

INFORMATION PAPER

Nuclear Fuel Cycle Transport

The IAEA Regulations and their Relevance to Severe Accidents

Dedicated to the safe, efficient and reliable transport of radioactive materials



Nuclear Fuel Cycle Transport

The IAEA Regulations and their Relevance to Severe Accidents

Introduction

The design and performance standards for packages used for the transport of radioactive material, including nuclear fuel cycle material, are defined in the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material¹, in order to ensure safety under both normal, and even accident conditions of transport for the more highly radioactive materials. The underlying philosophy of the Regulations is that safety is vested principally in the package and its design is related to the potential hazard; i.e. the more hazardous the material the tougher the package. There is a large body of evidence to show that the IAEA test requirements are severe and cover all accidents which can be realistically envisaged in transport.

Nuclear power and the nuclear fuel cycle

Nuclear power has been providing clean, affordable electricity in many parts of the world for nearly half a century. It currently supplies some 16% of the world's demand for electricity from over 400 reactors in 31 countries and is expected to continue to play an important role in meeting the world's increasing demand for affordable and sustainable electricity.

The national and international transport of nuclear fuel cycle materials is essential to support this activity. To sustain the nuclear power industry, fuel cycle materials have to be transported safely and efficiently. The nature of the industry is such that most countries with large-scale nuclear power industries cannot provide all the necessary fuel cycle services themselves and consequently nuclear fuel cycle transport activities are international.

Nuclear fuel cycle materials

Nuclear fuel cycle materials come in a variety of chemical and physical forms and the potential hazards they present differ widely. This section describes the main characteristics together with the risks they would pose in the highly unlikely event of an accident.

Uranium ore concentrate

Uranium ore concentrate is a material of low radioactivity and it does not present a large radiological hazard. There is a minor risk due to the toxicity of the powder if it is released and is ingested. In this respect it is no different from most heavy metal compounds such as lead ores.

Uranium hexafluoride

Uranium hexafluoride (Hex) is also of low activity and the radiological risk is not great but any person exposed to a release of Hex would suffer due to its chemical toxicity. This is the case with many industrial chemicals, e.g. chlorine and ammonia.

Uranium dioxide powder

Uranium dioxide powder for the manufacture of new uranium fuel elements is also classified as low activity material. Again there is a minor toxic risk if the powder is released and ingested.

Uranium fuel assemblies

Fabricated uranium fuel assemblies are also benign. The fuel for the majority of nuclear reactors consists of assemblies of rods each filled with ceramic uranium oxide pellets enriched in the fissile component of uranium, U-235, to about 5%. The chemical hazard is negligible and the radiological hazard is low. As with all enriched uranium intermediate fuel materials the primary hazard is radiological in the event of a criticality excursion; i.e. an unwanted nuclear chain reaction. This is prevented by the design of the package and the configuration of the packages in transport.

Special criticality safety assessments are required for packages containing fissile material and tests are specified appropriate to the duty and design.



Spent fuel and vitrified high-level waste

Spent fuel and vitrified high-level waste are intensely radioactive and need to be heavily shielded. However they are inherently stable and, being a ceramic material, are very difficult to disperse. The solid nature of the products is one of the most important safety factors. The material is characterised by long-term stability and low solubility in water. Chemical and toxic risks are negligible when compared to the radiological risk.

Plutonium

Plutonium is very toxic and in its powder form is easily dispersed. The primary risk is due to toxicity except in the event of criticality which is controlled by the package design. Plutonium can be transported as MOX fuel which is a stable ceramic and not easily dispersed.

Mixed oxide fuel

Mixed plutonium/uranium oxide (MOX) fuel elements, in which the enriched uranium isotope is replaced by plutonium, are very similar to uranium fuel elements and also ceramic in nature. The chemical hazard is negligible and the radiological hazard is low except in the event of a criticality excursion. This is controlled in the same way as for enriched uranium fuel; i.e. by the design of the package and the configuration of the package during transport.

IAEA Regulations for the Safe Transport of Radioactive Material

The IAEA Regulations set the basis for nuclear fuel cycle materials in transport. The philosophy of the Regulations is that safety is ensured primarily by the package whatever mode of transport is used. The package has to provide shielding to protect workers, the public and the environment against the effects of radiation. All this has to be achieved under both normal and accident conditions of transport. In addition, it is important to reduce radiation doses to workers and the public as far as reasonably achievable by adopting best practice at the operating level.

The Regulations provide for various types of packages and the designs are based on the nature of the radioactive material they are to contain. This graded approach to packaging whereby the package integrity is related to the potential hazard - the more hazardous the material the tougher the package - is important for efficient commercial transport operations.

Road, rail and sea transport are all commonly used for nuclear fuel cycle materials. Air transport has been used but only to a limited extent.

IAEA tests for packages

The IAEA Regulations prescribe the appropriate test procedures for the various package types.

Un-irradiated materials

Un-irradiated materials from the front end of the fuel cycle; i.e. ore concentrate, Hex, uranium oxide powder and fresh fuel, are relatively benign and the potential hazard is low. Packages for these materials are required to maintain their integrity during normal transport conditions and are designed to withstand a series of tests simulating these conditions; e.g. a water spray, a free drop, a stacking test and a puncture test to reproduce the kind of treatment packages may be subjected to during routine transport.

Of the front end materials, Hex is different in so far as it is a solid which can give off a toxic vapour. This material is transported in large steel cylinders holding up to approximately 12 tonnes. In addition to the normal tests, these packages also are subjected to a pressure test which they must withstand without leakage and unacceptable stress, and also a thermal test.

Irradiated materials

Irradiated materials from the back end of the fuel cycle, notably highly radioactive spent fuel and vitrified high-level wastes, are transported in high integrity, heavily shielded and massive steel packages. The IAEA Regulations specify a series of rigorous tests to ensure the integrity of these packages in accidents such as crashes involving high impacts, in long duration fires or after submergence in water.

IAEA impact tests

The impact tests include a requirement for these high duty packages to survive a 9 metre drop test onto a flat, unyielding surface without giving rise to a significant release of radioactivity. This drop test is very severe because in an impact with an unyielding surface all the kinetic energy of the falling package has to be absorbed by the package in the deformation and damage it sustains. An unyielding surface is a hypothetical concept. In real-life situations, a package could impact such objects as concrete roads, bridge abutments and piers. All these will yield to some extent and therefore a proportion of the energy of the moving package can be absorbed by the target. The 9 metre drop test onto an unyielding surface is therefore relevant to impacts onto real-life objects as a result of a high speed crash; e.g. in the case of a spent fuel transport cask, the test is equivalent to a crash onto a concrete slab at 250 km per hour.



IAEA fire test

Fire also is a consideration in the transport of nuclear fuel cycle materials since it increases the potential for release of radioactive materials to the environment and for this reason packages must be able to withstand fires. The IAEA thermal test specifies that packages for the more hazardous nuclear fuel cycle materials have to withstand a fully engulfing fire of 800°C for 30 minutes without significant release of activity. Analytical and experimental studies have shown that the conditions generated in this regulatory test are more severe than in a realistic transport accident such as a collision with a gasoline tanker resulting in a fully engulfing fire for a prolonged period.

IAEA immersion test

The immersion test is designed to ensure safety in the event of accidents at sea. Packages for spent fuel, MOX fuel and vitrified high-level radioactive waste have to undergo an immersion test equivalent to a water depth of 15 metres for 8 hours without loss of shielding or significant release of radioactivity. In addition, these packages are subjected to immersion at 200 metres for 1 hour and the containment system must not rupture.

Accident studies

Sea transport accident study

The IAEA coordinated a technical research project² to determine the consequences of accidents at sea. The sea transport of spent fuel and vitrified high-level waste was the main focus of the study. Potential accident scenarios, probabilities and severities were established using historical data sources of marine accidents. Ship fires and collisions were covered separately as well as combined fire and collision events. The IAEA Research Project concluded that the probability of ships being affected by such accidents is very low.

From a fire test on a cargo ship it was concluded that even if a ship fire reached a hold where these packages are stowed, a cask is unlikely to fail and release significant quantities of radioactivity. For collisions, extensive analytical work on the structural behaviour of ships and packages was carried out.

It was concluded that ship collisions are unlikely to damage the casks because the collision forces would be relieved by the collapse of the ship structures and not by the casks.

In the unlikely event of the cask sinking, the rate of release of radioactive material into the sea would be very slow since the containment of the cask is unlikely to have been lost. In this hypothetical scenario the radiation doses received by people who consume marine foods affected by the accident would be negligible compared with doses from the natural background. The study concluded that the risks posed by the sea transport of spent fuel and vitrified high-level waste are very small. This also is the case with respect to other nuclear fuel cycle materials, the activity of which is far less.

Road and rail transport accident study

The US Department of Energy recently commissioned a detailed study of severe transport accidents which have occurred in the USA over the past 20 years³. The accidents analysed did not involve radioactive materials. However, the study focused on accidents which allegedly had the potential to cause significant damage to a transport cask.

Accident reports for twelve very severe road and rail accidents, involving high impacts, fires, explosions or water immersion were studied to determine how the conditions generated in these accidents compare with the regulatory tests and how such conditions would have affected spent fuel transport casks. Some of these accidents involved impacts such as high speed train derailments and the collapse of bridges and viaducts which resulted in road vehicles falling onto concrete roads or plunging into rivers and others involved fires and explosions.

The study strongly concluded that even under these extreme accident conditions the casks would not have been significantly damaged and would have retained their integrity.



Summary

The IAEA Regulations for packages for the transport of nuclear fuel cycle materials requires a demonstration of the successful performance of the package in impact tests relevant to crashes, thermal tests which simulate fires and water immersion tests relevant to accidents at sea.

Any programme of testing related to potential transport accidents must ensure that the tests are representative of all accidents which can be realistically envisaged. There is a large body of evidence to demonstrate that the current IAEA test requirements fully meet this criterion.

For decades the nuclear transport sector has safely and securely managed shipments of nuclear materials; this record of success is a tribute to the effectiveness of the regulatory framework as well as the collective competence of the entities performing packaging and transport activities.

References

- 1 IAEA Regulations for the Safe Transport of Radioactive Material, TS-R-1; 2005 Edition, International Atomic Energy Agency, Vienna, 2005
- 2 Severity, Probability and Risk of Accidents During Maritime Transport of Radioactive Material, Final Report of Co-ordinated Research Project 1995-1999, IAEA-TECDOC-1231, International Atomic Energy Agency, Vienna, July 2001
- 3 Comparison of Selected Highway and Railway Accidents to the 10 CFR71 Hypothetical Accident Sequence and NRC Risk, US Department of Energy, 8 April 2003

Photographs

- 1 Uranium ore processed and turned into powder "yellowcake"
- 2 Drums of uranium ore concentrate
- 3 48" Hex cylinders
- 4 Uranium fuel assembly
- 5 Tie-down for fresh fuel transport
- 6 Unloading a cask of vitrified high-level waste, Mutsu-Ogawara Port, Japan
- 7 Road transport of spent fuel in Japan
- 8 Cask for MOX fuel
- 9 Sea transport of vitrified high-level waste
- 10 Unloading operations, Barrow Port, UK
- 11 Preparing drums of uranium ore concentrate for transport
- 12 Front end transport in France
- 13 Rail-road transfer at Valognes Terminal, France
- 14 Rail transport of spent fuel in UK
- 15 Purpose-built vessel, Mutsu-Ogawara Port, Japan



Remo House
310-312 Regent Street
London W1B 3AX
United Kingdom
Tel: +44 (0)20 7580 1144
Fax: +44 (0)20 7580 5365
Web: www.wnti.co.uk
Email: wnti@wnti.co.uk