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The Need to Adapt the IAEA Regulations for the Safe Transport of Radioactive Material (RAM) to Evolutions in Use and Technology of Transport Conveyances

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Abstract

The technologies and means of transport used for the carriage of goods by sea and air have considerably evolved in recent decades whereas criteria and regulatory requirements concerning the limitation of radioactive material on board ships or aircraft, originating for most the part in the 1970s and 1980s, have not followed this trend. Container shipping by sea has become the predominant means of transport, and sea vessel sizes continue to increase. Air freight transport is increasingly provided by passenger airliners, and cargo-only aircraft are now, in most cases, derivatives of passenger aircraft adapted for transport of cargo. Land vehicles and wagons adapted to transport of standard containers have now become widely available.

With the evolution in the means of transport, the need to update regulatory criteria and requirements currently in force has become more and more necessary, especially those concerning the Transport Index (TI) and Criticality Safety Index (CSI) limits and the definition of exclusive-use shipment conditions for the transport of radioactive material. The different types of transport conveyances proposed by airline and marine shipping companies for international carriage of freight and the main evolutions of these conveyances in recent decades are presented in this paper. Amendments for updating the regulatory requirements in line with these evolutions are proposed and discussed so as to improve transport operations and reduce their cost without reducing the level of safety.

Introduction

Container shipping by sea has become the predominant means of transport for goods in packages, including radioactive materials, while it was anecdotic in the 1970s, and, since that time the size of container ships and their cargo holds have significantly increased. During this same period, the size and technology of aircraft used for the transport of freight also significantly evolved. The increase in the size of the passenger aircraft offering greater cargo capacity combined with a low volume of air cargo compared to the number of passengers carried on certain routes has led the airlines serving these routes to stop offering all-cargo flights: they only offer to carry air cargo in passenger aircrafts. As for

shipping by sea, carriage by rail and road of radioactive materials, especially when such shipments are part of a multimodal transport including sea, is now principally executed by using freight containers. The carriage of radioactive material in freight containers throughout the entire chain of transport makes handling operations easier, shorter, and contributes to the reduction in the dose uptake of handling agents in seaports and other transhipment sites when carrying out loading and unloading operations. A reflection is proposed on the need to adapt the IAEA Regulations for the Safe Transport of Radioactive Material to these developments.

Evolution of container shipping and evolution of rules for carriage of radioactive material (RAM) by sea

Evolution of use of containers in commercial shipping

In a total of 8,400 million tons (all cargo) carried by sea in 2010, containers represented 16% of the total tonnage, while in 1980 they represented less than 3% [1]. The gross tonnage carried in containers by sea grew from 100 million tons in 1980 to 1,350 million tons in 2010 [1]. The increase in the market share of the container ships at the expense of conventional cargo ships can also be observed in the evolution of the world fleet of commercial vessels: the container ship fleet grew from less than 2% of the world fleet in 1980 to over 13% in 2011 while the share of general cargo vessels has dropped from 17% to less than 8% during the same period [1]. Furthermore, a part of the general cargo ship fleet built in the 1970s has been modified into container ships as from the 1980s [1]. This expansion in the use of containers is also the case for radioactive material, reflecting the fact that the main maritime routes are now almost exclusively served by regular lines using container ships or other kinds of ships adapted to carrying freight containers, such as roll on-roll off (ro-ro) and general cargo ships.

Evolution of container ships in size and capacity

Numerous publications on international transport by sea show the extraordinary and constant increase in size and capacity of container ships over the years. The first generation of container ships was composed of modified bulk vessels or tankers that could transport up to 1,000 TEUs (TEU: twenty-foot equivalent unit, 20x8x8 feet), exclusively on the converted decks. Construction and use of the first fully cellular container ships (FCC) entirely dedicated to handling containers really started in the 1970s with a capacity of 2,500 TEUs. The size of container ships has not ceased to increase, having recently reached the capacity of 18,000 TEUs.

Typical arrangement of general cargo ships in the 1970s and earlier compared with those of current container ships

The arrangement of general cargo ships used after World War II until the 1970s is more or less the one adopted for the Liberty Ship Class. Typically a Liberty Ship is fitted with five cargo holds separated by bulkheads, each separated vertically by a ‘tween deck,’ offering a total of 10 different cargo spaces for

a total volume of about 15,850 m^3 in a ship of approximately 135 m long x 17 m wide x 8.5 m draft (figure 1) [7].The largest cargo space is the hold No. 2, the size of which is 22 m long x 17 m wide x 7.3 m high. The cargo loaded on this kind of ship is essentially under deck.

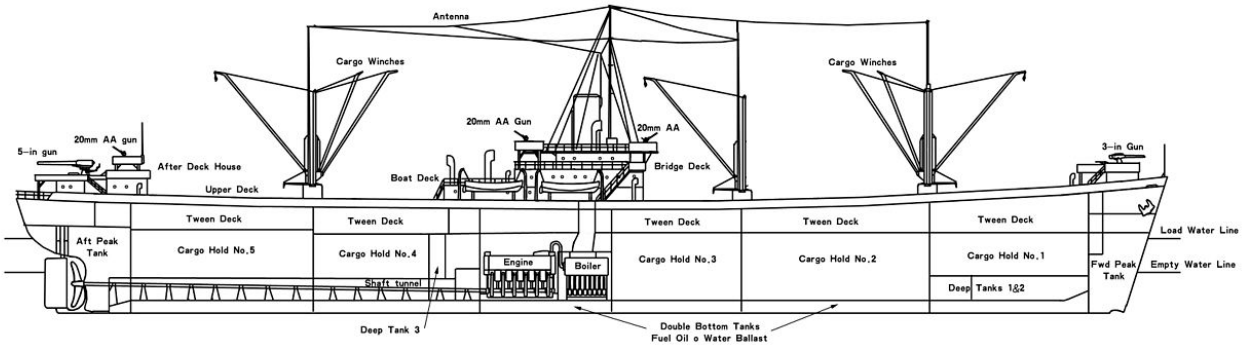

Figure 1 – Cargo spaces in a Liberty Ship

Ships of today with the same overall dimensions as a Liberty Ship may be fitted with fewer cargo holds but of higher capacity, while the largest container ships may have about the same number of cargo holds as a Liberty Ship, again with higher capacity. Today, a medium-size container ship with a capacity of 2,500 TEUs (figure 2), of approximately 200 m long x 32 m wide x 10 m draft, may be subdivided into only 6 holds while the total volume of cargo can reach 93,750 m^3 (2,500 TEUs), nearly 6 times more than in a Liberty Ship. The containers loaded on this kind of ship are predominantly on deck (40% under deck, 60% on deck).

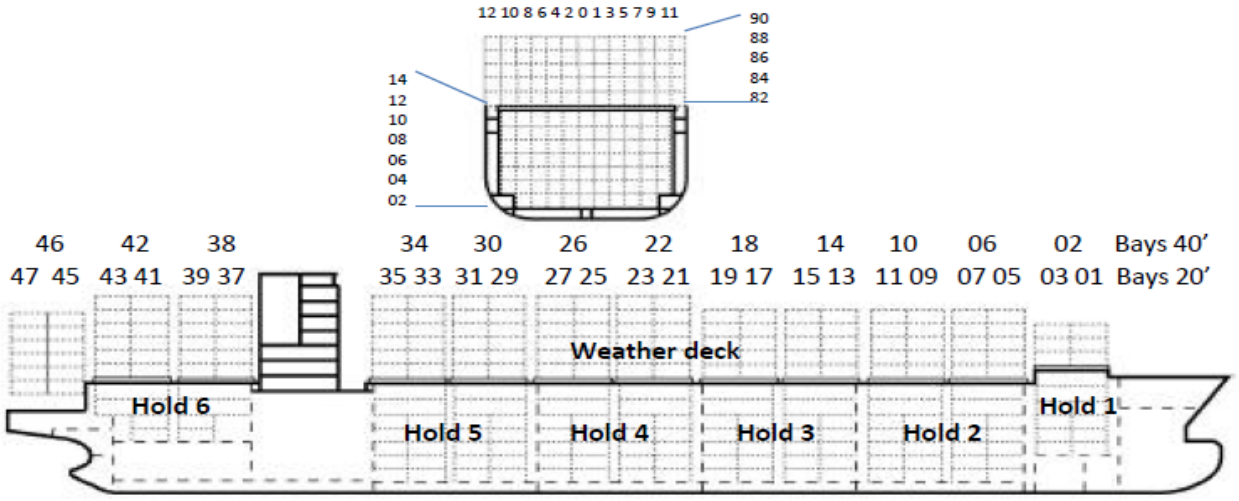

Figure 2 – Cargo spaces in a container ship in the range of about 2500 TEUs

Evolution of the main rules and limits in force concerning transport of RAM by sea

The current IAEA Regulations for the Safe Transport of Radioactive Material [2] contains specific requirements concerning the transport of radioactive material by sea which, for the most part, have not changed significantly since the 1970s. In particular, definitions concerning “conveyance,” “freight container,” “defined deck area,” “vessel,” and “exclusive use,” as well as requirements for segregation

during transport by sea are quite the same as those already stipulated in the 1973 Edition of the IAEA Regulations [3]. Although the sizes of the holds have significantly increased, the Transport Index (TI) and Criticality Safety Index (CSI) limits per hold have remained as they were in 1973.

Constraints generated by these limits for containerized RAM

Occasionally, consignments of packages of fissile material transported in large freight containers by rail in a single train cannot be loaded aboard a single ship, even though the ship is much larger than the train having brought the cargo to the port. This is due to the limits assigned per hold (which are more or less equivalent to those assigned per railway wagon, whilst holds are much larger than railway wagons), and the low number of holds with which certain container ships are fitted. This complicates the organization of multimodal shipments. As the radioactive materials are packed in large freight containers, it would be possible to express the segregation constraints for criticality safety and for radiation protection differently than by a limit assigned per hold or defined deck area, or to enlarge those limits, without decreasing the safety. This would also provide more flexibility in the choice of arrangements of stowage of containerized radioactive material cargo aboard container ships, so that other constraints, such as those associated with physical protection of nuclear material or with marine insurance policies, can be more easily met.

Evolutions proposed for carriage by sea of RAM packed in large freight containers

- Large freight containers: The definition given to this term is questionable. This definition is not completely homogenous between regulations, and the definitions given to small and large freight containers introduce confusion regarding the qualification of open containers. In contrast to the IAEA Regulations [2], in the IMDG Code [4], freight containers are required to be in accordance with the International Convention for Safe Containers (CSC) and, CSI and TI limits associated with the use of large freight containers are restricted to closed containers. The following clarifications should be provided in order to avoid misinterpretation:
    - In the IEA Regulations, any ISO freight container complying with the CSC (closed and open-top 10-foot ISO containers and larger, 10-foot ISO flat racks and larger, 20-foot ISO platforms and larger) should be considered as a large freight container, since the useful volume of all these kinds of freight containers is much larger than 3 m^3.
    - In the IMDG Code, the restriction on the use of the enlarged limits of the TI and CSI per hold, compartment, defined deck area, or total vessel when the radioactive materials are in large freight containers to closed containers should be eliminated: having the radioactive cargo in closed containers rather than in open containers does not reduce the risk of radiation exposure and does not reduce the risk presented by fissile material in holds, compartments, defined deck areas and the total vessel.

Table 1 – Exclusive use in cases of shipments in large freight containers (LFC)

Consignment requiring exclusive use (from Annex III of IAEA Regulations [2])	Large freight container	Hold, compartment or defined deck area
(e) *Packages* or *overpacks* having an individual *TI* greater than 10 or	X	X (a)
a *consignment CSI* greater than 50	X	X (b)
(f) *Packages* or *overpacks* having maximum *radiation level* at any point on external surfaces exceeding 2 mSv/h	X + Special arrangement	X (a)
(g) Loaded *conveyance* or *large freight containers* with total sum of *TI* exceeding the values given in Table 10	X (if the sum of the TIs in the freight container exceeds 50)	X (if the sum of the TIs in the hold, compartment or defined deck area exceeds 200)
(h) Loaded *conveyances* or *large freight containers* with total sum of *CSI* exceeding the values given in Table 11 for "not under *exclusive use*"	X (if the sum of the CSIs in the freight container exceeds 50)	X (if the sum of the CSIs in the hold, compartment or defined deck area exceeds 50) (b)
(j) Up to 45 g of *fissile nuclides* on *conveyance*, either packaged or unpackaged, in accordance with provisions of para 417(e) and 520(d)	X	X (a)
(k) *Packages* containing *fissile material* classified as non-fissile or fissile-excepted under para 417(a)(i) or (iii) of 2009 Edition of these Regulations (para 822)	X	X (a)

(a) Except for shipments which are in closed freight containers

(b) The consignment shall be handled and stowed so that the sum of CSIs in any group does not exceed 50 and so that each group is handled and stowed in order to maintain a spacing of at least 6 m from other groups. When the sum of CSIs in a single container exceeds 50, this single container shall be handled and stowed so as to maintain a spacing of at least 6 m from other radioactive cargo.

- Exclusive use: The definition given to this term ("use of a conveyance or of a large container") clearly indicates that this qualification can apply to a large freight container without necessarily being applied to the conveyance carrying this large freight container. However, when implementing certain of the requirements for exclusive use (for example when para 567 of the

IAEA transport regulations [2] is applicable), confusion may arise on how the limit must be interpreted. Clarification should be provided to distinguish the situations in which exclusive use applies to the conveyance or to the large freight container, and those in which exclusive use applies to the conveyance and to the large freight container. Table 1 is a proposal of how exclusive use should apply in cases of shipments in large freight containers with current limits.

- Conveyance: Possibility of having more than one defined deck area on the weather deck of a ship should be introduced. Specifically, the division of weather decks into several defined deck areas corresponding, for example, to one or more contiguous 40-foot bays, should be authorized.
- Segregation rules for radiation exposure (TI limits): Taking into account the fact that Radiation Protection Programme (RPP) must be established and implemented when carrying radioactive material on-board ships, the current 200 TI limit above which exclusive use of the hold, compartment, or defined deck area is required when carrying radioactive material in large freight containers should be withdrawn. This 200 TI limit does not apply to LSA-I while the TI of a complete load of certain LSA-I in a freight container may reach or exceed 50. Segregation distances should be primarily determined according to the provisions of the applicable RPP. Table 2 illustrates the specific rules proposed for TI accumulation.

Table 2 – TI segregation rules proposed as alternative to those currently in force for large freight containers

Item	TI limit for non exclusive use
Package	≤ 10
Large freight container	≤ 50
Hold, compartment or defined deck area	~~200~~ → No limit
Total vessel	No limit
Segregation	According to the Radiation Protection Programme

- Segregation rules for criticality safety (CSI limits, segregation distances and shipment approval): If the sum of CSIs in a hold, compartment, or defined deck area is between 50 and 100, exclusive use is required. This range should be reviewed because of the increasing size of the holds. For comparison, a single train may carry an unlimited CSI without exclusive use and without shipment approval provided the CSI of each wagon and of each consignment does not exceed 50 ([2] and [6]) allowing much more CSI per unit length than in a container ship. In the

case where large containers are used, it is suggested that the current 50 CSI limit per hold, compartment, or defined deck area be increased up to 100 CSI in non-exclusive use and up to 200 when the hold or the defined deck area is under exclusive use, provided that the CSI of each large freight container does not exceed 50 and that the stowage is such that a spacing of at least 6 m is maintained between the groups of containers with CSI less than 50. Table 3 illustrates the specific rules proposed for CSI accumulation.

- Mixed loading: Authorization of intervening space between freight containers containing radioactive material to be occupied by non-radioactive material cargo in freight containers in a hold or defined deck area, even in the case of exclusive use of this hold or defined deck area, should be introduced (this is currently authorized only in intervening holds or defined deck areas free of radioactive cargo) [2].

Table 3 – CSI segregation rules proposed as alternative to those currently in force for large freight containers

Item	Non exclusive use	Container under exclusive use	Container and conveyance under exclusive use	
Package	≤ 50	No limit (*)	-	-
Large freight container	≤ 50	≤100 (*)	≤ 50	≤100 (*)
Consignment	≤ 50	No limit	No limit	No limit
Hold, compartment, defined deck area	~~≤ 50 →~~≤ 100	~~≤ 50 →~~≤ 100	~~≤ 100 →~~ ≤ 200(*)	~~≤ 100 →~~ ≤ 200(*)
Total vessel	No limit	No limit	No limit	No limit
Segregation (in all directions)	6 m between groups with CSI less than 50	6 m between container with CSI greater than 50 and other radioactive material	6 m between groups with CSI ≤ 50	6 m between container with CSI greater than 50 and other radioactive material
Equivalent distance on board containerships	One container space (**) fore and aft; Three container spaces athwartships; Only one group per vertical line unless separated by a deck and a minimum vertical distance of 6 m			

(*) shipment approval required if the CSI exceeds 50

(**) container space means a distance of not less than 6 m fore and aft or not less than 2.4 m athwartships [4]

Evolution of civil aircraft used for carriage of air freight and evolution of rules for carriage of radioactive material by air

Evolution of air freight market since the 1970s

- Cargo aircraft: The largest cargo aircraft were developed in the 1970s and 1980s for military needs and are still in operation, even if some technological evolutions have been introduced since that time for the most recent versions of those aircraft. Today, civil aircraft designed for air carriage of cargo under service are either military aircraft reconverted for civil use (An-12 and An-124 from Antonov) or aircraft derived from military cargo aircraft (L-100 from Lockheed derived from the C130 Hercules). The other full-cargo aircraft are mostly derivatives of passenger aircraft.
- Combination cargo and passenger aircraft: Combi-aircraft are aircraft that can be used to carry either passengers, as an airliner, or cargo as a freighter, and may have a partition in the aircraft cabin to allow both uses simultaneously in a mixed passenger/freight combination. Many airliners were operating such aircraft in the 1980s and 1990s. Today, only a few major airlines still operate wide-body combi-configured aircraft.
- Passenger aircraft: Due to the size of the cargo holds with which large passenger aircraft are fitted a significant part of air freight is now carried in passenger aircraft. Since the 1970s air freight carried in the cargo holds of passenger aircraft has not ceased to increase, and the trend is that the share of 'belly cargo' (cargo in passenger aircraft) will continue to increase at the expense of the cargo in freighters [8].
- Aircraft Unit Load Devices (ULD): An ULD is a unit designed to enable individual pieces of cargo to be assembled, comprising an aircraft pallet and a pallet net, an aircraft pallet and a pallet net over an igloo, or an aircraft container. The standardization of techniques and equipment used for handling and stowage of cargo in passenger aircrafts has played a key role in the growth of the market share of air freight with passenger aircraft. Today, most of the cargo carried by air is packed in ULDs prior to loading in the holds of an aircraft as shown in figure 3.

Figure 3 – Unit Load Devices in passenger and cargo aircraft

These evolutions, in particular the fact that now most air cargo is carried in passenger aircraft and that on certain routes only the use of passenger aircraft is possible, have led to the need, as long as safety is not impaired, to the revision of the restrictions put on radioactive material transport in a passenger aircraft.

Evolution of the main rules and limits in force concerning transport of RAM by air

The current IAEA and ICAO Regulations for the transport of radioactive material [2][5] contain specific requirements concerning the transport of radioactive material by air which, for the most part, have not changed significantly since the 1970s. In particular, definitions concerning “conveyance” and “exclusive use,” as well as requirements for segregation during transport by air, are quite the same as those already contained in the 1973 edition of the IAEA Regulations [3]:

- Conveyance: any aircraft
- Exclusive use: the sole use, by a single consignor, of a conveyance or of a large freight container, in respect of which all initial, intermediate and final loading and unloading […] are carried out in accordance with the directions of the consignor or consignee, […]
- Segregation:
    - For radiological purposes: based on the Transport Index (TI) accumulation limits per conveyance for non-exclusive use shipments (50 in a passenger aircraft, 200 in a cargo aircraft), and on segregation measures such that the dose received by the personnel is less than the limit permitted according to their classification for radiation exposure for exclusive use shipments.
    - For criticality safety purposes: based on the Criticality Safety Index (CSI) accumulation limit (50 in an aircraft not under exclusive use, 100 in a cargo aircraft when under exclusive use).
    - Exclusive-use shipments are forbidden on passenger aircraft.

In contrast, the number of situations where exclusive use is required has increased over time.

Constraints generated by these limits for the organization of the shipment

Some rules are excessively restrictive, for example the combination of the current definition of "exclusive use" (use of the means of transport by one consignor) with that of the "means of transport" (the whole aircraft) implies that exclusive use requires full chartering of the aircraft which increases considerably the cost of these shipments. For example, the carriage of less than 45 g of U-235 contained in three individual excepted packages of a few kg each as fissile excepted material following the new para 417 (e) of IAEA SSR-6 was impossible by aircraft due to the cost of this solution (full chartering of a cargo aircraft), whereas in the past those packages were usually carried not under exclusive use in passenger aircraft.

Evolutions proposed for the carriage by air of RAM

- Exclusive use: To avoid full chartering of the aircraft in cases where exclusive use applies, the following amendments are proposed:
    - "Exclusive use" should be restricted to a cargo space of an aircraft, other cargo spaces should be authorized for the transport of other cargo but not radioactive material.
    - Certain consignments under "Exclusive use" should be authorized in passenger aircraft, as proposed in table 4, without increase of danger to the passengers.

Table 4 – Exclusive use in cases of shipment in an aircraft

Consignment requiring exclusive use (from Annex III of IAEA Transport regulations [2])	Passenger aircraft	Cargo aircraft
(e) *Packages* or *overpacks* having individual *TI* greater than 10 or	X	X
consignment CSI greater than 50	Forbidden	X (*)
(f) *Packages* or *Overpacks* having maximum *radiation level* at any point on the external surfaces exceeding 2 mSv/h	Forbidden	Special arrangement
(g) Loaded *conveyance* or *large freight containers* with total sum of *TI* exceeding the values given in Table 10	X (TI>10/package, TI≤50/aircraft)	X (TI >50)
(h) Loaded *conveyances* or *large freight containers* with total sum of *CSI* exceeding the values given in Table 11 for "not under *exclusive use*"	Forbidden	X (*)
(j) Up to 45 g of *fissile nuclides* on a *conveyance*, either packaged or unpackaged, in accordance with the provisions of para 417(e) and 520(d)	X	X
(k) *Packages* containing *fissile material* classified as non-fissile or fissile-excepted under para 417(a)(i) or (iii) of the 2009 Edition of these Regulations.	X	X

(*) The consignment shall be handled and stowed so that the sum of CSIs in any group does not exceed 50 and so that each group is handled and stowed in order to maintain a spacing of at least 6 m from other groups. When the sum of CSIs in a single container is between 50 and 100, this single container shall be handled and stowed so as to maintain a spacing of at least 6 m from other radioactive cargo.

Conclusions

The amendments proposed in this article to adapt the IAEA Regulations for the Safe Transport of Radioactive Material to the evolutions of container shipping, as well as to those of the transport of air cargo, show that it would be possible, by making small adjustments to the rules, to significantly improve transport operations and significantly reduce their cost without decreasing safety.

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