Radiation Protection Principles Underlying the IAEA Transport Regulations and Transport Experience Under Normal and Accident Conditions

by A.N. Tse

INTRODUCTION

Radioactive materials are widely used in medicine, industry, and research. In connection with such uses, these materials are transported between the manufacturers, the processors, the users, and the waste disposal facilities. Because radioactive materials emit radiation that may cause harm to humans and the environment, these materials must be controlled during the entire cycle from manufacture to final disposal, including transportation.

Millions of radioactive material packages are transported each year. A survey conducted in 1975 showed an annual volume in the USA of about 2.5 million pacakges Ref. [1]. About one-third of the packages contained only very small quantities of radioactive materials. The most common modes for transporting radioactive materials in the USA were truck and passenger aircraft, the latter being used mainly to transport short-lived radiopharmaceuticals. The Federal Republic of Germany reported about 150 000 shipments in 1975 Ref. [2], 50 000 packages were transported in Italy in 1978 by one of the major firms involved in the use and transport of radioisotopes Ref. [3]; in Poland, about 100 000 packages of radioactive material were transported in 1978 Ref. [4].

RADIATION PROTECTION PRINCIPLES UNDERLYING TRANSPORT REGULATIONS

The radiation protection principles underlying the IAEA transport regulations are basically derived from recommendations of the International Commission on Radiological Protection (ICRP), which apply to all aspects of radiation protection. ICRP Publication No. 9 Ref. [5] stated that the objectives of radiation protection are to prevent acute radiation effects and to limit the risks of late effects to an acceptable level. It recommended maximum dose limits for members of the public and for workers who are exposed to radiation in the course of their work. As any exposure to radiation may involve some degree of risk, the ICRP further recommended that *all unnecessary exposure be avoided* and that all doses be kept *as low as is reasonably achievable,* economic and social considerations being taken into account. The IAEA transport regulations are designed to provide adequate safety protection to members of the public and to transport workers involved in transportation of radioactive materials.

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The radiological risks involved in transportation of radioactive materials may be divided into two groups: those associated with normal conditions of transport and those occurring as a result of accidents. During normal transport, radiation levels outside packages of radioactive material expose transport workers who are handling or transporting these packages. Also, external radiation levels expose members of the public who are in the vicinity of these packages. The main protection measures are (1) to limit the external radiation exposure rates at or near the surfaces of packages to low levels by the use of shiedling materials, (2) to specify the minimum separation distance between the packages and areas occupied by persons, and (3) to minimize the exposure time when feasible.

In case of accidents involving packages of radioactive materials, the contents of these packages could be released and could expose persons in the vicinity to direct radiation or through inhalation or ingestion of radioactive material. The main protection measures are (1) to contain the materials in strong packages so that the radioactive content is unlikely to be released or become unshielded even under accident conditions, (2) to limit package content, and (3) to utilize quality assurance procedures to minimize the probability of release of the contents or the creation of excessive external radiation levels as a result of human error.

Quantities of radioactive materials with high hazard potential must be transported in accident-resistant packages. However, quantities with a low hazard potential may be transported in packages designed to withstand only the rigours of normal transportation. In determining the hazard potential, the following factors are considered: the radionuclides to be shipped, their physical and chemical forms, and the quantity of radioactivity in the package.

In addition to the protection provided by the packaging, shippers and carriers are required to exercise procedural controls such as maintaining minimum separation distances to limit the radiation exposure to transport workers and members of the general public to acceptable levels. Packaging design, contents limitations and, when necessary, procedural controls to limit the number of fissile packages in a shipment are required to prevent criticality.

EXPOSURE DATA ON TRANSPORT WORKERS AND MEMBERS OF THE PUBLIC DURING NORMAL TRANSPORTATION

Most packages containing materials that give off penetrating radiation have sufficient shielding that the radiation levels outside the packages are very low. However, it is frequently impracticable to require that packages be shielded so that external radiation levels are insignificant. Therefore, members of the public or transport workers who come near these packages might receive certain small radiation exposures. The exposure data from normal conditions of transportation are summarized below.

Members of the Public (Other Than Transport Workers)

Several subgroups of the public can be exposed to radiation from shipments of radioactive materials: passengers riding in passenger aircraft carrying shipments of radiopharmaceuticals, persons in surface vehicles occupying the same transportation link as the shipments (on link); and persons along the transportation link (off link).

Table 1. Members of the public: Estimated annual doses from transport of radioactive materials in the USA Ref. [6] (under normal transport conditions)

Transportation mode and population subgroup		Annual individual dose (mrem)	Annual collective dose in 1975 (person-rem)
Air:	passengers	0.34 (ave)* 108 (max)**	2330
Truck:	on link	1.9 (max)	172
	off link	0.009 (max)	348
	While stopped	1.3 (max)	1000
Rail:	on link	not evaluated	0.012
	off link	0.017 (max)	23
Water:	persons in port area	not evaluated	0.9
	persons in vicinity of storage area	not evaluated	0.4

* average
** maximum

The radiation exposure received by members of the public is expected to be very low. Table 1 shows annual dose equivalent estimates for various subgroups of the public based on a risk assessment study for the USA Ref. [6]. The maximum annual dose, 108 millirem (mrem), for aircraft passengers was derived under conservative assumptions that a passenger flies 500 hours per year between the two US airports that have the highest traffic in radioactive material shipments. In practice, however, it is extremely unlikely that a passenger would receive such a dose. As a comparison, the average radiation dose to individuals in the USA from natural background sources is about 100 mrem per year and the annual collective dose in the USA from natural background is about 20 000 000 person-rem.

Transport Workers

The amount of radiation received by a transport worker is dependent on the number of packages to be handled and the external radiation levels around these packages. Most transport workers involved in radioactive material shipments are expected to receive annual doses much less than the dose limit for individual members of the public recommended by ICRP. In some cases, however, when large numbers of packages are handled through a single facility, certain transport workers may receive annual doses higher than the limit for members of the public. Such transport workers should operate under a radiation protection programme with appropriate instruction, training, and monitoring.

Surveys were conducted in the USA and other countries to estimate doses received by various groups of transport workers. Some results of these surveys are summarized in Table 2. Italy reported that average annual dose equivalents received in 1978 by the drivers involved in road transport were about 160 mrem and the maximum was about 1300 mrem

Table 2. Transport workers: Estimated annual doses from radioactive material shipments (under normal transport conditions)

Location	Transportation mode and population subgroup		Annual individual dose (mrem)				Annual collective dose (person-rem)
USA Ref [6] (Total packages transported in 1975 ~2.5 million)	Air:	pilots	0 53	(ave)*,	2.5	(max)**	16
		flight attendants	6	(ave),	13	(max)	112
		ground crew	85	(max),			11
	Truck	crew	870	(max)			2580
		storage	500	(max)			261
	Rail:	crew	1.2	(max)			0.9
		storage	25	(max)			0.7
	Water	crew	3.7	(max)			5.7
		stevedores	not evaluated				1 1
France Ref. [7]							
Saclay	Truck:	crew					
	1976	(7 persons)	25	(ave)			0.17
	1977	(8 persons)	22	(ave)			0.18
	1978	(8 persons)	42	(ave)			0.34
Cadarache	Truck:	crew					
	1976	(21 persons)	166	(ave)			3.48
	1977	(33 persons)	62	(ave)			2.06
	1978	(32 persons)	254	(ave)			8.14

* average
** maximum

Ref. [3]. Poland reported that in 1978, annual doses of the five drivers monitored ranged from 50 to 530 milliroentgens (mR) with an average annual dose of 270 mR Ref. [4].

TRANSPORT ACCIDENT EXPERIENCE

During the past 30 years, millions of packages of various types of radioactive and fissile materials, including reactor wastes and irradiated fuels, have been transported by various modes. A very small number of these packages were involved in accidents and an even smaller number resulted in any release of radioactive content or increased radiation levels outside the packages.

Over a 5-year period (from 1971 to 1975), there were 144 accidents involving radioactive materials reported to the US Department of Transportation Ref. [8]. In 36 cases, there were some indications of release of contents or excessive radiation levels. Most of the releases involved minor contamination from packages containing low-level radioactive materials.

In the United Kingdom, the Radiochemical Centre at Amersham reported that, of over 200 000 packages shipped per year, only one package has been involved in a major aircraft crash Ref. [9]. The aircraft burned and the package's outer carton was destroyed, but there was no leakage of radioactivity. On the average about one of Amersham's packages was damaged each month due to mishandling at an airport — usually crushed by a vehicle during mechanical handling. In only one case there was leakage of radioactive material and considerable spread of contamination.

In Poland, accident experience from 1971 through 1975 showed eight transportation accidents involving radioactive materials Ref. [10]. None of these had significant consequences from the radiological point of view. In only two cases were small areas around the transport units contaminated, and in one case the loading area inside a vehicle was contaminated.

India reported that, of over 70 000 packages of radioactive materials shipped from Trombay, only four packages were involved in accidents Ref. [11]. Three were run over by vehicles at the airports during trans-shipment. Although the outer packages and the tin containers were deformed, the vials containing the materials were intact and no contamination was found on the outer surfaces of the damaged packages. The fourth accident involved a gamma irradiation unit. The package was thrown off the truck into a 15-foot-deep stream during an accident to the vehicle. There was no increase in the radiation level on the outer surface of the shielding container and no damage was caused to the internal mechanical parts.

There have been several recent accidents. Three accidents, two in the USA and the other in Canada, are discussed briefly below. In September 1977, a tractor-trailer loaded with 40 000 pounds of natural uranium concentrate (yellowcake) in 55-gallon steel drums overturned after colliding with three horses in a farming area in Colorado Ref. [12]. Thirty-two of the fifty drums were thrown through the top of the trailer near the front and a total of about 12 000 pounds of concentrate spilled from the drums. To prevent spreading of the material by wind, the truck and spill area were initially covered by heavy plastic sheeting. Cleanup operations were completed in 10 days. Radiation doses received by the cleanup personnel and the air concentration in the vicinity of the cleanup operation were monitored. The results indicated that intakes of uranium by members of the public and by cleanup personnel were far less than the intake required to cause adverse health effects.

Four steel cylinders (each with a capacity of 8500 kg uranium) containing natural uranium hexafluoride were on a train when it derailed on March 21, 1977, near Rockingham, North Carolina Ref. [13]. The cylinders were mounted on steel cradles that were securely fastened to trailers that in turn were riding on flatcars in standard piggyback fashion. All four trailers and cylinders were damaged in the derailment. Three cylinders were thrown free of the train wreckage. The fourth cylinder stayed in the wreckage and was exposed to fire involving a carload of ammonium nitrate. There was no leakage, no breach of the containers, and no radioactive contamination. The steel cylinders were dented but not ruptured.

In December 1976, at Laterriere, Quebec, a truck containing 40 000 litres of gasoline collided with a stationary truck carrying a density gauge with a caesium 137 source Ref. [14]. A fire started and burned for about 90 minutes. The gauge lost its lead shielding, presumably through a hole while the lead was molten during the fire, which resulted in a maximum radiation field of 3 rems per hour at the surface. There was no radioactive contamination.

Release of radioactive material or elevated external radiation levels during transportation may occur as a result of human error or insufficient quality control procedures. Two examples in the USA are outlined below. In December 1971, a passenger aircraft was contaminated by a leaking package of molybdenum-99; before the contamination was discovered, 917 passengers had travelled aboard the aircraft Ref. [15]. The aircraft was removed from service and subsequently decontaminated. Passengers who had flown on this contaminated aircraft were notified by telephone and through the press. Survey check stations were set up in the ten cities at which the aircraft had stopped. The results of the survey indicated that neither passengers nor employees had been subjected to a personal health hazard. Numerous items of baggage were found with a small amount of contamination. They were decontaminated and returned to the owners.

In April 1974, a gamma source exchanger containing iridium-192 was transported in a passenger aircraft from Washington, D.C., to Atlanta, Georgia, then transferred to another flight to Louisiana Ref. [16]. It was discovered at the destination that the package was improperly shielded, which resulted in high external radiation levels. Worst case estimates based on time and motion studies indicated transport workers may have received radiation doses ranging from minimal to about 134 roentgen (R) for one employee. Measurements were conducted to obtain worst-case simulation of exposures to passengers during the accident. The result indicated that the highest exposure rate at seat level was about 4.6 R/hr.

RISK ASSESSMENT

Risk assessment for transportation of radioactive materials is performed to quantify the impacts on persons and the environment and to project the impacts from future shipments. These impacts may include radiation exposure from normal conditions of transport and from accidents. Emphasis is placed on radiological health effects, but all environmental impacts, both radiological and nonradiological, are assessed. The results of the assessment can provide information on the adequacy of the current regulatory control. The methodology can also be used in cost-benefit analyses of alternatives.

There have been many risk assessments performed in the area of radioactive material transportation by various countries. Two US risk assessments, one completed and the other in progress, are discussed briefly below for the purpose of illustration. One assessment deals generically with the environmental impact from transportation of radioactive materials into, within, and out of the United States Ref. [6]. The radiological and nonradiological impacts were based on shipment data collected in a 1975 survey in the USA The survey data were extrapolated to 1985 and radiation doses to transport workers and members of the public evaluated. Risks from transportation accidents were estimated based on probabilities of occurrences and postulated radiation exposures for each of eight accident severity categories. Alternative conditions of transport were considered and changes in risks evaluated.

The results of the assessment indicated that the radiological risks from radioactive material are small. The consequences of a major release of plutonium or polonium in a densely populated area could be significant, but the probability of such an event is extremely low. Some of the individual and collective doses estimated by the assessment were presented in Tables 1 and 2.

As a continuation of the above generic assessment, a second investigation was initiated in the USA to develop information on the transportation of radioactive materials in urban areas. A working draft assessment was issued in 1978 Ref. [17]. The urban study considers special features of the urban setting such as high population density and its daily variations, shielding effects of buildings, the effects of local meteorology and micrometeorology, and the convergence of transportation traffic. New York City is used for model development, but the methodology used is applicable to other urban areas.

CONCLUSION

The experience obtained over the past 30 years demonstrates that the transport of radioactive materials has achieved a high standard of safety. Under normal conditions of transport, individual doses were shown to be within the dose limits recommended by ICRP. Accident experience indicates that, although accidents have occurred, the resulting radiological consequences were not serious. It is therefore concluded that the transport regulations are, in general, adequate and effective.

However, to take into account operating experience, technical advances, and the continual increase in numbers of radioactive material shipments, the transport regulations and their effectiveness are examined from time to time. The IAEA plans a comprehensive review of its transport regulations every 10 years. The next revision is planned for 1983 and work has already begun. The goals of such an examination are to ensure that regulations are technically current in order to limit radiation doses to all exposed individuals to a level as low as reasonably achievable, to avoid any unnecessary exposure, and to further reduce the already small risks of accidents in a cost-effective manner.

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