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Original Article

Effect of Spray System on Fission Product Distribution in Containment During a Severe Accident in a Two-Loop Pressurized Water Reactor

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ABSTRACT

The containment response during the first 24 hours of a low-pressure severe accident scenario in a nuclear power plant with a two-loop Westinghouse-type pressurized water reactor was simulated with the CONTAIN 2.0 computer code. The accident considered in this study is a large-break loss-of-coolant accident, which is not successfully mitigated by the action of safety systems. The analysis includes pressure and temperature responses, as well as investigation into the influence of spray on the retention of fission products and the prevention of hydrogen combustion in the containment.

1. Introduction

In the event of a large-break loss-of-coolant accident (LB LOCA) in a pressurized water reactor (PWR), coolant mass and energy are first released from the reactor coolant system to the containment through the break. This type of accident occurs in a high-pressure cold-leg pipe in its worst condition, which is a guillotine type of break. In such accidents, the primary system envelope is breached [1].

If the accident is not successfully mitigated by the action of safety systems, core meltdown, relocation and release of radioactive material to the containment through the break, followed by reactor vessel failure and debris ejection will eventually occur. To prevent early containment overpressurization due to heat load in an accident scenario, spray systems and fan coolers are provided in the design of nuclear power plants. They also have the function of enhancing the early depletion of radionuclides from the atmosphere.

The applicability of CONTAIN for the determination of radiological source terms of a PWR under conservative release conditions is demonstrated [2].

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The containment response during the first 24 hours of such a cold-leg LB LOCA in Beznau nuclear power plant with a two-loop Westinghouse PWR was simulated with the CONTAIN 2.0 computer code [3], which was developed by Sandia National Laboratories under U.S. Nuclear Regulatory Commission sponsorship. Initial and boundary conditions, which result from processes not modeled by CONTAIN, were obtained from simulation with the RELAP5/SCDAP code [4].

Core–concrete interaction, including the attack of the basemat concrete by molten core material, was modeled with the CORCON code, which is included in CONTAIN.

The analysis is focused on the thermal–hydraulic aspect of the containment response. Pressure and temperature responses, as well as the influence of spray on the depletion of fission products from the atmosphere and hydrogen distribution in the containment, are considered.

In support of the analysis for Beznau nuclear power plant (Switzerland), a safety analysis report, and detailed RELAP5/SCDAP and CONTAIN models of the plant are developed [5].

The Beznau PWR is a Westinghouse-designed nuclear power station with a rated thermal power of 1,130 MW. There are two primary coolant loops. Each loop contains a U-tube steam generator, a reactor coolant pump, and associated piping. A single pressurizer is attached to the hot-leg piping in one of the two loops. Two accumulators are attached to each cold leg. A large, dry, subatmospheric containment building surrounds the reactor systems. Specifications of the containment are shown in Table 1. Beznau has two separate spray systems in the containment. The two spray systems operate independently, with a capacity of 45 kg/s [5], via spray nozzles located in the upper compartment of the containment. The actuation time of the spray system is determined by an overpressure signal (the set value is 2.0 bara). Operation of the spray system is helpful in decreasing the average pressure by condensing steam. Additionally, the cold droplets from spray nozzles, as heat sinks, also lower the average temperature in the containment.

2. Materials and methods

2.1. *CONTAIN code description*

The CONTAIN 2.0 computer code is an integrated analysis tool used for predicting the physical conditions, chemical compositions, and distributions of radiological materials inside a containment building following the release of material from the primary system in a light water reactor accident. It can also predict the amount of source term released to the environment [3].

The fission product behavior modeled in CONTAIN includes radionuclide decay, decay heating, atmosphere transport processes, transport in liquid pathways, iodine scrubbing, release of fission products from hosts, and release of fission products during core–concrete interactions.

CONTAIN allows the analyst to subdivide the containment into any number of nodes or cells, each of which consists of a well-mixed repository of gases (the atmosphere) as well a number of solid heat transfer structures that exchange heat with the atmosphere through an appropriate array of heat transfer correlations [3].

The CONTAIN code includes developmental models for melt ejection from the reactor pressure vessel (RPV) and dispersal from the cavity.

Table 1 – Specification of Beznau containment.

Parameter	Value
Free volume (m^3)	47,500.0
Containment elevation (m)	55.0
Containment inner radius (m)	19.0
Concrete wall thickness (m)	1.1
Steel liner thickness (m)	0.006
Cavity concrete floor thickness (m)	4.0

2.2. *CONTAIN input model—containment compartments*

The model of the containment is presented by 15 cells in Fig. 1. The containment dome is defined as Cell 12. Cell 15 represents the RPV, which is inactive in the present calculations and is treated as a dummy cell. Cells 3 and 10 are the crane wall annulus. The cavity and instrument tunnel volumes are represented by Cell 2, while the containment sump is modeled as Cell 1. Reactor pool is modeled by Cell 11. The steam generator rooms on the left and right sides are represented by Cells 4 and 8. The reactor coolant pump rooms on the left and right sides are represented by Cells 5 and 7. The free volumes below the steam generators are modeled as Cells 6 and 9. Cells 13 and 14 model gap volume and environment, respectively.

Fourteen flow paths and 22 engineering vents are modeled. Connections between compartments are shown schematically in Fig. 1 (each connection may represent several flow paths or engineering vents). Flows between compartments are modeled by applying the hybrid flow solver [3].

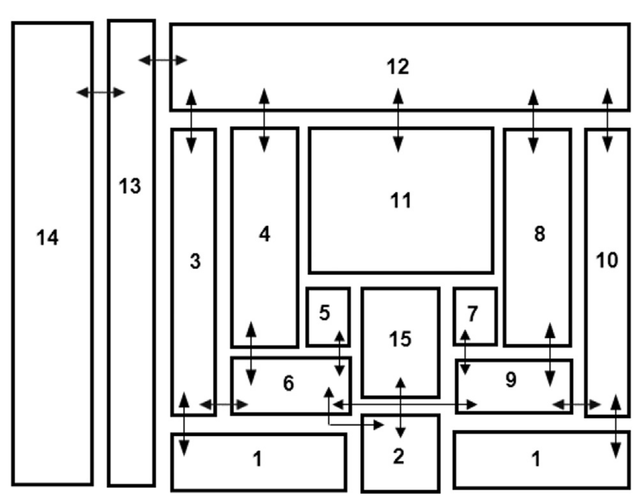

Fig. 1 – Containment compartments and flow paths.