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VALIDATION AND VERIFICATION SUMMARY REPORT FOR GRIMHX AND TRIMHX (U)

By

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INTRODUCTION

As part of the code Certification process [1], codes used by Reactor Physics to calculate values in Technical Specifications or Safety Analyses must undergo formal Validation and Verification [2]. GRIMHX and TRIMHX are codes used in such a manner. This report summarizes and consolidates the work done to date on the Validation and Verification of these two codes.

GRIMHX [3] is a 3-D static reactor code which uses finite difference algorithms to solve the neutron diffusion equation in hex-z geometry. TRIMHX [3] is the time dependent version of GRIMHX and solves the delayed neutron precursor equations in addition to the neutron diffusion equation. Both of these codes were developed at SRS in the early 1970's.

SUMMARY

Since their inception, GRIMHX and TRIMHX have undergone verifications and validations. These have taken the form of verifications against numerical experiments (exact solutions), comparisons against other diffusion theory codes, validation against experiments and against MCNP. These experiments have involved transients which represent dropped rods, rod withdrawal and pulsed sources. Although the code has evolved over the intervening years, comparisons have been made between the versions initially used to benchmark the code, and those currently in production status at SRS. These comparisons show that the code is still calculating the same results. Throughout the V&V effort, GRIMHX and TRIMHX have been found to accurately calculate the eigenvalue, flux distribution, reactivity worth and in the case of TRIMHX, the time dependent response of SRS cores.

DISCUSSION

1.0 Verification

1.1 Numerical Experiments [4]

In 1974, TRIMHX was verified using three numerical test problems. For the first two tests, analytic solutions were available for comparison. In the third test, a series of static asymptotic calculations are used for comparison. Each of these tests were characterized by the following attributes:

- 2 energy groups
- 1 to 6 delayed neutron families
- six-fold sector symmetry in the horizontal plane
- one mesh point per hex (horizontally)
- ten mesh points per layer axially
- a step change in reactivity at time 0

The first of these test problems considered a bare homogeneous reactor with a spatially uniform perturbation in production cross section. The second test differed from the first only in that the reactor modeled was heterogeneous. The third test used a heterogeneous reactor perturbed by reducing the thermal absorption cross section in the center of the reactor. This created an axially uniform step change in the reactivity at time 0.

The results of Experiment 1 are shown in Figure 1 and Table I, while the results of Experiment 2 are shown in Table II. Both of these tests had exact solutions using point kinetics equations. A comparison of these results is presented in Tables I and II which show TRIMHX was in excellent agreement with the exact solution at all points (for the first test to within .5%). It should be noted that during these tests it was found that the use of the exponential transform in TRIMHX gave more accurate results.

Since the point kinetics model solution was not valid for the third test, a dynamic reactivity was inferred from the asymptotic period found by using a calculated neutron lifetime. Figure 2 shows the radial distribution of the thermal flux between that calculated and measured. Agreement between the transient and asymptotic shape is excellent (<.1% error). Results for Experiment 3 with and without the exponential transforms are presented in Table III.

These experiments show that the TRIMHX solution method provides an effective means of analyzing multidimensional reactor problems accurately.

1.2 HTGR Benchmark [5]

As part of the effort to verify GRIMHX, a benchmark problem was developed under the auspices of the Mathematics and Computations division of the American Nuclear Society. The benchmark problem consisted of a HTGR core representation with 60-degree rotational symmetry in 2-D surrounded by a graphite reflector. This benchmark was part of a cooperative effort between SRL, ORNL, and General Atomic (GAC) to verify their hexagonal finite difference codes.

The results of the benchmark are presented for the three codes GRIMHX(SRL), VENTURE(ORNL), and BUG180(GAC) in Table IV. These results show that GRIMHX is indeed solving the finite differenced neutron diffusion equation correctly. The input data records for this benchmark currently exist on the author's dataset.

1.3 Comparison of TRIMHX to the Adiabatic Model [6]

In 1988, Bill Graves made a 2-D, one-point per mesh, coarse mesh comparison of TRIMHX versus the adiabatic model for a mockup of the Fast Scram Shutdown System. The test involved modeling the injection of He-3 into three hollow rods in the core and performing an analysis ignoring the temperature feedback.

The adiabatic model employs a static reactor code (GRIMHX) to prepare input for a point kinetics code which provides assembly power as a function of time. This amounts to assuming that the computed flux shapes are based on the delayed neutron precursors being at equilibrium. The adiabatic model produced results which differed from those calculated by TRIMHX by less than 1.0%. The results for total reactor power as a function of time are shown in Table V. It should be noted that TRIMHX produces edits of power as a function of time directly.

2. VALIDATION TO EXPERIMENT

2.1 Pulsed Neutron Experiments [7]

Pulsed neutron experiments were carried out in the Process Development Pile (PDP) at SRL. The test involved a hexagonal core surrounded by a hexagonal reflector. Control assemblies and fuel assemblies (E-D charge) were representative of typical SRS lattices. This core was then pulsed by a $^{3}H(d,n)^{4}He$ accelerator source.

The test was modeled using TRIMHX in 2 groups, 60-degree symmetry, 3 points per mesh, 20 axial mesh points, and 6 neutron precursor families.

Two assumptions were incorporated into the TRIMHX analysis. The first of these is that discrepancies between calculated and measured values are due to errors in input parameters and not the calculation method. Therefore, with a normalization procedure, these differences can be removed. This can be seen in Figures 3 and 4. The second assumption was that if the space-time response of the reactor is adequately calculated using normalized parameters, then static subcritical reactivity can be derived by using the same neutronics model and parameters (i.e. in the GRIMHX code).

The space-time calculational method is unaffected by the problems of kinetic distortion and prompt and delayed harmonics. Kinetic distortion results from spatial and spectral differences between the fundamental prompt and delayed neutron modes. To the extent 2-group treatment was adequate, the effects of delayed and prompt harmonics and kinetic distortions were directly included in the space-time calculation of the experiments. Although the reflected lattice produced kinetic distortion and harmonic distortion which invalidates the conventional methods of determining reactivities, for illustration Table VI compares the conventional and space-time results. The space-time results were found using data only after the fundamental mode had been established.

Comparisons of the calculated to measured data showed that after suitable normalization of the production cross sections the overall prompt neutron response to a pulsed source was well represented. These comparisons were made against experiments at critical conditions and at varying degrees of subcriticality. In all cases there was good agreement between the measured and calculated k_{eff}. The space-time method should be among the most accurate of methods proposed to date for deducing the subcritical reactivity from pulsed neutron experiments.

2.2 Space-time Experiments

2.2.1 2-D Experiments [8]

In 1974 experiments were carried out to measure delayed neutron holdback in the PDP. The control and fuel (E-D charge) were representative of typical SRS lattices. TRIMHX (2-D) was used to model the reactor response. Two experiments were conducted; the first involved an initial flux shape peaked in the center, the second a flux shape dished in the center. Reactivity transients were initiated by dropping 2 or more ^{235}U bearing rods into the lattice at selected perturbation sites in Gang 3 as this location maximized flux tilt. Gold pin activation was used to measure the radial flux shape. Flux tilts between pairs of detectors were determined (i.e. tilt (A/B) = $[ø(t)/ø(0)]_A/[ø(t)/ø(0)]_B$) from the gold pin activation and from TRIMHX calculated fluxes and compared.

The geometry of Experiment 1 is shown in Figure 5. In this experiment the perturbation was initiated by dropping three perturbation rods into prepared fuel sites. Four detectors were placed in interstitial positions, and TRIMHX was used to calculate the time response out to approximately 90% of the asymptotic value. Due to computing cost, GRIMHX was used to determine the asymptotic solution.

The geometry used in Experiment 2 is shown in Figure 6. In this case the perturbation was initiated by the dropping of two perturbation rods into prepared fuel sites. In this experiment, the number of detectors were doubled and the detectors were moved to actual fuel sites. Once again GRIMHX was used to calculate the asymptotic solution.

In the analysis of both experiments, the exponential transform option was used in TRIMHX. Also, the $\nu\Sigma_f$ value input to TRIMHX was adjusted to produce agreement with measured data such as static k_{eff}, flux shape and perturbation worth. It should be noted that the asymptotic flux distribution is not normalized even though the perturbation worth is.

The results from Experiment 1 (Figure 7) show that the tilt between detector pairs is well represented by GRIMHX/TRIMHX. In particular the fraction of delayed neutron holdback in the total tilt has been calculated very accurately. Some discrepancies remained in the absolute tilt with errors of as much as 4%. Much of this error may be attributable to the interstitial placement of the detectors. Since the product of flux times volume at the cell level is the smallest spatial flux editable, TRIMHX is unable to compute values for the interstitial spaces directly, but instead they must be inferred from the flux in surrounding cells. As seen in Figure 8, Experiment 2 was found to be more accurate. This increased accuracy has been attributed to the placement of the detectors in fuel positions where the TRIMHX code can calculate the flux directly.

In addition to the flux tilts, the net reactivity addition to the lattice was calculated by GRIMHX to be 15.4 cents. The reactivity change was also found by inserting the measured stable period into the Inhour equation. The Inhour calculated value was also 15.4 cents.

This validation shows that TRIMHX/GRIMHX can accurately reproduce the flux shapes (as measured by tilt ratios), the reactivity worth of the perturbation and the thermal reactor response under transient conditions from a variety of radial flux shapes. This was possible, however, only with the use of normalized cross sections. Also, space-time effects associated with transients near prompt-critical have not been tested.

2.2.2 3-D Space-time [9]

In 1977 zero power tests were performed in the PDP to allow further measurement of delayed neutron holdback. Control and fuel (E-D charge) were typical of SRS operation. Three experiments, each initiated from stable critical reactor conditions, were conducted which measured neutron flux responses and used these to compute flux tilts. TRIMHX was used to model the reactor response, and the calculated flux tilts were compared to those measured. Descriptions of the three experiments follow.

The reactivity perturbation in Experiment 1 was initiated by dropping three rods (each containing ^{235}U slugs on the bottom and ^{6}Li on top) into the central hex of the core. This distorted the flux shape in the axial and radial dimensions, but not in the azimuthal. The space-time effect of delayed neutron holdback was relatively small in this transient as shown by the small difference between tilts at the end of the rod insertion (5.1 sec) and the asymptotic tilts (see Figures 9, 10 and 11).

Experiment 2 began from the same core configuration as Experiment 1 with the exception of three rods (^{235}U slugs in the bottom and Al in the top) being dropped into each of two hexes in Gang 3 (for a total of 6 rods). This produced a flux tilt in the axial, radial and azimuthal directions. The space-time effects of delayed neutron holdback was most pronounced in the radial and azimuthal directions, but was small in the axial.

In Experiment 3, the reactivity perturbation was caused by pulling one full length Cadmium (Cd) rod from all Gang 1 assemblies (about 20% of the core) at 3.05 cm/sec. Due to the slow rate of withdrawal, the observed delayed neutron holdback was very small.

The results from Experiment 1 are shown in Figures 9, 10 and 11; results from Experiment 2 are shown in Figures 12, 13 and 14; results from Experiment 3 are shown in Figures 15, 16 and 17. In all cases the exponential transform was used to accelerate convergence, and as they were in the 2-D experiments, the two-group macroscopic cross sections were normalized to better match the observed data. The results from these experiments showed that the measured tilts from detectors paired axially, radially and diagonally were well represented by TRIMHX/GRIMHX. The influence of delayed neutron holdback in the tilts was calculated accurately, however, small discrepancies in some of the individual tilts were evident. The largest discrepancy for experiment 1 was 2.3%; for experiment 2 was 2.4%; and for experiment 3 was 4.8%. In all comparisons, the tilt discrepancy was largest when a detector close to a region of positive reactivity was involved.

In addition to the flux tilts, an analysis of the $\phi(t)/\phi(0)$ kinetic data was calculated using the Inhour equation. Perturbation reactivity worths compared well with those calculated by GRIMHX using normalized cross sections. This can be seen in Figure 18.

These experiments demonstrate that TRIMHX accurately predicts the course of zero-power thermal reactor transients in 3-D. The time dependence and magnitude of delayed neutron holdback were directly tested.

3. VALIDATION AGAINST MCNP [10]

In 1989 MCNP was used to validate GRIMHX for the determination of safety rod worths. Safety rod worths were computed by each code for a variety of initial flux shapes, rod configurations and material contents. Since the original issue of this document, these results have been recomputed, and it is expected that the report will be reissued. Until that time, the results and conclusions drawn from the first report will not be reported here.

4. COMPARISONS OF PAST AND PRESENT CODE VERSIONS

In 1989 Gregory reran the HTGR benchmark problem on the current production version of GRIMHX. Tables VII and VIII show the results of this benchmark [11] were identical to those found when running the original version of the code. Eigenvalue, flux distribution and number of outer iterations were all tested using the benchmark and found to be exactly the same as those determined earlier . In 1990 this benchmark was run again by Trumble on GRIMHX and was also used to test the static solution of TRIMHX . Table IX shows the results of these calculations [12] with both GRIMHX and TRIMHX converging to the same value as the original benchmark. As part of this later work, a consistency check was also run on the results of TRIMHX versus those found via the adiabatic model (GRIMHX plus point kinetics). These results (Figure 19) show that TRIMHX models the core during a transient in an accurate and predictable manner.

5. QUALITY ASSURANCE

This report was generated under QA Task 90-044-1, Certification Plan for GRIMHX, TRIMHX and GILDA Codes.

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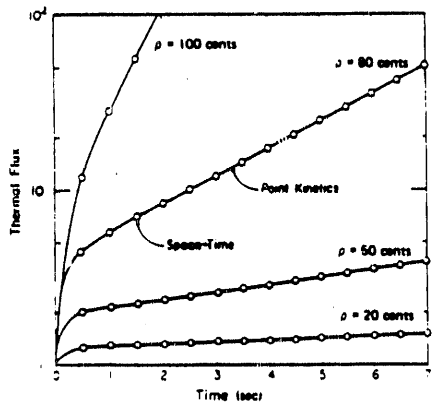


Fig. 1. Reactor midpoint thermal-neutron flux (normalized to unity at time zero) versus time for four values of reactivity.

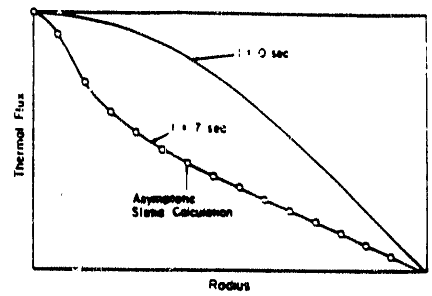


Fig. 2. Thermal-neutron flux at reactor midplane versus reactor radius (linear plot).

TABLE I

Test I Results

Time (sec)	Point Kinetics			3D (Δt = 50 msec)	
	Δt = 0.5 msec	Δt = 5 msec	Δt = 50 msec	With Transform	Without Transform
0	1.000	1.000	1.000	1.000	1.000
1	5.896	5.896	5.896	5.874	5.897
2	8.426	8.430	8.477	8.454	8.488
3	11.975	11.985	12.086	12.054	12.100
4	17.018	17.037	17.230	17.184	17.259
5	24.186	24.220	24.563	24.495	24.610
6	34.373	34.430	34.017	34.918	35.095
7	48.850	48.945	49.920	49.798	50.058

TABLE II

Test II Results

Time (sec)	Point Kinetics	3D (Δt = 50 msec)	
	(Δt = 50 msec)	With Transform	Without Transform
0	1.000	1.000	1.000
1	5.870	5.896	5.920
2	8.446	8.482	8.512
3	12.039	12.096	12.142
4	17.157	17.249	17.321
5	24.452	24.599	24.708
6	34.848	35.084	35.248

TABLE III

Test III Results

Time (sec)	TRIMHX With Transform			TRIMHX Without Transform		
	Δt = 5 msec	Δt = 25 msec	Δt = 50 msec	Δt = 5 msec	Δt = 25 msec	Δt = 50 msec
0.0	1.000	1.000	1.000	1.000	1.000	1.000
0.5	10.647	10.500	10.406	10.668	10.605	10.538
1.0	15.552	15.495	15.491	15.436	15.569	15.581
1.5	20.624	20.623	20.697	20.602	20.703	20.791
2.0	26.988	27.035	27.188	26.949	27.139	27.315
2.5	35.242	35.354	35.612	35.179	35.497	35.793
3.0	46.003	46.210	46.619	45.905	46.408	46.878
3.5	60.044	60.391	61.019	59.897	60.666	61.388
4.0	78.365	78.918	79.860	78.148	79.299	80.384
4.5	102.271	103.121	104.508	101.955	103.646	105.255
5.0	133.458	134.735	136.752	133.003	135.461	137.312

TABLE IV

Neutron Multiplication Constant k_{eff} from Contributed Solutions of the 2-D HTGR Benchmark Problem

Computer Program		GRIMHX		VENTURE	BUG180
		Coarse Mesh[1]	Standard		
Equivalent Number of Mesh Points Per Hexagon	1	1.11321	1.12725	1.12725	
	3	1.11735	1.12102		1.11672
	6	1.11863	1.12028	1.12027	
	12				1.11777
	24			1.11929	
	48				1.11823
	54			1.11900	

TABLE V

Total RX Power

	Relative Power	
Time, sec	TRIMHX	Adiab. Approx.
0.05	1.0000	1.0000
0.06	0.9856	0.9899
0.07	0.9596	0.9658
0.08	0.9281	0.9352
0.09	0.8952	0.9026
0.10	0.8630	0.8704
0.20	0.8096	0.8094
0.30	0.8036	0.8035
0.40	0.7953	0.7982
0.50	0.7905	0.7934
1.0	0.7704	0.7732
2.0	0.7407	0.7424
3.0	0.7161	0.7175
4.0	0.6945	0.6958
5.0	0.6753	0.6764

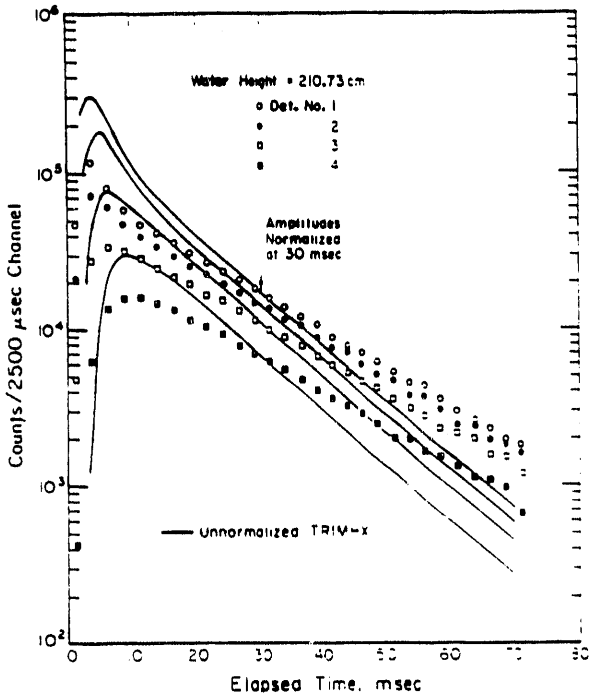


FIGURE 3 Measured and Calculated Prompt Neutron Responses in the Reflected Lattice at 210.73-cm Water Height - Unnormalized Diffusion Parameters

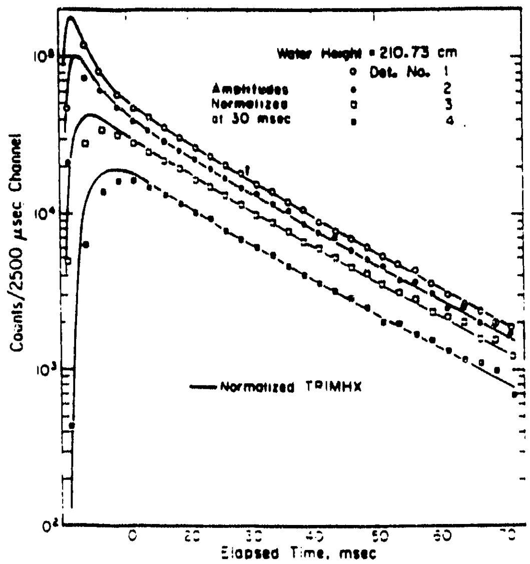


FIGURE 4 Measured and Calculated Prompt Neutron Responses in the Reflected Lattice at 210.73-cm Water Height - Normalized Diffusion Parameters

TABLE VI

Measured and Calculated Reactivities for the Reflected Lattice in the PDP

	Reactivity[a] by				
Water Height, cm	Normalized TRIMHX	Detector	Gozani	Garelis-Russell	Sjöstrand
241.50[b]	-0.00101[c]				
210.73	-0.01128	1	-0.00918	-0.00855	-0.01038
		2	-0.00952	-0.00939	-0.00995
		3	-0.01043	-0.01049	-0.00939
		4	-0.01157	-0.01068	-0.00914
174.71	-0.03139	[illegible]	-0.02278	-0.02269	-0.02805
		[illegible]	-0.02430	-0.02344	-0.02669
		3	-0.03122	-0.02967	-0.02971
		[illegible]	-0.03818	-0.03515	-0.02972
153.13	-0.05234	[illegible]	-0.03737	-0.03937	-0.04857
		[illegible]	-0.03854	-0.04193	-0.04553
		3	-0.04673	-0.04675	-0.04412
		[illegible]	-0.07129	-0.06628	-0.05427

a. Reactivity (ρ) = $ β_{eff} where β_{eff} = 0.0075762 or $(k_{eff} - 1)/k_{eff}$

b. Measured critical water height

c. Normalized GRIMHX

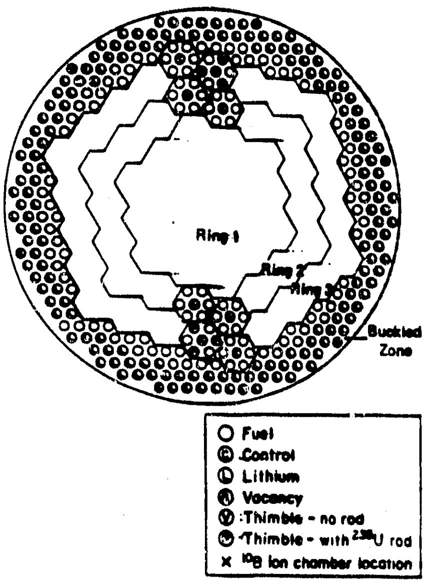


Fig. 5. Geometry for TRIMHX calculations of Experiment 1.

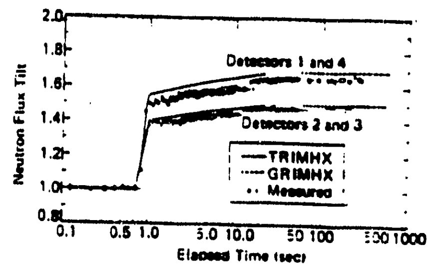


Fig. 7. Measured and calculated flux tilts from Experiment 1.

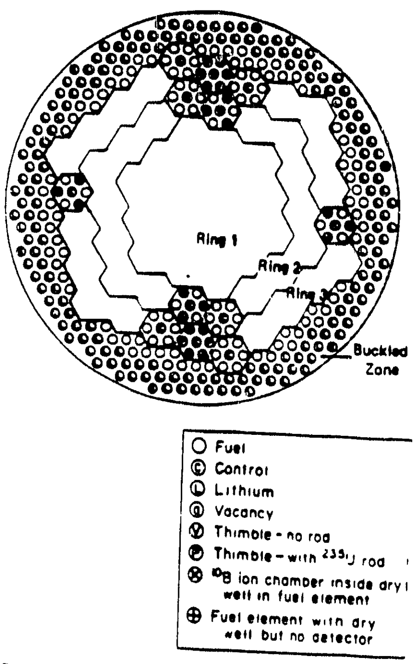


Fig. 6. Geometry for TRIMHX calculations of Experiment 2.

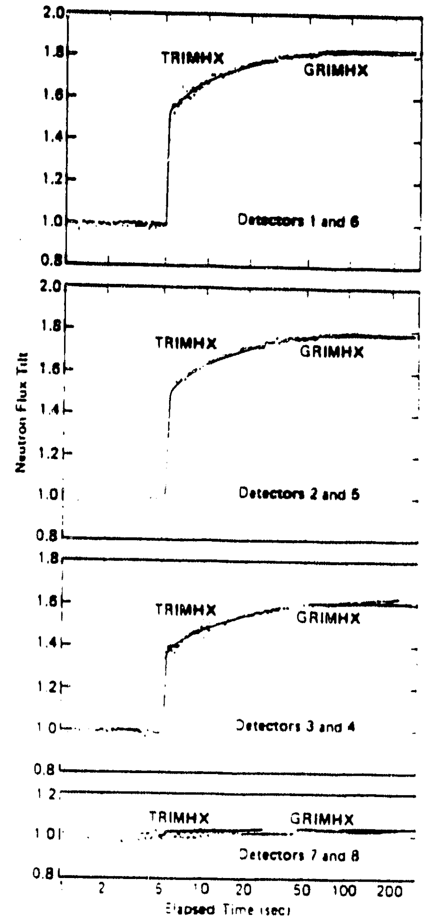


Fig. 8. Measured and calculated flux tilts from Experiment 2.

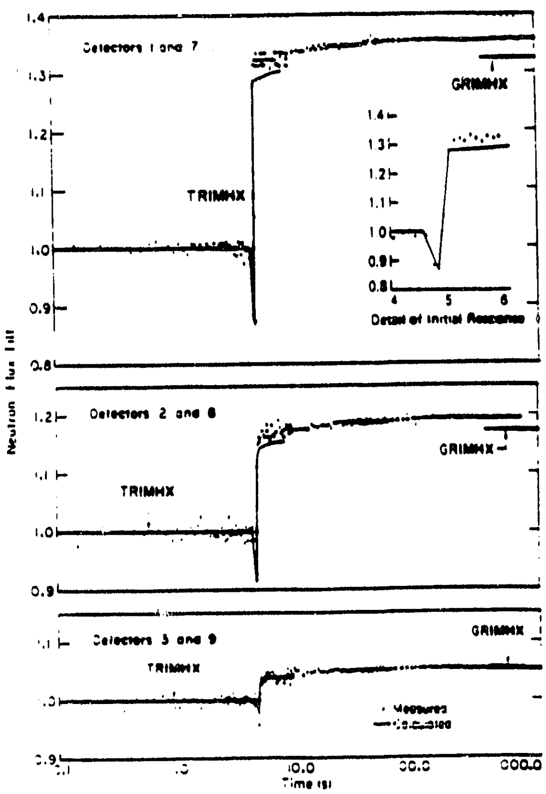


Fig. 9. Axial flux tilts of Experiment 1.

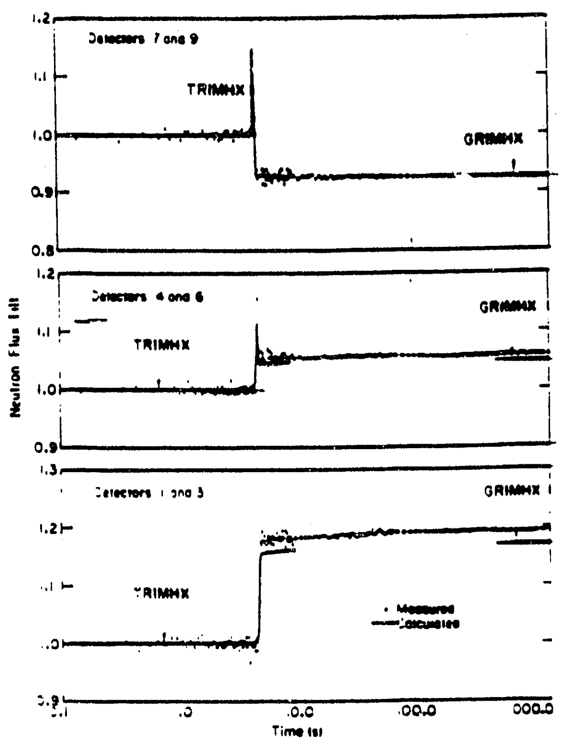


Fig. 10. Radial flux tilts of Experiment 1.

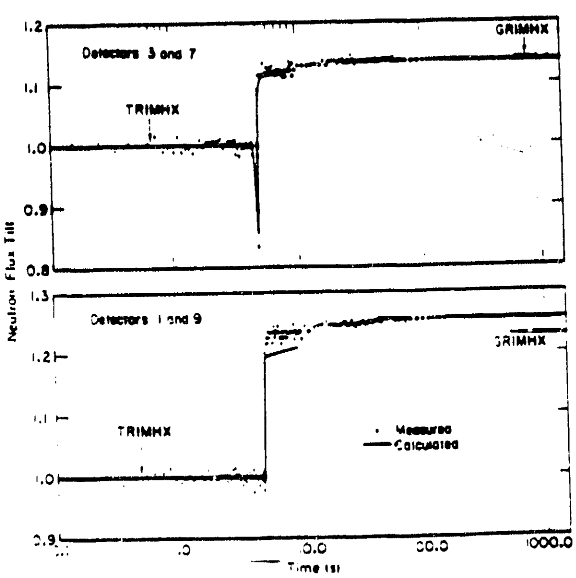


Fig. 11. Diagonal flux tilts of Experiment 1.

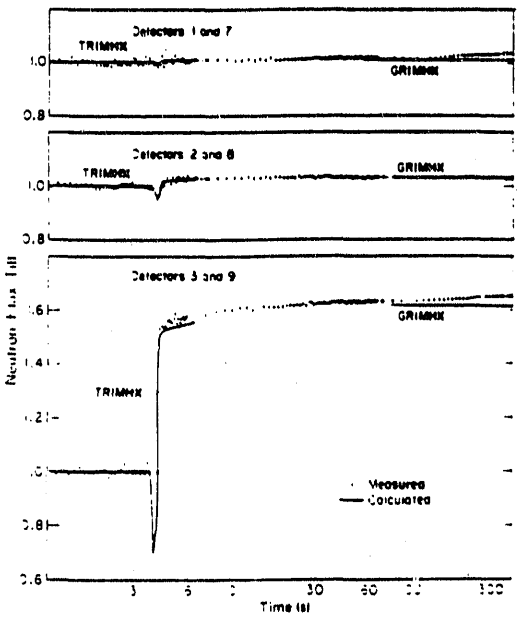


Fig. 12. Axial flux tilts of Experiment 2.

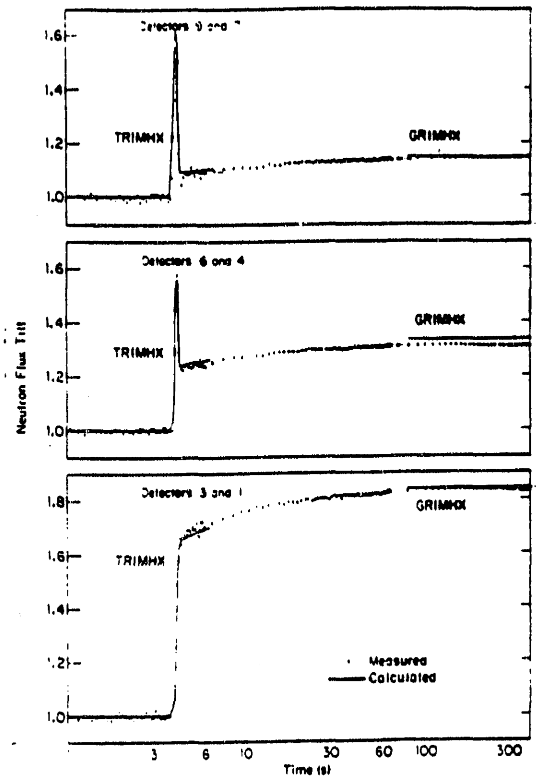


Fig. 13. Radial flux tilts of Experiment 2.

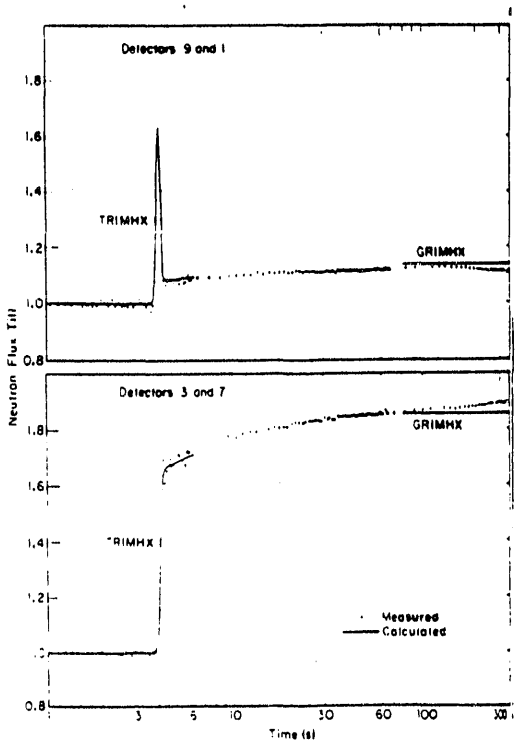


Fig. 14. Diagonal flux tilts of Experiment 2.

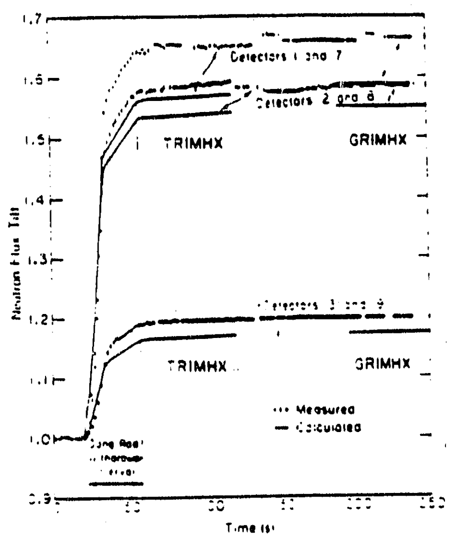


Fig. 15. Axial flux tilts of Experiment 3.

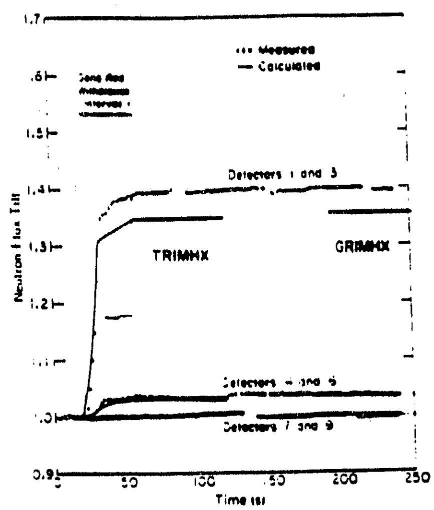


Fig. 16. Radial flux tilts of Experiment 3.

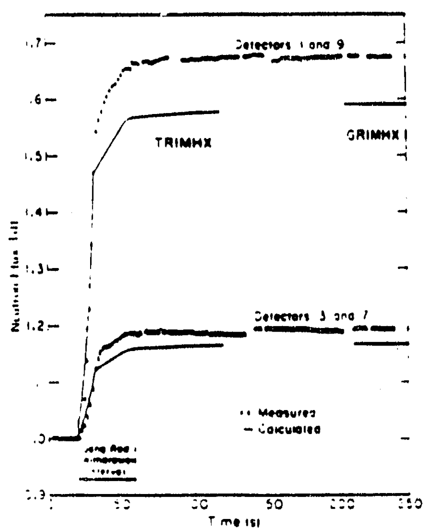


Fig. 17. Diagonal flux tilts of Experiment 3.

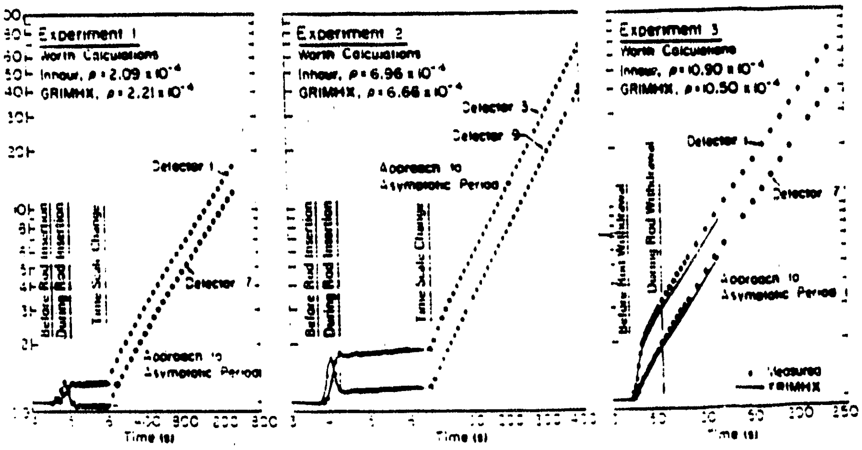


Fig. 18. Flux behavior at various detectors during the transient experiments.

TABLE VII. GRIMHX Benchmark results 1975/present

1975 GRIMHX Results

Pts/	Eigenvalue		Computational Requirements*	
hex	standard	coarse mesh	outer iter	CPU sec
1	1.12725	1.11321	17/26	5/8
3	1.12102	1.11735	18/20	6/7
6	1.12028	1.11863	26/24	10/10

*stand./c.mesh

1989 GRIMH2 Results

Pts/	Eigenvalue		Computational Requirements*	
hex	standard	coarse mesh	outer iter	CPU sec
1	1.12724	1.11320	18/44(26)	1.8/2.5(1.5)
3	1.12101	1.11734	27/31(20)	1.7/2.1(1.4)
6	1.12026	1.11862	28/42(24)	2.2/3.4(2.0)

*stand./c.mesh(prod.)

TABLE VIII.

Computed Flux Values - 1 Point per Hex, Coarse Mesh
(1975/1989)

Hex*	Group 1	Group 2	Group 3	Group 4
1	141.8/141.7	322.8/322.8	43.57/43.57	159.2/159.2
2	202.7/202.7	477.1/477.1	71.24/71.24	293.4/293.4
4	227.2/227.1	532.4/532.4	79.63/79.62	343.7/343.6
7	216.9/216.8	508.9/508.8	76.13/76.12	328.5/328.4
11	183.2/183.1	430.9/430.8	64.34/64.33	265.3/265.2
16	167.1/167.1	393.6/393.5	58.76/58.76	241.9/241.8
22	169.2/169.1	396.0/396.0	59.17/59.16	254.8/254.8
29	135.6/135.5	343.4/343.3	51.85/51.84	281.4/281.4
37	102.7/102.6	222.2/222.2	32.92/32.91	258.8/258.7
46	8.121/8.122	48.38/48.38	8.528/8.528	369.9/369.8
56	0.163/0.163	3.947/3.948	0.844/0.845	127.7/127.6

* hex locations identified in Appendix

TABLE IX.

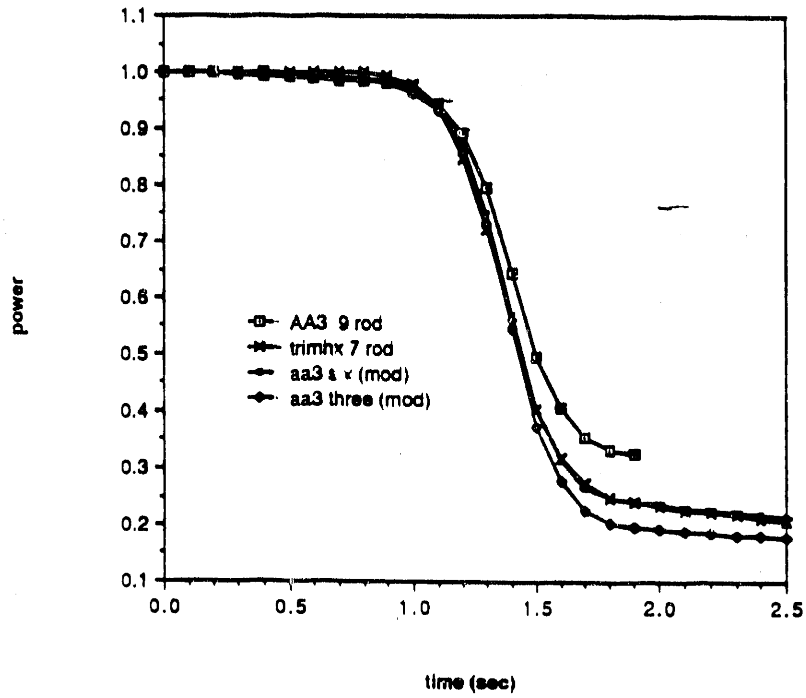
Results from TRIMHX/GRIMHX Benchmark
Keff and Timings

Code	Normalization	Keff	CPU time	# outers
GRIMHX	Power	1.11320	2.55 sec *	44 *
GRIMHX	Production	1.11320	1.59 sec	26
TRIMHX	Power	1.11320	1.74 sec	28
TRIMHX	Production	1.11320	1.78 sec	29

* with flux over-relaxation turned off; time = 1.77 sec, # outers = 30

Fig. 19.

TRIMHX vs AA3 power transients



Case	Rod Worth
AA3 9rod	BE-2s
AA3 six	BE
AA3 three	BE
Trimhx seven	BE-2s

END

DATE
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