AFRRI CONTRACT REPORT

Calorimetric dose measurements and calorimetric system developed for the Armed Forces Radiobiology Research Institute

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INTRODUCTION

An absorbed-dose calorimeter measures kerma caused by the absorption of gamma rays and fast neutrons. It basically operates through the following principle: The absorption of radiation in material results in an increase of the temperature of the material; this temperature increase is directly proportional to absorbed dose and is not dependent on dose rate or the ionization density of the radiation (1). Since the magnitude of such temperature increases is small (on the order of 10^{-3} K/rad), a sensitive thermistor is used to detect the change.

A calorimeter can be calibrated directly in terms of energy per unit mass by depositing a known amount of energy into the calorimeter's central absorbing element (or core) with an electric heater. When a TE plastic calorimeter is used, a small amount of the energy deposited by radiation does not appear as heat. About 4% of the energy is consumed by radiochemical reactions in the plastic (2), so a correction must be made for this thermal defect.

MATERIALS AND METHODS

The calorimeter used for these measurements (see Figure 1) was designed specifically to measure kerma in A-150 plastic. To achieve this goal, it was necessary to have a minimum amount of material surrounding the core. The core is a sphere of A-150 plastic, 1.27 cm in diameter. The point of measurement is at the center of the core, which is behind 0.63 cm of A-150 plastic. This amount of material is

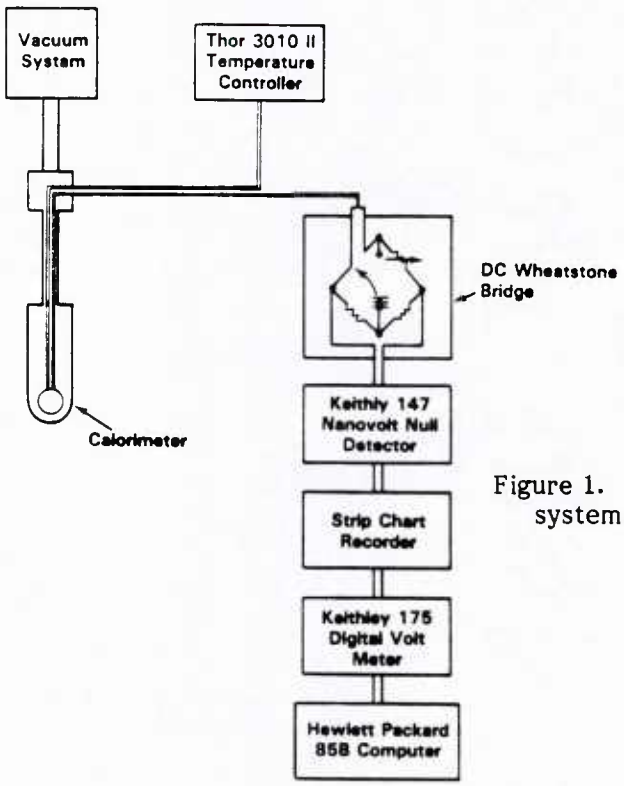

Figure 1. Block diagram of calorimeter system, indicating major components

enough to ensure secondary charged particle equilibrium for cobalt-60 gamma rays, but it is more than is needed to establish secondary charged particle equilibrium for neutrons from the reactor. Therefore, a correction was made for the absorption of neutrons in the material between the point of entry and the center of the core.

An aluminum vacuum shell, approximately 0.02 cm thick, surrounds the calorimeter's central elements. The vacuum provides insulation, which helps reduce heat loss from the core.

Figure 2 shows a block diagram of the equipment used in the calorimetric system. The change in resistance of the core thermistor was measured by the Wheatstone bridge and the null detector. This signal was displayed on a strip chart recorder and interfaced to a computer by means of a voltmeter. An example of the output signal is shown in Figure 3. The vacuum system and temperature controller were used to control the temperature of the calorimeter.

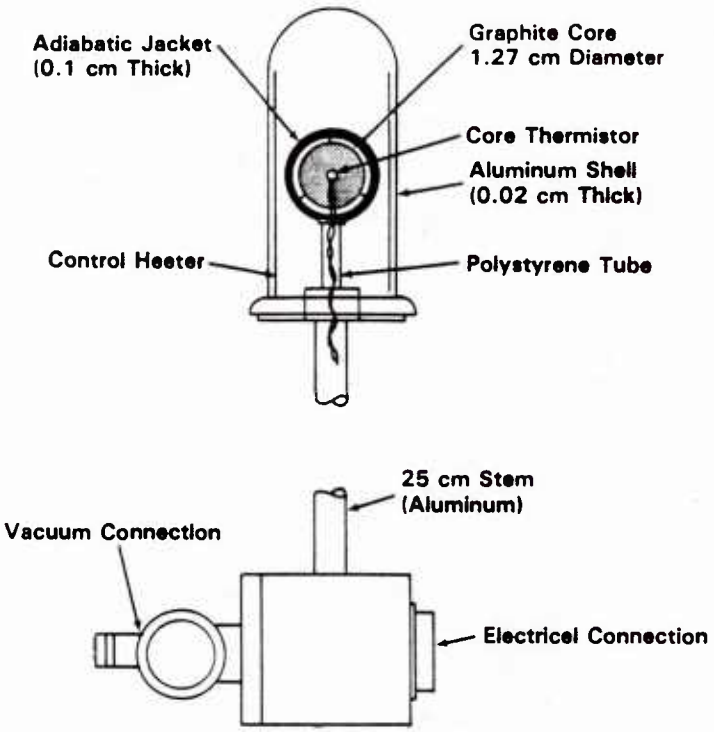

Figure 2. Cutaway drawing of internal construction of calorimeter (not to scale)

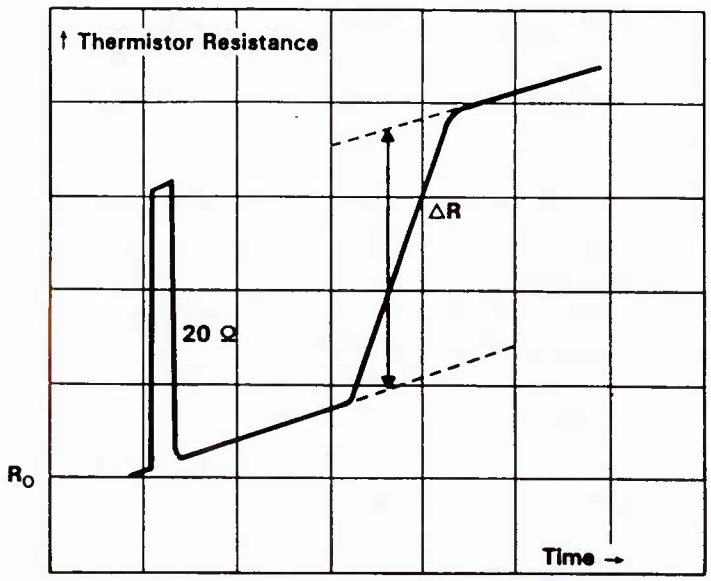

Figure 3. Recorder trace indicating response of Wheatstone bridge to change of 20 ohms and then to change in resistance of core thermistor due to heat deposited in core by radiation

Electrical calibration of the calorimeter was performed with a current source connected to the calibration heater element, which is imbedded in the core. Electrical heating of the core results in a response that corresponds to a known amount of energy per unit mass. This response is measured as the relative change in core thermistor resistance, ΔR, divided by the initial resistance value before the input of energy, R_O. The calibration factor, C, then becomes:

$$C = \frac{E}{m} \cdot \frac{R_O}{\Delta R}$$

where E is the energy deposited, m is the core mass, and $R_O/\Delta R$ is the fractional thermistor resistance change. The electrical energy deposited is calculated, knowing the core heater resistance and the current flowing through it (1).

During radiation measurement, a value is determined for $\Delta R/R_O$, which is then multiplied by the calibration factor to yield dose. An additional correction of 4% is made for the thermal defect; therefore:

$$D_{A\text{-}150} = C \cdot \frac{\Delta R}{R_O} \cdot T$$

where C is the calibration factor and T is the thermal defect correction of 1.04.

Kerma in the neutron field is determined by making an additional correction to account for the absorption of neutrons in the A-150 plastic upstream of the center of the core. The absorption in the 0.02-cm-aluminum vacuum shell was considered

negligible. These corrections differed for each irradiation condition, because the relative amounts of neutrons and gamma rays present were different. The three conditions are listed in Table 1 along with the absorption corrections used to calculate kerma (3).

Table 1. Irradiation Conditions and Absorption Corrections

Condition	Absorption Correction
6" lead	1.104
Bare	1.078
12" water	1.006

RADIATION SOURCES

Cobalt-60

The Cobalt-60 facility consists of 104 separate cobalt-60 elements stored under approximately 5 meters of water. The total activity was 100,000 curies as of September 1981. Depending on the arrangement of the elements, unilateral or bilateral exposures may be obtained. By varying the number of elements and the distance from the source, the dose rate may be varied from approximately 1 to 5700 rad/min.

When a source is selected, it is automatically raised from its safe storage position by an elevator. There are two such elevators, one on either side of the irradiation support. These elevators can be moved away from the source to distances of several meters. The source drives are controlled with electronic timers so that the duration of the exposure can be preset.

Reactor

The reactor at AFRRI is a General Atomics (TRIGA) Mark-F pool-type reactor, which is capable of both steady-state and pulsed modes. The reactor produces a modified uranium-235 fission spectrum with neutron-to-gamma ratios ranging from 0.05 to 30. The maximum power limitations are 1.0 MW (thermal) and 2500 MW (thermal) in the steady-state and pulsed modes, respectively.

Dosimetry at AFRRI's TRIGA reactor is currently performed with paired ionization chambers (tissue-equivalent plastic and magnesium). During steady-state reactor runs, where the dose rate is on the order of 40 rad/min, this technique has proven sufficient. However, in the pulsed mode, up to 10,000 rad may be given in a very short time (msec), causing the chambers to saturate. The pulsed mode, although used frequently, has not been adequately studied in terms of the neutron-to-gamma ratio and the spectra in the exposure rooms.

The reactor exposure room is approximately a cube (with 3.5-meter sides). The wall nearest the reactor has a cylindrical protrusion that allows the reactor core to be placed somewhat farther into the room. The normal irradiation reference position is 1 meter from the center of the core.

LINAC

The AFRRI linear accelerator (LINAC) is a traveling wave electron accelerator powered by a pulsed source of high-power microwave radio frequency. The LINAC may be operated in two distinct modes: one produces electron beams (13-20 MeV) and the other produces either higher energy (20-45 MeV) electron beams or bremsstrahlung fields.

Most experimental work currently done using the AFRRI LINAC requires the use of the first mode, that is, a beam of electrons with initial energy ranging from 13 to 20 MeV. The pulse is from 0.01 to 5.0 microseconds. A water scatterer is often used to decrease the energy of the electron beam and to increase the field size. Occasionally, shielding or a scattering device is placed between the target and the LINAC port to further reduce the energy and broaden the spectrum. The dose rate and the field size then depend on the initial energy of the electrons, use of water scatter, distance from the LINAC, and use of shielding or other scattering devices. Some common experimental configurations are listed in Table 2 (pulse width equal to 4 microseconds).

Table 2. Common Experimental Configurations

Initial Energy (MeV)	Water Scatter	Approx. Energy Striking Target (MeV)	Pulse Rate (pulse/sec)	Target Distance (meters)	Approx. Field Size (cm diam.)	Dose Rate (rad/pulse)
18.6	Yes	13.7	60	1.0	14	160
18.6	Yes	13.7	15	3.5	42	15
18.6	Yes	13.7	15	4.0	49	12
13.5	Yes	9.3	30	1.0	16	250
13.5	No	12.7	15	3.2	21	490
13.5	Yes	8.3	15	5.0	78	7
13.5	No	12.0	30	5.0	47	50

EXPERIMENTAL PROCEDURES

COBALT-60

The calorimeter and an AFRRI ionization chamber (Exradin T-2) were placed at the same distance (approximately 30 cm) from the cobalt-60 source elevators. The calorimeter and the chamber were supported on a wooden table placed between the two source elevators. The vacuum pump for the calorimeter was supported on an adjacent table. Cables were strung up to the shielded entry door, and then taped to the wall so that the door could close without crushing the cables. The calorimeter's electronics rack was operated in an area adjacent to the cobalt-60 source control room.

Monitoring was achieved by the use of electronic timers to control the duration of the exposures, and a spherical ionization chamber placed approximately 1 meter from the source elevators.

Appropriate corrections were made to the ionization chamber readings to account for local air temperature and pressure. The calorimetric measurements were taken in sets of approximately ten replicate runs to improve the standard error of the mean for each set.

REACTOR

Two ionization chambers were set up, along with the calorimeter, at a distance of 1 meter from the reactor core. The ionization chambers were Exradin T-2 model (0.5 cc); one was constructed of A-150 plastic and the other was of magnesium. A 50-cc AFRRI chamber served as a monitor.

The calorimeter's vacuum system was also in the exposure room. The entire vacuum system was shielded with boron-loaded paraffin blocks so that it could not become activated.

A series of steady-state and pulsed exposures was taken at several power levels to determine the saturation corrections for pulsed irradiations.

LINAC

The measurement configuration at the LINAC was different from that used at the reactor because of the higher energies encountered. Both the calorimeter and the AFRRI ionization chamber (Exradin T-2) were placed within a polystyrene block, which is normally a part of a SCRAD phantom (25 x 25 x 25 cm). Both the chamber and the calorimeter measured the dose at an effective depth of 2.67 g/cm^2, which is approximately the point of maximum dose within the phantom. With both electron and bremsstrahlung beams, the position of the dose maximum extends over several centimeters.

The calorimeter and chamber were placed on a table at distances ranging from approximately 2 to 6 meters from the beam pipe exit window. The calorimeter's vacuum system was placed on an adjacent table. The calorimetric signal passed through approximately 150 feet of shielded signal cable. The calorimeter's electronics were set up in the LINAC experimental area, near the electrometer for the ionization chamber.

DATA ANALYSIS

Calorimetric Calibration

The calorimeter is calibrated electrically by passing a known current through the core heater for a known time and observing the response in terms of the normalized resistance change (i.e., $\Delta R/R_o$). The electrically equivalent "dose" (J/kg) is computed from the following formula:

$$D = \frac{\left(\frac{V}{1.3} \Big/ 1000\right)^2 R_H t}{m_c}$$

where V is the calibration circuit voltage, R_H is the core heater resistance, t is the duration of the heating in seconds, and m_c is the mass of the core in kg. The factor of 1.3 accounts for the voltage division in the calibration circuit, and the factor of 1000 yields the correct units of joules.

Table 3 shows the calibration circuit voltages, equivalent doses, duration times, and observed $\Delta R/R_o$ values.

Table 3. Electrical Calibration Parameters

Voltage (V)	Dose (Gy)	Time (s)	$\Delta R/R_o$
.534	17.26	60	4.49×10^{-4}
.823	41.42	60	1.08×10^{-3}
1.600	148.07	60	3.86×10^{-3}

These values yield an average electrical calibration factor of:

$$C_E = 3.84 \times 10^4 \text{ Gy}/\Delta R/R_o$$

To cross-check this calibration, the core thermistor was calibrated in terms of temperature response. The data were fitted with an exponential least squares fit (Figure 4), yielding a value for the percent change per unit temperature of -4.467% per ^oC with a correlation coefficient of 0.99.

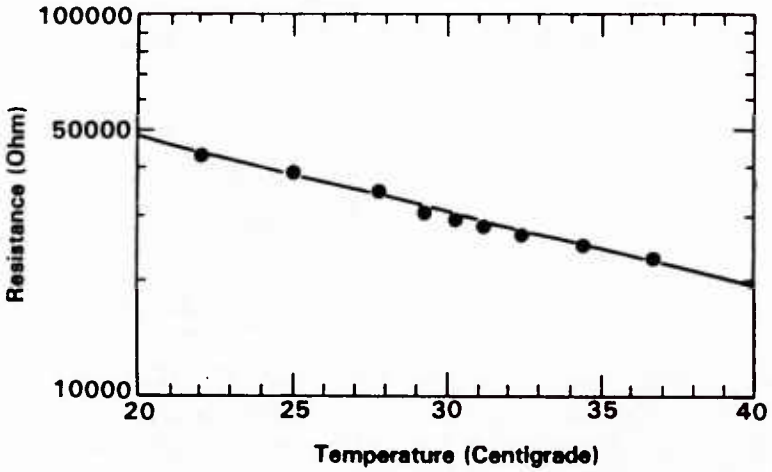

Figure 4. Plot of core thermistor resistance as function of core (A-150 plastic) temperature

The formula for specific heat can be used to evaluate the calorimeter's response another way:

$$S = \frac{E}{m \Delta t}$$

where S is the specific heat, E is the quantity of energy put into the substance, m is its mass, and t is the resultant temperature increase. Rewritten, this equation yields:

$$\frac{E}{m} = \Delta t \, S$$

where we can observe that the energy per unit mass will again be the dose.

The calorimeter was irradiated by a series of identical exposures of 12.03 Gy (tissue) of cobalt-60 gamma rays. The average value of the responses was:

$$R = 3.02 \times 10^{-4} \Delta R/R_o$$

Using the thermistor coefficient allows the determination of a temperature increase, and multiplying that by the specific heat of A-150 plastic (1.72 $J/^oC$) measured by Domen (4) yields the dose:

$$\frac{3.02 \times 10^{-4}}{4.467} \cdot 1.72 \cdot 10^5 = 11.63 \text{ Gy}$$

Thus the value of the calibration factor based on the thermal calibration is:

$$\frac{11.63}{3.02 \times 10^{-4}} = 3.85 \times 10^4 \text{ Gy}/\frac{\Delta R}{R_o}$$

This is almost indistinguishable from the electrical calibration:

$$C_E = 3.84 \times 10^4 \text{ Gy}/\frac{\Delta R}{R_o}$$

Calorimetric Dose Calculations

When the electrical calibration is used to calculate the dose from the response shown above, it yields:

$$D_{A-150} = R \cdot C_E \cdot T_D$$

where T_D is the thermal defect correction of 1.04 and the other symbols have their previous definitions.

$$3.02 \times 10^{-4} (1.84 \times 10^6) \ 1.04 = 12.06 \text{ Gy A-150}$$

This value should be compared to the value of dose computed to have been delivered to the center of the calorimetric core. This dose was computed as follows:

The measured exposure was $X = 1270$ roentgen

$$D = f \times A_{eq}$$

$$D = 0.957 \quad 1270 \quad 0.99 \quad 0.01 \quad \text{Gy/rad}$$

$$D = 12.03 \text{ Gy}$$

where F is the ratio of mass-energy absorption coefficients for tissue and air, and A_{eq} is the attenuation correction factor.

The delivered value is within 0.3% of the measured value. To summarize, the calibrations based on electrical and thermal methods agree, and the electrical calibration yields values of dose that are identical to values computed from National Bureau of Standards-calibrated chambers.

RESULTS

Tables 4-6 show the results of measurements that were taken during two sessions, July 1984 and March 1985. All of the individual calorimetric runs used to calculate the average values in the tables are shown in Appendix A. The first session concentrated on the reactor, and the second session dealt with the LINAC. Each time, a set of measurements was taken at the cobalt-60 source as a reference.

The cobalt-60 results show good linearity and reproducibility. The reproducibility between the two cobalt-60 measurements demonstrates the long-term stability of the calorimetric response.

Table 4. Cobalt-60 Results, July 1984

Set	Date	Nominal Dose Rate	Measured Dose Rate (A-150 rad/min)
1	7/10	7000	6950
2	7/11	1000	1050
3*	7/12	5000	2500
4	7/12	3000	3030

* Could be result of one source element not being in place

Table 5. Calorimetric Results at Reactor, July 1984

Date	Condition		Dose (rad)
7/16	Bare	100 kW	3,270
7/17	Bare pulses	6.5 MW	5,050
		13.8 MW	9,450
		19.9 MW	13,300
	12" H_2O	100 kW	460
7/18	6" Pb	100 kW	570
		200 kW	1,250
7/19	6" Pb pulses	8.8 MW	1,290
		15.4 MW	2,300
		21.3 MW	3,190

Table 6. LINAC Results, March 1985

Date	Radiation	Dose (Gy A-150 Plastic)
3/5	Cobalt-60	35.6
3/5	Cobalt-60	22.5
3/7	LINAC X rays 2.25 m	22.1
3/7	LINAC electrons 2.25 m	54.5
3/7	LINAC electrons 4 m, 4 μs	127.0
3/7	LINAC electrons 4 m, 3 μs	91.6
3/8	LINAC electrons 4 m, 2 μs	62.8
3/8	LINAC electrons 4 m, 1 μs	33.0
3/8	LINAC electrons 6 m, 4 μs	54.1
3/8	LINAC electrons 4 m, 18.4 MeV	24.6

DISCUSSION AND CONCLUSIONS

UNCERTAINTIES

The precision of the measurements primarily depends on the signal-to-noise ratio for the particular irradiation condition. To improve the determination of a particular value of kerma or kerma rate, several replicate runs were taken. The standard error of the mean for most of these measurements was between ±0.5% and 1.5%. Other sources of random uncertainty include data analysis imprecision, monitor reproducibility, and calibration uncertainties.

The accuracy, or systematic uncertainty, is dependent on the calibration of the calorimeter and on the correction factors applied in the calculation of kerma. Estimates of the accuracy from similar measurements were approximately ±2.5% (5). This includes an uncertainty of approximately ±1.5% in the value used for the thermal defect corrections (6).

The overall uncertainty in the determination of kerma and kerma rate by means of calorimetric measurement was determined by adding the estimated random and systematic uncertainties in quadrature. The individual sources of uncertainty are shown in Table 7. The overall value thus obtained is ±2.9%.

Table 7. Sources of Uncertainty

Electrical calibration	0.25%
Measurement repeatability	0.5%
Geometry	0.5%
Thermal defect	1.5%
Kerma correction	2.5%

CONCLUSIONS

The calorimetric system provides an accurate method for determining the absorbed dose from the radiation beams at AFRRI. The calorimeter's response is independent of dose rate and ionization density, which makes it valuable for comparing the performances of dosimetry systems.

It was decided that a TE calorimetric system should be constructed specifically for AFRRI. This project was completed, and the system is described in Appendix B. Instructions for operating the system are also included.

ACKNOWLEDGMENTS

The author wishes to thank G. H. Zeman, M. Dooley, L. J. Goodman, D. Eagleson, E. J. Golightly, and T. H. Mohaupt for their help during these difficult measurements.

APPENDIX A. DATA LIST

The following pages contain tables of data from each calorimetric run taken at AFRRI during two measurement sessions.

Cobalt-60	Electrons 252 cm
5.89×10^{-4}	1.38×10^{-3}
5.73×10^{-4}	1.38×10^{-3}
5.80×10^{-4}	1.37×10^{-3}
5.56×10^{-4}	1.39×10^{-3}
5.65×10^{-4}	1.38×10^{-3}
5.57×10^{-4}	1.38×10^{-3}
5.87×10^{-4}	1.38×10^{-3}
5.60×10^{-4}	1.38×10^{-3}
5.61×10^{-4}	1.37×10^{-3}
5.61×10^{-4}	1.39×10^{-3}
	1.40×10^{-3}
	1.41×10^{-3}

X-Rays LINAC	Electrons 4 m (4 μs)
5.65×10^{-4}	3.97×10^{-3}
5.65×10^{-4}	3.20×10^{-3}
5.66×10^{-4}	3.18×10^{-3}
5.58×10^{-4}	3.21×10^{-3}
5.50×10^{-4}	3.21×10^{-3}
5.59×10^{-4}	3.20×10^{-3}
5.51×10^{-4}	3.21×10^{-3}
5.52×10^{-4}	3.21×10^{-3}
5.56×10^{-4}	3.22×10^{-3}
	3.25×10^{-3}
	3.23×10^{-3}

Electrons 4 m (3 μs)	Electrons 4 m (1 μs)
2.33×10^{-3}	8.28×10^{-4}
2.31×10^{-3}	8.39×10^{-4}
2.29×10^{-3}	8.40×10^{-4}
2.34×10^{-3}	8.31×10^{-4}
2.32×10^{-3}	8.32×10^{-4}
2.35×10^{-3}	8.33×10^{-4}
2.33×10^{-3}	8.43×10^{-4}
2.33×10^{-3}	8.34×10^{-4}
2.31×10^{-3}	8.40×10^{-4}

Electrons 4 m (2 μs)

1.58×10^{-3}
1.59×10^{-3}
1.59×10^{-3}
1.57×10^{-3}
1.57×10^{-3}
1.58×10^{-3}
1.58×10^{-3}
1.61×10^{-3}
1.63×10^{-3}

Electrons 6 m (4 μs)

1.36×10^{-3}
1.36×10^{-3}
1.36×10^{-3}
1.37×10^{-3}
1.36×10^{-3}
1.38×10^{-3}
1.39×10^{-3}
1.39×10^{-3}
1.39×10^{-3}
1.38×10^{-3}

7/12/84 Cobalt-60 3000 rad

2.53×10^{-3}
2.40×10^{-3}
2.39×10^{-3}

7/12/84 Cobalt-60 5000 rad

3.33×10^{-3}
3.08×10^{-3}
3.14×10^{-3}
3.08×10^{-3}

7/11/84 Cobalt-60 1000 rad

1.31×10^{-3}
1.34×10^{-3}
1.33×10^{-3}
1.37×10^{-3}
1.33×10^{-3}

7/10/84 Cobalt-60 7000 rad

8.76×10^{-3}
8.81×10^{-3}
8.79×10^{-3}
8.85×10^{-3}
8.88×10^{-3}

7/16/84 Bare Reactor 100 kW

2.40×10^{-3}
2.26×10^{-3}
2.58×10^{-3}
2.51×10^{-3}
2.69×10^{-3}

7/16/84 Reactor Pulses 6 nVt

9.62×10^{-4}
9.44×10^{-4}
1.10×10^{-3}

7/17/84 Reactor 12" H_2O 100 kW

3.02×10^{-4}
3.14×10^{-4}
3.38×10^{-4}
3.22×10^{-4}

7/18/84 Reactor 6" Pb 100 kW

7.10×10^{-4}
1.01×10^{-3}
7.09×10^{-4}
5.78×10^{-4}
5.08×10^{-4}

7/18/84 Reactor Pulses 6" Pb 12 nVt

7.81×10^{-4}
7.72×10^{-4}
7.47×10^{-4}
6.60×10^{-4}

7/19/84 Reactor 6" Pb 100 kW

5.75×10^{-4}
5.75×10^{-4}
5.77×10^{-4}
6.00×10^{-4}
5.80×10^{-4}

7/19/84 Reactor 6" Pb 200 kW

5.91×10^{-4}
6.18×10^{-4}
4.07×10^{-4}

APPENDIX B. OPERATIONAL PROCEDURES FOR CALORIMETER

These procedures are written as a checklist. The user is assumed to be somewhat familiar with the equipment. If you are not familiar with the equipment, study the equipment manuals and then follow the instructions below.

EQUIPMENT CHECK

The equipment includes:
- Calorimeter
- Vacuum pump with connectors
- HP-85 computer (HP-IB interface and 64K memory needed)
- Keithley voltmeter
- Calibration circuit
- Cables

If any of these items are missing, locate them or contact your supervisor.

PLACEMENT OF EQUIPMENT

1. The HP-85 computer, the Keithley voltmeter, and the calibration circuit are normally in an equipment cart, along with the cables and the calorimeter in its wooden case (see Figure 4).

2. The vacuum pump does not need to be kept with the other equipment.

3. The electronic equipment should be placed in the control area adjacent to the radiation source to be used.

EVALUATING THE CALORIMETER

1. The A-150 plastic core must be kept at low pressure. If you suspect that the calorimeter's vacuum valve has been opened to air, evacuate the calorimeter.

2. If the calorimeter has been opened to air for longer than 2 days, you must evacuate the calorimeter and irradiate it to approximately 150 kilorad using cobalt-60 or electrons before attempting measurements.

3. If you have not operated the vacuum system before, consult the equipment manuals before doing so. All valves of the vacuum system should be closed. The calorimeter's vacuum valve should be closed. The mechanical pump should then be switched on. (The diffusion pump will not be switched on until later.)

4. Connect the calorimeter to the brass valve on the pump by means of the stainless steel bellows. Check to be sure that the O-rings are clean and well seated. Secure the calorimeter with a ring stand clamp. Open the brass valve slowly (the bellows will compress and may pull the calorimeter toward the pump).

5. Open the calorimeter's valve slowly. After a few minutes, switch on the diffusion pump. Allow the calorimeter to pump this way for about 1 hour. Observe the vacuum gauge, which should indicate a pressure of just a few torrs.

CONNECTING CABLES

1. After the calorimeter has been evacuated and the electronics have been placed in the appropriate location, connect the calorimeter to the cable end that has a dark-green female connector. This connector mates with the calorimeter's connector. It is keyed and has a quarter-turn bayonet-type mechanism.

The other end of the cable has a blue male multipin connector that plugs into the rear of the calibration circuit. A short cable with banana jacks at the end is connected from the rear of the calibration circuit to the input of the Keithley digital multimeter.

2. The Keithley will normally be left connected to the HP-85 computer. However, it is prudent to verify that the interconnecting cable and HP-IB interface module are plugged into the Keithley and the HP-85, respectively.

3. The Keithley multimeter should be in the resistance mode, and the display should read approximately 10,000 ohms. If an open circuit or short circuit is indicated, recheck the connections.

4. Turn on the calibration circuit and run it for a few seconds. Select both the core and the jacket on the mode switch, and verify that some voltage appears on the panel meter in both positions. This checks the continuity of the calibration heaters. If the panel meter indicates no voltage, again check the connections.

SETUP FOR MEASUREMENTS

1. After it has been determined that the calorimeter is operating properly, disconnect the cable and set the calorimeter at the irradiation position. A white line on the exterior of the calorimeter indicates the height of the core, and the top of the calorimeter has a centering spot.

2. Make sure that the vacuum valve is not inadvertently opened while you are setting up the system.

3. Bring the cable into the irradiation room and connect it to the calorimeter. After the final fine position adjustments and checks, tape the cable down or otherwise secure it into position.

TEMPERATURE EQUILIBRATION

After the calorimeter has been set in place for measurements, it must be allowed to come to equilibrium with its surroundings. Although the temperatures of most rooms are within a few degrees of each other, such differences are very large compared to the temperatures that the calorimeter will actually be measuring when it is irradiated. (These are on the order of 10^{-3}°C.) Allow a few hours for the calorimeter to equilibrate.

The reactor presents the most serious equilibration problem. The calorimeter should be placed in the reactor's exposure room some time during the afternoon preceding a measurement session. It should be connected to the electronic system and left on overnight. No further entries into the exposure room should be made until early the next morning (approximately 6:30 a.m.), when the reactor room lights should be turned on and left on. These lights create a rise of several degrees in room temperature, so the calorimeter will have to equilibrate again for approximately 2 hours. If the lights are turned on at 6:30, the system should be ready by 9:00 a.m.

The drift rate of the calorimeter can be checked periodically by acquiring the plotting data with the READIN program or by observing the reading of the Keithley digital multimeter.

COMPUTER ROOM

The operation of the HP-85 computer requires the program tape cassette and a blank tape (or tapes). The program tape should be "write inhibited," and the blank data tapes should be capable of being written.

The program will autostart. The program tape should be inserted into the HP-85, and the power switch should then be turned on. At this point, a menu will appear on the screen with a list of the following subprograms:

LOADR
READIN
LSTSQ
DNLOAD
EPLOT

The control keys K1 through K9 are used to select the subprograms. The programs are self-prompting and require either a yes or no (Y/N) or an input of numerical data.

Procedure

1. Enter date (D,M,Y) and time (H,M,S).

2. Select READIN. This program will ask for file names and run parameters.

3. When data entry is finished, write the data onto a blank tape with DNLOAD. This program will also prompt the user.

4. When the data are to be analyzed, run the EPLOT program to select the intervals of analysis. This program automatically scales the plot to display maximum sensitivity.

5. Program LSTSQ analyzes the data and calculates a net slope value and a displacement. Either of these quantities can be calibrated to produce dose or dose-rate values.

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