Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Study on Engineered Safety Features of a Research Reactor

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1. Introduction

Engineered Safety Features (ESFs) are safety systems that are provided mainly to limit or mitigate the consequences of anticipated operational occurrences and DBAs [1]. Sometimes the terminology ESF is used, as a broad sense, to include all the safety related systems. The ESFs of a research reactor are conceptually identified as defined in many Codes and Standards [1, 2, 3]. Normally, in the nuclear industry, ESFs are defined as features to prevent, limit, or mitigate the release of radioactive material, not including features of a reactor trip or features used only for normal operation [3]. The safe shutdown of a research reactor can be ensured by safety systems for a reactor trip, adequate decay heat removal from the core and confinement of radioactive material. The latter two safety system categories are identified as ESFs of a research reactor as follows; reactor pool coolant boundary, natural convection cooling with flap valves, and a reactor confinement system.

2. Reactor pool coolant boundary

In a research reactor, the large pool water is at the heart of safety. The pool water inventory of a research reactor should be guaranteed to maintain the natural convection for removing the core decay heat during and after all design basis events. Therefore, the pool is designed and fabricated in Seismic Category I, and the connected systems outside the pool are designed to be located above the top of the reactor or to install siphon breakers in the system [4].

The Primary cooling pump may be installed below the core level due to the acceptance of a Net Positive Suction Head (NPSH) of a pump. When a loss of coolant event occurs below the reactor core position, the pool water is drained below the core by a siphon effect, and the core can no longer be cooled through natural circulation. Thus, the siphon break lines are an ESF component that are provided to guarantee the pool water inventory to be more than a minimum level for the natural convection core cooling when a loss of coolant event occurs.

However, most primary cooling pipes of a research reactor are large in size due to a minimization of the system pressure loss and consideration of the NPSH for the cooling pump. For a large main pipe, it may be difficult for the siphon to be broken with a small siphon breaker. To prevent the siphon effect during a large pipe break, the size and location of the siphon breaker should be determined by considering the undershooting height (Figure 1).

A numerical simulation using the commercially available CFD code, ANSYS CFD, which solved the Navier-Stokes, turbulent model, and two-phase model, was performed to evaluate the undershooting height for a research reactor. The pool water surface is modeled by the standard free surface model and the opening type boundary condition. The meshes are composed of a tetrahedral type. A grid size sensitivity analysis was performed, and it was determined that an acceptable convergence was reached for the number of cells of at least 3,800,000. The employed two-phase models [5] and turbulent model [6] were shown in Table 1.

The results of the numerical calculation show that the undershooting height is less than 1.5m with both models as shown in Table 1. Therefore, the end of the siphon break line at which the air is ingressed, shall be located by considering the undershooting height for the ESF design.

Table 1. Numerical models and results

LOCA line size	Siphon break line size	Two phase model	Turbulent model	Undershooing height
10 inch	2 inch	Homogeneous model	SST model	1.27m
		Inhomogeneous model		0.74m

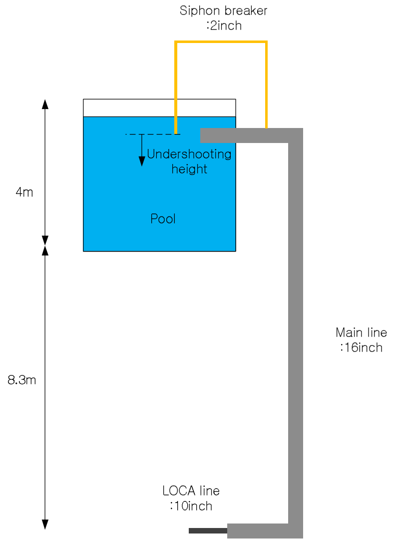

Figure 1. Geometry for the numerical simulation

3. Natural convection cooling with flap valves

The primary cooling system can be designed to flow downward through the core for the core heat removal during normal power operation. After a reactor trip due to design basis events including a loss of electric power and a loss of flow, the core decay heat still exists and is designed to be removed by the natural convection for a research reactor. Because the flow direction during the natural convection to remove the decay heat is an upward flow, the ESF is designed to avoid core damage during the flow direction inversion under decay heat removal. This is the most important design feature from a decay heat removal point of view.

To remove sufficiently the core decay heat when the flow inversion occurs after a reactor trip, a fly wheel is attached to each primary pump shaft. When the primary cooling pumps are turned off, the PCS downward flow is still maintained by the inertia force of the fly wheel. The PCS including the flywheel is designed and fabricated in Safety Class 3 and Seismic Category I.

When the power of a research reactor is relatively high and the decay heat is not sufficiently removed by the flywheel, an additional active core heat removal system is required [7].

When the flow rate is sufficiently reduced by a flywheel or an active core heat removal system, the flap valves installed on the PCS inside the pool is passively opened. The openings of these valves provide flow paths for the natural convection from the flap valves through the core to remove the residual decay heat when the reactor pool level is maintained above the flap valve and the top of the core.

To guarantee natural convection, the flap valves are installed in two separated trains, and the flap valves are designed and fabricated in Safety Class 3 and Seismic Category I.

The decay heat is dissipated into the reactor pool. The pool water is available to be an ultimate heat sink when the pool inventory is enough to absorb the heat.

4. Reactor confinement system

Most research reactors operate at low temperature and low pressure, and internal pressure in the reactor building is not high when accidents occur. An environmental impact assessment should be performed to determine whether the source term, confinement leak rate, and radiation dose are within acceptable limits. Then, the containment concept applied to the design of large nuclear power plants does not need to be applied to a small scale research reactor. Instead, the concept of confinement is adopted for the research reactor. The confinement, unlike the containment, allows a small controlled release through the barrier, but must control the ventilation air flow through a predefined path in a controlled manner.

The confinement system is the function of containing radioactive material with a reactor building to prevent or mitigate its unplanned release into the environment. The confinement system comprises the reactor building together with isolation dampers on barrier penetrations. The reactor building also protects the reactor, safety related systems, and components from external hazards.

5. Conclusion

Our research work sought to specifically identify the ESFs of a research reactor. Because the pool of the research reactor is important to safety, the pool water should be maintained through the pool integrity and siphon breakers. The size and location of siphon breaker should be designed by considering the undershooting height. When the pool water is guaranteed by the ESFs, the core decay heat is removed by natural convection through the designed flap valves. To mitigate the release of radioactive material, the confinement concept is used instead of the containment for a small scale research reactor.

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