Fact Sheet

Nuclear Fuel Cycle Transport – Back End Materials

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1 Rail transport of spent fuel in UK

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Introduction

Today, nuclear power provides approximately 10% of global electricity making affordable, clean, carbon-free energy available to millions of people the world over.[1] The use of nuclear reactors to produce electricity has required a wide range of radioactive material transports over several decades. These transports have supported all stages of the nuclear fuel cycle from uranium mining, to fuel processing and transport to reactor sites, to fuel reprocessing for recycling, spent fuel storage and disposal.

The transport of radioactive materials is strictly governed by an established system of international regulations and their adoption has led to an impressive record of safety. In over half a century there has never been a single transport incident which has resulted in significant radiological damage to mankind or the environment.

Nuclear fuel cycle transports are commonly designated as either front end or back end. The front end covers all the operations from the mining of uranium to the manufacture of new fuel assemblies for loading into the reactors, i.e. the transport of uranium ore concentrates to uranium hexafluoride conversion facilities, from conversion facilities to enrichment plants, from enrichment plants to fuel fabricators and from fuel fabricators to the various nuclear power plants. The back end covers all the operations concerned with the spent fuel which leaves the reactors, including the shipment of spent fuel elements from nuclear power plants to reprocessing facilities for recycling, and the subsequent transport of the products of reprocessing. Alternatively, if the once-through option is chosen, the spent fuel is transported to temporary storage facilities pending its final disposal. In addition, radioactive waste from operations and decommissioning of nuclear power plants are transported to recycling plants or final disposal sites.

This fact sheet covers the transport of back end materials, mainly covers spent fuel and high level waste (HLW). The details of the transport of front end materials can be found in the WNTI Fact Sheet: Nuclear Fuel Cycle Transport – Front End Materials.

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What are back end materials?

Fuel used in a nuclear power plant generates electricity for three to five years. After this time it becomes less efficient and needs to be replaced. This spent fuel still contains 96% of the original uranium, but also about 3% of fission products, and 1% of plutonium. At this stage, spent fuel can either be sent for storage pending final disposal, or reprocessed to recover the uranium and plutonium.

The residual uranium can be recycled. The plutonium which is produced in the reactor contains fissile nuclides, i.e. it can support a nuclear chain reaction. It can be combined with uranium to produce Mixed Oxide (MOX) fuel. The fission products are transformed into a solid insoluble glass form by a vitrification process and stored pending final disposal, for instance into a deep geological repository.

2 Road transport of spent fuel in Japan

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Why are back end materials transported?

Once spent fuel is removed from the nuclear reactor it can be stored temporarily at the power plant site, shipped to off-site interim storage facilities, or shipped to reprocessing plants.

A number of countries including Japan, Germany, Switzerland, Belgium, the Netherlands, France, Russia, India and the United Kingdom reprocess a portion of their spent fuel. The main commercial reprocessing/recycling facilities are based in France and the United Kingdom. Countries which send their spent fuel to France or the United Kingdom for reprocessing retain ownership of all the products, including any waste products, which must be returned to them. After shipment to the country of origin, the waste is stored for eventual disposal. Plutonium returned as MOX fuel is loaded into reactors for electricity production.

Shipment of back end materials on an industrial scale commenced in the early 1960s when nuclear power started to become an important source of electricity in several countries worldwide. Spent fuel was the first of the back end products to be transported. Later, plutonium was returned to the country of origin, initially as plutonium powder and latterly as MOX fuel. The first shipment of vitrified high-level waste took place in 1995 and many shipments of this type have since taken place, by sea and by rail.

3 Purpose-built vessel, Mutsu-Ogawara Port, Japan

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How is this material transported?

Stringent, comprehensive and universally recognised regulations

The transport of back end material, as with all other radioactive material transport, is carefully regulated to protect people, property and the environment. The International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material were first published in 1961 and have been revised regularly to keep pace with scientific and technological developments.[2] Today, the IAEA Regulations have been adopted or used as a basis for regulations in more than 60 Member States. Further, the principal organisations having responsibility for transport by land, sea, air and inland water have incorporated the IAEA Regulations into their own Regulations. In addition, the United Nations Model Regulations for the Transport of Dangerous Goods have always referred to the IAEA Regulations.[3] As a result, the Regulations apply to transports of radioactive material almost anywhere in the world.

Back end materials are essentially solid products

The solid nature of the products – spent fuel, MOX fuel, and vitrified high-level waste – is an important safety factor. The materials are characterised by longterm stability and low solubility in water and would stay contained in a solid form after any accident. Spent fuel and MOX fuel are both made of hard ceramic pellets that are contained in zirconium alloy metal tubes (fuel rods). The difference lies in the content; spent fuel contains uranium (96%), plutonium (1%) and fission products (3%) and is highly radioactive, while MOX fuel is made of uranium and plutonium oxides and has a low level of radioactivity. In the case of vitrified high-level waste, the vitrification process allows the fission products to be incorporated into a molten glass which is then poured into a stainless steel canister, where it solidifies. As a result, the fission products are immobilised and the highly radioactive vitrified product is protected by the stainless steel canister.

Back end materials are transported in dedicated packages

In accordance with the IAEA Regulations, spent fuel, MOX fuel, and vitrified high-level waste are transported in specially designed transport packagings known as flasks or casks (termed as Type B packages in the Regulations). They are specially designed for the particular radioactive material they contain, they provide protection to people, property, and the environment against radiation and are designed to withstand severe accidents. Type B packages range from drum-size to truck-size, but are always highly resistant and heavily shielded.

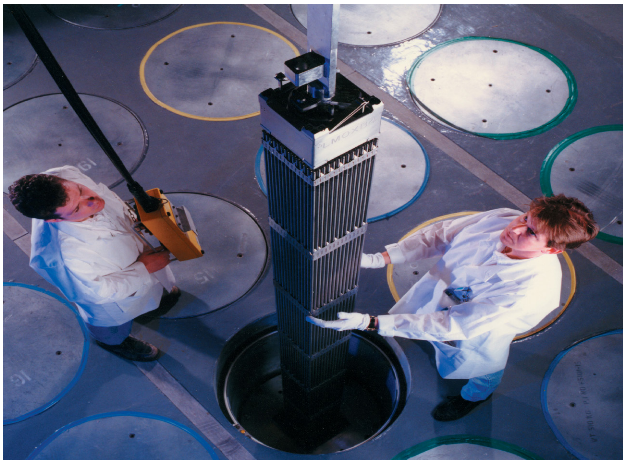
Packages have to meet stringent tests

The philosophy of the IAEA Regulations is that safety is ensured by the packaging no matter what mode of transport is used. Under the Regulations the packaging design has to meet a series of rigorous impact, fire and immersion tests, notably:

- two drop tests – a 9 metre drop onto an unyielding surface and a 1 metre drop onto a steel punch bar; sequentially in worst-case drop angles;
- a subsequent fire test in which the package is subjected to a fully engulfing fire of 800°C for 30 minutes;
- immersion test where the cask is then subjected to conditions equivalent to 15 metre submersion for 8 hours. For casks designed for the more highly radioactive materials there is an enhanced immersion test of 200 metres for 1 hour.

These tests ensure that packages can withstand transport accidents involving crashes, fires or submergence which can be realistically envisaged and, in the case of fissile materials, ensure that no chain reaction can ever occur. National competent authorities must certify the Type B package. Once the packaging design has been approved, it can be used for surface transport by truck, train, ship or air.

Regulations have also been introduced for the transport of highly radioactive materials by air in packages, designated as Type C. The requirements for a Type C package include additional tests to ensure that it can maintain its integrity under air accident conditions. In 2012, a dry run was carried out to demonstrate the TUK-145/C handling procedure including delivery of the energy absorbing container by road, delivery of the SKODA VPVR/M cask by rail, making up the TUK-145/C package at the airport, and two options of its loading on board the aircraft (on a truck and a roller system)[4]. The packages have been used in the global project for return of high enriched uranium.



5 MOX fuel assembly

4 MOX fuel pellet

6 MOX fuel cask unloading operation

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Safety demonstrations

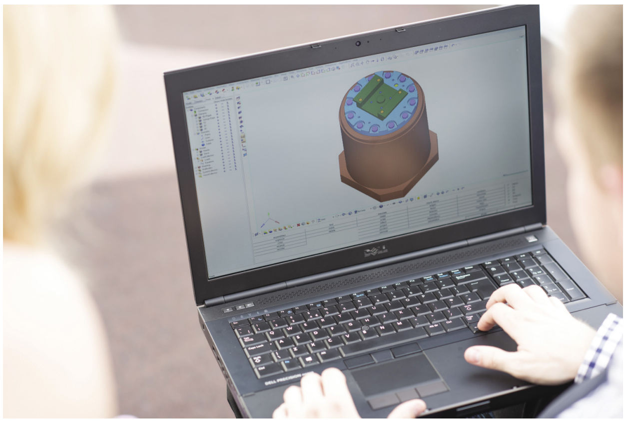
Several demonstration tests have been carried out to show the large safety margin and robustness of Type B packages. For example, engineers and scientists at Sandia National Laboratories* conducted a wide range of tests in the 1970s and 1980s on Type B packages. These tests included truck impact tests at 98 and 138 km/h in which truck trailers carrying packages were impacted into 3 metre thick concrete barriers, and a diesel locomotive crashed into a Type B package at 131 km/h at a simulated rail crossing[5]. Similarly the UK Central Electricity Generating Board conducted a public demonstration in 1984 in which a 140 tonne train travelling at 164 km/h was driven into a Type B package[6]. Post-crash assessments showed that packages suffered only superficial damage and would not have released their contents. Although spectacular, these demonstration tests were not as severe as the IAEA series of tests summarised above. This shows the IAEA series of tests are conservatively representative of real world accidents.

* Sandia National Laboratories is a national security laboratory operated for the USA Department of Energy by the Sandia Corporation, a Lockheed Martin Company (responsible for performing a wide variety of energy research and development projects)

Sea transport: purpose-built vessels

In the case of sea transport of back end materials, the ship design adds to the safety provided by the transport packaging. In 1993, the International Maritime Organization introduced the voluntary Code for the Safe Carriage of Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes in Flasks on Board Ships (INF Code), complementing the IAEA Regulations. These complementary provisions mainly cover ship design, construction and equipment. The INF Code was adopted in 1999 and made mandatory in January 2001.[7] It has introduced advanced safety features for ships carrying spent fuel, MOX fuel or vitrified high-level waste.

The basic design for ships complying with the highest safety rating of the INF Code (known as INF3) is a double hull construction around the cargo areas with impact resistant structures between hulls, and duplication and separation of all essential systems to provide high reliability and accident survivability. Over the past two decades, INF3 type ships have been used to transport back end materials between Europe and Japan. The details of the INF Code can be found in the WNTI Fact Sheet: The INF Code and purpose-built vessels.



7 Advanced computer methods are used to design transport casks

8 IAEA drop test

9 IAEA fire test

International Recommendations and Guidance for Transport Security

The overarching Convention relating to security of international transport (and in some respects, domestic transport) is the Convention on the Physical Protection of Nuclear Material (CPPNM). A subsidiary document, INFCIRC/225/Rev. 5 (IAEA Nuclear Security Series No. 13) provides recommendations to States to establish, maintain and sustain an effective physical protection regime, including during transport. This guidance should be used by States as a basis for their domestic legislation and regulation, and the Implementing Guides of the IAEA Nuclear Security Series provide further guidance for regulators, operators and carriers.

Specialised transport companies

Experienced and specialised transport companies have safely and routinely transported back end materials on an industrial scale since the 1960s. These companies have well developed transport systems and carefully manage back end transports around the world following required safety procedures. As an example, comprehensive and effective emergency response plans are in place, incorporating emergency arrangements for all modes of transport. These are routinely tested to ensure that public health and the environment are well protected in the unlikely event of an incident.

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The facts speak for themselves

The international transport of nuclear fuel cycle materials has played an essential role in bringing the benefits of nuclear power to people the world over. These transports have supported all stages of the nuclear fuel cycle including uranium mining, fuel manufacture, fuel reprocessing, spent fuel management, waste storage and disposal.
The transport of fuel cycle materials is strictly regulated ensuring nuclear fuel cycle transport can be carried out safely, not only under normal conditions but under all accident conditions of transport which can be realistically envisaged. In over half a century there has never been a significant transport incident involving the release of radioactive material.

07

References

1 Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, 2021 Edition, IAEA, Vienna (2021).

2 INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 2018 Edition, IAEA Safety Standards Series No. SSR-6 (Rev. 1), IAEA, Vienna (2018).

3 UNITED NATIONS, Recommendations on the Transport of Dangerous Goods, Model Regulations, ST/SG/AC.10/1/Rev.21, 2 vols, UN, New York and Geneva (2021).

4 S. Komarov, et al. 'DESCRIPTION OF TYPE C TUK-145/C PACKAGE DESIGN. CERTIFICATION IN RUSSIA', The 17th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2013), 18 – 23 August, 2013, San Francisco, California, USA

5 C. J. Mora, et al. '"We Crash, Burn and Crush": A History of Packaging at Sandia National Laboratories 1978 – 1997', The 12th International Conference on Packaging and Transportation of Radioactive Material (PATRAM 98), 10-15 May, 1998, Paris, France

6 'Transporting Spent Nuclear Fuel: An Overview', U.S. Department of Energy, Office of Civilian Radioactive Waste Management, March 1986

7 INTERNATIONAL MARITIME ORGANIZATION, Revised Recommendations on the Safe Transport of Dangerous Cargoes and Related Activities in Port Areas, 2007 Edition, MSC.1/Circ.1216, IMO, London (2007).

10 Unloading operations

11 Purpose-built vessel

12 Loading cask of vitrified high-level waste into ship's hold

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