of the types and limited quantities of radionuclides in Type A packages and the requirements, among others, of providing abundant absorption material inside the package. No incident involving Type A packages of radiopharmaceutical shipments has resulted in significant exposure to transport workers or the general public.

The rapid growth of the use of radiopharmaceuticals in hospitals and clinics has caused a dramatic increase in the number of shipments of medical isotopes in recent years (Table 4). For example, it was estimated that in the United States in 1973 there were about 800,000 shipments of radioactive materials. Seventy-five percent of these shipments were carried on aircraft, mostly on passenger aircraft. Of those carried by air, more than 95% were small amounts being shipped for medical use. The number and size of shipments may be expected to increase continuously. Radiation exposure to cargo handlers, airline crews, and the general public under normal transport conditions will also increase unless steps are taken to reduce them. For this reason, the AEC, in cooperation with DOT and FAA, has carried out a series of studies and surveys to evaluate the adequacy and effectiveness of the regulations for the transportation of radioactive material by air.

Measurements on Aircraft

Beginning in early 1973, AEC and FAA initiated investigations of radiation levels in passenger aircraft (Table 5). At Chicago and Boston, radiation levels in actual flights known to be carrying packages of radioactive material were measured.

While we found that the Chicago results were within expected limits, the radiation levels in some aircraft in Boston were higher than expected — a maximum dose rate of about 20 mrem/hr with the average of the maximum dose rates of 7 mrem/hr for the surveyed flights. Data on package placement related to the higher radiation levels in Boston indicated personnel were not loading packages of radioactive material in accordance with the requirements of FAA regulations. While FAA was taking steps to correct the apparent noncompliance by carrier-loading personnel, the AEC spot-checked shipments of radioactive materials at airports in San Francisco, St. Louis, and New York and found no other indications of the unsatisfactory loading procedures.

After the FAA took corrective action, Logan Airport was resurveyed and we found that the levels of radiation had been reduced significantly. On all but two flights the maximum dose rate at the passenger seat levels was below 4 mrem/hr.

Based on the data collected in these surveys, we estimate that the maximum individual dose to a passenger who commutes frequently or to stewardesses resulting from the transport of radioactive material aboard passenger aircraft is unlikely to be more than 150 mrem/year, and the average radiation dose to those receiving the highest exposure to be about 50 mrem/year. The estimated maximum dose to a pilot, under normal conditions of transport, is unlikely to be more than about 10 mrem/year. I want to emphasize that these estimates are the *maximum* doses. Most passengers receive only a small fraction of 1 mrem/year. As a matter of fact, we estimate that the average individual annual dose to the 6 million persons traveling on passenger aircraft carrying radioactive materials is about 0.25 mrem/year. These exposures may be compared with the Federal Radiation Protection Guide of 500 mrem/year (Table 6) to an individual member of the public or an annual average dose to the population of 170 mrem/year from all sources of radiation other than medical exposures or exposures from natural background.

The Future

But simply because the exposures appear "within limits" does not mean we should be complacent about reducing exposures where practicable. I can assure you the AEC is not; presently, among other things, we are investigating the increase in shielding and transportation costs if more restrictive controls were imposed on radiation levels from packages. The Atomic Industrial Forum provided an estimate that the transportation costs of radiopharmaceuticals would be increased by 25% if the TI limit were lowered from 10 to 3 TI for each package, more than 75% if lowered to 1 TI, and 164% if ^{99}Mo generators were prohibited on passenger aircraft. Another AEC-sponsored study, this one by Gordon Brownell of Massachusetts Institute of Technology and Massachusetts General Hospital, was completed in July of this year.

With the continual increases in numbers of shipments, we should continue to examine the standards to assure that the radiation dose and the probability of occurrence of accidents and incidents remain low. We are studying ways by which the radiation dose to all exposed individuals can be reduced to a level as low as practicable to avoid unnecessary exposures and to reduce the probability of accidents and incidents. We urge that the shippers of radiopharmaceuticals, the Society of Nuclear Medicine, and the transport industry also carefully examine the best methods of transport to assure safety. And finally, we believe that it is feasible to deliver packages of radiopharmaceuticals to hospitals and clinics rapidly and safely by passenger aircraft.

Table 5. Programs to Assess Exposures from Transportation of Packages

Program	Objective	Results
Oklahoma City study	To measure dose rate – simulated loading conditions	Max. dose rate 3.4 mrem/hr
Boston – Chicago radiation survey	To measure dose rate – actual loading conditions	Found and corrected violation of loading procedures
		Max. dose rate 4.5 mrem/hr (Second Boston survey)
Airlines survey	To collect information on distribution of packages on passenger flights	10% flights carried packages of radioactive materials for busiest airports and 3% average over U.S.

Table 6. Radiation Exposures (Comparative Information)

Annual whole-body exposures from natural background radiation (cosmic radiation; radioactivity in rocks, soil, building materials; radioactivity in body)	
United States	70-200 mrem (0.07-0.2 rem)
Special areas	Average
Brazil	
Volcanic areas	1,600 mrem (1.6 rem)
Monozite sand areas	500 mrem (0.5 rem)
India	
Monozite sand areas	1,300 mrem (1.3 rem)
Federal Radiation Council (FRC) Guides – Annual whole-body exposure	
Occupational exposure	5,000 mrem (5 rem)
Individual in population	500 mrem (0.5 rem)
Suitable sample population group	170 mrem (0.17 rem)
Medical exposures to localized portion of body	
Average chest x-ray	20-500 mrem (0.02-5 rem)
Range for fluoroscopic examination of gastro-intestinal tract	5,000 mrem (5 rem)
First detectable clinical effects (acute exposures)	25,000-100,000 mrem (25-100 rem)
Cosmic radiation exposure to whole-body during round trip flight – Washington, D.C. to West Coast at 35,000 ft.	3-5 mrem (0.003-0.005 rem)