NEACRP-L-269

Validation of Neutronic Calculations for Distorted Core Configurations Arising in Accident Situations of LMFBRs

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Summary Report from the 25th Meeting of NEACRP (1982)
to CSNI

18749

1. Introduction

Since a fast reactor core under normal operational conditions is not assembled in its most reactive configuration, redistribution of core materials (fuel, steel, sodium) during the evolution of an accident, may have the potential of leading to a severe nuclear power excursion. The accurate prediction of the associated reactivity changes requires sophisticated neutronics methods. Diffusion theory is inadequate when voided regions develop during the accident phases and also when compacted regions of fissile material are generated. Many critical experiments on simulated steel relocations in the upper and lower core/blanket region and simulated slumping configurations have been performed since about 1972 /1-4/. The interpretation of these experiments was not yet satisfactory, partly because of deficiencies in the nuclear data used, partly because differences between transport methods (S_N) and Monte Carlo could not be explained sufficiently well, therefore leaving the interpretation of distorted core configurations as a not yet completely solved problem. Recent measurements in the Federal Republic of Germany and in Japan have reinvestigated this topic; computations with transport methods, especially those which are used in accident-analysis codes like SIMMER, were applied and the results were compared with those obtained in diffusion approximation.

The NEACRP discussed the various contributions presented at its 25th Meeting /5-8/ and decided to forward the summary of the discussion to CSNI.

This summary will be kept brief, because

(a) part of the results of the investigations in the Federal Republic of Germany (SNEAK, Karlsruhe) have already been published /9,10/

(b) both the German and the Japanese investigations are submitted for publication in a forthcoming special issue of Nuclear Science and Engineering.

2. Present Status of the Interpretation of Distorted Core Configurations

It is essential to verify whether the modelling of the various accident phases by complex computer codes as e.g. SAS3D and SIMMERII results in a correct description of the associated reactivity effects. Therefore these codes have to be tested against benchmarks and experiments. The neutronic parts of these codes can be checked to a great extent by experiments in critical assemblies, if material compaction of fuel and local material dilution in slumping situations are simulated. If the primary power burst does not have sufficient dispersive potential, clad material may be moved to the colder axial blanket structures: steel may freeze out and can form massive blockages. This steel relocation can also be simulated in critical assemblies and the associated reactivity effects can be studied. Experiments have been performed in the SNEAK-12 and FCA-VIII/2 assemblies in Karlsruhe and Tokai-mura, respectively. SNEAK was fuelled with enriched uranium, in FCA a central zone of an equivalent radius of 9.3 cm with the composition of the prototype reactor MONJU was simulated; this test zone was surrounded radially by a uranium driver.

The results of SNEAK-12 experiments for cavities, streaming channels and the redistribution of steel have been discussed already in 1981 /10/. It was shown that the associated reactivity effects can be predicted by S_4-transport theory and first order perturbation theory to an accuracy of about 10 % or less.

The slumping of fuel was simulated in both assemblies by compacting fuel material in one half of the core, diluting correspondingly fuel regions in the other half of the assembly; the fuel density in the compacted regions was increased up to about a factor of two. In SNEAK the experiments emphasized fuel compaction near the core/blanket interface, with and without additional layers of steel, thus simulating molten pool configurations in accident analyses. The radius of the slump-region was varied. In FCA-VIII, the radial dimension of the slumping zone was kept constant, the regions of fuel displacement were successively widened axially.

In SNEAK also a slump-in configuration was modelled by compacting fuel around the midplane of the assembly.

In addition to the measurement of reactivities, fission rate traverses have been determined: the comparison with calculations enables to test the reliability of theory to predict the power distribution in such distorted configurations.

The results of the experiments and the theoretical interpretation can be summarized as follows: Although the data sets used are different, the experimental results can be predicted to an accuracy of 15 to 20 %, if transport theory (S_4P_0) in (r,z) geometry is used and special precautions are taken to describe neutron streaming. Diffusion theory gives very poor results with deviations of more than 50 % for slump-out configurations near the lower core/blanket interface. The deviation of the diffusion theory results from experiment would be in the non-conservative direction in a safety analysis. Fig. 1 compares the experimental results from SNEAK-12 with transport methods. The reactivity is plotted versus the diameter of the simulated meltdown zone. The theoretical results are obtained with the two-dimensional transport code SNOW /11/, and the transport and diffusion options in the SIMMER-II code. Fig. 1 is taken from Ref. 12.

In fuel compaction cases first order perturbation theory (with respect to the reference transport solution) underestimates the reactivity changes, the more the larger the compacted fuel mass is. In all these cases direct Δk-calculations in S_4 should be performed.

This analysis shows that reactivity changes in accident analyses can be predicted to a reasonable accuracy, if transport theoretical methods are used. In those cases where reactivity tables are used in an accident analysis, they have to be calculated correspondingly with transport methods to guarantee reliable results. The results of the experiments for the various slumping configurations confirm the previously obtained observation that the interpretation of distorted core configurations using S_4-transport theory gives sufficiently accurate results in the safety analysis of LMFBRs.

It should be kept in mind that, according to previous discussions of the Committee in 1976 /13/ and 1978 /14/, yet larger uncertainties may arise from an unsufficient modelling of the non-neutronic aspects in the evolution of the accident sequences, although a convincing progress has been made by introducing very laborious tools like SIMMER into the safety analysis of LMFBRs.

As far as the fission rate traverse measurements are concerned, all contributions show fairly good agreement of the theoretical results with experiment by 10 % and less. Fig. 2, taken from Ref. 7, compares theory and experiment of the Japanese contribution.

Experiments are underway in Karlsruhe with mixed oxide fuel in rod geometry in a test zone, approaching thus the situation of a fast power reactor. It is expected that the results, described in this review, will be confirmed.

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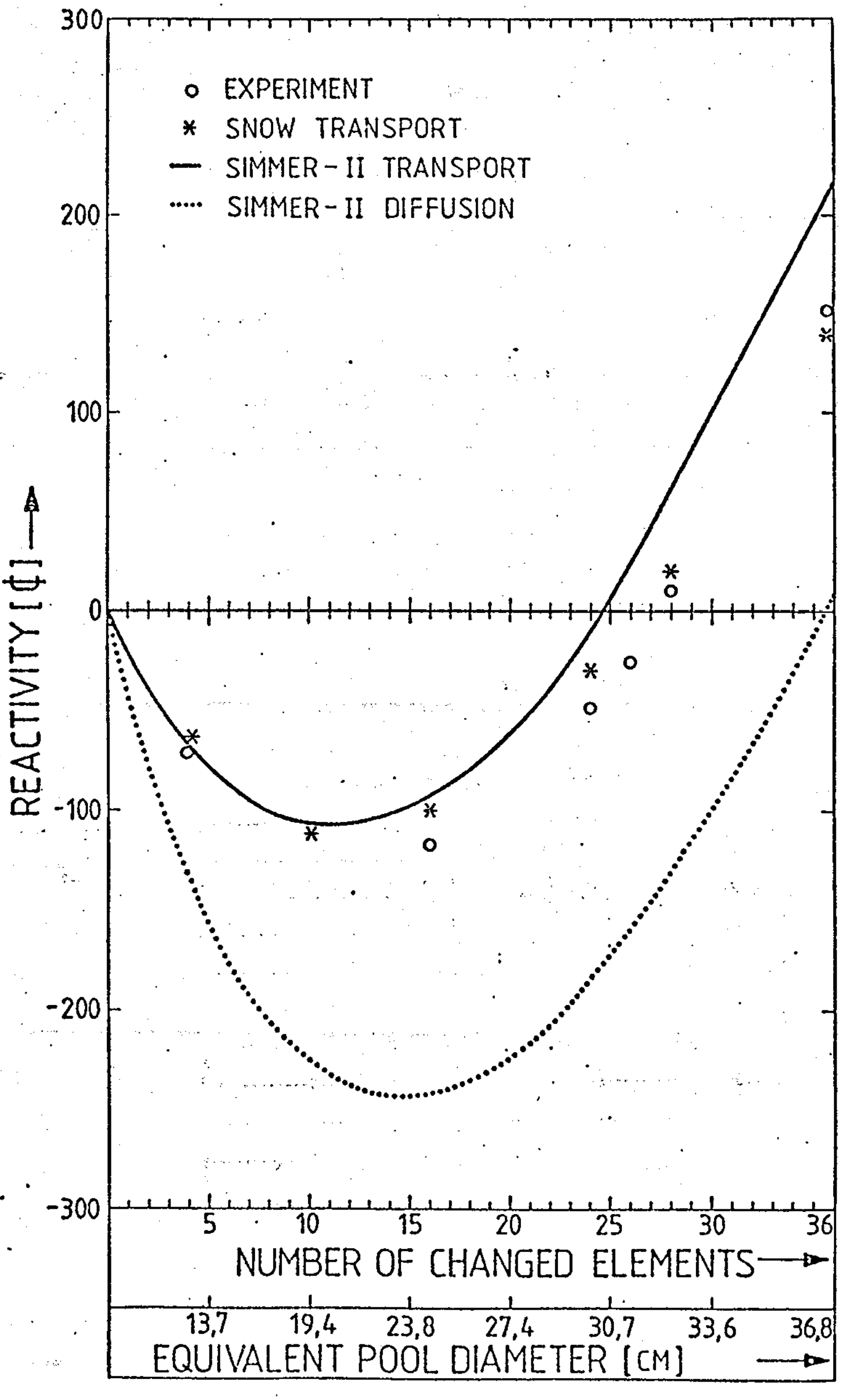

Fig. 1 Reactivity vs. diameter of simulated meltdown zone

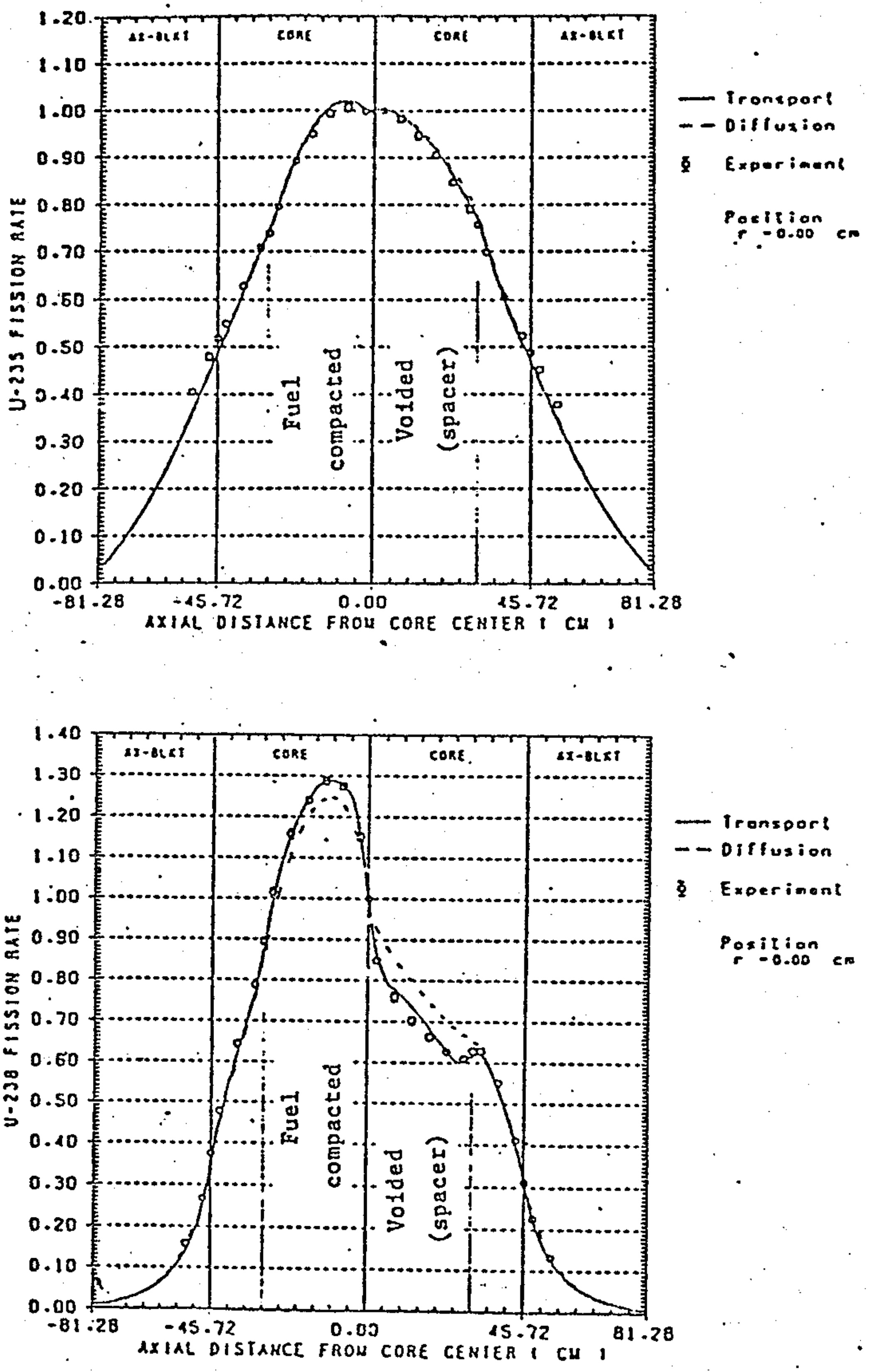

Fig. 2 Axial distribution of ^{235}U and ^{238}U fission rate in FCA VIII-2 A2 (center)