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THE EFFECT OF INCOHERENCY ON VOIDING DYNAMICS IN
LMFBR WIRE-WRAPPED SUBASSEMBLIES

Hans K. Fauske, Michael A. Grolmes, and Robert E. Henry

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INTRODUCTION

Current accident analysis tools in the United States (SAS, etc.) are based upon one-dimensional treatment of the sodium behavior in wire-wrapped subassemblies under accident conditions. As such, calculated values of sodium voiding rates (in the case of loss of flow (LOF) with failure to scram) and dryout and cladding failures (in the case of loss-of-pipe integrity (LOPI) with scram) are on the conservative side in view of the large radial temperature gradients existing at boiling inception (see Fig. 1). This point is clearly illustrated in Fig. 2 for the LOF case, although the degree of conservatism still remains to be established for a 217-pin subassembly. The purpose of this paper is therefore to discuss the intrasubassembly incoherence effects including proposed modeling and experiments to determine the magnitude of these effects in a full-size LMFBR subassembly.

INCOHERENCE EFFECTS AND MODELING APPROACH

Boiling at essentially zero superheat³ and the existence of large radial temperature gradients within the subassembly permits void growth in the central subassembly with net *positive* flow. The large momentum and frictional pressure drops normally associated with low pressure two-phase flows suggest flow diversion from boiling to nonboiling subchannels (interconnected channel effect). A local excursion of the classic Ledinegg instability will occur for each new subchannel that experiences boiling, and *inlet flow reversal is not suggested to occur prior to reaching bulk coolant saturation*. The magnitude and consequence of such an excursion depends largely on the existing power level.

In the LOF case (high heat flux conditions), the time for reaching inlet flow reversal can be estimated by *diverting all the flow* from the subchannels as they experience boiling to the remaining nonboiling subchannels while at the same time satisfying overall pressure boundary conditions. The void formation is expected to be relatively insensitive to two-phase flow effects (flow regimes etc.) because of the large thermal inertia of the fuel pin structure. This simple approach suggests that the time from boiling inception to inlet flow reversal may be as

long as several seconds, as compared to less than half a second predicted by one-dimensional modeling (SAS). At this time the central void region may have penetrated 30-40 cm down into the subassembly. The extent of the liquid-vapor region prior to dryout can be estimated from the simple condition that the all-vapor flow pressure gradient must equal the all-bypass liquid flow pressure gradient. For LOF conditions, this occurs when the central void region penetrates ~ 10 cm into the heated region, i.e., the dryout region is likely to follow closely behind the downward moving central void region as a result of continuous local excursions.

The above picture suggests that two-dimensional voiding and early dryout within individual subassemblies may be experienced during a loss-of-flow accident, with implications that the sodium voiding reactivity is overestimated when based upon one-dimensional modeling. Furthermore, before the subassemblies are completely voided, clad melting may take place (the time for clad melting following dryout is of the same order as the estimated time for inlet flow reversal). Therefore, fission-gas release from the gas plenum (recalling that cladding expands away from the fuel during the loss-of-flow transient) may also affect the voiding pattern as well as early clad relocation. On the other hand, in the LOPI case, large radial and axial heat sinks exist (see Fig. 1), in addition, to relatively low coolant heat fluxes in the central channels (<20% of nominal) at the time of boiling inception. The combined effects of large heat sinks and low heat fluxes lead to insufficient flow diversion in this case suggesting the possibility of temporary quasi-steady boiling in the absence of dryout and return to all-liquid flow conditions.

The incoherent voiding picture or the interconnected channel effect discussed above appears to be substantiated by experimental data, including transient data obtained with single-, 7-, and 19-pin test bundles. Comparing inlet flowmeter data of the single- and 7-pin R-series⁴ and OPERA tests⁵ and the more recent 19-pin P2 test (see Fig. 2), clearly show a decreasing trend in inlet flow perturbations with respect to boiling inception and voiding progression as the pin bundle geometry increases. The above experimental facts can be consistently interpreted based upon the "interconnected channel effect." Particularly, the gradual decrease in inlet flow over 3-4 s while substantial voiding must have taken place in the P2 test, would appear to be explainable only by flow diversion to outer subchannels along the hexcan flats while the inner region experienced dryout, clad melting and relocation (fuel melting and relocation also a possibility) with still net positive flow through the bundle. The heat loss from the hexcan undoubtedly enhanced this effect, but certainly would not explain by itself the rather gradual decrease in inlet flow conditions following boiling inception.

INCOHERENCE EFFECTS AND EXPERIMENTAL APPROACH

The role of radial incoherencies in subassembly voiding can be experimentally investigated by employing a triangular bundle, such as that shown in Fig. 3, which approximates a 1/6 segment of a full hexagonal duct fuel assembly. In order to achieve the proper temperature distributions

within such a triangular configuration, the hydraulic diameters of the subchannels along the two walls must be decreased so that these regions experience the same power-to-flow ratio as the triangular subchannels in the central region of a subassembly. In the current 15-pin design for the OPERA facility this is accomplished by using reduced wire wraps on the pins adjacent to two walls and inserting filler wires (thermocouples) between the pins along these walls. The remaining wall is spaced from the heater elements by full-sized wire wraps, and the three internal pins are also wrapped with full-sized spacer wires. This design then results in a strong two-dimensional temperature profile at inception of boiling, which enables one to experimentally investigate the role of these radial and axial heat sinks on the time to inlet flow reversal within the test section and the overall two-dimensional voiding behavior itself.

In using triangular bundles to simulate large subassembly behavior, the effect of swirl flow around the outer regions of large pin bundles and its effect on the voiding behavior must be examined. Small wire-wrap test bundles, such as 7- and 19-pin arrays, have observed extensive swirl flow around the outside of the test configuration. This swirl flow can exceed the angle of the wire wrap itself, and therefore, must be considered when large bundle simulations are proposed. Dye-injection experiments at ANL in a transparent 91-pin wire-wrap geometry,⁶ have shown that the dye front moves somewhat ahead of the wire-wrap angle and the experimental maximum of the dye moves at a rate less than the angle of the wire wrap. Similar experiments with salt injection have been conducted at HEDL⁷ for 217-pin wire-wrap array and these are compared to the 91-pin results in Fig. 4. This illustrates that the outer swirl flow for very large pin bundles is reduced to an angle considerably less than that characteristic of the spacer wire, and in fact, is almost nonexistent. In terms of the axial and radial temperature gradients illustrated in Fig. 1, it would appear that the swirl flow phenomenon is a second-order effect when considering subassembly voiding. Therefore, the triangular bundle configuration, which basically has no swirl flow as a result of reduced wire wraps and filler strips along the wall, is capable of obtaining the necessary experimental conditions to investigate the two-dimensional voiding characteristics of large pin bundle configurations.

REFERENCES

1. W. W. Marr, Argonne National Laboratory, personal communication, May 1977.
2. J. H. Tessier, Argonne National Laboratory, personal communication, May 1977.
3. H. K. Fauske, "Nucleation of Liquid Sodium in Fast Reactors," *Reactor Technology*, 15(4), Winter 1972-1973.
4. M. A. Grohms et al., "R-series Loss-of-flow Safety Experiment in TREAT," Proc. Fast Reactor Safety Meeting, Beverly Hills, California, April 2-4, 1974, USAEC-CONF-740401.
5. R. E. Henry et al., "A Sodium Expulsion Test in a 7-pin Geometry," Proc. Fast Reactor Safety Meeting, Beverly Hills, California, April 2-4, 1974, USAEC-CONF-740401.
6. D. R. Pedersen et al., "91-element Crossflow Tests," Reactor Development Progress Report, ANL/RDP-16, pp. 9.7-9.10, May 1973.
7. R. E. Collingham et al., "217-pin Wire-wrapped Bundle Coolant Mixing Test," HEDL-TME-71-146 (Nov 1971).

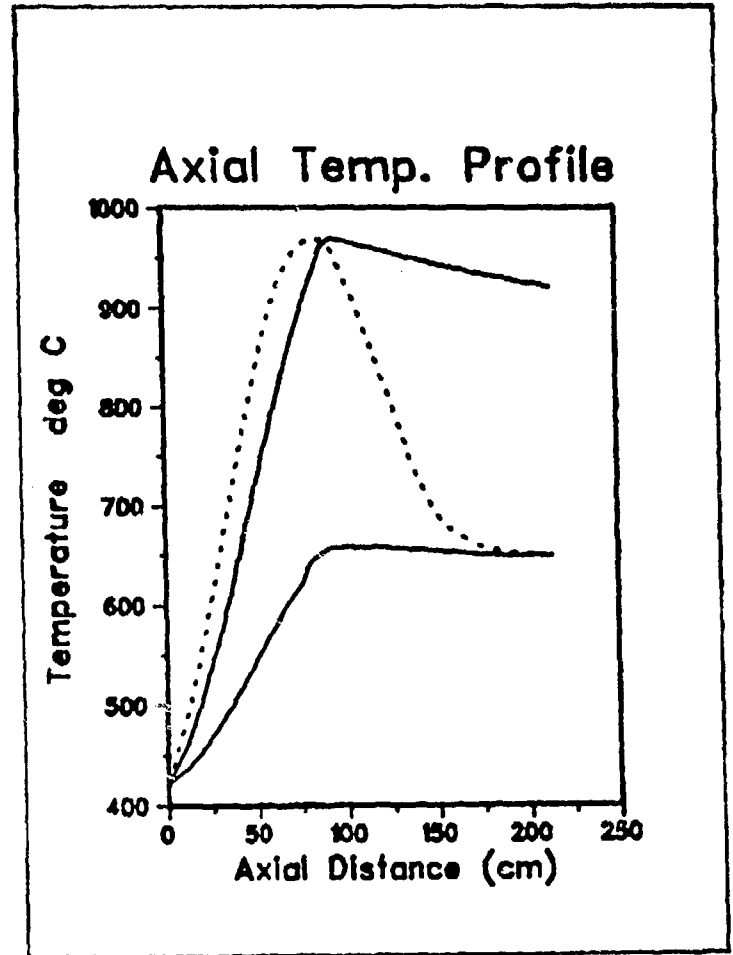
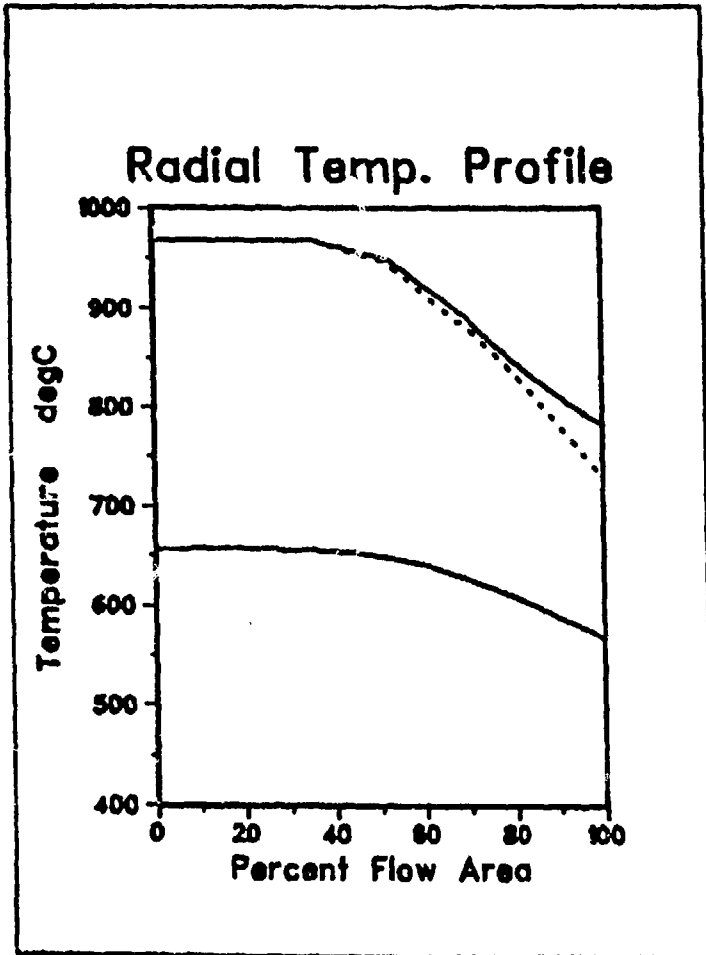


Fig. 1. Radial and Axial Temperature Profiles for Hypothetical FFTF Undercooling Transients; Solid and Dotted Lines Represent LOF without Scram and LOPI with Scram, Respectively. The temperature profiles were obtained using the COBRA code.¹

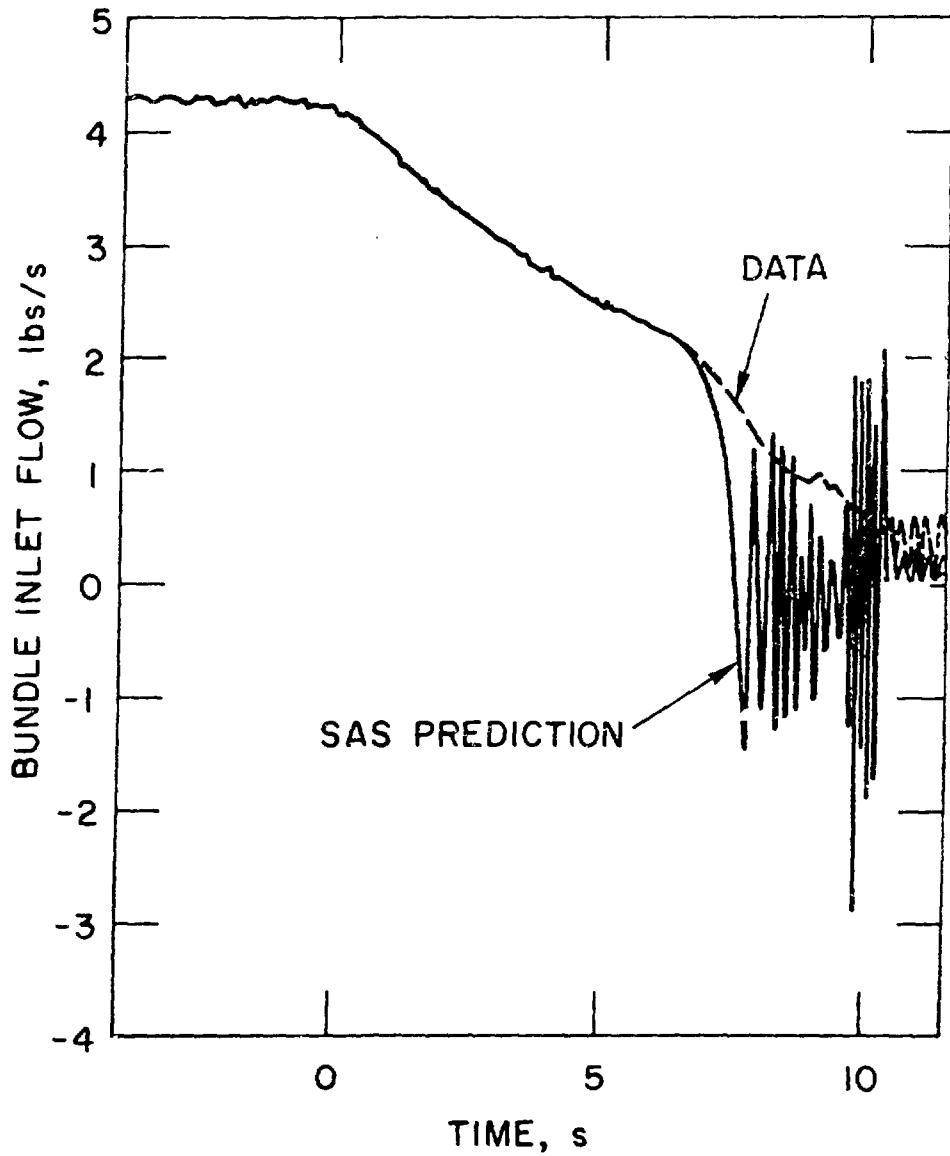


Fig. 2. Comparison of Measured Inlet Flow Behavior in a 19-pin In-pile Experiment (P2) Simulating a FFTF Pump Coastdown Accident with SAS Prediction.² Rapid inlet flow reversal is indicated by SAS prediction, while the experiment shows a rather gradual decrease in inlet flow over 3-4 seconds.

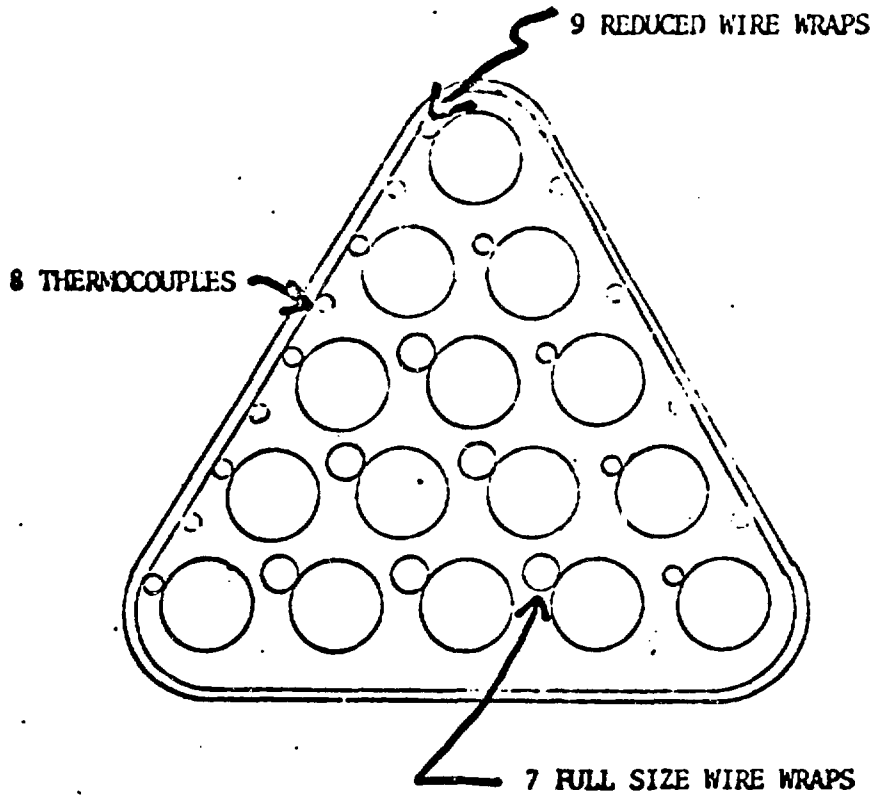


Fig. 3. 15-pin Triangular Configuration.

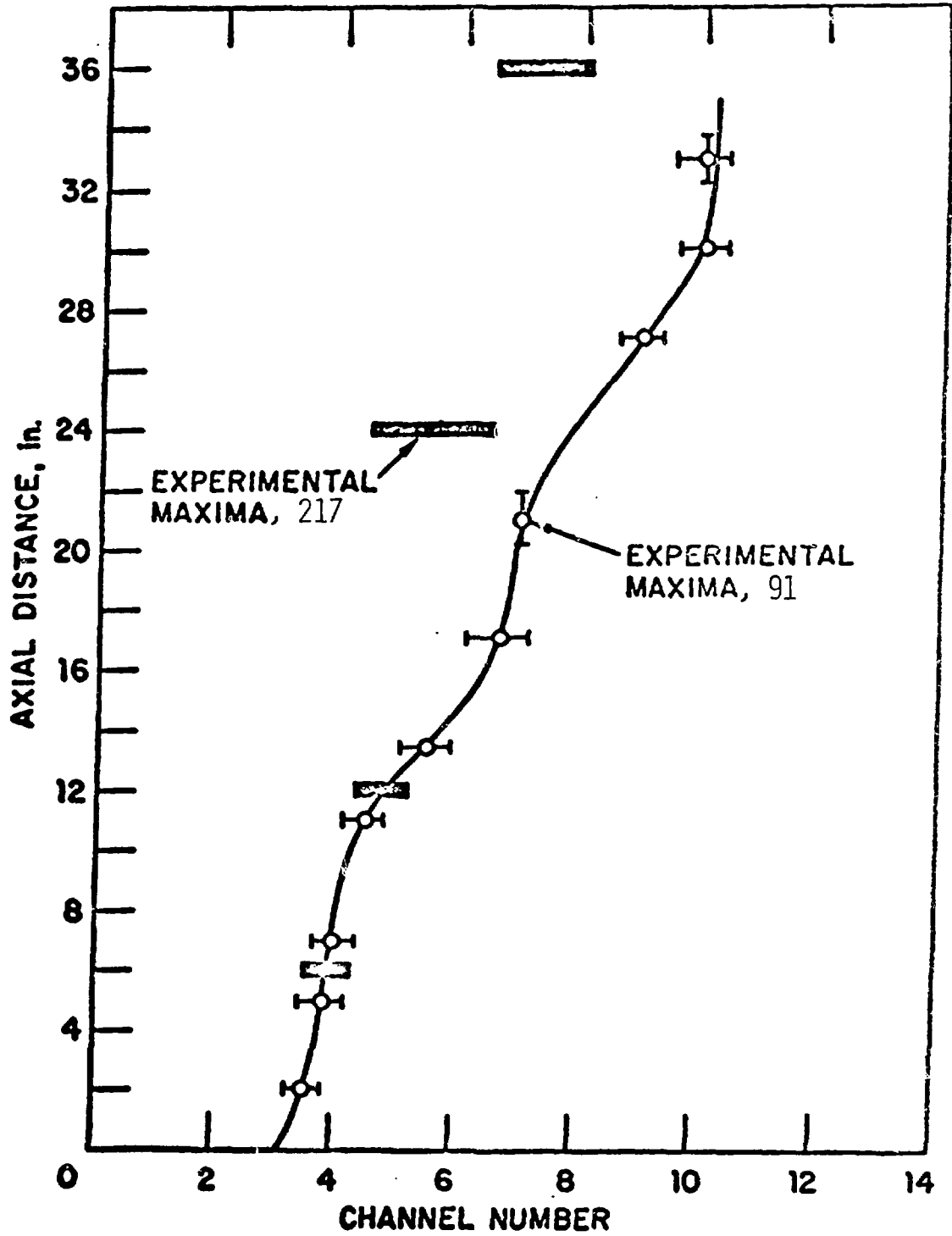


Fig. 4. Comparison of 91-element Data with 217-element Data.