Maritime security and nuclear cargoes

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Civilian nuclear operations entail the transportation of sometimes substantial quantities of radioactive material. These can range from large quantities of weakly radioactive fresh fuel for power reactors, with the corresponding removal of highly radioactive spent fuel and operational wastes, to the shipment of small quantities of radioactive isotopes ("sources") for medical, industrial or research purposes and their subsequent disposal. In relation to the civilian nuclear fuel cycle, there may also be relatively large quantities of radioactive material produced by "back-end" activities, such as the reprocessing of spent fuel to recover plutonium and then create mixed oxide, or MOX, fuel.[1] In between these extremes, there are occasional consignments of fresh and spent fuel to and from research reactors, together with the associated wastes. In many of these cases, circumstances will dictate that consignments are dispatched overland, or by air, but there are some cases where a substantial maritime component is entailed and where there will be particular security and safety concerns that arise from that. Traditionally, the focus of this concern has been on the possibility of accidents, which might result in environmental contamination or human harm, but more recently, and certainly since 11 September 2001, the locus of concern has somewhat shifted to risks that might arise from the activities of non-state armed groups, or terrorists (or even pirates). This is the focus of the present review.

Nuclear ships

As indicated above, much transportation of nuclear material is overland and thus beyond the scope of the present discussion, but there are prominent cases where dedicated ships are used, either on grounds of convenience or because of the long distances involved. In the cases of Sweden and Japan, all their significant nuclear sites are on the coast. In the former case, the Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering AB) services sites using a specially built nuclear transportation vessel, the M/S *Sigyn*.[2] This carries spent fuel and operational wastes from the four power station sites to the various holding and disposal facilities. Japan carries spent fuel and waste from its rather larger number of nuclear power reactors to a central service site at Rokkasho on the north-eastern coast of Honshu using a small fleet of specially built ships. These vessels will also convey MOX fuel rods from the reprocessing of spent fuel at Rokkasho back to the power station sites when the manufacturing capability for this activity is completed. The extensive British civil nuclear support industry also services its customers in various places in Europe through the use of specially built or specially

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converted vessels.[3] In these cases, the conditions of the sea voyage are such as to facilitate onward land transportation, which may mean that they are carried on the vehicles that will be used for onward transit. These ships are presently operated by International Nuclear Services, on behalf of the British Nuclear Decommissioning Authority, successor to British Nuclear Fuels Ltd.

Early in the development of its nuclear industry, Japan decided to reprocess its spent fuel in France and the United Kingdom. This necessitated the transfer of spent fuel from Japan to Europe and the subsequent return to Japan of separated plutonium (only once), the regular return of MOX fuel and the occasional return of high-level wastes. This gave rise to the development of ships dedicated to these voyages and the formation of a company, Pacific Nuclear Transport Limited (PNTL), to provide the ships. Again, the ships are operated by International Nuclear Services.

This activity has now been going on for more than 30 years. For the most part, spent fuel has been transported via the most direct route across the Pacific and through the Panama Canal to France or the United Kingdom, with return cargoes of MOX fuel taking a longer route around the tip of South Africa, across the Indian Ocean and north through the Tasman Sea. This latter route involves negligible time close to land, reflecting the higher security sensitivity of (plutonium-containing) MOX fuel.[4] Consignments of high-level waste may take any of the three possible routes. Because of this long experience, PNTL ships were involved in the 2004 shipment of surplus weapon-grade plutonium from the United States to France and the subsequent return to the United States of a batch of MOX fuel for US reactors: a project that was known as ”Eurofab”.

Japan is building its own capacity to reprocess and use its commercial spent fuel, so it is likely that the trade with Europe may diminish with time. On the other hand, there are international trends that may increase the demand for maritime transportation. There is a reviving interest in civilian nuclear power around the globe and the volume of demand in particular regions, or by particular states, may be such as to justify service by sea. Like Japan and Sweden, states may plan to place all their major facilities on the coast.[5] Economics and non-proliferation considerations, leading to international cooperation on fuel services, may also result in more shipment of nuclear materials (particularly back-end materials) by sea.[6]

A great deal of nuclear material is also transported by sea in containers on large container ships, where it is carried along with the usual variety of commercial cargo. These consignments will include refined uranium ore (”yellow cake”) as well as other front-end materials, such as uranium hexafluoride and fresh fuel, all of which are characterized by low radioactivity. Container ships also transport smaller amounts of back-end material produced by the operation of research reactors, which do not require a dedicated ship. An example of this would be the Open Pool Australian Lightwater research reactor at Lucas Heights, south of Sydney. This is a 20 Megawatt pool reactor, which was built by contractors from Argentina, who supplied the original fresh fuel. Fresh fuel now comes from a European source, and spent fuel is presently sent to France for reprocessing, from where there are periodical returns to Australia of conditioned waste (that is, radioactive waste that has been immobilized and packaged so that it is suitable for safe handling and disposal) and operational wastes. These are consigned by special shipping container but on ordinary commercial ships. Like power reactors, the mode of servicing for research reactors will generally depend on factors of convenience and security. Research reactors located near suitable ports and over water from their suppliers will frequently use shipping containers and commercial ships for both fuel supply and the return of spent fuel, as in the Australian case. For reasons of security the countries concerned will wish to avoid as far as possible public discussion of the precise arrangements.

The regulatory framework

All this movement of nuclear material around the globe is governed by a detailed set of guidelines, which arise from international conventions and the work of such international institutions as the International Maritime Organization (IMO) and the International Atomic Energy Agency (IAEA). These guidelines are implemented—often more rigorously than the guidelines themselves dictate—by the nuclear companies in the countries concerned and by the various domestic security agencies with which they cooperate. In the United Kingdom, this is the Office for Civil Nuclear Security, which is part of the Health and Safety Executive.

In the first instance, the international transportation of nuclear material is governed by the Convention on the Physical Protection of Nuclear Material, deposited with the IAEA.[7] The Convention came into force in 1987 and the present number of parties is 142, including all major states, but there are parties with significant nuclear activity that are not signatories: for example, Iran.[8] However, the Convention is only concerned with international transportation and specifically reserves the "rights of a State regarding the domestic use, storage and transport".[9] For international transportation the Convention places responsibility on any exporting state to satisfy itself that nuclear material will be protected at levels specified in Annex I to the Convention. Crucially, Annex I lays out minimum levels of physical protection for nuclear material during international transport. In all cases there is a requirement for special precautions including, as appropriate, guards and barriers, and also advanced notification to appropriate authorities of all arrangements.[10] States parties engaged in the international transfer of nuclear material are required to cooperate on the design and operation of systems of physical protection of nuclear material, both directly and through the IAEA.[11] They are also required to adopt domestic legislation criminalizing a range of activities regarding interference with the safe transfer of such material and to act in the event that an offender is within their jurisdiction. In addition, for the more sensitive Category I materials, there is a requirement for constant surveillance by escorts and conditions that assure close communication with appropriate response forces. There is also an amendment to the Convention, which was adopted in 2005, and which would extend the protective regime, particularly in respect of terrorism. This, however, is not yet in force.[12]

The other United Nations agency that is relevant to these discussions is the International Maritime Organization, headquartered in London. Arising from its general concern for safety at sea, the IMO developed the International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-level Radioactive Wastes on Board Ships (or INF Code). The Code, which became mandatory in 2001, evolved a certification system for ships based on the amount of radiation produced by the cargo as a whole, which distinguished between three classes of ship: the highest category was designated INF3; INF2 and INF1 ships were, in turn, certified for smaller quantities of total radiation.[13]

The detailed requirements for the transportation of nuclear materials are contained in the IAEA's Regulations for the Safe Transport of Radioactive Material[14] and The Physical Protection of Nuclear Material and Nuclear Facilities.[15] These specify what the hazards may be from the various materials and the conditions under which they may be transported. Among the requirements for shippers of such materials is the formal preparation of threat assessments in relation to particular kinds of cargo on particular routes (called the Design Basis Threat, DBT). These DBTs combine intelligence on the likely intentions and capabilities of potential threat groups with knowledge of the security arrangements that are in place, including the availability of countermeasures and other contingency arrangements. For each voyage a specific Transport Security Plan is also required. Generally, it would be true to say that the maritime consignment of large quantities of sensitive nuclear material is attended by a great deal of thought and preparation, including considerable efforts to anticipate how parties intent on diverting or otherwise interfering with a shipment might proceed and to devise countermeasures. Of course, much of this cannot be revealed, and for obvious reasons. On the other hand, there is sufficient information in the public domain to address public anxieties on the matter effectively.

The threat from terrorists or pirates

The terrorist threat to shipments of nuclear material by sea was the subject of a detailed report by this author in 2006.[16] This assessment was initiated because of publicly expressed concern about the Eurofab shipment and particularly a fear that it might be seized by terrorists, who might then make a bomb. In the event, the investigation was broadened to encompass other kinds of nuclear shipment and other ways that terrorists might exploit them.

Many of the envisaged threat scenarios begin with terrorists intercepting a shipment and then taking control of the ship. For the most sensitive of cargoes, i.e. those that contain a substantial quantity of fissile material, the relevant regulations stipulate ships that have a significant defensive capability. They have armed guards[17] and they have escorts. In the PNTL case, where long ocean voyages are concerned, this requirement is discharged by using two identical ships, both of which are fitted for heavy-calibre weapons and carry a group of specially trained security personnel and both of which are capable of carrying the consignment. The ships are also equipped with state-of–the-art surveillance capabilities, so that the prospect of being approached unnoticed is very small. And, of course, if an approach is noticed, the supposed assault craft are going to come under heavy fire. Some PNTL ships (and this included the Eurofab ships) are fitted with 30mm rapid-fire naval guns. Altogether, there is very considerable room for doubting that there are presently any terrorist groups that have the capability to take nuclear cargo carriers in these circumstances. Clearly, the same would apply to pirates who might intend to take a nuclear transport vessel and, perhaps, hold the ship and its cargo for ransom.

It might be thought that there would be ways to circumvent these defensive arrangements by using some kind of subterfuge to board the ship or ships. Terrorists might do this by taking advantage of nautical conventions that require ships to come to the aid of other vessels in distress, or by attempting to coerce crew members, or by contriving the placement of "sleepers". This, of course, is the stuff of the Hollywood thriller but, in the circumstances of shipments on dedicated ships carried under the regulatory framework outlined earlier, it is implausible. Certainly, in the case of PNTL ships, crew turnover is very low, so the insinuation of a sleeper would have to be a long-term project, especially if that person were to have access to sensitive areas on the ship. PNTL ships also operate a two-key system, under which a single individual would not have access to sensitive areas without the acquiescence of another crew member with the appropriate clearance. Again, attempts to blackmail crew members into assisting an assault (like attempting to place a sleeper) would have to begin long before the ship goes to sea, and this lengthy period of time increases the risk of discovery. Just to complete the set of countermeasures to these possibilities, it might be noted that there are protocols that provide for what should be done in the matter of allowing on board persons who may appear to be victims of a maritime emergency.

Notwithstanding all these considerations, it will now be assumed, for the sake of argument, that the ship has been taken. Again there are a number of possibilities regarding what might happen next. Most obviously, in the case of plutonium cargoes, there might be an attempt to remove the sensitive material from the ship. Again, the conditions of shipment make removal a formidable problem. As provided for in the regulations, plutonium-containing material is carried in massive forged-steel casks, weighing in the order of 100 metric tons, and of such a dimension in regard to the hold-space that their end-lids cannot be removed until they are taken from the hold.[18] For this, the terrorists are going to have to supply their own, very substantial, lifting equipment. This requirement will also apply to the removal of the hatch covers. On-board cranes that are available for this purpose on other voyages are deliberately removed for the most sensitive cargoes.

The ship (or ships) will need to be taken to a port with appropriate facilities, which raises two further problems. Where would this port be and what are the chances of getting there without being intercepted? This will be particularly problematic since the position of the ship and its cargo will have been continuously monitored from the outset of the voyage and the fact that its progress has been interfered with will have been known from the very beginning of the assault. It might be imagined that all global location systems had been disabled and continuing messages of reassurance had been dispatched on schedule. But, even here, it should be noted that the security agencies and shipping companies of the dispatching state will have devoted considerable effort to anticipating such intentions and the chances that they could be successfully carried through are extremely small.

The foregoing discussion assumed that the ship was taken in mid-ocean, which is the reason for the highest level of security and particularly for those measures whose object is to introduce a substantial element of delay into any efforts to divert the cargo. In the case of coastal cargoes of the most sensitive materials, the ships involved are much closer to support capabilities, which, of course, are on stand-by. In a similar way, overall security arrangements for other cargoes will generally take into account the sensitivity of the material being carried as well as a general assessment of the security threat. While shipments of high-level waste from reprocessing cannot be made the basis of a nuclear explosive device, they could, in principle, be used to make a radiological weapon or to contrive a significant environmental contamination. The security measures taken ensure that there are enormous problems in contriving these scenarios, if the starting material is a substantial consignment on a dedicated ship. To begin with, the radiation levels of the material are so high that it must be carried in massive transportation flasks, which implies all the difficulties described above for MOX fuel, with the additional danger for terrorists or pirates of receiving a lethal dose if and when they get to open them. In addition, there is the problem that the radioactive material (fission products) is held in solid ceramic glass, which would make it difficult to remove.

Beyond these scenarios, there are those that entail using the whole ship and cargo as the basis for contriving some sort of radiological event by somehow dispersing the nuclear contents in the environment by explosion or fire. Presumably this would take place close to land, or in harbour. Again, there are enormous technical difficulties in achieving this. The transportation casks are manufactured to provide great resistance to fire (and emersion) and are rigorously tested to ensure that this is so. If that were not enough, the ships themselves have considerable fire resistance. The only thing that might be done is to assault the vessel with an explosive-laden fast assault craft, as in the case of the USS *Cole* (October 2000), or to attack using an aeroplane. In none of these cases are the transportation flasks likely to be breached, although depending on the explosive burden in each case, there might be significant damage to the ship. The PNTL vessels are double-hulled so that sinking is very improbable, but an attack of this kind would undoubtedly be a media event. It is highly unlikely, however, to be a nuclear event.

Those who speculate about the danger that terrorists might make and detonate a nuclear explosive device are usually thinking of the possibility that they might get hold of highly enriched uranium (HEU).[19] HEU denotes uranium that is enriched in the isotope uranium-235 beyond the natural percentage of 0.7% to at least 20% (the remainder is uranium-238), though this level of enrichment, at the bottom of the range, is some way from a suitable material for nuclear detonation purposes. Enrichments in the order of 80% or higher are required for the fabrication of the sort of crude weapon to which terrorists might aspire. Theoretically, there are two marine locations where HEU might be found. One of these is new fuel rods on a nuclear-propelled submarine (though not all have fuel of this very high enrichment). Readers may speculate for themselves about the difficulty that may be had in getting hold of these. The other source is fresh fuel for research reactors that are still operating on fuel of this sort of enrichment. Precisely because of the proliferation danger of this material, such reactors have been progressively replaced by newer models that operate at much lower enrichment.[20] Such cargoes of weapon-suitable material as still persist will not generally contain sufficient by themselves for bomb fabrication (and, of course, it would need to be extracted from the fuel assembly). As noted earlier, such cargoes will be in a special shipping container and are likely to be “buried” deep under other containers on a commercial ship. In this case, pirates or terrorists might take the ship (assuming it came within their range and no special protective precautions were taken) but they would need to take it to a container port to get at the cargo, supposing in the case of pirates that they actually knew what was there. It may be presumed that these matters would be addressed in a Transport Security Plan. In the case of known piracy hot spots, such as off the coast of Somalia, these plans could include arranging closer support from one of the many warships in the region, but taking a wider berth might be a better option. To judge by recent events, with ships taken more than 1,000 nautical miles from the Somali coast, this might need to be a very wide berth indeed.

Conclusion

There is continuing concern about the possibility that terrorists might get hold of nuclear material and make a nuclear-based weapon of some kind. This is serious enough for us to keep under constant review the circumstances under which such materials are held and transported. As far as the maritime movement of substantial quantities of such materials is concerned, it is the case that large quantities, and particularly proliferation-sensitive materials, will be carried on dedicated ships, which offer enhanced security measures that are mandated by international agreement. In this case, the security threat is more theoretical than real since, as is well known, terrorists and pirates prefer “soft” targets: the panoply of security measures employed on these ships is such as to make them a very hard target indeed. Not only are the ships extremely well defended and externally supported but the nature of the transportation packaging is such as to present an insuperable barrier to the removal of the nuclear cargo. The bottom line here is this: if terrorists do make and detonate a nuclear explosive device, they will not do it through snatching a nuclear cargo on the high seas. In so far as there is a risk that terrorists get hold of nuclear material to make some sort of weapon, they are very much more likely to obtain this material from on land, although their prospects are not very good there either. This is where the focus of security concern needs to be.

Similarly, scenarios that entail the use of ship and cargo together as some kind of radiological weapon seem implausible in the light of the manifold obstacles to achieving any substantial effect. However, in this case, there is (as noted above) every possibility of a media event, which would present a problem for the various authorities and for which it would be prudent to prepare.[21] None of this is a reason for complacency. But it is a reason for having confidence in the security arrangements that attend the maritime shipment of major nuclear cargoes, built as they are on a continuing review of the technical possibilities and on the capabilities and intentions of terrorist groups.

The matter of piracy is different. As indicated, there is a possible threat to shipments of nuclear material on commercial container ships (with all the caveats earlier noted). Under present circumstances, and without the precautions which were the subject of earlier speculation, this could result in the ship being taken, with the nuclear material then falling into pirate or terrorist hands: a very undesirable outcome. The answer to this is perhaps beyond my brief here. It would require the international community to get serious about the Somali piracy problem by adopting more effective policies and rules of engagement for its military forces.

Notes

1. The fission process, which is at the heart of nuclear energy production, is precipitated and maintained by a flux of neutrons. These not only initiate the fission of uranium-235 atoms but they also convert uranium-238 atoms into plutonium isotopes, including plutonium-239, which is also fissile and can be used for energy production. Reprocessing extracts the plutonium from spent fuel, which is then mixed with depleted uranium (uranium-238) to make mixed oxide fuel. Front-end and back-end refer to the activities undertaken in the nuclear fuel cycle before and after the nuclear fission process.
2. For details of the vessel, routes and conditions of transportation of the radioactive material, see <www.skb.se/upload/publications/pdf/SKB%20Transport%2028.2.08.pdf>.
3. By contrast, the equally extensive French civil nuclear support industry uses largely land transfer to support its European customers.
4. The route around Cape Horn is also a possibility (according to company documents) but has never been used for MOX fuel shipments. The route that passes by the tip of Africa and through the Tasman Sea (between New Zealand and Australia), in particular, accounts for the long-time interest in this trade from persons in New Zealand, including the present author.
5. There is an advantage to doing this that has nothing to do with the transport of nuclear material. Nuclear power plants need copious amounts of cooling water. Locating them by the sea makes supplying such a need easy, and it avoids the necessity of large, unsightly cooling towers.
6. See the recent article on this topic by Mohammed I. Shaker, 2008, "The Internationalization of the Nuclear Fuel Cycle: An Arab Perspective", *Disarmament Forum,* no. 2, pp. 33–41.
7. Signed at Vienna and New York, 3 March 1980, entry into force 8 February 1987, document INFCIRC/274/Rev.1
8. To download a copy of the Convention and see its current status, go to <www.iaea.org/Publications/Documents/Conventions/cppnm.html>.
9. Convention on the Physical Protection of Nuclear Material, Article 2(3).

10. There is no requirement for states to provide information regarding arrangement if it would "jeopardize the security of the State concerned or the physical protection of nuclear material" (Convention on the Physical Protection of Nuclear Material, Article 6(2)).
11. The IAEA maintains an Office of Nuclear Security for precisely this purpose.
12. "Nuclear Security—Measures to Protect against Nuclear Terrorism, Amendment to the Convention on the Physical Protection of Nuclear Material", document GOV/INF/2005/10-GC(49)/INF/6, 6 September 2005. This amendment requires ratification by two-thirds of states parties (approximately 95 ratifications) for entry into force. As of July 2010 it has 39 contracting states, and 22 ratifications.
13. For more details of the code, see the IMO's web pages at <www.imo.org/safety/mainframe.asp?topic_id=354>. The code was adopted by and is reproduced in IMO resolution MSC.88(71), 27 May 1999, document MSC 71/23/Add.1, at <www.imo.org/includes/blastDataOnly.asp/data_id%3D15456/88%2871%29.pdf>.
14. IAEA, 2009, Regulations for the Safe Transport of Radioactive Material, Safety Requirements no. TS-R-1, Vienna, at <www-pub.iaea.org/MTCD/publications/PDF/Pub1384_web.pdf>.
15. IAEA, The Physical Protection of Nuclear Material and Nuclear Facilities, document INFCIRC/225/Rev.4 (Corrected), at <www.iaea.org/Publications/Documents/Infcircs/1999/infcirc225r4c/rev4_preface.html>.
16. Ron Smith, 2006, *Terrorism and Maritime Shipment of Nuclear Material,* at <www.pntl.co.uk/pdf/Terrorism_Nuclear_Cargo.PDF>. The study was carried out with the cooperation and support of the nuclear companies in Japan, France and the United Kingdom, who are responsible for most of the present transportation of nuclear material on dedicated ships. These are, respectively, the Overseas Reprocessing Company of Japan; Areva, France; and British Nuclear Fuels Limited (now the Nuclear Decommissioning Authority). Through them the author was able to meet with officials responsible for preparing cargoes and conducting the shipments as well as persons in the various security agencies in the countries concerned, who were responsible (in concert with the relevant company officials) for making security arrangements. The author was also able to see the facilities and technology for handling the various cargoes, including the ships and the technology associated with packaging them for transportation, as well as the training and equipment of the security personnel involved.
17. The United Kingdom's armed guards are members of the Civil Nuclear Constabulary, which is responsible for guarding nuclear establishments in the United Kingdom and for providing the security force on board ships of Pacific Nuclear Transport Limited. Other countries with a nuclear industry have corresponding organizations but the Civil Nuclear Constabulary is the only one with a sea-going component. For this purpose, other countries will tend to use military or paramilitary forces as required.
18. For further details of the conditions of transportation, the ships and the characteristics of the transportation flasks see the PNTL web site, <www.pntl.co.uk>, as well as the site of International Nuclear Services, <www.innuserv.com>.
19. See, for instance, Matthew Bunn and Anthony Wier, 2005, "The Seven Myths of Nuclear Terrorism", *Current History,* April, pp. 153–161. In contrast to using HEU, attempting to use a plutonium cargo to make a nuclear explosive device faces much greater problems at the weapon design stage.
20. This is the focus of the United States Government's Global Threat Reduction Initiative.
21. On the basis of numerous discussions with officials involved in preparing for these shipments, the author would not be at all surprised to discover that such plans were already in existence.