

MASTER

A CRITICAL EXPERIMENTAL STUDY OF INTEGRAL PHYSICS PARAMETERS
IN SIMULATED LMFBR MELTDOWN CORES

by

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A Critical Experimental Study of Integral Physics Parameters
in Simulated LMFBR Meltdown Cores

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A program of measurements designed to provide experimental data for the validation of analytical methods used in the neutronics part of LMFBR accident analyses, has recently been completed at Argonne National Laboratory. A considerable volume of critical experimental data already exists for normal, undamaged LMFBR cores, and the size of the calculational and cross-section data errors is well established. However, this knowledge cannot be easily extrapolated to severely distorted accident configurations because of the large changes in neutron spectrum and system leakage properties (including streaming in large cavities) which are induced by redistribution of materials. The available experimental data on the physics of damaged LMFBR cores^{1,2,3} are inadequate for use in the systematic validation of calculational methods for a variety of reasons. The present program provides a clean, benchmark set of experiments with large reactivity changes (involving ~18.5% core volume distortions) for use in the methods validation.

The reference configuration for the measurements consisted of a single core zone with a typical LMFBR composition. A sequence of idealized configurations was designed to follow from this reference to simulate, in a static or "snap-shot" sense, the sequence of configurations that might result from a loss-of-flow

transient. Both symmetric and axially asymmetric configuration distortions were included in the program. Figure 1 shows a schematic view of the sequence of slumping into the center of the core and outward toward the core/blanket interface, both cases being accompanied by corresponding void cavities in the core. The large volume of fuel distorted represents an upper limit of expected core volume distortions under accident conditions.

Table I itemizes the measurements performed in each configuration of the sequence. The measurements were designed to characterize the neutronics of the distorted cores as completely as possible in the short time available for the measurement program.

The experimental methods used for the program were all developed earlier and have been used with success in a large number of critical experiments programs. From the experimentally-determined configuration reactivities, the worths of the configuration changes were determined. Some specific safety parameters (viz. ^{238}U Doppler worth, B_4C control rod worth) were included.

Analysis of the measurements were performed using ENDF/B-IV nuclear data and two-dimension diffusion theory methods in 29 energy groups. Cross-Sections were generated for appropriate compositions using the MC²-2/SDX codes^{4,5}. Eigenvalue calculations were performed using isotropic diffusion coefficients, and with bi-directional Benoist diffusion coefficients⁶ to account for neutron streaming effects in the non-cavity regions. The final calculations used Gelbard diffusion-coefficients⁷ in core regions for neutron energies above 2 keV to apply a transport correction to the leakage calculation. The void cavity regions were treated with isotropic diffusion coefficients based on the transport cross-sections of the low density structural material comprising the Zero Power Reactor -9 (ZPR-9) matrix.

Table II lists the experimental and calculated configuration eigenvalues for the configurations shown in Fig. 1. The computed $\Delta k/k$ conversion factors are also listed. The C/E values lie within the range observed in earlier critical experiments on undamaged cores. It is interesting to note that the neutron streaming correction associated with the use of the Benoist diffusion coefficients and the transport correction associated with the use of Gelbard diffusion coefficients were significantly larger for the distorted configurations than for the reference configuration; reflecting the greater importance of leakage in the distorted configurations.

Table III summarizes the results of the reactivity worth determinations. It is seen that the calculational worth predictions (representing differences in eigenvalues) are poor. Refinement in calculational methods (using the Gelbard diffusion coefficients rather than isotropic D's) produced a marked improvement in the calculated predictions, but the final C/E values are far from satisfactory. Improvements in the diffusion theory treatment of streaming in the void cavity regions⁸ or transport theory calculations will evidently be necessary to obtain better agreement with measurement. The trend of over-prediction of the fuel slump-out negative worth and underprediction of fuel slump-in positive worth shown in Table III has been observed in earlier experiments.²

The results of the present program provide a detailed characterization of the neutronics of LMFBR accident configurations. These results provide a valuable means for validating nuclear data and neutronics analysis methods used in accident analyses. Thus far, it has been found that the use of straight diffusion theory for the neutronics analysis of distorted cores results in a non-conservative misprediction of the material redistribution reactivity worth results. Further efforts are underway to attempt to separate this miscalculation

into a component attributable to the ENDF data alone and a remaining component due to the approximations inherent in the cross section preparations and diffusion steps of the analyses.

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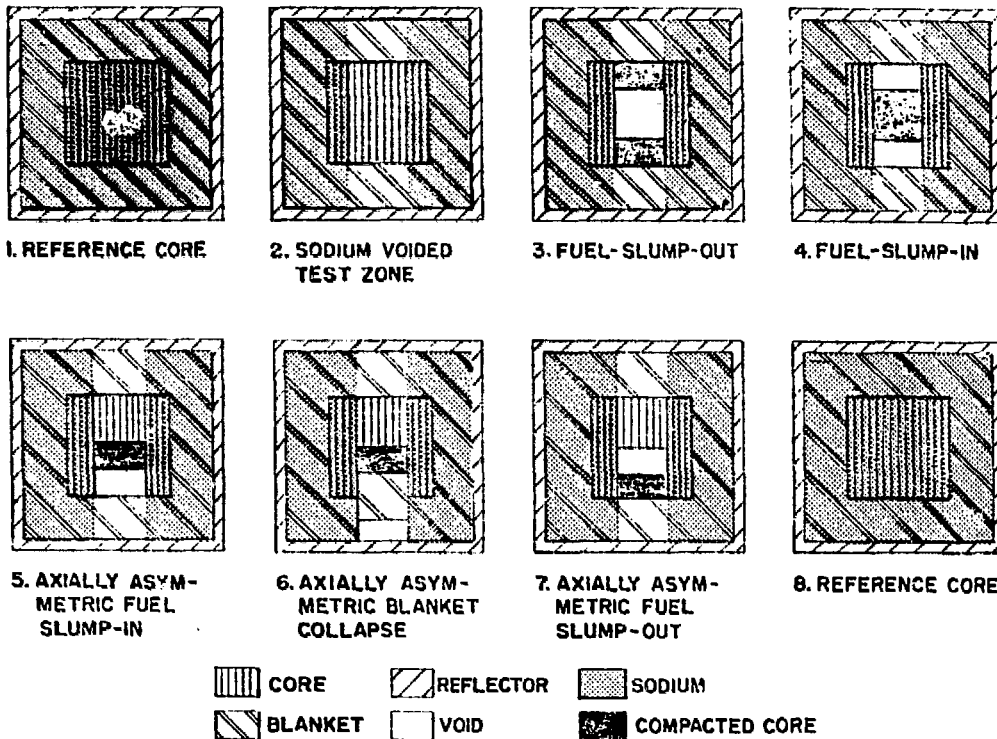


TABLE I. Program of Measurements in the Safety Related Critical Experiments

Configuration	k_{eff}^a	Neutron Spectrum	Central Reactivity Worth	Axial Reactivity Worth Profiles	$^{235}U(n,f)$ Reaction Rate Profiles (Axial)(Radial)	^{238}U Doppler Worth	B_4C Control Rod Worth	β/λ^d	β^e
1. Reference Core	✓	Core Center	$^{239}Pu, ^{240}Pu, ^{238}U, ^{235}U, ^{10}B, Na, SST^f$	$^{239}Pu, ^{238}U, SST^f$	✓ ✓	Core Center	Core Center	✓	✓
2. Sodium Voided Reference	✓		"	"	✓				
3. Symmetric fuel Slump-Out	✓		"	"	✓				
4. Symmetric fuel Slump-in	✓	Core Center	"	"	✓ ✓	Core Center	Core Center	✓	
5. Asymmetric fuel Slump-in	✓		$^{235}Pu, ^{238}U, SST, ^{10}B$	"	✓				
6. Asymmetric fuel Slump-in with blanket collapse	✓				✓				
7. Asymmetric fuel Slump-out	✓		$^{239}Pu, ^{238}U, SST$	"	✓				

^aThe changes in k between the configurations gave the worths of these configuration changes.

^bThe foil locations were determined based on Monte Carlo code validation requirements.

^cThe control rod height was kept equal to core height.

^dRatio of beta effective to prompt neutron lifetime.

^eBeta effective.

^fStainless Steel.

TABLE II. Results of Configuration Eigenvalue Determinations

Configuration	Eigenvalue		C/E	Calculated In/%Δk/k Conversion Factor
	Experimental	Calculated		
1. Reference (Fig. 1.1)	1.0009	0.99093	0.990	975.61
2. Sodium Void Test Zone (Fig. 1.2)	0.9970	0.98577	0.989	971.86
3. Axially Symmetric Fuel Slump-out (Fig. 1.3)	0.9889	0.97388	0.985	969.57
4. Axially Symmetric Fuel Slump-in (Fig. 1.4) ^a	1.0012	0.98308	0.982	965.18
5. Axially Asymmetric Fuel Slump-in (Fig. 1.5) ^a	0.9862	0.97231	0.986	970.02
6. Axially Asymmetric fuel Slump-in with blanket collapse (Fig. 1.6) ^a	0.9920	0.98060	0.989	970.02
7. Axially Asymmetric fuel Slump-out (Fig. 1.7)	0.9916	0.97875	0.987	970.51

^aThese configurations had an effective core radius of 42.39 cm. All others had an effective core radius of 44.19 cm.

TABLE III. Results of the Determination of the Worths of Configuration Changes

Parameter	Reactivity Worth (Ih)		C/E
	Experimental	Calculated	
1. Worth of Sodium Voiding Test Zone Relative to Reference	-386.3 ± 1.9	-498.1	1.289
2. Worth of Axially Symmetric Slump-out Relative to Sodium Voided Test Zone	-781.1 ± 12.8	-1149.6	1.472
3. Worth of Axially Symmetric Slump-in Relative to Sodium Voided Test Zone	+2106.1 ± 57.2	+1213.1	0.576
4. Worth of Axially Asymmetric Slump-in Relative to Sodium Voided Test Zone	+655.0 ± 11	142.8	0.220
5. Worth of Axially Asymmetric Slump-in Wirth Axial Blanket Collapse Relative to Sodium Voided Test Zone	+1218 ± 24	947.0	0.777
6. Worth of Axially Asymmetric Slump-out Relative to Sodium Voided Test Zone	-264 ± 2	-434.0	1.644