

Safety and Security Aspects for the Effective Shipment of Radioactive Materials with Maritime Transportation

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ABSTRACT: The International Atomic Energy Agency (IAEA) estimates that 10 million shipments of radioactive materials are transported annually. Each shipment is made up of either a single package or a number of packages transported from one location to another. The vast majority of these shipments, some 95%, relate to non-fuel cycle transports such as the transport of smoke detectors, and cobalt sources for medical purposes. Only 5% relate to nuclear fuel cycle transports. This study investigates the safety stability aspect, harmonized regulation based transportation, sustaining shipment aspect for the transportation of radioactive materials by ships. Consequently the originality of this paper appears the alignment of existing maritime rules and regulations with the IAEA regulations in order to provide easy understanding and usage for the establishment of code of safe and secure practices for seafarers with the countermeasures and harmonized regulations that are practically implemented by the navigation officers and Master.

1 INTRODUCTION

Each day thousands of shipments of radioactive material are transported on international and national routes. These consignments, which are carried by road, rail, sea, air and inland waterway, can range from smoke detectors, and cobalt sources for medical uses, to reprocessed fuel for use in electricity generation. The 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. Today, more than 60 member States and the UN Model Regulations for the Transport of Dangerous Goods along with modal agencies such as the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) have adopted safety requirements and standards based on the IAEA Regulations. As a result, the IAEA Regulations apply to the transport

of radioactive materials almost anywhere in the world.

In addition, shipments comply with the safety requirements of the shipping states' governments. Packages used for the transport of nuclear materials are designed to retain their integrity during the various conditions that may be encountered while they are being transported and to ensure that an accident will not have any major consequences. Regulatory performance tests include fire, impact, immersion, pressure, heat and cold. Maritime transportation is integral to the whole process of matching product to markets. The transport of dangerous goods, such as Class 7 – radioactive materials – must be conducted in a manner to assure safety to life and the environment (IMDG Code, 2005). It must also be done cost-effectively taking into account the ISPS Code which is not technically focused on the transportation of dangerous goods in general sense.

The transport of radioactive materials is intentionally regulated to protect human, property and the environment. Shipments of radioactive materials must comply with relevant physical protection requirements developed by the IAEA, as well as the safety requirements of the Modal Organizations such as the IMO and ICAO.

1.1 *Transport security*

After the Second World War the increased pace of industrialization around the world led to growth in the transport of goods classified as dangerous, including petroleum products, gases, explosives, petrochemicals, acids and radioactive material. Because of the safety related issues linked to the intensifying international and multimodal movement of dangerous goods, in the early 1950s the Transport and Communications Commission of the United Nations Economic and Social Council (ECOSOC) acknowledged a need for a uniform system of transport regulation. It was recognized that a consistent approach to regulating dangerous goods transport provided the best way of ensuring consideration of all hazards (WNTI Review Series No. 1, 2006).

After the attacks of September 11th, 2001, concerns intensified over the vulnerability of U.S. ports to acts of terrorism. One particular concern involves the possibility that terrorists would attempt to smuggle illegal fissile material or a tactical nuclear weapon into the country through a cargo container shipped from overseas. This testimony discusses the programs already in place to counter such attempts, new initiatives now under way to enhance the nation's security against such attempts, and the key challenges faced in implementing these various efforts.

Maintaining secure as well as safe transport remained a priority at the IAEA in 2005. Work continued on developing guidelines on transport security. These guidelines were the subject of a Technical Meeting in 2006. These guidelines also request the IAEA Secretariat to report on the planning and work of the International Expert Group on Nuclear Liability (INLEX) (ICCP, 2004).

The safe and efficient transport of radioactive materials is vital to many aspects of modern life, from the generation of electricity, to medicine and health, scientific research, and agriculture. All these industries are becoming increasingly global in terms both of products and services. Maintaining safe and secure national and international transport by all modes is essential to support them. Radioactive material is only one of a total of nine classes of

dangerous goods that are routinely transported worldwide (Dixon, 2001).

The IAEA General Conference, in 1998, recognized that "compliance with regulations which take account of the Agency's Transport Regulations is providing a high level of safety during the transport of radioactive materials. in accordance with Resolution GC(42)/RES/13 (Croxford, 2005).

Transport of nuclear fuel cycle materials is conducted within a rapidly changing environment. Transporters of radioactive materials have an outstanding safety record. Indeed, the transport of radioactive materials could be regarded as a model for the transport of other classes of dangerous goods. The industry has a long track record over several decades. It is noteworthy that where there have been transport incidents involving radioactive materials, and these have been few relative to the number of such transports, they have been without major radiological consequence for health and the environment. The incidents there have been, have largely been transport events involving radioactive materials, not radiological events involving transport. There is good evidence that packages conforming to the International Atomic Energy Agency standards offer sufficient protection under accident conditions. That is not the conclusion only of those in the industry; that is the conclusion of the international community of nations, members of the IAEA.

There are two principal reasons for this outstanding safety record. It is due primarily to well-founded regulations developed by such key intergovernmental organizations as the International Atomic Energy Agency with the essential contributions of the Member States who participate actively in the regulation implementation and revision processes, and their reflection in the international transport safety regime of modal, regional and national regulations. It is due also to the professionalism of those in the industry. There shall be a necessary synergy between the two, between the regulators whose task it is to make and to enforce the rules for safe, reliable and efficient transport, and those whose job it is to transport within the rules. Both, the regulator and the transporter, can be more effective in achieving their purposes when they co-operate in the interest of mutual understanding.

1.2 *The Recommended safe and secure transport of radioactive materials*

Nuclear power industry is generating electricity in 31 countries, supplying over 16% of the world's demand. To sustain this important source of energy, it is essential that nuclear fuel cycle materials

continue to be transported safely and efficiently (Dixon, 2001). When the transportation of nuclear materials is examined they can be mainly categorized with the following manner:

Front end materials- Uranium ore concentrate: Uranium ore is widely distributed. The main sources are in North America, Australia, South Africa and Eastern Europe.

Uranium hexafluoride: Hex produced from the conversion of UOC is a very important intermediate in the manufacture of new reactor fuel. In storage and during transport the Hex material inside the cylinders is in a solid form. Hex is also stored in these cylinders prior to being transported to an enrichment plant. Hex is routinely transported by road, rail or sea, or more commonly, by a combination of transportation modes. Hex cylinders are transported using trailers, rail wagons or standard ISO flat rack containers.

Enriched uranium hexafluoride: Only 0.7% of natural uranium is 'fissile', or capable of undergoing fission, the process by which energy is produced in a nuclear reactor. This is enriched to the level required for most common types of nuclear reactors. Commercial enrichment plants are in operation in the USA, Western Europe and Russia and this gives rise to extensive international transport operations involving Hex between conversion and enrichment plants. Smaller universal cylinders are used to transport enriched Hex. These cylinders are some 76 cm (30") in diameter and are loaded in overpacks to guard against a criticality excursion i.e. an unwanted fission reaction. The loaded overpacks are generally transported using ISO flat rack containers for transport to fuel fabrication plants.

Fabricated uranium fuel: Reactor fuel is generally in the form of ceramic pellets. The pellets are encased in metal tubes to form rods which are then arranged into a fuel assembly ready for introduction into a reactor. The fuel assemblies are transported in specially designed packages and the configuration of packages during transport guarantees that criticality excursions could not occur.

Back end materials, Spent fuel, MOX fuel, and vitrified high-level waste: Fuel is discharged periodically from nuclear reactors, typically after about three to five years as it becomes less efficient. This highly radioactive 'spent' fuel can either be sent to a reprocessing plant or stored pending final disposal.

Non-fuel cycle radioactive materials: Radioactive materials are also widely used in gamma processing which provides 40% of the world's sterile medical disposables and devices (from swabs and syringes to hip joints and heart valves) as well as sterile

ingredients for pharmaceuticals. Large sources are also used for sterilisation purposes in the food industry and in many industrial applications, for example in the radiography of high duty metal fabrications. These gamma sources are manufactured in very few countries and sea transport is therefore vital to distribute them from the manufacturers to several hundred users worldwide. Radioactive materials are also used in medicine for diagnostic purposes and therapy, and in the manufacture of radiopharmaceuticals (Dixon, 2001).

IAEA has been the body responsible for developing requirements governing radioactive material transport for more than 40 years. Radioactive material is considered as one of the nine classes of dangerous goods, which are transported all over the world on a regular basis. The transport of the so-called Class 7 radioactive material, like that of the other eight classes of dangerous goods, is regulated by the international community through the organizations established by the UN in the second half of the 20th century. The dangerous goods transport safety regime is established under the United Nations umbrella. In compliance with the ECOSOC request, IAEA works in close co-operation with the UN Committee of Experts, as well as with specialized UN agencies such as the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO) and the UN Economic Commission for Europe, responsible for the various sets of modal transport requirements (WNTI Review Series No.1, 2006).

2 IDENTIFICATION OF COUNTERPARTS INVOLVED IN TRANSPORTATION

The World Nuclear Transport Institute has consultative status with the International Maritime Organization (IMO) and with the United Nations Committee of Experts on the Transport of Dangerous Goods. World Nuclear Transport Institute has observer status with the International Atomic Energy Agency (IAEA). IAEA Director General, Dr. ElBaradei invited WNTI to attend meetings of the Transport Safety Standards Committee (TRANSSC), the premier IAEA body charged with considering implementation and revision of the IAEA Transport Safety Regulations. Through the WNTI participation in this committee and the related cycle of IAEA meetings industry collectively now has the opportunity to register its views on implementation of the IAEA transport safety regulations, which forms a basis for international, regional and domestic regulation, to identify any problems arising from existing regulations, and to propose changes to them (WPP-

01, 2001). There is a great deal attendant on transport, particularly and properly for the transport of dangerous goods. There are national, regional and international standards and regulations to govern transport safety, efficiency and reliability (WPP-04, 2004).

3 MARITIME TRANSPORTATION CONCERN

3.1 *Port security concern on nuclear materials*

The current security environment of course has an impact on the manner in which nuclear materials are moved within, and between, countries. Seaports, rail yards, airports – all have adopted increased security to guard against unauthorized access to radioactive materials. For example, ocean ports have significantly reduced the amount of time that radioactive material may be held at terminals prior to loading or after unloading and yet, the latter often is a function of waiting for customs clearance before freight can be removed from the port premises. Material in transit now frequently has to be moved to specially guarded, secure facilities, where the total length of time between unloading and reloading is also limited. Rising security concerns also have an impact on the risk assessments carried out by insurance companies providing coverage for both vessels and cargo. Owners of the materials are concerned about the ‘perceptions of risk’ attached to the movements of their materials, because it affects not only premiums, but the potential for delays as a result of increasing restrictions imposed by ports, recognized organizations in accordance with the ISPS Code or inland transport authorities. Security related communication between all parties involved in shipment of radioactive materials is essential to ensure that current warnings are received in a timely manner for assessment, and incorporation into transport plans, and to ensure a prompt response from qualified entities in the event of an incident (Green, 2006).

3.2 *Shipping aspect and carriage of nuclear materials*

There are 63 non-governmental organizations, including the World Nuclear Transport Institute (WNTI), which have consultative status with IMO, while 36 intergovernmental organizations have concluded Co-operation Agreements with IMO. In relation to dangerous goods, the IMO committees with responsibility for technical decisions are the Maritime Safety Committee (MSC) and the Marine Environment Protection Committee (MEPC). Amongst the sub-committees, the Sub-Committee on Dangerous Goods, Solid Cargoes and Containers

(DSC), which reports to MSC, is the most active in this field. When IMO adopts instruments, it strives for consensus in order to have them implemented by as many States as possible. IMO adopts both conventions and codes. Member governments are responsible for implementing a convention by agreeing to make it part of national law, whereas codes have the status of recommendations (WNTI Review Series No.1, 2006).

Radiation sources used in the oil and gas industry are frequently transported between service company bases and points of use; they are sometimes transferred or redirected to new locations and may be moved, removed for temporary storage or reallocated within a field or between sites. They are vulnerable to loss or theft or simply to being misplaced. Service companies and operators must keep detailed and accurate records to account for the whereabouts of sources at all times so as to prevent accidental occupational exposure or unauthorized disposal. For sources used on offshore platforms and rigs, the keeping of an up-to-date record at an appropriate onshore location would aid recovery of the sources in the event of a serious incident. The likelihood of loss or damage is greater for portable or mobile sources (particularly small items such as smoke detectors and beta lights). Every effort must be made to locate radiation sources that are not accounted for and the regulatory body must be notified promptly of any loss. Sources that are lost or ‘orphaned’ present a radiological risk to the public and constitute a potentially serious hazard to any individual member of the public who attempts to remove a source from safe containment. They may become a significant economic burden and risk to the wider public if, for example, they are recycled with scrap metal. Unnecessary risks that may result in the loss of a source ought to be avoided; for example, it is desirable that source containers are not lifted over the sea. When sources must be manipulated and where there is a risk of loss, suitable precautions need to be taken (IAEA-TCS-0103, 2002). A plate covering the annulus around a well logging tool, or a chain connecting the source to the handling rod while it is being inserted into the tool, is sufficient to prevent a disconnected source from falling into a well. A tarpaulin may be used to cover deck grating during an emergency procedure to recover a disconnected source from the projection tube of a radiographic exposure container (IAEA Safety Report Series No.34, 2003).

3.3 *Packaging of nuclear materials*

The containers in which radiation sources are transported, moved and stored are generally designed to provide adequate shielding and radiation safety

under most climatic conditions. They demand a degree of maintenance that may need to be increased in more arduous working environments, for example, in salty or sandy environments where corrosion and increased wear may be of concern. Installed gauges often remain in position for long periods of time and it is important that they are kept clean so that identification markings, labels or other safety markings. Otherwise, in the longer term, the obvious profile, discernible relevant markings and even the source's identity may be lost. The care and maintenance of ancillary equipment for controlling the radiation source (tubes and cables used for radiography and handling rods used for well logging) are similarly very important (IAEA Safety Report Series No.34, 2003). The 1985 Edition of the IAEA Regulations provided for four types of packages, depending on the activity and physical form of their radioactive content, these are expressed as follows: excepted; industrial; Type A; and Type B (WNTI Review Series No.1, 2006).

3.4 *Development of Regulations for the Sea Transport of Dangerous Goods*

The need for international regulations governing the carriage of dangerous goods by sea was recognized by the 1929 International Conference on the Safety of Life at Sea (SOLAS), which recommended that rules on the subject should have international effect. The Safety of Life At Sea Conference of 1948 adopted a classification system for dangerous goods and certain general provisions concerning their carriage in ships in Chapter VI of the SOLAS Convention. It also recommended further study with the object of drafting international regulations. Meanwhile, in 1956 the UN Committee of Experts published its first Recommendations, which offered a general framework to which existing modal dangerous goods transport regulations could be adapted and within which they could develop. The ultimate aim of the UN Orange Book was to bring uniformity to maritime and other modal transport rules on a worldwide basis.

As a further step towards meeting the need for international rules governing the carriage of dangerous goods in ships, the International Conference on Safety of Life at Sea in 1960 laid down a general framework of provisions in Chapter VII of the SOLAS Convention. The Conference also invited IMO to undertake a study with a view to establishing a unified international code for the carriage of dangerous goods by sea in co-operation with the UN Committee of Experts, taking account of existing maritime practices and procedures. The Conference further recommended that the unified code prepared by IMO should be adopted by the

governments party to the SOLAS Convention. Following completion of the necessary development work, the International Maritime Dangerous Goods (IMDG) Code was adopted by the fourth IMO General Assembly in November 1965. Like the other modal dangerous goods requirements, the IMDG Code covers nine classes of dangerous goods. Class 7 radioactive material is covered through incorporation in the IMDG Code of the relevant provisions of the IAEA Regulations for the Safe Transport of Radioactive Material (IMDG Code, 2005). During the 1980s, the scope of the IMDG Code was extended to include provisions and requirements for the transport of substances and materials harmful to the marine environment, identified as marine pollutants. Inclusion of marine pollutants in the Code also assisted in the implementation of Annex III of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by its 1978 Protocol 61 (the 1973/78 MARPOL Convention). Annex III contains the regulations for preventing pollution by harmful substances carried in packaged form, including packages in portable tanks, freight containers, road tankers and rail tank wagons. The harmful substances covered by MARPOL Annex III are thus those identified by GESAMP 63 as marine pollutants in the IMDG Code. GESAMP has not considered packaged radioactive material in the context of marine pollutants and Annex III does not apply to radioactive material. In addition to the IMDG Code, the IMO introduced the Code for the Safe Carriage of Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes in Flasks on Board Ships (the INF Code) in 1993 (WNTI Review Series No.1, 2006).

The gamma and neutron sources used in these tools are normally transported in separate heavy containers termed shipping shields or carrying shields. They are Type A transport packages (or sometimes Type B for the neutron source) that meet the specifications for Category III labelling as defined by the IAEA Regulations for the Safe Transport of Radioactive Material (IAEA Safety Requirements, 2005). They may be transported by road in the vehicles of the logging companies to the land well. When they are to be used offshore, the shields are usually contained in an overpack. This may be a large thickwalled box (external dimensions about 1.75 m × 1.75 m × 1.75 m) that also serves as a storage container at the well site. The dose rates of the ¹³⁷Cs source are significant but not normally isotropic owing to the construction of the source assembly. Dose rates may exceed 7.5 μSv/h for up to 30 m in the forward direction and about 4 m behind the operator. The radiation from the source is directed away from any occupied areas. The dose

rates of the neutron sources can exceed 7.5 $\mu\text{Sv/h}$ for distances of up to about 4 m. In addition to a 'set' of sources used in the logging tools, the logging engineer will need a number of field calibration sources to carry out final checks on the tools before beginning the log. Master calibrations are periodically performed on the tools at the logging company's operations base. These tests will involve putting the sources into the tools or into a section of the tool and either placing the tool inside a calibration block or placing a block over the source position on the tool. The master calibration for the neutron-gamma logging tool involves generating neutrons while the tool is inside a tank filled with a suitable fluid (for example, clean water). The tank and its contents remain radioactive for a short time (up to 30 min) after the tool has been switched off. The logging tools and the sources they contain are subjected to very high downhole temperatures and pressures. The sources normally fall within the definition of 'special form radioactive material' as sealed sources satisfying the test criteria specified by the IAEA and ISO standards. Nevertheless, the sources are normally given the further protection of a special container (a pressure vessel) whenever they are in the shield or logging tool. The sources also need frequent checks for leakage of radioactive substances in accordance with test criteria specified by ISO standards (IAEA Safety Report Series No.34, 2003).

4 CONCLUSION

Radioactive material plays an important role in our lives. Radioactive material being shipped includes uranium ores, nuclear fuel assemblies, spent nuclear fuel, radioisotopes and radioactive waste. Every year, millions of packages containing radioactive material for use in medicine, agriculture, industry, defence and science are transported across international borders via roads, rails, air and sea. Transport of these materials must be carefully regulated to ensure the safety of transport workers and the public, as well as property and the environment.

The IMO has established international standards for ships carrying certain high activity radioactive material, such as irradiated nuclear fuel, high level waste and plutonium, called the INF Code. The INF Code sets forth requirements in areas of ship design or equipment including damage stability, fire protection, temperature control of cargo spaces, structural considerations, cargo securing arrangements, and electrical arrangements. The analysis and results in this study are primarily focused on these high activity materials.

While this study encompassed marine transport of packaged radioactive material on four different types of ships: container ships, roll-on/roll-off (Ro-Ro) ships, general cargo (breakbulk) ships, or purpose-built ships, the results of the study are applicable to any ship transporting radioactive material that complies with the applicable cargo ship requirements of the International Convention for Safety of Life at Sea (SOLAS), as well as with the specific requirements of the IMDG Code for the radioactive material considered. In addition, for ships that carry shipments of INF code materials, this study takes into consideration special provisions of the three separate classes of ships, depending on the total maximum radioactive quantity that may be carried on board:

- Class INF 1 Ships: ships that are certified to carry INF cargo with an aggregate activity less than 4000 TBq,
- Class INF 2 Ships: ships that are certified to carry irradiated nuclear fuel or high level wastes with an aggregate activity less than 2×10^6 TBq and those certified to carry plutonium with an aggregate activity less than 2×10^5 TBq,
- Class INF 3 Ships: ships that are certified to carry irradiated nuclear fuel or high level wastes and those certified to carry plutonium with no restriction of the maximum aggregate activity of material.

Consequently this study was mainly concentrated on safety and environmental awareness issues for the carriage of nuclear materials via by ships. The outcomes would be utilized not only the industry itself but the Maritime Training and Education (MET) institutions that are providing relevant training on the carriage of dangerous goods such as Class 7.

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