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# The SAS4A/SASSYS-1 Sodium Boiling Model for LMFBR Whole Core Analysis

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by Floyd Dunn

The SAS4A and SASSYS-1 codes [1,2] use a common boiling model for the analysis of hypothetical core disruptive accidents and shutdown heat removal transients in LMFBRs (Liquid Metal Fast Breeder Reactors). In both codes, an integrated approach is needed in which boiling of the sodium in a large fraction of the core is coupled with single-phase thermal hydraulics for the rest of the primary heat transport system, as well as with fuel pin heat transfer. Providing a boiling model that can be validated reasonably well with experiments and that can also run in a reasonable amount of computer time for a whole-core analysis requires the use of physical models that contain the essential features of the boiling process without being excessively detailed, as well as the use of efficient numerical methods for solving the resulting equations.

Even though whole-core boiling analysis requires treating a very complex three-dimensional system, there are a number of aspects that greatly simplify the task. First, unlike the situation in water reactors, boiling in an LMFBR is restricted to the core subassemblies and maybe the radial blanket subassemblies. Second, the subassemblies have solid duct walls, so the only interactions between subassemblies are hydraulic coupling through the inlet plenum, limited heat transfer through the duct walls, and the effects of reactivity feedbacks on the whole-core power level. Third, boiling in a subassembly is mainly one-dimensional except maybe just after boiling inception. Finally, the main purposes of boiling calculations in these codes are to determine the coolant voiding reactivity and to evaluate the amount of cooling of the fuel pins, so it may not be necessary to include all of the aspects of boiling in great detail.

There are some aspects of sodium boiling that can cause problems with many typical numerical methods. First, flow in both the normal direction and reverse flow must be considered. Second, boiling in sodium can lead to sharp interfaces between large vapor bubbles and liquid sodium. A typical numerical scheme with a fixed Eulerian axial mesh may have trouble resolving a sharp interface unless a very large number of closely spaced nodes are used. Third, a small volume of liquid can produce a very large volume of vapor. This can cause problems if iterations are used to obtain consistency between solutions of mass conservation equations and vapor pressure equations. The numerical methods used in SAS4A and SASSYS-1 avoid these problems.

SAS4A and SASSYS-1 use a multi-channel treatment for the reactor core. Each channel represents a subassembly or a group of similar subassemblies. The channel model contains a fuel pin, its associated coolant, and a structure that represents a fraction of the duct wall. Usually, the average fuel pin in the subassembly is used to represent the whole subassembly. By using a number of channels to represent different groups of subassemblies, it is possible to represent a three-dimensional core with models that are mainly one-dimensional.

The boiling model approach used in SAS4A and SASSYS-1 is to build much of the physics into a one-dimensional model with a moderate number (up to 48) of axial nodes. This model is a multiple-bubble slug ejection model, as illustrated in Fig. 1. A number of vapor bubbles, separated by liquid slugs, can be treated. In addition to a fixed Eulerian mesh of axial nodes, the model uses a Lagrangian node moving with each liquid-vapor interface to resolve the sharp interfaces. Bubbles contain only vapor, except for a liquid film left on the cladding and on the structure or duct wall. The vapor pressures at the liquid-vapor interfaces drive the flow in the liquid slugs, which are treated with a one-dimensional, incompressible flow treatment. Saturation conditions are assumed in a vapor bubble. Evaporation from the liquid-vapor interfaces supply the vapor for the bubbles. The boiling model is coupled to heat transfer equations for the fuel pin and for the structure. The cladding surface and structure surface heat fluxes determine the evaporation or condensation rates of the films. The evaporation rate from a liquid-vapor interface is obtained from a semi-analytic approach that gives the heat flux through the boundary of a semi-infinite body, given its initial temperature and the time variation of the interface temperature.

Two models are used for vapor bubbles: one for small bubbles and the other for larger bubbles. For small bubbles, the vapor pressure is uniform within a bubble. Vapor volume changes are determined by the motion of the liquid-vapor interfaces. The pressure in a bubble is determined by the relationship between the rate of change of the volume and the rate of vapor production due to heat flow through the cladding surface and the liquid-vapor interfaces.

For larger bubbles, the heat flow through the liquid-vapor interfaces is ignored, but vapor velocities and axial pressure gradients within the bubble are computed. At each fixed node boundary within a bubble and at each liquid-vapor interface, a vapor pressure and a vapor mass flow rate are computed for each time step. In addition to the saturation condition, the equations solved for each node are a vapor mass conservation equation and a vapor momentum equation. Finite differencing in space and time is used to solve these equations. The equations are linearized about the values at the beginning of the time step, and fully implicit time differencing is used, leading to a requirement to solve for all of the pressures and flow rates in a bubble, simultaneously. Since the non-zero elements in the matrix that must be solved are all near the diagonal, the solution by Gaussian elimination is not time-consuming. Because the equations are linearized and solved directly, no iteration is involved in the solution.

The liquid films on the cladding and structure are treated separately, with the film thickness at each node decreasing or increasing due to evaporation or condensation. After cladding film dryout at a node, no more evaporation, and no more heat flow, from the cladding to the coolant occurs at that node until it is rewet by a re-entering liquid slug. Currently, a static film treatment is used in SAS4A and SASSYS-1, but soon a film motion model similar to that [3] used in SAS3A and SAS3D will be added. This model will account for film motion under the influence of gravity, the shear forces from the vapor streaming by, the drag in the cladding or structure, and the coolant pressure gradients.

A new bubble is formed at any fixed Eulerian node in the liquid or at a point near an existing liquid-vapor interface whenever the liquid temperature exceeds the local saturation temperature by a specified amount of superheat.

Automatic time step controls limit the changes in vapor pressure, vapor flow rate, liquid slug flow rate, and liquid-vapor interface motion during a time step.

References

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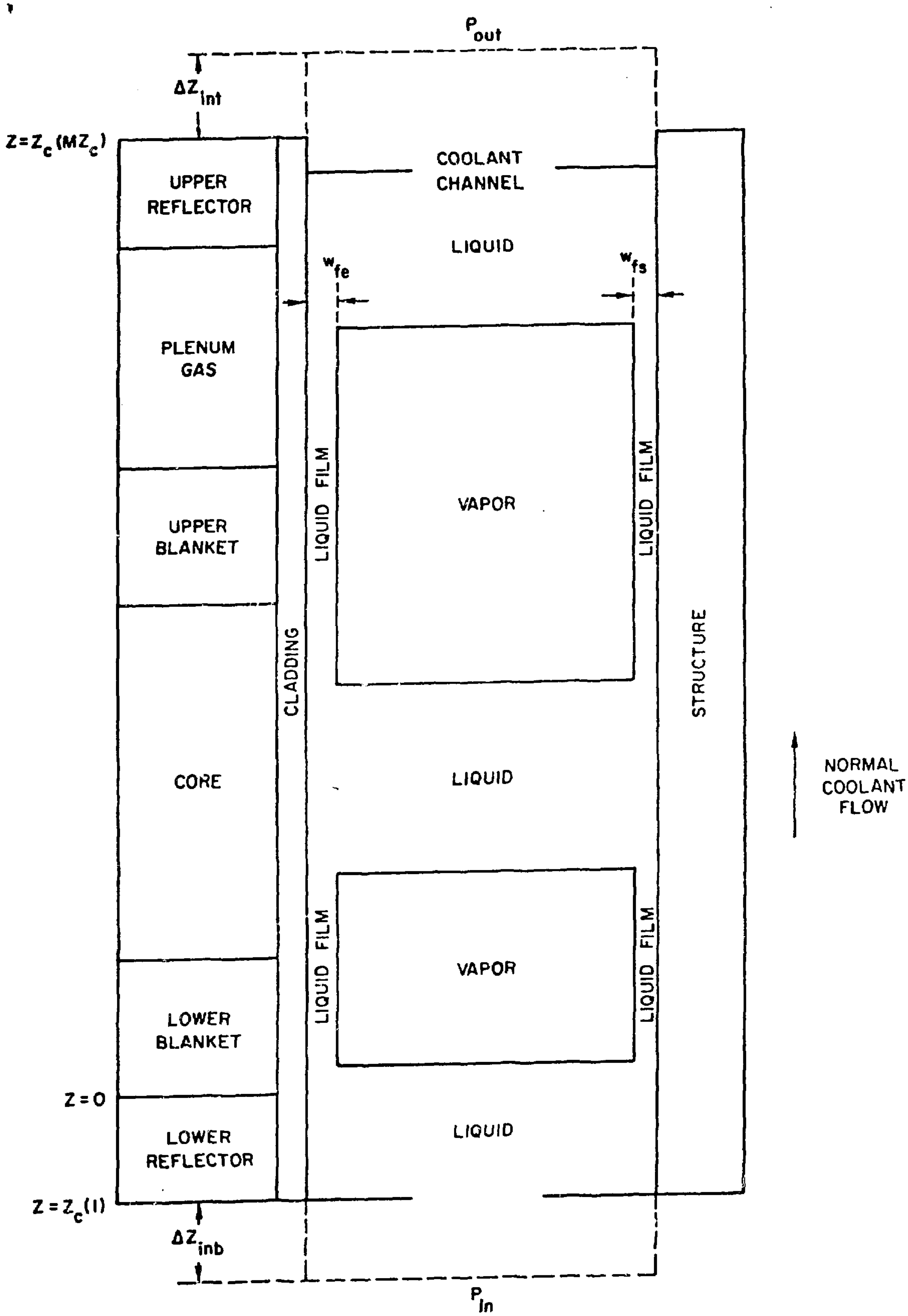


Fig. 1. The SAS4A/SASSYS-1 Multiple Bubble Slug Ejection Model