TC-1963

FFTF REACTOR CHARACTERIZATION PROGRAM
ABSOLUTE FISSION RATE MEASUREMENTS

Hanford Engineering Development Laboratory

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Prepared for the U.S. Department of Energy
under Contract No. DE-AC14-76FF02170

DOE-Richland, WA

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Contract No.
DE-AC14-76FF02170

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PRELIMINARY DOCUMENT

This document contains information of a preliminary nature prepared in the course of work under U.S. DOE Contract DE-AC14-76FF02170. This information is subject to corrections or modification upon the collection and evaluation of additional data.

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May 1981

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ABSTRACT

Absolute fission rate measurements using modified National Bureau of Standards fission chambers were performed in the Fast Flux Test Facility at two core locations for isotopic deposits of ^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{237}Np, ^{239}Pu, ^{240}Pu, and ^{241}Pu. Monitor chamber results at a third location were analyzed to support other experiments involving passive dosimeter fission rate determinations.

ACKNOWLEDGMENTS

The authors wish to acknowledge the continuing support and direction from Robert Bennett, Tom King and Ed Sheen throughout all phases of the work. Rory McBeath, Bruce Zimmerman and Steve Thompson helped with experiment preparation and conduct of the measurements. Neil Hoitink contributed to the experiment with helpful discussions. Dale McGarry (NBS) helped with the conduct of monitor chamber measurements during the passive dosimeter fission rate measurements in the IRT. Lee Carter performed the Monte Carlo calculations of fission chamber scattering corrections.

CONTENTS

FIGURES

TABLES

TABLE (Cont'd)

I. INTRODUCTION

The Fast Flux Test Facility (FFTF) is a liquid-sodium-cooled test reactor designed to irradiate LMFBR fuels and materials at prototypic temperature and flux conditions. Accurate core environment neutronics characterization is an integral part of any subsequent test evaluation. Consequently, a Reactor Characterization Program (RCP)[1] was formulated to measure the important neutron-induced reaction rates in-core during reactor operation. The program consists of three phases to be performed prior to routine operation of the facility. The first phase consisted of very low power (0-1 MW) measurements of fission rates and neutron and gamma spectra in the core region by active and passive techniques in a controlled temperature environment. The second phase will consist of the irradiation of passive sensors in fuel pin cladding contained in reactor characterizers, which are designed to resemble normal reactor components as closely as possible. Second phase measurements will be performed at a power level of 4 MW (1% of full power). The final phase will consist of a similar irradiation at full reactor power. The absolute fission rate measurements were performed during the program's first phase.

A listing of the first phase neutronics measurements[2] is given in Table I. The absolute fission rate measurements using special absolute fission chambers were undertaken as Experiment 5. Run-to-run power level normalization relating measurements in Experiment 5 to those of Experiments 2, 3, 8 and 10, was accomplished by including a "monitor" absolute fission chamber in each experiment.

The controlled temperature environment for these experiments was provided by an In-Reactor Thimble (IRT). This thimble was a 12.2 m (40 ft.) vertical port in the configuration of a double wall vacuum "bottle" in which dry N_2 cooling was also included. The sensors were operated at 70°F, even though the reactor sodium coolant outside the IRT was at a temperature of 400°F.

The IRT took the place of a fuel assembly in the centrally located core position 3202 as showin in Figure 1. Fission chambers for Experiment 5 were nominally located at the core midplane and the upper axial reflector. Chamber insertion

and positioning in the IRT was accomplished using an Experiment Insert (EI). Positioning data, EI design, and monitor chamber locations will be discussed in detail in subsequent sections of this report.

TABLE I
FFTF-RCP PHASE 1 EXPERIMENTS

Sequence Number	Description	Power Level
2	Proton recoil proportional counter	$K_e<1$
3	Proton recoil emulsions	$K_e<1$
4	Axially traversable fission chambers	0.2 - 10 kW
5	Absolute fission chambers	0.5 - 2 kW
8	Fission product yield	100 kW
10	SSTR and passive dosimeter calibration	200 kW
12	Passive dosimeter irradiation	1 MW

The RCP passive dosimeter fission rate determination goal accuracies for U and Pu isotopes are in the range of 2 - 5% (1σ). This means that the goal measurement accuracies for the absolute fission chamber experiment are in the range of approximately 2% or better.[2] In order to ensure the best measurement possible, a collaborative effort between HEDL and the National Bureau of Standards (NBS) Center for Radiation Research was established. NBS has performed similar measurements using a double fission chamber.[3] In order to adapt the NBS methodology to the FFTF-RCP, the chamber operating characteristics were improved for operation in an environment more severe than is encountered in the laboratory. This report details the required development effort, experiment hardware design, and measurement plan, as well as present the final analysis of the FFTF experiment data.

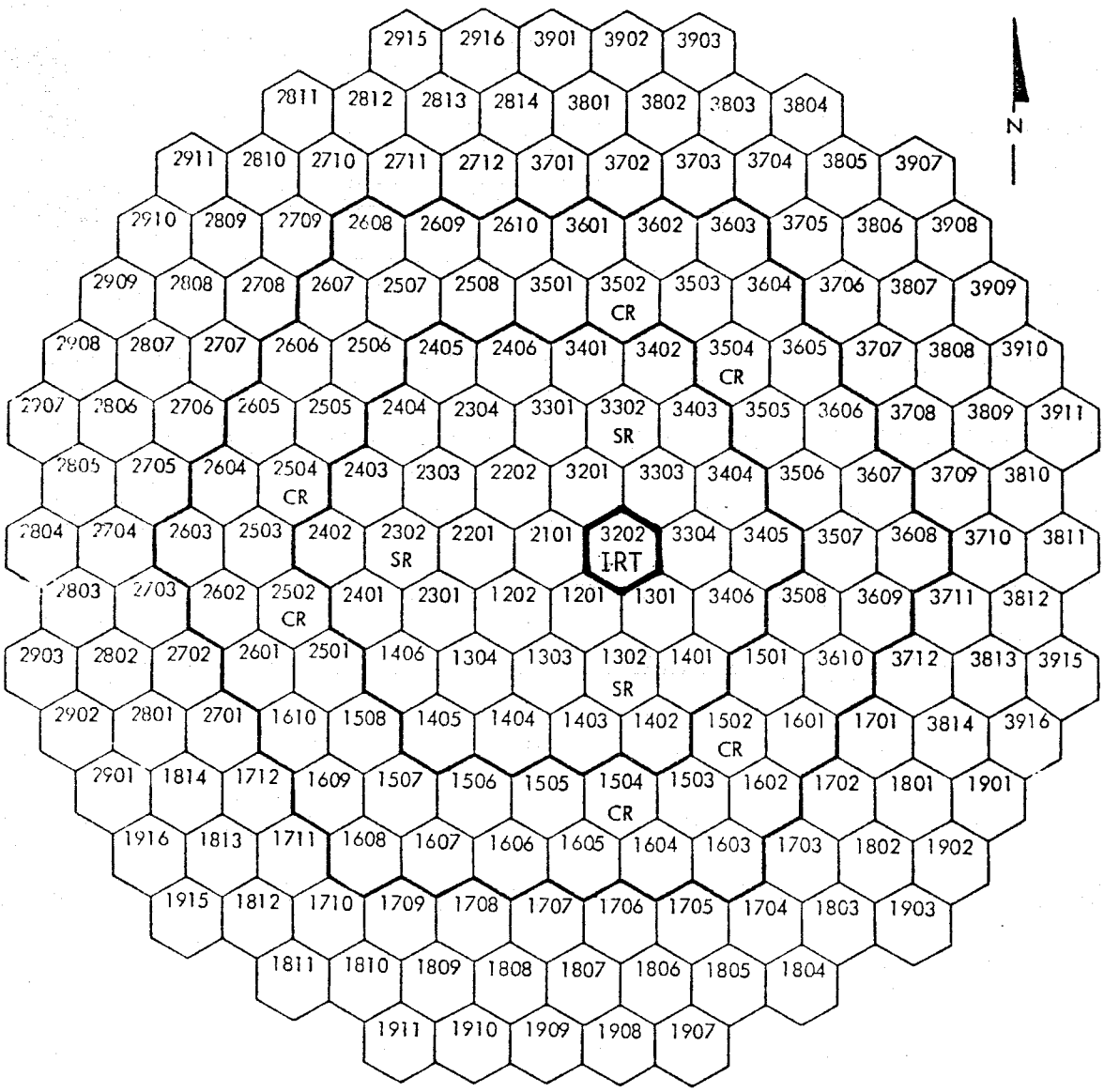

Figure 1. FFTF Core Cross Section with IRT Location Shown.

II. MEASUREMENT PREPARATION

A. Ruggedized Absolute Fission Chamber

As mentioned in the first section, the NBS absolute double fission chamber was redesigned to be more rugged and therefore more easily used in adverse environments. Initial efforts in this area were performed as part of a more general program in LMFBR instrumentation development. The major part of the effort, however, was undertaken in direct support of the FFTF-RCP.

The fission chamber (re)design criteria were established to meet, as a minimum, FFTF-RCP requirements. During reactor characterization a set of chambers was to be placed in the IRT. The IRT was a vertical access port extending from the reactor operating deck, through the vessel head, and through the reactor core at a position just off the center axis. Maximum thimble temperature could reach 204°C (400°F), the liquid sodium temperature at zero power, if the instrument cooling system failed to keep the experiment environment at a nominal 21°C (70°F). The capability to make measurements in gamma radiation fields greater than 10^6 R/hr was also desired.

The more conventional absolute fission chamber, as discussed in Reference 3, is a gas flow device which utilized teflon insulator components assemblied in a manner to provide easy access and changeout of fissionable material deposits of known composition and mass. Though suitable for laboratory or zero power facility experiments, use of the device in a power reactor environment required additional development.

The absolute fission chamber was redesigned to be a sealed device but with the capability to change out deposits being retained. Because of certain requirements related to weld and seal fabrication, and to improve general resistance to harsh environments, the wall and electrode material was respecified to be stainless steel instead of aluminum. All teflon insulator components were replaced with ceramic counterparts. Internal component tolerances were tightened and coaxial cable stem connections were used in order to eliminate vibration

induced microphonic noise - a persistent problem with the laboratory units. The mass of all components was kept to a minimum and the electrical connections were placed at a significant distance from the chamber to reduce scattering effects. For the same reason, all components were fabricated from hydrogen-free materials (as in the laboratory version). An exploded drawing of the ruggedized fission chamber is presented as Figure 2. The chamber is divided into an upper and lower detector. Fissionable material deposits on stainless steel substrates are placed back-to-back in the foil retainer to form a common cathode and inherently are described by the same spatial coordinates. Each collector is a split ring notched to accept the center conductor of one cable forming the stem. In this manner, the collector is removable to allow deposit changeout and microphonic noise is minimized. All internal conductors, except deposit substrates, are electroplated with Au and the foil holder diameter is 0.001-inch less than the chamber internal diameter to maintain good, nonmicrophonic electrical contacts. Because the chamber internal component dimensions are nearly the same as those of the laboratory version, the electron collection time in both devices is believed to be approximately equal, $\sim$ 70 nsec.[3]

One of the major advantages of the ruggedized fission chamber as compared to the laboratory version is the ability to change out deposits but still have a hermetic (no gas flow) detector. This is accomplished by use of a miniature chamber valve and a secondary top-of-chamber seal. The secondary C-seal is a commercially available component which seals the cover to the chamber flange and is usable even after many deposit replacements. The C-seal is a lead coated, stainless steel ring. The valve assembly consists of a threaded female opening protruding from the side of the chamber. A small annealed copper seal is located at the bottom of the protrusion. An allan set screw with a polished end is used to close the gas flow opening - a small hole in the side of the valve protrusion. Once a new set of deposits are in place inside the chamber, the upper detector components are replaced and the chamber cover is loosely reinstalled. The chamber can then be purged with counting gas and sealed. If operation of the chamber at temperatures greater than 100°C is anticipated, bakeout at a more elevated temperature is necessary after a thorough cleaning of the chamber internals.

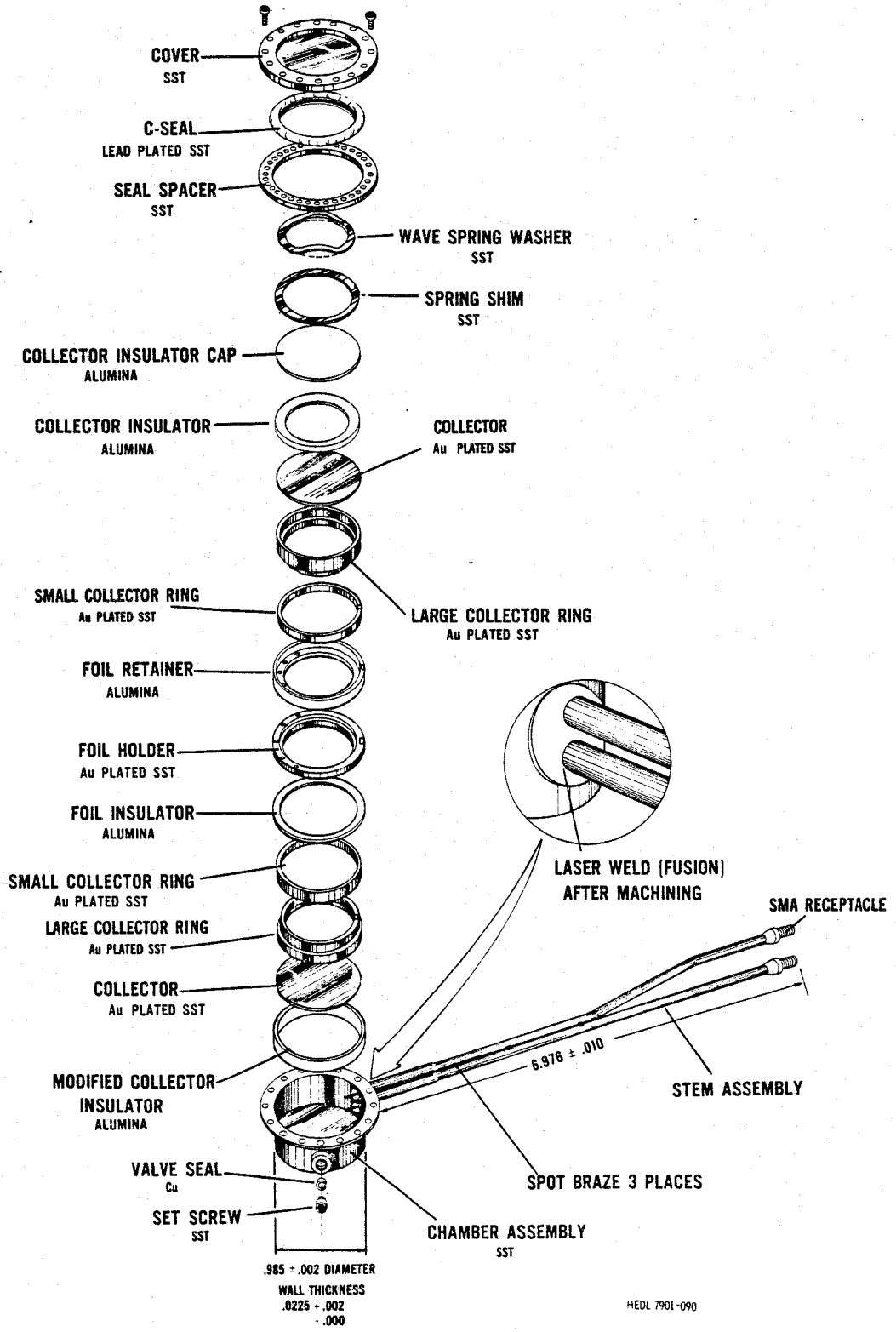

FIGURE 2. Ruggedized Absolute Fission Chamber.

The individual fission chamber components were selected based on their exceptional tolerance to harsh environments. Gross component failure should not prove to be the limiting factor for operation to temperatures of 540°C (1000°F). The stem assembly is fabricated using parallel sections of commercial grade SiO_2-insulated, stainless steel sheath, coaxial cable. Satisfactory performance of this component to temperatures of 600°C and radiation doses exceeding 10^{16} nvt is believed possible. The alumina internal insulators should exhibit, as a minimum, similar characteristic limits. The fissionable deposits are fabricated by vacuum deposition of oxide or fluoride compounds which are characterized by very high melting points. Deposits of both types have been heated to 500°C or greater with no material loss detected.[4] The deposits are discussed in detail in the next section. For chamber use at temperatures greater than 300°C, an uncoated stainless steel C-seal is recommended.

Fission rate measurements using the double fission chamber are not exceptionally sensitive to system gain changes because deposit events produce pulses of relatively high pulse amplitude. As discussed in Reference 3 and in subsequent sections of this report, the fission fragment differential pulse height distribution is typified by the spectrum presented as Figure 3. The integrated count rate above V_u is corrected to determine the absolute fission rate. Integral pulse height curves, commonly referred to as integral bias curves, are often used to compare the operational characteristics of commercially available fission chambers and are particularly useful in judging gain stability. Curve A of Figure 4 is the corresponding integral bias curve for the differential spectrum of Figure 3. System gain changes can be thought to produce corresponding shifts in V_u, the upper discriminator level, along the abscissa of either graph. It can be seen that with prudent selection of deposit thickness, large rate variations will not occur even for appreciable gain changes.

Gain stability is directly related to hardware (preamplifier-amplifier-discriminator) stability, fill gas density changes, and outgassing from chamber internals. The first is secondary to this discussion. The latter two need to be considered. The gas purge and fill procedure normally results in a slightly greater-than-atmospheric pressure (density) fill. Gain shifts of less than -1%

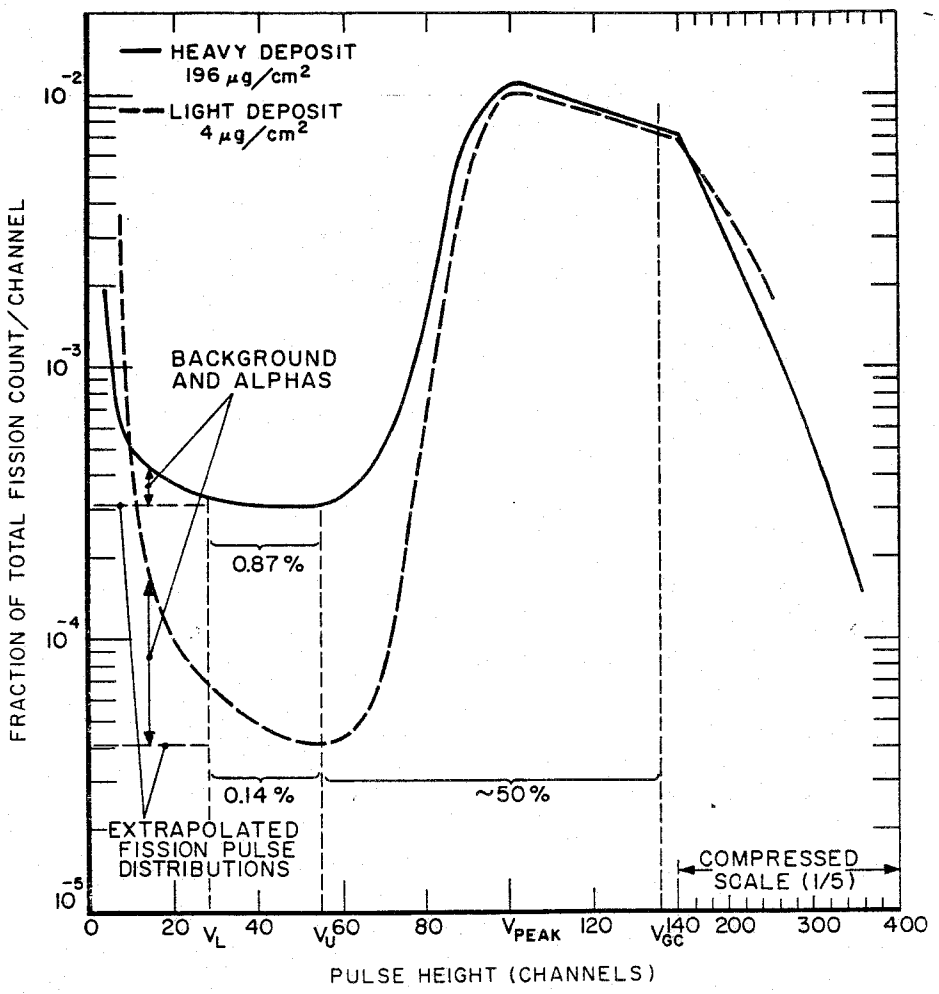

Figure 3. Absolute Fission Chamber Typical Differential Pulse Height Distribution.

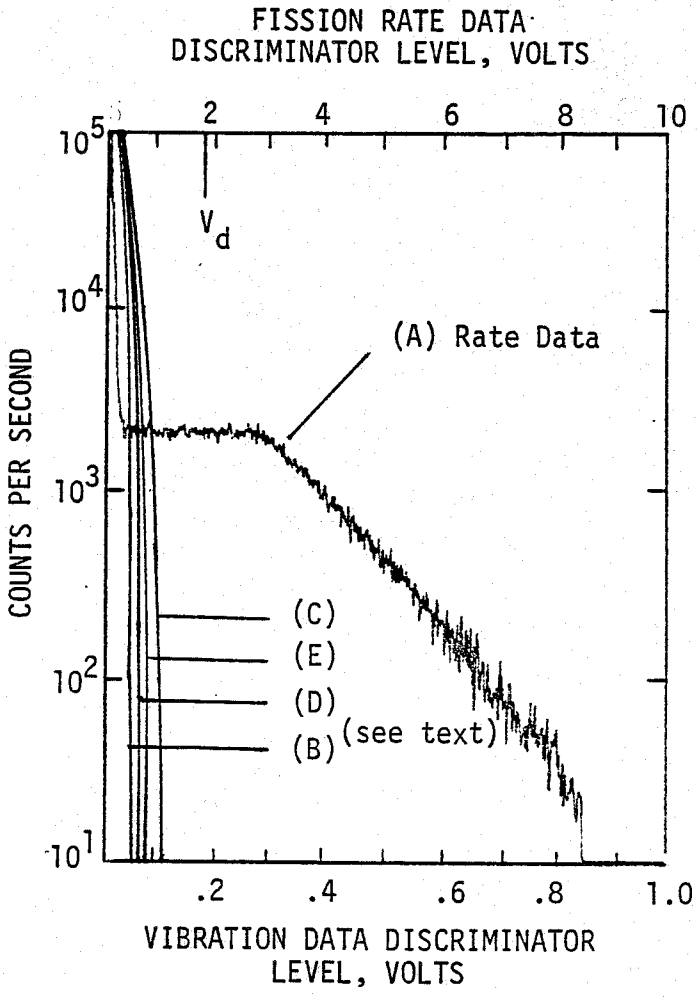

Figure 4. Ruggedized Fission Chamber Typical Integral Bias Curves.

per week are not difficult to attain at room temperature with the valve and seal designs previously described. Gain shifts many times greater can be compensated for by shaping amplifier gain readjustments just perior to measurement. Chamber outgassing problems can occur at elevated temperatures as will be discussed.

A prototype ruggedized chamber was extensively tested in simulated power reactor environments with successful results. Studies of chamber performance under conditions of vibrational loading, high gamma irradiation and high temperature were completed.

The ruggedized chamber is very tolerant of microphonic environments. Curves B, C, D, and E of Figure 4 illustrate the typical chamber response to various levels of vibrational loading. These data are for the bottom detector, no fission source present, vibrational direction perpendicular to chamber central axis. Under 1g loading amplitude at 0 Hz (B), 15 Hz (C), 100 Hz (D) and 500 Hz (E), the noise level is increased but stays well below $V_u/4$. Fission rate measurements using internal ^{252}Cf deposits show equivalence to within a 0.2% (1σ) counting statistical precision. Comparative tests using the chamber laboratory version often resulted in preamplifier pulse saturation. The ruggedized chamber microphonic response is about the same as seen using sealed, commercially available fission chambers.

The ruggedized fission chamber bias saturation response as a function of gamma radiation dose rate is presented as Figure 5. The detector bias under optimum conditions is set to 100-150 volts. From the 0 R/hr data, detector bias stability is found to be good. However, in high gamma fields loss of ion pairs via recombination with secondary electrons becomes significant and saturation is seen to occur only at higher bias. It is evident that care must be expercised if the chamber is used in fields above 1×10^6 R/hr.

Prototype fission chamber operation was tested at elevated temperatures by thermal cycling and steady state measurements. Thermal cycling tests were performed to check chamber hermeticity under rapidly varing conditions. The

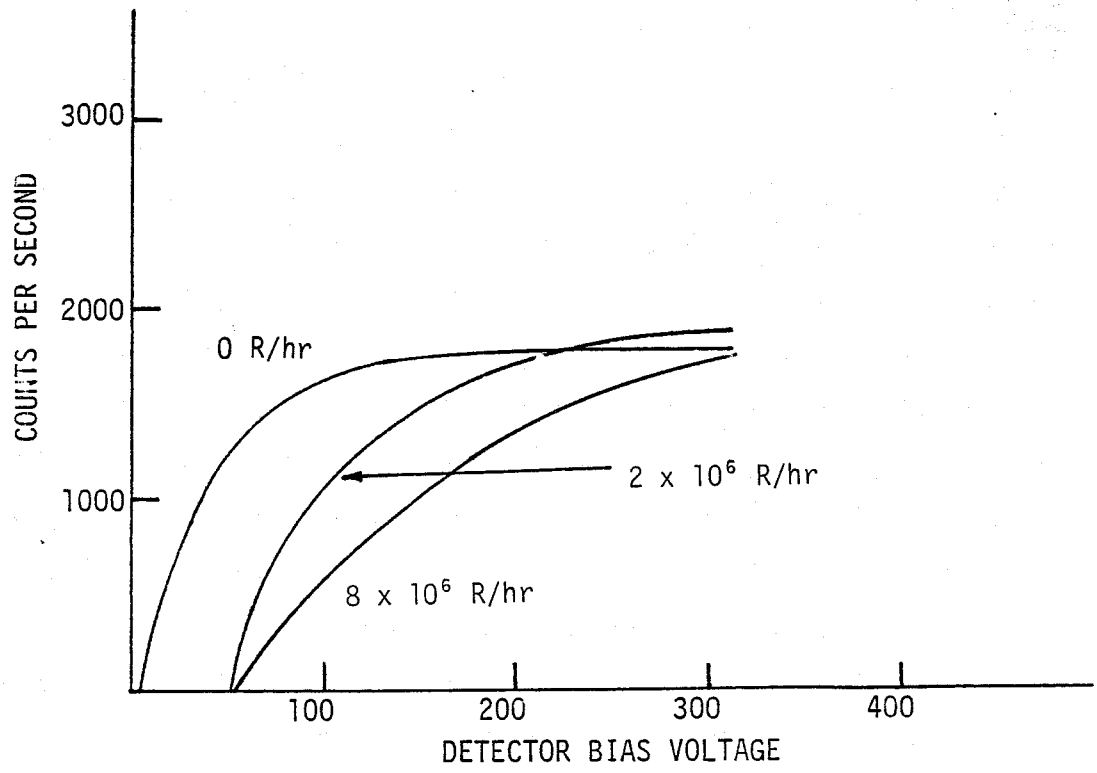

FIGURE 5. Ruggedized Fission Chamber Typical Saturation Curves as a Function of Gamma Field Intensity.

prototype chamber was cycled between 38°C and 323°C (100°F and 450°F) on a period of approximately 20 minutes for ten repetitions. The fission fragment differential distribution peak position was noted on the cool side of each cycle. No peak shifting occurred, which indicated that no gain shifting occurred due to chamber leakage.

Initial fission rate measurements in the laboratory at elevated temperature yielded less than satisfactory results. In the range 120°C to 230°C, significant degradation of the pulse height distribution occurred. However, the chamber recovered after cooling. The effect was attributed to outgassing of adsorbed impurities, probably dominated by H_2O, from chamber internals. A cleaning and bakeout procedure was devised to correct this problem. These procedures are summarized in Table II. Chamber performance improved dramatically at high temperature with the implementation of the procedures.

Little or no fission fragment pulse distribution distortion occurred during subsequent development tests. Laboratory absolute fission rate measurements at room temperature and 204°C (400°F) produced equivalent results.

In summary, development of the ruggedized version of the NBS double fission chambers was successful. Performance in the worst-case, FFTF-IRT environment (204°C, 10^6 Rad/hr, 15-800 Hz at 1g) was checked and found to be satisfactory. This effort has wider application, and it should prove straightforward to make absolute fission rate measurements in thermal environments up to 540°C (1000°F).

B. Fissionable Deposits

A very important part of the FFTF-RCP absolute fission rate measurement effort was the specification, procurement, and assay of the fissionable deposits. A similar effort undertaken at Aerojet Nuclear Company, Coupled Fast Reactivity Measurement Facility (CFRMF) is described in detail in Reference 3 and is indicative of the consideration given to deposit use.

TABLE II

ABSOLUTE FISSION CHAMBER CLEANING, BAKEOUT AND PURGING PROCEDURES

Cleaning

1. Disassemble chamber completely except for gas valve seal.
2. Wash ceramic internals: soak in acetone for five minutes;
   boil in distilled water for ten minutes;
   wash with alcohol for five minutes;
   blow dry with air gun immediately after removal from wash.
3. Wash metallic internals: wash with acetone for five minutes;
   ultrasonic wash with alcohol for five minutes;
   blow dry with air gun immediately after removal from last wash.
4. Fissionable deposits <u>are not</u> subjected to cleaning.
5. Reassemble chamber (including deposits) without tightening/sealing cover.

Bakeout and Purging

6. Purge with argon for 30-60 minutes at temperature 50-100°F higher than anticipated operating temperature.
7. Turn off heater, continue argon purge until chamber is below 100°F.
8. Purge with P-10 for 20-30 minutes.
9. With P-10 purge continuing, seal chamber.

*for operation at room temperature, Steps 6 and 7 may be omitted, as well as cleaning.

Fifteen deposits were employed for the FFTF measurements. Most were procured from the Joint Research Centre, Central Bureau for Nuclear Measurements (CBNM), Geel, Belgium. The choice of the Geel-CBNM laboratory was based on their ability to make double-rotated vacuum evaporation deposits. The ^{238}U deposits were oxide deposits prepared at Los Alamos National Laboratory (LANL). One ^{239}Pu deposit and the ^{241}Pu deposit were made at Oak Ridge National Laboratory (ORNL).

The fissionable material deposits purchased from Geel were in the form of anhydrous actinide fluorides. Fluorides have lower sublimation temperatures than oxides. Fluorides also tend to deposit as single molecules while oxide molecules tend to form clumps as they stream from the crucible to the backing. For fluorides it is not necessary to heat the backings, and the single molecules adhere better than clumps. The preparation of such deposits at Geel is described in Reference 4.

A listing of the deposits, their reference mass, and impurity content is included as Table III. A complete set of backup deposits was provided by additional inventory at NBS. Assay of the RCP foils was accomplished by comparison to reference NBS deposits, using alpha counting and fission counting in benchmark fields. An assay information summary is included in Appendix C. These data were the result of assays and chemical analyses performed by at least two laboratories (NBS, ORNL and Geel). NBS obtained fissionable material from ORNL and shipped it to Geel for deposition.

C. Data Acquisition System

The Data Acquisition System (DAS) was engineered to accommodate simultaneous input of three double fission chambers, requiring six identical, chained counting channels. A block diagram of the DAS is shown in Figure 6. A photograph of the system is presented as Figure 7. A seventh channel was included for background noise detection. The shaping amplifiers, ORTEC model 450, could also be used in the differential input mode for common mode noise rejection, if needed. Using 0.5 μsec differentiation and integration time constants, the resulting unipolar output pulse FWHM was typically 1.5 μsec and the nominal counting channel deadtime was less than 3 μsec.

TABLE III

FFTF-RCP ABSOLUTE FISSION CHAMBER REFERENCE FISSION FOILS

Isotope	Deposit ID	Principle Isotope Mass	Batch Impurity Composition (atom percent)	
^{232}Th	02N-9	621 μg ± 2%	-	
^{237}Np	37K-05-1	68.3 ± 1.1%	-	
^{233}U	23K-02-8	30.71 ± 1.5%	^{232}U	<0.6 ppm
			^{233}U	99.76
			^{234}U	0.018
			^{235}U	0.009
			^{236}U	<1.0 ppm
			^{238}U	0.21
^{235}U	25A-03-1	30.96 ± 0.77%	^{234}U	0.1822
	25A-03-2	30.91 ± 0.77%	^{235}U	99.0829
			^{236}U	0.0353
			^{238}U	0.6996
$^{238}D_U$	28G-5-1	735.7 ± 1.2%	^{234}U	0.00016
			^{235}U	0.01755
			^{236}U	<0.00001
			^{238}U	99.9823
$^{238}N_U$	28NC-5-1	651.7 ± 0.9%	^{234}U	0.0054
			^{235}U	0.7194
			^{238}U	99.2752
^{239}Pu	49K-005-1	0.0983 ± 0.8%	^{238}Pu	<0.001
	49K-001-3F	1.788 ± 0.6%	^{239}Pu	99.978
	49K-0-3F	4.893 ± 0.6%	^{240}Pu	0.021
	49K-02-3F	25.33 ± 0.5%	^{241}Pu	0.0005
	49K-03-2F	35.10 ± 0.5%	^{242}Pu	0.0005
	49K-4-1	468.1 ± 0.6%	^{244}Pu	<0.0002
^{240}Pu	40L-2-3F	221.4 ± 0.8%	^{238}Pu	0.0109
			^{239}Pu	0.6727
			^{240}Pu	98.5191
			^{241}Pu	0.4289
			^{242}Pu	0.3679
			^{244}Pu	0.0006
			^{241}Am	0.17
^{241}Pu	41K-03-1(L)	8.71 ± 2.5% (10/13/80)	^{238}Pu	0.001
			^{239}Pu	0.972
			^{240}Pu	0.255
			^{241}Pu	98.653
			^{242}Pu	0.118
			^{244}Pu	0.002
			^{241}Am	15.0

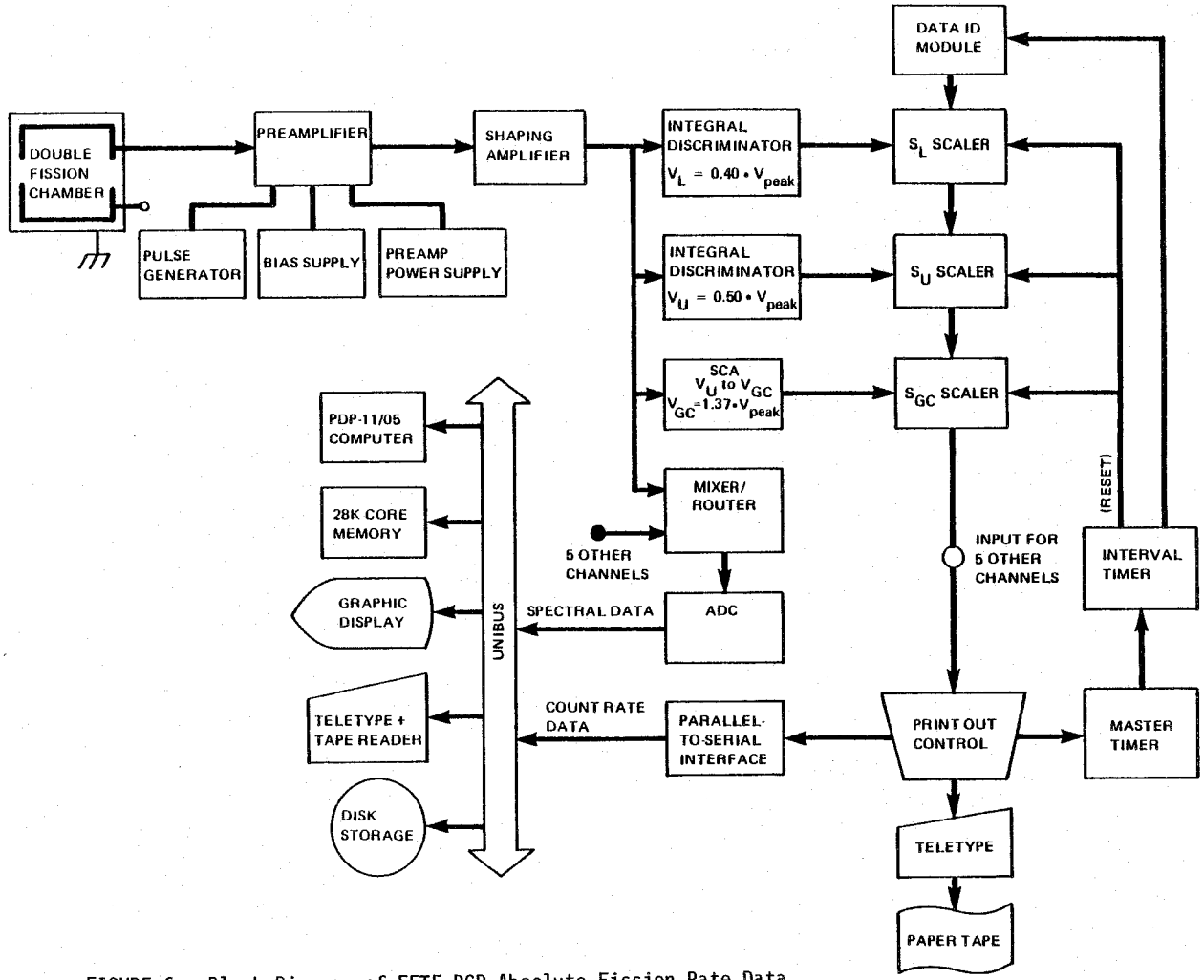

FIGURE 6. Block Diagram of FFTF-RCP Absolute Fission Rate Data Acquisition System.

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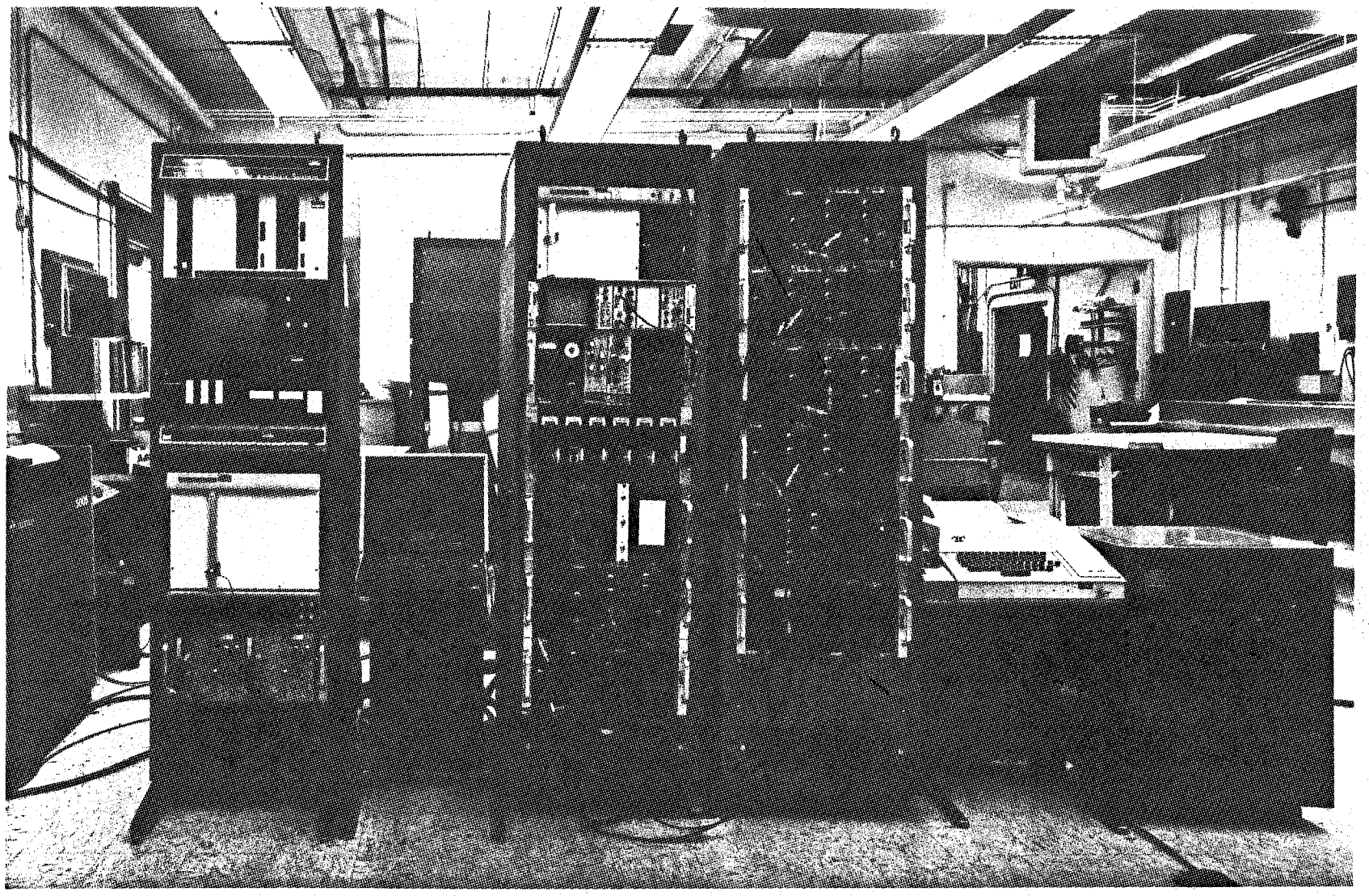

FIGURE 7. Photograph of FFTF-RCP Absolute Fission Rate Data Acquisition System.

Each channel was modeled after the triple scaler system employed by the NBS for similar measurements in the past.[3] The count rate above the lower discrimination level V_L (see Figure 3) is called S_L and above the upper discriminator V_U, is called S_U. These two independent integral discriminators set in the valley of the pulse height distribution gave redundant records of the number of fissions, reducing the possibility of error due to scaler malfunction. Under normal conditions (maximum noise amplitude well below V_L), the difference in the counts, S_L and S_U, was used to infer the number of valid fission counts between V_L and zero, on the basis of the assumption that the pulse height distribution was flat between $0 \leq V \leq V_U$. The estimated fraction of the fission pulses in the range $0 \leq V \leq V_U$ is termed the extrapolation-to-zero (etz) correction. The etz correction was taken from $(1-S_U/S_L)$ data as will be discussed with the results analyses in Section IV. The reproducibility of the $(1-S_U/S_L)$ data under normal conditions was good enough that this quantity provided a reliable indicator of any significant electronic noise above V_L. The counting window of the single-channel analyzer was set on the peak of the pulse height distribution so that the count S_{GC} (GC = gain check) was a sensitive monitor of gain stability. The pulse height analyzer was used to set up the triple scaler systems, particularly to adjust the amplifier gain so that the relative position of the discriminators and the peak of the fission fragment pulse height distribution corresponded to the specification given in Figure 3. The distribution was also monitored to determine overall chamber performance. The use of multi-channel analyzers for primary data acquisition was not considered prudent due to the large deadtimes associated with such units.

The DAS assembled for the FFTF-RCP measurements was comprised of seven NIM standard scaler systems chained in series and connected to a PDP 11/05 as well as a TTY/papertape unit. Thumbwheel data tagging modules were fabricated so all data output would be identifiable. The PDP 11 configured by Tennecomp Inc. into their Model TP 5/11 operated in a foreground/background mode. Thus, simultaneous pulse height spectrum compilation and data acquisition program operation was possible. The DAS was set up to collect fission fragment pulse height spectra from all six channels during a measurement, as well as accept, format and store scaler count data and other important information (date, time,

etc.). The software written to perform these tasks was named NIMIN and is included in Appendix A. Software written to perform preliminary, near real-time data analyses (program AFR and AFRS1) is included in Appendix B and will be discussed in Section III.

D. Experiment Insert

The experiment insert (EI) was used to place and position the absolute fission chambers, accompanying thermocouples, and signal cables into the IRT. The EI was composed of two sections: the upper instrument stalk and the lower instrument canister. A simplified drawing of the stalk is presented as Figure 8, and the canister as Figure 9. The canister held three detectors at any one time at the following core axial locations:

0" (core midplane)
+21.25" (upper axial reflector)
-14.75" (lower core, monitor chamber position).

The stalk was the tubular extension for handling the canister, routing signal cables, locating cable penetration seal plug, and locating a sodium seal plug (in case of IRT rupture). The assembled EI was approximately 40-feet long terminating at one end on IRT bottom and the other end at the operating deck level.

The coaxial signal cables in the canister were metal-sheathed, SiO_2 insulated, therefore radiation and temperature tolerant. The cables in the stalk were teflon insulated, having adequate radiation and temperature (250°C) tolerance for out-of-core use. The characteristics of these cables, including the short sections comprising the absolute fission chamber stem, are listed in Table IV.

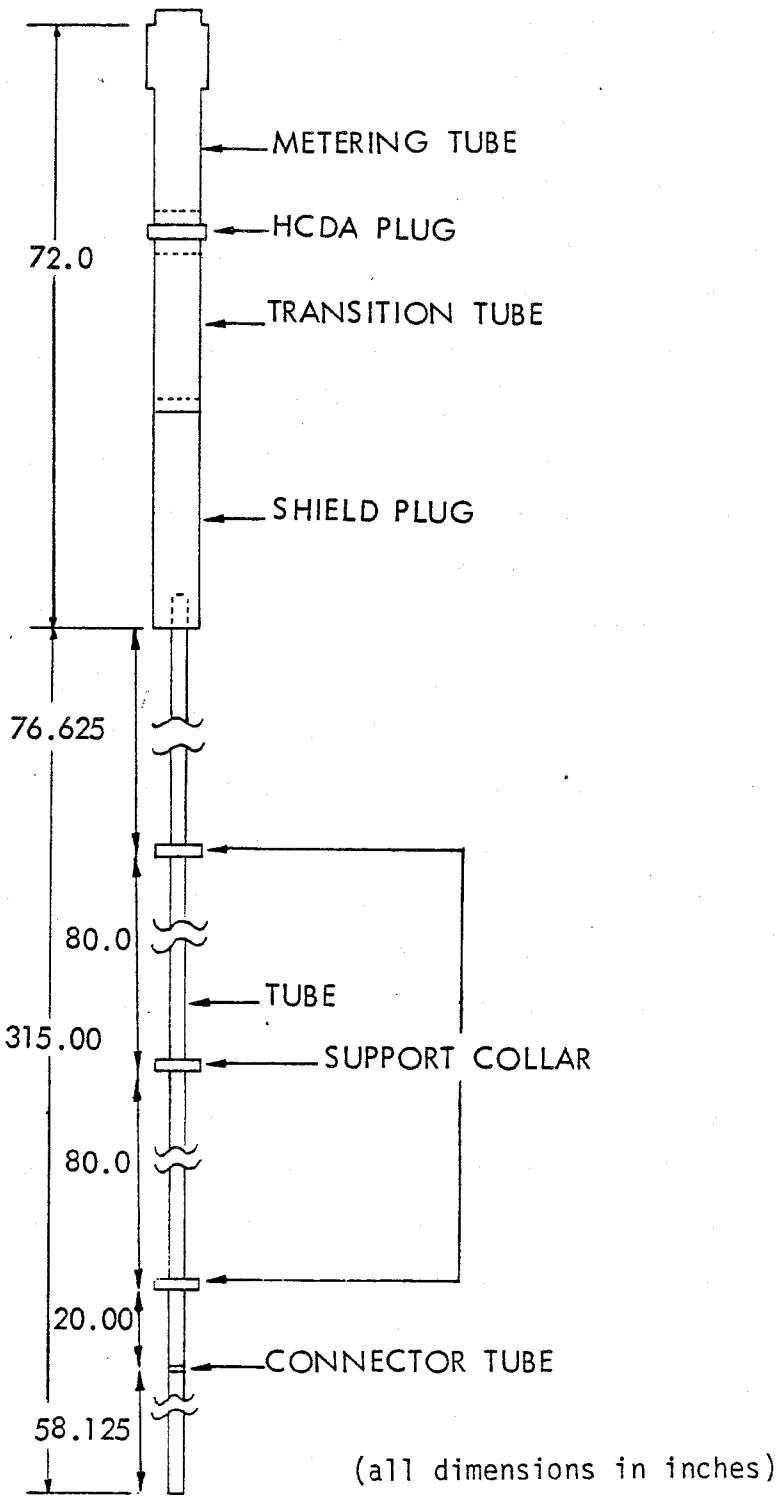

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FIGURE 8. Absolute Fission Chamber Experimental Insert Stalk.

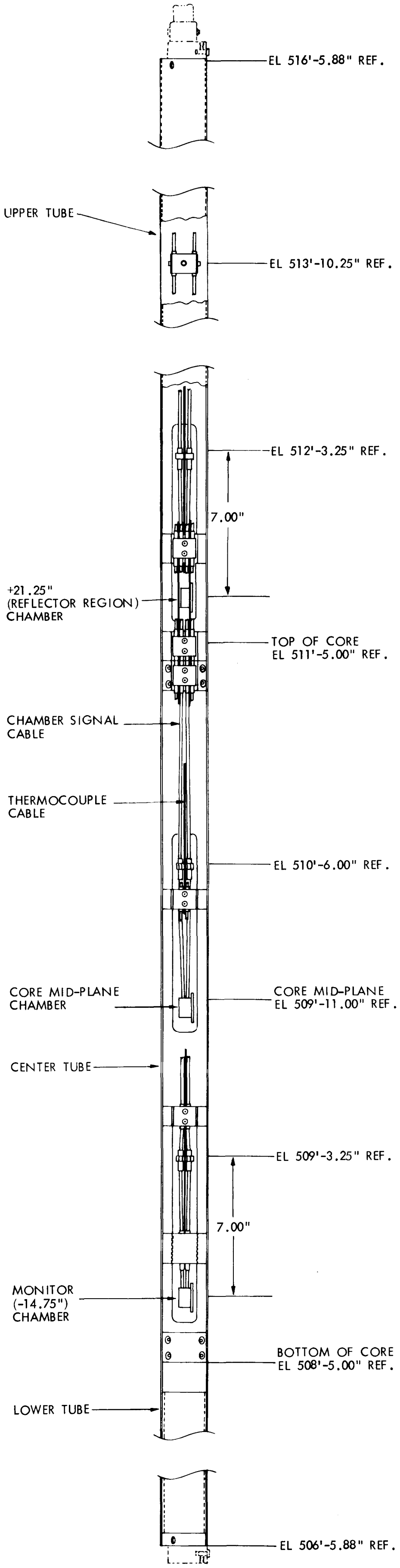

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Figure 9. Section Drawing of Experiment Insert Instrument Cannister.

TABLE IV

DESCRIPTIVE SUMMARY OF RCP-AFCS SIGNAL CABLES

Location/Use	Type/Description	Insulation	Capacitance (pf/ft)	Impedance (ohms)
detector stem assemblies	hardline coaxial 3.91 mm OD	SiO_2	16	97
instrument canister	hardline coaxial 3.91 mm OD	SiO_2	16	97
instrument stalk	RG 180B/U 3.68 mm OD x 13.7 m long (0.145" OD x 45 ft long)	Teflon	15	95

The EI was assembled and tested under prototypic conditions prior to use in the FFTF. The results of these tests are discussed in Reference 5. This effort was useful in that two problems were shown to exist: 1) RF and ground loop noise rejection methods had to be incorporated into the system, and 2) allowance for differential linear expansion of stalk and cable had to be made even though teflon and stainless steel expansion coefficients are nearly equal.

III. MEASUREMENT PLAN AND PROCEDURE

Two considerations in planning the measurements were deadtime and statistical uncertainty minimization. In order to achieve overall measurement uncertainty of about 2% in a situation where deposit mass uncertainty may approach this magnitude, a goal of 0.1% or less for deadtime and statistical uncertainties was established. With regard to deadtime losses, using a system of nominal resolving time of 3 μsec, deposit masses were selected and reactor power specified to keep counting rates below ∿2500 cps. The goal statistical uncertainty was achieved by specifying counting time to accumulate several million counts.

The strategy devised to use all isotopes at both core midplane and upper axial reflector in Experiment 5, and appropriate monitor chambers for Experiments 2, 3, 5, 8, and 10, is summaried in Table V. Eight fission chambers, as described in Section II A., were fabricated and assembled in order to implement

the plan with minimum reactor down time. The corresponding chamber identification numbers are included in the table. As indicated in Section II C, six identical channels were included in the DAS for simultaneous counting using three double fission chambers.

Considerable effort was expended before, during, and after the FFTF measurements, to measure counting channel deadtime accurately. NBS normally employs a variation of the two-source method using a source attenuator in an access port to their research reactor. The analyzer-pulser method was successfully applied at HEDL. A third, much simpler method was later devised based on a dual delayed-pulse generator (Canberra 1407P or equivalent). Dual-pulser results agreed with the two more involved methods. Because deadtime depends on discriminator level in RC-shaped, leading edge discrimination networks and because in this experiment optimization required non-normal discriminator level settings, the dual-pulser method proved useful. The procedure employed using the double pulser to measure deadtimes is outlined in Table VI. The final results were corrected by 0.31%, a factor calculated by comparing the dual-pulser-measured τ_D and the deadtime determinable by the two-source method combining results from Experiments 8 and 10.

IV. MEASUREMENT RESULTS

The results presentation is divided into three sections. The results from Experiment 5, the actual isotopic fission rate measurement experiment, are presented in Section IV A and IV B. The normalization measurements, using the monitor chambers, are presented in Section IV C. The preliminary results were calculated using the DAS computer and the analysis code AFR (and subroutine AFRS1) as listed in Appendix B. AFR took raw total count data from up to ten determinations, computed a mean rate, corrected it for deadtime and added the etz correction. In order to determine the absolute fission rate and its associated uncertainty, further corrections to the preliminary data were required. The statistical uncertainty computed using AFR was included, as were the deposit mass measurement uncertainties, the correction for fissions in minor isotopic constituents of each deposit, and the deposit self-absorption correction. These

TABLE V

ABSOLUTE FISSION CHAMBER USE STRATEGY FOR FFTF-RCP

Experiment	Run	Chamber Location	Chamber ID	Isotope-ID-Mass	Reactor Power	Expected Count Rate	Counting Time
2-3	-	monitor (+21")	RCP 7	^{239}Pu(49K-4-1)468.1 µg blank	subcritical	1-10	-
5	1	reflector (+21")	4	^{240}Pu(40L-2-3F)221.4 ^{241}Pu(41K-03-1(L))8.71 (10/13/81)	0.9 kW	536 351	105 min
		midplane (0")	1	^{235}U(25A-03-1)30.96 ^{239}Pu(49K-03-2F)35.10		1310 1394	
		monitor (-15")	8	^{239}Pu(49K-02-3F)25.33 ^{239}Pu(49K-0-3F)4.893		830 160	
	2	reflector	5	^{237}Np(37K-05-1)68.3 ^{238}N$_U$(28NC-5-1)651.7	2 kW	445 1090	60 min
		midplane	3	^{238}D$_U$(28G-5-1)735.7 ^{232}Th(02N-9)621		2846 545	
		monitor	8			3320 641	
	3	reflector	2	^{235}U(25A-03-2)30.91 ^{233}U(23K-02-8)30.71	0.65 kW	827 1201	105 min
		midplane	4			1910 483	
		monitor	8			830 160	
	4	reflector	1		0.65 kW	830 190	60 min
		midplane	2			1310 1890	
		monitor	8			830 160	
	5	reflector	3			462 83	150 min
		midplane	5			2050 3263	
		monitor	8			3320 641	
8 & 10	-	monitor (-15")	6	^{239}Pu(49K-001-3F)1.788	100 kW(8) 200 kW(10)	8500(8) 17,000(10)	2 hour (8) 4 hour (10)
				^{239}Pu(49K-005-1)0.0983		640(8) 1300(10)	

TABLE VI

DUAL DELAYED PULSER DEADTIME MEASUREMENT PROCEDURE

1. Display detector pulse-height spectrum and adjust gain to optimize according to Figure 3.
2. Adjust discriminator levels as would be accomplished for an actual rate measurement using analyzer.
3. Determine mean pulse height for particular spectrum.
4. Adjust both primary and delayed pulse to mean pulse height level.
5. Starting with delayed pulse widely separated from primary pulse, decrease pulse separation until counting rate decreases by one half.
6. Measure this delay between beginning of two pulses at input of shaping amplifier.
7. Measure width of primary pulse at discriminator level at output of shaping amplifier.
8. Average of time delay and pulse width a good measure of system mean deadtime. Former will be greater than latter. The preamp pulse time delay is believed to be too conservative an estimate because it does not take into account possibility of very large pulse starting after a small pulse tripping the discriminator first. The pulse width measurement with the double pulser yields a value somewhat shorter than found using more sophisticated methods in some cases.

all will be discussed in more detail in Section IV.B. Note that free-field rates were also determined by including a chamber scattering correction. The goal accuracies relate, however, to the in-situ results.

A. Data and Preliminary Analyses

Data acquisition according to the experiment plan outlined in Table III necessitated data set identification coding and deposit identification coding. For further reference, the coding descriptions are reported here. With regard to the fissionable deposits, the thumbwheel data identification modules were numeric only, so the alphanumeric deposit ID numbers were converted as listed in Table VII. With regard to the data sets, which were stored on diskettes with backup and archived, the ID codes were formulated according to a Month-Day-R-Sequence-# Determinations. Corresponding spectra sets replaced R with an H and deleted the number of determinations. The data sets obtained during the FFTF-RCP are described and identified in Table VIII (refer to Table III).

The DAS program NIMIN facilitated data acquisition, labeling, and storage. Between experiment runs, the program AFR and its detached subroutine, AFRS1, were used to perform preliminary data analyses. AFR/AFRS1 output for Experiment 5, Run 1, is included in Appendix B as a sample. The output consists of a listing of the important measurement parameters, deadtime-corrected rates, count rate ratios for each determination, the deadtime correction used, and experimental and theoretical standard deviations. The mean rate is corrected for etz and the "corrected" fission rate is presented. The preliminary rates are corrected only for deadtime and etz. The associated uncertainty results from combining the larger of the mean experimental or theoretical standard deviation, the uncertainty due to deadtime determination uncertainty, and the calculated etz uncertainty. In dividing total counts, C_K, (K=L,U,GC) by counting time, T, to yield a rate, any uncertainty in specified counting time was neglected as it was less than 0.001%.

The mean deadtime, τ_K, determined for each channel (component serial numbers on record) are listed in Table IX. These values were determined using the

TABLE VII

RCP ABSOLUTE FISSION CHAMBER DEPOSIT IDENTIFICATION

NBS ID	Isotope	Mass	Chamber Placement	Numeric ID
25A-03-1	^{235}U	30.96 µg	RCP 1 top	925031
49K-03-2F	^{239}Pu	35.10	1 bottom	949032
25A-03-2	^{235}U	30.91	2T	925032
23K-02-8	^{233}U	30.71	2B	923028
28G-5-1	$^{238}D_U$	735.7	3T	928851
02N-9	^{232}Th	621	3B	999029
40L-2-3F	^{240}Pu	221.4	4T	994023
41K-03-1(L)	^{241}Pu	8.71 (10/13/80)	4B	941031
37K-05-1	^{237}Np	68.3	5T	937051
28NG-5-1	$^{238}N_U$	651.7	5B	992851
49K-001-3F	^{239}Pu	1.788	6T	490013
49K-005-1	^{239}Pu	0.0983	6B	490051
49K-4-1	^{239}Pu	461.8	7T	994941
(blank)	--			999999
49K-02-3F	^{239}Pu	25.33	8T	949023
49K-0-3F	^{239}Pu	4.893	8B	994903

TABLE VIII

RCP EXPERIMENT 5 DATA FILE IDENTIFICATION

Archived Data ID Number	Description[1]
012RØ1Ø5	10/12/81 Run 1 CMP: 235/239 UAR: 240/241 first accumulation, 5 determinations
012RØ2Ø5	second accumulation of Run 1
012RØ31Ø	third accumulation of Run 1
012R21Ø6	10/12/81 Run 2 CMP: 238D/232 UAR: 237/238N first accumulation, 6 determinations
012R221Ø	second accumulation of Run 2
013R31Ø5	10/13/81 Run 3 CMP: 240/241 UAR: 235/233 first accumulation, 5 determinations
013R321Ø	second accumulation Run 3
013R33Ø5	third accumulation Run 3
013R41Ø5	10/13/81 Run 4 CMP: 235/233 UAR: 235/239 first accumulation, 5 determinations
013R42Ø5	second accumulation Run 4
014R51Ø5	10/14/81 Run 5 CMP: 237/238N UAR: 238D/232 first accumulation, 5 determinations
014R521Ø	second accumulation, Run 5
014R531Ø	third accumulation, Run 5
014R541Ø	fourth accumulation, Run 5

[1]Refer to Table III for additional information.

procedure described in Section III. Data pertaining to three additional channels assembled for use during Experiments 8 and 10 are also included. An estimated uncertainty of ±0.2 μsec was assigned to these values. Because all the measured rates were low (<5000 cps) a linear approximation for the deadtime correction was applied to determine the corrected count rate S_K:

$$S_K = R_K (1 + R_K \tau_K) \tag{1}$$

where R_K denotes the uncorrected count rate, C_K/T. All rates were calculated and the deadtime correction was applied before averaging. For Experiment 5, deadtime corrections were 1% or less; thus the maximum expected uncertainty contribution to the final absolute fission rate data was about 0.1%.

Several standard deviations were calculated for N repetitions and included in the preliminary data output. They are defined as follows:

$$\text{experimental standard deviation } \underline{\Delta}\ s(S_K) = \left\{ \frac{\sum_{j=1}^{N} (S_{KJ} - \overline{S}_K)^2}{N-1} \right\}^{1/2} \tag{2}$$

predicted standard deviations $\underline{\Delta}$ SIGMA, where

$$\text{SIGMA}(S_U) = \overline{S}_U \, (\overline{C}_U)^{-\frac{1}{2}} \tag{3}$$

$$\text{SIGMA}(S_L/S_U) = \left\{ \frac{\overline{S_L/S_U}(\overline{S_L/S_U}-1)}{\overline{C}_U} \right\}^{1/2} \tag{4}$$

$$\text{SIGMA}(S_{GC}/S_U) = \left\{ \frac{[\overline{C}_U - (\overline{C}_U \cdot \overline{R_{GC}/R_U})]\ (\overline{C}_U \cdot \overline{R_{GC}/R_U})}{\overline{C}_U^{\,3}} \right\}^{1/2}, \tag{5}$$

and mean values of the above, where

$$\text{s Mean} = \frac{s(S_K)}{\sqrt{N}} \tag{6}$$

TABLE IX

RCP ABSOLUTE FISSION CHAMBER DAS DEADTIMES

Channel	τ'_L & τ'_U	τ''_L & τ''_U	$((\tau'+\tau'')/2)$	$\tau_{L,U}=1.0031((\tau'+\tau'')/2$	τ'_{GC}	τ''_{GC}	$((\tau'+\tau'')/2)$	$\tau_{GC}=1.0031((\tau'+\tau'')/2)$
1	2.15 μsec	2.32	2.235	2.24	1.62	1.94	1.780	1.78
2	2.05	2.30	2.175	2.18	1.62	1.92	1.770	1.78
3	2.18	2.41	2.295	2.30	1.64	1.92	1.780	1.78
4	2.08	2.31	2.195	2.20	1.58	1.88	1.730	1.74
5	2.10	2.36	2.230	2.24	1.61	1.92	1.765	1.77
6	2.10	2.30	2.200	2.21	1.61	1.92	1.765	1.77
X1	2.02	2.28	2.150	2.16				
X2	2.07	2.32	2.195	2.20				
HP	2.08	2.28	2.180	2.19				

τ' = measured at $V_L \simeq V_U$ level using output pulses from shaping amplifier.

τ'' = measured at V=0 level using input pulses to shaping amplifier.

$$\text{SIG Mean} = \frac{\text{SIGMA ( )}}{\sqrt{N}} \tag{7}$$

Before the corrected (preliminary) rates were calculated using the AFCS DAS program AFR, the etz correction and associated uncertainty were determined. The etz correction, ETZ, is described in Reference 3, and was calculated using

$$ETZ = 1 + V_L/V_U(\overline{S_L/S_U}-1). \tag{8}$$

For these measurements $V_L/V_U = 0.80$. The statistical uncertainty in specifying ETZ was taken as five times the larger of either s Mean of SIG Mean of the S_L/S_U set of any set of determinations. In computing the total ETZ uncertainty, 27% of the final correction was summed in quadrature with the statistical part in order to account for systematic error (to be consistent with Reference 3).

The preliminary corrected rates were then calculated from the expression:

$$\text{Preliminary corrected rate} \triangleq CR = ETZ \cdot \overline{S}_U \tag{9}$$

for each accumulation set. The total uncertainty associated with the preliminary corrected rates was calculated by taking the square root of the sum of the squares of uncertainties associated with statistical uncertainty (larger of s Mean or SIG Mean of S_U), the etz correction, and the deadtime correction.

Sample output of the AFR analysis code is presented in Appendix B, in the form of output for the 012RØ1Ø5 measurement. Data from the complete preliminary analysis set will be used in the next section, where appropriate, to explain and present the calculation of the final results.

B. Absolute Isotopic Fission Rate Results

The work sheets used to generate the final results from the AFR analyses and foil assay data are included in Appendix C. In generating the final results, the mean uncorrected (except for deadtime) rates from the AFR code were averaged

and the statistical uncertainty in the mean value was taken as the mean predicted standard deviation. It was considered inappropriate to use the experimental uncertainty values, which were generally greater due to fluctuations in reactor power.

The data and expressions used to generate the statistical uncertainties, dead-time corrections and uncertainties, and etz corrections and uncertainties (included as part of the AFR code) were presented in the previous section. In order to compute the final results, corrections and uncertainties for deposit self-absorption and fissions in impurity constituents were made, and the deposit mass assay uncertainties were factored in.

The correction for fission fragment absorption in the deposit was taken to be t/2R, where t is the thickness of the deposit in $\mu g/cm^2$, and R is the average fission fragment range in the deposit material. The reference range used was that for U_3O_8, 7.74 ± 0.90 μg U_3O_8/cm^2.[3] In Reference 3, this value was corrected for the difference in oxygen content for actinide dioxide by assuming that the range is proportional to $\sqrt{A}$ where A is the effective atomic mass evaluated according to the expression $\sqrt{A} = \sum_j n_j A_j / \sum_j n_j A_j^{\frac{1}{2}}$ (n_j are the atom fractions). The resulting corrections were found to be 0.69% per 100-μg U/cm^2 for UO_2, and 0.66% per 100-μg Pu/cm^2 for PuO_2. The values were not corrected for the lighter fluoride deposits used in the FFTF-RCP because the difference was considered negligible. In the case of the thicker ^{232}Th, ^{237}Np, and ^{240}Pu deposits, the effective atomic mass used was calculated using fluoride parameters. These corrections were 0.96% per 100-μg Np/cm^2 for NpF_4 and per 100-μg Th/cm^2 for ThF_4, and 0.80% per 100-μg Pu/cm^2 for PuF_3. The estimated uncertainty in the absorption correction is taken to be 25% of the correction or 0.35%, whichever is larger. The non-zero floor on this uncertainty is necessary because surface roughness and diffusion of fissionable material into the platinum substrate could dominate the fragment absorption processes for light deposits. A significant fraction of the fragments that are emitted nearly parallel to the deposit plane may be scattered enough to affect the absorption probability and the fission pulse-height distribution in the very low pulse-height range. However, only the difference in the in-scatter and out-scatter would affect the absolute

efficiency. The net scattering effect is expected to be slightly biased toward scattering into the active volume of the chamber, but this is compensated for by flat extrapolation of the pulse-height distribution. Hence, no adjustment for fragment scattering was made. The self-absorption correction for each deposit is listed in Table X.

Before the correction for fissions in minor isotopic constituents was performed, the preliminary rates (corrected for deadtime and etz) were corrected for self-absorption and normalized to the deposit absolute mass. The associated uncertainties in these corrections plus the counting statistical uncertainty were combined to determine the total uncertainty (square root of the sum of the squares).

The results were then corrected for impurity fissions using an iterative process. The correction factor for fissions for impurity isotopes ^{i}I for a deposit of primary isotopic composition ^{p}I was found using the expression

$$\text{impurity fissions correction factor} = \frac{n_p \sigma_p^f}{\sum_i n_i \sigma_i^f + n_p \sigma_p^f} \qquad (10)$$

where n represents atom fraction and σ the microscopic fission cross sections. Deposit composition data are listed in Table III. The cross sections used are listed in Table XI. The iterative process was begun by calculating the correction factors for ^{233}U, ^{235}U, and ^{239}Pu. Rates for threshold isotopes were then calculated, with experimental rates for fissile constituents. This process was then repeated at least twice, always using current values for each calculation. The final impurity correction results are summarized in Table XII (see Appendix C for details).

The final absolute isotopic fission rate results as measured during RCP Experiment 5 are presented as spectral indices in Table XIII for core midplane (CMP) and Table XIV for the upper axial reflector (UAR). These values are in-situ values, that is, they have not been corrected for chamber scattering of reactor neutrons. The spectral index is a spectrum averaged microscopic cross section

TABLE X

FFTF-RCP ABSOLUTE FISSION RATE DEPOSIT
SELF-ABSORPTION CORRECTIONS

Deposit	Fission Chamber	Self-Absorption Correction
25A-03-1	RCP 1T	1.0017
49K-03-2F	1B	1.0018
25A-03-2	2T	1.0017
23K-02-8	2B	1.0017
28G-5-1	3T	1.0401
02N-9	3B	1.0471
40L-2-3F	4T	1.0140
41K-03-1(L)[1]	4B	1.0054
37K-05-1	5T	1.0052
28NC-5-1	5B	1.0358
49K-001-3F	6T	1.0001
49K-005-1	6B	1.0000
49K-4-1	7T	1.0246
49K-02-3F	8T	1.0013
49K-0-3F	8B	1.0003

[1]self-absorption relatively high due to gold cover layer.

TABLE XI

FISSION CROSS SECTIONS USED TO DETERMINE IMPURITY FISSION CORRECTION FACTORS[1]

Isotope	σ_f (CMP)	σ_f (UAR)
^{233}U	2.72 ± 10% barns	6.33 ± 20%
^{234}U	.321 ± 20%	0.1999 ± 30%
^{235}U	2.02 ± 5%	3.98 ± 10%
^{236}U	0.101 ± 20%	0.0466 ± 30%
^{238}U	0.0446 ± 10%	0.0214 ± 20%
^{239}Pu	1.915 ± 5%	3.826 ± 10%
^{240}Pu	0.381 ± 10%	0.287 ± 20%
^{241}Pu	2.57 ± 10%	5.93 ± 20%
^{242}Pu	0.297 ± 20%	0.187 ± 30%
^{244}Pu	0.4 ± 100%	0.3 ± 100%
^{241}Am	0.276 ± 20%	0.191 ± 30%

[1]Cross sections are FFTF spectrum averaged and were used for the initial part of an iterative procedure as explained in the text.

TABLE XII

DEPOSIT BATCH IMPURITY FISSION CORRECTION FACTORS

Batch	CMP Correction Factor	UAR Correction Factor
23K	0.99989 ± .001%	0.99992 ± .001%
25A	0.99954 ± .006%	0.99987 ± .002%
28G	0.99203 ± .014%	0.97105 ± .051%
28NC	0.7502 ± .49%	0.4330 ± 3%
40L	0.9368 ± .12%	0.8477 ± .26%
41K	0.9765 ± .35%	0.9885 ± .18%
49K	0.99995 ± <.001%	0.99998 ± <.001%

TABLE XIII

FINAL RESULTS: IN-SITU ABSOLUTE ISOTOPIC FISSION RATES AS REFERENCED TO ^{239}PU FISSION RATE AT THE FFTF CORE MIDPLANE

Isotope	Spectral Index $\sigma_f(I)/\sigma_f(^{239}Pu)$	Total Uncertainty	Percent Fractional Uncertainties[1]	
^{233}U	1.513	±1.7% (1σ)	0.09	statistical
			0.05	deadtime
			0.16	etz
			0.35	self-absorption
			1.5	mass
			0.001	impurity fission
			1.55	subtotal
^{235}U (25A-03-1)	1.038	±1.1%	-03-1	
			0.05	
			0.06	
			0.14	
			0.35	
			0.77	
			0.006	
			0.86	
^{238}U	0.0227	±1.6%	0.05	
			0.07	
			0.81	
			0.35	
			1.15	
			0.014	
			1.45	
Normal U	0.0226	±1.8%	0.04	
			0.09	
			0.77	
			0.35	
			0.95	
			1.16	
			1.72	
^{239}Pu	1.		0.05	
			0.06	
			0.15	
			0.35	
			0.5	
			0.001	
			0.63	

[1] Summed in quadrature with ±0.63% uncertainty of 49K-03-2F at CMP. Note that quadrature sum of fractional errors is not truly independent of ^{239}Pu total error, so the total spectral index error reported here is an upper bound value.

TABLE XIII
(continued)

FINAL RESULTS: IN-SITU ABSOLUTE ISOTOPIC FISSION RATES AS REFERENCED TO ^{239}PU FISSION RATE AT THE FFTF CORE MIDPLANE

Isotope	Spectral Index $\sigma_f(I)/\sigma_f(^{239}Pu)$	Total Uncertainty	Percent Fractional Uncertainties[1]
^{240}Pu	0.2018	±1.4%	0.06 0.07 0.88 0.35 0.8 0.12 1.25
^{241}Pu	1.36	±2.7%	0.08 0.04 0.24 0.35 2.5 0.35 2.58
^{237}Np	0.1828	±1.3%	0.04 0.08 0.22 0.35 1.1 1.18
^{232}Th	0.00556	±2.7%	0.095 0.09 1.23 1.18 2.0 2.63

TABLE XIV

FINAL RESULTS: IN-SITU ABSOLUTE ISOTOPIC FISSION RATES AS REFERENCED TO ^{239}PU FISSION RATE[1] AT THE FFTF UPPER AXIAL REFLECTOR

Isotope	Spectral Index $\sigma_f(I)/\sigma_f(^{239}Pu)$	Total Uncertainty	Percent Fractional Uncertainties[2]	
^{233}U	1.513	±1.7% (1σ)	±0.06	statistical
			0.05	deadtime
			0.12	etz
			0.35	self-absorption
			1.5	mass
			0.001	impurity fission
			1.55	subtotal
^{235}U	1.015	±1.1%	-03-1	
			0.11	
			0.03	
			0.18	
			0.35	
			0.77	
			0.002	
			0.87	
^{238}U	0.00598	±3.4%	0.07	
			0.07	
			0.81	
			0.35	
			1.15	
			0.051	
			1.45	
Normal U	0.00561	±4.4%	0.08	
			0.09	
			0.77	
			0.35	
			0.95	
			2.90	
			3.17	
^{239}Pu	1.		0.11	
			0.03	
			0.22	
			0.35	
			0.5	
			0.001	
			0.66	

[1]The ratio of the UAR reference ^{239}Pu rate to that used in Table XI at core midplane equals 0.671 ± 0.91%.

[2]Not listed is ±3.0% estimated fractional systematic error in fertile isotope measurements in UAR included in total uncertainty values.

TABLE XIV
(continued)

FINAL RESULTS: IN-SITU ABSOLUTE ISOTOPIC FISSION RATES AS REFERENCED TO ^{239}PU FISSION RATE[2] AT THE FFTF UPPER AXIAL REFLECTOR

Isotope	Spectral Index $\sigma_f(I)/\sigma_f(^{239}Pu)$	Total Uncertainty	Percent Fractional Uncertainties
^{240}Pu	0.0761	±3.3%	0.06 0.04 0.99 0.35 0.8 0.26 1.34
^{241}Pu	1.50	±2.7%	0.07 0.03 0.43 0.35 2.5 0.18 2.57
^{273}Np	0.0604	±3.3%	0.085 0.09 0.34 0.35 1.1 1.21
^{232}Th	0.00145	±4.3%	0.16 0.07 1.87 1.18 2.0 2.98

ratio, that is, a rate normalized to a reference rate but compensated for differences in deposit mass and atomic weight. The spectral index of isotope 1 referenced to isotope 2 is found from the measured fission rate FR_1 and FR_2, as follows:

$$\text{spectral index} = \frac{FR_1}{FR_2} \cdot \frac{A_1/M_2}{A_2/M_2} \qquad (11)$$

where A is the atomic weight and M the deposit mass. In Appendix C, the results were computed in terms of a calibration factor relating ^{239}Pu fission rate to reactor power. This value is imprecise at this time, therefore, the alternate form of reporting was chosen. In Table XIII and XIV, the total uncertainty components have been broken down.

As is seen from the Experiment 5 plan outlined in Table V, the runs within this experiment were performed at various reactor power levels. The monitor chamber count rates were used for run-to-run power level normalization.

The results for ^{238}U and Normal U in the upper axial reflector (Table XIV) differ from each other by more than the reported fractional uncertainty sum. The midplane results from the two deposits are in agreement, however. The possibility of radial and axial gradients combined with different chamber placement in the upper axial reflector for the two deposits was investigated. Reaction rate gradients from a three-dimensional diffusion theory calculation performed during pre-experment planning were examined, and the calculated reaction rate gradients were too small to explain the discrepancy. As of this writing, the disagreement is not completely resolved. There is the possibility that significant streaming may have occurred vertically along annular gaps between IRT and/or EI walls, something not determinable via diffusion theory calculations. A ±3.0% fractional systematic error was thusly figured into the fertile isotope total uncertainty for the UAR results. For comparison purposes with other IRT experiments requiring fissions/gram for ^{238}U, the results from the depleted uranium will be used.

In-situ fission rate data were required to provide the absolute basis for passive dosimeter fission rate determination using dosimeters in dummy chambers. To compare results with future reactor neutronics calculations, which may be unable to model the fission chamber, the fission rates must be corrected for neutron scattering in the chamber material. Scattering correction factors were calculated using a Monte Carlo code (see Appendix D for details) for ^{239}Pu and ^{238}U at the midplane and upper axial reflector locations. The ^{239}Pu factors were applied to all fissile deposits, and the ^{238}U factors were applied to all other (threshold reaction) deposits. Table XV lists the multiplicative correction factors and associated uncertainties from the Monte Carlo runs. Spectral indices corrected for chamber scattering are presented in Table XVI and XVII.

C. Normalization of Results to Other RCP Measurements

Just as the runs within Experiment 5 were normalized to one another using the monitor chamber, so too were the various experiment measurements listed in Table I. Monitor chambers were used (1) to normalize proton recoil experiment data (IRT Experiments 2 and 3) to ^{239}Pu fission rate, and (2) to normalize passive fission dosimeter irradiations (IRT Experiments 8 and 10) to ^{239}Pu total fissions/gram.

Fission chamber RCP 7 was used in the +21" UAR position for monitoring during Experiment 2. ^{239}Pu deposit 49K-4-1 (mass 468.1 μg ± 0.6%) was loaded in the top position, and a blank in the bottom (for background noise detection). The corrected measured rate data for this experiment are provided in Table XVIII. Chamber RCP 7 was used in the same manner during Experiment 3 and the results are similarly reported in Table XIX. Because of the low counting rates in both these experiments, the ETZ correction was deduced from a weighted average over all four runs according to the inverse square of the mean standard deviation in S_L/S_U for each run, and the systematic part of the associated error was taken as 40% of the correction.

Fission chamber RCP 6 was used in the -15" (core bottom) monitor position for Experiments 8 and 10. Monitor-chamber-determined ^{239}Pu fission rates were

TABLE XV

FREE-FIELD FISSION RATE CORRECTION FACTORS*

Isotope	Core Midplane	Upper Axial Reflector
^{233}U	.991 ± 1.2% (1σ)	.972 ± 1.4%
^{235}U	.991 ± 1.2%	.972 ± 1.4%
^{238}U	1.017 ± 1.1%	1.033 ± 1.3%
^{239}Pu	.991 ± 1.2%	.972 ± 1.4%
^{240}Pu	1.017 ± 1.1%	1.033 ± 1.3%
^{241}Pu	.991 ± 1.2%	.972 ± 1.4%
^{237}Np	1.017 ± 1.1%	1.033 ± 1.3%
^{232}Th	1.017 ± 1.1%	1.033 ± 1.3%

*Multiply in-situ isotopic fission rate by correction factor to obtain free-field fission rate.

TABLE XVI

FREE-FIELD ABSOLUTE ISOTOPIC FISSION RATES AS REFERENCED TO ^{239}PU FISSION RATE AT FFTF CORE MIDPLANE

Isotope	Spectral Index $\sigma_f(I)/\sigma_f(^{239}Pu)$	Total Uncertainty
^{233}U	1.513	±1.7% (1σ)
^{235}U	1.038	±1.1%
^{238}U	0.0233	±2.3%
Normal U	0.0232	±2.3%
^{239}Pu	1.	
^{240}Pu	0.2071	±2.1%
^{241}Pu	1.36	±2.7%
^{237}Np	0.1876	±2.1%
^{232}Th	0.00571	±3.2%

TABLE XVII

FREE-FIELD ABSOLUTE ISOTOPIC FISSION RATES AS REFERENCED TO ^{239}PU FISSION RATE AT FFTF UPPER AXIAL REFLECTOR

Isotope	Spectral Index $\sigma_f(I)/\sigma_f(^{239}Pu)$	Total Uncertainty
^{233}U	1.513	±1.7% (1σ)
^{235}U	1.015	±1.1%
^{238}U	0.00636	±3.9%
Normal U	0.00596	± 4.8%
^{239}Pu	1.	
^{240}Pu	0.0809	±3.8%
^{241}Pu	1.50	±2.7%
^{237}Np	0.0642	±3.8%
^{232}Th	0.00155	±4.7%

TABLE XVIII

FFTF-RCP EXPERIMENT 2 - PROTON RECOIL CHAMBER SPECTROMETER
MONITOR CHAMBER NORMALIZATION DATA

Control Rod Configuration	Run ID	Mean Absolute Fission Rate[1,2]	Total Uncertainty	Correction Factors		Percent Fractional Uncertainties
3 primaries @23.5 in. 6 secondaries fully inserted	2271A140	2.63×10^{-3} f/s/μg^{239}	±2.1% (1σ)	deadtime: ETZ: self-absorption: impurity fissions:	1.0000026 1.0437 1.0246 0.9999	0.87 statistical - deadtime 1.75 ETZ 0.62 self-absorption 0.6 mass <.001 impurity fissions
3 primaries @36 in. 6 secondaries @ 12 in.	2281B156	2.06×10^{-2} f/s/μg^{239}	±2.0%	deadtime: ETZ: self-absorption: impurity fissions:	1.0000207 1.0437 1.0246 0.9999	0.22 statistical - deadtime 1.75 ETZ 0.62 self-absorption 0.6 mass <.001 impurity fissions

[1] Monitor chamber position at +21" above core midplane (upper axial reflector).

[2] Deposit used was 49 K-4-1 @468.1 μg ± 0.6% ^{239}Pu.

TABLE XIX

FFTF-RCP EXPERIMENT 3 - PROTON RECOIL EMULSIONS
MONITOR CHAMBER NORMALIZATION DATA

Control Rod Configuration	Run ID	Mean Absolute Fission Rate	Total Uncertainty	Correction Factors		Percent Fractional Uncertainties
primaries fully inserted secondaries fully inserted	2282B18	1.69×10^{-3} f/s/μg^{239}	± 3.4% (1σ)	deadtime: ETZ: self-absorption: impurity fissions:	1.0000018 1.0437 1.0246 0.9999	2.7 statistical - deadtime 1.79 ETZ 0.62 self-absorption 0.6 mass <.001 impurity fissions
3 primaries @36" secondaries fully inserted	2282C53	5.21×10^{-3} f/s/μg^{239}	± 2.1%	deadtime: ETZ: self-absorption: impurity fissions:	1.0000052 1.0437 1.0246 0.9999	0.87 statistical - deadtime 1.75 ETZ 0.62 self-absorption 0.6 mass <.001 impurity fissions

then normalized to those obtained using RCP 8 during experiment 5. This quantitative comparison was used to specify the total fissions/μg for all isotopes at the CMP and UAR positions for the passive irradiations. RCP 6 was loaded with ^{239}Pu deposits 49K-001-3F (1.78 μg ± 0.6%) and 49K-005-1 (0.0983 μg ± 0.8%), top and bottom, respectively. The AFCS data acquisition system described earlier in this report was augmented with eight-decade scalers which were not interrupted during the entire irradiation in order to determine total fissions. The final results for these two measurements are presented as Table XX and XXI.

V. RESULTS, DISCUSSION AND CONCLUSIONS

Absolute fission rate measurements, using modified NBS absolute fission chambers with isotopic fissionable deposits, were successfully completed in the FFTF IRT during acceptance testing. The goal of 2-5% accuracy fission rate mapping in special characterizer assemblies in later phases of the Reactor Characterization Program required a careful series of passive dosimeter calibration measurements in the IRT.

The core mid-plane results, extrapolated to power levels in passive sensor experiments (Table XX and XXI), had final uncertainties in the range 0.9% to 2.7%. This range of uncertainties is small compared with other uncertainties inherent in passive dosimeter radiometric fission rate determinations. The results obtained in the upper chamber, which was in a relatively softer neutron spectrum, were in the same range as the core midplane results for the fissile deposits, but were larger (3-5%) for the threshold type deposits. The larger uncertainties are a result of a measured discrepancy between the ^{238}U fission rate results obtained from two deposits. However, the primary purpose of the upper chamber measurements was to investigate possible neutron spectrum dependence of the fission product yields. Threshold type fissionable isotopes are not expected to exhibit neutron energy dependence, so the midplane results satisfy programmatic requirements for non-fissile samples.

TABLE XX

FFTF-RCP EXPERIMENT 8 - FISSION YIELD EXPERIMENT
MONITOR-CHAMBER-DERIVED TOTAL FISSIONS (IN SITU)

Isotope	CMP Total In-Situ Fissions	UAR Total In-Situ Fissions
^{233}U	1.284×10^{8} f/μg ± 1.8% (1σ)	8.611×10^{7} ± 1.8%
^{235}U	8.734×10^{7} ± 1.2%	5.74×10^{7} ± 1.2%
^{238}U*	1.882×10^{6} ± 1.7%	3.33×10^{5} ± 3.4%
^{239}Pu	8.270×10^{7} ± 0.9%	5.548×10^{7} ± 0.9%
^{240}Pu	1.662×10^{7} ± 1.5%	4.203×10^{6} ± 3.4%
^{241}Pu	1.113×10^{8} ± 2.7%	8.252×10^{7} ± 2.7%
^{237}Np	1.525×10^{7} ± 1.5%	3.381×10^{6} ± 3.4%
^{232}Th	4.74×10^{5} ± 2.6%	8.31×10^{4} ± 4.2%

*Data from depleted uranium deposit.

TABLE XXI

FFTF-RCP EXPERIMENT 10 - SSTR AND PASSIVE DOSIMETER CALIBRATIONS
MONITOR-CHAMBER-DERIVED TOTAL FISSIONS (IN SITU)

Isotope	CMP Total In-Situ Fissions	UAR Total In-Situ Fissions
^{233}U	3.974×10^{8} f/μg ± 1.8%	2.666×10^{8} ± 1.8%
^{235}U	2.704×10^{8} ± 1.2%	1.772×10^{8} ± 1.2%
^{238}U*	5.83×10^{6} ± 1.7%	1.03×10^{6} ± 3.4%
^{239}Pu	2.560×10^{8} ± 0.9%	1.717×10^{8} ± 0.9%
^{240}Pu	5.146×10^{7} ± 1.5%	1.301×10^{7} ± 3.4%
^{241}Pu	3.447×10^{8} ± 2.7%	2.555×10^{8} ± 2.7%
^{237}Np	4.721×10^{7} ± 1.5	1.047×10^{7} ± 3.4%
^{232}Th	1.47×10^{6} ± 2.6%	2.57×10^{5} ± 4.5%

*Data from depleted uranium deposit.

The free-field results (Table XVI and XVII) will be used to compare with future neutronics calculations. The core midplane free-field uncertainties lie in the 1.4% to 2.7% range, while the upper location results have uncertainties from 1.4% to 4.2%. Spectral index comparison with calculations will be limited accordingly. It is possible that results from passive dosimeter measurements in the IRT will resolve the ^{238}U discrepancy and consequently reduce the final uncertainties on all non-fissile results.

In conclusion, the primary purpose of the absolute fission chamber measurements was achieved, and the results will be used in analysis of other IRT fission rate measurements using radiometric techniques. Comparison of spectral indices results with neutronics calculations will be performed in the future, and other IRT fission rate measurements may be used to reduce uncertainties in this comparison.

VI. REFERENCES

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2. "FFTF Reactor Characterization Experiments-Neutronic Experiments," HEDL-TC-1904, edited by J. A. Rawlins (to be published).

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4. J. Van Audenhove, P. DeBievre, J. Pauwels, F. Peetermans, M. Gallet, A. Verbruggen, "The Preparation and Characterization of Reference Fission Foils," presented at World Conference of the International Nuclear Target Development Society, Munich, September 11-14, 1978.

5. J. L. Fuller, B. D. Zimmerman, D. M. Gilliam, J. A. Grundl, "Mockup Testing of the FFTF Reactor Characterization Program Absolute Fission Chamber System," HEDL-TC-1308, 1980.

APPENDIX A

DATA ACQUISITION SOFTWARE LISTING

```
C TIL-0245

20.01 C PROGRAM 'NIMIN', 10/11/80 RCP VERSION
20.02 O CT
20.10 X FCHR(7,27,12);T "                                    PROGRAM 'NIMIN'",!,!
20.11 X FTGL(2,1);X FTGL(4,0)
20.12 T "'NIMIN' DISPLAYS AND STORES PULSE COUNTING DATA FROM AFC HARDW
ARE       THROUGH ORTEC INC. SPECIAL INTERFACE."
20.18 T " MULTI-NETWORK PULSE HEIGHT          ANALYSIS IS ALSO PROVIDED."
20.30 T !,"COUNTING INTERVAL MUST BE LONG ENOUGH FOR DATA OUTPUT (> 60
SECS.) ",!
20.40 D 30
20.74 X FT(3);X 1^3000;X FCHR(7,27,12)
20.76 T "NIMIN SET-UP CONTINUED:",!,!
20.80 T !,!,"STANDBY WHILE ARRAYS ZEROED"; F N=1,198;S S(N)=0
20.82 T !
20.84 D 30.10
20.86 T !,!

21.36 T !,!;A "SPECIFY NUMBER OF DETERMINATIONS (< 11): ",DETER
21.38 T !;A "SPECIFY ADC REAL TIME IN SECONDS: ",T
21.40 T !;A "SET PRINT OUT CONTROL CYCLE MODE SWITCH TO 'TIMED RECYCLE'
",QZ
21.42 T !;A "MANUALLY RESET ALL TIMERS ",QQZ
21.44 T !;A "SET TWO ADC'S TO 'COINC' MODE ",QQZ;T !
21.46 T !,!
21.47 A "SPECIFY 'RT', THE FFTF TIME AT START OF EXPERIMENT (HRMNSC):
",RT
21.48 T !,!,!;A "PRESS ...'RETURN'... TO START ADC'S AT APPRX RT-3 SEC
                    THEN START COUNTING HARDWARE AT RT   ",Q1
21.50 I(Q1-0START)21.52,21.52,21.52
21.52 X FADC(1,2,-T);X 1^2000;X FTGL(2,0)

22.08 S D=1;S N=1
```

```
22.10 X FX(-2,013122,135)
22.20 X FX(-2,013070,261000)
22.25 X FX(-2,175612)
22.27 S ERR=0
22.30 O R
22.40 F N=1,204;S S(N)=FCHR(-1)
22.50 O TK

23.10 F N=1,204;S S(N)=S(N)-48
23.15 I(S(1)-0)27.10,23.20,23.20
23.20 S DATE(D)=S(1)*1.E5+S(2)*1.E4+S(3)*1.E3+S(4)*100+S(5)*10+S(6)
23.22 S CDE(D)=S(8)*10+S(9)
23.24 S INT(D)=S(10)*1000+S(11)*100+S(12)*10+S(13)
23.26 S TIM(D)=S(15)*1.E5+S(16)*1.E4+S(17)*1000+S(18)*100+S(19)*10+S(20
)
23.28 S C(D,1)=S(22)*1.E5+S(23)*1.E4+S(24)*1000+S(25)*100+S(26)*10+S(27
)
23.30 S C(D,2)=S(29)*1.E5+S(30)*1.E4+S(31)*1000+S(32)*100+S(33)*10+S(34
)
23.32 S C(D,3)=S(36)*1.E5+S(37)*1.E4+S(38)*1000+S(39)*100+S(40)*10+S(41
)
23.34 S C(D,4)=S(43)*1.E5+S(44)*1.E4+S(45)*1.E3+S(46)*100+S(47)*10+S(48
)
23.35 S C(D,5)=S(50)*1.E5+S(51)*1.E4+S(52)*1.E3+S(53)*100+S(54)*10+S(55
)
23.38 S C(D,6)=S(57)*1.E5+S(58)*1.E4+S(59)*1.E3+S(60)*100+S(61)*10+S(62
)
23.40 S C(D,7)=S(64)*1.E5+S(65)*1.E4+S(66)*1.E3+S(67)*100+S(68)*10+S(69
)
23.42 S C(D,8)=S(74)*1.E5+S(75)*1.E4+S(76)*1000+S(77)*100+S(78)*10+S(79
)
23.44 S C(D,9)=S(81)*1.E5+S(82)*1.E4+S(83)*1000+S(84)*100+S(85)*10+S(86
)
23.46 S C(D,10)=S(88)*1.E5+S(89)*1.E4+S(90)*1000+S(91)*100+S(92)*10+S(9
3)
```

```
23.48 S C(D,11)=S(95)*1.E5+S(96)*1.E4+S(97)*1000+S(98)*100+S(99)*10+S(1
00)
23.50 S C(D,12)=S(102)*1.E5+S(103)*1.E4+S(104)*1000+S(105)*100+S(106)*1
0+S(107)
23.52 S C(D,13)=S(109)*1.E5+S(110)*1.E4+S(111)*1000+S(112)*100+S(113)*1
0+S(114)
23.54 S C(D,14)=S(116)*1.E5+S(117)*1.E4+S(118)*1.E3+S(119)*100+S(120)*1
0+S(121)
23.56 S C(D,15)=S(123)*1.E5+S(124)*1.E4+S(125)*1000+S(126)*100+S(127)*1
0+S(128)
23.58 S C(D,16)=S(130)*1.E5+S(131)*1.E4+S(132)*1000+S(133)*100+S(134)*1
0+S(135)
23.60 S C(D,17)=S(137)*1.E5+S(138)*1.E4+S(139)*1.E3+S(140)*100+S(141)*1
0+S(142)
23.62 S C(D,18)=S(147)*1.E5+S(148)*1.E4+S(149)*1000+S(150)*100+S(151)*1
0+S(152)
23.64 S C(D,19)=S(154)*1.E5+S(155)*1.E4+S(156)*1000+S(157)*100+S(158)*1
0+S(159)
23.66 S C(D,20)=S(161)*1.E5+S(162)*1.E4+S(163)*1000+S(164)*100+S(165)*1
0+S(166)
23.68 S C(D,21)=S(168)*1.E5+S(169)*1.E4+S(170)*1000+S(171)*100+S(172)*1
0+S(173)
23.70 S C(D,22)=S(175)*1.E5+S(176)*1.E4+S(177)*1000+S(178)*100+S(179)*1
0+S(180)
23.72 S C(D,23)=S(182)*1.E5+S(183)*1.E4+S(184)*1000+S(185)*100+S(186)*1
0+S(187)
23.74 S C(D,24)=S(189)*1.E5+S(190)*1.E4+S(191)*1000+S(192)*100+S(193)*1
0+S(194)
23.76 S C(D,25)=S(196)*1.E5+S(197)*1.E4+S(198)*1.E3+S(199)*100+S(200)*1
0+S(201)

24.10 G 25.10
24.12 % FCHR(27,23);X 1^3000;X FCHR(7,27,12);T !,"DATA PARAMETERS ARE:"
,!
24.14 T !,"      DATE: ",%8.00,DATE(1),"          EXPT. CODE: ",%3.00,"
```

```
  ",CDE(1),"      TIME:",%6.00,RT
24.16 T !,"      INTERUAL: ",%4.00,INT(1),"          COUNTING TIME: ",%4.0
1,TIM(1)/10
24.18 T !,!,!,"DATA:"
24.20 T !,!,"DETERMINATION:",%3.00,D,"      ACCUM. NOISE COUNTS:",%7.00,
C(D,25)
24.21 I(ERR-0)24.22,24.22,27.80
24.22 T !,!,"    DEPOSIT          CL          CU          CGC          CL/C
U      CGC/CU",!
24.30 S I=1
24.32 T %8.00
24.34 T !, C(D,I)," ",C(D,I+2),"   ",C(D,I+3),"   ",C(D,I+4),"       ",%5.
04,C(D,I+2)/C(D,I+3),"    ",C(D,I+4)/C(D,I+3)
24.35 T %8.00
24.36 T !,C(D,I+1)," ",C(D,I+5),"   ",C(D,I+6),"   ",C(D,I+7),"       ",%5
.04,C(D,I+5)/C(D,I+6),"    ",C(D,I+7)/C(D,I+6)
24.37 X FCHR(7);X 1^1000
24.38 S I=I+8
24.40 T %8.00;D 24.34
24.42 T %8.00;D 24.36
24.43 X FCHR(7);X 1^1000
24.44 D 24.38
24.46 T %8.00;D 24.34
24.48 T %8.00;D 24.36
24.49 X FCHR(7);X 1^3000;T !
24.52 I(D-DETER)24.54,26.02,26.02
24.54 C F I=1,205;S S(I)=0
24.56 S D=D+1;S N=1;G 22.25

25.10 I(D-2)24.12,24.20,25.11
25.11 I(D-4)24.12,24.20,25.12
25.12 I(D-6)24.12,24.20,25.13
25.13 I(D-8)24.12,24.20,25.14
25.14 I(D-10)24.12,24.20,25.15
25.15 I(D-12)24.12,24.20,25.16
```

```
25.16 I(D-14)24.12,24.20,25.17
25.17 I(D-16)24.12,24.20,25.18
25.18 I(D-18)24.12,24.20,25.19
25.19 I(D-20)24.12,24.20,24.20

26.02 X FT(3)
26.04 X 1^2000;X FCHR(7,27,12);X 1^2000
26.10 T !,!,"EXPERIMENT COMPLETED - ADC'S STOPPED - STOP 773 TIMERS"
26.12 T !,!,"STANDBY TO INITIATE DATA STORAGE"
26.14 X 1^15000;X FCHR(7,27,12);X 1^1000
26.16 T "DATA STORAGE SEQUENCE USING L T 17:"
26.18 T !,!,!;A "WHEN DISK READY TYPE 'START'  ",Q5
26.20 I(Q5-0START)26.18,26.22,26.18
26.22 T !,!,!,"WHEN PROMPT 'FILE:' APPEARS, RESPOND WITH DATA FILE NAME
 "
26.24 T !,"FORMAT IS MONTH-DAY-'R'-CODE-#DETERMINATIONS; EG., 917R0110
"
26.25 T !,!,"EXPERIMENT CODE IS:",%3.00,CDE(1),"          #DETERMINATIO
NS =",DETER
26.26 T !
26.27 L T 17
26.30 L S
26.31 T RT
26.32 T DATE(D)
26.34 T CDE(D)
26.36 T INT(D)
26.38 T TIM(D)
26.40 F J=1,D;F K=1,24;T C(J,K)
26.42 T !
26.44 L C
26.48 T "RATE DATA STORED",!,!
26.50 T !,!,!;A "ARE THERE CORRESPONDING HISTOGRAMS TO SAVE? (YES/NO):
 ",Q6
26.52 I(Q6-0YES)26.76,26.54,26.76
26.54 T !,!,!,"WHEN PROMPT 'FILE:' APPEARS, RESPOND WITH HISTOGRAM FILE
```

```
 NAME."
26.56 T !,"FORMAT IS MONTH-DAY-'H'-CODE; EG., 917H01 "
26.58 T !
26.70 L S
26.72 X FLD(1,2048);L C
26.74 T !,"HISTOGRAM DATA STORED",!;X 1^600
26.76 X FT(3);X FT(1)
26.78 T !,"LIBRARY LIST FROM L T 17",!
26.80 L L
26.90 T !,!,"PROGRAM END",!
26.92 X 1^5000;X FT(3);X 1^2000
26.94 X FTGL(2,1)
26.99 Q

27.10 C RESET ERROR CORRECTION
27.20 X 1^1000;X FCHR(7);X 1^200;X FCHR(7);X 1^200;X FCHR(7);X 1^200;X
FCHR(7);X 1^200;X FCHR(7)
27.30 S ERR=1
27.50 F I=1,204;S S(I)=S(I+1)
27.59 G 23.20
27.80 T "   ERR FLAG UP"
27.89 G 24.22

30.01 T !,!,!;X FTGL(2,0);X FTGL(3,0)
30.02 A "ARE AMPLIFIER GAINS SET FOR UPEAK=CH100 ? (YES/NO)  ",Q11
30.03 I(Q11-0YES)30.04,30.10,30.04
30.04 T !,!,!,"PROGRAM IS TERMINATED - INPUT PROGRAM 'GILLIAM' TO SET/C
HECK GAINS"
30.06 Q
30.10 T !,!,!,"FOLLOW EACH INSTRUCTION BELOW - PRESS ...'RETURN'...TO C
ONTINUE"
30.12 T !,!,!
30.14 T !;A "TURN OFF (STOP) TIMER #1 AND CYCLE MODE SWITCH ON PRINTOUT
 CONTROL    ",Q10
30.18 T !;A "READY TTY AND LEADER PAPERTAPE  ",Q12
```

```
30.22 T !;A "SET 'DATE-CODE-INTERVAL-DEPOSIT' ID ON BLACK DATA MODULES
 ",Q13
30.26 T !;A "SET COUNTING TIME ON TIMER #3  ",Q14
30.30 A "SET INTERVAL TIME ON TIMER #2  ",Q15
30.34 A "SET TOTAL EXPERIMENT TIME (THEREFORE ADC REAL TIME) ON TIMER #
1  ",Q16
30.36 D 31
30.38 T !,!;A "READY SHORT INTERVAL FLUX MONITOR SYSTEM  ",Q17
30.80 R

31.02 C SUBROUTINE TO SET UP 6 CHANNEL DISPLAY
31.03 T !;A "SET THUMBWHEEL #1 TO '00001'   ",QQA
31.04 X FTGL(2,0);X FTGL(3,0)
31.10 X FSTP(1,2);X FZER(1,2048)
31.12 X FORG(1,1)+FORG(2,1025)
31.14 X FVPOS(500)
31.20 X 1^1000
31.22 X FCUR(1,1);X FCUR(2,768)
31.24 X 1^1000
31.26 X FTGL(2,1);X FTGL(3,1)
31.28 X 1^1000
31.29 T !;A "SET THUMBWHEEL #1 TO '00769'   ",QQB
31.30 X FTGL(4,1)
31.40 X 1^1000
31.42 X FCUR(1,100)+FCUR(2,356)
31.90 C RETURN

96.10 F I=0,512;X FPL(4*I,FB(0,I+1))
96.99 Q

97.02 X FCHR(7,27,12)
97.04 T !,!,!,!,!
97.06 A "RCP-AFCS CHANNEL USED:",CH
97.10 X FCHR(7,27,12)
97.18 T %6.00
```

```
97.20 T "RCP-AFCS CHANNEL: ",CH
97.22 T !,!
97.30 S L=(CH-1)*256+85
97.32 S U=(CH-1)*256+110
97.40 F I=L,U;T I,FMCA(I),"        ",I-((CH-1)*256),!
97.50 T !,!
97.52 S LL=(CH-1)*256+20
97.54 S UL=(CH-1)*256+256
97.60 T "MEAN CHANNEL="
97.62 S MC=FPMOM(LL,UL,1)/FPMOM(LL,UL,0)
97.64 T MC,MC-((CH-1)*256)
97.99 Q

98.01 X FSTP(1,2)
98.02 X FZER(1,2048)
98.04 X FADC(1,2,-100)
98.06 Q

99.01 L S NIMIN;T "E A"!;W A;T "*G 20.10"!;L C;L L
*
```

APPENDIX B

DATA PRELIMINARY ANALYSIS SOFTWARE LISTING

```
*W
C TIL-0245

60.10 C 2/18/81 VERSION OF AFR (DELETABLE DETERMINATIONS)
60.11 X FCHR(7,27,12)
60.12 T "                                   PROGRAM 'AFR'"
60.13 X FTGL(2,0)
60.14 T !,!,"'AFR...' READS DISKETTE-LT17  RCP-AFC COUNT AND HISTOGRAM
DATA (ENTERED VIA 'NIMIN' OR 'PTAPE' FORMAT)."
60.16 T " THE COUNT DATA IS THEN REDUCED IN THE   CONVENTIONAL NBS MANN
ER AND DISPLAYED FOR HARDCOPY."
60.18 T "THE HISTOGRAM DATA  IS ALSO DISPLAYED FOR HARDCOPY. DEAD TIME
DATA ENTERED/COMPUTED VIA    GROUP 62."
60.19 T " AFREXEC IS FIRST IN SET OF CHAINED ROUTINES."
60.20 T !,!
60.22 A "SPECIFY NUMBER OF NETWORKS IN EXPERIMENT
                                (FOR MONITOR: 2, FOR OTHER: 6):      ",CH
60.24 T !;A "SPECIFY MONITOR CHAMBER NUMBER (6, 7 OR 8):                  "
,MC
60.29 T!,!;A "IS PRINTER READY(YES/NO)?
",Q1
60.30 I(Q1-0YES)60.28,60.32,60.28
60.32 A "IS DATA DISC IN LT17 AND ON-LINE?                                ",Q2
60.34 I(Q2-0YES)60.32,60.35,60.32
60.35 T !,!,!,!
60.36 T !,"DATLA WRITTEN FOR UL=0.8*UU"
60.37 T !,"CHANGE LINE 64.21 IF DIFFERENT DISCRIMINATOR SETTINGS USED"
60.40 X 1^3000
60.60 X FT(3);I(CH-2)60.62,60.62,60.64
60.62 S CC=4;G 60.70
60.64 I(CH-6)60.66,60.68,60.68
60.66 S CC=4;G 60.70
60.68 S CC=20
60.70 S KC=CC+4;S U=0
```

```
61.10 T !,!
61.11 X FCHR(7,27,12)
61.12 T "DATA READ SEQUENCE:"
61.14 T !,!,"CURRENT LT-17 DIRECTORY:"
61.15 L T 17;L L
61.17 TYPE !,!,"WHEN PROMPT 'FILE:' APPEARS INPUT RATE DATA FILE NAME"
61.18 T !,!;A "SPECIFY NUMBER OF DETERMINATIONS IN DATA FILE:  ",D
61.20 L A
61.21 A JIM
61.22 A DATE
61.24 A CDE
61.26 A INT
61.28 A TIM
61.30 F J=1,D;F K=1,24;A R(J,K)
61.32 L C
61.34 T !,!,"RATE DATA READ - STANDBY FOR SPECTRUM DISPLAY"
61.36 O C;T "STANDBY FOR SPECTRA DISPLAY";O T
61.39 T !,!,"WHEN PROMPT 'FILE' APPEARS INPUT SPECTRA FILE NAME",!,!
61.40 L A
61.42 X FLR(1,2048);L C
61.43 O CT
61.44 T !,"HISTOGRAM DATA READ "
61.45 D 85
61.48 G 80.10
61.49 X FTGL(2,0);X FTGL(3,0)
61.50 F I=1,D;F K=1,24;S C(I,K)=R(I,K)
61.51 F I=1,D;F K=1,24;S R(I,K)=0.0
61.52 T !,"DATA LIST AND ANALYSIS FOLLOWS - STANDBY"
61.54 T !,!,!

62.10 C DEADTIME DATA
62.20 S T(3)=2.24
62.21 S T(4)=2.24
62.22 S T(5)=1.78
```

```
62.30 S T(6)=2.16
62.31 S T(7)=2.16
62.32 S T(8)=1.78
62.40 S T(11)=2.30
62.41 S T(12)=2.30
62.42 S T(13)=1.78
62.50 S T(14)=2.20
62.51 S T(15)=2.20
62.52 S T(16)=1.74
62.60 S T(19)=2.24
62.61 S T(20)=2.24
62.62 S T(21)=1.77
62.70 S T(22)=2.21
62.71 S T(23)=2.21
62.72 S T(24)=1.77

63.10 C DATA ANALYSIS
63.12 S TIM=TIM/10.
63.20 C DIVIDING FOR RATES
63.22 F J=1,D;F K=3,8;S R(J,K)=C(J,K)/TIM
63.24 F J=1,D;F K=11,16;S R(J,K)=C(J,K)/TIM
63.26 F J=1,D;F K=19,24;S R(J,K)=C(J,K)/TIM
63.28 X FTGL(2,0)
63.30 C CORRECTING FOR DEAD TIME
63.32 F J=1,D;DO 70
63.40 C CALCS FOR AVERAGES: MEAN
63.42 F K=1,KC;S CAV(K)=0;S SAV(K)=0;S QAV(K)=0;S QBV(K)=0;S QRV(K)=0
63.44 F J=1,D;D 71
63.50 F K=1,KC;S CAV(K)=CAV(K)/D;S SAV(K)=SAV(K)/D;S QAV(K)=QAV(K)/D;S
QBV(K)=QBV(K)/D;S QRV(K)=QRV(K)/D
63.70 C CALCS FOR EXP. STD. DEV.
63.72 F K=1,KC;S Z1(K)=0;S Z2(K)=0;S Z3(K)=0
63.74 F J=1,D;D 72
63.76 F K=1,KC;S X1(K)=FSQT(Z1(K)/(D-1));S X2(K)=FSQT(Z2(K)/(D-1));S X3
(K)=FSQT(Z3(K)/(D-1))
```

```
63.78 C X'I'(K) = EXP. STD. DEV.
63.80 C CALCS FOR PRED. STD DEV.: SIGMA
63.81 S L=4
63.82 F K=L,3,L+3;S S1G(K)=SAU(K)*(1./FSQT(CAU(K)))
63.83 F K=L,3,L+3;S S2G(K)=FSQT(QAU(K)*(QAU(K)-1)/CAU(K))
63.84 F K=L,3,L+3;S S3G(K)=FSQT(((CAU(K)-(CAU(K)*QRU(K)))*(CAU(K)*QRU(K
))))/(CAU(K)^3))
63.85 S L=L+8
63.86 I(L-CC)63.82,63.82,63.90
63.90 C CALCS FOR S MEAN
63.92 S RTD=FSQT(D)
63.94 F K=1,KC;S M1(K)=X1(K)/RTD;S M2(K)=X2(K)/RTD;S M3(K)=X3(K)/RTD
63.96 C CALCS FOR SIG MEAN
63.98 F K=1,KC;S G2M(K)=S2G(K)/RTD;S G1M(K)=S1G(K)/RTD;S G3M(K)=S3G(K)/
RTD

64.02 C CALCS FOR DEAD TIME CORRECTION: D1T
64.03 S XM=5
64.04 S L=4
64.06 F K=L,3,L+3;S D1T(K)=SAU(K)/(CAU(K)/TIM)
64.07 C CALCS FOR ETZ CORRECTION: ETZ
64.08 F K=L,3,L+3;S ETZ(K)=1.0+XM*(QAU(K)-1.0)
64.68 S L=L+8
64.70 I(L-CC)64.06,64.06,64.89
64.89 L T 18
64.90 L I AFRS1

70.01 C DEAD TIME SUBROUTINE
70.10 S L=4
70.12 F K=L,3,L+3;S S(J,K-1)=R(J,K-1)*(1+R(J,K-1)*T(K-1)*1.E-6);S S(J,K
)=R(J,K)*(1+R(J,K)*T(K)*1.E-6);S S(J,K+1)=R(J,K+1)*(1+R(J,K+1)*T(K+1)*1
.E-6)
70.20 S L=L+8
70.30 I(L-CC)70.12,70.12,70.40
70.40 C R
```

```
71.01 C AVERAGING SUBROUTINE
71.10 S L=4
71.20 F K=L,3,L+3;S CAV(K)=CAV(K)+C(J,K);S SAV(K)=SAV(K)+S(J,K);S QAV(K
)=QAV(K)+S(J,K-1)/S(J,K);S QBV(K)=QBV(K)+S(J,K+1)/S(J,K);S QRV(K)=QRV(K
)+R(J,K+1)/R(J,K)
71.30 S L=L+8
71.40 I(L-CC)71.20,71.20,71.50
71.50 R

72.01 C EXP. STD. DEV. SUBROUTINE
72.10 S L=4
72.20 F K=L,3,L+3;S E1(K)=SAV(K)-S(J,K);S E2(K)=QAV(K)-S(J,K-1)/S(J,K);
S E3(K)=QBV(K)-S(J,K+1)/S(J,K)
72.30 F K=L,3,L+3;S Z1(K)=Z1(K)+E1(K)*E1(K);S Z2(K)=Z2(K)+E2(K)*E2(K);S
 Z3(K)=Z3(K)+E3(K)*E3(K)
72.40 S L=L+8
72.50 I(L-CC)72.20,72.20,72.60
72.60 C R

80.10 X 1^1000;X FT(3);X 1^1000
80.12 X FCHR(7,27,12);X 1^2000
80.14 T "RAW DATA FOR FIRST TWO CHANNELS: "
80.15 S K=4
80.20 T !,!
80.22 T "DETER#     CLT       CUT      CGCT          CLB       CUB      CGCB
"
80.24 T !,!
80.26 F J=1,D;T %3.00,J,%7.00,R(J,K-1),R(J,K),R(J,K+1),"   ",R(J,K+2),R
(J,K+3),R(J,K+4),!
80.30 T !,!;A "ARE ALL DETERMINATIONS TO BE ANALYZED (YES/NO):   ",Q1
80.32 IF(Q1-0YES)81.10,80.40,81.10
80.40 T !,!,!;G 61.49

81.10 X FTGL(2,0)
```

```
81.12 T !,!;A "HOW MANY DETERMINATIONS ARE TO BE DELETED FROM ANALYSIS:
  ",ND
81.20 T !,"INPUT INDICIES OF DELETED DETERMINATIONS:  ",!
81.30 F I=1,ND;T "INPUT INDEX NUMBER: ",I;A "  ",DD(I)
81.40 S L=0
81.42 F I=1,D;D 82
81.50 S D=D-ND
81.52 G 61.51

82.10 S M=0
82.20 S M=M+1
82.30 IF(M-ND)82.40,82.40,82.50
82.40 IF(I-DD(M))82.20,82.70,82.20
82.50 S L=L+1
82.60 F K=1,24;S C(L,K)=R(I,K)
82.70 C

85.01 C SUBROUTINE TO SET-UP 6 CHANNEL DISPLAY
85.02 X FTGL(4,0)
85.04 X FCUR(1,1)+FCUR(2,768)
85.06 X FTGL(2,0);X FTGL(3,0)
85.08 T !;A "SET THUMBWHEEL 1 TO '00001' - HIT RETURN ",QQA
85.10 X FTGL(2,1)
85.11 X FVPOS(500);X FTGL(3,1)
85.12 T !;A "SET THUMBWHEEL 1 TO '00769' - HIT RETURN ",QAA
85.14 C X FVPOS(500)
85.16 C X FTGL(3,1)
85.18 X FTGL(4,1)
85.19 X 1^1000
85.20 X FCUR(1,100)+FCUR(2,356)
85.99 R

90.10 L S AFR;T "E A"!;T "X FTLIM(1550)"!;W A;T "%G 60.10"!;L C;L L
*
```

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%W
C TIL-0245

65.01 C PROGRAM AFRS1 - 2/18/81 RCP VERSION
65.08 S K=4
65.09 X FT(3)
65.10 X 1^2000;X FCHR(7,27,12);X 1^2000
65.15 T !,"REACTOR TIME AT START OF DATA COLLECTION: ",%6.00,JIM
65.16 T !,"DIM DATE:",%7.00,DATE,"                                DIM CODE:",%3.0
0,CDE
65.18 T !,"COUNTING TIME (REAL-SECS):",%7.00,TIM,"      DIM INTERVAL:",%
5.00,INT
65.20 T !,"TOP CH#-0-DEPOSIT:"%7.00,"    ",C(D,K-3)
65.22 T !,"BOTTOM CH#-0-DEPOSIT:",C(D,K-2)
65.24 T !,!,
65.26 T "DETER#    SUT      SLT/SUT    SGCT/SUT       SUB      SLB/SUB    SGC
B/SUB",!
65.30 F J=1,D;T %2.00,J," ",%6.02,S(J,K)," ",%6.04,S(J,K-1)/S(J,K)," "
,S(J,K+1)/S(J,K),"  ",%6.02,S(J,K+3)," ",%6.04,S(J,K+2)/S(J,K+3),"  ",S
(J,K+4)/S(J,K+3),!
65.34 T !,!,!,!
65.38 T "MEAN:",%6.02,SAU(K),%6.04," ",QAU(K),"  ",QBU(K),"  ",%6.02, S
AU(K+3),%6.04," ",QAU(K+3),"  ",QBU(K+3)
65.42 T !,"S:",%3.02,"      ",X1(K),%5.04,"  ",X2(K),"    ",X3(K),"
",%3.02,X1(K+3),%5.04,"  ",X2(K+3),"    ",X3(K+3)
65.46 T !,"SIGMA:",%3.02,"  ",S1G(K),%5.04,"  ",S2G(K),%5.04,"    ",S3G(
K),"      ",%3.02,S1G(K+3),%5.04,"  ",S2G(K+3),"    ",S3G(K+3)
65.50 T !,"S MEAN:",%5.04,M1(K)," ",M2(K),"    ",M3(K),"    ",M1(K+3),"
",M2(K+3),"    ",M3(K+3)
65.54 T !,"SIG M:",%5.04," ",G1M(K)," ",G2M(K), "    ",G3M(K),"    ",G1M(
K+3),"  ",G2M(K+3),"    ",G3M(K+3)
65.58 T !,"DT COR:",%5.04,D1T(K),"                              ",D1T(K+3)
65.62 T !,!
65.63 D 77
```

```
65.64 T "ALL RATES ABOVE CORRECTED ONLY FOR DEADTIME",!
65.66 T "DEADTIMES USED (USEC)  -TOP: TL=",%3.02,T(K-1),"   TU=",T(K),"
   TGC=",T(K+1),!,"                                -BOT: TL=",T(K+2),"   TU=",T(
K+3),"   TGC=",T(K+4)
65.67 X 1^4000;X FT(3)
65.68 X 1^2000;X FCHR(7,27,12);X 1^2000
65.69 T !,!,"FINAL FISSION RATES FROM DATA:",%6.00,DATE,%3.00,CDE,!,"DE
POSITS:",%7.00,C(D,K-3),"  ",C(D,K-2)
65.70 D 78
65.71 S C1R=ETZ(K)*SAV(K);S C2R=ETZ(K+3)*SAV(K+3)
65.72 T !,!,!,!,!,"CORRECTED FISSION RATE (1/SEC) - TOP:    ",%7.03,C1R
,"  +/-",%0,VT
65.74 T !,"                                      - BOTTOM: ",%7.03,C2R,"  +/-"
,%0,VB
65.76 T !,!,!,"ETZ CORRECTION - TOP:    ",%5.04,ETZ(K),"  +/-",%0,E1UN,
!,"                 - BOTTOM: ",%5.04,ETZ(K+3),"  +/-",%0,E2UN
65.78 T !,!,!,"CORRECTIONS NOT APPLIED: ",!,"     FRAGMENT SELF-ABSORBT
ION",!,"     IMPURITY FISSIONS",!,"     NEUTRON SCATTERING PERTURBATION
S",!,"    FRAGMENT SCATTERING"
65.80 T !,!,"DT ERROR OF +/- 0.2E-6 SEC INCLUDED
65.81 T !,"ETZ ERROR ALSO INCLUDED"
65.82 I(U-0)65.90,65.88,65.90
65.88 D 76
65.90 X 1^2000;X FP(0,0,5);X FT(2);X FT(3)

66.01 X 1^2000;X FCHR(7,27,12);X 1^2000
66.02 T "VERIFICATION FOR DATA:", %6.00,DATE,%3.00,CDE,!,"DEPOSITS:",%7
.00,C(D,K-3),C(D,K-2)
66.10 T !,!
66.18 T "DETER#     CLT       CUT      CGCT            CLB       CUB      CGC
B"
66.20 T !,!
66.22 F J=1,D;T %3.00,J,%7.00,C(J,K-1),C(J,K),C(J,K+1),"    ",C(J,K+2),
C(J,K+3),C(J,K+4),!
66.24 X 1^4000
```

```
67.01 C PLOTTING SOFTWARE
67.12 S AA=120;S BB=30;S XC=600
67.14 S LL=0
67.15 X FP(0,XC+100*1.2549,BB+310)+FP(1,XC+100*1.2549,BB+120)
67.16 C DRAWING AXES
67.18 X FP(0,AA,BB+310)
67.20 X FP(1,AA,BB)+FP(1,AA+320,BB)
67.21 X FP(0,AA+100*1.2549,BB+310)+FP(1,AA+100*1.2549,BB+120)
67.22 X FP(0,XC,BB+310)
67.24 X FP(1,XC,BB)+FP(1,XC+320,BB)
67.26 S NL=1+512*U;S NH=512+512*U
67.30 F N=NL,NH;D 75
67.52 C DRAWING AXES DIVISIONS
67.54 F I=1,4;D 67.58
67.56 G 67.64
67.58 X FP(0,AA+50*1.2549*I,BB)+FP(1,AA+50*1.2549*I,BB+10);G 67.60
67.60 X FP(0,XC+43*1.2549+(I-1)*50*1.2549,BB);G 67.62
67.62 X FP(1,XC+43*1.2549+(I-1)*50*1.2549,BB+10)
67.64 X FP(0,AA,BB+70)+FP(1,AA+10,BB+70)+FP(0,AA,BB+140)
67.66 X FP(1,AA+10,BB+140)+FP(0,XC,BB+70)+FP(1,XC+10,BB+70)
67.68 X FP(0,XC,BB+140)+FP(1,XC+10,BB+140)+FP(0,AA,BB+210)
67.70 X FP(1,AA+10,BB+210)+FP(0,XC,BB+210)+FP(1,XC+10,BB+210)
67.72 X FP(0,AA,BB+280)+FP(1,AA+10,BB+280)+FP(0,XC,BB+280)+FP(1,XC+10,B
B+280)
67.76 F I=1,11;D 67.80
67.78 G 68.08
67.80 X FP(0,AA-40,250-I*20+BB);X FT(2);G +67.82+.01*I
67.82 S ZZ=50*I-50
67.83 T "L"
67.84 T "O"
67.85 T "G"
67.86 R
67.87 R
67.88 T "C"
```

```
67.89 T "O"
67.90 T "U"
67.91 T "N"
67.92 T "T"
67.93 T "S"

68.08 C LABELING ORDINATE
68.10 F I=1,5;D 68.14
68.12 G 68.18
68.14 X FP(0,XC-70,BB-70+I*70);X FT(2);T "10";G 68.16
68.16 X FP(0,XC-80,BB-60+75*I);X FT(2);T %2.00,LL-1+I
68.18 C LABELING ABSCISSA
68.20 F I=1,6;D 68.24
68.22 G 68.54
68.24 X FP(0,-35+AA+(55*1.2549*(I-1)),BB-40);G 68.26
68.26 S ZZ=50*I-50;G 68.28
68.28 I(ZZ)68.30,69.30,68.32
68.30 S ZZ=1;X FT(2);T "    1"
68.32 I(ZZ-50)68.30,68.34,68.36
68.34 X FT(2)
68.36 I(ZZ-100)68.30,68.38,68.40
68.38 X FT(2);T "100"
68.40 I(ZZ-155)68.42,68.42,68.44
68.42 X FT(2)
68.44 I(ZZ-200)68.30,68.46,68.48
68.46 X FT(2);T "200"
68.48 I(ZZ-250)68.30,68.50,68.50
68.50 X FT(2)
68.52 X 1^1000
68.54 F I=1,3;D 68.58
68.58 S ZZ=100*I+200;G 68.60
68.60 X FP(0,XC+110*1.2549*(I-1),BB-40);G 68.62
68.62 I(ZZ-250)68.67,68.64,68.65
68.64 S ZZ=257;G 68.67
68.65 I(ZZ-500)68.67,68.66,68.68
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```
68.66 S 22=512;G 68.67
68.67 X FT(2);T %3.00,22
68.68 S K=K+8;S U=U+1
68.80 I(K-CC)68.82,68.82,68.90
68.82 X 1^5000;X FT(3)
68.84 X FT(2);G 65.10
68.86 X FTGL(2,1)
68.90 X FT(2)
68.91 X FT(3)
68.92 Q

75.01 C PLOTTING SUBROUTINE
75.10 I(FMCA(N))75.12,75.12,75.20
75.12 R
75.20 S A=N-512*U
75.22 I(N-(256+512*U))75.30,75.30,75.40
75.30 X FP(0,AA+A*1.2549,(FLOG(FMCA(N))/2.301259-LL)*70+BB))
75.32 X FP(1,AA+(A-1)*1.2549,(FLOG(FMCA(N))/2.301259-LL)*70+BB))
75.34 R
75.40 X FP(0,XC+(A-257)*1.2549,(FLOG(FMCA(N))/2.30159-LL)*70+BB))
75.42 X FP(1,XC+(A-257+1)*1.2549,(FLOG(FMCA(N))/2.30159-LL)*70+BB))
75.44 R

76.02 C POWER LEVEL CALCULATION
76.04 T !,!,!
76.06 S XRF=1.0000;S C=6.55E4
76.10 I(MC-6)76.84,76.12,76.16
76.12 S TMAS=1.788E-6;S ETMAS=1.073E-8;S BMAS=0.0983E-6;S EBMAS=7.864E-
10
76.14 G 76.30
76.16 I(MC-7)76.10,76.18,76.22
76.18 S TMAS=0;S ETMAS=0;S BMAS=0;S EBMAS=0
76.20 G 76.30
76.22 I(MC-8)76.10,76.24,76.84
76.24 S TMAS=25.33E-6;S ETMAS=1.266E-7;S BMAS=4.893E-6;S EBMAS=2.936E-8
```

```
76.30 S PTHI=(C1R/TMAS)/(C*XRF)
76.32 S ETP=PTHI*FSQT((ETMAS/TMAS)^2+(UT/C1R)^2)
76.40 S PBHI=(C2R/BMAS)/(C*XRF)
76.42 S EBP=PBHI*FSQT((EBMAS/BMAS)^2+(UB/C2R)^2)
76.44 G 76.90
76.84 T "INCORRECT MONITOR CHAMBER SPECIFICATION"
76.85 T !,"POWER CALCULATION ABORTED"
76.86 R
76.90 T "MC DEPOSIT MASS ERROR INCLUDED ALSO IN POWER CALCS"
76.91 T !,!,"REACTOR POWER (WATTS):"
76.92 T %0.00
76.94 T !,!,"     BASED ON TOP DEPOSIT     ",PTHI," +/-",ETP
76.96 T !,"     BASED ON BOTTOM DEPOSIT: ",PBHI," +/-",EBP
76.99 R

77.01 C ETZ UNCERTAINTY DETERMINATION
77.10 S G1M=G2M(K)
77.12 S G3M=G2M(K+3)
77.14 S M1=M2(K)
77.16 S M3=M2(K+3)
77.20 I(G1M-M1)77.30,77.40,77.40
77.30 S E1UM=5*M1
77.32 G 77.50
77.40 S E1UM=5*G1M
77.50 I(G3M-M3)77.52,77.60,77.60
77.52 S E2UM=5*M3
77.54 R
77.60 S E2UM=5*G3M
77.62 R

78.01 C TOTAL UNCERTAINTY CALC
78.10 S H1M=G1M(K)
78.12 S H3M=G1M(K+3)
78.14 S H1=M1(K)
```

```
78.16 S N3=N1(K+3)
78.20 I(H1M-N1)78.30,78.40,78.40
78.30 S P1UN=N1
78.32 G 78.50
78.40 S P1UN=H1M
78.50 I(H3M-N3)78.52,78.60,78.60
78.52 S P3UN=N3
79.54 G 78.70
78.60 S P3UN=H3M
78.64 S SA=SAVK)
78.66 S SB=SAVK+3)
78.70 S VT=FSQT((P1UN^2)+(SA^2*E1UN^2)+(2.E-7*SA^2)^2)
78.80 S VB=FSQT((P3UN^2)+(SB^2*E2UN^2)+(2.E-7*SA^2)^2)

91.10 L S AFRS1;T "E T"!;W A;T "*G 65.01"!;L C;L L
*
```

012R0105 Fuel

REACTOR TIME AT START OF DATA COLLECTION: 91800
DIM DATE: 101280 DIM CODE: 1
COUNTING TIME (REAL-SECS): 300 DIM INTERVAL: 400
TOP CH#-0-DEPOSIT: 949023
BOTTOM CH#-0-DEPOSIT: 994963

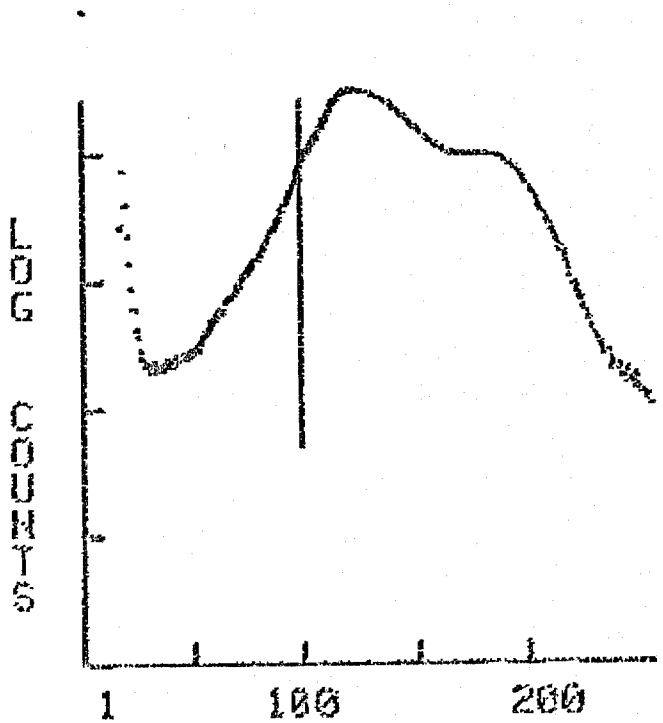
DETER#	SUT	SLT/SUT	SGCT/SUT	SUB	SLB/SUB	SGCB/SUB
1	1399.49	1.0014	0.5101	271.64	1.0013	0.7166
2	1386.73	1.0013	0.5097	267.38	1.0014	0.7137
3	1384.50	1.0013	0.5110	266.92	1.0015	0.7164
4	1420.02	1.0014	0.5101	275.56	1.0014	0.7157
5	1410.34	1.0013	0.5110	272.15	1.0013	0.7148
MEAN:	1400.22	1.0013	0.5107	270.73	1.0014	0.7155
S:	15.2	0.0000	0.0010	3.60	0.0001	0.0012
SIGMA:	2.16	0.0001	0.0000	0.95	0.0001	0.0016
S MEAN:	6.7980	0.0000	0.0005	1.6116	0.0000	0.0005
SIG M:	0.9677	0.0000	0.0003	0.4256	0.0001	0.0007
DT COR:	1.0031			1.0006		

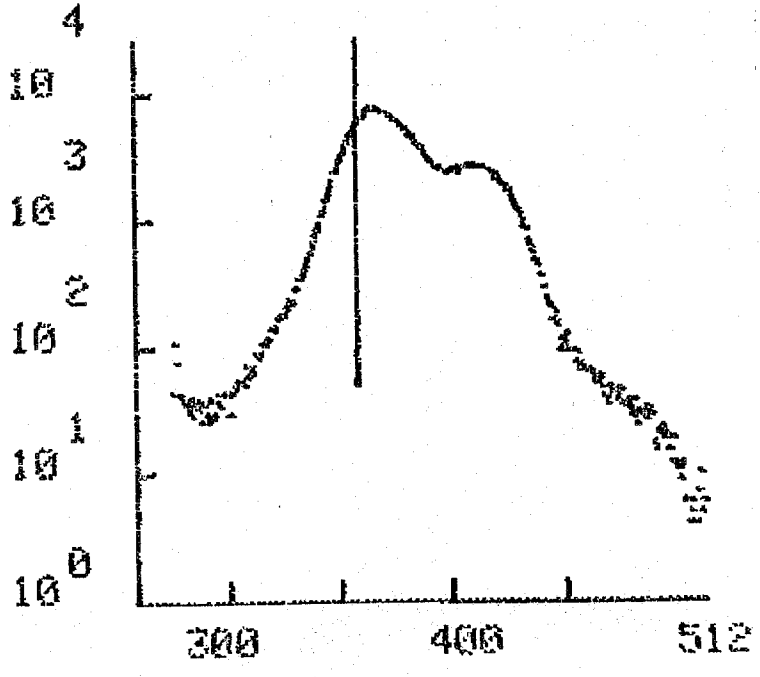
ALL RATES ABOVE CORRECTED ONLY FOR DEADTIME
DEADTIMES USED (USEC) -TOP: TL= 2.24 TU= 2.24 TGC= 1.78
-BOT: TL= 2.18 TU= 2.18 TGC= 1.78

```
FINAL FISSION RATES FROM DATA:  101280     1
DEPOSITS:    949023      994963



CORRECTED FISSION RATE (1/SEC) - TOP:        1409.589  +/-  6.797960E+00
                               - BOTTOM:      272.602  +/-  1.611550E+00


ETZ CORRECTION - TOP:        1.0067  +/-  1.264810E-04
               - BOTTOM:     1.0069  +/-  2.921590E-04


CORRECTIONS NOT APPLIED:
     FRAGMENT SELF-ABSORBTION
     IMPURITY FISSIONS
     NEUTRON SCATTERING PERTURBATIONS
     FRAGMENT SCATTERING

DT ERROR OF +/- 0.2E-6 SEC INCLUDED
ETZ ERROR ALSO INCLUDED


MC DEPOSIT MASS ERROR INCLUDED ALSO IN POWER CALCS

REACTOR POWER (WATTS):

     BASED ON TOP DEPOSIT        8.496000E+02 +/-  5.900800E+00
     BASED ON BOTTOM DEPOSIT:    8.505750E+02 +/-  7.164730E+00
```

VERIFICA
TION FOR DATA: 101280 1
DEPOSITS: 949623 994593

DETER#	CLT	CUT	CGCT	CLB	CUB	CGCB
1	419119	418538	213872	81551	81443	58380
2	415268	414734	211769	80277	80168	57229
3	414602	414071	212307	80151	80028	57348
4	425242	424661	217017	82737	82619	59146
5	422340	421774	216248	81599	81596	58339





REACTOR TIME AT START OF DATA COLLECTION: 91900
DIM DATE: 101290 DIM CODE: 1
COUNTING TIME (REAL-SECS): 300 DIM INTERVAL: 400
TOP CH#-0-DEPOSIT: 925031
BOTTOM CH#-0-DEPOSIT: 949032

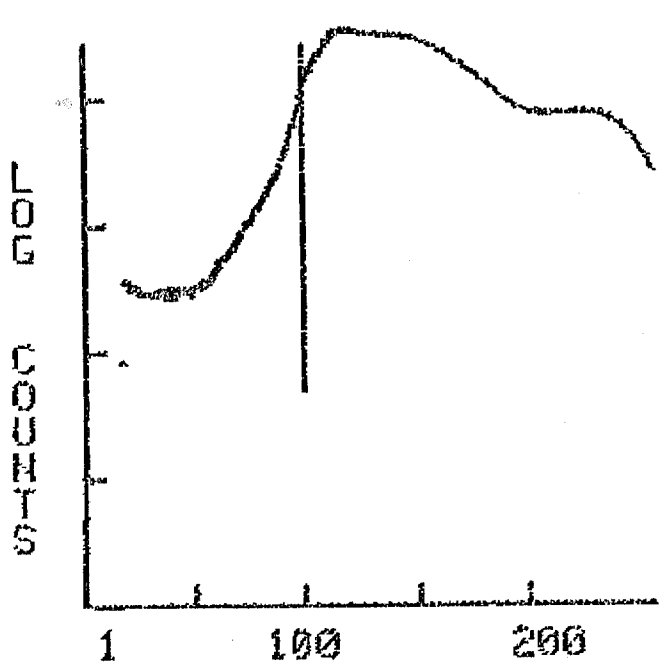
DETER#	SUT	SLT/SUT	SGCT/SUT	SUB	SLB/SUB	SGCB/SUB
1	2206.23	1.0010	0.4073	2364.26	1.0011	0.5284
2	2187.52	1.0010	0.4085	2338.62	1.0011	0.5280
3	2181.90	1.0010	0.4087	2334.25	1.0011	0.5279
4	2241.39	1.0010	0.4076	2399.55	1.0011	0.5274
5	2215.69	1.0010	0.4073	2375.16	1.0011	0.5282
MEAN:	2206.55	1.0010	0.4079	2362.37	1.0011	0.5280
S:	23.8	0.0000	0.0007	26.9	0.0000	0.0004
SIGMA:	2.72	0.0000	0.0006	2.81	0.0000	0.0006
S MEAN:	10.646	0.0000	0.0003	12.050	0.0000	0.0002
SIG M:	1.2159	0.0000	0.0003	1.2582	0.0000	0.0003
DT COR:	1.0051			1.0052		

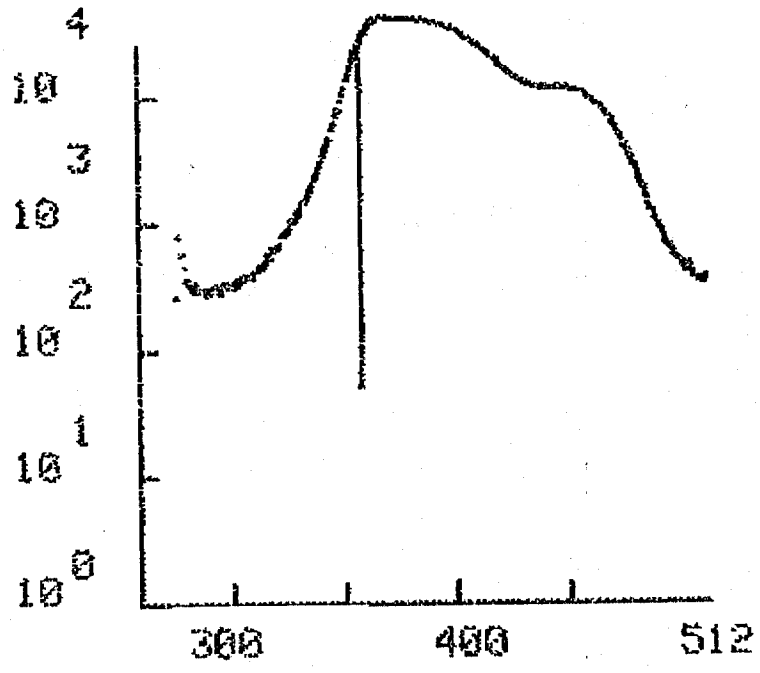
ALL RATES ABOVE CORRECTED ONLY FOR DEADTIME
DEADTIMES USED (USEC) -TOP: TL= 2.30 TU= 2.30 TGC= 1.78
-BOT: TL= 2.20 TU= 2.20 TGC= 1.74

```
FINAL FISSION RATES FROM DATA:  101289     1
DEPOSITS:    925031      949032



CORRECTED FISSION RATE (1/SEC) - TOP:        2217.640  +/-  1.0654670E+01
                               - BOTTOM:     2375.440  +/-  1.2050650E+01


ETZ CORRECTION - TOP:        1.0050  +/-  8.7418500E-05
               - BOTTOM:     1.0055  +/-  9.8631100E-05


CORRECTIONS NOT APPLIED:
     FRAGMENT SELF-ABSORBTION
     IMPURITY FISSIONS
     NEUTRON SCATTERING PERTURBATIONS
     FRAGMENT SCATTERING

DT ERROR OF +/- 0.2E-6 SEC INCLUDED
ETZ ERROR ALSO INCLUDED
```

VERIFICATION FOR DATA: 101288 1
DEPOSITS: 925631 949632

DETER#	CLT	CUT	CGCT	CLB	CUB	CGCB
1	659191	658545	269154	706419	705628	373961
2	653620	652987	267633	698795	698013	369621
3	651982	651318	267086	697465	696716	368896
4	669659	668995	273616	716982	716105	378831
5	662033	661355	270276	709625	708863	375583





REACTOR TIME AT START OF DATA COLLECTION: 91800
DIM DATE: 101280 DIM CODE: 1
COUNTING TIME (REAL-SECS): 200 DIM INTERVAL: 400
TOP CH#-0-DEPOSIT: 994023
BOTTOM CH#-0-DEPOSIT: 941031

DETER#	SUT	SLT/SUT	SGCT/SUT	SUB	SLB/SUB	SGCB/SUB
1	857.31	1.0074	0.8230	583.03	1.0033	0.5706
2	847.10	1.0074	0.8236	572.85	1.0035	0.5721
3	847.56	1.0072	0.8251	574.56	1.0032	0.5742
4	870.42	1.0072	0.8229	595.27	1.0031	0.5717
5	861.49	1.0070	0.8238	586.47	1.0031	0.5724

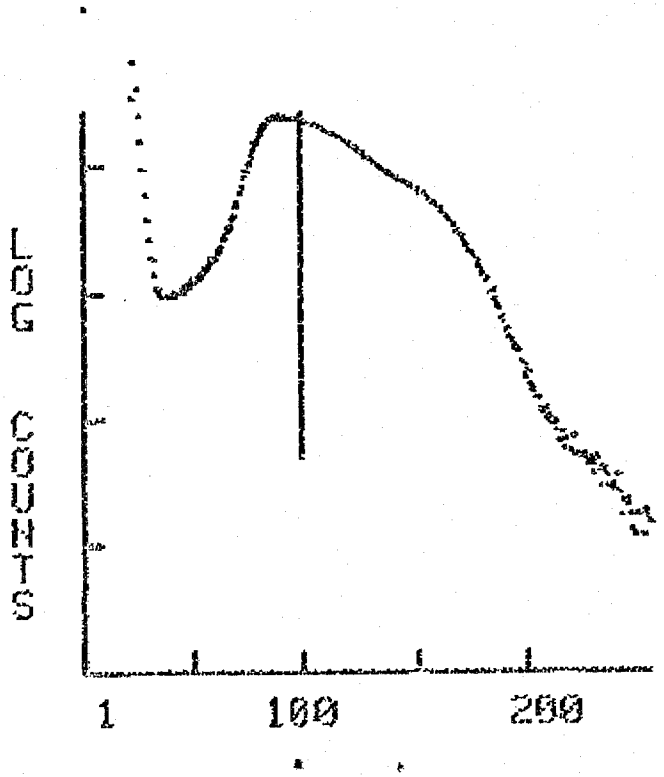
MEAN:	856.79	1.0073	0.8237	583.64	1.0032	0.5722
S:	9.84	0.0002	0.0009	7.89	0.0002	0.0013
SIGMA:	1.69	0.0002	0.0008	1.40	0.0001	0.0012
S MEAN:	4.3990	0.0001	0.0004	3.5295	0.0001	0.0006
SIG M:	0.7565	0.0001	0.0003	0.6242	0.0001	0.0005
DT COR:	1.0019			1.0013		

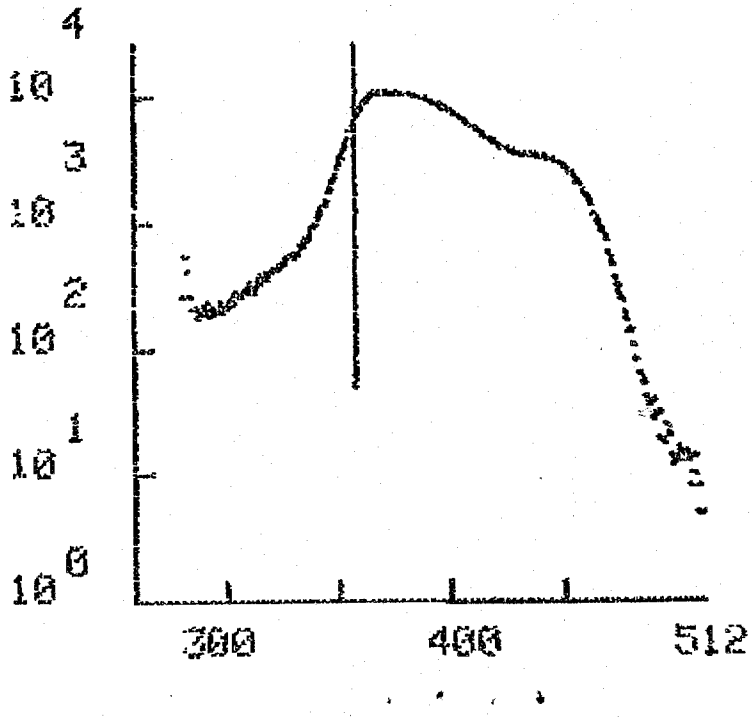
ALL RATES ABOVE CORRECTED ONLY FOR DEADTIME
DEADTIMES USED (USEC) -TOP: TL= 2.24 TU= 2.24 TGC= 1.77
-BOT: TL= 2.21 TU= 2.21 TGC= 1.77

```
FINAL FISSION RATES FROM DATA:  191280     1
DEPOSITS:    994023      941031



CORRECTED FISSION RATE (1/SEC) - TOP:        887.839  +/-  4.399000E+00
                               - BOTTOM:     593.096  +/-  3.529520E+00


ETZ CORRECTION - TOP:        1.0363  +/-  3.961000E-04
               - BOTTOM:     1.0162  +/-  4.092290E-04


CORRECTIONS NOT APPLIED:
     FRAGMENT SELF-ABSORBTION
     IMPURITY FISSIONS
     NEUTRON SCATTERING PERTURBATIONS
     FRAGMENT SCATTERING

DT ERROR OF +/- 0.2E-6 SEC INCLUDED
ETZ ERROR ALSO INCLUDED
```

VERIFICATION FOR DATA: 101290 1
DEPOSITS: 994023 941631

DETERM	CLT	CUT	CGCT	CLB	CUB	CGCB
1	258688	256700	211396	175267	174683	99740
2	255520	253650	209043	174042	173434	99288
3	255607	253792	209552	172694	172149	98917
4	262505	260620	214617	178899	178348	102029
5	259754	257951	212648	176255	175713	100644





APPENDIX C

NBS TRANSMITTALS ON RESULTS CALCULATIONS

UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

April 8, 1981

John A. Rawlins
Core Physics
Hanford Engineering Development Co.
Westinghouse Hanford Company
Richland, WA 99352

Dear John,

Enclosed are my 2nd level analysis work sheets for Experiment 5. In-Situ and Free-Field Fission Rates with estimated uncertainties (1σ) are given in Tables 2 and 3. The work sheets which lead to these results are discussed briefly below.

Pages 5-1 through 5-5 list data from the program AFR along with weighted averages for the quantities S_U and ETZ. The ETZ data from AFR was supplemented and/or replaced by revised results from the recorded pulse-height distribution in a few cases where amplifier saturation noise obscured the scaler results. On pages 5-2 and 5-5 the U-238 Etz's from AFR are replaced by 'best guess' values derived from detailed analysis of the pulse height distributions. Additional special treatment of U-238 was also required to justify a lower error estimate for the results from these heavy deposits. The basis for this special treatment is that the effective masses of the heavy U-238 deposits used in the FFTF experiment were derived from fission-counting comparisons with standard deposits which are much lighter. To a large extent, the higher uncertainties in the ETZ and self-absorption corrections for the heavy deposits in the FFTF runs are cancelled out by almost identical corrections applied in the fission counting comparisons to the standard deposits at NBS. The residual uncertainty then becomes primarily dependent on the thickness of the standard deposits rather than that of the working deposits. Pages 5-5 through 5-8 show the deviation of the 'best guess' ETZ's and the reduced error estimates.

In Table 1 are listed the In-Situ results prior to correction for fission in minor isotopic constituents. Table 1 includes error estimates for the following factors: statistics, dead-time, self-absorption, mass assay, and ETZ.

Pages MIC-1 through MIC-14 give the derivation of the correction for fission in minor isotopic constituents and the derivation of the errors in these corrections. This correction requires an iterative process in principle, but in fact the process converges in one step. The case of the normal uranium deposit again requires special treatment. Here the special treatment is required because of the correlation with the U-235 fission rate.

In Table 2 the results from Table 1 are corrected for fission in minor isotopic constituents and the complete In-Situ results and errors are given. In Table 3 the Free-Field results are given, based on Table 2 and Core Physics Memo of February 24, 1981.

The results in Tables 2 and 3 are little changed from the 1st level analysis. The largest changes are due to the revised scattering calculations from L. L. Carter. These scattering calculations changed the power level normalization uniformly for all the In-Situ results. The changes cancel out for the Free-Field results for the fissile isotopes. The revised ETZ's for U-238 made changes of up to 0.7% in the U-238 fission rates. The discrepancy in the U-238 fission rates in the upper axial reflector was not resolved. I continue to believe that the possibility of unexpectedly large gradients in the fast neutron flux should be checked if possible. The revised Am-241/Pu-241 cross section ratio gave a change of 1.44% in the CMP fission rate of Pu-241. Overall, the many refinements that Fuller and I have labored over have produced little change in the results. The errors in the In-Situ results are within the goal accuracy limits for all the CMP fission rates.

The 2nd level analysis for Experiments 8 and 10 should be ready very shortly.

Sincerely,

David M. Gilliam

David M. Gilliam
Nuclear Radiation Division

Enclosures

cc: J. A. Grundl
E. D. McGarry
J. L. Fuller
R. S. Caswell

TABLE 2.

EXP. 5: IN SITU FISSION RATES

	CMP fissions/(s·μg·kw)	UAR fissions/(s·μg·kw)
U-233	124.85 ± 1.55 %	83.74 ± 1.55 %
U-235	84.94 ± 0.86 %	55.67 ± 0.87 %
U-238 (depleted)	1.834 ± 1.45 %	0.324 ± 1.45 %
U-238 (norm. uran.)	1.827 ± 1.72 %	0.304 ± 3.17 %
Pu-239	80.43 ± 0.63 %	53.95 ± 0.66 %
Pu-240	16.166 ± 1.24 %	4.088 ± 1.34 %
Pu-241	108.27 ± 2.58 %	80.25 ± 2.57 %
Np-237	14.83 ± 1.18 %	3.288 ± 1.21 %
Th-232	0.461 ± 2.63 %	0.0808 ± 2.98 %

TABLE 3.

Exp. 5: FREE-FIELD FISSION RATES

	CMP fissions/(s·μg·kw)	UAR fissions/(s·μg·kw)
U-233	123.73 ± 1.96 %	81.40 ± 2.09 %
U-235	84.18 ± 1.48 %	54.11 ± 1.65 %
U-238 (depleted)	1.865 ± 1.88 %	0.335 ± 1.95 %
U-238 (norm. uran.)	1.858 ± 2.04 %	0.314 ± 3.43 %
Pu-239	79.71 ± 1.36 %	52.44 ± 1.55 %
Pu-240	16.44 ± 1.66 %	4.223 ± 1.87 %
Pu-241	107.30 ± 2.85 %	78.00 ± 2.93 %
Np-237	15.08 ± 1.61 %	3.397 ± 1.78 %
Th-232	0.469 ± 2.93 %	0.0835 ± 3.25 %

TABLE 1.

- IN SITU -

PRIOR TO CORRECTION FOR FISSION IN MINOR ISOTOPES

Principal Isotope	Deposit Label	CMP fissions/(s·μg·kw) ± combined errors		UAR fissions/(s·μg·kw) ± combined errors	
		statistical err. %* dead-time err. %	self-abs. err. %† mass err. % ETZ† err. %	statistical err. %* dead-time err. %	self-abs. err. %† mass err. % ETZ† err. %
U-233	23K-02-8	124.86	± 1.55%	83.742	± 1.55%
		0.09	0.35	0.06	0.35
		0.05	1.5	0.05	1.5
			0.16		0.12
U-235	25A-03-1	85.117	± 0.86%	55.742	± 0.87%
		0.05	0.35	0.11	0.35
		0.06	0.77	0.03	0.77
			0.14		0.18
U-235	25A-03-2	84.851	± 0.86%	55.613	± 0.85%
		0.10	0.35	0.07	0.35
		0.04	0.77	0.04	0.77
			0.11		0.11
U-235	Average of Above	84.984	± 0.86%	55.678	± 0.87%
U-238	28G-5-1	1.8483	± 1.45%	.33354	± 1.45%
		0.05	0.35	0.07	0.35
		0.07	1.15	0.07	1.15
			0.81		0.81
Norm. U	28NC-5-1	2.4355	± 1.27%	.70275	± 1.27%
		0.04	0.35	0.08	0.35
		0.09	0.95	0.09	0.95
			0.77		0.77
Pu-239	49K-03-2F	80.438	± 0.63%	53.953	± 0.66%
		0.05	0.35	0.11	0.35
		0.06	0.5	0.03	0.5
			0.15		0.22

TABLE 1. (continued)

Principal Isotope	Deposit Label	CMP fissions/(s·μg·kw) ± combined errors statistical err. %* / dead-time err. % self-abs. err. %† / mass err. % / ETZ‡ err. %	UAR fissions/(s·μg·kw) ± combined errors statistical err. %* / dead-time err. % self-abs. err. %† / mass err. % / ETZ‡ err. %
Pu-240	40L-2-3F	17.257 ± 1.24% 0.06 0.07 0.35 0.8 0.88	4.8227 ± 1.32% 0.06 0.04 0.35 0.8 0.99
Pu-241	41K-03-1(L)	110.88 ± 2.56% 0.08 0.04 0.35 2.5 0.44	81.184 ± 2.56% 0.07 0.03 0.35 2.5 0.43
Np-237	37K-05-1	14.831 ± 1.18% 0.04 0.08 0.35 1.1 0.22	3.2883 ± 1.21% 0.085 0.09 0.35 1.1 0.34
Th-232	02N-9	0.4608 ± 2.50% 0.095 0.09 1.18 2.0 2.63	0.08083 ± 2.87% 0.16 0.07 1.18 2.0 2.98

* Includes statistical part of ETZ error.

† Self Abs. Err = 25% of corr. or 0.35% whichever is larger } EXCEPT FOR U-238 SAMPLES

‡ ETZ Err = 27% of correction

⊙12R0105	1500	Wt = 1	EXPT 5-1
⊙12R0205	1500	1	
⊙12R0310(2del)	2400	1.6	all from Feb. 23, 1981
	5400 Tot	3.6	"Final Data Analysis" runs with revised dead times.

Ch	Su	Dep Code mass (Ag Prin Iso) self-absrpt corr	$\overline{Su}$	Precision % / DeadT Err %	ETΣ	Fract Stat Err in ETΣ ×E-04	$\overline{ETΣ}$	ETΣ & DEAD T CORRECTED S combined imprecision dead T corr (%)
1	1400.22 1411.91 1399.61	49023	1403.20	.04/.03	1.0067 64 64	1.3 1.2 1.1	1.00648 ±.00006 not persnl -del	1412.29 ±0.05% 844.64 w {.04 stat {.03 dead T
2	270.73 274.37 270.63	4903	271.70	.08/.01	1.0069 67 66	2.9 3.5 2.7	1.00671 ±.00016	273.52 ±0.08% 846.83 w
3	2206.55 2223.33 2205.61	25031 30.96 1.0017	2210.79	.03/.05	1.0050 50 52	.9 .9 1.0	1.00509 ±.00005	2222.04 ±0.06% {.03 stat {.05 dead T
4	2362.37 2382.67 2361.54	49032 35.10 1.0018	2367.64	.03/.05	1.0055 55 53	.9 1.3 .8	1.00541,1 ±.00006	2380.45 ±0.06% {.03 stat {.05 dead T
5	856.78 863.94 855.29	4023 221.4 1.0140	858.11	.05/.02	1.0363 368 364	4.0 4.2 3.1	1.03648 ±.0002	889.41 ±0.06% {.05 stat {.02 dead T
6	583.64 588.16 583.04	41031 8.71 1.0054	584.63	.06/.01	1.0162 159 162	4.1 3.0 2.5	1.01612 ±.0002	594.05 ±0.06% {.06 stat {.01 dead T
PT	849.61 856.42 849.02							851.24
PB	850.57 861.80 849.95							853.41

Q-12 R2106 1200 sec Wt 1
Q 12 R2210 (2 del) 1600 sec 1.3333₃

2800 sec Tot 2.3333₃

EXP 5-2

Ch	S_u	DEPOSIT CODE / dep mass / self absorpt corr	$\overline{S_u}$	Precision % / Dead T	ETZ	Fract. Stat. Err in ETZ × E-04	$\overline{ETZ}$	ETZ & Dead T Corrected S ± stat. err's & dead T err.
1	3770.57 4558.48	49023	4220.80	.03/.09	1.0063 63	1.0 .8	1.0063 ±.00006₄	4247.40 ±0.10 % 2540.2 w {.03 stat .09 dead T}
2	729.69 881.33	4903	816.34	.066/.02	1.0064 64	1.9 1.5	1.0064 ±.00011	821.57 ±0.07 % 2543.62 w
3	2827.73 3421.15	28851 735.7 1.0401	3166.83	.03₄/.07	1.0512 513	2.8 2.3	Best Guess 1.0487 1.0513 ±0.00018	3321.05 ~~3329.29~~ ±0.08 % {.04 stat .07 dead T}
4	592.88 717.07	029 621 1.0338	663.85	.07₃/.015	1.0460 455	6.4 6.9	1.0457₁ ±.0005	694.19 ±0.09 % {.09 stat .01 dead T}
5	499.55 606.10	37051 68.3 1.0052	560.44	.08/.01	1.0126 127	3.3 2.6	1.0127 ±.0002	567.55 ±0.08 % {.08 stat .01 dead T}
6	952.21 1152.42	2851 651.7 1.0358	1066.62	.058/.024	1.0604 606	8.4 4.1	Best Guess 1.0530 1.0605 ±.0004₃ peak @ ch 174	1123.15 ~~1131.15~~ ± 0.08 % {.07 stat .02 dead T}
PT	2286.92 2764.94							2560.07
PB	2291.27 2767.65							2563.47

EXP 5-3

		wt
Q13 R3105	1000	1
Q13 R3210	2000	2
Q13 R3305	1000	1
	4000 sec	4

Ch	S_u	Dep Code / dep mass / self absorp corr	$\overline{S_u}$	Precision % / Dead T	ETZ	Inact. Stat. Err in ETZ x E-04	$\overline{ETZ}$	ETZ & Dead T Corrected — S ± stat. errors & dead T error
1	1618.56 1132.43 1138.98	49023	1255.60 (1294.47) 1st 2 only	0.045/0.028	1.0064 66 63	1.7 1.2	1.0064_8 ±.00009	1263.73 ± 0.05 % 755.79 w { .05 stat { .03 dead T
2	311.94 218.62 220.42	4903	242.40	.102/.05	1.0067 74 76	3.3 3.4 4.3	1.0072_8 ±.00017	244.16 ± 0.10 % 755.93 w
3	3550.52 2488.51 2504.37	4023 221.4 1.0140	2757.98	.03/.06	1.0321 327 326	2.1 1.9 3.0	1.0325_3 ±.00015	2847.68 ± 0.07 % { .03 stat { .06 dead T
4	919.33 644.64 648.97	41031 8.71 1.0054	714.40	.06/.016	1.0161 163 164	3.7 2.9 5.2	1.0162_8 ±.0002	726.02 ±0.07 % { .06 stat { .02 dead T
5	1663.85 1165.80 ⎫ ★ (5≠6) 1171.37 ⎭ S_{u5}/S_{u1}	25032 1.0280 (30.91) 1.0017 1.0295 ⎫ agree 1.0284 ⎭ w/in .03%	1291.71	.044/.029 (1.[illegible]53) —([illegible]) 1.0041 Analyzer 1.0040		[illegible] 1.3	1.0041 ±.0002	1297.00 ±0.06 % { .05 stat { .03 dead T
6	2488.35 1743.65 ⎫ ★ (5≠6) 1756.83 ⎭ S_{u6}/S_{u1}	23028 (30.71) 1.5374 ⎫ 1.0017 1.5397 ⎭ agree w/in .26% 1.5425	1932.07 ≠ 1933.12 + (1991.88) — 1st 2 only	.04/.04	1.0042 43 (1.0703) analyzer 1.0043	0.9 1.0 4.5	1.0043 ±.0002	1940.38 ±0.06 % { .04 stat { .04 dead T
PT	981.85 687.03 690.82							761.68
PB	979.82 687.18 693.01							761.80

★ ratio S_u / S_u-monitor same for either Ch 5 or Ch 6 electronics. S_u apparently unaffected by noise in S_L on Ch 5.

\+ Incl. all 3 runs changer ratio to monitor by +0.055%

≠ Adjusted; based on 1st 2 runs only. Adjustment 0.055%

Q14 R 4105 (12el) 1200 sec Wt 2.4
Q14 R 4210 (5del) 500 sec 1
1700 3.4

EXP 5-4

Ch	S_u	Dep Code dep mass self-abs. corr.	$\overline{S_u}$	Precision % / DeadT	ETZ	Fract. Stat. Err. ± ETZ × E-04	$\overline{ETZ}$	ETZ & Dead T Corrected – S ± stat. errors & DeadT err.
1	1034.06 777.45	49023	958.59	0.078/.021	1.0067 67	1.6 3.2	1.0067 ±.0001$_6$	765.01 ±0.08 % 597.14 w { .08 stat { .02 DeadT
2	200.17 150.75	4903	185.63	.18/.004	1.0071 63	3.9 7.2	1.0068$_6$ ±.0004	186.91 ±0.18 % 578.68 w
3	1622.99 1221.26	25032 30.91 1.0017	1504.83	.06/.03	1.0043 39	1.0 1.8	1.0042 ±.0001	1511.13 ±0.07 % { .06 stat { .03 DeadT
4	2370.00 1779.24 S_{u4}/S_{u1}	23028$_{30.71}$ 2.2919 1.0017 2.2886	2196.25	.05/.05 (1.0421) (1.0165) analyzer 1.0059$_3$		2.7 3.4	1.0059$_3$ ±.0005	2207.27 ±0.09 % { .07 stat { .05 DeadT
5	1065.77 800.31	25031 30.96 1.0017	987.69	.08/.02	1.0066 70	1.6 3.0	1.0067 ±.0001$_6$	994.33 ±0.08 % { .08 stat { .02 DeadT
6	1167.82 877.11	49032 35.10 1.0018	1082.32	.07/.02	1.0081 78	1.7 3.0	1.0080 ±.0001$_7$	1090.97 ±0.07 % { .07 stat { .02 DeadT
PT	627.43 471.74							581.64
PB	629.02 473.35							583.23

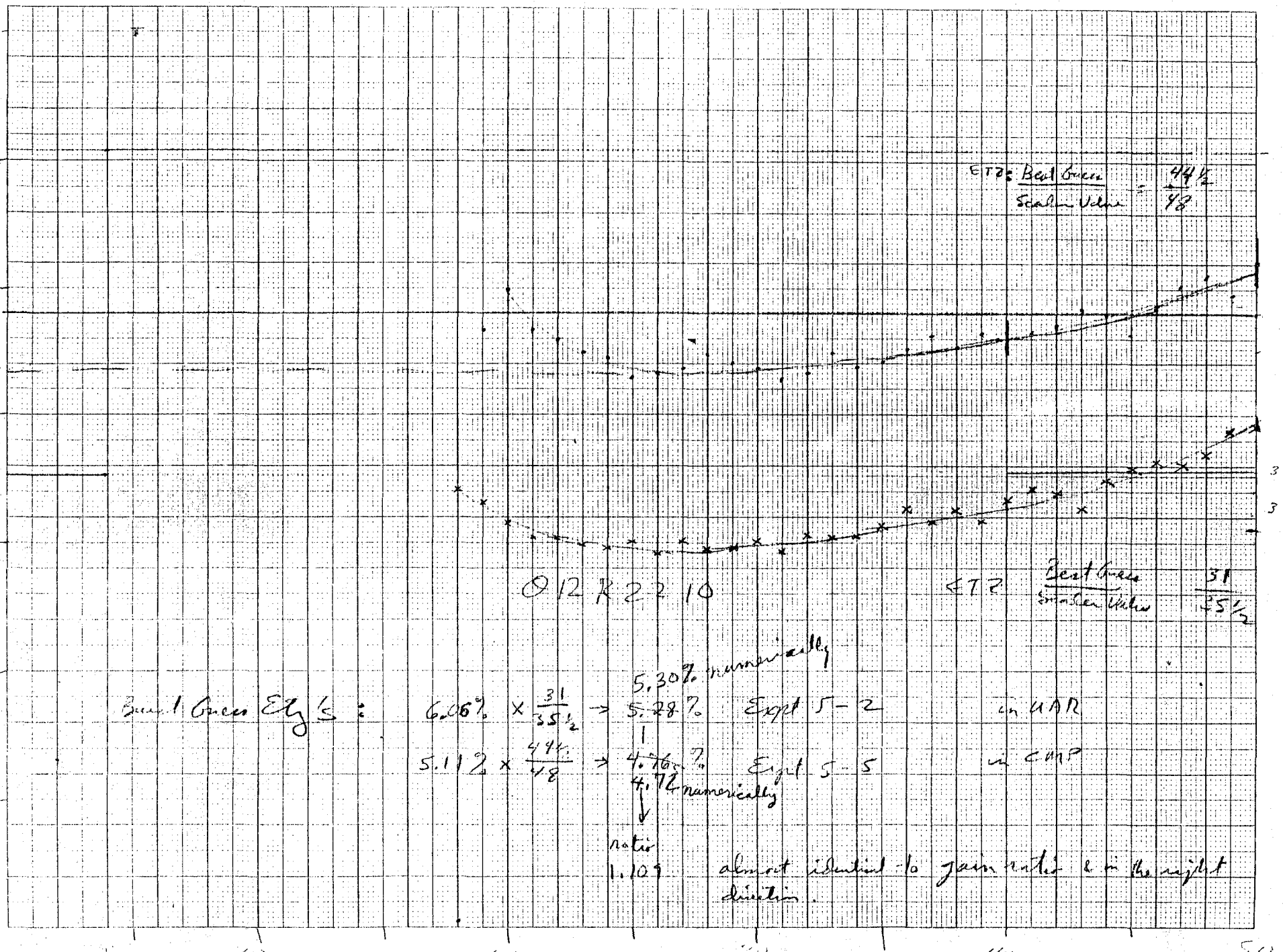
@14R5105	12el	800	Wt	0.4
@14R5210		2000		1
@14R5310		2000		1
@14R5410		2000		1
		6800		3.4

EXP 5-5

Ch	S_4	Deposit Code dep. mass self-attn. corr	$\overline{S_4}$	Precision %/Dead T	ETZ	Fract. Stat. Err in ETZ x E-04	$\overline{ETZ}$	ETZ & Dead T Corrected - S ± stat. errors & dead T Err.
1	3170.62	49023	3010.20	.02/.07	1.0062	1.1	1.0064	3029.66
	2989.16				66	.7	±.0005	±0.07 %
	2977.54				65	.9		
	2999.72				64	.7		1811.93 w
								{.02 stat .07 dead T
2	613.75	4903	582.68	.05/.01	1.0066	2.6	1.0066	586.52
	578.41				66	1.7	±.0001	±0.05 %
	576.25				65	1.6		
	580.94				67	1.8		1815.90 w
3	1903.08	37051	1810.88	.028/.04	1.0083	2.2	1.0082	1825.91
	1797.46	68.3			83	1.1	±.000065	±0.05 %
	1793.27	1.0052			83	1.1		{.03 stat .04 dead T
	1805.04				83	1.2		
4	2789.89	2851	2651.34	.024/.06	1.0515	6.6	Best Guess 1.0472 1.0514	2776.48 2787.62
	2629.59	651.7			516	2.4	±0.00015	± 0.07 %
	2625.63	1.0358			511	2.2		{.03 stat .06 dead T
	2643.39				516	3.1		
5	424.27	28851	403.28	.06/.01	1.0671	10.	Best Guess 1.0600 1.0671	427.48 430.37
	400.39	735.7			672	7.3	±.0004	±0.07 %
	399.29	1.0401			679	6.8		{.07 stat .01 dead T
	401.79				664	6.6		
6	86.08	029	81.24	.13/.0	1.0690	22.5	1.0692	86.86
	80.58	621			699	17.3	±.0010	0.17 %
	80.38	1.0471			699	19.3		{.16 stat .0 dead T
	80.81				680	14.6		
PT	1922.92							1826.08
	1813.61							
	1806.31							
	1819.57							
PB	1927.62							1830.10
	1816.67							
	1809.75							
	1824.86							

ZYNC

914R5310



Beat Green Eg½ : 6.06% × 31/35½ → 5.30% numerically → 5.28% Expt 5-2 in UAR

5.11% × 44½/48 → 4.76% Expt 5-5 in CMP → 4.72% numerically

ratio 1.109

almost identical to gain ratio 1 in the right direction.

C-13

8.5-6

28G-5-1 ETZ from Q14 R5310 spectrum
extrap 0/min 10 pts to zero rather than (40-50)
→ reduction / 0.883 / scale ETZ's

6.79% × .883 → 6.00%

28G-5-1 Q12R2210

5.13% × .949 → 4.87%

SPECIAL TREATMENT OF U-238

28NC-5-1 / 28NC-2-4 std = 2.52₇ ± .64% via thermal neut fiss counting

28NC-2-4 ETZ @ 1.3 ATM = 2.3% → ERR .58%
self absorpt 1.40% → ERR .35%

MIN Error prob

1.27
- .64 Fiss Cty rel std — (actually cancels to some extent)
- .58 Std ETZ @ 1.3 atm
- .35 Std self absorpt — mass .95%
- .7 Std mass — ETZ .77%
- .5 Non PHD distortion in diff chamber & pressure

1.91%
Replacing
- .90 self abs
- .95 mass
- 1.39 Ety error

28G-5-1

28G-5-1 / 28S-2-2 = 2.993, ± .74%
in ISNF

28S-2-2 ETZ @ 1.3 ATM = 2.55% → Err .64%
Self absorpt 1.34% → Err .34%
Mass ± .88%

1.45
- .74 Fiss Ct rel to Std (actually cancels to some extent)
- .64 Std Ety
- .35 Std self absorpt — mass 1.15
- .88 Std Mass
- .5 PHD distortion — ETZ .81

Power Normalization : 6.55 E-2 f/s/μg/watt @ -15"

Corrections to free field : (In-situ) × .991 ±1.2% → free field fiss rate
(Assumed = equal to CMF values)
Feb 24, 81 Core Physics Memo

49K-02-3F 25.33 ± 0.5% μg → Self absorpt. 0.132 %
Corr = 1.00132

Fissions in Other Isotopes :

	a/o	σ_x / σ_9		$\sigma_x a_x / \sigma_9 a_9$
238	< 0.001			
239	99.978			
240	0.021	(15.98/79.6)(239/240)	.200	4.20 E-5
241	0.0005	(105.7/79.6)(239/241)	1.317	6.58 E-6
242	0.0005			
244	< 0.0002			

$$\frac{1}{1 + \sum_x \frac{\sigma_x a_x}{\sigma_9 a_9}}$$

$$\frac{1}{1 + 1.08\,E\text{-}4} = 0.99995$$

Scatt Self-absorpt Other Isotopes Comp. Corr

$(.991) \times 1.00132 \times .99995 = 0.99226$

Conversion factor

$$.99226 \times (6.55\,E\text{-}2)^{-1} \times \begin{Bmatrix} 1/25.33\ \mu g \\ 1/4.893\ \mu g \end{Bmatrix} \rightarrow \begin{Bmatrix} 0.59806 \text{ for } 49K\text{-}02\text{-}3F \\ 3.09605 \text{ for } 49K\text{-}0\text{-}3F \end{Bmatrix}$$

$Pu-240$ Spontaneous Fission

$t_{1/2\,SF} = 1.34 \times 10^{11}\ y$

$\dot{F} = \lambda N$

$221.4\ \mu g \rightarrow \frac{221.4 \times 10^{-6}\ \ 6.022 \times 10^{23}}{240.05} = 5.55 \times 10^{17} = N$

$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{(1.34 \times 10^{11}\ yr)(3.1558 \times 10^{7}\ \frac{sec}{yr})} = 1.639 \times 10^{-19}$

$\lambda N = 0.091$ counts/sec spont. fission.

NEGLIGIBLE FOR EXPT. 5.

Corrections for Fission in Minor Isotopic Constituents

1ST Iteration

U-5, U-3, Pu-9, — by calculation

U-8, U-N, Pu-1, Pu-0 — by exper. values where possible

2ND Iteration

all isotopes - by exper. values where possible & completion of error analysis.

1ST Iteration:

U-5	atom percent composition
U-4	0.1822 ± .0030
U-5	99.0829 ± .0150
U-6	0.0353 ± .0050
U-8	0.6996 ± .0010

σ_f CMP	σ_f UAR
barns	barns
0.321_4 ±20%	0.199_9 ± 30%
2.02 ± 5%	3.98 ± 10%
0.101_1 ±20%	0.0466_2 ± 30%
0.0446 ±10%	0.0214 ± 20%

$\frac{\sigma_x n_x}{\sigma_5 n_5}$	CMP	UAR
U-4	0.00029(6)*	0.00009(2)
U-6	0.00002(1)	0.00000(0)
U-8	0.00016(2)	0.00004(1)
$\sum_x \sigma_x n_x / \sigma_5 n_5$	0.00047(7)	0.00013(2)
Correction	0.99953(7)	0.99987(2)

* Value in ( ) is uncert. in last digit.

U-235

Prelim. corrected fission rates: Fiss/kw sec μg

CMP	UAR
84.94	55.67

$Pu-239$

	atom % comp.	$\bar{\sigma}_f$, CMP (b)	$\bar{\sigma}_f$ UAR (b)
$Pu-9$	99.978(1)	1.915 ±5%	3.826 ±10%
$Pu-0$	.021(1)	0.381 ±10%	.287 ±20%
$Pu-1$	.0005(2)	2.57 ±10%	5.93 ±20%
$Pu-2$	.0005(2)	0.297 ±20%	0.187 ±30%

$\bar{\sigma}_x n_x / \bar{\sigma}_9 n_9$	CMP	UAR
$Pu-0$	0.00004(1)	0.00001
$Pu-1$	0.00001	0.00001
$Pu-2$	<0.00001	<0.00001
$\sum_x \bar{\sigma}_x n_x / \bar{\sigma}_9 n_9$	0.00005(1)	0.00002
Correction	0.99995(1)	0.99998 negl. error.

Prelim corrected fission rates:

fiss/(kw sec μg)

CMP	UAR
80.434	53.952

U-233

	atom % comp	CMP σ_f (b)	UAL σ_f (b)
U-3	99.76(1)	2.72 ±10%	6.33 ± 20%
U-4	0.018(4)	.3214 ±20%	0.1999 ± 30%
U-5	0.009(2)	2.02 ± 5%	3.98 ± 10%
U-8	0.21(1)	0.0446 ± 10%	0.0214 ± 20%

$\sigma_x n_x / \sigma_3 n_3$	CMP	UAR
U-4	.00002	0.00001
U-5	.00007(2)	0.00006(2)
U-8	.00003	0.00001
$\sum_x \sigma_x n_x / \sigma_3 n_3$	.00012(2)	0.00008(2)
Correction	0.99988(2)	0.99992(2)

Prelim. corrected fission rates:

fiss/(kw sec μg)

CMP	UAR
124.85	83.74

Normal Uranium :

U-n	atom % composition	CMP σ_f (b)	UAR σ_f (b)
U-4	0.0054 (10)	.3214 ± 20%	.1999 ± 30%
U-5	0.7194 (30)		
U-8	99.2752 (30)	0.0446 ± 10%	0.0214 ± 20%

28NC-5-1 mass : 651.7 μg U-8

U-5 mass : $\frac{.7194}{99.2752} \times \frac{235}{238} \times 651.7 = 4.663$ μg U-5

	CMP	UAR
Fiss Rate Contrib. from U-5 : (Experimental values)	84.94 × 4.663/651.7	55.67 × 4.663/651.7
	0.60776 f/sec/μg/hw	0.3983 f/sec/μg/hw
	±	±
Gross Fiss Rate :	~~2.4452~~ 2.4355 f/sec/μg/hw	~~0.70775~~ .70275 f/sec/μg/hw

Gross Fiss Rate Less Exper. Correction for U-5 :

1.82774	0.30445
~~1.8374~~ f/sec/μg/hw	~~0.30942~~ f/sec/μg/hw
±	±

Calculated Correction for U-234: $1/(1+\sigma_4 n_4/\sigma_5 n_5)$

CMP	UAR
0.9976 1 (12)	0.99949 (22)

Completely Corrected U-8 Fission Rate

1.8270	0.30429
~~1.8367~~ f/sec/μg/hw	~~0.30926~~ f/sec/μg/hw

Total Correction (Corrected/Gross)	~~0.7511~~	~~0.4370~~
	0.7502	0.4330

1.69 % U-8 fission effect
.87 U-5 fission
1.42 U-5 alpha fuel
5.20 / 1.87 ; 5.3 % } 1.95 %

.33266 (66)*

1.30113 (6926)

Error in U-norm results

Factors		CMP $\frac{\partial \text{Conv ratio}}{\partial \text{variable}}$ (%/%)	UAR $\frac{\partial \text{conv result}}{\partial \text{variable}}$ (%/%)
U-n gross fission rate	1.27%	+1.33 %/%	+2.29 %/%
U-5 fission rate	.87%	.33 %/%	1.31 %/%
U-5 atom fraction	.42%	.33 %/%	1.31 %/%
resulting respective error factors:		1.69%	2.91 %
		.29%	1.14
		.14%	.55
Error in corrected U-8 fission rate from U-norm data.	Quad Sum	1.72 %	3.17 %

Errors quoted for fission in other isotopes

U-norm:

sensitivity of $\overbrace{\sigma_5 \eta_5 / \sigma_8 \eta_8}^{\text{exper. term}}$ to

CMP

			× →	
U-8 fiss rate	$\frac{\frac{.33266}{.33090} - 1}{.4\%} = 1.33\%/1\%$		1.27	1.69
U-5 fiss rate	1%/1%		.87	.87
U-5 atom fract	1%/1%		.42	.42
				1.95%

UAR

U-8 fiss rate	$\frac{1.30913}{1.28813} - 1 = 4.08\%$ / $.4\%$ = $\frac{4.08\%}{1\%}$	1.27	5.1
	1%/1%	.87	.8
	1%/1%	.42	.4
			5.27

Depleted U-238

	atom % Composition	CMP σ_f (b)	UAR σ_f (b)
U-4	0.00016 (5)	.3214 ± 20%	0.1999 ± 30%
U-5	0.01755 (10)		
U-8	99.9823 (10)	.0446 ± 10%	.0214 ± 20%

28G-5-1 mass: 735.7 μg

U-5 mass: $\frac{.01755}{99.9823}\left(\frac{235}{238}\right) 735.7 = 0.1275\,\mu g$ U-5

	CMP (f/sec/μg/kw)	UAR (f/sec/μg/kw)
U-5 Fiss Contrib (Experimental)	84.94 × 0.1275/735.7 =	55.67 × 0.1275/735.7 =
	0.01472 ± 1.8%*	0.00965 ± 1.8%
Gross Fiss rate	1.8483 ~~1.8529~~	0.33354 ~~0.33580~~
Net	1.8336 ~~1.8382~~	0.32389 ~~0.32615~~

Calc. U-4 correction: $1/(1+\sigma_4 n_4/\sigma_8 n_8)$

	0.99999 negl err.	0.99998 negl err.
Fully Corrected Fiss Rate	1.8336 ~~1.8382~~	0.32388 ~~0.32614~~
Correction	~~0.99207~~ 0.99203	~~0.97123~~ 0.97105

* combined atom perc. is {.57% ... .87% ... [illegible]

U-5 [illegible] → .00??2 (14) [illegible]

[illegible] 0.02979 (50)

Pu-241

	atom % comp.	CMP σ_f (b)	UAR σ_f (b)
Pu-8	.001	~.4 ± 100%	~0.3 ± 100%
Pu-9	.972 (1)		
Pu-0	.255	0.381 ± 10%	0.287 ± 20%
Pu-1	98.653	2.57 ± 10%	5.93 ± 20%
Pu-2	.118	0.297 ± 20%	0.187 ± 30%
Pu-4	.002	~0.4 ± 100%	~0.3 ± 100%
Am-1	15.0 (5)	0.276 ± 20%	0.191 ± 30%

41K-03-1(L) mass: 8.71 μg

Pu-9 mass: $\frac{.972}{98.653}\ \frac{239}{241}\ 8.71 = 0.0851\ \mu g$ Pu-9

Pu-9 Fiss. Contrib. (Exper.) from p. MIC-2:

	$80.434\ \frac{.0851}{8.71} =$	$53.952\ \frac{.0851}{8.71} =$
	0.7859 f/fiss/sec/μg	0.5271 f/fiss/sec/μg
Gross Fiss Rate	110.88	81.184
Rate Corrected for Pu-9	110.09	80.657

Calculated Corrections

$\sigma_x n_x / \sigma_{41} n_{41}$	CMP	UAR
Pu-8	< .0001	< .0001
Pu-0	.0004	.0001
Pu-2	.0001	< .0001
Pu-4	< .0001	< .0001
Am-1	.0163 (36)	.0049 (18)
$\sum_x \sigma_x n_x / \sigma_{41} n_{41}$	.0168 (36)	.0050 (18)
Correction	0.9835 (35)	.9950 (18)

Fully Corrected Results for Pu-241	108.27	80.25	f/fiss/sec/μg
Total Correction for Fiss in M.I.C. for Pu-241	0.9764(35)	0.9885(18)	

Pu-240

	atom % composition	40L-2-3F component mass μg	CMP σ_f (b)	UAR σ_f (b)
Pu-238	.0109		~.4 ±100%	~.3 ± 100%
Pu-239	.6727(3)	1.5054		
Pu-240	98.5191(6)	221.4	0.381 ± 10%	0.287 ± 20%
Pu-241	.4289(6)	.9679		
Pu-242	.3679(3)		0.297 ±20%	0.187 ±30%
Pu-244	.0006		~.4 ±100%	~.3 ±100%
Am-241	.17(5)		0.276±20%	0.191 ± 30%

Pu-9 & Pu-1	Fiss. Contrib.	CMP f/μg/sec/fiss	UAR f/μg/sec/fiss
± 1.5% {.66% 1.39%	Pu-9	80.434 $\frac{1.5054}{221.4}$ = .5469	53.952 $\frac{1.5054}{221.4}$ = .3668
± 2.90 {2.58% 1.32	Pu-1	108.27 $\frac{.9679}{221.4}$ = .4733	80.25 $\frac{.9679}{221.4}$ = .3508
	Pu-1 + Pu-9	1.0202	.71776
	Gross Fiss Rate	17.226	4.8141
	Gross Less Pu-1 & Pu-9	16.206	4.0965

Calculated Corrections

$\sigma_x n_x / \sigma_0 n_0$	CMP	UAR
Pu-8	.0001(1)	.0001(1)
Pu-2	.0029(6)	.0024(9)
Pu-4	<.0001	<.0001
Am-1	.0013(5)	.0012(6)
$\Sigma_x \sigma_x n_x / \sigma_0 n_0$	.0043(8)	.0037(11)

· Pu-240 Cont'd.

	CMP	UAR
Corrected Fission rate for Pu-240	16.136	4.081_3
Total Correction	0.9367 ± 1.1%	0.8478 ± .22%

Summary of Preliminary In-situ fission rates at the end of the 1st Iteration for Correction for Fission in Minor Isotopic Constituents:

	CMP f/(sec·kw·μg)	UAR f/(sec·kw·μg)
U-3	124.85	83.74
U-5	84.94	55.67
U-8	1.8336 ~~1.8382~~	.32388 ~~.32614~~
U-n	1.8270 ~~1.8367~~	.30427 ~~.30923~~
Pu-9	80.434	53.95_2
Pu-0	16.136	4.081_3
Pu-1	108.27	80.25
(Np	14.809	3.2834
Th)	.45494	.07980

2ND Iteration

U-235: Now Corr. for U-8 by exper value →

CMP: $\frac{.6996}{99.0829} \quad \frac{238}{235} \times 1.830 \pm <2\% \rightarrow .01314$ f/(s·kw·μg) or (÷ by 84.94) .000154 ± <.0000030 exper. $n_8\sigma_8/n_5\sigma_5$

UAR: $\frac{.6996}{99.0829} \quad \frac{238}{235} \quad \frac{.318 \pm <6\%}{55.67} \rightarrow$ .0000408 ± <.0000025

· agree within prev. error estimates. No further iteration needed.

		CMP	UAR
25A	Final MIC Corrections	0.99954 (6) (±.006%)	0.99987 (2) (±.002%)
U-4	calc	.00029 (6)	.00009 (2)
U-5	—	1.00000	1.00000
U-6	calc	.00002 (1)	.00000 (0)
U-8	exper	.00015 (0)	.00004 (0)
	Tot Inverse	1.00046 (6)	1.00013 (2)
	Final In-Situ Fission Rates	84.94 ± 0.86%	55.67 ± 0.87%

Pu-239 Pu-0, Pu-1 now by exper value for $\bar{\sigma}_x \bar{n}_x / \bar{\sigma}_9 \bar{n}_9$

$\bar{\sigma}_0/\bar{\sigma}_9$

Pu-0 $\frac{.021}{99.978} \frac{\widetilde{240}}{239} \frac{16.135}{80.434}$ ±<2% = .0000423 ± negl. err

$\frac{.021}{99.978} \frac{240}{239} \frac{4.0816}{53.952}$ = <2% = .0000160 ± negl. err

Pu-1 $\frac{.0005}{99.978} \frac{241}{239} \frac{107.88}{80.434}$ ±<3% = .0000068 ± negl err

$\frac{.0005}{99.978} \frac{241}{239} \frac{80.29}{53.952}$ ±<3% = .0000075 ± negl err

Calc Cm for Pu-242 as before.

		CMP	UAR
49K	Final MIC Correction	0.99995 ± negl err	0.99998 ± negl. err
Pu-9	—	1.00000	1.00000
Pu-0	exper	.00004	.000016
Pu-1	exper	.00001	.000008
Pu-2	calc	<.00001	<.00001
	Total Inverse	1.00005	1.000024
	Final In-Situ σ_a	80.434 ± 0.63%	53.952 ± 0.6%

U-233

U_5 & U_8 corr now by exper. data

U-5

$$\frac{.009 \ (\text{or } 22\% \pm .002)}{99.76} \quad \frac{235}{233} \quad \frac{84.94 \ (\pm 1.8\%)}{124.85} = .00006 \pm .00001$$

$$\frac{.009}{99.76} \quad \frac{235}{233} \quad \frac{55.67}{83.74} = .00006 \pm .00001$$

U-8

$$\frac{.21 \ (\pm 5\%)}{99.76} \quad \frac{238}{233} \quad \frac{1.830 \ (\pm < 2\%)}{124.85} = .00003 \text{ neg cor}$$

$$\frac{.21}{99.76} \quad \frac{238}{233} \quad \frac{.318 \ (\pm < 6\%)}{83.74} = .00001 \pm \text{neg cor}$$

U-4 as before

		CMP	UAR
23K	final MIC correction	0.99989(1)	0.99992(1)
U-3	—	1.00000	1.00000
U-4	Calc	.00002	.00001
U-5	exper	.00006(1)	.00006(1)
U-8	exper	.00003	.00001
	Tot Inverse	1.00011(1)	1.00008(1)
	Final In-site Fission Rates	124.85 ± 1.55%	83.74 ± 1.55%

U - NORM. NO CHANGE FROM 1ST Iteration

U-238 (depleted) " " " " " "

Pu-241

$Pu-240$ correction by exper. values

$$\frac{.255}{98.653} \quad \frac{240}{241} \quad \frac{16.135 \ (\pm < 3\%)}{107.88} = 0.0004 \text{ Neg cor}$$

$$\frac{.255}{98.653} \quad \frac{240}{241} \quad \frac{4.0816 \ (\pm < 3\%)}{80.29} = 0.0001 \text{ Neg cor}$$

No change.

Pu-240 NO Change

2ND Iteration gave no significant changes.

Summary of Corrections for Fission in Minor Isotopic Constituents

Batch Label and Isotopic assay (atom percent)		Core Mid Plane Combined Correction / Separate Correction Components	Upper Axial Reflector Combined Correction / Separate Correction Components
23K		0.99989 (1) *	0.99992(1)
^{232}U	< .6ppm	< 0.00001	< 0.00001
^{233}U	99.76(1)	1.00000	1.00000
^{234}U	0.018(4)	0.00002	0.00001
^{235}U	0.009 (2)	0.00006(1)	0.00006(1)
^{236}U	< 1.0 ppm	< 0.00001	< 0.00001
^{238}U	0.21(1)	0.00003	0.00001
25A		0.99954(6)	0.99987(2)
^{234}U	0.1822(30)	0.00029(6)	0.00009(2)
^{235}U	99.0829(150)	1.00000	1.00006
^{236}U	0.0353(50)	0.00002(1)	< 0.00001
^{238}U	0.6996(10)	0.00015	0.00004

* The numbers in ( ) are the uncertainties in the least significant digits. If no error is stated, the estimated error is less than 1 unit in the

(Table Cont'd)

28G		0.99203(14)	0.97105(50) (±.051%)
^{234}U	0.00016(5)	0.00001	0.00002
^{235}U	0.01755(10)	0.00802(14)	0.02979(53)
^{236}U	<0.00001	<0.00001	<0.00001
^{238}U	99.9823(10)	1.00000	1.00000
28NC		0.7502(37) (±.49%)	0.4330(130) (±3.0%)
^{234}U	0.0054(10)	0.0004(1)	0.0005(2)
^{235}U	0.7194(30)	0.3327(66)	1.3091(693)
^{238}U	99.2752(30)	1.0000	1.0000

(Table Cont'd)

49K		0.99995	0.99998
^{238}Pu	< 0.001	< 0.00001	< 0.00001
^{239}Pu	99.978(1)	1.00000	1.00000
^{240}Pu	0.021(1)	0.00004	0.00002
^{241}Pu	0.0005(2)	0.00001	< 0.00001
^{242}Pu	0.0005(2)	< 0.00001	< 0.00001
^{244}Pu	< 0.0002	< 0.00001	< 0.00001
40L		0.9368(11)	0.8477(22)
^{238}Pu	0.0109	0.0001(1)	0.0001(1)
^{239}Pu	0.6727(3)	0.0339(5)	0.0899(13)
^{240}Pu	98.5191(6)	1.0000	1.0000
^{241}Pu	0.4289(6)	0.0293(8)	0.0860(25)
^{242}Pu	0.3679(3)	0.0029(6)	0.0024(9)
^{244}Pu	0.0006	< 0.0001	< 0.0001
^{241}Am	0.17(5)	0.0013(5)	0.0012(6)

41 K		0.9765(34)	0.9885(18)
^{238}Pu	0.001	<0.0001	<0.0001
^{239}Pu	0.972(1)	0.0073(3)	0.0066(2)
^{240}Pu	0.255	0.0004	0.0001
^{241}Pu	98.653	1.0000	1.0000
^{242}Pu	0.118	0.0001	<0.0001
^{244}Pu	0.002	<0.0001	<0.0001
^{241}Am	15.0(5)	0.0163(36)	0.0049(18)

Pg 1 of

EXP 8

Isotope	CMP 10^{13} f/g (in situ)	UAR 10^{13} f/g (in situ)
U-233	12.838 ±1.79%	8.611 ±1.79%
U-235	8.734 ±1.24%	5.724 ±1.24%
U-238	0.1882 ±1.70%	0.0330 ±5.66%
Pu-239	8.270 ±0.89%	5.548 ±0.89%
Pu-240	1.6593 ±1.53%	0.4196 ±1.61%
Pu-241	11.133 ±2.73%	8.252 ±2.72%
Np-237	1.523 ±1.48%	0.3376 ±1.50%
Th-232	0.0468 ±2.65%	0.00821 ±3.00%

Pg 2

EXP 10

Isotope	CMP 10^{13} f/g (in situ)	UAR 10^{13} f/g (in situ)
U-233	39.743 ±1.79%	26.657 ±1.79%
U-235	27.039 ±1.24%	17.721 ±1.24%
U-238	0.583 ±1.70%	0.1020 ±5.66%
Pu-239	25.603 ±0.89%	17.174 ±0.89%
Pu-240	5.137 ±1.53%	1.299 ±1.61%
Pu-241	34.47 ±2.73%	25.55 ±2.72%
Np-237	4.714 ±1.48%	1.0451 ±1.50%
Th-232	0.145 ±2.65%	0.0254 ±3.00%

UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

May 23, 1980

Dr. John Rawlins
FFTF Project
Hanford Engineering Development Lab.
Westinghouse Hanford Corporation
Richland, WA 99352

Dear John:

Jim Fuller suggested that I send you some documentation on the mass assay of the deposit 49K-4-1 which was used as a monitor during the neutron spectrometry tests at the FFTF in February. This information is summarized below.

Deposit Label: 49K-4-1

Backing: Platinum Disk, 0.75 in. DIA X 0.005 in. thick.

Deposit Geometry: 0.50 in. disk centered on backing

Uniformity of Thickness: Has not been measured. Color of deposit is uniform across diameter, indicating uniformity within ± 10%.

Batch Label and Isotopic Composition: Batch ORNL 277A

Isotope	Atom Percent
239	99.978 ± 0.002
240	0.021 ± 0.002
241	0.0005 ± 0.0003
242	0.0005 ± 0.0003
244	< 0.0002

^{239}Pu Alpha Activity:

(a) 1.082×10^{6} sec^{-1} by NBS Radioactivity Section

(b) 1.071×10^{6} sec^{-1} ± 0.8% by NBS Neutron Field Standards Group (Gilliam)

Alpha Activity Ratio to Reference Deposit:

4.500 ± .27%

Fission Counting Ratio to Reference Deposit in Thermal Neutron Field:

4.492 ± .7%

Published Reference Deposit (49I-1-2) Mass:

104.8 μg Pu-239 ± 1.0%

Derived Mass Values:

(1) Alpha activity (b) above and half-life value of 24,119 ± 26 yr (Int. Jour. of App. Radiation and Isotopic, 29 No. 8, Aug. 1978.):

466.8 μg Pu-239 ± 1%

(2) Ratio to NBS Reference Deposit

471.6 μg Pu-239 ± 1%

(The mass assay of the reference deposit is discussed in the 1975 paper by Grundl, et al: "Measurements of Absolute Fission Rates," Nucl Tech, 25, No. 2, p. 237.

The second value of 471.6 μg Pu-239 ± 1% is the currently recommended value. However, a revision of our reference deposit mass assay is underway at the present time, and it looks probable that the reference deposit mass will be revised downward by 0.5% to 1.0%, which will bring the two results above into better agreement.

On another matter, the data processing for the February tests, I have a few comments to make. Jim Fuller and I have discussed the fission chamber results. I had only one minor reservation about the results: that the S_L/S_U ratio was higher than would be expected for a flow chamber. This deviation is caused (at least in part) by compression of the gas in the sealed chamber, but it is possible that the S_L/S_U ratio was also increased by noise pick-up. Fuller is checking to see how the peak/valley ratios from runs at the gamma pit compare to those from runs at the FTR. If we are to keep the full usefulness of the S_L/S_U ratio as a noise diagnostic, then we are going to have to find a way to account for the influence of chamber filling pressure. We are working on the problem jointly.

Sincerely,

David M. Gilliam

D. M. Gilliam
Center for Radiation Research
Neutron Field Standards

Pg 3

Pu-239

Reference Deposit Assay

Techniques Employed: (LASL)
(1) IDMS (Isotope Dilution Mass Spectrometry)
(2) Absolute alpha countng with specific activity from
  (a) literature half-life
  (b) quantitative depositon

Accuracy: ± 0.4%

Working Deposit Assay

Comparison to Reference Deposit by: (1) Alpha counting
(2) Fission counting

Estimated Errors ~ ± 0.3% to ± 0.4% in comparisons. Assessed errors slightly larger than initial estimate if fission and alpha comparisons were not consistent within estimated uncertainty.

U-235

Reference Deposit Assay

Techniques: Same as for Pu-239 (except IDMS @ NBS)

Accuracy: ± 0.5%

Working Deposit Assay

Comparison to Reference Deposit: (1) Fission counting (± 0.60%)
(2) Alpha counting (± 1.45%)
(given low weighting)

Pu-240

Working Deposit Assay

1.) IDMS (CBNM Geel) ± 0.9%
2.) Absolute alpha activity with literature half-life ± 0.8%
(agreement better than ± 0.1%)

Pg 4

Np-237

Reference Deposit Assay

Technique: Absolute alpha counting with specific activity by
(1) Literature half-life
(2) Quantitative deposition

Accuracy: ±1.0%

Working Deposit Assay

Comparison to Reference Deposit: (1) Alpha countng (± 0.3%)
(2) Fission Counting in ISNF (0.3%)
Agreement of fission & alpha ratios: 0.44%

Natural Uranium

Reference Deposit Assay

Techniques: (1) IDMS (NBS)
(2) Fission comparison to ^{235}U Ref. Dep. with thermal neutrons + 28/25 isotope ratio
(3) Absolute alpha counting with specific activity by quantitative deposition

Accuracy: ± 0.7% [(3) given low weight]

Working Deposit Assay

Comparison to Ref. Dep by thermal-neutron induced fission counting ± 0.64%

Depleted Uranium

Reference Deposit Assay

Techniques: (1) IDMS (NBS)
(2) Fission ratio to Nat. Uran. Ref. Dep in Cf-252 Neutron field
(3) Absolute alpha activity with specific activity from literature half-life

Accuracy: ± 1.0%

Working Deposit Assay

Comparison to Reference Deposit in Intermediate-Energy Standard Neutron Field (ISNF): ± 0.74%

Pg 5

U-233

Reference Deposit Assay

Techniques: (1) Absolute alpha counting using literature half-life for specific activity
(2) Thermal-neutron induced fission ratio to Pu-239 deposit
(a) maxwelliam spectrum
(b) monoenergetic neutrons with 35 milli-electron volt energy

(1) and (2) differed by 0.84%

Accuracy: ± 1.5%

Working Deposit Assay

Comparison to Reference Deposit: (1) Thermal-neutron induced fission counting (± 0.31%)
(2) Alpha counting (± 0.5%)

(1) and (2) differed by 0.23%

Accuracy: ± 0.3%

Th-232

Reference Deposit Assay

Technique: Absolute alpha counting using literature half-life for specific activity

Accuracy: ± 2 %

Working Deposit Assay

Comparisons to Reference Deposit: Alpha counting
Fission counting in ISNF

Accuracy: ± 2%

Pg 6 of 6

Pu-241

Working Deposit Assay

Techniques: (1) Absolute alpha counting of Am-241 build-up over five month period, beginning 22 months after separation
(2) Thermal-neutron induced fission comparison to Pu-239 deposit in a 35 meV monoenergetic beam

(1) and (2) differed by 2.4%
Equally weighted average used. Estimated accuracy ± 2.5%

Choice of Geel - CBNM laboratory: No U.S. laboratory was equiped to make double-rotated vacuum evaporation depositions. (LASL used to have this capability, but not now - at least, not for outside purposes.)

Choice of Fluoride as Chemical Form: Has lower sublimation temperature than oxides. Fluorides tend to deposit as single molecules while oxide molecules tend to condense into clumps as they stream from the crucible to the backing. For fluorides it is not necessary to heat the backings, and the single-molecules adhere better than clumps.

APPENDIX D

HEDL-CALCULATED FREE-FIELD SCATTERING CORRECTIONS

From: Radiation and Shield Analysis **Hanford Engineering Development Laboratory**
Phone: 6-5193 and 6-0153 W/B-47
Date: February 18, 1981
Subject: PERTURBATION IN FISSION CHAMBER MEASUREMENTS
DUE TO NEUTRON SCATTERING WITHIN CHAMBER

To: JA Rawlins

cc: RA Bennett
WL Bunch
JW Daughtry
RS McBeath
FS Moore
PA Ombrellaro
LLC - File/LB
SAS - File/LB

Ref: (1) DSI, JA Rawlins to LL Carter, November 21, 1980.

(2) LL Carter and ED Cashwell, "Particle Transport Simulation With The Monte Carlo Method," TID-26607, ERDA Critical Review Series, U. S. Energy Research and Development Administration, Technical Information Center, Oak Ridge, TN (1975).

Monte Carlo calculations have been made to determine fission rate changes due to the perturbation caused by the presence of the fission chamber at two axial locations within the IRT. The axial locations considered were core midplane and 80 cm below core midplane with the pristine spectra obtained from Ref. 1. Fission rates were calculated for ^{238}U and ^{239}Pu.

The calculations summarized in Table 1 are for infinitely dilute concentrations of ^{238}U and ^{239}Pu, and hence, do not include self-shielding due to the fissionable materials. Difficulties were experienced in obtaining good precision in the calculations so that the ratios given in Table 1 are only accurate to about one percent (one standard deviation). The largest statistical errors resulted for the calculation of the ^{239}Pu fission rate with the softer spectrum, even though more computer time was expended on this case. For this case more than 75% of the fissions occur in the resonance range below 1 keV, and the random walk integration over the resonances increases the statistical error substantially.

The source was biased (Ref. 2) in both energy and angle to improve the precision of the Monte Carlo calculations. To obtain greater precision one would need to make longer computer runs or possibly utilize more sophisticated biasing techniques.

The computer drawn model of the fission chamber is shown in Figure 1. The materials utilized for the main portion of the chamber are shown in the expanded view of Figure 2. Both materials and dimensions were utilized as specified in Reference 1.

Neutrons were started uniformly on the spherical surface (radius=3.84 cm) shown in Figure 1 with a cosine inward distribution. The source strength was normalized to yield a unit flux everywhere within the sphere for the pristine configuration with detector absent.

ENDF/B-IV neutron cross sections were utilized in the calculations.

L. L. Carter

L. L. Carter

S. A. Schenter

S. A. Schenter

llr

Attachments: Table 1
Figures 1 and 2

Table 1

FISSION RATES FOR UNIT EXTERNAL FLUX

	Fission Rate (fissions/g)	
	^{238}U	^{239}Pu
Core Midplane Spectrum		
Detector Included	9.711×10^{-5} (0.91%)*	4.552×10^{-3} (1.05%)*
Detector Materials Treated as Zero Density	9.883×10^{-5} (0.60%)	4.511×10^{-3} (0.62%)
Ratio	0.983 (1.1%)	1.009 (1.2%)
80 cm Below Core Midplane		
Detector Included	8.441×10^{-6} (0.96%)	2.002×10^{-2} (1.2%)
Detector Materials Treated as Zero Density	8.719×10^{-6} (0.79%)	1.945×10^{-2} (0.79%)
Ratio	0.968 (1.3%)	1.029 (1.4%)

*One standard deviation statistical error in the Monte Carlo calculation.

Figure 1. Calculational Model of Fission Chamber
(neutrons start on spherical surface)

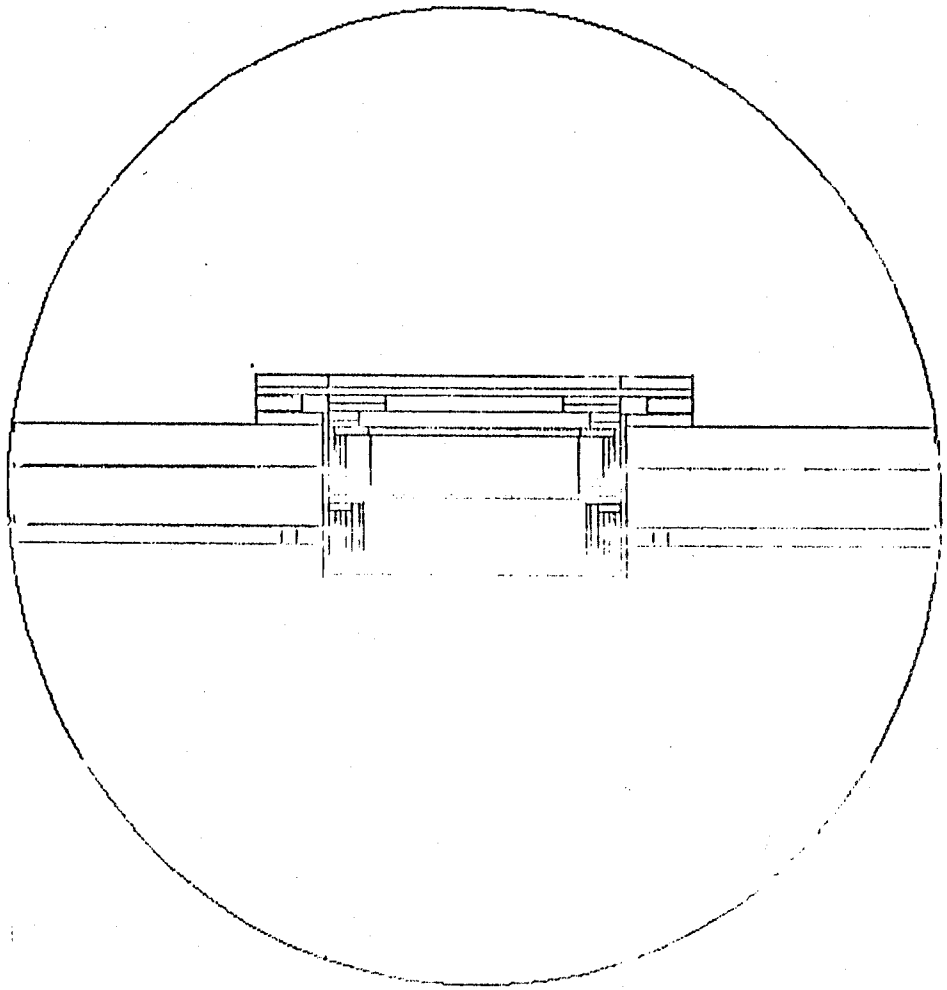
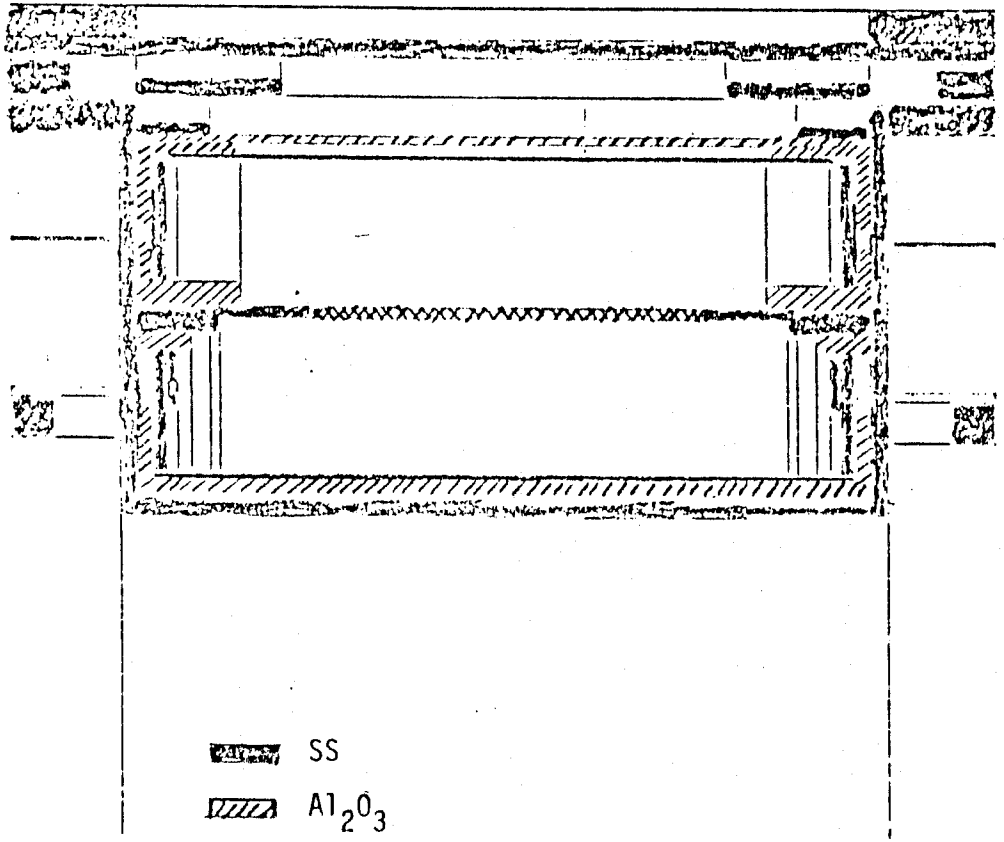


Figure 2. Expanded View of Calculational Model Showing Materials



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