A Study to explain the collision proof properties associated with the ships operated by Pacific Nuclear Transport Ltd and to provide an explanation of their damage survivability in the event of a collision.

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Abstract. To date there have been many reports and papers presented considering the effects of ship fires and collisions on the transport packages (casks). This paper discounts the possible effects on the individual package but considers purely, the survivability of the vessel after a severe collision with another vessel.

1. Introduction

In the 1970's British Nuclear Fuels Limited (BNFL) decided to develop a design for purpose-built vessels for nuclear transport, which would provide enhanced protection for the ship, crew and cargo thereby increasing the safety and reliability of transportation operations. Following wide consultation with Lloyds of London, The Salvage Association and other leading salvage companies, and as a result of Japanese standards developed at the same time, today's Pacific Nuclear Transport Limited (PNTL) Fleet was constructed. Since construction, equipment such as radar, communication and monitoring equipment has been regularly upgraded in line with technological developments. These enhancements along with the operating experience have maintained the consistently high standards of operational safety.

The ships were constructed with collision resistant structures that provide additional protection around the cargo spaces[1]. Watertight longitudinal and transverse bulkheads form the inner shell surrounding the cargo space. The structure and sub-division of the hull is designed so that the vessel will stay afloat after it has sustained damage, which is in excess of the extent specified for Class 1 chemical tankers as required by the IBC Code (International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk)[2]. As previously mentioned, the wing tank and void spaces are structurally reinforced to prevent impact damage being sustained by the transport casks within the holds, in the event of a severe collision with another vessel. For the purposes of design, the colliding vessel was assumed to be about 24,000 tonnes displacement travelling at 15 knots. (Based on the type T2 Tanker).

A review of the longitudinal strength of the ship, taking account of both the static and dynamic stresses exerted on the vessel during service, showed that the maximum total bending stress was approximately 0.8 kgf/cm^2 (78N/mm^2)which was about 40% of the permissible level as stated in the Classification society's Rules. The additional collision resistant structure in the wing and void spaces, is incorporated in the hull, where it contributes to the longitudinal strength of the vessel, hence the low value of bending stress. However this adds approximately 400 tonnes of additional steel to the lightweight of the vessels. The consequence of this is that the strength of design provides a good margin of safety to cater for increased bending moments arising from any loss of buoyancy following damage. It is also worth noting that the hatch covers have been designed and structurally strengthened to such an extent that it is possible to temporarily hold a transport flask during cargo operations, weighing up to 120 tonnes which gives a good example of the extraordinary strength of the overall structure.

2. Construction Considerations

The construction of the present PNTL fleet takes in to account the requirements of all the relevant National and International regulations. All PNTL vessels comply with these regulations and are therefore no different to any other UK registered ship in that they are subject to statutory inspection and certification in order to guarantee their continued operation.

The INF Code (International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High Level Wastes on Board Ships)[3] became mandatory on 1st January 2001. Its origins can be traced back to the time when the construction of the present fleet was being considered. It could be said that the INF Code ***now*** was the blueprint ***then***, used by BNFL for the construction of their fleet. It is interesting to note that the first of these vessels came in to service in 1978, (fifteen years before the code was adopted and twenty three years before the code became mandatory).

The survivability of the vessels after grounding or collision was a major design consideration for the fleet at this time. A datum was established to ensure this requirement was met and, as previously stated, this was taken to be a collision with a 24,000 tonne tanker travelling at a speed of 15 knots. The collision was considered to impact the struck vessel at ninety degrees, amidships.

The original calculations were carried out using Minorsky's energy absorption theory [4] (an empirical formula based on the volume of damaged steel). Since this time, due to advances in computer technology, more involved calculations can now be undertaken in a much shorter time scale. Allowance can now be made in the calculations for the specific structural arrangement of a striking ships bow and that of the struck ships side.

3. Studies to support the above

With the passage of time, the above considerations still hold good. The original design specifications remain unchanged, however, the assumed colliding vessel (a T2 type oil tanker) no longer exists.

There have been several studies and papers produced which look into the effects of an INF Class ship being involved in a collision. Most of these papers seek to assess the effects on the transport flask and the potential impact on the environment.

In the paper, "Evaluation Method of Absorbed Energy in Collision of Ships with Anti-Collision Structure"[5], it is shown that the advanced analyses suggests that a PNTL ship can withstand a collision with ships far larger than a T2 Tanker and in these specific situations, the vessels can survive severe collision without the cargo being affected. There appear however, to have been no studies produced which specifically consider the survivability of an INF vessel, beyond the regulatory requirements, with respect to the vessel's stability following a collision.

4. Survivability

Contrary to popular belief, BNFL has never claimed that their INF vessels are unsinkable. It is interesting to note however that these ships have been specifically designed so that in an emergency situation one, or even all of the five cargo holds can be filled with water to the level of the top of the uppermost cask and the vessel will still remain stable and afloat.

Differing accident scenarios have been considered over the years and what was once thought to be realistic or credible twenty years ago is now a very different case. The events of Sept 11th 2001 in the U.S. have opened up a new spectrum for fantastic accident scenarios to be considered as credible. Probability and risk have still however to be considered with a sensible and balanced approach.

It should be remembered that the original basis for the safe transportation of nuclear material is to ensure that the safety of the public and the environment is provided by the package alone regardless of the mode of transport. The fact that the ship provides additional protection to the package should not be forgotten. It is evident that the whole focus has moved away from this original concept and the ships are being identified, wrongly, as a potential weak link. This could not be further from the truth. With the regulatory requirements governing the construction of the vessels and flasks, it is difficult to envisage a safer design and means of transportation by sea.

Considering PNTL's operational safety record and the mandatory requirements of the IBC Code, the INF Code and the Japanese Kaisa 520 [6], there is now an even stronger argument to support the case that transporting radioactive substances by sea is a safe operation. When conducted to the stringent requirements of the relevant International Governments, Regulators, Departments and Regulations, it should provide an example to all of how the business of sea transport should be conducted.

5. Collision

In case of collision between two ships, the damage to the struck ship and its cargo is mainly influenced by:

- The speed and displacement and the dimensions of the striking ship.
- The shape and material properties of the striking bow.
- The collision angle.
- The point of impact on the vessel under consideration.
- The structural properties of the vessel under consideration.

The double hull of a PNTL ship is designed to withstand at least the energy impact equivalent of the Type 2 Tanker. It is conservatively assumed that the penetration of the cargo hold is possible in a severe collision situation.

The following examples taken from actual data for the PNTL vessel, Pacific Sandpiper, show the effects likely to be encountered following a collision. The purpose of this paper however is to provide evidence of the survivability beyond the regulatory minimums and takes no account of any of the on board procedures which would undoubtedly take place to minimise these effects.

6. Collision proof properties of PNTL vessels

(How unlikely it is that transport vessels would sink after a collision)

The vessel under consideration was specifically built as a dedicated carrier of irradiated nuclear fuel, High Level Waste and Plutonium, in special transport casks. The casks are carried on transport frames, which in turn are bolted to the ship's structure. The vessel has a total of five cargo holds, each of which has space for a number of casks, and each hold has permanently installed cargo cooling machinery. The vessel has collision resistant structure fitted over the full length of the cargo spaces. This structure consists of the Main and Upper Decks outboard of the cargo holds being constructed steel plate. There are additional collision flats fitted above and below the Main Deck at approximately 1.5 metre spacing, and the tank top is constructed of very heavy steel plate. Access to the cargo hold is arranged below Upper Deck level by constructing a passageway along the full lengths of the cargo spaces. Access to this passageway is at the aft end of the cargo space through a Clean Room. The space outboard of the cargo holds is sub-divided, port and starboard, into eight wing tanks below the Main Deck. The bulkheads that form these wing tanks are continued above the Main Deck level to the Upper Deck. The attached information is taken from a damage stability study commissioned by BNFL, to investigate the extent of collision damage that a PNTL vessel will survive and still be afloat, with positive stability. The assumption is that progressive damage has been sustained however the causation has not been defined.

In addition to the different National requirements, in order to meet the requirements of the INF Code, with respect to damage stability, the vessel must comply with the following:
Type 1 ship survival capability and location of cargo spaces in Chapter 2 of the IBC Code or regardless of the ships length, the damage stability requirements in Part B-1, Chapter II-11 of the International Convention for the Safety of Life at Sea, 1974, as amended (SOLAS).

The following collision scenarios display the survivability after a severe collision. The results have been obtained by inputting data in to the damage stability program for the ship and progressively considering the instantaneous flooding of certain compartments and analysing the stability of the vessel at the new hydrostatic equilibrium. It must be remembered that this exercise has been conducted not to display compliance with the requirements of the regulations, but purely as a display of the survivability of a PNTL vessel in various stages of bulkhead damage. No account has been taken of the effects of sea state or wind strength.

Typical Loading Plans for Departure (Fuel Tanks Filled to 98%) and Arrival (Fuel Tanks Filled to 10%) have been selected with the vessel loaded with 20 casks, distributed throughout all 5 holds. The vessel is also loaded with ballast in order to ensure a realistic sailing condition

For each of the Loading Conditions three ‘Levels’ of damage have been investigated:

Damage Condition 1.	An extensive mid-ships damage, extending over four Wing compartments, with the damage extending to the hold longitudinal bulkhead and from the bottom to the top of the vessel.
Damage Condition 2.	The condition is as with Damage Condition 1, but, with the damage extending inboard to the centreline of the vessel.
Damage Condition 3.	The condition is as with Damage Condition 2, but, with the damage partially extending the full width of the vessel.

A summary and diagram of the vessels conditions, for the Intact and Damage conditions investigated, is contained in the table that follows.

7. Conclusion

From the supplied data, it can be seen that the Pacific Sandpiper would survive damage far in excess to that required by the relevant codes. The vessel would remain afloat with positive stability thus ensuring valuable time for remedial action to be undertaken. The attached results in no way reflect any inadequacy of the respective codes but give a clear indication of the forward thinking of the design team at conception.

References:

[1] Spink H. E., The Design of Ships for the Transport of Nuclear Fuels. International Conference on transportation for the Nuclear Industry. May 1988

[2] International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code). International Maritime Organization.

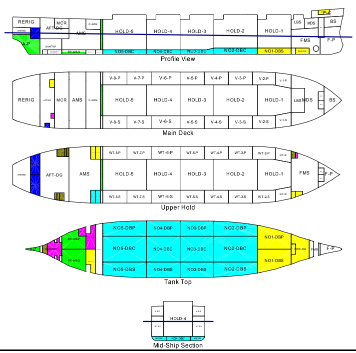
[3] International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High Level Radioactive Wastes on Board Ships. (INF Code). International Maritime Organisation.

[4] Minorsky V. U., An Analysis of Ship Collisions with Reference to Protection of Nuclear Power Plants, Journal of Ship Research (1959) 1-4.

[5] Suzuki K., Ohtsubo H., Sajit C., Evaluation Method of Absorbed Energy in Collision of Ships with Anti-Collision Structure.

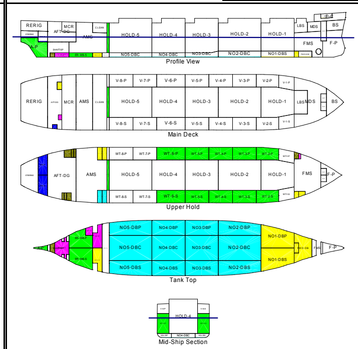
[6] Safety Requirements for Sea-going Ships Carrying Spent Nuclear Fuel Shipping Casks. Note by Japan International Maritime Organisation MSC XL/25/1.

Intact Departure



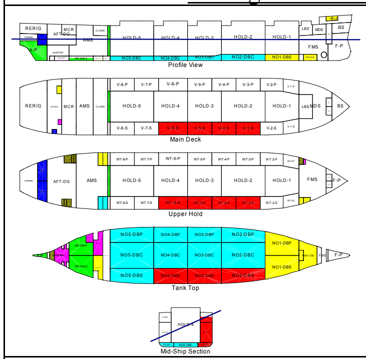
Draft Aft:	6.238 m
Draft Mid:	5.641 m
Draft Fwd:	5.045 m
Trim:	1.193 m
Heel:	0 Deg.
KGf:	6.036 m
GMf:	1.127 m

Intact Arrival



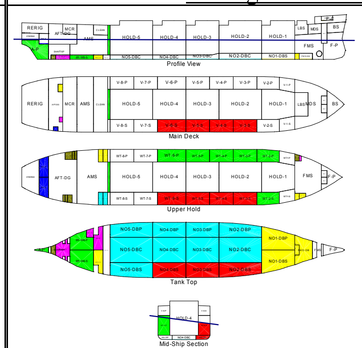
Draft Aft:	6.024 m
Draft Mid:	5.910 m
Draft Fwd:	5.797 m
Trim:	0.227 m
Heel:	0 Deg.
KGf:	6.315 m
GMf:	0.781 m

Damage Condition 1



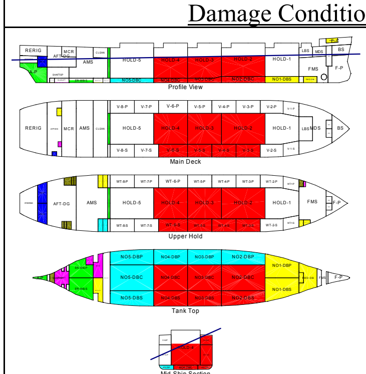
Draft Aft:	6.242 m
Draft Mid:	6.163 m
Draft Fwd:	6.085 m
Trim:	0.158 m
Heel:	22.49 Deg.
KGf:	5.910 m
GMf:	1.841 m

Damage Condition 1



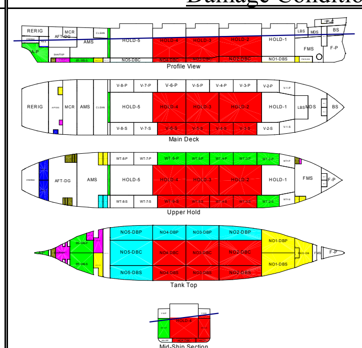
Draft Aft:	5.977 m
Draft Mid:	5.820 m
Draft Fwd:	5.663 m
Trim:	0.314 m
Heel:	7.15 Deg.
KGf:	6.324 m
GMf:	0.443 m

Damage Condition 2



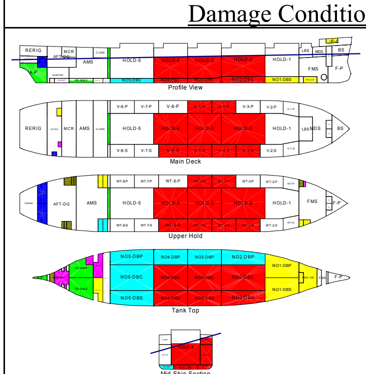
Draft Aft:	6.668 m
Draft Mid:	7.469 m
Draft Fwd:	8.271 m
Trim:	1.603 m
Heel:	22.68 Deg.
KGf:	6.151 m
GMf:	1.470 m

Damage Condition 2



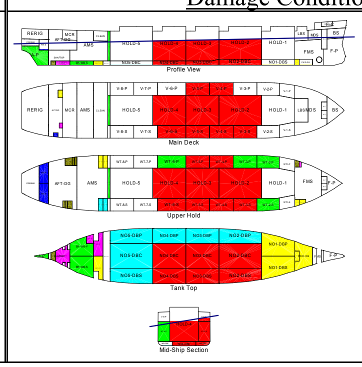
Draft Aft:	6.482 m
Draft Mid:	7.440 m
Draft Fwd:	8.397 m
Trim:	1.915 m
Heel:	6.76 Deg.
KGf:	6.317 m
GMf:	1.300 m

Damage Condition 3



Draft Aft:	6.796 m
Draft Mid:	7.609 m
Draft Fwd:	8.422 m
Trim:	1.626 m
Heel:	15.14 Deg.
KGf:	6.158 m
GMf:	1.558 m

Damage Condition 3



Draft Aft:	6.464 m
Draft Mid:	7.411 m
Draft Fwd:	8.357 m
Trim:	1.893 m
Heel:	8.75 Deg.
KGf:	6.408 m
GMf:	1.106 m

KEY

- Fuel Oil
- Auxiliary Fuel Oil
- Fresh Water
- Water Ballast
- Lubricating Oil
- Miscellaneous Tanks
- Damaged Compartment