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A Spatially Continuous
Approach to the Description
of Incoherencies in
Fast Reactor Accident Analysis

Final Report

by

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INTRODUCTION AND SURVEY

The research of this contract concerns the exploratory development of a method for the treatment of the spatial variations of temperatures, power and material densities in the core, as they appear initially and as they further progress through simulated accidents. The emphasis is on the lateral variations. Current programs (e.g. SAS) treat the lateral variations only in several large steps, by subdividing the core into a small number of channels (e.g. ten), with no lateral variation within each channel.

Preliminary investigation of the power variation (in terms of: fuel area at power P in dP) showed that the lateral variation can be better approximated by a continuous curve rather than by a few steps (see original proposal, Ref. 1). The actual lateral variation is closer to a continuous curve than originally estimated, if also the lateral variations across individual subassemblies are accounted for. The basic concepts adopted for this research consist therefore of continuous distributions rather than step-type functions. The variations are represented in the form of areal and volumetric distributions, which give the area or volume of a certain material, temperature or power as a function of the respective variable. Examples are: $v(P)$ = fuel volume at power P in dP , $v(T_f)$ = fuel volume at temperature T_f in dT_f .

Recent and current efforts in accident analysis in the U.S.A. have been primarily directed toward reactors which are substantially smaller than the commercial breeders to be developed later. The small size has an important impact on the accident progression, principally due to the small and largely negative sodium void reactivity. This impact is reflected, to a certain extent, in the methods and the detail needed for the analysis of accidents.

For larger reactors the description of the lateral variation of temperatures, power, and density is probably more important than for smaller ones.

Lateral variation leads to "incoherent" accident progression. These nonuniform (incoherent) progressions may be quite different from the uniform progressions which are automatically assumed when only a single fuel rod is treated per subassembly or per channel, i.e. in a group of subassemblies. Such differences may be magnified in the further accident progression.

The development of more sophisticated accident analysis methods will likely have to include the treatment of within-subassembly incoherencies. The investigations of Ref. 2 showed that accident consequences can be reduced substantially in severe accidents by treating the inter-subassembly incoherencies (whereas there is virtually no effect in benign accidents). A similarly strong impact upon consequences is to be expected also for intra-subassembly incoherencies. It can be expected that incoherencies increase the variability of accident consequences. This suggests the application of the accident-spectra-progression approach (Refs. 3,4). Therefore, the research of this contract deals with the development of parametric models for the treatment of intra-subassembly incoherencies for use in PARSEC (e.g. Ref. 2).

Originally, it was planned to employ the concept of volumetric distributions for the entire core. The first phase of this research was conducted along these lines. Later it was realized that the description of an accident progression would probably be more accurate if a certain channel structure is retained and volumetric distributions are applied within each individual channel.

COMPREHENSIVE EVALUATION OF THE APPROACH AND THE PROGRESS

The general approach is similar to the Wigner-Seitz cell approach as applied in thermal reactor neutronics calculation: The geometrical detail of the core is represented as an array of identical cells (or several types of

cells). The heterogeneous cells are treated in advance, applying special theoretical methods (transport theory). The results of the cell treatment are expressed as lumped parameters which represent the "homogenized" cells in a subsequent global calculation.

The "global" calculation in accident analysis is the channel based treatment with no distinction between the fuel pins in a channel (single-pin approximation, as applied in SAS or PARSEC). The incoherent accident progression will manifest itself through a variation of the fuel-pins behavior (e.g. in temperatures and material densities) around the single-pin values. It cannot be expected however that the single-pin results characterize the "average" of the incoherent results.

Generally speaking, the implementation of the Wigner-Seitz cell approach requires that the methods are available for treating the cell, or at least for providing the information from which the time-dependent cell-behavior can be constructed. At present, only the variations of power and temperature across subassemblies are well enough known to allow implementation of the Wigner-Seitz cell treatment.

As in the Wigner-Seitz cell approach, the detailed variation within cells is to be lumped into average parameters to be used in the global calculations. But, for the treatment of incoherencies, this approach needs to be augmented for the following reasons: The major effect of incoherent progression is that the initiation of material motions across the reactor and thus the related reactivity insertion is spread out in time. Then, positive reactivity ramp rates can be reduced, and positive and negative reactivity insertions can overlap in a wider range which results in a more effective compensation of positive reactivity insertions. Any treatment of incoherencies must retain the key variations exhibited by the intra-subassembly incoherence. Therefore,

from the condensation of the detailed spatial information one must derive a distribution, which describes the variations. E.g. instead of an average fuel-temperature value, a fuel-temperature distribution is determined, which gives the amount of fuel at a variable temperature T.

Several concepts or approaches not previously used in accident analysis or newly developed have to be combined in a successful treatment of incoherencies with a cell type approach.

First, the variations within the cells have to be described as a function of space and time. Superposition and synthesis techniques can be successfully employed for some phenomena. E.g., the space-time variation of preboiling temperatures can, in a first approximation, be synthesized as a superposition' of the following information:

- Lateral variation of temperatures in a subassembly for a flat power distribution, in the stationary state.
- Lateral variation of the power distribution in the stationary state.
- Assumption of a weak time-dependence of the lateral temperature shapes.
- Axial variation of the temperatures for a subassembly calculated in the single-pin approximation.

The analogous descriptions of sodium boiling, but even more of clad and fuel motion are clearly much more complicated than the preboiling temperature distributions. More information is needed before analytic representations of the space-time dependence can be attempted.

Second, the space dependent initial information is condensed into volumetric distributions for all subassemblies.

Third, the time dependency of the volumetric distributions is approximately introduced in the form of a time dependent mapping (including shifting, stretching, and first order distortions), based on calculations in single-pin approximation.

Fourth, the space dependent information is condensed with the reactivity worth as weighting, which gives the reactivity worth distributions (e.g. the Doppler reactivity worth of temperature-T fuel in a subassembly, as function of T).

Fifth, the "initial order" of the subassemblies in a channel is determined, as a basis for sequencing the onset of various phenomena (sodium boiling, film dry-out, etc.) within the channels.

The first phases of a Wigner-Seitz cell type approach for the treatment of intra-subassembly incoherencies have been developed and implemented in a special PARSEC version in this research. It includes the complete treatment of variations in power and temperature and a simulation of incoherent sodium boiling. Detailed comparisons with SAS-type volumetric distributions are performed. Accident simulations are performed and are compared within the framework of the code; i.e. calculations with and without incoherency treatment are performed.

Comparison of early phases of LOF accident simulations (preboiling) show relatively little difference in the results. This is understandable since during the preboiling phases of an LOF accident, the description of the "global" behavior of the core suffices. The details of the global behavior are well enough described by the average values (e.g. of temperatures, power and material densities) in an eight-channel representation.

The simulation of incoherent sodium boiling in the comparison calculations indicates a significant impact of the incoherent treatment. Much larger variations should show up if clad and fuel motion influence the further accident progression. But this latter accident phase could not be treated yet with this approach due to the lack of sufficiently detailed information.

It appears that the approach developed and explored in this research has the potential to provide parametric models for incoherency treatment in PARSEC. However, future work along these lines is needed to extend the approach and concepts developed here to treat material motion and the interaction of failed subassemblies when sufficient physics knowledge becomes available. Since incoherencies in the accident progression are very complex phenomena, involving both individual subassemblies and the whole reactor core, a substantial effort is needed to continue the development of the approach of this work so that it can be used for the risk analysis of commercial fast breeder reactors.

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4. K. O. Ott, "Probabilistic Fast Reactor Accident Analysis," Invited paper; to be presented at the ANL Topical Meeting on "Improved Methods for Analysis of Nuclear Systems", Tucson, Arizona, March 1977. Proceedings to be published in Nucl. Sci. & Eng.

LIST OF PUBLICATIONS REPORTING
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1. L. B. Luck, "A Spatially Continuous Approach to the Description of Incoherencies in Fast Reactor Accident Analysis," Ph.D. Thesis, Purdue University, Dec. 1976.
2. Ph.D. Thesis issued as Report of the School of Nuclear Engineering, Purdue University, PNE-76-114.
3. K. O. Ott, "Probabilistic Fast Reactor Accident Analysis," Invited paper; to be presented at the ANL Topical Meeting on "Improved Methods for Analysis of Nuclear Systems", Tucson, Arizona, March 1977. Proceeding to be published in Nucl. Sci. & Eng.
4. L. B. Luck and K. O. Ott, "A Spatially Continuous Approach to the Description of Incoherencies in Fast Reactor Accident Analysis," Publication in preparation; to be submitted to Nucl. Sci. & Eng.
5. L. B. Luck and K. O. Ott, "A Treatment of Intra-Subassembly Variations in the Progression of Fast Reactor Accidents," submitted to Trans. Am. Nucl. Soc.