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QUARTERLY TECHNICAL PROGRESS REPORT
LMFBR PHYSICS PROGRAMS
JANUARY - MARCH 1970

AEC Research and Development Report

Atomics International
North American Rockwell

P.O. Box 309
Canoga Park, California 91304

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QUARTERLY TECHNICAL PROGRESS REPORT

LMFBR PHYSICS PROGRAMS

JANUARY - MARCH 1970

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AI-AEC-12911

Atoms International
North American Rockwell

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Canoga Park, California 91304

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AI-AEC-12946

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Program: Civilian Power, LMFBR

AEC Task: 5-B, Reactor Physics, Fast-Reactor Physics Experiments

Project Manager: H. A. Morewitz

Reporting Period: January-March 1970

General Order: 7701

Subaccount: 14610

AEC Category: 04-01-61-02.2

Principal Investigators: T. H. Springer, R. J. Tuttle, L. A. Mountford

I. PROJECT OBJECTIVES

The objectives of this project are to (1) determine reactivity, temperature, and Doppler coefficients of various materials in a variety of fast-reactor spectra; (2) investigate effects due to different geometric arrangements of such materials, including the variation of the surface-to-mass ratio; (3) provide experimental results for checking theoretical predictions; and (4) develop improved experimental and theoretical methods for treatment of problems in the field of fast-reactor physics.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1970

The series of experiments dealing with the reactivity worth of tantalum over a very large range of surface-to-mass values was expanded to include not only solid cylinders from diameters of 1/8 to 1-3/4 in. but also clusters ranging from 3 to 18 rods, each 3/4 in. in diameter. The experiments carried out on clusters were conducted both with and without sodium around the rods. Preparations were also made to investigate annular-shaped Ta control rods. Overall a very extensive investigation is underway to evaluate full-size engineering mockups of typical FBR control-rod designs.

Analytical studies in support of the experiments were carried out during this reporting period to evaluate the adequacy of the various analytical models for calculating the worths of the somewhat complex geometrical control-rod shapes. Using ENDF/B cross-sections for Ta, the TRIX code for self-shielding factors and the MCL code for mean chord lengths, one is able to calculate by eigenvalue differences the worths of the various large Ta rods and clusters in a manner that is in reasonably good agreement with experiment. Discrepancies as large as 25%

Figure 1. Specific Reactivity of Tantalum Rod Clusters With and Without Sodium, Core 17

(the calculations predicting a more negative worth) were previously obtained using perturbation theory. It has been shown that many of the samples are sufficiently large that perturbation calculations apparently give incorrect results. A technique involving the calculation of the worth of several Ta samples using a measured neutron spectrum was used to evaluate the effects of differences in a calculated and experimentally determined central spectrum in Core 17 of the Epithermal Critical Experiments Lab (ECEL) reactor. A visual comparison of the fine structure of the measured and calculated spectra shows various discrepancies, but the calculated worth of Ta using the calculated spectrum does not vary by more than 0.2% from the same calculation using the measured spectrum.

A pin-type test zone that is a very close geometrical and physical simulation of a full-scale Fast Breeder Reactor core has been designed and fabricated. Studies in this core will reduce uncertainties in typical measured core parameters, uncertainties that may be inherent in the more common plate-type heterogeneous systems.

III. PROGRESS DURING REPORT PERIOD

Reactivity measurements with multipin clusters of tantalum were repeated after filling the space between pins with sodium. The 18-pin cluster thus formed a very realistic mockup of a segment of an LMFBR control rod. Comparison of these results with those obtained without Na showed that the Na had negligible effect on the worth of the Ta. These results are summarized in Table 1 and shown in Figure 1.

TABLE 1
REACTIVITY OF TANTALUM CLUSTERS

Number of Tantalum Pins	Mass (gm)	Specific Reactivity ($10^{-3}\$/\text{gm}$)	
		No Sodium	Sodium
1	483	-3.21 ± 0.21	-
3	1448	-3.17 ± 0.07	-
6	2896	-3.07 ± 0.03	-2.99 ± 0.03
12	5797	-2.85 ± 0.02	-2.85 ± 0.02
18	8692	-2.59 ± 0.01	-2.59 ± 0.01

Figure 2. Specific Worth of Tantalum vs $N\bar{\ell}$ in Core 17

To relate the multipin measurements to the single sample measurements that cover a much wider surface-to-mass range, a common parameter is required. Use of the atomic thickness, $N\bar{\ell}$, has proved successful. This parameter is the product of the atom density and the mean chord length through the sample. The mean chord length is easily calculated for simple shapes, but the multipin clusters are beyond the scope of direct calculation. For the multipin clusters, Monte Carlo-type programs are used. One of these (CCP) which is adaptable to any arrangement of material will also calculate escape probabilities if macroscopic cross-sections are entered. The specific reactivity of Ta is measured in the multipin clusters and the single samples are shown in Figure 2.

As has been discussed before, perturbation-theory calculations of tantalum reactivity agree well with the thin samples but become increasingly poor for thick samples, overpredicting the worth by about 25%. Preliminary eigenvalue-difference calculations give good agreement at the thickest samples. It appears that the flux depression due to the massive samples exceed that acceptable for simple perturbation-theory calculations. It is expected that perturbation calculations using the perturbed real and unperturbed adjoint fluxes will bridge the gap between the regions of applicability for perturbation theory and eigenvalue-differencing.

A cross-section library with Ta has been prepared for more detailed eigenvalue calculations.

Measurements of the flux spectrum with proton-recoil counters were combined with the calculated spectrum to calculate the reactivity of Ta with perturbation theory. The results showed negligible difference from results based only on the calculated spectrum, partly because of compensating changes in the spectrum.

Measurements in earlier ECEL cores had shown Eu_2O_3 to be a strong absorber. Since Ta was not included in those measurements, new Eu_2O_3 samples were made and measured in the present core for direct comparison with Ta. The infinitely dilute worth of Eu_2O_3 is 3.4 times that of Ta, on an equal mass basis. This makes possible a lighter-weight control rod with a reduced gamma-ray heating rate and a smaller load for the drive mechanisms. In addition, europium-capture products have greater worth than the capture products of tantalum, resulting in a longer rod life.

The reactivity worths of several small samples were measured in the void cavity provided for measurements with the multipin cluster. These results are listed in Table 2.

TABLE 2
SMALL-SAMPLE WORTHS

Sample	Mass (gm)	Specific Reactivity ($10^{-3}\beta/\text{gm}$)
PuO ₂	66.2	+12.36
Inconel-750	81.6	-0.443
Tantalum	163	-3.34
Hafnium	179	-2.73
Eu ₂ O ₃	6.0	-17.53
Eu ₂ O ₃	13.9	-17.33
B ¹⁰	5.7	-205.14
B ¹⁰	13.5	-187.22

Attempts that were made in the past to determine the reactivity worth of oxygen in various fast-reactor spectra have frequently resulted in spurious and inconsistent values that were dependent upon the sample being investigated. One source for this difficulty lay in the possibility that the samples being studied had absorbed some water vapor. To evaluate this situation several oxide samples (Pb, Mg, etc) were left exposed to air for several months after being initially baked out. Each sample showed small gains in weight, thus suggesting the possibility of water absorption. New hermetically sealed samples will be prepared for future measurements.

As part of the comprehensive review of Doppler-effect measurements for the LMFBR program, selected sets of experimental data taken in earlier ECEL cores have been re-analyzed. This was done to put all of the results provided to this review on an equal framework, because several improvements to the analysis programs have been made since the first measurements were done. Some minor adjustments in the results have been made.

The required scope of this review has been investigated to provide the best treatment to the most useful data. Thus measurements of the U^{238} Doppler effect will receive the major emphasis. As part of this investigation the usual expression for the variation of the Doppler effect with temperature has been reformulated. This was done to reduce the interaction between two of the three parameters determined in fitting a curve to the experimental data. The new formula now results in little interaction and has no discontinuities in the parameters.

Calculations of the Doppler effect of U^{238} in Core 17 show some disagreement as the total effective moderator scattering cross-section changes. The results of these calculations are compared with the experimental values in Table 3.

TABLE 3
DOPPLER EFFECT OF URANIUM-238 IN CORE 17

Sample	Mass U^{238} (gm)	$S + \sigma_{\text{pot.}}$ (barns)	$\Delta\rho$ (300 to 700°K) ($10^{-5} \text{ } \phi/\text{gm } U^{238}$)	
			Calculated	Experimental
U	184.4	30.7	-4.25	-4.50
UC	95.9	50.7	-4.05	-4.85
UO ₂ , 7-Pin Cluster	146.9	66.4	-3.80	-6.05

These calculations were compared with calculations for Core 14 and showed somewhat better agreement, but the cause of the present discrepancy remains obscure.

The systematic bias exhibited between calculated and measured central reactivity worths has been the subject of a continuing analysis. The average of the ratio of calculated to measured reactivities for 276 pairs of calculation and measurement is 1.16. The dispersion about the mean is 0.21 (20%). This average is based on measurements in 22 critical assemblies with B, Ta, U^{235} , U^{238} , Pu^{239} , and Pu^{240} . Further analysis, to determine the effect of using evaluated delayed-neutron fractions somewhat higher than Keepin's and to detect any trend in time, is continuing.

Figure 3. Uranium-235 Fission Rate in ECEL-17A

The fission rates of U^{235} and Pu^{239} as a function of position in Core 17 were measured. These measurements were made using solid-state detectors calibrated by means of alpha-particle counting. Traverses were made with the 18-pin tantalum cluster in place and with the cavity empty. Preliminary results, subject to revision for reactor power calibration and corrections for isotopic impurities, are shown in Figures 3 and 4. The calculated fission rates are for an unperturbed core with only a small central cavity. Calculations will be done for the actual core configuration.

The importance of fission neutrons as a function of position was measured in Cores 17 and 18, using a small Cf^{252} spontaneous fission source. The results were normalized by using the calculated neutron production rate in the reactor to equate the measured and calculated production of neutron importance. The normalized experimental points are compared with the calculations in Figures 5 and 6. In Figure 5 the calculated distribution for Cf^{252} neutrons, which have a slightly harder spectrum than U^{235} neutrons, is shown. It is clear that the calculated importance at the center exceeds the measured values by about 31%. Assuming the same discrepancy to hold for neutrons of all energies, this would lead to a discrepancy of 31% between calculated and measured central reactivity worths.

Tantalum foils were irradiated in the Ta control-rod cluster to determine the activation rate. Foils of the same cross-section area as a pin were placed between pin segments to obtain the volume-averaged activation, and small strips were wrapped around pins to obtain the surface activation. The saturated activity obtained from these measurements was 8.20×10^3 dps/gm/watt compared to the calculated infinitely dilute value of 22.39×10^3 . An autoradiograph made with one of these foils showed little depression within the pin, but a significant gradient across it. This suggests that the cluster acts more as an homogeneous medium than as an heterogeneous array.

Measurements of gamma-ray heating by use of Li^7F thermoluminescent dosimeters (TLD) were largely unsuccessful. The TLD used was in the form of powder, which was distributed across the cross-section of pin segments in the cluster. After activation the powder was read in a commercial TLD reader. Because the reader was not intended for use with powder an adapter was made

Figure 4. Plutonium-239 Fission Rate in ECEL-17A

Figure 5. Normalized Neutron Importance in Core 17

Figure 6. Normalized Neutron Importance in Core 18

to permit heating powder samples. Heat transfer to the powder was poor and satisfactory glow curves were not obtained. By comparison with samples irradiated by a Co^{60} source the dose in the Ta cluster was determined to be (12 ± 7) rad/hr/watt. To improve this measurement, thin rods of Li^7F and ultrathin discs of Li^7F in Teflon have been ordered. These dosimeters can be read in the reader without need for an adapter; satisfactory glow curves are expected.

The nuclear and mechanical design work for the cylindrical cores has been completed. Proposed technical specifications covering the new cores have been prepared, as have been the supporting document and the requested license amendment.

An extensive series of transient calculations has been made to determine the shutdown behavior of the cylindrical cores. These calculations used MARS, which provides for expansion and explosive shutdown. While some minor differences with the results predicted for the spherical cores in the 1960 preliminary safeguards report were observed, in general these predictions were in agreement with the current results. In particular the new calculations verified the low temperatures generated in the test region in an excursion. For a transient terminated by vaporization of driver fuel (the ultimate shutdown mechanism) the test region temperature increases by 88°C . For a transient terminated by fuse release and expansion the temperature of the driver reaches 500°C and the test region temperature rise is negligible.

A comprehensive listing of the material and hardware requirements for Core 20 has been prepared. Some of these items require a design decision while others require only fabrication or modification.

A prototype of the full-length fuse assembly for the cylindrical driver region has been assembled and tested satisfactorily.

All of the 2-by-2-in. fuel pieces required for Core 20 have been fabricated. The hexagonal fuel elements have been nearly completed: only brazing of the fuel tubes in place remains to be done. Techniques to be used in filling these elements with sodium were used in filling the calandria for the tantalum cluster. In that calandria 92% of the volume was filled with sodium. Most of the void fraction is at the top (filling end) of the can.

Conceptual designs have been prepared for miniature fission counters and a reactivity oscillator. These devices would allow measurements to be made within a fuel tube of a hexagonal fuel element, thus causing a minimal perturbation to the core.

IV. EVALUATION OF EFFORT

The analyses carried out during this reporting period on experiments dealing with the reactivity worths of tantalum have proven to be very useful in reducing the uncertainty in the calculated reactivity control associated with typical FBR control rods. It has been shown that a single calculational technique for predicting the worth of all of the various Ta samples is not adequate, but by using different techniques that are applicable to different surface-to-mass regions one is able to predict the experimental results to better than $\pm 10\%$. This improvement between the calculated and experimental values leads to increased confidence in the calculation of the degree of control afforded by control rods in a typical FBR. New investigations into other absorber materials such as Eu_2O_3 have indicated the possibility of developing more efficient control rods that have reduced mass and heating rates.

Attempts to measure the heating rates in Ta control rods have not been particularly successful using the TLD detector method. Although some of the difficulties are at present related to problems in reading small Li^7F powder samples, the method may not be capable of achieving good accuracy. However, a better evaluation of the capabilities of this technique will be made in the next quarterly period when Li^7F dispersed in Teflon will be tried as a detector.

V. NEXT REPORT PERIOD ACTIVITIES

Investigations of Eu_2O_3 as a control material will be continued with primary emphasis on the change in the specific worth as a function of the surface-to-mass ratio. New irradiations performed to establish the heating rate in Ta will be carried out with TLD detectors that consist of Li^7F dispersed in Teflon.

Assuming that the 15% enriched UO_2 is delivered by June 1, the existing core (Core 17) will be disassembled, the matrix system will be taken apart, and

the new hexagonal matrix system installed. Reloading to achieve a critical pin-type core will be begun.

The Doppler review and evaluation task as well as the code-testing effort will be continued. Calculation will also be started to predict the measured Eu_2O_3 worth determination and thus to establish the uncertainty in the applicability of the results to FBR control-rod systems.

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Program:	Reactor Physics		
AEC Task:	5-E, Theory and Computation for Reactor Analysis and Design		
Project Manager:	H. A. Morewitz		
Reporting Period:	January-March 1970		
General Order:	7701	Subaccount:	14320
		AEC Category:	04-01-61-02.1

Principal Scientists: L. B. Levitt, J. Spanier

I. PROJECT OBJECTIVES

The basic objective of this project is to advance the state-of-the-art of Monte Carlo applications to the analysis of fast reactors and fast-critical assemblies. This development is needed so that experimental programs as well as design studies may be optimized through the use of computer programs capable of describing complicated geometric configurations while calculating the effects of localized perturbations. These objectives will manifest themselves in the ultimate development of fast-reactor criticality codes and specialized codes to treat perturbations due to changes in temperature, density, and material composition. The objectives of this project are related to Tasks 9-3.3 and 9-4.5 outlined in WASH-1109, LMFBR Program Plan, Volume 9, Physics.

II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1970

The Monte Carlo fast-critical assembly code VIM-1 has been completely debugged and has satisfactorily passed every checkout test to which it has thus far been subjected, including several benchmark critical-assembly calculations.

III. PROGRESS DURING REPORT PERIOD

The cause of the previously reported high eigenvalues for JEZEBEL, GODIVA, ZPR-3-48, and ZPR-3-11 as calculated by VIM-1 has been found and corrected. The error was in the storage of the angular data, which inadvertently caused the elastic scattering to be isotropic at all energies. Corrected VIM-1 results calculated for the four assemblies are given in Table 1.

TABLE 1
CORRECTED VIM-1 RESULTS

Assembly	Number of Histories	Maxwellian Fission Temperature (Mev)	K _{eff}	Leakage	Computer Running Time, CDC 6600 (sec)
GODIVA	50,000	1.28	1.012 ± 0.004	0.5768	240
JEZEBEL	50,000	1.41	1.015 ± 0.004		184
ZPR-3-48 (Heterogeneous Mockup)	10,000	1.374	0.998 ± 0.009	0.0340	1110
ZPR-3-11 (Spherical Mockup)	19,600	1.28	1.010 ± 0.005	0.0417	775

Monitoring of spectral indices in a central region has been put into the spherical geometry version of VIM-1. Spectral indices calculated for JEZEBEL are:

$$\frac{\sigma_f(\text{U}^{238})}{\sigma_f(\text{U}^{235})} = 0.210 \pm 0.002 \text{ (experiment: } 0.205 \pm 0.008)$$

$$\frac{\sigma_f(\text{Pu}^{239})}{\sigma_f(\text{U}^{235})} = 1.392 \pm 0.004 \text{ (experiment: } 1.49 \pm 0.03)$$

The rate of convergence of these two fission ratios is shown in Figures 1 and 2 respectively where these ratios are plotted as a function of the number of neutron histories followed. Spectral indices calculated for GODIVA are:

$$\frac{\sigma_f(\text{U}^{238})}{\sigma_f(\text{U}^{235})} = 0.177 \pm 0.001 \text{ (experiment: } 0.156 \pm 0.005)$$

$$\frac{\sigma_f(\text{Pu}^{239})}{\sigma_f(\text{U}^{235})} = 1.370 \pm 0.003 \text{ (experiment: } 1.42 \pm 0.02)$$

Figure 1. Plot of Fission Ratio

Figure 2. Fission Ratio, Additional Plot

Figure 3. JEZEBEL Integrated-Flux Spectrum
(VIM, 50,000 histories)

It should be noted that these results are based on our preliminary VIM library which does not yet contain Category-II ENDF/B data.

In addition to the central fission ratios a group-flux monitoring package has been inserted into the spherical version of VIM-1. Integrated fluxes are computed by group for core and blanket using both analog and statistical estimation procedures. Preliminary 2000-history results for ZPR-3-11 (homogenized spherical mockup) show sufficient agreement with CAESAR (diffusion-theory) calculations to indicate that the new flux package is debugged. In addition the rate of convergence is surprisingly good for so short a run (2 min on CDC-6600). However, some significant spectral differences between VIM and CAESAR, especially in the blanket, have been observed and these could account for the larger U^{238} fission rate observed in VIM. A quantitative appraisal of these differences, however, must await results based on a longer computer run.

For Jezebel the integrated-flux spectrum appears well converged (see Figures 3 and 4) with the Group-4 (peak) flux converged to better than 1% and in good agreement with experiment.

Plans were made to convert VIM-1 to the IBM System 360 for use on North American Rockwell's Model 85 and ANL's Model 75 in Idaho where extensive use of VIM-1 is contemplated.

A new library tape was made for use on the Kirtland Air Force Base CDC-6600, along with a test case. The test case was run successfully under both the Chippewa system and SCOPE 3.2 at Kirtland.

Revisions to input and output portions of VIM were made to conform with the users'-manual portion of the VIM topical report. Draft of the revised VIM-1 topical containing newly obtained results and revised input/output information has been completed.

A statistics package has been put into VIM-1 and checked out.

An abstract titled "Monte Carlo Eigenvalue Calculations of Fast Critical Assemblies Using VIM-1" has been submitted to the June ANS meeting. The abstract outlines the main features of the VIM-1 Code and presents a summary of eigenvalue calculations made with VIM-1.

Figure 4. Group-4 Flux Spectrum (JEZEBEL, 50,000 histories)

A comprehensive review of recently published work on adjoint Monte Carlo methods has been started as part of the preparation for a state-of-the art review article on Monte Carlo methods. A review of recent work on Monte Carlo perturbation methods, synthesizing them with some new ideas of our own, has been begun, both for the review article and to form a basis for our own work on perturbation methods during FY 1970-1971.

IV. EVALUATION OF EFFORT TO DATE

The successful checkout of VIM-1 establishes that a nonmultigroup fast-critical assembly Monte Carlo code can now be used as a tool for analyzing fast-critical experiments and that benchmark calculations can now be done with standardized sets of heterogeneous input data. Even large critical assemblies such as ZPR-3-48 need not be run longer than 1 hr on the CDC-6600 to evaluate major reactor parameters such as k_{eff} , integrated group fluxes, and central fission ratios. We are now able to proceed to more difficult calculations of such quantities as control-rod worths, activation ratios, or void coefficients with the confidence that the basic-data handling, source generation, and collision procedures are correctly and efficiently doing the tasks for which they were designed.

AI will work with ANL Idaho in developing the use of VIM-1 as part of their experimental analysis procedure; this will provide necessary feedback from outside users to enable us to achieve our goal of maximum simplicity of input preparation as well as expert guidance in the choice of experiments involving reactivity perturbations to be studied in later versions of VIM.

V. NEXT REPORT PERIOD ACTIVITIES

Documentation of present results on selected benchmark fast-critical assembly calculations will be prepared. Work will continue on the state-of-the-art Monte Carlo review article. An IBM-360 version of VIM-1 will be prepared. "Naive" random-number correlation will be inserted into both versions. Work on programs to implement to new unresolved resonance-region treatment will proceed.

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Program:	General Reactor Physics		
AEC Task:	26-A, Cross-Section Analysis		
Project Manager:	II. A. Morewitz		
Reporting Period:	January-March 1970		
General Order:	7762	Subaccount:	13130
		AEC Category:	04-40-01-03.1

Principal Scientists: H. Alter, C. L. Dunford

I. PROJECT OBJECTIVES

The objectives of this project are to produce and maintain an up-to-date set of basic nuclear data, produce and evaluate multigroup constants, and improve present-day methods of neutronic calculations as related to microscopic and macroscopic nuclear data. To accomplish these objectives, existing experimental and theoretical information on nuclear data will be surveyed, analyzed, and compiled. Automated methods will be provided to periodically update compiled data, and nuclear model calculations will be developed and used to help fill gaps in the data. An automated system will be developed and maintained for the ready production of multigroup constants. Spectra-generating techniques for production of realistic multigroup constants will be developed and incorporated into the system. The data and methods produced are needed to improve reliability for calculating advanced reactor concepts. In particular the realization of these project objectives will be used in ensuring that the LMFBR design incorporates adequate margins for safety and economy. The accomplishment of the stated project objectives is related to successful implementation of the LMFBR Program Plan in the areas of acquisition of nuclear data (Task 9-1.2), and compilation and distribution of evaluated data (Subtask 9-1.2.2).

II. MAJOR ACCOMPLISHMENTS IN FISCAL YEAR 1970

A re-evaluation of neutron cross-section data for uranium-235 in the energy range $15 \text{ kev} \leq E \leq 15 \text{ Mev}$ was completed. These data were checked, found to be free of mechanical error, and forwarded to the National Neutron Cross-Section Center (NNCSC) at Brookhaven National Laboratory for placement on the revised ENDF/B data file.

The new compact version of the interactive computer graphics system SCORE, including programming for the automated fitting of Reich-Moore resonance parameter data, was completed. Requirements for this version are only 125 K-bytes of computer core memory.

III. PROGRESS DURING REPORT PERIOD

A. INTERACTIVE COMPUTER GRAPHICS

A revised resonance-region module for use in SCORE has been completed and tested. New features include selection from several resolution and Doppler functions and a choice of Breit-Wigner, Reich-Moore, or Adler resonance formulae. All resonance parameters, resolution, and Doppler functions are stored in a single direct-access data set. An auxiliary program (RAP) has been written to update and maintain this data set.

A graphic simulator for the IBM-2250 has been completed and found useful in testing graphic subroutines when a 2250 display console is unavailable. The basic philosophy behind this simulator is to provide a facsimile of the interaction by a user at the 2250 console through card input. In practice this method has proven to be somewhat awkward but very valuable since there is no ready accessibility to a computer with an attached display console.

A byproduct of the development of the simulator was a computer program that takes the response from the 2250 buffer and translates them to the response required to generate a hard-copy reproduction on a SC4020. This capability will be added to SCORE in the near future.

Several modifications have been made to the experimental data storage and retrieval system. To save disk-storage space the data points are now stored 55 to a block instead of 56. The SCORE display containing a list of the available nuclides from which the user selects his choice for retrieval has been modified so that the name of the nuclide currently residing in the direct-access data set is displayed in large characters.

Considerable flexibility has been added to the Legendre calculation option for angular data. After an evaluated curve has been determined for a set of angular data the user may input the order of fit desired (less than 25). The

coefficients are calculated and the reconstructed curve is displayed along with both the evaluated curve and the experimental data on the expand (12-by-12 in.) display. The numerical values of the coefficients are listed on the righthand side of the display.

A new data-listing option has been completed. The data currently being considered in SCORE may be listed on the 2250 at up to twenty points at a time. The list contains the point coordinates, references, and status of the data set, i.e. active, deleted, or the entire data set for a given reference had been deleted. The status can be changed from active to deleted or vice versa by a light pen selection. The list may be paged forward or backward by the light pen.

No further progress has been made on the interfacing of SCORE with SCISRS II. A data tape containing experimental data in the SCISRS II format has not yet been made available.

B. CROSS-SECTION ANALYSIS

Several industrial contractors and national laboratories participated in a special benchmark calculation, the purpose of which was to determine if a given critical-assembly configuration calculated by the participants using a single-reference multigroup library and given assembly specifications would yield results which were less divergent than those obtained when the several participants generated their own multigroup libraries. The benchmark critical assembly chosen was ZPR-3-48 and the participants were to use the ANISN transport-theory code for the calculation. Parameters to be calculated included the eigenvalue, k_{eff} , and the ratio of nuclide activity relative to $\nu\sigma_f^{235}$. Comparisons of the calculated k_{eff} 's are given in Table 1, and of selected activity ratios in Table 2. The Los Alamos (LASL) value was calculated using the transport-theory code DTF in place of ANISN and served as a control for the results calculated with ANISN. Though there was some slight scatter in the calculated results, this scatter is significantly less than that obtained when many different methods and computer codes were used to process the microscopic cross-section data, generate multigroup libraries, and evaluate critical assemblies. Results for the calculated activity ratios were similarly close, with meaningful

TABLE 1
COMPARISON OF k_{eff} FOR ANISN BENCHMARK
(ZPR-3-48) CALCULATION

Participant	k_{eff}
AI	0.9901
ANL	0.9901
ANL(ID)	0.9901
B&W	0.9901
BNL	0.9901
CE	0.9901
LASL	0.9903
LRL	0.9902
ORNL	0.9901
PNL	0.9902

TABLE 2
COMPARISON OF SELECTED ACTIVITY RATIOS FOR
ANISN BENCHMARK (ZPR-3-48) CALCULATION

Participant	Sodium (σ_a)	Iron (σ_a)	Molybdenum (σ_a)	Uranium-238		Plutonium-239	
				(σ_a)	($\nu\sigma_f$)	(σ_a)	($\nu\sigma_f$)
AI	3.7501	2.1545	4.1117	0.6883	3.8373	4.5530	1.1219
ANL	3.7502	↓	4.1117	↓	3.8373	↓	1.1220
ANL(ID)	↓	↓	4.1116	↓	3.8378	↓	1.1220
B&W	↓	↓	4.1118	↓	3.8374	↓	1.1219
BNL	↓	↓	↓	↓	↓	↓	1.1220
CE	↓	↓	↓	↓	↓	↓	1.1220
LRL	3.7501	↓	↓	↓	3.8370	4.5529	1.1219
ORNL	↓	↓	4.1117	↓	3.8373	4.5530	↓
PNL	↓	↓	4.1119	↓	3.8370	4.5530	↓
LASL*	3.751	2.153	4.109	↓	3.844	4.553	1.122

*DTF used in place of ANISN.

differences recognizable, as one might expect, in the LASL results. It appears, then, that with reasonable effort it is possible to factor out effects of code and computer differences in neutron cross-section evaluation.

Modification of the several data-processing codes used to analyze ENDF/B data tapes, necessary because of changes in their data formats, was completed. Graphical displays and data listings were obtained for ENDF/B tapes 991, 992, and 997. Both the CRT's and listings of data were used to carry out a somewhat hurried Phase-I data review. Numerous errors in the data were found, documented appropriately, and forwarded to the NNCSC at BNL for corrective action. At the request of NNCSC several thousand CRT plots were also sent to aid in the Phase-I data review.

A review of the SCISRS I files for data relating to the ongoing evaluation of the tantalum isotopes was completed. The results of this review are summarized in the following paragraphs.

Experimental data covering the neutron-energy range of interest are available primarily for the total and radiative capture reactions only.

A large number of measurements have been made since the time of the last ENDF/B evaluation (1965). A spot check of the new SCISRS data for the $Ta^{181}(n,2n)$ reaction above 12 Mev compared to the 1965 evaluation reveals that the latter, which was based mostly on theory, was 50% high.

A review of tantalum-referenced data on the CCDN file (European Data Center) showed that several of the more recent data sets are not yet available through SCISRS.

Experimental data reported in other bibliographic references, i. e. CINDA, reveal that results of many measurements have not as yet been incorporated in the SCISRS I files.

Since the review of the SCISRS files was not wholly satisfactory, a more extensive review of the literature was undertaken. Among results to date of this review is the fact that some 8000 data points for the total cross-section of tantalum covering the energy range 1 ev to 50 kev are available from Columbia University. These data have not been previously available and represent a significant contribution to the evaluation of the tantalum isotopes; additional measured data can be obtained by interacting directly with the data measurers.

Use of the interactive graphics program SCORE is being investigated for aiding in evaluation of the tantalum isotopes.

Modification of the compound nucleus theory program to include an internally consistent calculation of Moldauer's "Q" value has been completed and tested. An algebraic interpretive subroutine has been completed which will allow the user to specify an algebraic expression as input to a program and permit the program to evaluate the expression. In this manner energy-dependence of optical model parameters can be described by the program user at execution time without having to modify the program. A report documenting the completion of a unified model of compound nucleus reactions was drafted.

The NCSAC Subcommittee on Fast-Neutron Reaction Cross-Sections and Thresholds met at Atomic International to discuss subcommittee and individual responsibility for the review of requests for measurements of reaction cross-sections. It was agreed that this subcommittee would review the pertinent portions of the U. S. Request Compilation for the purpose of supplying status comments and to propose modifications to be considered by the requestor if the request appears to be partially filled or if it needs to be clarified. As a result of this review the subcommittee will prepare a recommendation for specific measurements to be carried out over the next five years to best meet the high-priority needs of the U. S. Applied Nuclear Energy Program. It is the further responsibility of this committee to make specific recommendations if additional facilities, equipment, or manpower are considered necessary.

IV. EVALUATION OF EFFORT TO DATE

Analysis of fast-neutron cross-section data of interest to the LMFBR program has in the past been hampered by lack of a unified calculational model. The recently completed unified model of compound nucleus reactions will now permit consistent calculation of compound nucleus reactions of interest of cross-section evaluators. The remaining direct-reaction cross-sections may be calculated by an optical model code which also provides the necessary input compound nucleus formation probabilities for the reaction cross-section calculations. The results are useful for understanding the behavior of fast-neutron cross-sections and as an aid to the production of evaluated data in regions where no experimental data exist.

Because of the lack of ready accessibility to an IBM-2250 graphics console, a graphics simulator program has been created. This program, which provides for simulating the interaction of a 2250 console by means of card input, permits rapid checkout and testing of graphics software. The simulator has helped further the interactive graphics tasks.

An analysis of the results obtained for the ANISN ZPR-3-48 benchmark critical calculation illustrates that with reasonable effort it is possible to factor-out effects of computer code and computer hardware differences in Phase-II cross-section data testing. These results will be very helpful when we begin to correlate the calculations made by CSEWG participants for the fast benchmark critical assemblies.

V. NEXT REPORT PERIOD ACTIVITIES

Interfacing of SCORE with the Adler data-fitting program CODIII will continue. Attempts to obtain the necessary SCISRS II data tape to permit SCORE interfacing will be resumed. Phase-II data testing of the assigned fast benchmark criticals will proceed within the limitation of receiving corrected VERSION II ENDF/B data. The evaluation of the tantalum and tungsten isotopes will continue, with a cooperative effort with ORNL for including the gamma-ray production cross-sections.