Safety in the Transport of Nuclear Fuel Cycle Materials and Developments in Security Requirements

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Introduction

The design and performance standards for packages used for the transport of nuclear fuel cycle materials are defined in the International Atomic Energy Agency (IAEA) Regulations TS-R-1 (1) in order to ensure safety under both normal and accident conditions of transport. The underlying philosophy is that safety is vested principally in the package. The design and performance criteria are related to the potential hazard, i.e. the more hazardous the material the tougher the package.

Nuclear fuel cycle materials come in a variety of chemical and physical forms and the potential hazards they present differ widely. The main features are as follows;

Uranium ore concentrate (UOC)

UOC 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 UOC is no different from most heavy metal compounds.

Uranium hexafluoride (Hex)

Hex also is a low specific activity material and the radiological risk from natural and depleted material is not great. However there are hazards due primarily to the chemical toxicity of the substances formed on reaction with moist air. This is the case with many industrial chemicals. Enriched Hex is fissile and therefore presents a potential criticality risk but this is prevented by the design of the package and the configuration of the packages during transport.

Uranium dioxide powder (UO2)

UO2 of less than 5% enrichment for the manufacture of new uranium fuel elements is also classified as low specific activity material. The primary hazard is radiological in the event of a criticality incident. This is again prevented by the design of the package.

Fabricated uranium fuel

New fuel assemblies typically consist of sintered ceramic UO2 pellets formed into assemblies and transported in specially designed packages. The fuel is refractory and stable. The chemical hazard is negligible and the radiological hazard is low. The design and configuration of the packages during transport guarantees that criticality excursions could not occur.

Spent fuel and vitrified high-level wastes (VHLW)

Spent fuel and VHLW from reprocessing are intensely radioactive and need to be heavily shielded. However, they are inherently stable and refractory and very difficult to disperse. Chemical and toxic risks are negligible when compared to the radiological risk.

Mixed oxide fuel (MOX)

Mixed uranium/plutonium oxide fuel elements contain sintered ceramic pellets and are very similar to uranium fuel elements. The chemical hazard is again negligible. The radiological hazard is not great except in the event of a criticality excursion and this is controlled in the same way as for enriched uranium fuel.

Plutonium

Plutonium is a special case. This material is hazardous since it is very toxic and in its powder form can be easily dispersed. The primary risk is due to toxicity except in the event of criticality which is controlled by the package design. When plutonium is transported as MOX, a stable refractory ceramic, the toxicity risk is small.

Packages for nuclear fuel cycle materials

There are various categories of packages relevant to fuel cycle materials. ***Industrial packages*** are used for low specific activity materials, typically UOC or low-level waste, which can be transported in sealed 200 litre drums packed into a standard transport container. ***Type A packages*** are typically for fresh fuel. Hex is transported in steel cylinders. ***Type B packages*** are high duty packages which are used for the transport of some of the more radioactive nuclear fuel cycle materials, notably spent nuclear fuel, VHLW and MOX. ***Type C packages***, for air transport, have only recently been specified in the Regulations and are intended for potentially hazardous materials. They are likely to be used only for air transport of plutonium and MOX.

Test requirements for high duty Type B packages

The detailed requirements for the high duty Type B packages used for the transport of some highly radioactive nuclear fuel cycle materials, notably spent fuel and VHLW, and also plutonium and MOX, are set out in the IAEA Regulations. Tests are specified to ensure the integrity of the package in potential accidents such as crashes, fires or submersion in water. Type B packages are the main focus of this paper.

Impact tests for Type B packages relevant to collisions

The IAEA impact tests include a requirement for Type B packages to survive a 9m drop test, which results in an impact velocity of 30 mph, onto a flat unyielding, i.e. a completely rigid 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 target is a hypothetical concept. The surfaces of objects which a package could impact in real-life situations, such as concrete roads, bridge abutments and piers, would yield to some extent and therefore a proportion of the energy of the moving package would be absorbed by the object. The 9m drop test, which results in an impact speed of 30 mph onto an unyielding surface, is therefore relevant to impacts onto real-life surfaces at much higher speeds. For example, Ammerman (2) showed that for a monolithic steel spent fuel rail cask without an impact limiter the speed equivalent to the 9m drop test for an end-on collision onto hard soil or a concrete slab would be more than 150 mph. The results of a research project funded by the European Commission on the evaluation of the safety of casks impacting different surfaces have been reported by Tso and Farina (3). This work showed that the peak accelerations and forces in impacts onto real objects are less than 10% of those from a drop onto an unyielding target from the same height. Other similar studies on Type B packages for the transport of spent fuel (4,5,6) confirm that spent fuel casks will maintain their integrity and that transport accidents which can be realistically envisaged are less severe than the IAEA 9m regulatory drop test.

Vallee (4) also studied the impact behaviour of containers for the transport of plutonium dioxide powder under the same conditions as for the study on spent fuel casks for a range of real surfaces and configurations. The results again showed that the container maintained its integrity and real transport accidents would be less severe than the regulatory drop test.

Shirai et al (6) carried out experimental drop tests on a cylinder used for the transport of Hex onto an unyielding surface and also onto hard soils. This showed that a 9m drop onto an unyielding surface was much more severe than a 14m drop onto a hard soil.

Fire tests for Type B packages

Fire also is a concern in the transport of nuclear fuel cycle materials. The IAEA Regulations specify that packages for the more radioactive nuclear fuel cycle materials should be able to withstand fires. The IAEA thermal test specifies that Type B packages for the more radioactive nuclear fuel cycle materials must be able to withstand a fully engulfing fire of 800^0C for 30 minutes without significant release of activity.

Several studies have been carried out to investigate the ability of spent fuel casks to withstand long duration fully engulfing fires which could be caused by the rupture of an oil or gas pipeline or fires resulting from a train crash involving highly inflammable cargoes such as gasoline. For example in the work of Ito (5) a spent fuel cask was subjected to a regulatory fire test at $800^{\rm O}$C for 30 minutes and an analysis was carried out to determine the response to a realistically severe fire accident resulting from a collision with a tanker truck. The results indicated that the spent fuel cask remained sound and the conditions generated in the regulatory test were more severe than in the realistic accident. This also would be the case with VHLW casks which are similar to those for spent fuel.

Water immersion tests

Type B packages for the more radioactive materials have to undergo an immersion test equivalent to a water depth of 15m for 8 hours without loss of shielding or significant release of radioactivity. In addition, packages for spent fuel (and VHLW) are subjected to immersion for 1 hour at 200m and the containment system must not rupture.

For collisions, extensive analytical work has been carried out by the IAEA (7) on the structural behaviour of ships and spent fuel and VHLW packages. 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. The forces on the cask would be less than the forces imposed by the 9m drop test.

If the cask were to sink due to the sinking of the ship or by being pushed through the side by a collision it was concluded that recovery is likely if this occurs on the Continental Shelf. If the cask were not to be recovered, the rate of release of radioactive material into the sea would be very slow since the containment of the cask would be unlikely to have been lost. In this case, the radiation doses received by people who consume marine foods affected by the accident would be negligible compared with doses from the natural background due to the refractory nature of the material and the vast dilution which would occur. The same would apply to other nuclear fuel cycle materials, the activity of which is much less.

Comparison of recorded road and rail accidents with the regulatory tests for spent fuel casks

The USA Department of Energy commissioned a detailed study of twelve very severe road and rail accidents which did not involve nuclear fuel cycle materials. The accidents, which occurred in the USA in the past 20 years involved high impacts, fires, explosions, or water immersion. They have been analysed to determine how the conditions generated in these accidents compare with the regulatory tests and how they would have affected spent fuel transport casks (8).

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. The impacts which a spent fuel cask would have experienced in these accidents were much less severe than in the regulatory 9m drop test.

Some accidents involved fires, such as one which occurred when a liquid propane tanker collided with a bridge support in a road crash, and others which included explosion and hazardous chemicals, were also investigated. The conclusion was that such accidents would not have resulted in significant damage to a near-by spent fuel transport cask.

Security measures for nuclear fuel cycle transport

Security involves the various measures to guard against the consequences of intentional malicious acts. The main concern in the past was theft and diversion of nuclear material but the tragic events of 11 September 2001 in the USA, and other recent incidents, have heightened sensitivities to security in face of terrorist action. Whereas ***safety*** of radioactive material transport depends on the integrity of the package and is clearly the responsibility of the consignor, ***security*** is mainly the responsibility of the State, which has to set up the necessary regulatory framework.

The materials used in the nuclear fuel cycle industry have traditionally been subject to extensive national protection measures. This responsibility extends to the right of a State to oversee the security measures that are taken during the transport of material originating from or obligated to their country. A range of protection measures has been employed during transport, as deemed appropriate, ranging from the design of the package and the vehicles used as well as security forces, access control, employee screening, satellite tracking of shipments and co-ordination with local and national security authorities.

The objectives of the requirements of physical protection of such materials during transport is assisted by minimising both the total time the material remains in transport and the number and duration of transfers of the material, avoiding the use of regular movement schedules and limiting the advance knowledge of transport information including date of departure, route and destination to designated officials having a need to know that information.

For example, spent nuclear fuel assemblies and VHLW are transported by sea between Europe and Japan in purpose-built, dedicated ships operated by Pacific Nuclear Transport Limited as their sole business. Land transport of such materials is also by dedicated road and rail vehicles and routes are planned and approved by the competent regulatory bodies in the countries concerned. For example in the USA, the Department of Transportation approves and pre-inspects routes for spent fuel transport. The USA Nuclear Regulatory Commission also checks routes for law enforcement and emergency response capability.

Recent developments in security requirements

The IAEA plays a leading role in developing the international regulatory regime for the safe transport of radioactive materials. The focus in the past has been on safety but the IAEA has also recognised the need for the security or physical protection of nuclear material during transport. The Convention on the Physical Protection of Nuclear Material, signed in 1980, obliges Contracting States to ensure during international nuclear transport the protection of nuclear materials within their territory or on board their ships or aircraft. Security is now receiving much more attention.

UN and IAEA initiatives

In 2002, the IAEA initiated work on the need for enhanced measures for security in the transport of radioactive materials, including nuclear fuel cycle materials. This was intended to complement the security requirements in the UN “Model Regulations” (9) which contain a basic security level for the transport of all dangerous goods as well as additional requirements for an enhanced security level for goods defined as ‘high consequence dangerous goods’, which have the potential to give rise to serious consequences in the event of a terrorist incident. These include such materials as explosives, flammable bulk liquids and gases, potentially dangerous chemicals etc. as well as Class 7 radioactive materials in Type B or Type C packages. For all these so-called high consequence dangerous goods, not just nuclear fuel cycle materials, enhanced security requirements apply.

The International Maritime Dangerous Goods Code (IMDG Code) (10) became mandatory in 2004 and the current edition includes a chapter on security which will come into force in January 2006 (on a voluntary basis in January 2005). In the implementation of national security, competent authorities have to ensure that the organisations engaged in the transport of high consequence dangerous goods, notably carriers and consignors, implement a security plan that, *inter alia*, includes:

- the allocation of responsibilities to competent persons;
- adequate record keeping of materials transported;
- assessment of vulnerabilities in temporary storage, transfer, handling, etc;
- clear statements of measures including training, operating practices and resources;
- the reporting of threats and incidents;
- the evaluation of effectiveness of plans and procedures;
- measures to ensure the security of transport information and to limit its distribution as far as possible.

These requirements became part of the UN 'Model Regulations' in late 2003.

Security requirements for sea transport

The Safety of Life at Sea (SOLAS) Convention was revisited after the events of 9/11 in the USA, to enhance ship and port facility security. The London Conference on Security at Sea held in 2002 resulted in the International Ship and Port Facility Security Code (ISPS Code) and SOLAS amendments (11) to establish appropriate security plans for ship and port facilities. This came into in force July 2004.

In the UK, the Nuclear Industry Security Regulations (NISR 2003) (12) require all UK shipping operations to be approved and to produce a Transport Security Plan.

Special nuclear materials

In addition to the UN Model Regulations there is an international instrument developed by the IAEA, The Physical Protection of Nuclear Material and Nuclear Facilities, INFCIRC 225, (13). In this context nuclear materials are those which carry a potential risk of being used in a nuclear explosive device. This requires States to take appropriate measures to ensure security and includes the physical protection requirements for nuclear material in use, storage and during transport. Three categories of security are defined depending on the nature of the material.

The elements which a State's physical protection of such materials should include within the framework of its national law are specified and also the additional requirements for protection during transport. During international transport the responsibility for physical protection should be agreed between the States concerned. The shipping State should ensure that all the States involved in the transport, including transit States, can provide adequate measures for protection. Confidentiality of sensitive information which could compromise the physical protection of the material is an essential element of security.

The nuclear materials covered by INFCIRC 225, which could potentially be of use in the manufacture of a nuclear explosive device, are principally plutonium and highly enriched U235 and U233, for which the highest security category applies.

INFCIRC 225 now extends to national as well as international transport.

Security implications for nuclear fuel cycle transport

Currently the two International instruments relevant to security in the transport of nuclear fuel cycle materials are (i) INFCIRC 225 (13) for the transport of nuclear materials which carry a potential risk of being used in nuclear weapons and which requires three categories of security depending on the risk and (ii) the UN Model Regulations (9) for the transport of high consequence radioactive materials which require an enhanced security provision.

The security requirements in the UN Model Regulations classify materials in radioactive quantities greater than 3000A1 (see (1) for definition of A1 and A2) for special form materials, notably large radioactive sources for medical and industrial use, or 3000A2 for other radioactive materials as high consequence materials. On this basis all the low enriched uranium nuclear fuel used for electricity generation, typically < 6% U235, and its intermediates, including UOC, natural and low enriched Hex and the wastes from reprocessing operations, will be exempt from the enhanced security requirements and normal prudent precautions should suffice.

Hex could potentially give rise to a chemical hazard in the event of a severe accident because it produces corrosive products on exposure to moist air or water. This subsidiary hazard could be covered by the requirements of the Model Regulations for corrosive materials transported in bulk.

The requirements for safety and security have so far been decoupled. However, a view is emerging that security requirements should be referenced in the IAEA Safety Regulations with the development of an IAEA Security Series, much the same as the Safety Series. This is based on the premise that safety and security risks are not mutually exclusive but must be considered together and evaluated as a systematic integrated process. This would inevitably have consequences for the nuclear fuel transport community and this needs to be taken into account.

Conclusions

Safety of radioactive material transport depends mainly on the integrity of the package and is clearly the responsibility of the consignor. The IAEA regulations set standards for the packages and procedures used for the transport of nuclear fuel cycle materials to ensure safety under both normal and accident conditions. The underlying philosophy is that safety is vested principally in the package. There is a large body of evidence to demonstrate that the IAEA tests are severe tests which cover all accident situations which could be realistically envisaged in transport. More severe tests would not be justified on quantitative safety grounds.

Security for the transport for nuclear fuel cycle materials is mainly the responsibility of individual states, which have to set up the necessary regulatory framework. This ensures security through close monitoring of the transport operations, a degree of confidentiality where necessary, a strict international regulatory regime and commensurate security protection measures.

Un-irradiated nuclear fuel cycle materials present a low radiological hazard. This, together with the fact that the highly radioactive materials i.e. spent fuel and VHLW, are very refractory ceramic or vitreous materials, not easily dispersed and transported in very heavy robust containers, are also significant factors in ensuring security.

References

(1) International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, TS-R-1, (ST-1 as amended 2003), Vienna

(2) D J Ammerman, "NUREG/CR-6672: Response of Generic Casks to Collisions", Proceedings, PATRAM 2001, Chicago, IL, USA, September 2001

(3) C F Tso and M Farina, "Evaluation of the Behaviour of the TK6 Cask Impacting Real Targets", Proceedings PATRAM 2001, Chicago IL, USA, September 2001

(4) R E Vallee, "Numerical Study of the Mechanical Behaviour of Type B Radioactive Packages Impacting Real Targets", Proceedings, PATRAM 2001, Chicago, IL, USA, September 2001

(5) C Ito, H Yamakawa and T Saegusa, "Demonstration of the Safety of Spent Fuel Transport Casks under Regulatory Tests and Realistically Severe Accidents", Proceedings, PATRAM 2001, Chicago, IL, USA, September 2001

(6) K Shirai, H Akamatsu and C Ito, "Consideration of Impact Behaviour of Radioactive Packages onto Real Targets", Proceedings, PATRAM 1992, Yokohama, Japan, September 1992

(7) International Atomic Energy Agency, TRANSSC, Vienna, 5-9 February 2001, Paper TC-983.6

(8) USA Department of Energy National Transportation Program, "Comparison of Selected Highway and Railway Accidents to 10CFR71 Hypothetical Accident Sequence and NRC Risk", 8 April 2003

(9) Recommendations on the Transport of Dangerous Goods, Model Regulations, Volume 1, 13th Revised Edition, United Nations, New York and Geneva, 2003

(10) International Maritime Dangerous Goods Code (IMDG) Code, International Maritime Organization, London, 2004

(11) International Ship and Port Facility Security (ISPS) Code and Safety of Life at Sea (SOLAS) Amendments 2002, ISPS Code 2003 Edition, International Maritime Organization, London

(12) Atomic Energy and Radioactive Substances, The Nuclear Industries Security Regulations 2003, UK Statutory Instrument 2003, No. 403

(13) The Physical Protection of Nuclear Material and Nuclear Facilities INFCIRC/225/Rev.4 (corrected), IAEA, Vienna, 20 July 2000

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