Numerical analysis of the effect of a hypothetical fire in a cable spreading room on the release of radioactive materials

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ABSTRACT

This study evaluates the impact of a postulated fire in a cable spreading room (CSR) on the release of radioactive material into the environment. The analysis was conducted using the Fire Dynamics Simulator (FDS) version 6.9.1 [1].

In a nuclear power plant (NPP), the defense-in-depth (DID) concept of fire protection consists of three steps. The first step is to prevent the occurrence of a fire. The second step is to quickly detect and extinguish the fire to reduce the damage. The third and final step is to prevent the release of radioactive materials into the environment by ensuring the ability to safely shut down in the event of an uncontrolled fire scenario. In operating NPPs, a Post Fire Safe Shutdown Analysis (PFSSA) is performed to fulfill the third step of the DID [2].

However, in a permanently shut down nuclear power plant (PSNPP), the PFSSA is not required [3]. Since a nuclear reactor in a PSNPP is permanently shut down, it no longer releases radioactive material from the reactor coolant system (RCS) to the environment. Instead, the cooling function of the Spent Fuel Pool (SFP) is of particular concern. The loss of the SFP cooling function at PSNPP can result in the evaporation of cooling water in the pool, exposing fuel and potentially releasing radioactive material to the environment. For this reason, maintaining SFP cooling function at PSNPP is one of the main objectives of the third step of the DID.

Maintaining the SFP cooling function requires several supporting systems: a Component Cooling Water (CCW) system, an Essential Service Water (ESW) system, and power systems, among others. These support systems are designed with redundancy in mind. If one train is out of service due to a fire, the system can continue its function with the other redundant train.

The CSR is a fire compartment where cables from different systems are installed together. Therefore, there should be two or more CSRs to separate the trains based on the redundancy design concept. However, in some older PSNPPs, a single CSR existed without adequate separation between redundant trains.

If a fire breaks out in a cable spreading room where the separation between trains is not adequate, the systems that support the cooling of the SFPs may be damaged at the same time.

We performed a fire modeling analysis for a scenario where the redundant trains of a system supporting SFP cooling may be damaged simultaneously. To achieve this, we assumed a hypothetical cable spreading room that does not meet the deterministic separation requirements (i.e. 10 CFR 50 Appendix R Section III.G.2 [4]). The safety-related trains in the spreading room were arranged to the left and right without meeting the requirements. Fig. 1 shows the computational domain of a CSR that does not meet the deterministic separation requirements of Appendix R.

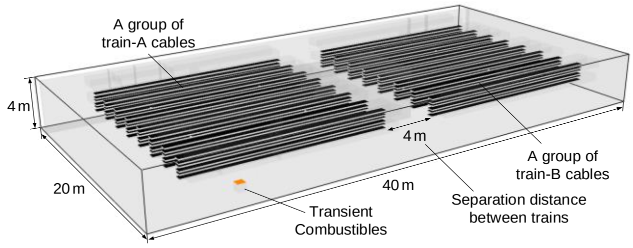

Fig. 1. Computational domain of a hypothetical cable spreading room (CSR) that does not meet deterministic separation requirements in a permanently shut down nuclear power plant (PSNPP).

Table I: Assumptions for fire scenarios in the cable spreading room

Scenario No.	Assumptions	
	Ignition point	Target cable tray location
1	The transient fire is located on the floor level beneath the A or B tray.	The target cable is located in the bottom tray closest to the fire.
2		The target cable is located in the top tray closest to the hot gas layer.
3	The transient fire is located on the floor between the A and B trays.	The target cable is located in the bottom tray closest to the fire.
4		The target cable is located in the top tray closest to the hot gas layer.

Table I shows the location of the ignition source in the CSR and the location of the target cable tray. In the fire scenario, a fire in the CSR was ignited by a single transient combustible. The transient fire is assumed to affect the upper cable tray. It is assumed that the cables in the cable tray are damaged according to the damage criteria of NUREG/CR-6850.

The heat release rate profile of the fire for transient combustibles was assumed to be in accordance with either NUREG/CR-6850 [5] or NUREG-2233 [6] for sensitivity analysis. The simulation domain was divided into two regions: the background region, which used 0.2 m cubic cells, and the region of interest, which was tested with cell sizes of 0.1 m, 0.05 m, and 0.025 m for grid sensitivity analysis. As a result, 0.1 m cubic cells were selected as the optimal grid resolution for the region of interest. The NUREG/CR-7010 FLASH-CAT model was used for the secondary ignition of the cable tray [7].

The analysis predicted that the SFP cable on the lowest target cable tray would ignite when the transient fire was located directly beneath the cable tray, with surface temperature and surface heat flux exceeding the damage criteria. In addition, in the event of ignition, the fire propagated horizontally along the cable tray. However, no vertical spread of the fire was observed. The cables of the other two systems (CCW and ESW) were largely unaffected by the transient fire, as the surface temperature and surface heat flux of the cables remained below the damage thresholds.

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