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MIXED OXIDE (MOX) NUCLEAR FUEL

PROBABILITIES OF SEVERELY DAMAGING ACCIDENTS AND INCIDENTS AT SEA

SUBMISSION TO THE FOREIGN AFFAIRS, DEFENCE AND TRADE COMMITTEE ON THE NEW ZEALAND NUCLEAR FREE ZONE EXTENSION

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SEA TRANSPORTATION OF UNIRRADIATED MOX FUEL

SUMMARY

Pacific Nuclear Transport Limited **(PNTL)**, the shipping arm of BNFL, operates two vessels *Pacific Pintail* and *Teal* that are currently adapted for the delivery of mixed oxide fuel (MOX) from the European fuel manufacturing plants to the Japanese nuclear power utilities. In March of this year a second consignment of MOX was delivered to Japan. The outward-bound voyage took the two vessels north of New Zealand through the Tasmanian Sea.

Should the MOX programme proceed to plan, then about 45 tonnes of plutonium reprocessed from previously contracted Japanese irradiated fuel will be incorporated into MOX fuel assemblies. The assumption is that this fuel will be delivered to Japan over the next ten years involving 20 or so voyages of the two ship flotilla – unlike the last shipment, which delivered a relatively small load of 28 MOX fuel assemblies, it is assumed that each of the two PNTL carriers will be about one half-loaded with MOX, that is each carrying MOX fuel of about 1 tonne plutonium content.

The risks of collision and fire on board the MOX carriers is assessed for the 'at sea' legs of the voyage, that is excluding the risk when the carrier ships are in the approaches to ports and berthing in harbours – the basis of this risk assessment is taken from a study in which an idealised and hypothetical ship, the *Glosten*, was designed to minimise the risk of damage from collisions and fires. These risks are presented in an 'at sea' envelope that loosely represents the risk profile for the carriers when passing through the Tasmanian Sea.

CREDIBLE ACCIDENTS FOR A 10 YEAR PROGRAMME OF MOX DELIVERIES

ACCIDENT SCENARIO	**LIKELIHOOD PER VOYAGE PER YEAR**	**NO EXPECTED OVER TOTAL MOX VOYAGES**	**LEAST SEVERE**	**MOST SEVERE**
a) Collision/Ramming	1:1,800	0.01	None eg Bump or Scrape	Flask(s) crushed open
b) Fire at Sea	1:17,300	0.01	None eg Contained Fire	Total Loss
c) Serious Fire at Sea	1:50 of all fires	<0.01	-	Radioactive Release
d) PNTL All Voyage Legs	1:16,000	<0.01	-	Radioactive Release
e) Fire in Ships Generally	1:245	N/A	-	Total Loss

The risks tabulated relate to the entire 'at sea' duration of the voyage, including for when passing through marine high-risk areas and congestion choke points. The 'at sea' risk of reportable but not necessarily serious fires on the *Glosten* at 1 in 17,300 years per voyage compares with the PNTL's assessment of the fire risk to its irradiated fuel ships (also of the Pacific class). However, if it is considered that only about 1 in 50 fires develop to seriously damaging fires, this suggests that the PNTL risks are much higher (by17300x50/16000=) x54 than the risk for the *Glosten.*

The risk to New Zealand could be further determined, albeit crudely, by isolating the voyage length when the PNTL carriers are in the region of New Zealand, this might reduce the risk further by a factor to 15 to 20.

These statistics, drawn from a collection of real ship fires for a variety of types and tonnage of ships, suggest that during the ten year MOX delivery programme the PNTL carriers would be expected to be at risk of a very small number of collisions and fires. Should there be a serious outbreak of fire on board then the crew might be forced to evacuate and abandon the vessel, this would increase the risk of collision and stranding and, course, the vessel could drift to and beach nearby a coastal community.

Statistics are, of course, just statistics predicting neither the certainty nor frequency of the sampled event. The MOX flasks on board the PNTL carriers are at a very low 'theoretical' risk of 1 in 85,000 which compares with the NASA space shuttle Columbus, designed to be fail-safe to a chance of one in a million (1:1,000,000), but which failed on its 27th launch (1:27) and, of course, *SS Titanic*, the unsinkable ship designed never to sink, that foundered on its maiden voyage (1:1).

JOHN H LARGE

SEA TRANSPORTATION OF UNIRRADIATED MOX FUEL - FREQUENCY OF ACCIDENTS

CREDIBILITY OF ACCIDENT INVOLVING SHIPS – FIRES AND COLLISIONS

Accidents involving ships include collisions, rammings, groundings, fire and explosions, foundering and miscellaneous causes including equipment and material failure and the result of hostile action. Such accidents occur in ports and approaches, at sea over continental shelves and slopes, and at deep ocean locations.

Idealised and 'Unsinkable' Ship

One relatively recent design for the 'unsinkable'[a] ship is the conceptual, radioactive waste emplacement ship *Glosten*.[1,b] The intended role of the *Glosten* was to transport 'sticks' or torpedoes of irradiated fuel which were to be remotely emplaced within the sea bed.

The design of the *Glosten* concept ship[c] would enable it withstand collisions, rammings, groundings, fire and extreme adverse weather conditions, although it was acknowledged that *Glosten* could not be expected to be proofed against all extremely damaging events. For this reason, the safety case compiled for the *Glosten* in its radioactive fuel-carrying role took into account a range of statistical probabilities associated with the common maritime risks of collisions, rammings, sinkings and fires.

Rammings and Collisions

Significant ramming and collision events were qualified as being those of sufficient severity that could, potentially, imperil the ship. However, this is not to imply that each event would actually result in serious damage, simply that the incident included the *potential* to escalate to a seriously damaging event.

Ramming and collision frequencies assumed for the *Glosten* were as follows:-

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[a] For many years, perhaps since the very onset of the formal design of ships, naval architects and marine engineers have endeavoured to produce the 'unsinkable' ship design. Brunel first introduced the design concept of cellular construction, including a watertight double bottom cavity, in the 1850s for the then revolutionary *SS Great Eastern* steamship. Other ships, including the *SS Titanic*, have claimed to be unsinkable but to date no ship design has been demonstrated totally resistance to accidental sinking, either as a result of battering by the natural elements or, perhaps less often, by the intervention of human error either at design or operation stages.

[b] *Glosten* was part of a US programme then considering the emplacement of radioactive spent fuel and HLW capsules in the sea bed – the 29,600 tonne displacement *Glosten* was to collect the waste, transport it to a deep water site and then emplace the waste in boreholes – like the similar Nuclear Energy Agency proposal of the late 1980s, the *Glosten* project was subsequently abandoned.

[c] Protection from sinking was to be provided by infills of urethane foam along the side wing tanks and on the bottom, with the foam also serving to provide collision and ramming protection - the foam and combined hull and bulkheads (of massive 74mm and 38mm thickness respectively) provide, so it is claimed, a collision energy absorption capacity of $3.16.10^{6}$kN-m that is sufficient to prevent penetration into the cargo hold by any vessel ramming at a speed of less than 24 knots, regardless of the mass or bow construction. The cargo holds carrying the radioactive waste would have been lined with 230mm of ceramic fibre insulation sufficient to isolate the cargo from a 72-hour fire of 928°C temperature. This compares with the design of the Pacific Nuclear Transport Limited (PNTL – a subsidiary of BNFL) ships that seems to correspond to a 15 knot impact with a 24,000 ton displacement vessel.

TABLE 1 SHIP COLLISION/RAMMING/GROUNDING PROBABILITIES - EACH OUTWARD BOUND TRANSIT

	PROBABILITY		
GENERAL LOCATION	**COLLISION**	**RAMMING**	**GROUNDING**
PORT AND APPROACHES	$1.90\ 10^{-4}$	$4.87\ 10^{-4}$	$7.79\ 10^{-4}$
CONTINENTAL SHELF	$1.82\ 10^{-6}$	-	-
CONTINENTAL SLOPE	$3.63\ 10^{-6}$	-	-
DEEP OCEAN	$4.13\ 10^{-5}$	-	-
TOTALS	**$2.37\ 10^{-4}$**	**$7.24\ 10^{-4}$**	**$15.03\ 10^{-4}$**

For this advanced ship design, the highest risk of collision and rammings occurs in harbours and the approaches to ports – these *Glosten* probabilities are based on an assumed rate of one collision per 100,000 encounters.

TABLE 1 provides the overall risk of collision (serious but not necessarily sinking) for each loaded journey of about once in every 4,200 years ($2.37.10^{-4}$), of incidents involving collision or ramming of about once every 1,400 years ($7.24.10^{-4}$), and for all incidents about once every 650 years ($15.03.10^{-4}$).

To apply this analysis to the MOX fuel delivery operations, modifications have to be made in account that each sea voyage includes at least two legs of port approach/departure and berthing, and for the voyage duration being approximately six times longer than that for *Glosten.* With two MOX carrying ships involved for each delivery but discounting these two ships might themselves collide with each other, this yields an overall collision risk of $\sim 5.3.10^{-4}$, with ramming $\sim 9.10^{-4}$ and all risks with grounding at $15.6.10^{-4}$, which resolves to a risk of a seagoing incident (not necessarily culminating in severe damage or sinking) of 30.10^{-4} or once every 333 years per two ship voyage, at some location anywhere along the entire voyage route.

Considering just the 'at sea' legs of the journey (continental shelf and slope and deep sea) then the collision risk is $0.47.10^{-4}$ or once every 1,800 years per two ship voyage.

This crude application of the statistics derived from the *Glosten* study, gives no regard to any interaction between the two PNTL vessels involved in the MOX deliveries, nor for any malicious act of terrorism or piracy.

The maximum flask capacity of a PNTL ship is 24 flasks dispersed over 5 holds. With each flask capable of holding 8 MOX assemblies, the maximum cargo capacity per voyage of a single ship is 192 fuel assemblies containing about 2 tonnes of plutonium. This maximum cargo is considerably larger than the 28 MOX assemblies (230 kg Pu) on board PNTL *Pacific Pintail*, which landed in Japan in March 2001. A second PNTL ship, Pacific *Teal*, acted as armed escort with her cargo holds empty.

Assuming future shipments to increase to on average one-half loads, to ship the MOX equivalent of the estimated 45 tonnes of plutonium reprocessed from the contracted Japanese fuel would require about 45 single ship loads at, say, two complete voyages per year, would occupy about 20 years. Loading both PNTL boats would halve this delivery period to ten years.

In summary: So, obviously, collisions involving delivery ships with some other vessel or structure are possible and, on the balance of probabilities, likely to occur at some time during the ten year period over which these shipments could be scheduled. Thus, a ramming/collision incident is a *credible* accident for the MOX delivery transfers by ship.

CREDIBLE ACCIDENTS FOR A 10 YEAR PROGRAMME OF MOX DELIVERIES

ACCIDENT SCENARIO	LIKELIHOOD PER VOYAGE PER YEAR	NO EXPECTED OVER TOTAL MOX VOYAGES	LEAST SEVERE	MOST SEVERE
A) COLLISION/RAMMING	1:1,800	0.01	SERIOUSLY DAMAGING	FLASK(S) CRUSHED OPEN

Frequency of Ship Fires

Statistical records for damage to and total losses of ships due to fire and explosion do not show any trend of reducing incidence with advancing fire containment/fighting technology. To the contrary, a generally increasing incidence of severely damaging fires and explosions on board ships is found, with fire and/or explosion contributing to about 30 to 40% of the total losses from all causes during the period 1974 to 1984.[2] In certain years losses from this cause alone reached 47% (1983), 46% (1982) and 45% (1977, 1980). During the previous decade (1960-70) fires and explosions contributed on average to 23% of the total losses.

World losses resulting from (serious) fires and explosions, expressed as a percentile of all serious incidents, on board ships are given in **TABLE 2** (attached).[3] Analysis of the statistics[4] of **TABLE 2** provides an insight into seriously damaging outcome of fires on board ships, the size and locations of ships most vulnerable.

First, although all losses due to fire and explosion represent a small proportion of the total World shipping (between 0.1 and 0.2%), fire and explosions on board ships contribute to, on average, 36% of the total losses from all causes. Secondly, vessels of the size of the PNTL MOX carriers, between 2,000 to 6,000 tonnes displacement, register the highest number of losses. Thirdly, accommodation, cargo and machinery spaces feature strongly in the location of the outbreak of fire and/or explosion. Fourthly, incidents involving fire and explosion on board ships occur about as frequently (if not at a slightly greater frequency) for berthed vessels than for vessels underway at sea.

In fact, fires and explosions nearby ports (when the vessel is in the approaches) significantly increase according United States shipping data,[5] with 97.5% of the fire and explosion accidents occurring in harbours and approaches, with the remainder of incidents occurring as a function of the time spent over each offshore depth.[d]

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[d] For its operation of a fleet of 5 irradiated fuel ships, BNFL assess the frequency of a seriously damaging fire on board a radioactive fuel transfer ship to be 3.10^{-5} per annum (about once in every 33,000 years for each ship year of operation) with the maximum collective radiation dose (if such an accident occurred nearby a large city) to be 300man-Sv (Salmon A, *The Transportation of Radioactive Waste*, Conference on Radioactive Waste Management, Tucson, March 1987). If such statistics are accepted, an accident is expected in BNFL's fleet of five ships operating over a twenty year period at a chance of 0.003 per annum. On the other hand, a study by the UKAEA predict (*Summary of the Risk Assessment Made of the Transport of Plutonium Nitrate*, Chicken J C, UKAEA, SRD R 187, 1980) the incidence of seriously damaging fire (sufficient to fail the flask) at once every million years for plutonium nitrate shipments from Scrabster. Since the incident of fire is greatest when in port or during the approaches (97.5%) (*The Effect of IAEA Regulations on the Design of Shielded Containers*, Dixon F ATOM N^{o}, 1984) the relative lengths of journey are not significant, so for the seven annual shipments of plutonium nitrate the UKAEA predictions include a staggering probability of once

Recently published research[6] for the period 1990 to 1999 notes that of the 291 total losses per year 40% of these foundered, 22.5% were wrecking or strandings and 17% were due to fire. For double hull designs, fire and explosion losses were at 48% which, in all probability, is in account of the generally more hazardous types of cargo carried by double hulled vessels. Other sources (European Parliament - A2-329/87) state that 75% of maritime accidents arise as a direct result of human error.

Referring once again the risk analysis undertaken for the *Glosten* concept ship:

TABLE 4 **SHIP FIRE AND EXPLOSION PROBABILITIES - EACH LOADED TRANSIT**

GENERAL LOCATION	**PROBABILITY OF FIRE / EXPLOSION**
PORT AND APPROACHES	$1.90\ 10^{-4}$
CONTINENTAL SHELF	$2.70\ 10^{-8}$
CONTINENTAL SLOPE	$5.40\ 10^{-8}$
DEEP OCEAN	$4.79\ 10^{-6}$
TOTALS	**$1.95\ 10^{-4}$**

This aspect of the *Glosten* accident analysis applies to a complete single voyage so the risk for the deep ocean and continental shelf (at sea) portions of the journey (applicable to sailings in the New Zealand EZ) is $4.81.10^{-6}$ or about once every 208,000 years per voyage. Again, the *Glosten* analysis includes all fires of a 'reportable' severity, the majority of which may not be severely damaging to the flasks.[e]

Applying the *Glosten* 'at sea' data to the MOX carriers requires factoring the chance by x12 with both boats being loaded over the longer journey length:

CREDIBLE ACCIDENTS FOR A 10 YEAR PROGRAMME OF MOX DELIVERIES

ACCIDENT SCENARIO	**LIKELIHOOD PER VOYAGE PER YEAR**	**NO EXPECTED OVER TOTAL MOX VOYAGES**	**LEAST SEVERE**	**MOST SEVERE**
A) COLLISION/RAMMING	1:1,800	0.01	NONE EG BUMP OR SCRAPE	FLASK(S) CRUSHED OPEN
B) FIRE AT SEA	**1:17,300**	**<0.01**	**NONE EG CONTAINED FIRE**	**SEE LATER**

Predicting the probability of a fire occurring on any one ship is rather more difficult. This is not only because maritime accident data is related to gross tonnage but, particularly, because of the range of different types of ships and the diversity of roles which these ships undertake. Such generalised and overall statistical data for commercial vessels is of limited relevance when considering specific ships that have quite specific functions.

This is not to imply that the MOX carriers are exempt from these statistics but, simply, that it is not at all clear where such a ship definitely fits into the broad range of available data - this

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every 7,000,000 years for each complete voyage. On this basis, the UKAEA safety analysis assumes that in the heavy cargo ro-ro ship used for this carriage only 1 in 1,400 fires will develop to severely damaging proportions.

[e]

difficulty is heightened because PNTL has not published its detailed accident analysis for the MOX carriers.

However, for its irradiated fuel transits, BNFL predicts that the chance of a serious damaging fire to be about 3.10^{-5} per annum (including approaches to and berthing in ports), that is about once in 33,000 years for each ship year of operation, of damage severity sufficient to result in a radioactive material release. Applied to the MOX delivery programme, there is a chance of one in 1,650 years, for each ten years of delivery, of radioactive release. The comparison between BNFL and *Glosten* suggests (if both are roughly correct) that on a specialised, well fire-protected ship one in fifty fires will develop to a severely damaging fire.

As a guide, Lloyds Register (1985) gives a probability for the total construction loss by fire for commercial vessels to be 0.00407 per year per vessel (a chance of once in every 245 years for each year of operation[f]). Of course covers many different types of ship carrying all categories of cargoes and, importantly, the contribution and involvement of human error in the onset and subsequent development of the fire. Even in account of the extra fire protective measures installed by PNTL on the MOX ships, comparison of the odds (1:245 to 1:33,000) suggests that the PNTL figure does not include for human factors.

CREDIBLE ACCIDENTS FOR A 10 YEAR PROGRAMME OF MOX DELIVERIES

ACCIDENT SCENARIO	LIKELIHOOD PER VOYAGE PER YEAR	NO EXPECTED OVER TOTAL MOX VOYAGES	LEAST SEVERE	MOST SEVERE
A) COLLISION/RAMMING	1:1,800	0.01	NONE EG BUMP OR SCRAPE	FLASK(S) CRUSHED OPEN
B) FIRE AT SEA	1:17,300	<0.01	NONE EG CONTAINED FIRE	TOTAL LOSS
C) SERIOUS FIRE AT SEA	**1:50 OF ALL FIRES**	**<0.01**	**-**	**RADIOACTIVE RELEASE**
D) PNTL ALL VOYAGE LEGS	1:16,000	<0.01 (1:1,650 YEARS)	-	RADIOACTIVE RELEASE
E) FIRE IN SHIPS GENERALLY	1:245	N/A	-	TOTAL LOSS

There are, however, a number of shortcomings with the statistics relating fires on ships which arise, principally, because the nature of the cause of the fire or explosion is not included in any great detail within the short reports from which the statistics are compiled, nor are all fire incidents included within the statistics.[7] Comparing the Local Authority Fire Brigades (LAFBs) records for fire incidents in ships at UK ports of **TABLE 5** illustrates such omissions.

The somewhat limited data of **TABLE 5** suggest that of all fires on board ships in berth about one-third (28% to 33%) develop to serious fires. This is not necessarily at odds with the implied fire development rate suggested by comparison of the *BNFL-Glosten* predictions that only one in fifty ship fires develop to seriously damaging fire sufficient to breach the flask containment, since it has to be acknowledged that to breach a dry-filled flask by fire alone, the fire severity would have to be extreme.[g,8]

So, adopting the fire risk data for the concept *Glosten* fuel ship design and that cited by PNTL for its irradiated fuel carriers, each MOX carrier runs a risk of a severe fire sufficient to damage a flask at a chance of between 1:1,700 to 1:16,000 per voyage per year.

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[f] For each and every successive year of operation.

[g] For example, the LAFB judgement of a serious fire is likely to relate to the intensity of firefighting required and fatalities, rather than the extreme of flame temperature and duration.

Temperature, Ferocity and Duration of Ship Fires

The ferocity and duration of shipboard fires are acknowledged to result in extremely high temperatures and for very long periods. Examples of fire damage to ships illustrate the fire intensity that can take hold and persist - for example, the fire on board the MV Betelgeuse (bridge and accommodation fire on a tanker) continued for several hours *"if not days"* and resulted in all of the port glasses melting.[9] In fact, the 1984 SOLAS amendments of the International Maritime Organisation (IMO) regulations stop short considerably below the containment of fires within the ship, with the bulkhead divisions requiring only to be proofed to 843oC, whereas fires can reach temperatures well in excess of this temperature, and aluminium alloy structures (now increasingly in use in ship superstructures) are only proofed to 200°C above ambient.

Actual fire temperatures on board ships are not readily available, although adopted fire temperatures of 982°C for both external (arising from a pool of hydrocarbon on the water surface surrounding a ship) and internal (machinery space) fires on board ships have been attained and exceeded.[10] To the contrary, recent experimental studies[11][12] suggest lower fire temperatures arise within holds of ships.[h]

Again as a guide and because of the diversity of shipping activities, the IMO records show the mean duration of serious fires at sea to be about 23 hours and fires when berthed about 20 hours - these statistics, collated for fire incidents over two decades, include a standard deviation of 68 and 44 hours respectively.

In summary: Statistics of past fires are difficult to decipher and apply to specialised ships, such as the BNFL *Pacific* class of ships currently in use as MOX carriers. PNTL claim that its equipment levels reduce the risk of serious fire damage on board its vessel, although it is not clear whether this reduction is gained by superior fire detection and firefighting equipment on board or whether the ships, generally by virtue off their design, present less of a fire hazard.

A dominant characteristic of ship fires is that unless the initial outbreak is suppressed quickly, then the fire will continue to progress in severity.[13] In other words, immediate fire suppression activities virtually exhausts the firefighting facilities carried on board ships and, eventually, crews have to abandon ship leaving the fire completely uncontrolled. As expected, if a fire on board a ship takes hold then the fire will rage for hours (if not days), so serious ship fires are prolonged events sweeping throughout the ship compartments.[i]
If PNTL ships rely upon superior fire detection and fire fighting equipment then, if these fail to contain and suppress the fire, there is risk that an unchecked fire will rage and spread through the ship in much the same way as other ships are damaged in fires.

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[h] One obvious limitation to the SANDIA work was the choice of cargo for ignition – Ref 11 and 12 assume a heat transfer rate of $30kW/m^2$ from a timber source, whereas it is acknowledged that hydro-carbon fires (such as the IAEA SS6 Thermal Test) will invoke heat transfer rates at and in excess of $70kW/m^2$.

[i] Engine room and machinery space fires appear most likely of all fires to lead to total loss of the ship.[i] The basic problem is that the engine room is one, single undivided compartment and although there may be sub-division for purifiers, works rooms and stores, the enclosures serving these areas are seldom wholly fire-resistant. Engine room fires at sea are usually fought by flooding the space with carbon dioxide, but the use of carbon dioxide can result in an additional hazard, that of static sparking and explosion where flammable atmospheres are present (see Butterwrth D J *Electrostatic Ignition Hazards associated with Preventative Release of Fire Control Agents, Studies on Carbon Dioxide*, CLM/RR/D2/47, October 1979). A serious shortcoming of carbon dioxide flooding is that the compartment has to be evacuated of all personnel before the flooding commences. The *M/S Sigyn* utilises a halon[i] flood system in the main engine room and water sprinklers in the flask cargo holds.

All that can be stated with certainty is that fires do occur on board ships, that all types of ship are at risk of fire, and that some of these fires are prolonged, high temperature and severely damaging, to the extent that these fires result in the total loss cargoes and ships.

Risks Overall

Within the range of statistics for incidents involving ships, the greater proportion involved are what are best described as 'bumps and scrapes' that are often assumed not to escalate to major incidents. On the other hand, serious losses at sea (either by fire or collision alone, or by combination of both) are not that infrequent and there seems to be little to differentiate between the risk posed to the most modern, well defended sea-going and sea bedded structures[j] and poorly maintained floating hulks.[14]

However, whatever the accident scenario, the circumstances imposed upon the flask and its contents must be sufficient to breach the containment of the flask;[k] then impose conditions onto the fuel that will induce radioactive release, either by pulverising the fuel and/or rapidly oxidising the fuel to produce fine particulates; and there must be an energetic mechanism in the general and wider vicinity of the accident site that will convey the radioactive release to a human population (or to some point in a path which will eventually result in exposure of a population).

Obvious mechanisms for breaching the flask containment are the very high forces arising in ship collisions and rammings; intense fire might also serve to breach the flask and, once breached, such will enhance the release fractions of the fuel; and a fierce fire burning for several hours, or more, on board a crippled ship drifting at sea or foundered on shore could provide sufficient plume lofting to a height where wind borne dispersion carries the radioactive plume to a landside community.

Of course, accidents are by their very nature accidental. Thus, it is beyond our wit to describe all possible combinations and severities of accidents, how frequently these might occur and, indeed, if any particular accident will ever occur. That said, accidents and very severe accidents do happen.

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[j] Losses such as the ro-ro ferry *Herald of Free Enterprise* at Zeebrugge, the offshore rig *Piper Alpha* in the North Sea and, most recently, the Estonian Baltic Ferry.

[k] The sufficiency of the fuel flask to withstand accident forces and conditions is set out by the *IAEA Safety Series 6, Regulations for the Safety Transport of Radioactive Materials,* edition as adopted by the particle State (Sweden adopts the 1990 Edition) – these regulations specify that the fuel flasks (Type B) should be capable of withstanding a number of tests, including a free drop onto an unyielding target from 9m, engulfment in a hydrocarbon fire at 800°C for 30 minutes, a spike impact and immersion in water. The TN17/2 flask complies with these requirements although the encapsulated fuel flask prototype (see Knopp, Ref 8) has yet to be tested.

TABLES AND DATA

TABLE 2 CHARACTERISTICS OF FIRE/EXPLOSION LOSSES

	1974	75	76	77	78	79	80	81	82	83	84
WORLD TONNAGE 10^6	304	334	364	385	397	404	411	412	415	413	409
TOTAL LOSSES											
N° TOTAL LOSSES	54	48	57	65	71	63	56	69	72	66	56
% FIRE/EXPL LOSSES	0.10	0.06	0.10	0.14	0.10	0.17	0.20	0.16	0.16	0.15	0.10
% TOTAL TONNAGE	0.34	0.31	0.32	0.31	0.35	0.56	0.43	0.39	0.35	0.33	0.32
% FIRE LOSS	29.5	19.5	29.5	45.1	28.9	31.2	45.0	41.8	46.0	47.2	30.7
LOCATION OF ALL FIRE/EXPLOSION INCIDENTS (TOTAL AND PARTIAL DAMAGE)											
% AT SEA	41	32	38	41	40	41	41	41	49	47	49
% PORT IN REPAIR	4	5	3	4	5	7	7	6	5	7	9
% PORT AT BERTH	54	59	59	55	55	52	52	53	46	46	42
N° TOTAL EVENTS	402	366	349	360	347	343	314	354	329	286	260
FIRES/EXPLOSIONS ARISING FROM COLLISION AT SEA											
% COLLISIONS	4.2	4.5	0.8	4.7	-	10.8	4.6	-	0.6	-	-
LOCATION OF OUTBREAKS OF FIRE/EXPLOSION (KNOWN AND REPORTED IN SUFFICIENT DETAIL)											
% ACCOMMODATION	20.6	16.1	11.8	9.0	12.9	10.3	10.5	11.5	20.9	13.1	12.8
% CARGO SPACE	29.3	34.4	37.1	32.2	30.1	26.9	27.2	37.8	25.8	24.1	26.7
% ELECTRICAL	5.6	2.9	0.8	0.8	2.9	4.5	5.7	3.4	3.1	2.6	5.6
% MACHINERY	33.8	37.7	43.2	49.0	45.6	48.8	49.6	41.2	45.8	58.7	50.8
% STOKEHOLDS	6.3	6.2	0.3	5.1	5.4	4.5	2.2	3.4	3.6	1.6	0.5
% OTHER	4.4	2.6	0.3	3.9	2.9	4.9	4.8	2.7	0.9	0.0	3.6
VESSEL SIZE TONNES (DISPLACED)			**N° OF TOTAL LOSSES**								
500- 1000	14	8	10	5	14	4	7	8	6	8	11
1000- 2000	9	12	9	10	19	13	10	16	11	11	11
2000- 4000	13	10	12	15	11	20	12	9	15	9	10
4000- 6000	4	5	6	8	7	-	3	5	8	6	3
6000- 7000	2	2	3	3	2	1	4	1	1	3	2
7000- 8000	3	3	2	3	3	5	1	2	4	2	1
8000-10000	1	3	4	5	6	7	4	8	10	12	4
10000- 15000	5	4	7	11	2	3	5	11	9	10	8
15000- 30000	2	1	2	1	5	5	4	4	3	-	4
30000- 50000	-	-	2	2	2	2	1	3	3	4	1
50000- 75000	1	-	-	2	-	1	1	2	1	-	1
75000- 100000	-	-	-	-	-	1	1	-	1	-	-
>100000	-	-	-	-	-	1	1	-	1	-	-

Notes: Excludes losses due to military action and known acts of terrorism, malicious acts sabotage, etc.

TABLE 3 % TOTAL LOSSES ARISING FROM FIRES AND EXPLOSIONS

YEAR	LOSS(%)	YEAR	LOSS(%)
1960	12	1974	30
1961	35	1975	20
1962	12	1976	30
1963	17	1977	45
1964	23	1978	29
1965	21	1979	31
1966	30	1980	45
1967	25	1981	42
1968	23	1982	46
1969	35	1983	47
1970	25	1984	31
AVERAGE	**23**	AVERAGE	**36**

TABLE 5 SHIP FIRES ATTENDED BY LAFBS

YEAR	TOTAL	FATAL	Nº F'MEN	JETS DEPLOYED				SERIOUS FIRES	
				1-2	3-4	5-7	>8	Nº	%
1974	575	5	214	148	7	9	0	164	28
1980	468	4	146	119	15	6	0	140	30
1981	460	5	162	123	8	1	2	133	29
1982	496	0	197	129	7	0	2	138	28
1983	462	2	167	143	5	2	1	151	33

Notes: 1 Fires attended whilst ship in port, includes repairs, etc
2 All other fires where the number of jets is not specified were put out using hose reels; the number of LAFB (not ship) main jets gives a crude indication of the extent and severity of the fire.

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