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FAST BREEDER BLANKET FACILITY
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MASTER

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ABSTRACT

This progress report summarizes the work performed using Purdue University's Fast Breeder Blanket Facility during the months January-March, 1979. Progress on the development and testing of experimental methods and techniques is reported. Preliminary experimental results for the Th-232 neutron capture experiment are reported and compared with the reaction rates calculated using the computer code 2DB. Preliminary gamma heating measurements in lead, as a function of radial position, are also presented. The effect of neutron interaction in the TLD dosimeters on the gamma heating measurements is also discussed.

REFERENCES

TASK B
(R.C. Borg and K.O. Ott) 1

TASK C
(R.M. Clikeman 2

I. INTRODUCTION 2

II. DEVELOPMENT OF EXPERIMENTAL EQUIPMENT AND TECHNIQUES 2

II.A. Foil Activation Measurements
(G.A. Harms, F.M. Clikeman
and R.H. Johnson 2

II.B. Proton-Recoil Proportional Counter
Measurements
(D.W. Vehar and F.M. Clikeman) 4

II.B.1. Neutron Spectrum Measurements 4

II.B.2. Neutron Spectrum Unfolding
(R.H. Johnson and D.W. Vehar) 6

II.C. Fission Rate Measurements Using Solid State
Track Recorder (SSTR) Techniques
(H.P. Chou, R.H. Johnson and F.M. Clikeman) 13

III. RESULTS OF EXPERIMENTAL MEASUREMENTS USING
THE FBBF FACILITY 15

III.A. Neutron Capture Reaction Measurements
(G.A. Harms and F.M. Clikeman) 15

III.B. Gamma-ray Heating Measurements
(K.R. Koch, R.H. Johnson and F.M. Clikeman) 17

REFERENCES

LIST OF FIGURES

Figure 1: Block diagram of electronics used for two-parameter measurements 7

Figure 2: Block diagram of electronics used for single-parameter measurements 8

Figure 3: Block diagram of electronics used to determine system timing performance under operating conditions with two-parameter measurements 9

Figure 4: Block diagram of pulse shape analyzer 10

Figure 5: Calculated and measured neutron energy spectrum at location A-6 11

Figure 6: Preliminary ^{232}Th capture rates in sector D. The dashed line indicates the result of the 2DB calculation. The error bars indicate the experimental data and account for only the counting statistics at one standard deviation. A gamma-ray yield of 36 gammas per 100 Pa-233 decays was used to determine the absolute Th-232 capture rate 16

Figure 7: Gamma-ray spectral weighted f-factors for CaF_2:Dy in Stainless steel and lead 18

Figure 8: Calculated gamma-ray energy spectra in the blanket of the initial FBBF loading 19

Figure 9: Gamma-ray heating rates in lead with no correction for neutron response as a function of radial position. The error bars shown for the experimental data are statistical errors at one standard deviation. The systematic errors which are not shown are estimated to be $\pm$ 6% 21

LIST OF TABLES

Table 1: Detectors and detector operating conditions 5

TASK B
(R.C. Borg and K.O. Ott)

Preliminary measurements of the neutron activation rates in several materials in the FBBF facility have shown disagreements with the results calculated using the computer code 2DB. The disagreement between the measured and calculated values extend from the interface between the transformer and blanket throughout the whole blanket to the interface between the blanket reflector interface. One possible cause for the disagreement between the calculated and measured values is thought to be the method in which the computer code 2DB handles the neutron sources. In order to check on the validity of the 2DB code for calculating the neutron spectra and reaction rates in the FBBF facility, a Monte Carlo calculation using the VIM code is being made. VIM is a continuous energy Monte Carlo code designed primarily for fast reactor criticality calculations. It features a versatile geometry capability and a detailed representation of the neutron physics. Two features not available in the production version of VIM were developed and used in the FBBF calculations. An external source option was available but code modifications were necessary to describe the FBBF sources more accurately. Also an option to follow the neutron chain life is being used which allows the neutron distribution to be calculated more accurately; the normal procedure only follows the first generation of neutrons. These calculations are expected to be completed during the next progress period.

TASK C
(F.M. Clikeman)

I. INTRODUCTION

The objectives of this task are: (1) the testing of experimental equipment and development of techniques for making experimental measurements in the blanket regions of the FBBF facility; (2) performing the check-out tests and preparing the operating procedure required for licensing and the safe operation of the FBBF facility; (3) performing measurements in the first blanket configuration of the FBBF. The progress of each of these tasks are summarized in the following subsections.

II. DEVELOPMENT OF EXPERIMENTAL EQUIPMENT AND TECHNIQUES

The testing and development of techniques used for neutron spectroscopy, integral neutron capture rates, fission rates and gamma dosimetry measurements continued during the quarter. Improvements were made in the computer codes used to determine the neutron spectrum from the proton-recoil distributions. Preliminary results of the measurement of the Th-232 neutron capture rate, neutron spectra and gamma heating rates are reported in the following sections.

II.A. Foil Activation Measurements
(G.A. Harms, F.M. Clikeman and R.H. Johnson)

In the determination of the absolute disintegration rate of neutron-irradiated samples using the Ge(Li) detector, the number of photons per decay of the radioisotope must be known. The sources of the yield factors are many and varied, with sometimes the values given

by the different researchers disagreeing by more than an order of magnitude. In many cases the error assigned to the gamma-ray yield is quite large and is the largest contributor to the uncertainty of the absolute disintegration rate measurement. Thus, although relative measurements made between foils irradiated in different parts of the FBBF blanket can be made quite accurately, the accuracy of the absolute determination of the activities and, therefore, the neutron reaction rates, will be limited by the accuracy with which the gamma-ray yield factors are known. In obtaining the absolute decay rates reported to date, the latest reported values for the gamma-ray yields of the photopeaks of interest were taken from Nuclear Data Sheets.[1] However, the values reported in Nuclear Data Sheets are compilations of the values reported by many experimenters, and only evaluated periodically. A time lag exists between the publication of new experimental results and the appearance of the evaluated results. The second major source of uncertainty in the determination of the absolute disintegration rates comes from the determination of the detection efficency of the Ge(Li) detector. Although the detector efficiency has been determined using reference sources acquired from the National Bureau of Standards, a certain amount of experimental uncertainty is still present in the efficiency calibrations, especially in the region between 150 and 300 keV. A number of gamma rays of interest in our work, especially those in the decay of Np-239 (produced by neutron capture in U-238) and from Pa-233 (produced by neutron capture by Th-232) lie in this region. Neptunium-239 is also produced by the alpha decay of Am-243 and Pa-233 is produced by the alpha decay of

Np-237. Calibrated sources, determined by the alpha activity of Am-243 and Np-237, are being fabricated by Dr. Roland Armani at the Argonne National Laboratory and will be used for the calibration of the detectors for the absolute determination of the neutron capture rate in U-233 and Th-232. Direct comparison of the activities produced by neutron capture in U-238 and Th-232 with these calibrated sources is expected to reduce the uncertainty of the measured absolute activities to about 1%.

II.B. Proton-Recoil Proportional Counter Measurements (D.W. Vehar and F.M. Clikeman)

II.B.1. Neutron Spectrum Measurements

Several changes have been made to the proton-recoil counting system described in previous progress reports. Three detectors are currently being used to obtain measurements over the full range of interest, rather than two. It was found that both the 8-atmosphere hydrogen and the 10-atmosphere methane detectors were being used to the limits of their capabilities in the region of overlap between the two detectors, and that improvements could be obtained by the use of an intermediate energy detector. Table 1 lists the detectors now being used, along with operating conditions for the detectors.

Two-parameter analysis is used for measurements with the H-8 and H-10 detectors, while single-parameter analysis is used with the M-10 detector. A "pulser tag" circuit has been added to allow for system dead time corrections with the single-parameter system. Pulser counts are stored in the recorded distribution below the pulse height dis-

TABLE 1

Detectors and detector operating conditions

Detector	Fill Gas Pressures (Atm)	Mode	Voltage	Energy Range (keV)
H-8	8.0 - H_2	Two-Parameter	4900	0.740 - 2.65
	0.2 - CH_4		4600	1.95 - 7.96
	0.002 - ^3He		4300	5.60 - 25.0
			4000	16.8 - 75.1
			3700	52.8 - 226.0
H-10	10.0 - H_2	Two-Parameter	5100	85.7 - 383.0
	2.0 - N_2			
	0.36 - CH_4			
M-10	10.0 - CH_4	Single-Parameter	5300	294.0 - 1260
	2.0 - N_2		4800	621.0 - 2660

criminator setting, so that an accurate number of pulser counts can be determined without interference between pulser and recoil proton pulses. The pulser tag circuit also allows the performance of the two-parameter timing system to be checked under operating conditions by recording only pulser counts in the presence of detector count rate. Any distortion of the distribution due to high count rates can thus be found. Figures 1-3 show block diagrams for the various systems. Also shown (Fig. 4) is a block diagram of the pulse-shape analyzer used in the previous three systems.

The PSNS-N data analysis codes have also been changed to permit the use of three detectors. Previous versions allowed only two detectors to be used. The changes involved rewriting of the data input section and only minor restructuring of actual program operation.

Figure 5 shows the neutron energy spectrum obtained for location A-6 at the FBBF centerline, with a calculated spectrum also shown. Corrections have been made for variations in W and for finite range effects in the detectors. Error bars shown represent statistical errors at the one-sigma level. The shapes of the two spectra match fairly well, with the experimental results showing only a very slightly harder spectrum. There is, however, about 20% difference in absolute magnitude. Reasons for this difference are currently being investigated.

II.B.2. Neutron Spectrum Unfolding
(R.H. Johnson and D.W. Vehar)

Versions of the PSNS-N data reduction codes[2] were previously adapted for use on the PDP-11/04 computer.[3] The last code module, PSNS-5, has been rewritten to incorporate an improved method of numerical differentiation.

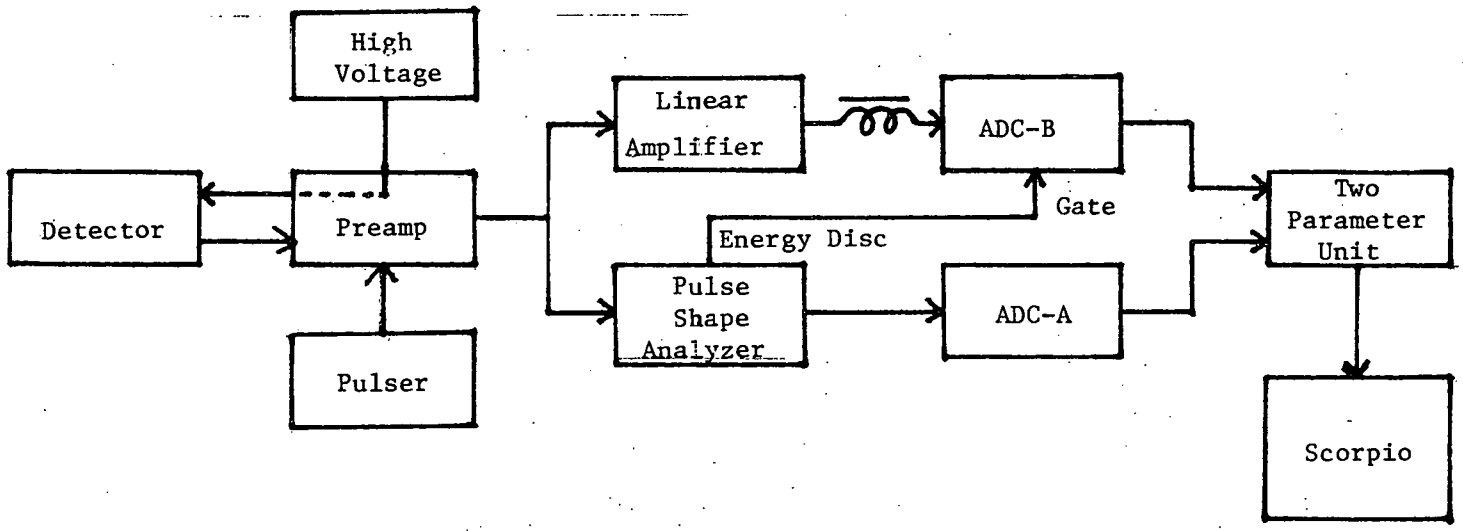

Figure 1: Block diagram of electronics used for two-parameter measurements.

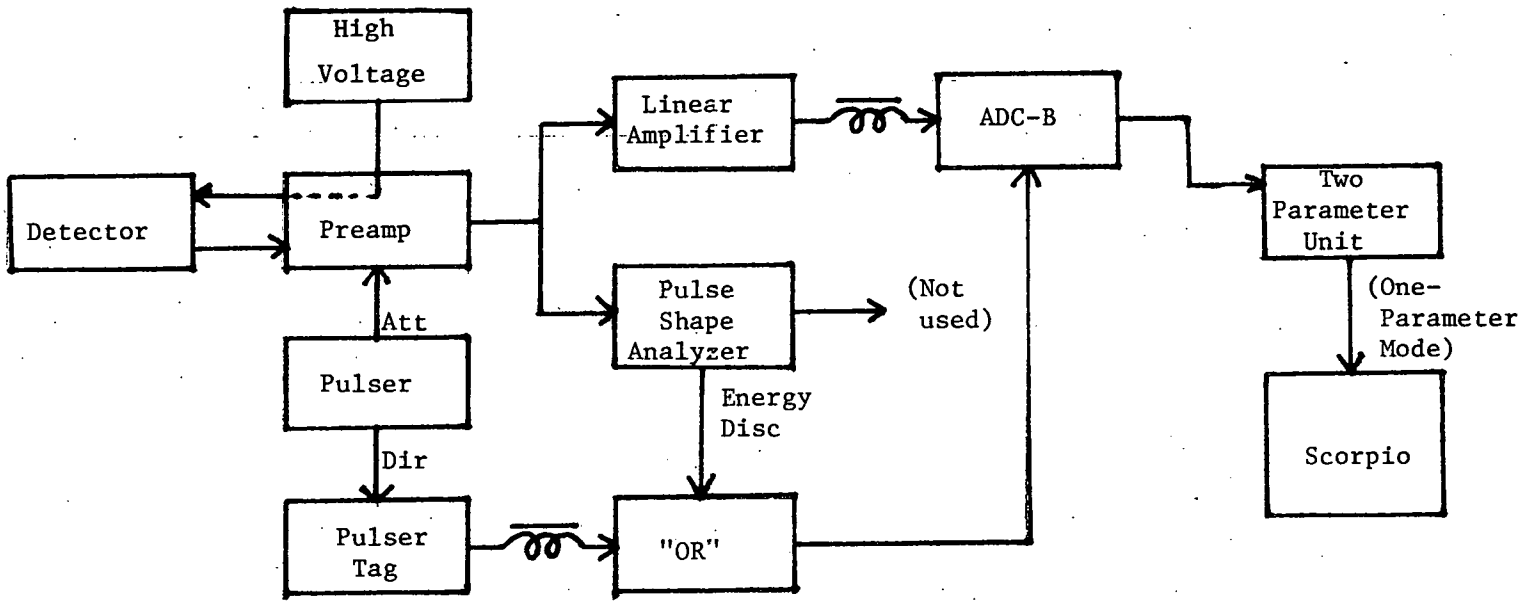

Figure 2: Block diagram of electronics used for single-parameter measurements.

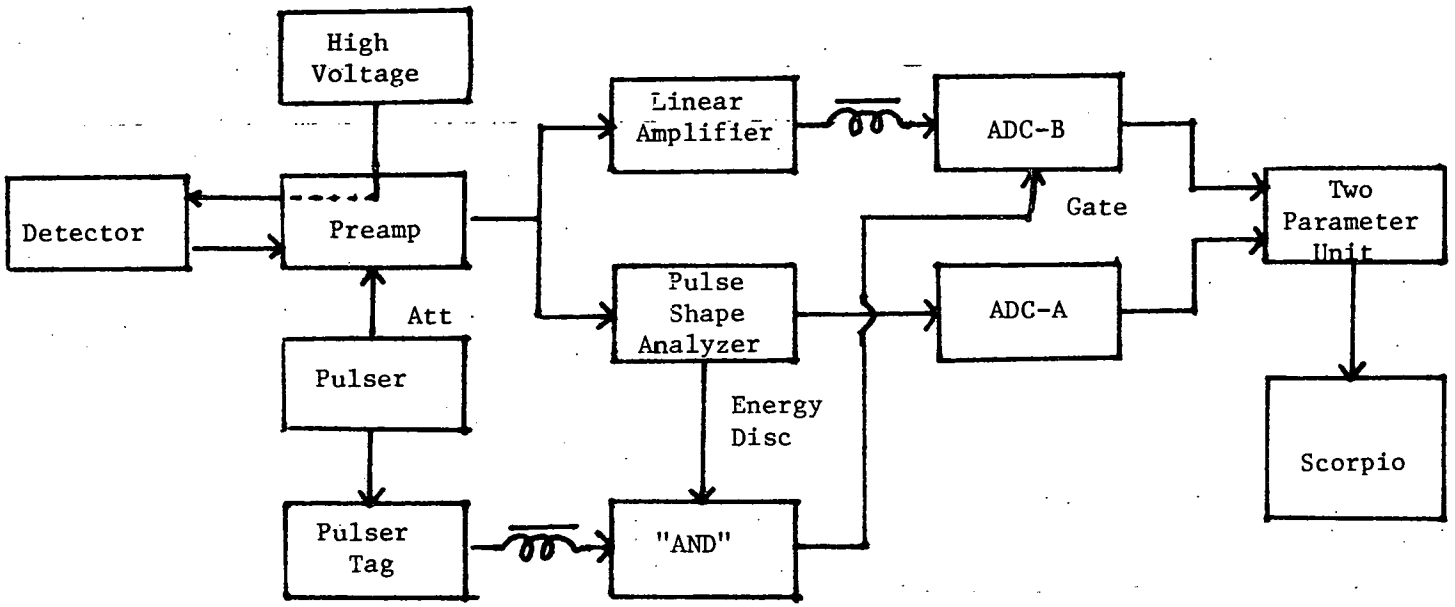

Figure 3: Block diagram of electronics used to determine system timing performance under operating conditions with two-parameter measurements.

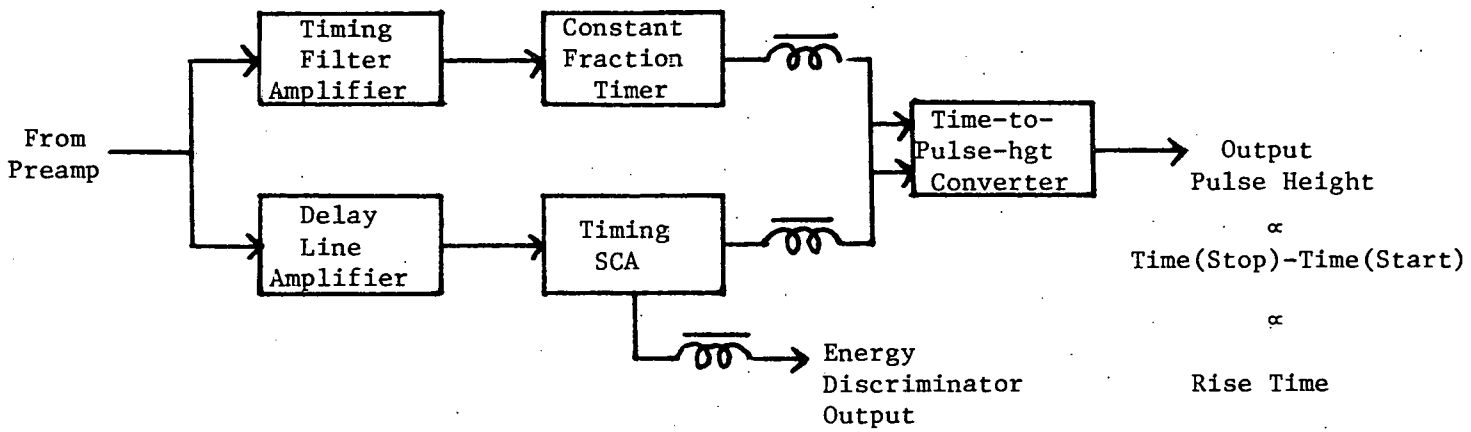

Figure 4: Block diagram of pulse shape analyzer.

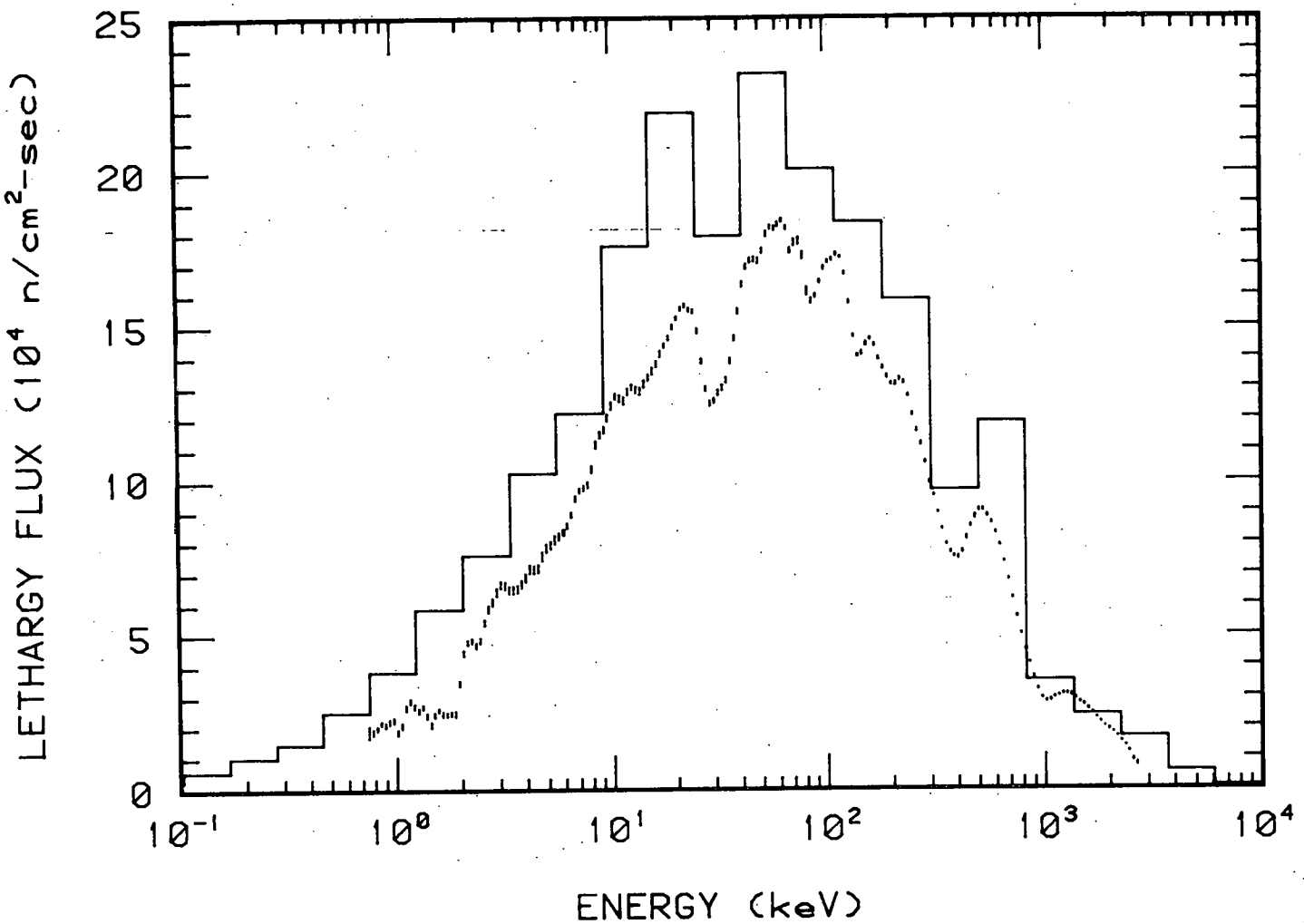

Figure 5: Calculated and measured neutron energy spectrum at location A-6.

The first four code modules of PSNS-N apply a series of corrections to the measured pulse height spectra. The result, for each gain run, is a histogram representation of the proton-recoil energy distribution P(E) in hydrogen- and methane-filled proportional counters. The energy-dependent neutron flux is ideally given by

$$\phi(E) = \frac{-E}{NT\sigma(E)} \frac{dP(E)}{dE} \quad ,$$

where N is the number of hydrogen atoms in the effective volume of the counter, T is the time duration of the measurements, and $\sigma(E)$ is the elastic scattering cross section of hydrogen.

PSNS-5 uses the least-squares differentiation technique. This technique has been shown to be susceptible to several types of errors,[4] although such errors are usually not expected to be large for relatively smooth spectra. Therefore, PSNS-5 has been rewritten to incorporate a numerical differentiation technique which is not susceptible to such errors.[4]

The histogram representation of the proton-recoil energy spectrum used as input to PSNS-5 is

$$P(E) = P_i \quad , \quad E_i \leq E < E_{i+1} \quad ,$$

where E_i is the lower boundary of the i^{th} data channel. The equation used by the new code module, named PSREV, is

$$\phi(E) = \sum_{i=2}^{m} \frac{-E_i}{NT\sigma(E_i)} G(E,E_i) (P_i - P_{i-1})$$

where m is the number of channels used in each gain run and $G(E,E_i)$ is an appropriate smoothing function. The smoothing function used in PSREV is a Gaussian (with correction terms necessary near the high and low energies of each gain run). The smoothing in PSNS-5 is an inherent part of the least-squares differentiation process and is not as easily adjusted as is smoothing in PSREV.

For proton-recoil spectra with good statistics PSNS-5 and PSREV give consistent results. However, PSREV can give better-resolved peaks; this can be helpful in performing energy calibrations. PSREV overlaps the unfolded neutron spectrum for each gain run in the same manner as PSNS-5. As an option, PSREV also outputs the neutron spectrum for each gain run which is an advantage in checking for problems in overlap regions between two runs.

II.C. Fission Rate Measurements Using Solid State Track Recorder (SSTR) Techniques

(H.P. Chou, R.H. Johnson, and F.M. Clikeman)

As described in the last progress report, the performance of the automatic track counting system suffered from the over travel of the microscope stage driving motors and the light output variation of the photometer. In the vertical direction, the over travel problem has been resolved by reducing the motor speed; in the horizontal direction, the over travel has been compensated using logic circuits. The circuit of the photometer was modified to improve its stability. To further minimize the effect caused by the light level drift, the threshold for identifying fission track events was chosen from the rather flat portion of the discrimination level curve. A masking plate was also used to cover

the chipped edges of quartz SSTR samples to give a reproducible scanned region. Several quartz SSTR samples with track numbers of the order of 10^4 were scanned repeatedly with the standard error of the mean for each sample being about 1% for four scans. Counting reproducibility among samples which were irradiated and etched under the same conditions is being examined.

An alternative method for counting fission tracks is also being tested. A SSTR sample is photographed and enlarged to a single 5 inch square film. The film is then scanned by an optical drum scanner (PHOTOSCAN 1000) which rotates with a constant speed and samples the film at a specified raster size. The optical density of each picture element is directly stored on a magnetic tape which is handled by the Purdue CDC computer system. With a raster size of 50 microns x 50 microns, the scanning time is about 45 minutes. The algorithm for counting tracks is similar to that used in the scanning optical microscope. The reproducibility of this method is now being investigated.

III. RESULTS OF EXPERIMENTAL MEASUREMENTS USING THE FBBF FACILITY

During the progress period the ^{232}Th $(n,\gamma)^{233}Th$ reaction and gamma-ray heating measurements in lead were made as a function of the radius in the blanket region of the FBBF facility. The results of the measurements are described in the following sections.

III.A. Neutron Capture Reaction Measurements
(G.A. Harms and F.M. Clikeman)

Nine thorium foils were irradiated at the axial midplane of the blanket in the odd-numbered radial experimental locations in sector D. The gamma spectra emitted by the irradiated foils were analyzed using a gamma yield of 0.360 ± 0.020 for the 311.9 keV gamma ray from the decay of the Pa-233, obtained from Nuclear Data Sheets, Vol. 24[5]. Preliminary results of the irradiation are shown in Fig. 6. The error bars account only for the error due to counting statistics and are drawn at one standard deviation. Also shown in the figure are the calculated Th-232 capture rates. The ratio of the calculated results to the experimental results is 0.90 at 23.7 cm (experimental position 1), falls to 0.82 at 59.2 cm (experimental position 13), and rises to 0.83 at 71.1 cm (experimental position 17). Gehrke et al. of Idaho National Engineering Laboratory[6] have measured the gamma-ray yield for the 311.9 keV gamma ray and reported a value of (38.6 ± 0.5) photons per 100 Pa-233 decays. The effect of using this yield would be to bring the experimental points down by 7.2% giving ratios of calculated to measured capture rates of 0.97 at 23.7 cm, 0.88 at 59.2 cm, and 0.89 at 71.1 cm. A systematic uncertainty of up to 3% is also present in the ratios due to the reported uncertainty in the strengths of the Cf-252 neutron source driving the FBBF facility.

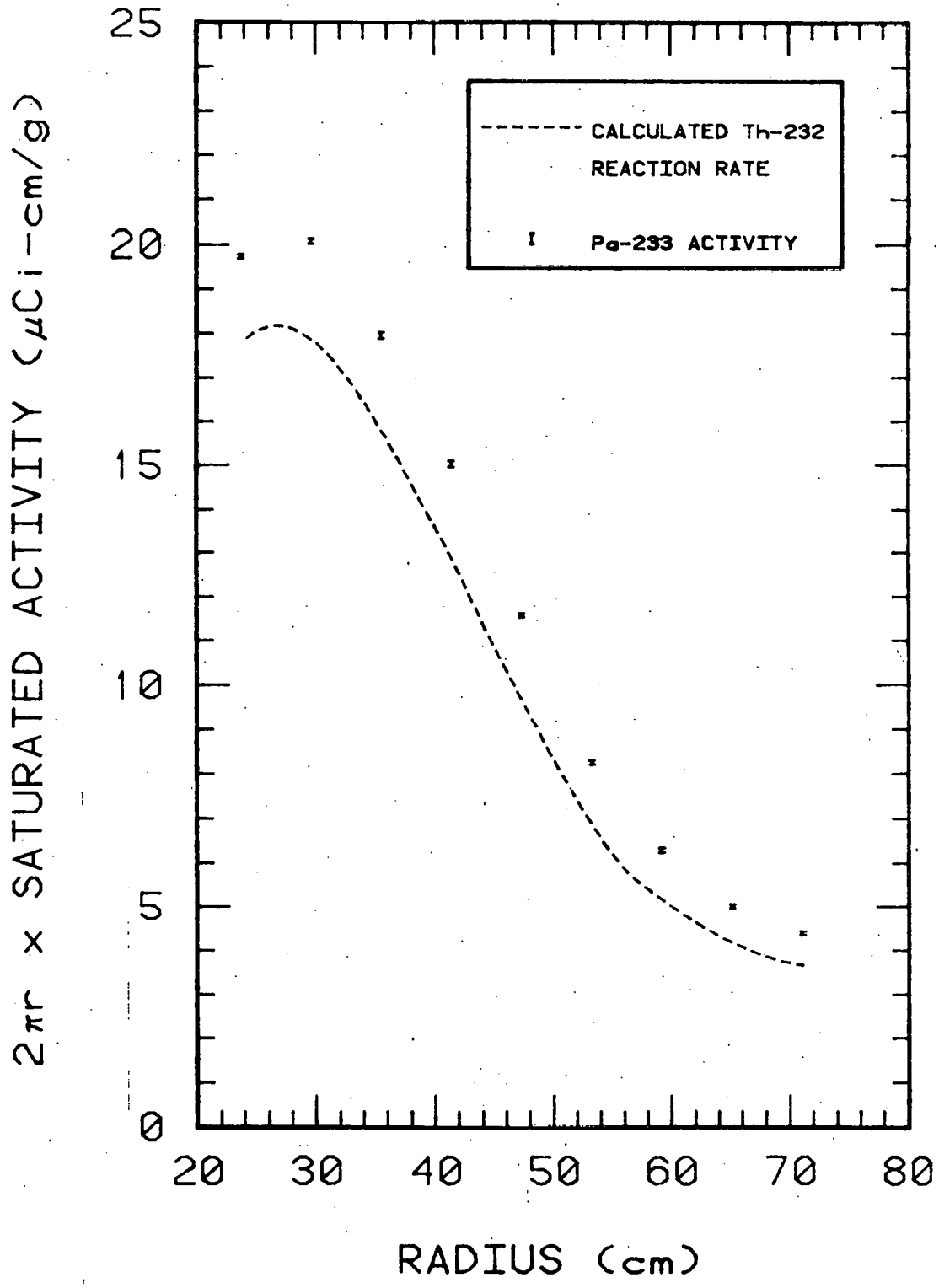

Figure 6: Preliminary ^{232}Th capture rates in sector D. The dashed line indicates the result of the 2DB calculation. The error bars indicate the experimental data and account for only the counting statistics at one standard deviation. A gamma-ray yield of 36 gammas per 100 Pa-233 decays was used to determine the absolute Th-232 capture rate.

III.B. Gamma-ray Heating Measurements
(K.R. Koch, R.H. Johnson and E.M. Clikeman)

Radial traverse measurements using both stainless steel and lead TLD holders have been completed in both sectors A and D of the FBBF. Axial traverses using stainless steel holders in four positions of sector A have also been completed. All necessary background measurements except for two of the axial traverses have also been completed. As soon as scheduling will permit, these final two background axial traverses will be made.

The most recently calculated gamma-ray spectra were used to recalculate the weighted f-factors for both the stainless steel and lead TLD holders. They are shown in Fig. 7. These f-factors are considerably different from those reported in the previous FBBF quarterly report since a cross-section misconstruction was found in the previous calculation. The most recent calculation resulted in approximately constant gamma-ray spectral shapes throughout both blanket regions, differing mainly in total flux. Figure 8 shows the latest ANISN spectra in the middle of the stainless steel blanket and in the middle of the aluminum blanket. The approximately constant f-factors are the result of the nearly constant spectral shapes.

Absolute dose calibrations have been completed for both precision TLD sets 1 and 2. A Gammabeam-150 cobalt-60 source was used to irradiate the TLD's and a Capintec Exposure Rate Meter with a 0.6 cm^3 ionization chamber was used to measure the total exposures. The TLD's were irradiated behind a 0.25 inch (0.635 cm) sheet of plexiglass. The calibrations resulted in extremely linear responses from 0.9 rads to 80 rads for the two precision sets of CaF_2:Dy TLD's. The relative calibrations are to

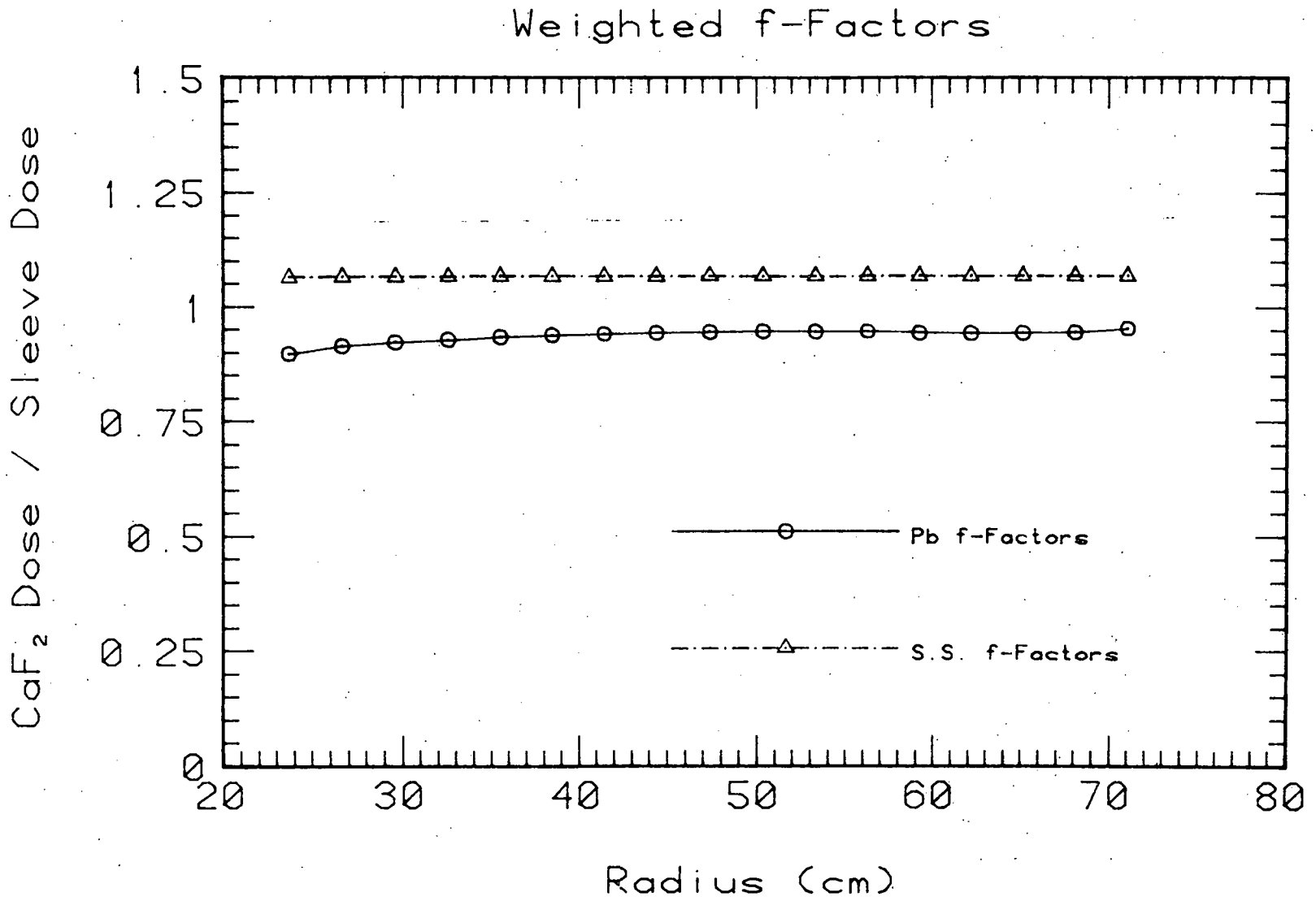

Figure 7: Gamma-ray spectral weighted f-factors for CaF_2:Dy in stainless steel and lead.

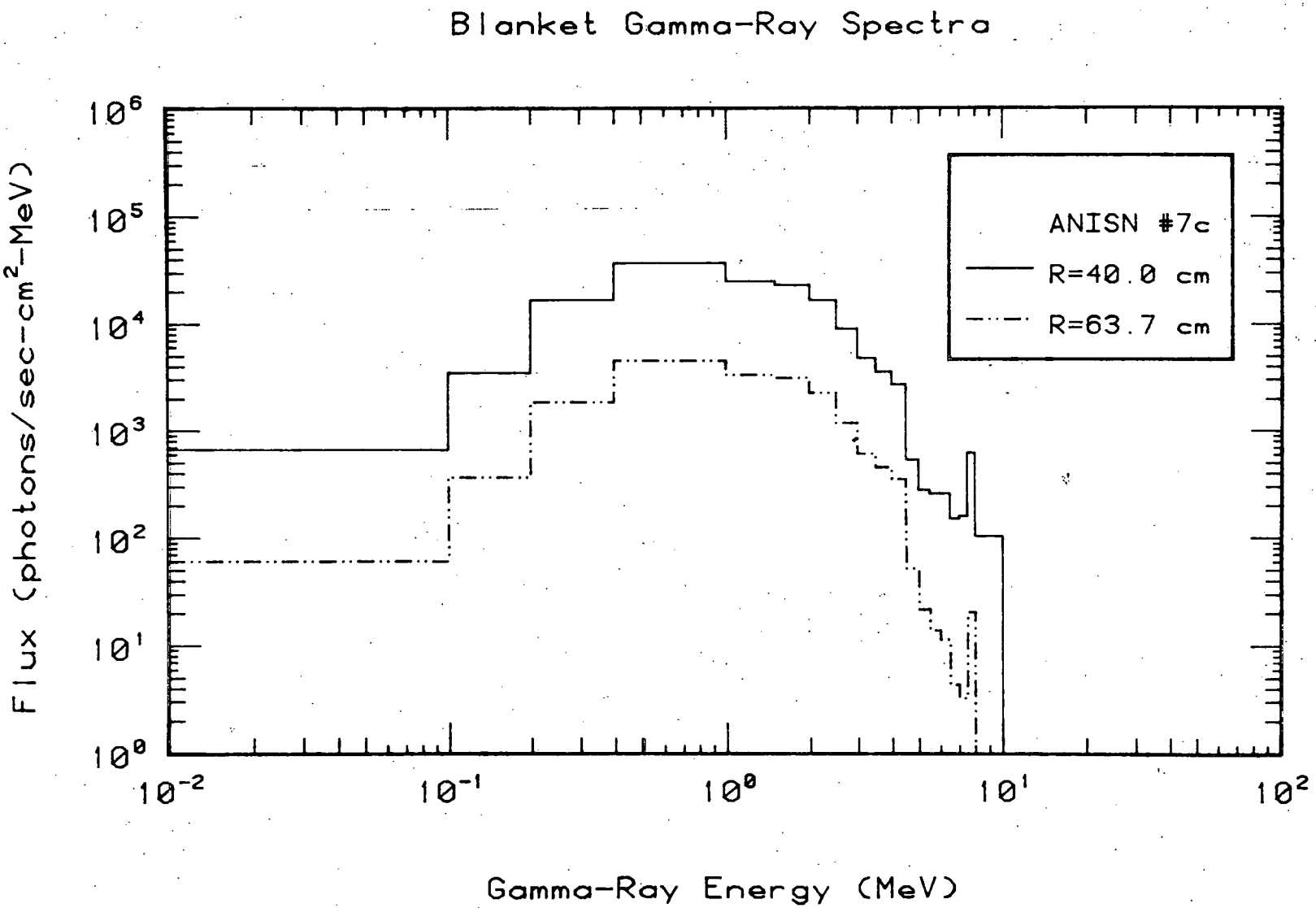

Figure 8: Calculated gamma-ray energy spectra in the blanket of the initial FBBF loading.

better than 1% accuracy with a 5% systematic error due to the exposure meter's calibration.

A check on the energy dependent f-factors for both stainless steel and lead at 1.25 MeV was made by using the same cobalt-60 source and ionization meter as for the dose calibrations. Stainless steel and lead holders, 0.0625 inches (0.159 cm) thick and containing 4 TLD's each, were irradiated at an exposure of about 45 Roentgens. The doses to the sleeves were then calculated from the exposure and the doses to the TLD's were determined from their dose calibration. The measured f-factor for stainless steel was 1.07 $\pm$ 1.8% which agrees well with the 1.0685 value calculated for four chips per holder from the one chip f-factors obtained from Simons and reported earlier.[7] The measured f-factor for lead was 0.956 $\pm$ 1.8% which is lower than the 1.0136 value calculated for four chips from Simons' f-factors. Agreement is considered reasonable because of the steep slope of the energy dependent lead f-factor at this energy.

Preliminary results have been obtained for gamma-ray heating rates in lead for a radial traverse at the axial midplane of sector D of the FBBF. The results with no corrections for possible neutron responses of the CaF_2:Dy TLD's are shown in Fig. 9 together with the latest ANISN results. The experimental errors shown are about 2% at the one-sigma level with about a 6% systematic error which is not shown in the figure. The calculated result is about 86% of the experimental result at the innermost blanket position and about 66% of the experimental result at the outermost blanket position.

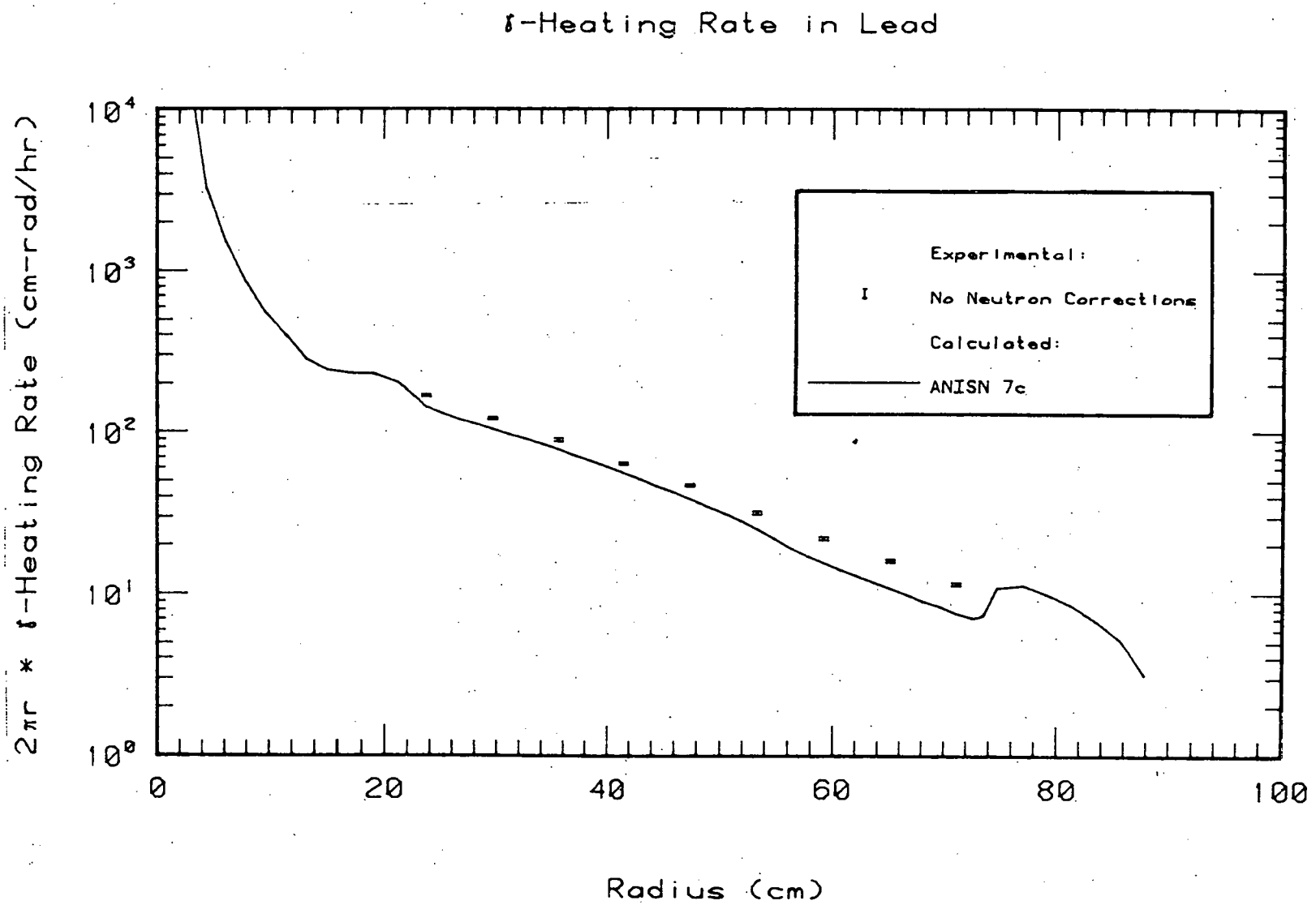

Figure 9: Gamma-ray heating rates in lead with no correction for neutron response as a function of radial position. The error bars shown for the experimental data are statistical errors at one standard deviation. The systematic errors which are not shown are estimated to be ± 6%.

Neutron corrections have been estimated from CaF_2 neutron sensitivities reported by Rinard and Simons[8] and also from neutron sensitivities measured by the FBBF personnel at Purdue.[9] The neutron sensitivities reported by Rinard and Simons yield about a 9% reduction in the experimental value at the innermost blanket position. Our neutron sensitivities yield about a 26% reduction at that same position. At the outermost blanket position the reduction is about 2% for the Rinard and Simons sensitivities and about 6% for our values. Using either set of correction factors, however, gives measured gamma-ray heating rates in lead at the outermost blanket position higher than the calculated value. It appears from the range of the calculated neutron corrections that more measurements of CaF_2 neutron sensitivities need to be made to allow better estimates of the neutron contributions to these TLD measurements.

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