The Transport of Radioactive Materials

by G.E. Swindell

Radioactive materials are being transported throughout the world in ever increasing quantities. They cover a very wide range from the radiopharmaceuticals and labelled compounds used in diagnostic nuclear medicine to the very high-activity spent fuel and wastes that arise in nuclear power plants and fuel reprocessing plants.

All of these materials are transported on land, sea or in the air in compliance with regulations which are now universally based on the IAEA Regulations for the Safe Transport of Radioactive Materials Ref. [1]. These regulations are designed to ensure adequate protection of transport workers, the public and the environment against the hazards of external radiation, the spread of radioactive contamination and, in the case of fissile materials, criticality.

The necessary safety measures are, to the extent possible, incorporated in the packagings in which the materials are transported. The packages can, in the vast majority of cases, be treated by the carrier in the same way as packages of other potentially dangerous goods. The transport workers who, in general, will have no specialized training must observe some relatively simple rules concerning the stacking of the packages and their segregation from persons and from unprocessed photographic film

DESIGN AND TESTING OF PACKAGINGS

Very small quantities of radioactive materials, either alone or incorporated in other devices, can be transported in packages which are exempt from special design requirements.

Larger quantities, such as those used in diagnostic nuclear medicine and in research, are transported in Type A packages which will withstand normal transport conditions, including the somewhat rough handling that may be expected. In serious accidents the containment of a Type A package may be ruptured and part of the contents dispersed into the environment. Upper limits are therefore prescribed in the regulations for the activities of individual radionuclides that can be transported in such packages. In order to qualify as a Type A packaging, specimens of the design must pass a series of performance tests which are designed to produce the type of damage that would be caused by small mishaps in normal transport conditions.

Larger quantities of radioactive materials, including sealed radioactive sources for medical and industrial purposes, spent nuclear fuel, high-level wastes and highly radiotoxic materials, must be transported in Type B packagings which are designed to withstand very severe accidents in all the modes of transport without any unacceptable loss of containment or shielding. The Type B packagings must pass an additional series of tests intended to produce the type of damage that would be caused by accidents involving very severe impacts, fires

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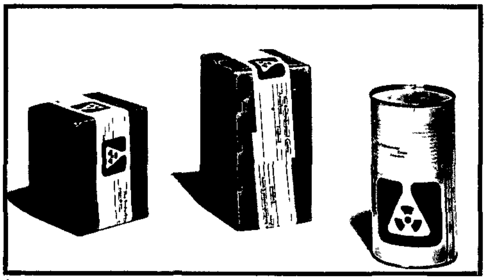

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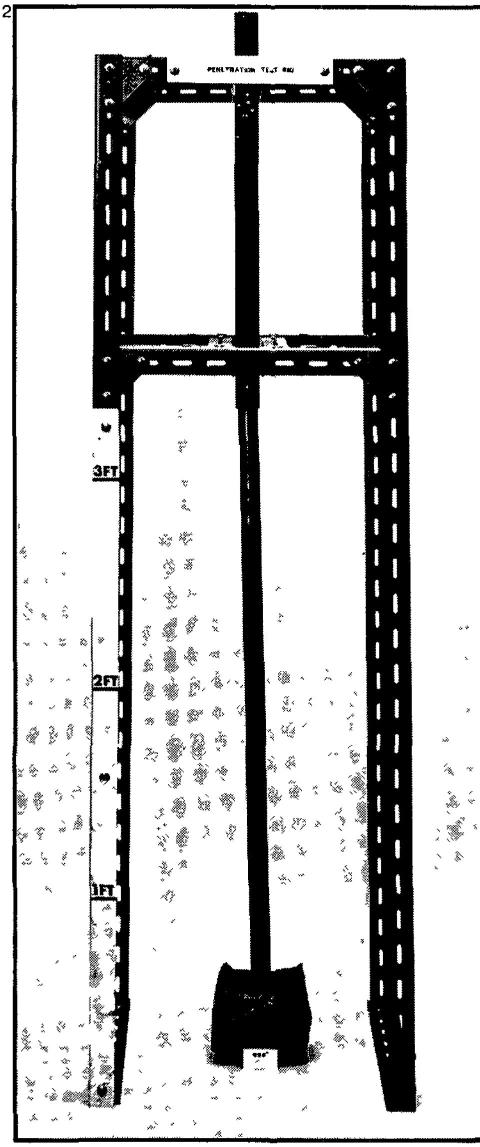

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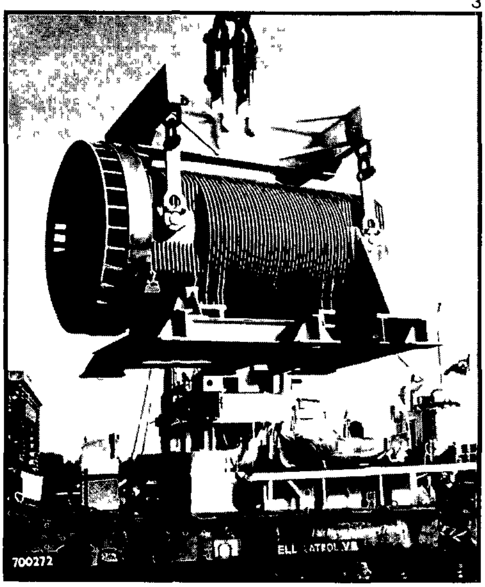

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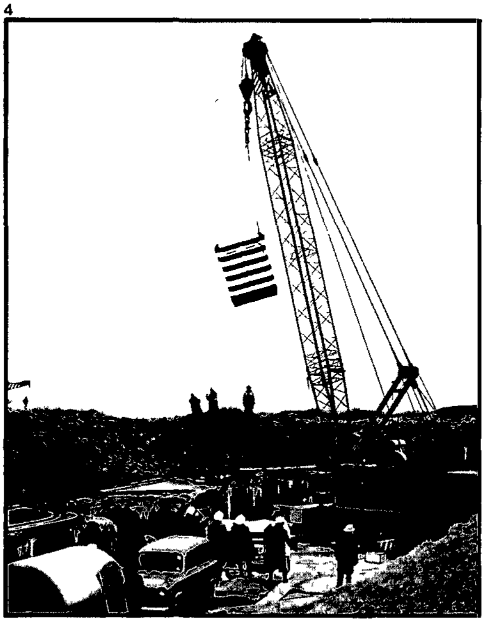

Fig.1. Two types of transport packages are prescribed by the regulations, Type A and Type B. This illustration shows typical examples of the former. Ref. [2]

Fig 2 Penetration tests for Type A packaging are carried out with equipment such as this. Ref. [3]

Fig 3. Highly radioactive material such as spent fuel is transported in Type B packaging, of which this Excellox flask is a typical example. Ref. [4]

Fig 4. Type B packaging must withstand several tests, one of which is the drop test, shown here. Ref [5] and immersion in water. The design of a Type B packaging must be approved independently by a competent national authority on the basis of a safety analysis report. There are no regulatory upper limits on the activities of radionuclides that can be transported in Type B packagings, but limits are of course specified in the approval certificate for a particular packaging.

VOLUME OF TRAFFIC AND ESTIMATED RADIATION DOSES

Extensive information has been collected in various countries, in particular the United States, on the number of consignments of different types of radioactive materials being transported annually, and on the collective doses and maximum individual doses received under normal transport conditions by transport workers and by selected groups of the public.

Examples of such information are shown in Tables I, II, and III.

TABLE I. Ref. [6]
Summary of radioactive material shipping in the United States

	1975		1985 (projection)	
Shipment type	Packages per year	Curies per year	Packages per year	Curies per year
Limited	7.03×10^5	2.14×10^3	1.83×10^6	5.50×10^3
Medical	9.10×10^5	5.78×10^6	1.71×10^6	1.50×10^7
Industrial	2.15×10^5	$9\ 39 \times 10^6$	$5\ 63 \times 10^5$	2.47×10^7
Fuel cycle	2.04×10^5	5.32×10^8	8.36×10^6	$8\ 41 \times 10^9$
Waste	1.52×10^5	2.68×10^5	6.27×10^5	1.11×10^6
Total	2.19×10^6	5.48×10^8	5.57×10^6	8.45×10^9

TABLE II. Ref. [7]
Estimated total annual collective dose and average individual dose to members of the public in the United States

	1975	1985
Total annual population dose (Man-rem)	9 790	25 400

$$\text{1975 average individual dose} = \frac{9\ 790}{20 \times 10^6} = 0.5 \text{ mrem}$$

TABLE III. Ref. [8]
Summary of maximum annual individual doses from radioactive material transport in the United States

Population Subgroup	1975 Max. (Avg.) Probable Dose (mrem)	
Airline Passengers	108	(0.34)
Cabin Attendants	13	(2.9)
Passenger Aircraft Flight Crew	2.5	(0.53)
All-Cargo Aircraft Flight Crew	61	(12)
Air Crew (other air modes)	5	
Truck Crew	870	
Van Crew	70	
Train Crew	1.2	
Ship Crew	3.7	
Freight Handlers	500	
Bystanders (pass. air)	85	
Bystanders (cargo air)	106	
Bystanders (other air modes)	60	
Bystanders (truck)	1.3	
Bystanders (rail)	1.65	
Off-link (truck/van)	0 009	
Off-link (rail)	0.017	
On-link (truck/van)	1.9	
Storage (rail)	25	

TRANSPORT ACCIDENTS

Accidents occur in all modes of transport and some of these inevitably involve packages of radioactive materials. In the United States, Hazardous Materials Incident reports have to be submitted in accordance with the Department of Transport regulations. During the period 1971–1975 about 32 000 such reports were submitted. Of these 144 related to incidents involving packages of radioactive materials and in 36 cases some release of the contents was reported. In no case has any release been observed from a Type B package as the result of an accident Ref. [9]. Small releases have, however, occurred as the result of incorrect assembly of a few Type B packages. These will be prevented in future by the application of improved quality assurance programmes.

This experience points to the adequacy of the current design standards for transport packages. It is very desirable, however, that statistics on accidents should be accumulated on a world-wide basis and the Agency has prepared plans for the collection of the necessary information on the number of accidents in relation to the total volume of traffic in radioactive materials.

In spite of the good safety record that has been maintained, studies are being undertaken in a number of countries on the future risks associated with the transport of nuclear materials

Table IV illustrates the assessed probability of occurrence of severe accidents in high population density areas in the United States and the resulting collective dose commitments. Table V compares the risks of early fatality from transport accidents with those resulting from other accidents.

TABLE IV. Ref. [10]
Estimated probability of occurrence and collective dose commitments from severe accidents (Class VIII) in high population density areas in the United States

Consignment	Probability of occurrence of severe accident		Collective dose commitment in man-rem	Organ
	1975	1985		
Co-60 315,000 Ci	1.02×10^{-10}	2.55×10^{-10}	284	Whole body
Pu 1.23×10^6Ci	1.06×10^{-11}	1.06×10^{-11}	3.15×10^6	Lung
			1.11×10^7	Bone
Spent fuel (rail cask)	1.8×10^{-10}	6.91×10^{-9}	1400	Whole body
			2.85×10^4	Lung
Spent fuel (truck cask)	2.99×10^{-9}	1.8×10^{-8}	215	Whole body
			4450	Lung

THE TRANSPORT OF PLUTONIUM BY AIR

Some disquiet has been felt in a number of countries over the safety of the transport of plutonium by air and, in the United States, Public Law 94-79, enacted in August 1975 places the following restriction on the Nuclear Regulatory Commission:

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

A Plutonium Air Transportable Package, Model PAT-1, has now been developed by the Sandia Laboratories which meets the NRC Qualification Criteria Ref. [12]. These criteria include the limitations on release, in post-accident conditions, specified in the IAEA Transport Regulations. The package design for which the Safety Analysis Report was recently published Ref. [13], has now been certified as capable of withstanding severe aircraft accidents.

TABLE V. Ref. [11]
Individual risk of early fatality by various causes [USNRC-WASH-1400]

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

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

EXPERIENCE IN THE TRANSPORT OF SPENT NUCLEAR FUEL

A considerable amount of experience gained in the international transport of spent nuclear fuel was reported at the International Conference on Nuclear Power and its Fuel Cycle, held at Salzburg in May 1977. The paper by H.W. Curtis Ref. [14] is of particular interest as it describes the formation of an international company, Nuclear Transport Limited, by Transnuklear GmbH, Transnucléaire S.A. and British Nuclear Fuels Ltd., to provide a service to United Reprocessors for the transport of spent fuel from European light-water reactors. More than 400 tonnes of spent uranium fuel have been transported from fifteen power reactors. A mixed pool of transport casks has been established for transporting the fuel by road, rail and sea. The choice of the transport mode is dictated largely by the locations of the reactors and the reprocessing plants. The service has worked satisfactorily, although problems have arisen and have been overcome. These problems include the build-up in the cask of crud detached from the surface of the discharged fuel which increases the radiation exposure of the workers, the sweating out of radioactive contamination from the surfaces of the casks after they have been cleaned, inadequate access to the reactor site and to the fuel storage pools, and the timely maintenance of the transport vehicles.

An impeccable safety record has been maintained and no accidents have occurred in a period of eight years.

The future trend will be towards the use of larger casks weighing between 75 and 100 tonnes with a capacity of 1.2 to 5 tonnes of uranium fuel. These heavy casks must be transported by rail or by sea. There will also be a trend towards the standardization of cask design and the allocation of identified flasks to serve specific countries and ultimately to serve specific reactors and reprocessing plants.

PHYSICAL PROTECTION OF SPENT FUEL DURING TRANSPORT

Spent fuel is probably most vulnerable to attack or theft during transport, and here certain measures can be applied to protect the material. These measures are, in general, supplementary to those necessary to protect persons and the environment against damage from the radioactive contents of the packages The Agency has taken the lead in preparing internationally agreed recommendations for physical protection in transport Ref. [15]. The recommended measures include:

Minimizing the total time during which nuclear material remains in transit;

Minimizing the number and duration of nuclear material transfers during transit;

Avoiding the use of regular movement schedules;

Predetermining the trustworthiness of all persons involved in the transport;

Advance notification of the receiver,

Restraint in the use of special markings on vehicles and in the use of open channels of communication for transmitting information concerning the consignments,

Selection of transport methods and routing,

Provision, in certain circumstances, of escorts or guards to give alarm, if necessary, to expedite handling and to help avoid misrouting.

References

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Materials (1973 Revised Edition), Safety Series No 6, IAEA, Vienna (1973)

[2] DIXON, F E., COHEN, L R , "Testing Type A Packagings", (Proc Int. Seminar on Test Requirements for Packaging for the Transport of Radioactive Materials, Vienna, 1971), IAEA, Vienna (1971) 94

[3] Ibid , p 101
[4] WILLIAMSON, S , "Application of Import Testing to Irradiated Fuel Flasks", ibid , p 565
[5] DIXON, F.E., DAVIES, A J , COHEN, L.R , "Furnace and Drop Testing of Type B Packagings", ibid , p 179
[6] Based on Table 1—2, US NUCLEAR REGULATORY COMMISSION, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes", NUREG-0170, USNRC, Docket No. PR-71,73 (40FR23768) (December 1977)
[7] Based on Table 4-20, ibid.
[8] Table 4-19, ibid
[9] PLATT, A M , et al , "United States Experience in the Transport of Radioactive Materials", (Proc Int Conf on Nuclear Power and Its Fuel Cycle, Salzburg, 2—13 May 1977), **4**, IAEA, Vienna (1977) 781
[10] Based on Table 5-12, US NUCLEAR REGULATORY COMMISSION, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes", NUREG-0170, USNRC, Docket No PR-71,73 (40FR23768) (December 1977)
[11] Table 5—16, ibid.
[12] UNITED STATES NUCLEAR REGULATORY COMMISSION, "Qualification Criteria to Certify a Package for Air Transport of Plutonium", NUREG-0360 (January 1978)
[13] UNITED STATES NUCLEAR REGULATORY COMMISSION, "Plutonium Air Transportable Package Model PAT-1", NUREG-0361 (June 1978)
[14] CURTIS, H W , "Experience of European irradiated fuel transport — the first four hundred tonnes", (Proc. Int. Conf on Nuclear Power and Its Fuel Cycle, Salzburg, 2—13 May 1977) **4**, IAEA, Vienna (1977) 767
[15] INTERNATIONAL ATOMIC ENERGY AGENCY, The Physical Protection of Nuclear Material, INFCIRC/225/Rev.1, IAEA, Vienna (1977)