Design, Construction and Testing of Packaging for the Transport of Radioactive Materials

by B.C. Bernardo

INTRODUCTION

Packages for transporting radioactive materials can be classified according to the conditions under which they are expected to retain their containment and shielding. Type A packaging is designed to withstand normal transport conditions but it is foreseen that under certain accident conditions it might release up to 1/1000 of its radioactive contents. Of this released material, 1/1000 might be absorbed by a transport worker or member of the general public. The overall assumption then is that one millionth of the contents of a Type A package might be absorbed by an individual. Based on this assumption, as well as on the radiotoxicity of the materials to be transported, limits on the contents of Type A packages are derived.

Type B packaging is intended to retain adequate shielding and containment under more severe accident conditions. There is no upper limit to the amount of radioactive material that may be transported in these packages; however, other factors such as the heat generated by the material must be dealt with in such a way that the packaging is not impaired.

DESIGN AND CONSTRUCTION

Design safety is preferred to operational control safety and is largely provided by the packaging. The regulations include provisions that packages shall be so designed that they are easily handled and properly secured during transport. Heavier packages are provided with lifting attachments. The outer layer of the package must not collect or retain water and the finish should be such that it may be easily decontaminated in case of surface contamination. Additional design requirements specify that the smallest overall external dimension is 10 centimetres and that account must be taken of variations in temperature to which the package may be subjected during transport and storage.

The design, fabrication and manufacturing techniques used should be in accordance with national or international standards or with those acceptable to the competent authorities. In addition, the package must be capable of withstanding the effects of any acceleration, vibration or vibration resonance which may arise during normal transport. The packaging materials and any components or structures must be physically and chemically compatible with each other and with the package contents, also taking into account their behaviour under irradiation. Components of the containment system must take account of the radiolytic decomposition of liquids and the generation of gas by chemical reaction and

Mr. Bernardo is a staff member in the Radiological Safety Section, Division of Nuclear Safety and Environmental Protection, IAEA.

radiolysis. All valves, other than the pressure relief valves, must be protected against unauthorized operation and be leak proof.

Type A packaging is designed such that when it is subjected to the tests demonstrating ability to withstand normal conditions of transport, (i.e., water spray test, free drop test, compression test and penetration test) there will be (a) no loss or dispersal of the radioactive content, and (b) no increase in the maximum radiation levels at the surface of the package above those prevailing before the test. Those packages designed for liquids are provided with sufficient absorbent material while those designed for compressed and un-compressed gases must, in addition, prevent loss or dispersal of the radioactive contents if the packaging is subjected to the additional free drop test and penetration test.

Type B (U) packages are designed to meet all the additional requirement specified for Type A packaging. When subjected to the tests demonstrating ability to withstand normal conditions of transport, a Type B (U) package must restrict the loss of radioactive contents to not more than $A_2^* \times 10^{-6}$ per hour, taking into account the external contamination limitations. When subjected to the tests demonstrating ability to withstand accident conditions (i.e., mechanical test, thermal test and water immersion test), it must retain sufficient shielding to ensure that the radiation level at 1 metre from the surface of the package does not exceed 1 rem/hr. The package is assumed to contain iridium-192 and have a radiation level of 10 mrem/hr at 1 metre from its surface before the tests. The accumulated loss of radioactive contents must be restricted to not more than $A_2^* \times 10^{-3}$ in a period of one week.

Furthermore, Type B (U) packages must be designed, constructed and prepared for shipment so that the heat generated within a package by its radioactive contents will not adversely affect the package. Specific additional requirements include compliance with the permitted radioactivity release limits: the package must not incorporate a feature intended to allow continuous venting during transport nor include a pressure relief system from the package's containment system that would allow the release of radioactive material to the environment.

Type B (M) packages have additional requirements which further limit the loss of radioactive contents after the tests for normal and accident conditions of transport.

TESTING OF PACKAGINGS

The tests for demonstrating ability to withstand normal conditions of transport are the water spray test, the free drop test, the compression test and the penetration test. These tests are aimed at simulating the damaging effects of both the climatic and mechanical conditions of normal transport, taking into account rough handling and minor mishaps. It is possible that during transport or even in storage packages may be exposed to heavy rains, hence the need for a water spray test. Similarly, while being handled or stacked in storage they may fall, indicating the requirement for a drop test. It is also not unlikely that packages may be subjected to a compressive load when larger or heavier packages are stacked on them and the need for a compression test can readily be seen. Objects that have penetrating properties (like pointed steel bars, etc.) may likewise fall on a package while it is in transport or in storage, so the need for a penetration test is recognized.

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* Definitions of A and A_2 limits are given in the first article in this Bulletin, "The IAEA Transport Regulations A Review of Their Development and Coverage".

Figure 1. Spent fuel shipping casks have been subjected to a series of crash tests at Sandia Laboratories in the USA. In this full-scale vehicle test, a railway locomotive, accelerated to 81.5 miles per hour by rocket sled, was allowed to crash into a transporter loaded with a fuel cask (red object). (Photo: Sandia Laboratories).

Figure 2. In another full-scale vehicle test, a railway wagon loaded with a fuel cask was crashed into this concrete wall at 81 miles per hour. (Photo: Sandia Laboratories).

Prototypes of the package must be subjected to the free drop test, the compression test and the penetration test, preceded in each case by the water spray test. It is possible that a package soaked in a driving rain may still suffer the effects of a fall or being compressed or penetrated. To give an idea of the rigorous and rather exacting requirements of the present transport regulations, some aspects of the tests are described.

Water spray test: Any water spray test is considered satisfactory provided that the spray is approximately equivalent to a rainfall rate of 5 centimetres per hour, uniformly distributed and for a duration of one hour.

Free drop test: In this test, the package falls onto the target so as to suffer maximum damage to the safety features to be tested and the falling distance measured from the lowest point of the package to the upper surface of the target is not less than 1.2 metre. Heavier packages fall from a lower height. For Fissile Class II packages, fibreboard or wooden packages, an additional free drop from a height of 0.3 metre is required.

In the **compression test,** the package is subjected for a period of 24 hours to a compressive load equal to the greater of 5 times the weight of the actual package or the equivalent of 1300 kg/m^2 multiplied by the vertically projected area of the package. The load is applied uniformly to two opposite sides of the package, one side being the base on which the package would normally stand.

Penetration test: The package is placed on a rigid, flat, horizontal surface and a bar of 3.2 centimetres diameter with a hemispherical end and weighing 6 kilograms is dropped from a height of one metre, with its longitudinal axis vertical, so that it falls onto the centre of the weakest part of the package.

In addition to the above tests, the following further tests for Type A packaging designed for liquids and gases are undertaken: an additional free drop test from a height of 9 metres so as to inflict maximum damage to the containment and another penetration test in which the falling distance of the bar is increased to 1.7 metre.

The tests for demonstrating ability to withstand accident conditions in transport, to which Type B packaging is further subjected are a mechanical test, a thermal test and a water immersion test. The package is subjected to the cumulative effects of the mechanical test and the thermal test in that order while a separate package is subjected to the water immersion test. Some aspects of the tests are described below.

The **mechanical test** consists of dropping a package twice onto a target in such a way that the damage it suffers in the drops will lead to the maximum damage in the thermal test which follows. For the first drop the package falls from a height of 9 metres onto a flat, horizontal, unyiedling surface so as to suffer maximum damage. For the second drop it falls onto a mild steel bar, 15 centimetres in diameter, from a height of 1 metre. The bar is rigidly mounted, is perpendicular to the target surface and must not be less than 20 centimetres long.

Thermal test: The mechanical test is followed by a thermal test in which the whole package is exposed to a temperature of 800°C for 30 minutes.

Water immersion test: The package is immersed in water with a head equivalent to at least 15 metres for a period of not less than 8 hours.

With these design requirements and tests specified for packages, one may still wonder whether the transport of radioactive materials including those of spent nuclear fuels, is indeed safe. The answer is yes; however, there is an ongoing review to determine the continuing adequacy of the present regulations. This effort is supported by a number of research and development programmes.

RESEARCH AND DEVELOPMENT PROGRAMMES

In response to an Agency enquiry in 1978, research and development work is presently being undertaken in Member States in order to evaluate the continuing adequacy of the package tests embodied in the regulations.

In Argentina, studies reviewing A_1 and A_2 values and differential cost-benefit analysis are being carried out. Canada reported a recently completed study on the comparative severity of furnace tests for packaging. Finland has done risk assessment studies of reactor waste transport and of spent fuel transport. France reported a number of studies including those on the safety of natural and depleted UF_6 in transport, radiolysis of water in lead casks, behaviour of PWR fuel during transport and the leaktightness of containments, an additional crush test and the development of a transport container for plutonium nitrate. The Netherlands is designing a shielded transport container for 0.1—1 megacurie quantities of krypton-85 in connection with the disposal of large amounts of this material. Poland reported on mechanical, thermal and radiation leakage tests that are being carried out. Sweden is developing basic risk assessment models in connection with transport of low- and medium-level wastes by ship through coastal waters and the resulting radiation dose to populations. R & D programmes in the United Kingdom include the review of A_1 and A_2 values, radioactivity leakage levels for B (M) and B (U) packages following an accident, the adequacy and relative severity of open fire and furnace test, leak testing, additional tests for air transport of Type B packages, fire resistance and thermal insulation of materials, and development of impact-resistant crushable structures.

In the United States, the Department of Energy's transport R & D programme covers the following three categories: (1) energy transportation planning and analysis, (2) risk assessment and testing, and (3) standards and information. One of the objectives under the first category is to predict trends in the development of the transport system through the year 2000 in order to identify in advance any safety or environmental problems. Under the second category, the objectives are to evaluate transport modes and to develop empirical and analytical data to assist in risk assessment and standards development. One of the objectives under the third category is to produce information exchange systems. Under category 2, full scale crash tests are carried out to learn more about severe transport accidents. The Plutonium Air Transportable Package (Model PAT-1) was produced as the result of a restriction on the air transport of plutonium until such a container had been developed and tested. In Japan, a safety assessment was made on sea transport of spent nuclear fuel. While it was shown that the probability of a ship carrying fuel casks sinking is very low, the radiation dose to the population that could result if such a ship sank in 200 and 2000 metres of water would still be within the limits given by the ICRP. Studies on the collapse behaviour of spent fuel casks in deep water resulted in the development of a pressure balancing valve designed to prevent such collapse. In the USSR, work has been done in transporting uranium hexafluoride in cylindrical containers. These were carried in standard open large-size 55 tonne trailers for marine transport of large and heavy loads, instead of closed freight containers. In India, 70 tonne casks have been fabricated to carry spent fuel and tests have shown that they conform to the regulations.

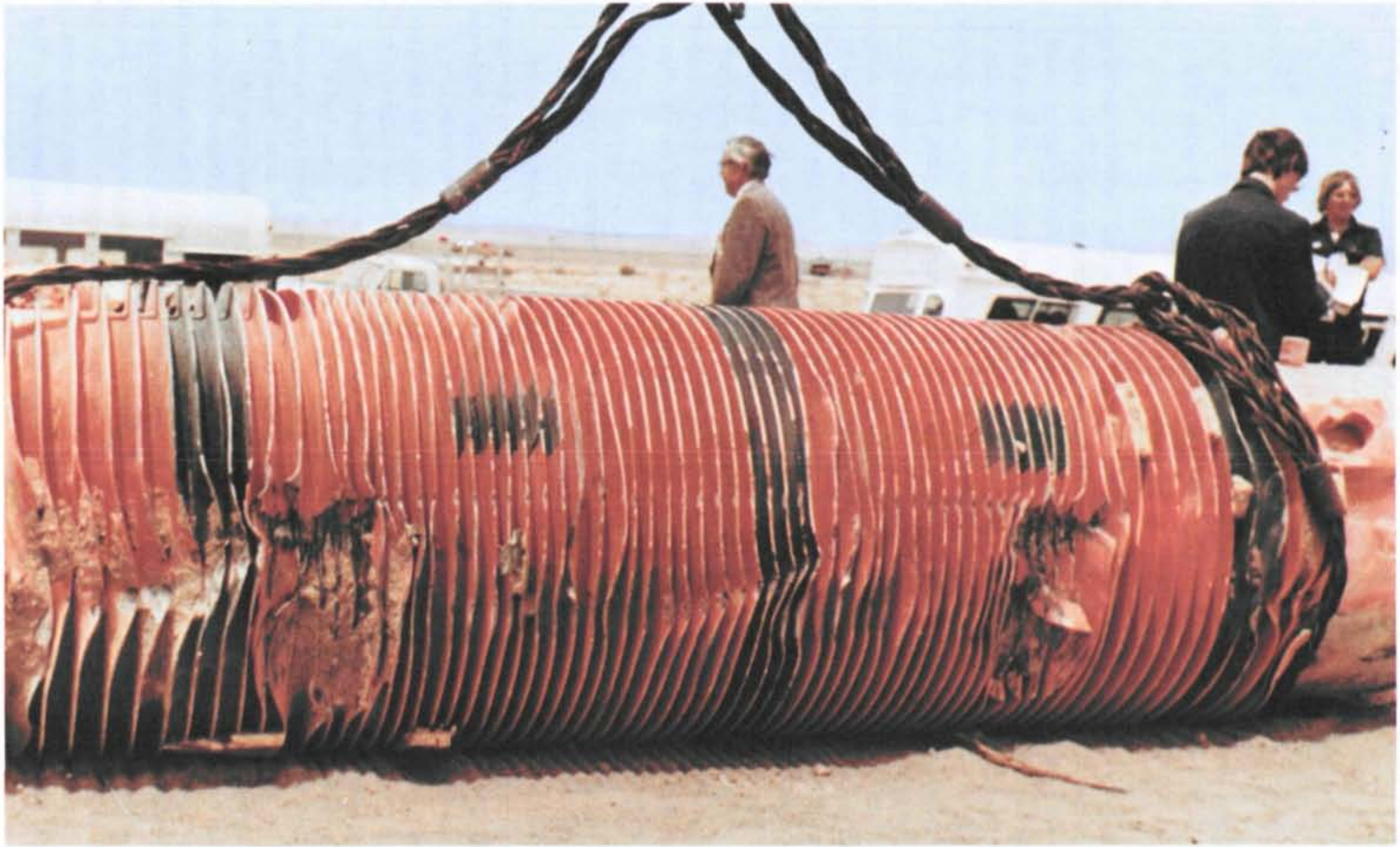

Figure 3. Fuel casks emerged from the crash tests with some exterior damage but intact. This cask was subjected to a full-scale vehicle test at 81.5 miles per hour. (Photo: Sandia Laboratories).

Figure 4. Rail wagon with a fuel cask undergoing a fire test. (Photo: Sandia Laboratories).

THE FUTURE

There is a growing trend towards more standardization in nuclear power stations as the standardized plant offers much in the way of improved safety, lower material costs, shorter procurement times, better reliability and economy, and shortened licensing time. This is apparently also the trend in the nuclear transport industry. With a sharp increase expected in the number of spent fuel shipments and with the beginning of high-level waste shipments, there could be a proliferation of cask and transport vehicle designs, which raises the question: Should there be fewer cask designs or are custom-designed special-purpose casks and vehicles a better way of meeting the need? The introduction of heavy shipping flasks has also required the development of a special eight-axle rail wagon able to transport these loads at the speeds of normal freight trains. Nevertheless, the trend is now towards one type of heavy flask for each reprocessing plant, supported by a small quantity of light flasks for special cases. The old flasks or similar replacements will, however, still be needed to service many of the existing reactors.