Annex 6

PROBABILITY AND SEVERITY OF FIRES ON BOARD SHIPS CARRYING RADIOACTIVE MATERIALS

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Abstract

This paper summarises the five UK contributions to the International Atomic Energy Agency's Co-ordinated Research Programme (CRP) on Accident Severity at Sea During Transport of Radioactive Material (CRP) on Accident Severity at Sea During Transport of Radioactive Material [1].

INTRODUCTION AND BACKGROUND

At the outset of the Co-ordinated Research Programme (CRP) on Accident Severity at Sea During Transport of Radioactive Material, concerns about the safety of transport of certain radioactive materials in large quantity had been addressed by the adoption by the International Maritime Organization's Assembly of the "Code for the Safe Carriage of Irradiated Nuclear Fuel and High Level Radioactive Wastes in Flasks on Board Ships" (INF Code). Concerns nevertheless remained in some quarters about the ability of flasks to remain safe in certain severe accident scenarios, particular to the marine transport mode. One such concern was the adequacy of the IAEA's fire test specification in the light of fire accident reports which showed average ship fire durations of ~20 hours.

The INF Code requires extensive fire detection and suppression measures on the ships carrying the largest quantities of INF material (INF 3). Nevertheless substantial quantities of INF material can be carried on ships meeting the intermediate (INF 2) standard. Therefore, as the cross channel roll-on roll-off (RO-RO) railroad ferry "Nord Pas-de-Calais" was in service to transport spent fuel from mainland Europe to the UK, it was considered appropriate to study this particular INF 2 ship in some detail with regard to fire accident conditions.

SCOPE OF UK STUDIES

Historical records were investigated to obtain an indication of the frequency, duration and severity of ships fires, particularly those which may have had the potential to pose a threat to the integrity of the Type B(U) or Type B(M) packages used to carry radioactive material in large quantity, such as irradiated nuclear flasks.

Data on ships fires were available at the International Maritime Organization (IMO), in the form of annual reports of incidents to the IMO's Fire Protection Committee and further data was available from other sources such as Lloyds Register of Shipping and from the Department of Transport's Marine Accident Investigation Branch.

There was no record in any of the data studied of a case where a Type B(U) or Type B(M) package was present on a ship where a fire incident has taken place of sufficient severity to have posed any threat to package integrity. Therefore analyses were carried out to produce an estimate of the frequency of fires on ships of capacity greater than 500 grt of all types which would have been suitable to carry Type B(U) or Type B(M) packages. Thus data for tankers and liquefied gas carriers were not included.

However, the usefulness of historical data to the current studies was limited, particularly as a means to estimate fire severity and duration. Such estimates were needed which might be compared against the standard IAEA fire test conditions which apply to Type B(U) and Type B(M) packages. These packages are designed with safety margins in hand relative to the test requirements and may be expected to fail progressively under conditions exceeding those of the regulatory tests.

Thus data for fire frequency was selected on the basis of qualitatively defined "severe fires", or "qualifying incidents" of fires/explosions, having the potential to threaten package integrity, but there was insufficient historical data to determine whether such incidents would in fact have caused any loss of integrity had a package been present during the incident. Thus the frequency data derived in these studies are very much upper-bound estimates of the frequency with which some loss of package integrity *might* occur and should not be read as frequencies with which loss of integrity *would* occur.

In order to establish the likely fire temperatures and durations to which a flask of irradiated fuel might be subjected, which could not readily be established from historical data, further work was carried out, using fire modelling techniques. Studies of the growth of fires initiating on the rail deck and in the engine room of the "Nord Pas-de-Calais" were performed to obtain temperature and duration data for this particular ship which would be representative of an INF 2 roll-on roll-off (RO-RO) rail/road ferry carrying mixed cargo.

ASSESSMENT OF FREQUENCY OF FIRE ON A VESSEL CARRYING IRRADIATED NUCLEAR FUEL [1]

A search was made of possible sources of information on shipping incidents. After consideration of the merits of various options, data on fires and explosions were purchased from Lloyd's, covering world-wide shipping, for the period 1984-93. A further similar purchase of data provided information relating to the number of ships in existence, with ship types categorised to be compatible with the fire records.

An analysis of the data was carried out to determine how many incidents would have been a potential threat to a nuclear flask, had one been carried as a cargo item. Oil tankers and liquefied gas carriers were excluded because of their inability to carry flasks.

The resulting fire frequency of 2.9×10^{-4} per ship·year was based on a total of 93 incidents identified according to specific criteria. If these criteria had not been applied, the fire frequency would have been 2.6×10^{-3} per ship·year. None of the fire incidents contributing to the main result arose as a result of a preceding collision.

The much lower rate of total losses from all causes for the UK compared with a world-wide basis is a good indication that the fire frequency quoted above is pessimistic. It is to be expected that ships meeting the INF 2 or INF 3 requirements should suffer lower, or considerably lower, fire frequency in view of the additional fire safety features required by the INF Code, compared with those of general shipping from which the fire frequency data was derived.

FREQUENCY OF A SEVERE FIRE ON THE FREIGHT FERRY "NORD PAS-DE-CALAIS" [2]

The ferry "Nord Pas-de-Calais" entered service for SNCF in December 1987, and up until 1996 completed three round trips every day between Dover and Dunkirk. It has two through decks, both of which can transport lorries; however the lower one is fitted with rails for the transportation of rail wagons. This lower deck can also be subdivided to separate "hazardous" from "non-hazardous" materials. Irradiated fuel was transported on a rail wagon in the "non-hazardous" area.

Having proposed a number of definitions for a "severe fire", two were selected as being appropriate. For a fire initiated in the non-hazardous area of the rail deck, a severe fire is defined as one which threatens the cargo. For a fire initiated in the compartments adjacent to the non-hazardous area of the rail deck, a severe fire is defined as one which breaches the containment of that compartment.

Shipping statistics from a range of sources were studied to establish credible frequencies for fires on ferries. The fire statistics published by the Marine Accident Investigation Branch of the Department of Transport were finally selected as the basis for calculating the frequency of fires on the rail deck and in adjacent compartments of the ferry. These were the initiating fire frequencies from which event trees were developed.

An event tree consists of an initiating event - in this case the initiating fire - and a series of branches, each denoting a possible outcome of a chain of subsequent events. A series of event trees were drawn to investigate under which circumstances an initiating fire could develop into a "severe fire". The frequency of these "severe fires" was calculated by assigning probabilities to each of the branches of the event trees.

Of the areas investigated, the highest frequency of a "severe fire" was found to be one initiating in the machinery space (i.e. separator/engine/generator area) of the ferry, the frequency of which was estimated as 3.8×10^{-3} per year. The second highest was a fire initiating on the lorry deck while the ferry was at sea, estimated as 1.7×10^{-3} per year. The overall frequency for a "severe fire" developing on the "Nord Pas-de-Calais", taking account of all scenarios, was estimated to be 7×10^{-3} per year. Assuming fifty flask movements annually, the frequency of such a fire developing while a flask is on board would be less than 2×10^{-4} per year.

It should be noted that this frequency is not related to any failure mechanisms of the flask, which are designed to withstand the specific fire criteria laid down by the International Atomic Energy Agency. The severity, in terms of fire temperatures and durations, also needs to be established in order to assess the threat of fire to a package. Further work was put in hand to quantify these.

STUDY OF TYPICAL TIMES FOR THE DURATION OF A SHIP FIRE [3]

Having established estimates for the frequency of a "severe fire" on the freight ferry "Nord Pas-de-Calais", Nuclear Transport Limited commissioned Safety and Reliability Directorate to investigate the duration time of a fire on a ship, with particular reference to Roll on/Roll off Ferries (RO-ROs).

Having consulted a number of organisations, only two of them were able to provide specific information on the duration of fires on ships. These were the International Maritime Organization (IMO) and the Marine Accident Investigation Branch (MAIB).

The IMO was found to have the largest number of fire reports which gave times to control and times to extinguish fires on ships. Over a period of 25 years, IMO has received a total of 382 fire casualty records reporting on ships' fires from all over the world: the shortest fire recorded was extinguished in one minute and the longest in seventy-one days. This produced an average time for a fire of 26 hours while the ship was in Port and 19 hours while underway. With such a range of duration times, these average figures are only of mathematical interest.

From the IMO and the MAIB a total of thirty reports were found for fires on RO-ROs/Car Ferries (Car Ferries and similar vessels have been included because of the difficulty in identifying true RO-ROs from the earlier reports). The most frequent figure reported was the time taken to extinguish the fire, so this was used to calculate the average time to extinguish a fire on a RO-RO/Car Ferry, and it was found to be 2 hr 20 mins.

Some reports also gave a time to control the fire which represented 42% of the extinguishment time, ie approximately 1 hr for a fire on a RO-RO. Further analysis of the reports reveals that over 70% of the fires started in the engine room and 95% of the fires were limited to the area in which they started.

The fire reports which were studied proved to be elusive in indicating how long the fire could be considered to be intense. However, using standard fire manuals, it was estimated that a fire could be considered intense for 50-60% of its life. For the longest fire recorded on a RO-RO/ Car Ferry the fire could be intense for as long as six hours.

Having thoroughly investigated all the available reports of fires, it was concluded that at present, there is insufficient historical data to reach a definitive conclusion on the time period that a fire on a ship would be considered to be intense.

FIRE MODELLING ON THE RAIL DECK AND IN THE ENGINE ROOM OF THE "NORD PAS-DE-CALAIS" [4]

The purpose of this further study was to investigate, using fire modelling techniques, the growth of fires initiating on the rail deck and in the Engine Room of the "Nord Pas-de-Calais", in order to establish the likely temperatures to which a flask of irradiated fuel may be subjected.

To determine the type and size of fire on the rail deck, a study was undertaken of the imported cargo inventories which the "Nord Pas-de-Calais" had carried. This established that of the eight wagons that could surround the flask, two would contain flammable commodities (e.g.

timber, chipboard, plastic tubes), four would contain non-flammable commodities (e.g. ash slag, steel tubes, mineral water) and the remaining two would be empty.

The HAZARD I computer code, developed by the National Institute of Standards and Technology in America, was used to model three fire scenarios on the rail deck. The code estimated that temperatures in the upper gas layer peaked at about 400°C after 20 minutes and then subsided due to the limited ventilation.

Four fire scenarios were modelled in the Engine Room involving burning fuel, all with varying levels of ventilation. In the event of a fire in the engine room of the "Nord Pas-de-Calais", dampers shut off the ventilation and fire-resisting doors seal off the engine room. With no air input, HAZARD I predicts that the fire burns out within 10 minutes. Even with the dampers staying open, the fire peaks after 20 minutes producing a ceiling temperature of about 130°C. The final fire scenario assumes a fire-resisting door does not close, and uses the average fire duration, as previously established, of 2½ hours. After this time the ceiling temperature had reached 400°C.

Because the temperature after 2½ hrs was still rising, this final scenario was run again with an extended time. This predicted that the ceiling temperature levelled off after 8 hours at 440°C; this temperature is well below that at which the integrity of the engine room ceiling would be considered to be threatened.

In none of these seven fire scenarios would the flask be exposed to conditions more severe than those specified in the IAEA Regulatory Thermal Test for an irradiated fuel flask.

PROBABILISTIC ASSESSMENT OF "NORD PAS-DE-CALAIS" FIRE SCENARIOS [5]

In a previous contract, the frequency of a severe fire on the Nord Pas-de-Calais was determined as 3.8×10^{-3} /year for the machinery space. Further work was done to determine the consequences of several fires covering a wide range of possible scenarios. The current project has focused on the mitigating factors without which most fires would eventually become severe.

A revised initiating frequency for fires has been determined, and new information about the ferry has been taken into account. Event tree analysis has been used to obtain frequencies for various fire scenarios in the separator room, generator room and engine room. These results have then been used to calculate frequencies for the specific scenarios featured in the previous work. The final results showed that, in particular, the frequency of a fire in the separator room in ventilation limited conditions was found to be 4.6×10^{-4}/year. A fire occurring with all fire doors and ventilation dampers open in the whole machinery space, leading to a ceiling temperature of 400°C after 2½ hours, would have a frequency of only 8.0×10^{-9}/year.

This very low figure reflects the initiating frequency of 2.7×10^{-2}/year, the probability that incidents will be safely dealt with, and the extent of mitigation, whereby potentially serious incidents are restricted in their consequences. However, the precise specification of the conditions defining this scenario is also a contributory factor in the attainment of such a low frequency. A more useful figure may be the frequency of 3.0×10^{-4}/year for the most serious machinery space scenarios, in which ventilation contributes to the severity of the fire.

CONCLUSIONS

Analyses have been carried out to produce an estimate of the frequency of fires on ships of capacity greater than 500 grt of all types which would have been suitable to carry Type B(U) or Type B(M) packages.

Data for fire frequency were selected on the basis of qualitatively defined "severe fires", or "qualifying incidents" of fires/explosions, having the potential to threaten package integrity and thus frequency data derived in these studies are very much upper-bound estimates of the frequency with which some loss of package integrity <u>might</u> occur and should not be read as frequencies with which loss of integrity *would* occur.

Fire modelling techniques have been applied to the rail deck and in the engine room of the "Nord Pas-de-Calais" to obtain temperature and duration data for this particular ship which would be representative of an INF 2 roll-on roll-off (RO-RO) rail/road ferry carrying mixed cargo.

Assuming typically fifty flask movements take place annually, using this particular ship, the frequency of a fire developing while a flask is on board, with potential to affect package integrity would be less than 2×10^{-4} per year.

IMO fire report records indicate an average time for a fire of 26 hours for ships in port and 19 hours while underway and only limited anecdotal information is available concerning fire severity. The average time taken to extinguish a fire, on a RO-RO/Car Ferry, was found to be 2 hr 20 min. However these data is of little usefulness in determining the times for which fires may be both sufficiently severe and sufficiently closely located to a flask to cause concern for its integrity.

It is concluded that at present, there is insufficient historical data to reach a definitive conclusion on the time period that a fire on a ship would be considered to be intense.

Fire modelling techniques have been used to estimate the growth of fires (severity and duration) initiating on the rail deck and in the Engine Room of the "Nord Pas-de-Calais".

Fire conditions on the rail deck were estimated to reach a temperature in the upper gas layer of about 400°C after 20 minutes and then to subside due to the limited ventilation.

In the event of a fire in the engine room of the "Nord Pas-de-Calais", dampers shut off the ventilation and fire-resisting doors seal off the engine room. With no air input, HAZARD I predicts that the fire burns out within 10 minutes.

Should the dampers stay open, the fire peaks after 20 minutes producing a ceiling temperature of about 130°C.

Assuming a fire-resisting door does not close, the engine room ceiling temperature reaches ~400°C after 2½ hours, levelling off after 8 hours at 440°C, a temperature well below that at which the integrity of the engine room ceiling would be considered to be threatened. Such a fire would have a frequency estimated at 8.0×10^{-9}/year.

In none of these seven fire scenarios considered would the flask be exposed to conditions more severe than those specified in the IAEA Regulatory Thermal Test for an irradiated fuel flask.

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