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Technical Bulletin **No. 0899-1**

MODELING GAS STRATIFICATION IN SMALL BREAK LOCA CONTAINMENT ANALYSES

PART I: STATE OF THE ART MODELING TECHNIQUES

OVERVIEW

This technical bulletin provides guidance on performing small break LOCA containment analyses in which gas stratification is expected to occur. The distribution and possible stratification of these gases in the containment determines the potential for flammability and may influence the effectiveness of passive heat sinks (and hence the containment pressure response). Thus, accurate prediction of the containment gas mixing and distribution is essential for reliable small break LOCA containment analysis.

These issues are addressed by first discussing the major modeling techniques used in state of the art computer codes and then by presenting results of validation exercises comparing MAAP4 and GOTHIC code calculations against data from the HDR E11.2 experiment (Refs. 1 and 2).

LUMPED PARAMETER METHODS

State of the art computer modeling of large, multi-compartment structures, such as nuclear plant containment buildings, typically involves the use of lumped parameter methods in which each containment compartment is modeled as a separate computational node. The nodes are then linked together by a set of flow paths which respond to the pressure and density differences between the interconnected nodes.

Gas flowing into a node is assumed to mix instantaneously and completely with the gas present in the node. This enables a single set of average gas properties to uniquely characterize the condition in a node (Ref. 1). Thus, the assumption implicit in the lumped parameter approach is that the gas is well mixed.

Typically, large break LOCA analyses have assumed homogeneous mixing of containment gases, for which the lumped parameter modeling approach is appropriate. However, for small break LOCA scenarios the gas mixing may be dominated by gas buoyancy and therefore non-uniform gas concentrations may exist within individual containment compartments and throughout the containment. This presents problems for the traditional lumped parameter modeling approach. On one hand, artificial mixing within each lumped parameter node dissipates the momentum of the gas flow and results in overmixing of the gas flow. On the other hand the coarse nodalization schemes traditionally used in lumped parameter LOCA analyses may not adequately represent the gas flow patterns or plume-like behavior of light, low momentum gases released during small break LOCA scenarios (Ref. 2).

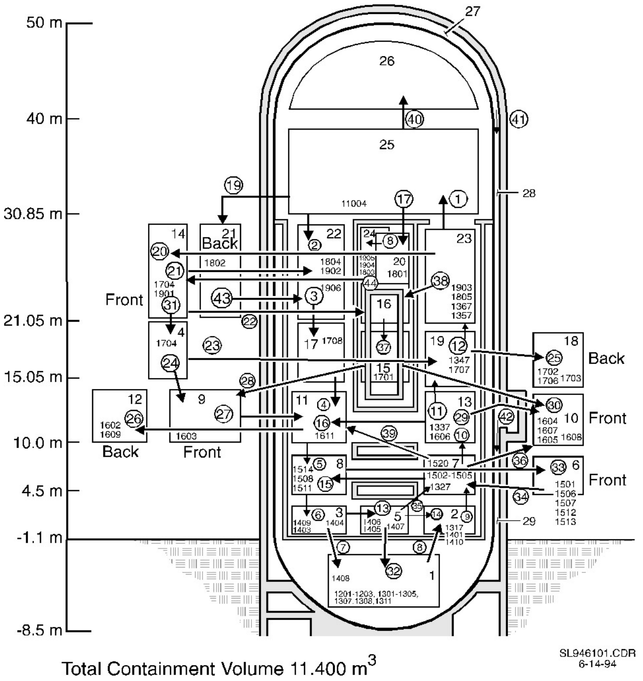

Figure 1 HDR Facility with MAAP4 Nodalization (Ref. 1)

Lumped parameter models are employed in both the GOTHIC (Ref. 2) and MAAP4 (Ref. 1) codes. GOTHIC also offers a distributed parameter option which addresses some of the shortcomings of the lumped parameter approach. However, when a typical nuclear safety analysis may consist of dozens of code runs to address base case and sensitivity sequences with accident end-times sometimes stretching into tens of hours, the detailed distributed parameter models become less attractive.

An alternate approach to the extremes of a pure lumped parameter or distributed parameter model is the addition of "sub-nodal physics" models to the standard lumped parameter method. This approach is unique to the MAAP4 Generalized Containment Model and is described, subsequently.

MAAP4 SUB-NODAL PHYSICS MODEL

There are three distinct sub-nodal physics models used by MAAP4 (Ref. 1):

1. *Counter-current gas flow through individual flow paths.* When the pressure difference across flow path is small, counter-current gas exchange may arise due to a density difference between the two compartments. The counter-current flow is superimposed on the pressure-driven, unidirectional flow.

2. *Gas stratification within a node.* The location of the interface between a lighter and a heavier gas within a node is calculated by MAAP4. This stratified layer penetration distance is compared to the location of flow paths venting gas form the node to determine the appropriate inter-nodal gas circulation pattern.

3. *Buoyant plumes.* If the gaseous effluent discharged from the reactor coolant system into the containment is much lighter than the surrounding atmosphere, it will rise like a plume with a high concentration of the effluent gas. The lighter gas will not uniformly mix within the receiving compartment as assumed by traditional lumped parameter methods. Thus, MAAP4 models the exchange of gas between compartments due to buoyant plume behavior.

HDR 11.2 TEST

Hydrogen mixing experiments conducted in the decommissioned Heiss Dampf Reaktor (HDR) nuclear reactor in Germany provide large-scale experimental data for testing the performance of computer models (Refs. 1 and 2).

As shown in Figure 1, HDR has a 200-ft (60-m) high, 65-ft (20-m) diameter containment with a hemispherical dome. The containment is characterized by a relatively large dome space, which constitutes 175,000 ft^3 (5000 m^3) of the 400,000 ft^3 (11,400 m^3) total free volume. The containment is highly compartmentalized with approximately 70 rooms interconnected by numerous flow junctions. Nevertheless, a dominant flow path can be identified by a pair of staircases and equipment shafts running from low elevations up to the dome at diametrically opposite positions. The HDR containment pressure boundary is a 0.67" (17-mm) thick steel shell with an air gap of 24 inches between the steel shell and the outer concrete wall.

In test E11.2, a small break LOCA was simulated by sequentially injecting steam then a hydrogen/helium mixture over a 16-hour time period. Following the gas injection phase, the containment was allowed to cool naturally for 15 minutes before an external spray system was actuated to cool the steel containment dome. The sprays were finally turned off after a simulated accident time of 19.8 hours.

Part II of this Technical Bulletin (TB 0899-2) will present results of validation exercises comparing MAAP4 and GOTHIC code calculations against data from the HDR E11.2 experiment (Refs. 1 and 2).

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