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Initiating Event Analysis for Floating Nuclear Power Plant: Tsunami Case

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1. Introduction

Initiating events (IE) selection is the first step to performing a risk assessment. Following this information, the series of plant responses are described in the event tree. Based on this, the core damage frequency can be calculated. This study is performed to demonstrate the selection process of the IE of the floating nuclear power plant (FNPP) in the case of a tsunami event. The design that will be used is the KLT-40S design (Akademik Lomonosov) from Russia. This design was chosen due to its provenness and operational experience. This study aims to create a list of initiating events for tsunami cases using the master logic diagram (MLD) method. The tsunamis are chosen because the FNPP is placed on the sea and the tsunamis will directly and significantly impact the FNPP.

2. Methods and results

The method that will be used for IE selection is the master logic diagram (MLD). MLD uses a similar approach to the fault tree without determining the failure probability[1]. There is no clear information about how many steps might be used for MLD, though, the initial step is the top event that is usually described as radioactive release/core damage, and the last step is the listing of initiating events[2], [3].

This study is performed using the following scheme:

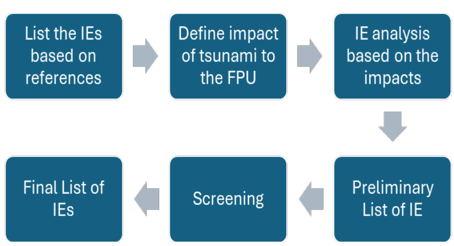


Fig 1. Study WorkFlow

Some references mentioned the importance of the screening process of the IEs generated to get more conservative results[3]. The screening process used in this study is based on several criteria:

1. Similarities;
2. Plant response; and
3. Screening results of references.

Additionally, several basic events might screened out from the final list due to the IAEA definition of initiating events as an identified event that leads to anticipated operational occurrences (AOO) or accident conditions[20].

2.1 List of IEs based on references

Based on references and the design of KLT-40S, the initiating events for FNPP include[4]:

1. Loss of coolant accident (LOCA);
2. Loss of electric power sources;
3. Loss of feedwater (LOFW);
4. SG tube rupture (SGTR);
5. Main feedwater line break (FWLB);
6. Loss of condenser vacuum (LOCV);
7. Small break of the feedwater pipeline;
8. Decrease of the reactor coolant system flow rate;
9. Guillotine break of the pressurizer surge line in reactor hot shutdown state;
10. Reactor vessel rupture (RVR); and
11. General transient (GTRN).

2.2 Possible condition of the FPU after tsunamis

The tsunami phenomena might happen against the FPU and have certain impacts on safety. As the source of tsunamis and wave direction can happen randomly, the impact on the FPU can be varied. Possible impacts to the FPU are flooding, crashing, and capsizing[5].

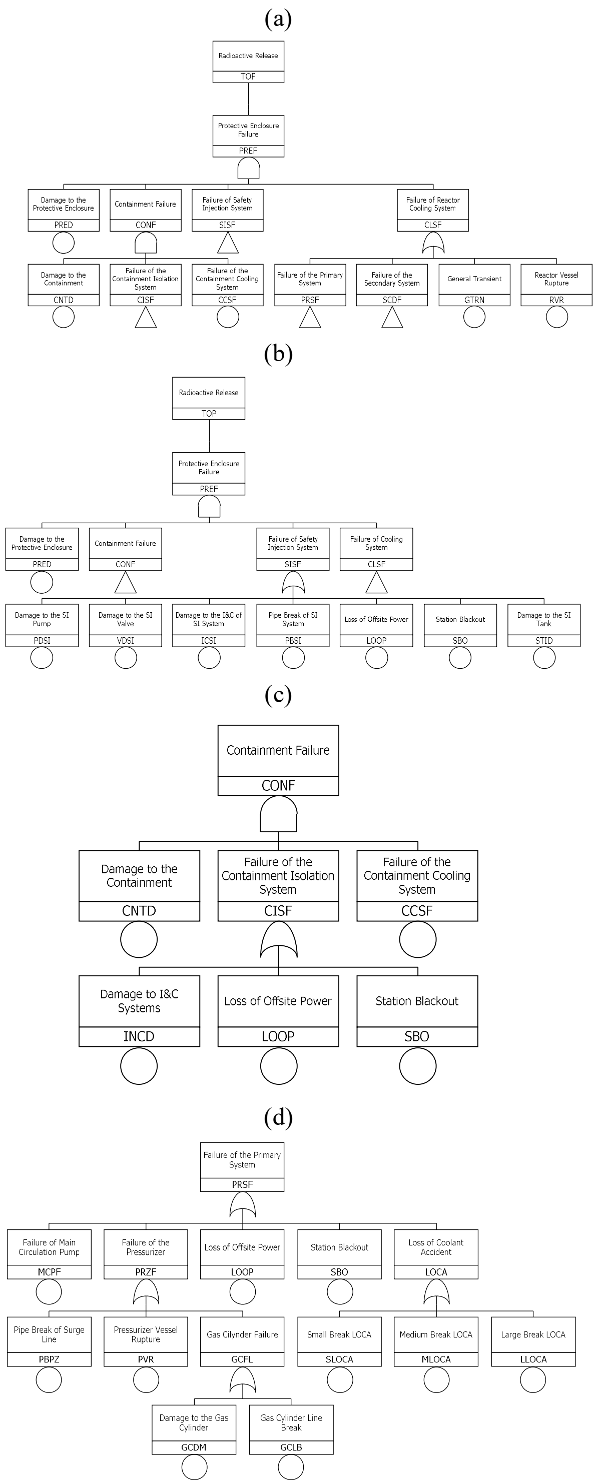
The FNPP facilities are usually supported with wavebreakers. These wave breakers have the functionality of reducing the wave velocity of a wave to the FNPP. Nevertheless, at some levels, the water might still strike the FNPP and cause any damage to the FPU.

Strong waves of tsunamis might move the FPU in a random direction. Sometimes, because of this situation, the FPU might crash the dock or the land.

Depending on the wave velocity and shape, the force of the wave might push certain parts of the FPU and make it capsized. The capsized condition might drown several parts of the FPU or make it upside down. The full upside-down case is very rare, especially for a big and heavy ship. The most common cases are the half-submerged case and several dominantly submerged cases. With the upper parts facing the sea body, the FNPP will be flooded with seawater and in the worst case will also damage several SSCs due to hard strike to the sea body.

2.3 PIE analysis results

From the analysis, the MLD for tsunami cases are:



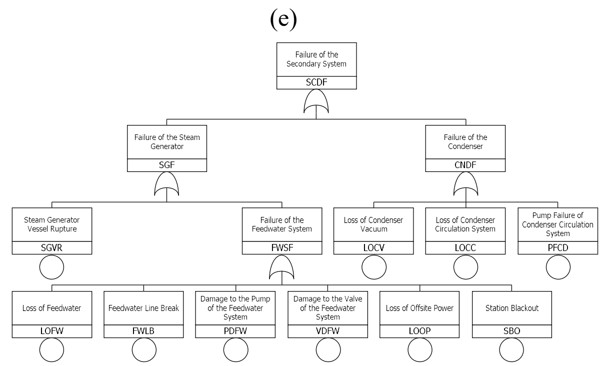


Fig 2. MLD for tsunami case of FNPP

MLD is constructed by the defense-in-depth (DiD) concept of the design. The protective enclosure (PE) is the reactor's first barrier to withstand the impact of external hazards, including tsunamis. The failure of the PE leads to radioactive release caused by damage to the PE (PRED), containment failure (CONF), failure of the safety injection system (SISF), and failure of the reactor cooling system (CLSF). Based on the DiD concept, containment is the second barrier, meaning that if it is broken, there will be radioactive release if the PE is also broken. PRED can happen either by physical damage caused by crashing or hydrostatic/hydrodynamic pressure caused by flooding. PRED can also be a basic event. However, PRED can not categorized as an IE because it will not lead to AOO or accident conditions by itself.

Furthermore, CONF might happen after several incidents simultaneously occur damage to the containment (CNTD), failure of the containment isolation system (CISF), and failure of the containment cooling system (CCSF). CISF can happen due to damage to I&C systems either physically or electronically, loss of offsite power (LOOP), or station blackout (SBO). LOOP and SBO might be caused by flooding and/or water splash. The basic events that will be categorized as IE are LOOP and SBO.

The SIS is the system that actuates when there is an abnormal condition inside the reactor. SISF means the failure of core cooling during an emergency. SISF is caused by damage to the SI pump (PDSI), damage to the SI valve (VDSI), damage to the I&C system (ICSI), pipe break of SI system (PBSI), LOOP, SBO, and damage to the SI tank (STID). The basic events that will be categorized as IE are LOOP and SBO.

CLSF occurs because of the failure of the primary (PRSF) and secondary system (SCDF), general transient (GTRN), or reactor vessel rupture (RVR). CLSF will increase the temperature and pressure of the containment along with radioactive release which might lead to CNTD if the safety injection system (SIS), containment isolation system, and containment cooling systems fail to manage the condition. The IEs are GTRN and RVR.

PRSF happens due to failure of the pressurizer (PRZF), damage of the main circulation pump (MCPD), LOOP, SBO, or LOCA including small LOCA, medium LOCA, or large LOCA. PRZF happens due to a pipe break of the surge line (PBPZ), damage to the valve of the pressurizer (VDPZ), pressurizer vessel rupture (PVR), and gas cylinder failure (GCFL) including damage to the gas cylinder (GCDM) or gas cylinder line break (GCLB). The basic events that will be categorized as IE are PBPZ, PVR, GCDM, and GCLB.

SCDF happens due to the failure of the SG (SGF) or the failure of the condenser (CNDF). SGF happens due to SG vessel rupture (SGVR) or failure of the feedwater system (FWSF). FWSF includes LOFW, FWLB, damage to the pump of the feedwater system (PDFW), damage to the valve of the feedwater system (VDFW), LOOP, or SBO. CNDF happens due to LOCV, loss of condenser circulation system (LOCC), or pump failure of condenser circulation system (PFCD). The basic events that will be categorized as IE are LOFW, PDFW, VDFW, LOOP, SBO, LOCV, LOCC, and PFCD.

Using the screening criteria previously mentioned, then the final list of IEs is as follows:

Table I: IE Analysis Results

No	Final IEs	Symbol	Previous IEs
1.	Feedwater Line Break	FWLB	FWLB
2.	Small Break LOCA	SLOCA	SLOCA
3.	Medium Break LOCA	MLOCA	MLOCA
4.	Large Break LOCA	LLOCA	LLOCA
5.	Loss of Condenser Vacuum	LOCV	LOCC
			LOCV
			PFCD
6.	Loss of Coolant Accident	LOCA	PBPZ
			PVR
7.	Loss of Feedwater System	LOFW	LOFW
			PDFW
			SGVR
			VDFW
8.	Loss of Flow Accident	LOFA	MCPD
9.	Loss of Offsite Power	LOOP	LOOP
10.	General Transient	GTRN	GTRN
11.	Reactor Vessel Rupture	RVR	RVR
12.	Station Blackout	SBO	SBO
13.	Damage to Gas Cylinder	GCDM	GCDM
14.	Gas Cylinder Line Break	GCLB	GCLB

3. Conclusions

MLD is one of the methods used for IE analysis, especially in limited design information. This study was carried out to perform IE analysis for FNPP in case of tsunami case. Based on the study it is found that 14 IEs need to be anticipated for tsunami cases of FNPP. The IEs are found out after the screening process from the original 29 basic events. The results of the study are still in line with the references as the IEs from the references are allocated in Table 1, despite the difference in the terms used.

ACKNOWLEDGEMENTS

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