EXTERNAL HAZARDS IN THE PRA OF OLKILUOTO 1 AND 2 NPP UNITS - ACCIDENTAL OIL SPILLS

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Abstract

Oil transports in Finnish territorial waters have increased significantly during the last 10 years. The Gulf of Finland is at this moment a very important route of oil being transported from Russia to the Western Europe. Although the number of accidental oil spills is decreasing in amount and in size, there is a growing concern of their effects to nuclear power plants (NPP's). The amounts of oil transported on the Gulf of Bothnia are much smaller than on the Gulf of Finland. However, accidental oil spills have occurred also there, the size and amount of which are smaller, though.

Accidental oil spills are often a result of grounding of a ship or collision of two ships, and often occur during harsh weather conditions like storm or dense fog. However, also coastal oil depots may break, the oil of which may spread over wide distances on the sea.

The modelling of initiating events resulting from accidental oil spills includes oil spill response actions performed by the regional rescue services, alarming of the oil spill by the emergency response centre to the NPP rescue services and spill response by the NPP's rescue services. It is unclear what the consequences are if drifted oil would enter the coolant water tunnels. The effect of different oil types to the operation of the safety-related service water systems and components are being assessed. In the ultimate case, an oil spill would clog the inlet channels thus failing the ultimate heat sink of the NPP units.

The licensee is evaluating what is the optimal way to operate the NPP units in the case that an oil slick is threatening the plant to ensure reactor core cooling and RHR. The continued operation of, and especially the cooling of, at least one auxiliary feedwater pump is critical in the mitigation of the initiating event. Strategies, like reversing the water flow of the cooling water channels or closing of the cooling water channels, are being evaluated.

1 Introduction

The Olkiluoto nuclear power plant (NPP) is situated on the Island of Olkiluoto in Western Finland on the coast of the Gulf of Bothnia. At the NPP, there are two operating units, Olkiluoto NPP units 1 and 2 (OL1 and OL2). These NPP units are boiling water reactors (BWR) built by ASEA-ATOM in the late 70's and early 80's. Both units' safety systems are divided into four redundant subsystems (divisions), each of which has a capacity of 50 %. Thus, two of the divisions must operate in order to successfully perform a given safety function. The decay heat removal system (RHRS) and component coolant water systems (CCWS) including the cooling of the diesel generators are dependent of sea water cooling via service water systems.

Oil transports on Finnish territorial waters have increased significantly during the last 10 years. The Gulf of Finland is at this moment a very important route of oil being transported from Russia to the Western Europe. Although the number of accidental oil spills is decreasing in amount and in size, there is a growing concern of their effects to NPP's along the coast. The amounts of oil transported on the Gulf of Bothnia are much smaller than on the Gulf of Finland.

Oil spill accidents may occur due to ship collisions or grounding of a ship. This may lead to an event in which the oil slick drifts to the shores of Olkiluoto. The oil spills in the Gulf of Bothnia have been small in size and the spilled oil has most often been the fuel of the ship itself.

2 Analysis of oil spill accidents

2.1 Description of the phenomena

During the year 2012, about 3 million tons of oil was shipped to or from Finnish [1, 2] and 2 million tons of oil to or from Swedish [3] harbours by the Gulf of Finland. Ships enter the Gulf of Bothnia mostly through the Sea of Åland, which lies between the Åland islands and Sweden. Most ships head then directly towards their destination, resulting in that close to Olkiluoto, there is no significant amount of oil transport.

The closest harbour to Olkiluoto is the Port of Rauma, which is the 5th largest port in Finland and is located about 13 km south of Olkiluoto. In the Bothnian Sea, there have been 12 reported oil spill accidents during the period 1969 - 2012, of which 3 have occurred in front of Rauma. Globally, the number of oil spill accidents has decreased although the amount of sea transportation has increased. This is thanks to improved maritime safety. Accidental oil spills are often a result of grounding of a ship or collision of two ships and they often occur during harsh weather conditions like a storm or dense fog. However, also coastal oil depots may break, the oil of which may spread over wide distances on the sea. The wind direction affects the direction of the current of the surface water. The wind direction, thus, affects the direction where the oil slick drifts. On the Island of Olkiluoto, the main direction of the wind is from south west and a wind direction along the coast line is common. The main direction of the surface water current is from south towards the north.

The behaviour of the spilled oil is affected by its specific gravity (its density relative to the density of water), volatility, viscosity and pour point, and by the current weather conditions. The spilled oil undergoes several weathering processes in the sea, e.g. evaporation, oxidation, emulsification, biodegradation, dispersion, dissolution, and sedimentation. The weathering processes depend on the characteristics of the spilled oil and change the characteristics themselves. Especially evaporation and emulsification change the characteristics of the oil into the characteristics of heavier types of oil, but evaporation, biodegradation, dissolution and sedimentation decrease the amount of oil in the slick. Emulsification, on the other hand, increases the volume of the oil slick. [4] Light oil types float on the surface of the water and evaporate easily. Heavier oil types may sink to the bottom or stay in the water column and drift below the surface. [5]

2.2 Response against oil spills

In case of an oil spill accident, the accident is reported to the Maritime Rescue Coordination Centre or to the Emergency Response Centre. The regional rescue services are alerted to perform the oil spill response. In Rauma, Uusikaupunki and Pori, there are ships equipped with oil booms and have the ability to collect oil at coastal waters.

A defence-in-depth principle is utilized in the oil spill response. The first barrier is the response by the regional rescue services at sea. The second barrier consists of oil booms on the islands close to Olkiluoto, which are permanently installed by the licensee. These oil booms may be deployed by boat and, thus, block the sounds between the islands close to the Olkiluoto Island in order to protect the oil from entering the inlet channels of the NPP units. Further, a third barrier consists of oil booms installed at the inlet channels of NPP units OL1 and OL2. These booms may be swiftly deployed by hand. The actions to deploy the oil booms on the islands and at the inlet channels are performed by the plant rescue services. Cleaning of travelling band screens, pumps and heat exchangers may be seen as a fourth barrier.

2.3 Consequences to the units

If oil would enter the inlet channel and further sink several meters to the inlet tunnel, the most severe consequences would be clogging of the traveling band screens, thus tripping the condenser coolant water pumps and the service water pumps. This would lead to loss of turbine condenser and feedwater to the reactor and loss of CCWS and RHRS. However, in such a situation, the traveling band screens could be cleaned one at a time, thus maintaining water flow to the service water systems. According to an independent expert analysis, high viscosity oil could decrease the pumping capacity by 20 % if it would enter the service water systems. It would affect only minimally on the capacity of the heat exchangers. Oil types of low viscosity would not affect the systems.

2.4 Modeling of oil spills and their response

In the PRA of OL1 and OL2, external hazards are modeled as an initiating event if the hazard leads to a transient and further to loss of equipment which is important to safety. In the analysis of the initiating event frequency of an oil spill accident, the hazard frequency and the response to the oil spill accident is modeled.

The hazard frequency is assessed by using the fact that during 1969 - 2012, no oil spill accidents have occurred with a potential impact to the Olkiluoto Island. Further, the wind direction distribution has been taken into account. In the modeling of the initiating event frequency, the oil spill response at sea by the regional rescue services is accounted for, as well as the deployment of oil booms in the sounds between the islands south of the Olkiluoto Island and in the inlet channels of the NPP units.

The observation time is modeled using the ASEP screening diagnosis model. The event probability "Observation time < 5 h" is the conditional probability of receiving the alarm in Olkiluoto in 5 h on the condition that the alarm has or has not been received by the emergency response center in 1 h. The response times are long; it would anyways take several hours before the NPP would be exposed to oil. The failure probability of the response by the rescue services and the deployment of the oil booms at the inlet channel is assumed to be 0.05 by expert judgment. The deployment of the oil booms between the islands is assumed to be 0.2, accounting for dependence on the deployment of oil booms in the inlet channels, as to a high probability, the same crew performs both actions.

It is assumed that if the oil would enter the inlet channel, it would also enter the inlet tunnel and clog the traveling band screens, thus resulting in a loss-of-feedwater transient event. In the modeling of the initiating event, an operator action to clean the traveling band screens is modeled. Failure to clean the traveling band screens would lead to loss of all service water systems.

3 Results

The modeling of the oil spill accident from the hazard event to the initiating event is presented in the event tree below.

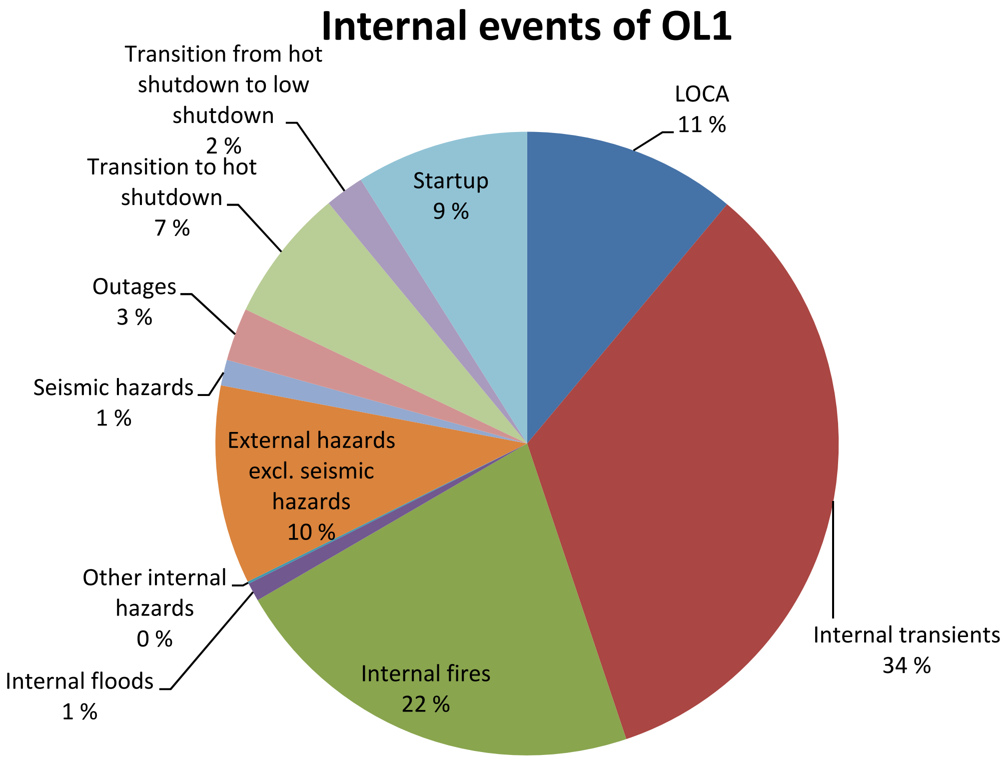
Figure 1: Event tree of the oil spill accident hazard

Oil spill accident frequency [1/a]	Observation time < 1 h	Oil spill stopped at sea	Observation time < 5 h	Oil boom between the islands	Oil boom at the inlet channel	Consequence	Frequency [1/a]
8.9E-4	0.999	0.95				Oil stopped at sea	8.5E-4
		0.05	0.9999	0.8		Oil stopped between the islands	3.6E-5
				0.2	0.95	Oil stopped before the inlet channel	8.5E-6
					0.05	Oil may enter the inlet tunnel	4.5E-7
			1.E-4			Oil may enter the inlet tunnel	4.5E-9
	1.E-3		0.5	0.8		Oil stopped between the islands	3.6E-7
				0.2	0.95	Oil stopped before the inlet channel	8.6E-8
					0.05	Oil may enter the inlet tunnel	4.5E-9
			0.5			Oil may enter the inlet tunnel	4.5E-7

Total	
Oil stopped at sea	8.5E-4
Oil stopped between the islands	3.6E-5
Oil stopped before the inlet channel	8.5E-6
Oil may enter the inlet tunnel	9.0E-7

The Birnbaum measure of the initiating event resulting from the accidental oil spill is about 0.06 and the contribution to the total core damage frequency is 0.4 %. The distribution of the contribution of the internal events to the core damage frequency is shown in Figure 2 and the relative contribution of the external hazards excluding seismic hazards to the core damage frequency is shown in Figure 3.

Figure 2: Distribution of internal events of OL1.

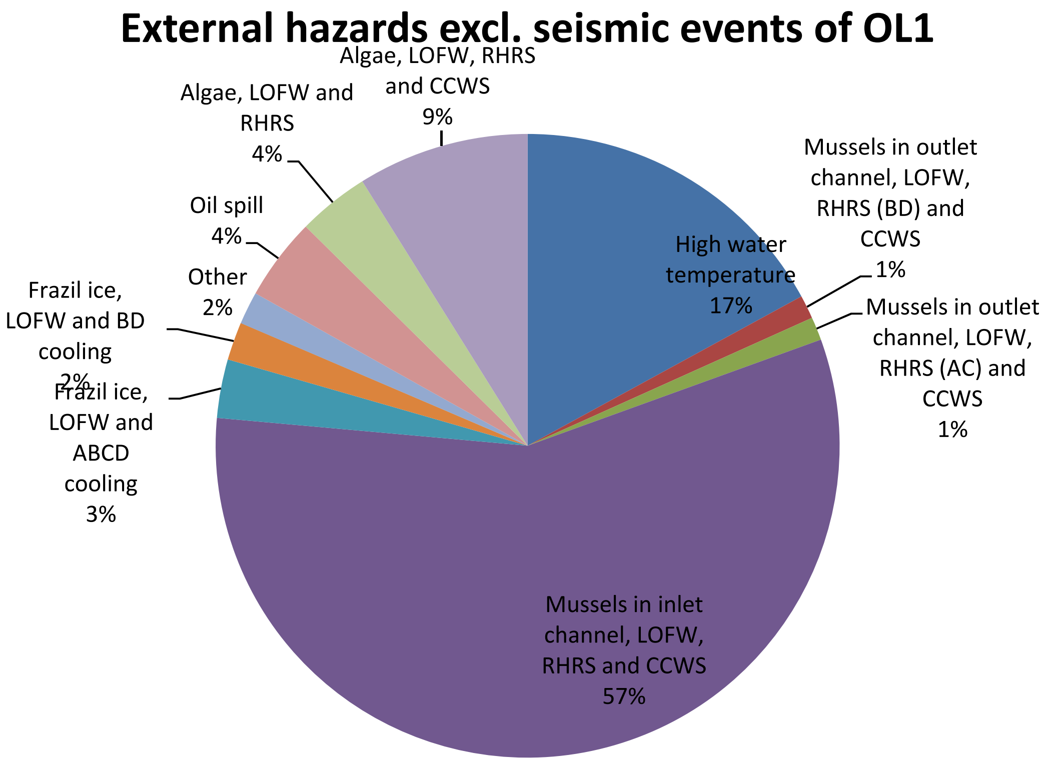


4 Discussion

The maritime traffic in the Gulf of Bothnia is rather scarce. Since there are no refineries on the coasts of the Gulf of Bothnia, not much oil is transported. Most of the oil spills originate from the oil used by the ships themselves, so the spills are rather small in size. During the history of the Olkiluoto NPP, there have not been any oil spill accidents at sea that have had the potential to impact the Olkiluoto NPP. There are multiple defence barriers which would stop the spilled oil from arriving near the Olkiluoto NPP. An eventual initiating event, resulting from loss of feedwater, CCWS and RHRS, would be rather severe, the Birnbaum measure being 0.06. However, the initiating event frequency being low, the hazard has only a small contribution to the core damage frequency.

The initiating event frequency estimate is conservative, since only heavy oil types would enter the inlet tunnels and the waters near Olkiluoto are shallow. This means that the oil with the potential to enter the inlet tunnel is in the water column and it would sink to the bottom before reaching the Olkiluoto Island. These phenomena are, however, very difficult to model.

Figure 3: Distribution of external hazards excl. seismic hazards.



5 Improvements to oil spill response due to the PRA

The modeling of the initiating event frequency due to an oil spill accident uncovered a weak spot in the information exchange between the emergency response center and the licensee, TVO. Earlier, there was no procedure to alert TVO in case of an oil spill accident at sea. The probability that the information would not arrive at TVO was estimated to be 0.5. Nowadays, this information arrives at TVO through an automatic alarm. Thus, if the alarm has arrived at the emergency response center, the probability that the information would not arrive at TVO is estimated to be 10^{-4}, which accounts for eventual equipment failures. This improvement decreased the inititating event frequency resulting from oils spills by 96 %. As a consequence, from being a major contributor to the core damage frequency, its contribution to the core damage frequency is rather small in the present model. The contribution to the core damage frequency from external hazards decreased from 20 % to 10 % in the update.

6 Conclusions

The maritime traffic in the Gulf of Bothnia is rather scarce. Most of the oil spills originate from the oil used as fuel by the ships themselves, so the spills are rather small in size. During the history of the Olkiluoto NPP, there have not been any oil spill accidents at sea that have had the potential to impact the

Olkiluoto Island. There are multiple defence barriers which would stop the spilled oil from arriving near the Olkiluoto NPP.

Improvements in oil spill response at the NPP, especially in the information exchange between the regional response centre and the NPP rescue services and installation of oil booms, has decreased the probability that an oil spill accident would affect the safety of the Olkiluoto NPP units.

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