APPENDIX H2: MARINE RELEASES AND FIRES

H2.1 Review of Marine Scenarios

H2.1.1.1 The 2000 DNV study of marine transport risk [38], on which the marine risk assessment in this EIA is based, identified two potential marine scenarios:

- Explosion caused by fire on board the vessel or from a leak caused by collision.
- Pool fires on the sea surface due to ignition of releases from the cargo tank caused by collision or grounding.

H2.1.1.2 These overall scenarios applicable to liquid hydrocarbon transport are consistent with categories of marine incident used elsewhere: fire/explosion, cargo spill, collision, striking, grounding, foundering and ranging (e.g. [60]). Only the first incident category (fire/explosion) represents a hazard to life scenario from the transport of Jet A1, although the other incident categories represent potential causes.

H2.1.1.3 For the marine transport risk analysis three scenarios are considered which are consistent with the above:

- Fire due to rupture/leak of Jet A1 from loaded vessel (M1)
- Vessel collision involving tanker with subsequent fire and sinking (M2)
- Cargo explosion on tanker (M3)

H2.1.1.4 Only scenarios within ~500 m of the jetty are included, as discussed in Section 10.2.3.

H2.1.1.5 The first scenario (M1) is sub-divided by the quantity of fuel spilt from a small release up to the full cargo as noted in Section H2.2. The second scenario (M2) is a modification to the first scenario (M1) to specifically allow for the additional consequences that could be involved if the spill/fire was caused directly by an incident involving another vessel that may be carrying a significant number of passengers.

H2.1.1.6 At the jetty, in addition to a fire due to a release from the vessel, a scenario is included (J2) based on a release from the loading arm connection between the vessel and the jetty. This may occur due to a variety of mechanical failures or human errors, but one of the main causes of loading arm or hose failure is vessel ranging, as identified in Paragraph H2.1.1.2. Other incidents at the jetty are included for releases from jetty equipment, the riser and the pipelines to the tank farm, based on the types of equipment present.

- Fire due to rupture/leak of Jet A1 from loaded vessel (J1)
- Fire due to rupture/leak of loading arm during unloading (J2)
- Fire due to rupture/leak of jetty equipment (J3)
- Fire due to rupture/leak of jetty riser (J4)

- Fire due to rupture/leak of submarine pipeline from jetty to Tank Farm ESDV (J5)

H2.1.1.7 McBride reviews incidents associated with jetties and marine transport of aviation fuel or kerosene in Appendix G Table G1 [9]. These incidents are summarised below:

Incident	Brief Description and ESR Comments
1976	A near miss occurred due to the use of an incorrect chemical (wrongly labelled) to remove rust stains around a ship's tank hatch covers on a tank containing highly flammable aviation fuel. The chemical reacted with the rust generating smoke. No fire occurred but there was considered to be the potential for a serious fire.
1981	Two marine tankers were in collision with each other resulting in minor damage to both ships, no injuries were reported. One tanker received damage to a port tank resulting in a spillage of aviation kerosene.
Manaus, Brazil, 1984	Fire in pump room of marine tanker when offloading kerosene due to rupture of flexible coupling. A spark from the pump ignited the leaking cargo.
Maryland, US, 1987	An explosion followed by a fire occurred on a petroleum tanker barge. Workers were cleaning the barge tanks which had previously contained jet fuel. 4 fatalities.
Ohara Bay, Japan, 1988	Explosion in a marine tankers slop tank caused extensive damage to bow. Cargo kerosene. No further details.
Immingham, UK, 1989	Fire in marine tanker when residual jet fuel leaked through a vacuum valve and ignited by cutting torch.
Bandar, Abbas, Iran, 1989	During unloading of jet fuel from a marine tanker, a spillage occurred which ignited. 12 fatalities.
Jacksonville, Florida, US, 1990	Ship struck dock and punctured four 200 mm fuel lines causing a spill of 50,000 litres of gasoline and jet fuel into river.
Stanstead, UK, 1991	A spill of jet fuel from a pipeline into a river formed a 10 km oil slick.
Marlborough, New York, US, 1991	A marine tanker barge ran aground causing a spill of 490 tonnes of kerosene into a river.
Madras, India, 1992	During overnight material transfer a spill of 1060 tonnes of kerosene occurred into a harbour through a valve failure on a receiving marine tanker.
Tampa Bay, Florida, US, 1993	A river transportation incident. Collision between inbound pusher tugs and tank barges with 1670 tonnes of jet fuel engulfed in flames and ablaze for 14 hours. Subsequently a barge carrying 6000 tonnes of phosphates hit the barge and 70 tonnes of fuel oil were spilt.
Hong Kong, 1993	An explosion occurred during welding after launch on bow deck of diesel/kerosene marine tanker barge at repair yard.
Malaysia, 1994	A collision of a marine tanker and a bulk carrier in a thunderstorm led to the tanker being holed in 2 tanks and 400 tonnes of jet fuel and gas oil to be spilled to the sea.

Incident	Brief Description and ESR Comments
1998	A barge exploded whilst residual jet fuel was being vacuumed from the tanks into a petroleum tanker on a pier. The vessel was being cleaned out for a new load of heating oil. Various possibilities for ignition of fuel vapours. PAFF tankers will carry only Jet A1 so such operations will not be required at the PAFF. The type of jet fuel in the incident was not specified. Jet A1 delivered to the PAFF does not produce a flammable vapour above its surface.
Netherlands, 1998	Lighter carrying 2050 tonnes of kerosene ran aground. The vessel was refloated and found to be leaking from its cargo tanks.

H2.1.1.8 Of these 16 incidents half involved a spill onto the water and half involved fires or explosions on the vessels. The largest spill specifically identified was 2050 tonnes, which is 2.5% of the cargo carried by the largest tankers that will visit the PAFF. Two incidents involved fatalities, either due to a spill and subsequent fire or due to an explosion on the vessel. The scenarios considered in this assessment cover the range of incidents above, plus much larger spills that are also considered possible.

H2.2 Marine Release Quantities

10.14.1.1 The tankers visiting the PAFF will be double hulled and use marine pilots and tug boats. The cargo tanks of double hull tankers are protected by wing tanks from side on collisions, and from groundings by the double bottom construction. Fore and aft ballast tanks protect the cargo tanks from end on collisions. The cargo is also sub-divided between typically 14 tanks. The numbers of large spills has been declining since the MARPOL Convention was amended to make double hulls (or similar) mandatory for new tankers of 5,000 dwt and above (see 10.3.3.13 to 10.3.3.18). It is therefore likely that a release from a PAFF tanker would be restricted to a single tank (~7% of dwt). However, since many of the largest releases from tankers historically have involved up to 100% of the cargo then a release from all tanks is also considered (see Section H2.4).

10.14.1.2 The marine spill probabilities used in this assessment and the fractions of the tanker load released are consistent with those used in the DNV 2000 report [38]:

- Small Leak - 0.3% of dwt
- Large Leak - 1% of dwt
- Rupture (single tank) - 7% of dwt
- Multiple rupture (all tanks) - 100% of dwt

Tanker Size (dwt)	Size of Leak	Spilt Quantity (tonnes)
20,000	Small	60
	Large	200
	Rupture- single tank	1400
	Multiple Rupture- all tanks	20,000
30,000	Small	90
	Large	300
	Rupture- single tank	2100
	Multiple Rupture- all tanks	30,000
45,000	Small	135
	Large	450
	Rupture- single tank	3150
	Multiple Rupture- all tanks	45,000
60,000	Small	180
	Large	600
	Rupture- single tank	4200
	Multiple Rupture- all tanks	60,000
80,000	Small	240
	Large	800
	Rupture- single tank	5600
	Multiple Rupture- all tanks	80,000

H2.3 Modelling of Fires Due to Marine Releases

H2.3.1.1 The extent of the fire hazard from a pool of Jet A1 on the sea is assessed based on the predicted area of a spill to a depth where ignition remains possible and a stable flame could propagate.

H2.3.1.2 A minimum thickness of ~10mm is required for flame spread on the sea (under well controlled experimental conditions it is possible to propagate a flame over kerosene a few mm thick [25] – 10mm is taken as a reasonable average for the minimum depth on water allowing for the cooling effect of the water and variations in surface height and spill depth).

H2.3.1.3 If a pool of Jet A1 on the sea is ignited, the fire will spread slowly (see Appendix H6, Section H6.3) across the extent of the pool and proceed to burn through its thickness at its burning velocity. For aviation fuel, this velocity is around 4 mm/min (0.053kg/m^2s). The fire and thermal impact range for fatality for releases on the sea are taken as equivalent to the pool radius, consistent with the DNV 2000 study [38].

H2.3.1.4 The modelling assumptions for these unconfined pool fires on the sea are given below.

Pool Fire Modelling Assumptions on The Sea					
Size of Release	**20,000 dwt**	**30,000 dwt**	**45,000 dwt**	**60,000 dwt**	**80,000 dwt**
Small Leak	50kg/s for 20 minutes continuous release	75kg/s for 20 minutes continuous release	112.5kg/s for 20 minutes continuous release	150kg/s for 20 minutes continuous release	200 kg/s for 20 minutes continuous release
Large Leak	167kg/s for 20 minutes continuous release	250kg/s for 20 minutes continuous release	375kg/s for 20 minutes continuous release	500kg/s for 20 minutes continuous release	667kg/s for 20 minutes continuous release
Rupture- 1 tank	1400 tonnes Instantaneous	2100 tonnes Instantaneous	3150 tonnes Instantaneous	4200 tonnes Instantaneous	5600 tonnes Instantaneous
Rupture- all tanks	20,000 tonnes*	30,000 tonnes*	45,000 tonnes*	60,000 tonnes*	80,000 tonnes*
* See below (H2.3.1.5) and Section H2.4 for modelling assumptions for multiple tank rupture					

H2.3.1.5 Whilst the small and large releases are treated as continuous flows resulting in an equilibrium pool fire, the tank rupture and multiple rupture are treated as instantaneous releases from a single tank followed by a flow from the remaining tanks (for multiple tank rupture) over a period consistent with historical experience for the largest oil spills (see Section H2.4).

H2.3.1.6 For an unconfined continuous release, the pool grows until equilibrium is reached where burning at the surface balances the release rate. The pool diameter is given by:

$$D = \sqrt{\frac{4Q}{\pi b}}$$

where:

D = pool diameter (m)
Q = release rate (kg/s)
b = burning rate (0.053 kg/m^2/s)

H2.3.1.7 For a rapid release, the pool grows steadily until it reaches a minimum thickness of ~10mm required for flame spread. The pool diameter may be expressed in terms of the average thickness as:

$$D = \sqrt{\frac{4M}{\pi t \rho}}$$

where:

D = pool diameter (m)
M = release mass (tonnes)
t = average pool thickness (m)
ρ = density (tonnes/m^3)

H2.3.1.8 For multiple tank rupture, the pool fire hazard range is assessed to be equivalent to the hazard range for a single tank rupture based on the analysis in Section H2.4. The resulting hazard ranges (equivalent circular pool radius) are given below.

Effect Distances for Sea Surface Pool Fires (M1 and J1)						
Size of Release	**Effect Distance (m)**					**Probability of Death**
	20,000 dwt	**30,000 dwt**	**45,000 dwt**	**60,000 dwt**	**80,000 dwt**	
Small Leak	17.3	21.2	26.0	30.0	34.7	1
Large Leak	31.7	38.7	47.5	54.8	63.3	1
Rupture- 1 tank	236	289	354	409	472	1
Rupture- all tanks	236	289	354	409	472	1

Fatalities for Sea Surface Pool Fires (M1 and J1)					
Size of Release	**Estimated Fatalities**				
	20,000 dwt	**30,000 dwt**	**45,000 dwt**	**60,000 dwt**	**80,000 dwt**
Small Leak	0.01	0.02	0.03	0.04	0.06
Large Leak	0.05	0.07	0.11	0.14	0.19
Rupture- 1 tank	2.6	3.9	5.9	7.9	10.5
Rupture- all tanks	2.6	3.9	5.9	7.9	10.5

H2.4 Modelling Major Releases (Multiple Tank Rupture)

H2.4.1.1 It is conceivable that a single tank rupture may lead to rapid release of cargo, but historical experience suggests that releases from multiple tanks (even from single hulled vessels) would take place over an extended period so the total spill volume would not be available to burn simultaneously. The period is likely to be more extended for the double hulled PAFF tankers.

H2.4.1.2 A review has been made of available information from the worlds largest oil spills. This ranking is based on information from the International Tanker Owners Pollution Federation Ltd (ITOPF [41]). Spill durations are not simply available, so this information has been identified separately from published information where available and is summarised below.

No.	Vessel	Year	Spill (tonnes)	Spill (%dwt)	Spillage Timescale
1	Atlantic Empress	1979	276,000	100%	15 days
2	ABT Summer	1991	260,000	N/A	N/A
3	Castillo de Bellver	1983	252,000	100%	N/A
4	Amoco Cadiz	1978	227,000	100%	2 weeks
5	Haven	1991	144,000	100%	N/A
6	Odyssey	1988	132,000	N/A	N/A
7	Torrey Canyon	1967	121,000	100%	12 days
8	Sea Star	1972	115,000	100%	6 days[1]
9	Irenes Serenade	1980	100,000	N/A	N/A
10	Urquiola	1976	101,000	N/A	300 tonnes/day[2]
11	Hawaiian Patriot	1977	95,000	N/A	N/A

No.	Vessel	Year	Spill (tonnes)	Spill (%dwt)	Spillage Timescale
12	Independenta	1979	95,000	100%	Note 3
13	Jakob Maersk	1975	84,000	100%	14 days
14	Braer	1993	84,500	100%	12 days
15	Khark 5	1989	70,000	38%	N/A
16	Aegean Sea	1992	67,000	85%	N/A
17	Sea Empress	1996	73,000	56%	7 days[4]
18	Katina P.	1992	72,000	N/A	N/A
19	Nova	1985	70,000	N/A	N/A
20	Prestige	2002	63,000	82%	6 days[1]
35	Exxon Valdez	1989	38,500	21%	13 hours[5]

Notes:
N/A No information was found
1 Vessel sank at the end
2 300 tonnes/day after initial unspecified release
3 Majority burned on vessel
4 1,000 tonnes in first 2 days, 7,000 next day, 20,000 next 2 days, next day total reached 70,000 tonnes (i.e. 42,000 tonnes)
5 0.96% spilt initially, 10.92% after 3.5hours, 19.78% after 13 hours

H2.4.1.3 Some information for around half the largest oil spills has been obtained. The typical spill duration identified above is 1-2 weeks, with the exception being the Exxon Valdez. The total spill for the Valdez was notably less than half that being considered here, although the tanker was much larger than the largest PAFF tankers at 180,000 dwt.

H2.4.1.4 All of the above spills relate to single hulled tankers, so they are expected to be conservative in terms of both fraction released and how quickly it was released compared to the double hulled PAFF tankers.

H2.4.1.5 The model for a multiple tank rupture of a PAFF tanker assumes an instantaneous release of 7% of the tanker contents based on loss from a single tank (5,600 tonnes for an 80,000 dwt tanker) followed by all the remaining load (93%) being released uniformly over three days.

H2.4.1.6 For the Sea Empress and the Exxon Valdez, some quantitative information has been found on the amount released as a function of time. This is presented below, together with the model adopted for the 80,000 dwt multiple tank rupture release from a PAFF tanker.

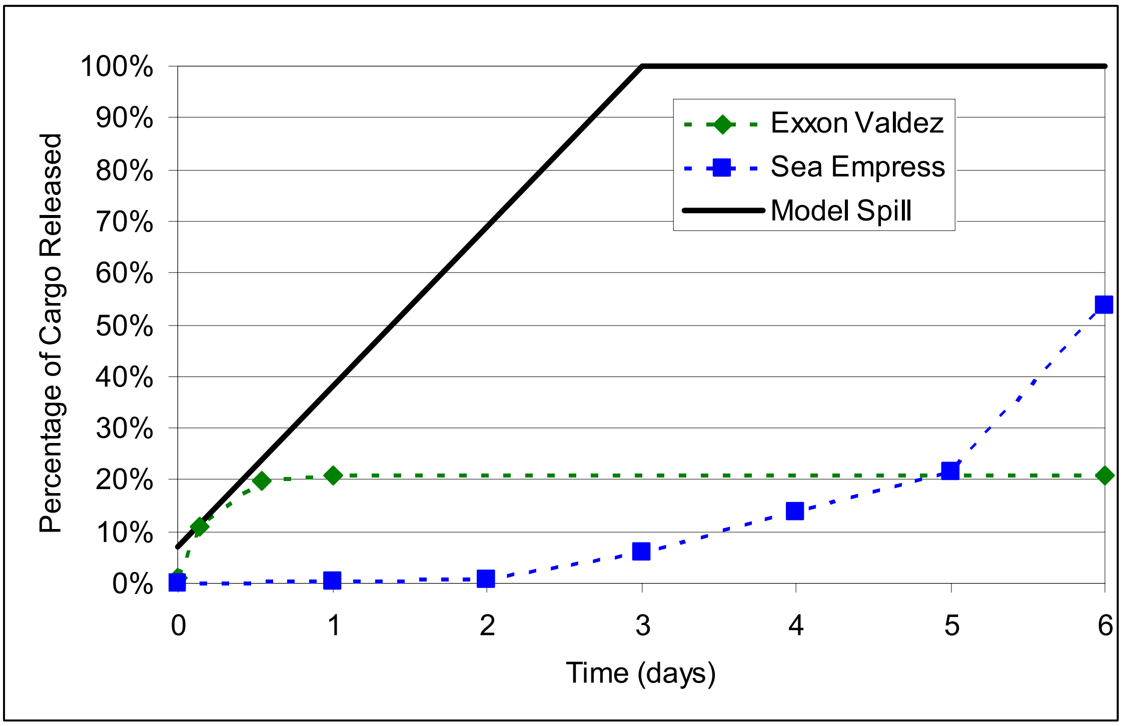

Figure H2.1: Major Marine Spill Release Experience and Comparison with PAFF Tanker Multiple Tank Rupture Release Model

H2.4.1.7 Based on the available information on large oil spills obtained, the selected profile of the release of Jet A1 from a PAFF tanker over time for a multiple tank rupture is a conservative assumption, possibly by a factor of 2 or more when compared to the majority of spill incidents for which data has been obtained. The initial percentage of the cargo spilt over the first half day for an 80,000 dwt PAFF tanker (the largest size) is similar to the worst incident identified for the speed of the release (Exxon Valdez), but the overall spill from the PAFF tanker modelled would be much larger than for this case.

H2.4.1.8 It is concluded that the assumption of an instantaneous loss of the contents of one tank (7%) followed by the release of the remaining 93% of the cargo over 3 days, is an appropriately cautious approach to modelling the worst case spill from a PAFF tanker.

H2.5 Multiple Tank Rupture Spill Area

H2.5.1.1 For a single tank rupture, the Jet A1 is assumed to be released instantaneously and form a uniform pool of equivalent thickness of 10 mm which then ignites. This is a cautious approach since the pool thickness will vary even for an instantaneous release, which will reduce the overall area of a pool fire, and the release will not be genuinely instantaneous. The 10 mm pool thickness from an instantaneous release from a single tank is however treated as the starting condition in the fuel spill risk assessment (Section 11).

H2.5.1.2 Results from the detailed study of the oil dispersion over time (Section 11) have been taken to estimate the maximum area an oil layer of 10 mm thickness could cover. The worst case identified has been used for this analysis, based on a release starting around high water on a spring tide during the dry season. The areas of sea surface covered to thicknesses of Jet A1 around 10 mm have been estimated based on these results for each hour after the spill. The thickness is reduced over this time by both dispersion and weathering of the Jet A1 (see Section 11). The resulting area estimates are shown below.

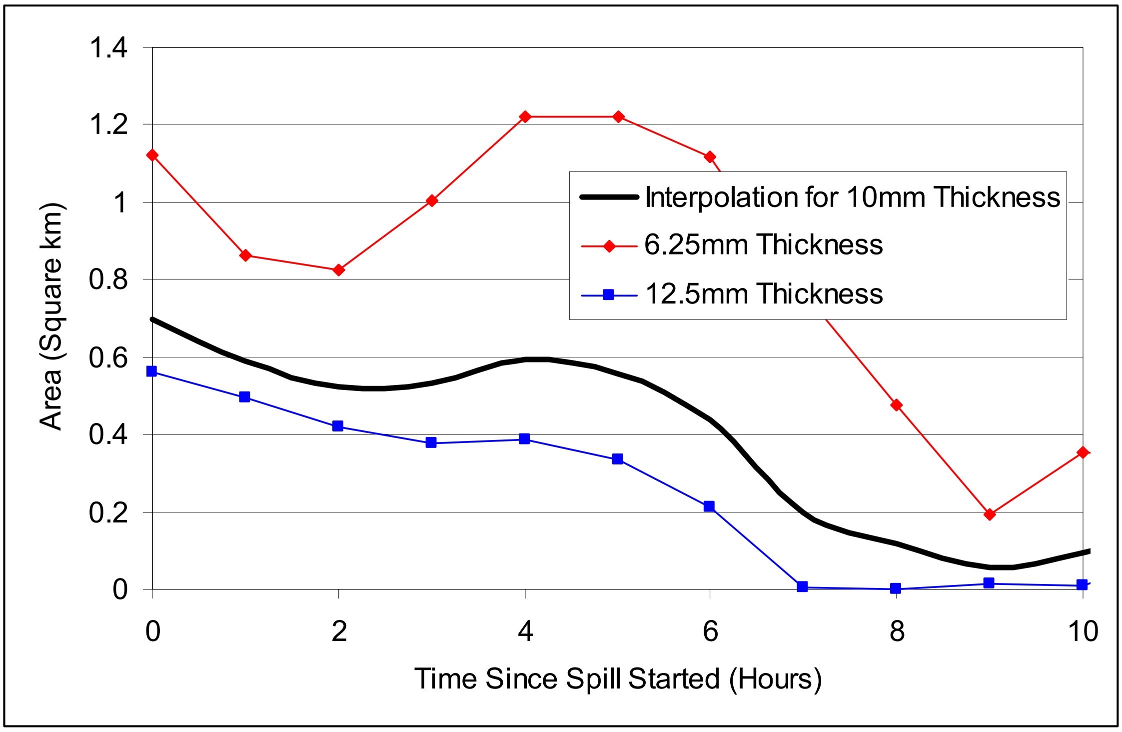

Figure H2.2: Predicted Area Covered to Different Thicknesses of Jet A1 Following a Multiple Tank Rupture of an 80,000 dwt PAFF Tanker Starting Around High Water on a Spring Tide During the Dry Season (Based on Oil Spill Modelling – see Section 11).

H2.5.1.3 The resulting estimates show that the largest predicted area covered by a release from a multiple tank rupture is predicted to occur at the start of the incident. Although similar levels may be achieved at some hours afterwards, the initial spill area estimate based on a 7% release spread to a depth of 10 mm is a conservative assumption for the potential pool fire area for a multiple tank rupture case. This is therefore used as a basis for the effect distance in this assessment.