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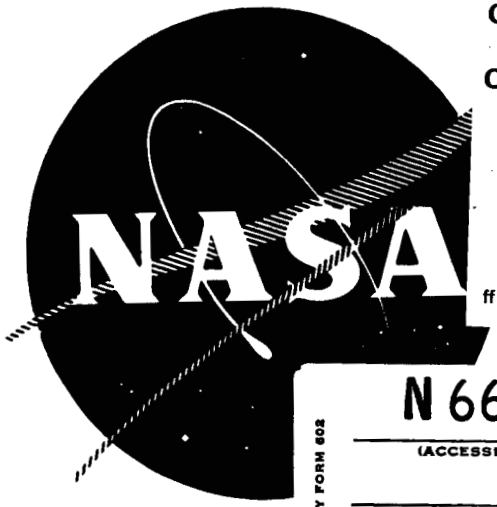

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TUNGSTEN RESONANCE INTEGRALS AND DOPPLER COEFFICIENTS

FIRST QUARTERLY REPORT

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LEWIS RESEARCH CENTER

Under Contract No. NAS3- 7982

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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TUNGSTEN RESONANCE INTEGRALS AND DOPPLER COEFFICIENTS

FIRST QUARTERLY PROGRESS REPORT

(July–September 1965)

By

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I. PROJECT OBJECTIVES

The objective of this project is to carry out an integrated experimental and analytical study of resonance integrals and Doppler coefficients of various samples of natural tungsten, separated tungsten isotopes, and UO_2-tungsten fuel.

Measurements of resonance integrals and Doppler coefficients are made in the 10.6-in. lattice of the Sodium Graphite Reactor Critical Assembly (SGR-CA), in which the flux spectrum in the resonance region is approximately 1/E. Both reactivity and activation methods are used; the reactivity oscillator is calibrated with the known resonance integral of gold, and in addition, the resonance integral of W^{186} will be measured over a limited temperature range by the activation technique.

Resonance integrals and Doppler coefficients for each sample are being calculated with TRIX-1, a fast-running resonance-integral code; a modified revision of ZUT-TUZ, a slower but slightly more accurate resonance-integral code, will be used as a check and to investigate some possible problem areas.

II. SUMMARY AND EVALUATION

Nuclear data required for calculations of resonance integrals, Doppler coefficients and sample reactivities have been compiled and evaluated. Effective resonance integrals have been calculated for two sample sizes with varying isotopic compositions. Real and adjoint fluxes for the SGR-CA lattice being used have been calculated. Reactivity worths have been calculated for an axial void and for samples of tungsten, U^{238}, and carbon.

Axial flux and source traverses have been made in the central void in the SGR-CA, the expected cosine shapes being obtained. Reactivity measurements under cadmium have been made on a number of samples, including natural tungsten, gold, lead, depleted uranium, aluminum, stainless steel, and lavite. The results indicate that a sensitivity of better than 0.01 cents is obtained for a single reactivity measurement taking 100 sec. This sensitivity is adequate for the resonance-integral measurements, and can readily be improved as required for Doppler measurements by taking data over a longer period of time. Calculated reactivities are consistently higher than those measured; however, the ratios of various calculated worths agree reasonably well with the corresponding ratios of experimental worths. The use of real and adjoint fluxes calculated with the cadmium sleeve taken into account should improve agreement with experiment.

These results also indicate that reactivity effects associated with scattering and structural materials are negligible. Measurements with and without cadmium end caps have demonstrated that end effects are quite small.

Taken together, all measurements and calculations thus far indicate that the method proposed for measuring resonance integrals and Doppler coefficients of tungsten samples is capable of getting good results. No major problem areas have arisen thus far, and work is proceeding on schedule. The activation measurements are governed principally by the schedule for the AEC-sponsored Advanced Doppler project, and will get under way shortly.

III. PROGRESS DURING REPORT PERIOD

A. THEORY

Initial resonance-parameter libraries for tungsten were constructed for use in the TRIX code.[1] These libraries were based on resonance parameters tabulated by the BNL Sigma Center together with other available data.

Later in the report period, preliminary resonance parameters derived from data from the RPI-Oak Ridge experiments[3] on separated tungsten isotopes became available, and TRIX libraries based on these parameters were constructed for W^{182}, W^{184}, and W^{186}. These are presented in Table 1, together with the previous library for W^{183}.

Effective resonance integrals for two typical sample sizes of natural tungsten were calculated with TRIX using both libraries. Effective resonance integrals were also calculated for isotopically pure samples for the larger (0.438-in.-diameter) sample. These results are given in Table 2.

A new 15-group analysis of the SGR-CA was completed. Thermal-group constants were obtained from a previous THERMOS analysis by Fillmore.[4] The library value of the thermal absorption cross section for graphite was adjusted to the value measured by DeJuren and Stewart[5] for the particular AGOT graphite in the SGR-CA. The value of ν for U^{238} was adjusted to mock up the transport-theory correction to fast fission in a lattice.[6] Group cross sections for U^{235} and U^{238} in the resonance region were calculated with TRIX.

The 15-group analysis was done with CAESAR,[7] a multigroup diffusion-theory code. Quantities calculated included neutron lifetime (1.277 msec), β_{eff} (0.007016), and real and adjoint fluxes for use in perturbation calculations. The calculated real and adjoint spectra at the sample position are plotted in Figure 1.

The critical loading resulting from this analysis is 18.4 fuel elements, which agrees well with the experimental value of 19.4 elements. (Although the standard loading in this lattice is 21 elements, each of the three outer elements is only partially loaded with fuel.)

Real and adjoint fluxes from this calculation, together with groupwise effective cross sections for tungsten calculated by TRIX from the previously mentioned library based on BNL Sigma Center data, were used to compute total

TABLE 1

RESONANCE PARAMETERS FOR TUNGSTEN ISOTOPES
(Sheet 1 of 2)

Isotope	Resonance Number	Energy (ev)	Γ_n (ev)	Γ_γ (ev)	g
W^{182}	1	4.17	0.00148	0.055	1
$\overline{\Gamma}_{no} = 0.0171$ ev$^{1/2}$	2	21.1	0.0401	0.055	1
$\overline{\Gamma}_\gamma = 0.055$ ev	3	114.7	0.290	0.055	1
$\overline{D} = 60$ ev	4	214	0.003	0.055	1
Spin = 0	5	250	1.1	0.055	1
$\sigma_{pot} = 5.0$ b	6	282	0.0029	0.055	1
	7	343	0.006	0.055	1
	8	378	0.13	0.055	1
	9	430	0.28	0.055	1
	10	486	0.5	0.055	1
	11	580	0.3	0.055	1
	12	658	0.16	0.055	1
	13	762	0.069	0.055	1
	14	922	0.4	0.055	1
	15	951	2.2	0.055	1
	16	1010	0.49	0.055	1
	17	1100	1.6	0.055	1
	18	1170	0.48	0.055	1
W^{183}	1	7.68	0.00174	0.075	3/4
$\overline{\Gamma}_{no} = 0.006$ ev$^{1/2}$	2	27.1	0.0433	0.075	3/4
$\overline{\Gamma}_\gamma = 0.075$ ev	3	40.6	0.0017	0.075	3/4
$\overline{D} = 150$ ev	4	46.1	0.154	0.075	3/4
Spin = 1/2	5	47.8	0.115	0.075	1/4
$\sigma_{pot} = 5.0$ b	6	66.0	0.0016	0.075	3/4
	7	100.8	0.10	0.075	3/4
	8	103.8	0.012	0.075	1/4
	9	137.9	0.04	0.075	3/4
	10	144.2	0.10	0.075	1/4
	11	154.8	0.40	0.075	1/4
	12	157.1	0.067	0.075	3/4
	13	173.7	0.13	0.075	3/4
	14	192.1	0.033	0.075	3/4
	15	235.5	0.022	0.075	1/4
	16	240.4	0.014	0.075	3/4
	17	243.4	0.019	0.075	3/4
	18	259.0	0.066	0.075	3/4
	19	280.2	0.30	0.075	3/4
	20	297.6	0.044	0.075	3/4
	21	323.4	0.20	0.075	3/4
	22	337.2	0.035	0.075	3/4
	23	348.3	0.17	0.075	3/4
	24	361.4	0.039	0.075	3/4
	25	391.6	0.043	0.075	3/4
	26	418.7	0.057	0.075	3/4

TABLE 1

RESONANCE PARAMETERS FOR TUNGSTEN ISOTOPES
(Sheet 2 of 2)

Isotope	Resonance Number	Energy (ev)	Γ_n (ev)	Γ_γ (ev)	g
W^{184}	1	102.1	0.0041	0.055	1
$\overline{\Gamma}_{no} = 0.0285$ ev$^{1/2}$	2	184.7	1.2	0.055	1
$\overline{\Gamma}_\gamma = 0.055$ ev	3	244.0	0.0023	0.055	1
$\overline{D} = 100$ ev	4	311	0.075	0.055	1
Spin = 0	5	424	0.040	0.055	1
$\sigma_{pot} = 5.0$ b	6	684	0.68	0.055	1
	7	787	0.06	0.055	1
	8	802	1.6	0.055	1
	9	961	1.6	0.055	1
	10	1000	0.14	0.055	1
	11	1090	3.4	0.055	1
	12	1140	0.34	0.055	1
	13	1270	1.2	0.055	1
	14	1410	2.7	0.055	1
	15	1430	0.25	0.055	1
	16	1520	1.3	0.055	1
	17	1800	1.1	0.055	1
W^{186}	1	18.83	0.318	0.055	1
$\overline{\Gamma}_{no} = 0.01785$ ev$^{1/2}$	2	171.5	0.027	0.055	1
$\overline{\Gamma}_\gamma = 0.055$ ev	3	197.6	0.0004	0.055	1
$\overline{D} = 95$ ev	4	218	0.53	0.055	1
Spin = 0	5	288	0.026	0.055	1
$\sigma_{pot} = 5.0$ b	6	407	0.075	0.055	1
	7	512	0.056	0.055	1
	8	543	0.50	0.055	1
	9	666	0.75	0.055	1
	10	732	2.2	0.055	1
	11	835	0.017	0.055	1
	12	968	1.1	0.055	1
	13	1080	0.65	0.055	1
	14	1130	0.45	0.055	1
	15	1190	0.77	0.055	1
	16	1420	0.25	0.055	1
	17	1510	1.2	0.055	1
	18	1800	0.10	0.055	1
	19	1940	0.55	0.055	1
	20	2040	0.40	0.055	1
	21	2120	0.11	0.055	1

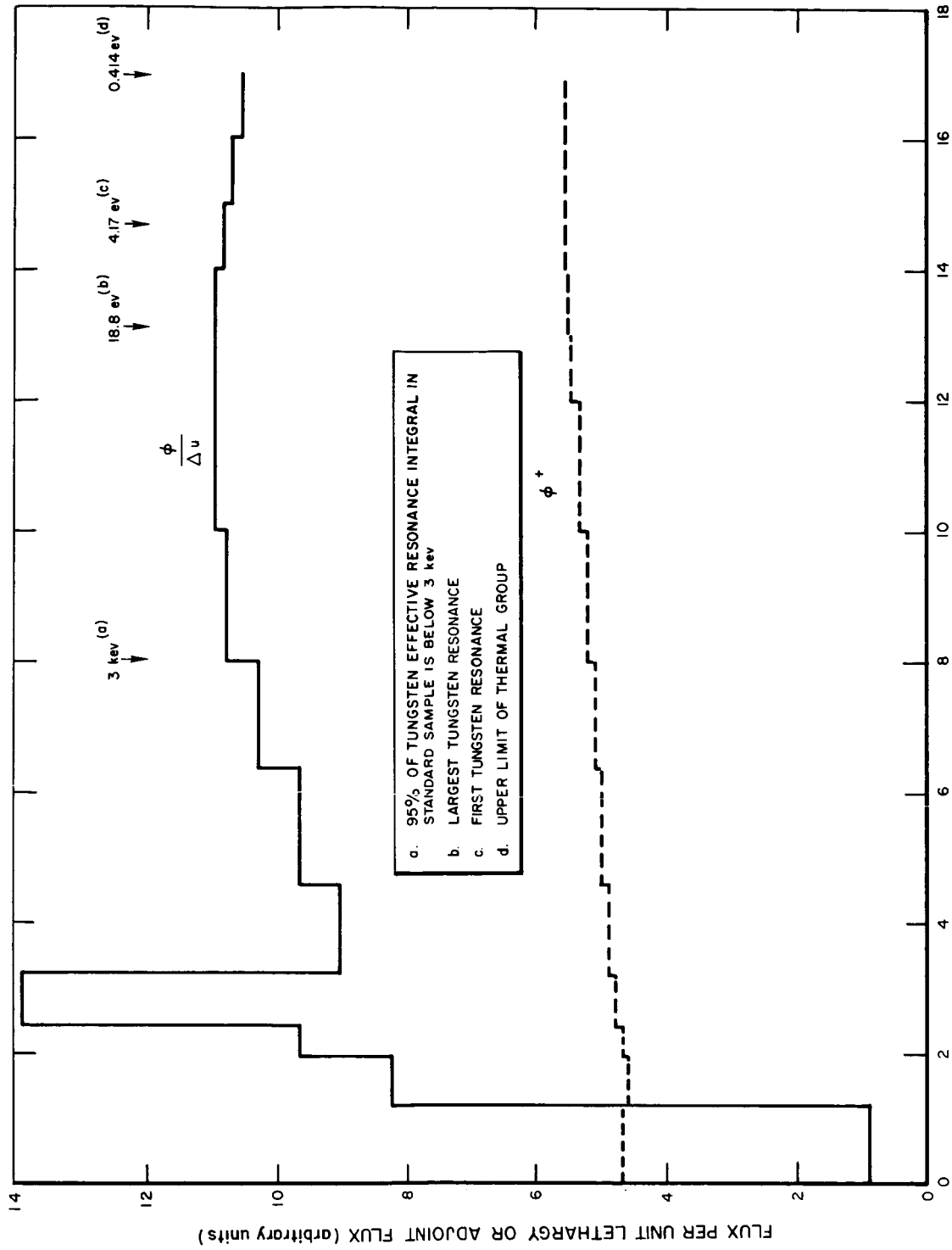

Figure 1. Calculated Spectra at Sample Position Without Cadmium

TABLE 2

CALCULATED EFFECTIVE RESONANCE INTEGRALS FOR TWO SAMPLE SIZES

Isotope	I_{eff} (b) at 20°C (excluding 1/v part)		
	0.438 in.* Pure Isotope†	0.438 in.* Natural†	0.25 in.* Natural†
W^{182}	21.9	40.0 (39.3)§	51.5 (50.7)
W^{183}	25.4	59.4	74.5
W^{184}	2.84	3.79 (3.95)	4.34 (4.58)
W^{186}	21.0	37.3 (36.8)	49.2 (48.5)

*Sample diameter
†Sample composition
§Values in parentheses were calculated with library based on RPI-Oak Ridge data.

and epithermal worths and Doppler reactivity coefficients for the two natural-tungsten samples and for four hypothetical 0.438-in.-diameter samples, each assumed to consist of a pure isotope of tungsten. These results are presented in Table 3 together with some experimental results (see Section III-B).

TABLE 3

REACTIVITY EFFECTS OF TUNGSTEN SAMPLES

Diameter (in.) (All samples 4.0 in. long)	Isotope	Total Worth (cents)		Epithermal Worth (cents)		Doppler Coefficient (10^{-4} cents/°C)
		Calculated	Experimental	Calculated	Experimental	
0.438	182	-21		-4.1		-0.92
0.438	183	-17		-4.0		-3.2
0.438	184	-4.0		-0.39		-0.30
0.438	186	-31		-5.1		-0.55
0.438	Natural	-25	-20	-5.0	-2.0	
0.25	Natural			-1.9	-0.81	

A number of corrections are needed before comparisons between calculation and experiment can be very meaningful. The most important of these are the effect of cadmium on the near-thermal real and adjoint flux spectra and on the lower energy limit of the 1/v part of the effective resonance integral. The calculated ratio of the epithermal worths of the two natural-tungsten samples, 0.38, agrees reasonably well with the measured ratio, 0.40.

Several additional results of interest appear in Table 4.

TABLE 4
MISCELLANEOUS REACTIVITY EFFECTS

Sample Description	Reactivity (cents)	
	Calculated	Experimental
U^{238}, standard size* (0.22% U^{235})		
Total worth	-5.8	-3.0
Epithermal worth	-1.35	-0.77
Inelastic-scattering worth	-0.0085	—
Carbon, standard size, inelastic scattering only	-0.016	—
Axial void, 2 in. diameter by 96 in. high	-4.0	-5.0

*Standard size = 0.438 in. diameter by 4.0 in. long

B. EXPERIMENT

1. Assembly Description

All measurements are being made in the Sodium Graphite Reactor Critical Assembly (SGR-CA) with fuel elements on a triangular 10.6-in. lattice spacing. The assembly consists of a vertical, two-layer array of hexagonal graphite logs, some of which have central holes in which fuel elements are placed. Plan, sectional, and perspective views are presented in Figures 2 through 4.

Graphite logs are 4 ft high and 4 in. across the flats. Individual logs can be removed from the core by pushing up from below with a jack extending through holes in the bottom plates supporting the logs. A fuel element consists of eight

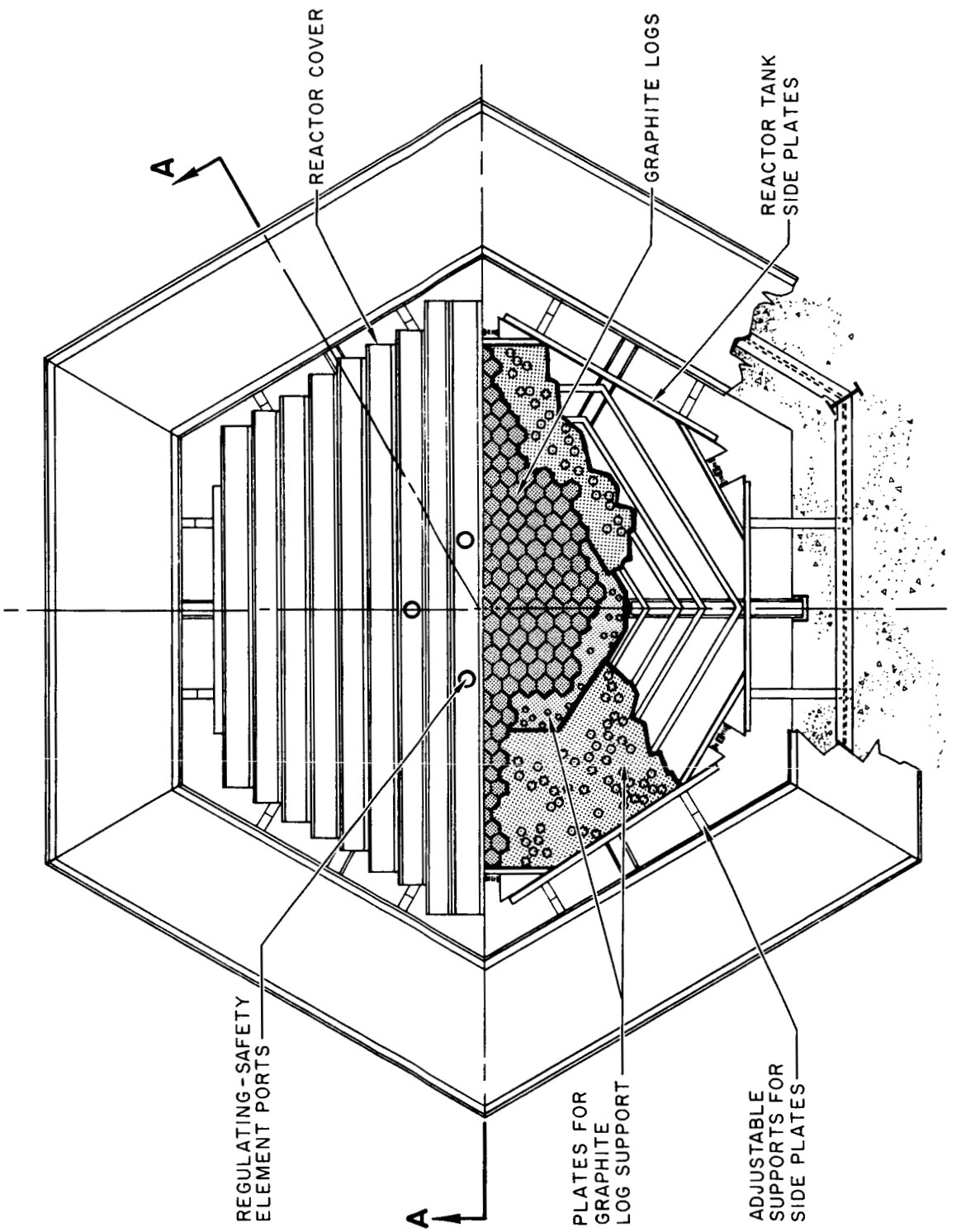

Figure 2. Plan View of SGR Critical Assembly

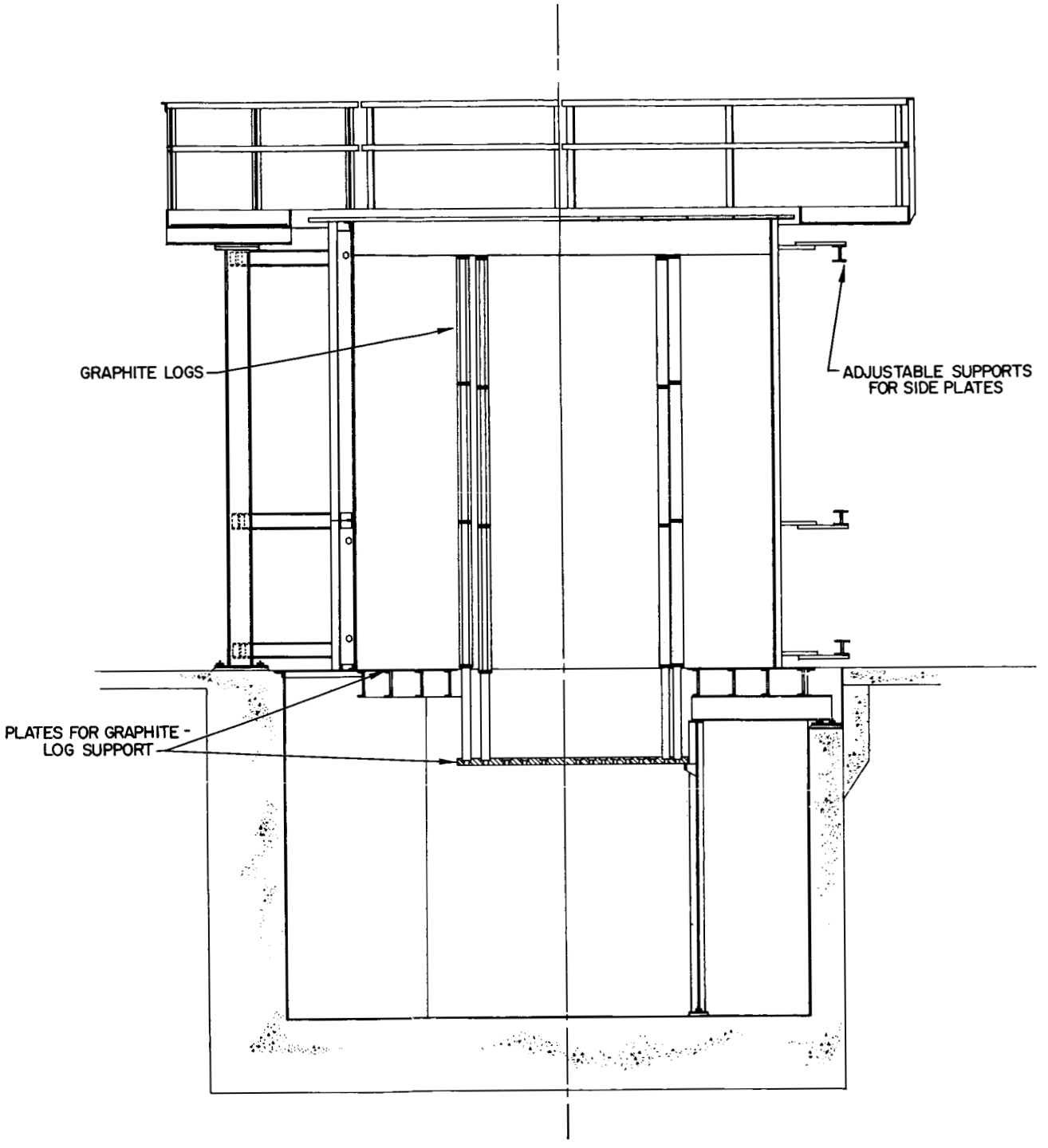

Figure 3. Sectional View of SGR Critical Assembly

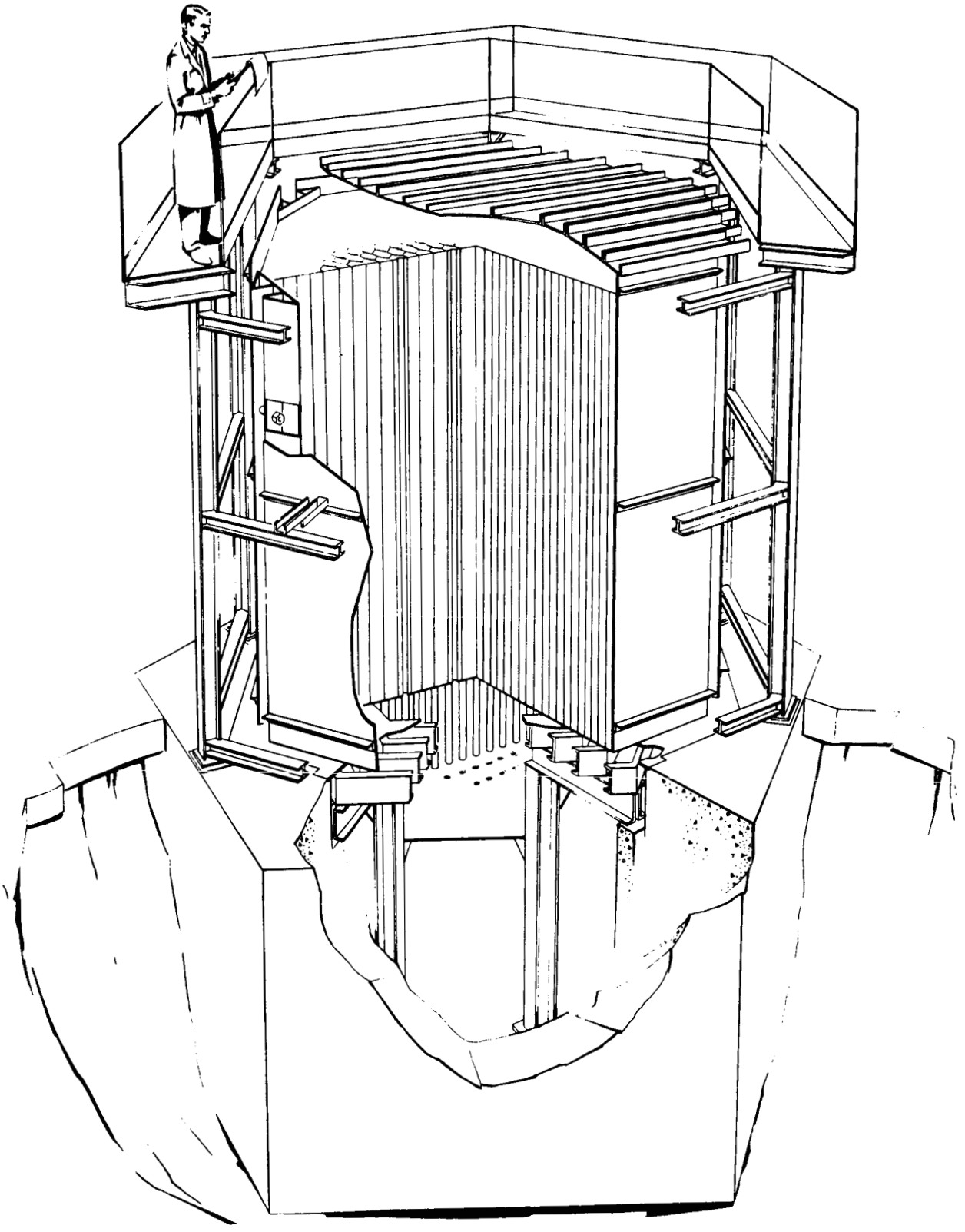

Figure 4. Perspective View of SGR Critical Assembly

1-ft-long hollow cylinders of uranium metal (1.96 wt% U^{235}) stacked in an aluminum tube, 1.875 in. OD and 1.795 in. ID. Control rods are Y-shaped pieces of silver-cadmium alloy, 0.032 in. thick. A more detailed description of the SGR-CA has appeared in a previous report.[8]

In the lattice used in both these measurements and the parallel AEC-sponsored Advanced Doppler Coefficients project, the central fuel element has been replaced by a hollow graphite log. Previous calculations[9] indicate that the closest approach to a 1/E spectrum in the SGR-CA is obtained in the 10.6-in. spacing with a central graphite region. The seven center logs can be raised and lowered as a unit with a pneumatic elevator to facilitate experimental changes or adjustments.

The standard lattice configuration for these measurements is shown in Figure 5. The core is 8 ft high, axially unreflected, and slightly over 4 ft in diameter with a radial reflector nearly 4 ft thick. For criticality without cadmium in the central hole, 18 fully loaded (8 slugs per element) and 3 partially loaded elements are required; the latter are the three outermost elements (see Figure 5), loaded with 3 ft of graphite and two slugs of fuel per element at the axial center. Under these conditions, the six central rods are fully withdrawn, control being maintained with the partially inserted seventh rod at the inner edge of the reflector. Control-rod perturbations on the spectrum at the center are thus negligible.

2. Activation Measurements

Measurements of both the resonance integral and the Doppler effect by the activation technique are planned for W^{186}, the only tungsten isotope suitable for this technique. A sample will consist of a 0.438-in.-diameter thin foil of natural tungsten sandwiched between the ends of two 0.438-in.-diameter by 2.0-in.-long natural-tungsten rods. Fabrication of 0.001-in.-thick foils has been attempted, but they have proved difficult to machine to the correct diameter; it may become necessary to use thicker foils.

3. Reactivity Measurements

A number of preliminary measurements have been performed in the SGR-CA at room temperature. Axial traverses in the 2-in.-diameter central axial void were made with fission counter and an Sb-Be neutron source to verify the expected cosine shape for real or adjoint flux. The fission-counter data were fitted quite well (rms deviation less than 0.2%) by a cosine. If the source traverse is made

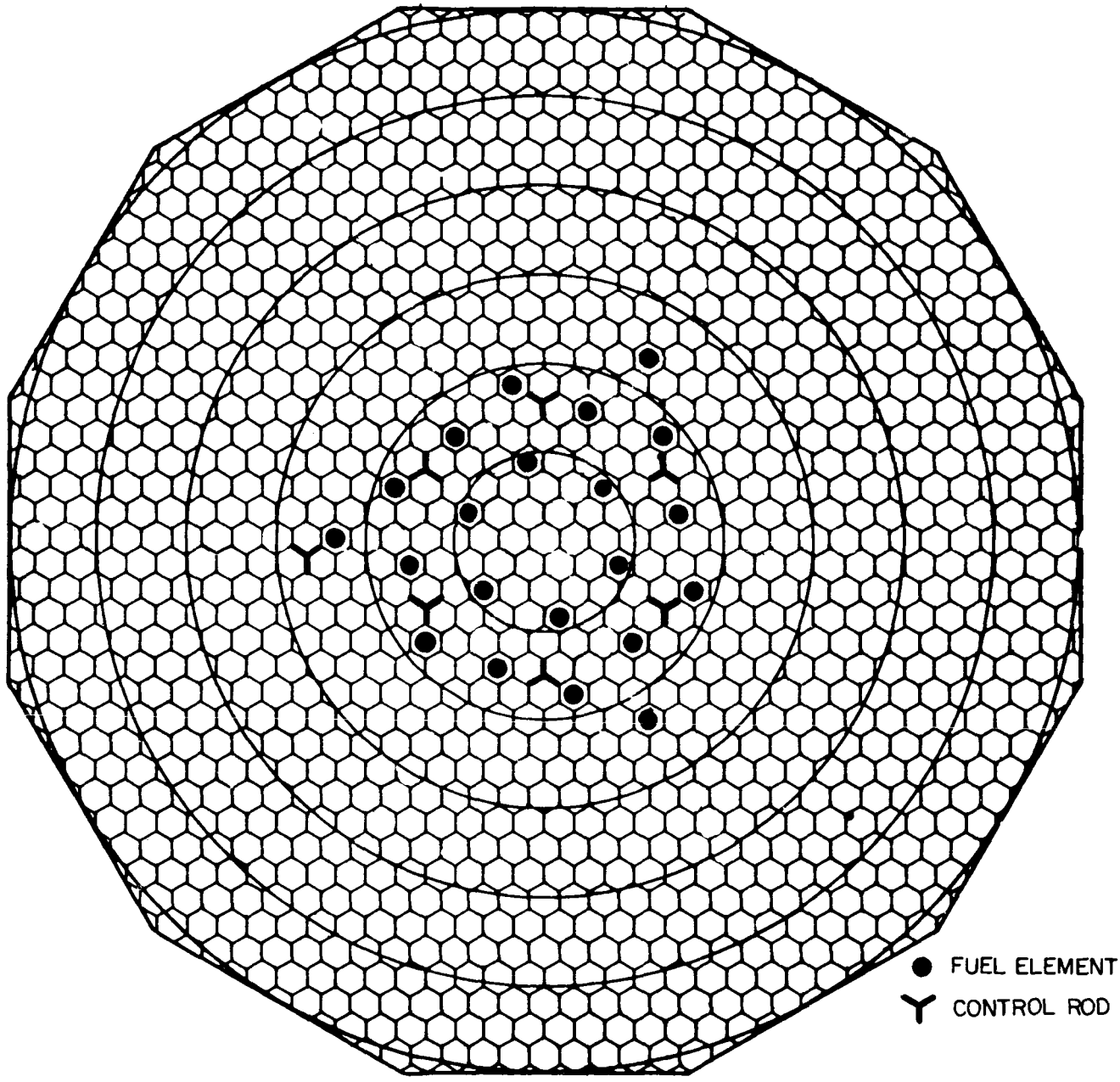

Figure 5. SGR-CA Critical Core Loading for 10.6-in. Lattice Space

at two different power levels, the source importance can be separated out from the resulting reactivity data.[10] Within the rather large scatter of the experimental points, the source-importance data were also fitted with a cosine (rms deviation about 5%). The maximum variation in the product of flux and adjoint over the length of a 4-in. sample is 0.4% with the parameters determined from these fits.

Reactivity measurements in the SGR-CA have been made with the aid of an oscillator that alternately inserts and withdraws the sample. The oscillator, assembled and tested during this report period, consists of an operator-controlled reversible motor driving a cable-and-drum unit, with the cable attached to a 13-ft aluminum tube, 1.25 in. OD. The centers of the sample and dummy locations are 54 in. apart, each being 27 in. from the center of the oscillator tube. A mechanical stop at each end of the stroke positions either sample or dummy at the core center in a precise, reproducible way.

The procedure for making a reactivity measurement is as follows. With the oscillator tube at the top of its travel, so that the empty sample position ("dummy") is at the center of the core and the sample is above the core, the reactor is made just critical. The tube is then driven all the way in; in this position, the sample is at the center and the dummy is below the core. This position is maintained for about 40 to 100 sec; then the tube is returned to its original position for an equal length of time to remeasure the base-point reactivity. The neutron level of the assembly is measured with an ionization chamber whose current feeds a voltage-to-frequency converter connected to a 400-channel time analyzer.

From the analyzer output, which is in the form of counts per channel (a typical channel width is 1 sec), the reactivity is determined by means of a power-history or "reactivity-vs-time" technique discussed in detail by Carpenter.[10] In this technique, the neutron kinetic equations are integrated numerically at each analyzer time step to determine the reactivity from the known power history.

The only reactivities of interest in measurements with this ossillator are the reactivities with the dummy in and with the sample in; subtracting one from the other gives the reactivity associated with the sample alone. In the case of the elevated-temperature measurements, the "sample" consists of a tungsten slug in a heated oven and the "dummy" consists of a similar slug (it need not be identical) in an unheated

oven. Here the reactivity of interest is the difference between the reactivity with the sample at elevated temperature and that with the sample at room temperature.

The main source of error in this technique is the random fluctuations of the neutron population of the reactor, as sampled by the detector; therefore, the precision of a given measurement is inversely proportional to the square root of the product of power level and measurement time. In the SGR-CA operating at full power, the result of a measurement lasting 100 sec has a standard deviation of better than 0.01 cents.

Reactivity measurements (under cadmium) were made on samples of natural tungsten, gold, lead, depleted uranium, aluminum, stainless steel, and lavite. The resonance integral of tungsten will be calibrated in terms of that of gold. Lead has a very high ratio of scattering to absorption, and serves to check possible scattering effects on reactivity. Depleted uranium is another material with a well-known resonance integral. Aluminum, steel, and lavite are all structural materials. Results of these measurements are presented in Table 5.

TABLE 5

MEASURED SAMPLE REACTIVITIES UNDER CADMIUM

Material	Sample Dimensions (in.)	Weight (g)	Reactivity (cents)
Natural Tungsten	Standard*	188.456	-1.97 (-20.15 bare)
Natural Tungsten	Standard	182.466	-1.95 (-19.86 bare)
Natural Tungsten	0.25 diameter	61.582	-0.84
Gold	0.235 diameter by 3.69 long	49.872	-1.18
Gold	0.030 diameter	0.8757	-0.054
Lead	Standard	110.587	-0.005
Aluminum	Standard	28.725	-0.004
Depleted Uranium	Standard	184.7559	-0.77
Stainless Steel	Standard	77.854	-0.18
Lavite	Standard	23.290	-0.04

*Standard sample dimensions: 0.438 in. diameter by 4.0 in. long.

These measurements were made with a 0.030-in.-wall cadmium sleeve, 1.33 in. OD by 6 in. long, at the center of the core. Two cadmium end caps, 1.15 in. diameter by 0.030 in. thick, were at each end of the sample in the oscillator tube. These were worth only -0.25 cents; furthermore, measurements of the two standard tungsten samples without end caps yielded the same answer, within error, as with end caps. These facts indicate that end effects with the 6-in. cadmium sleeve are quite small.

The small values of reactivity measured for lead and aluminum indicate negligible scattering effect on reactivity.

C. RELATED PROJECTS (AEC-sponsored Doppler projects)

1. Advanced Doppler Coefficients

Some possible causes of the discrepancy between experimental results and TRIX-1 calculations for the effective resonance in gold for very thick samples (low S/M values) have been investigated. The discrepancy cannot be explained by uncertainties in resonance parameters or reasonable experimental errors. Analysis of both resonance-integral and Doppler data over a wide range in S/M allows separation of the contributions of some of the resonances, because the maximum contribution of a particular resonance to the resonance integral occurs at a different S/M value from that for the maximum Doppler contribution. The most probable source of difficulty in the theory appears to be the validity of the narrow-resonance approximation for moderator collisions for broad resonances such as the lowest gold resonance.

A new Doppler capsule for simultaneous exposures of up to 14 foils has been constructed. Such an arrangement can evaluate the entire resonance integral curve in gold at a given temperature in a single exposure.

The spatial and spectral dependence of the flux near the sample is being investigated with detector foils of dysprosium (for 1/v absorptions), indium (1.3 ev), gold (4.9 ev), tungsten (18.8 ev), and cobalt (132 ev). There measurements and their analysis are not yet complete.

2. Fast-Spectrum Doppler Measurements

Measurements of reactivity and temperature coefficients are continuing in Core 13, with a 30-vol %-carbon test region and a calculated median fission

energy of 62 kev. Temperature coefficients of several nonfissile materials were measured in the standard core and in polyethylene blankets. These materials were tungsten, tantalum, U^{238}, $U^{238}O_2$, thorium, and thorium oxide.

A calculated thermal-expansion correction has been applied to the tungsten measurements; the resulting Doppler coefficients (20 to 800°C) are -2.9×10^{-5} ¢/°C in the standard core and -1.1×10^{-4} ¢/°C in the 1/2-in. polyethylene blanket.

A mockup of the high-temperature oven, identical with the proposed design except for the use of lavite as insulating material, has operated at 1470°K for 90 minutes, but failed after 12 minutes at 1520°K. Extrapolation of results obtained during these tests indicates that the power required to operate the oven at 2000 and 2300°K would be of the order of 300 and 550 watts respectively. Insulating materials capable of withstanding higher temperatures have been ordered.

IV. ACTIVITIES DURING NEXT REPORT PERIOD

A complete set of 15-group calculations will be carried out for the SGR-CA with the central cadmium sleeve present. From the resulting real and adjoint fluxes, the effect of cadmium-induced spectral distortion on sample worths can be computed. An effective cutoff energy will be calculated for the central cadmium sleeve.

Sample and dummy ovens will be installed in the oscillator tube and initial reactivity measurements on heated samples will be made. Measurements will be made on gold samples over a wide range in S/M, to calibrate the oscillator for resonance-integral measurements.

Initial activation measurements will be carried out on W^{186}. Flux maps with resonance detectors will be completed and analyzed.

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