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DOSE AND FLUX MEASUREMENTS
ON GODIVA RADIATION EFFECTS EXPERIMENTS

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ABSTRACT

Flux and dose measurements of fast neutrons, thermal neutrons and gamma rays under perturbing conditions using Godiva as a source are described and discussed. The limitations of single monitoring devices are noted. It is pointed out that in order to improve the accuracy of flux and dose measurements in radiation effects studies, specific detectors must be used at the position of the experimental object.

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CHAPTER 1

INTRODUCTION

The Godiva reactor has been used by many organizations both within and outside of Los Alamos as a source of neutrons and gamma rays for radiation effects studies. Many of these users have depended upon dose calibration numbers furnished to them by N-2 and by H-4. Monitoring of exposures has been done using sulfur detectors, fission counters and other systems.

It has long been the contention of one of us that the accuracy of the calibration numbers used is questionable for these types of experiments. In particular we refer to the perturbations introduced when one exposes sizeable electronic or other systems or multiples thereof. It is impossible to predict accurately how the cluttering up of the area around the source will affect the actual fluxes or doses measured at some point of interest. Also, it is impossible to state, a priori, that a single reference monitor in some particular location will be an accurate index of some number needed at some other area in the general locale.

These experiments were designed to measure as completely as possible the radiation environment at a particular location of interest.

CHAPTER 2

EXPERIMENTAL SETUP AND RESULTS

A number of measurements of neutron flux, neutron dose and gamma dose were made in connection with radiation effects experiments performed on August 27 and 28 using Godiva as the source. These measurements were done using standard foil and dosimeter systems to determine (under the conditions of exposure) the perturbing effects of the irradiated objects on the in-air beam.

The measured fluxes and gamma doses found under the different exposure conditions are given in Table 1. The numbers used to establish these values are the same as those used in other studies*. These include the fission cross-sections:

plutonium $\sigma_f = 774$ barns at thermal energy,

plutonium $\sigma_f = 2$ barns at E 4 Kev,

neptunium $\sigma_f = 1.5$ barns at E 750 Kev,

uranium $\sigma_f = 0.54$ barn at E 1.5 Mev.

*J. A. Sayeg, E. R. Ballinger and P. S. Harris. Dosimetry for the Godiva II Critical Assembly -- Neutron Flux and Tissue Dose Measurements. LA-2310 (September 1959).

They also include a cross section of $\sigma = 0.230$ barn for $E > 2.5$ Mev for the $S(n,p)P$ reaction.

The neutron doses calculated from these measured fluxes are shown in Table 2. The measured gamma ray doses are repeated in this table. From measurements made in air it has been found that the total fast neutron dose may be estimated by multiplying the flux determined by plutonium activation by an appropriate conversion value. For the in-air case the conversion is $2.43 \times 10^{-9} \text{ (rad/n/cm}^2\text{)} \phi_{\text{Pu}}(\text{n/cm}^2 > 4 \text{ Kev}) = \text{dose in rads}$. The estimated dose using this relation is also shown in the table. It will be noted that except in one case, the estimate is accurate to better than 90%. In the one case three inches of polyethylene were purposely interposed between Godiva and the detector in order to moderate the source spectrum. Sulfur flux measurement only as an index of total neutron dose in air has been widely used in Godiva experimentation. For this condition the conversion factor used to determine dose is $1.35 \times 10^{-8} \text{ (rad/n/cm}^2\text{)} \phi_{\text{S}}(\text{n/cm}^2 > 2.5 \text{ Mev})$. The estimates of fast neutron dose using measured sulfur fluxes are also given in the table. Here the discrepancy between estimate and measurement is wide and scatters badly. Finally, the measured gamma dose to fast neutron dose ratios are given. These also vary widely.

The flux ratios of $>750 \text{ Kev} / >4 \text{ Kev}$; $>1.5 \text{ Mev} / >4 \text{ Kev}$; $>2.5 \text{ Mev} / >4 \text{ Kev}$; and $\text{thermal} / >4 \text{ Kev}$ are shown in Table 3. The flux ratios under "in-air" measurement conditions are also shown. It will be noted that the ratios found in these experiments run about the same as found

for the in-air general case (shown in Table 3) for the >750 Kev to >4 Kev ratio. For >1.5 Mev to >4 Kev and >2.5 Mev to >4 Kev the ratios found are in general lower, while the thermal to fast ratios are generally higher.

CHAPTER 3

DISCUSSION

These experiments have pointed up a number of facts of interest in the use of Godiva as a radiation source.

In any situation in which the area in the neighborhood of the source is fairly well crowded with experimental objects (as can be noted in Fig. 1), prediction of dose to the objects is impossible if any sort of accuracy is desired. In many cases the fast neutron total dose estimate, using the standard formulae for distance and temperature rise,* is not even close to the measured value. For example, in burst #3 at 56.5", where 3" of polyethylene was purposely interposed between the source and the detector, the dose estimate from temperature rise is ~2.5 times the actual measured value. Other estimates are not as bad as this case but seldom do they approach the measured dose.

It will be noted from Table 2, however, that the flux as measured by a plutonium foil surrounded by B¹⁰ can be used to give a reasonable

*J. A. Sayeg, E. R. Ballinger and P. S. Harris. Dosimetry for the Godiva II Critical Assembly -- Neutron Flux and Tissue Dose Measurements. LA-2310 (September 1959).

estimate of total fast neutron dose in all cases except for the polyethylene shielded situation. Here, the in-air conversion factor of 2.43×10^{-9} rad/n/cm² for E>4 Kev is applicable. From the information given in Table 3 one would estimate that the use of a single neptunium foil (shielded with cadmium) at each position of interest would give a total fast neutron dose value within $\pm 25\%$ of the true value.

On the other hand, Table 2 and Table 3 show that neither a single uranium-238 foil nor a single sulfur pellet can be used to estimate total fast neutron dose under these conditions. This is important when one considers that sulfur detectors in the neighborhood of the test object have been widely used to convert to dose.

It is apparent that the variation of accuracy of estimate using different foils is due to the insensitivity of fast neutron single collision dose to variation in total fast spectrum of the source. At the same time there is the seemingly anomalous situation in which the estimated dose is very sensitive to changes in the high energy end of the spectrum. What occurs is that neutrons may disappear from the high energy end through single scatters, but still remain "fast" and contribute a significant proportion of the total dose at some energy below the high energy detector threshold. Thus, since there is only a factor of four difference in energy deposition over the fission neutron spectrum and only a fraction of the total neutrons escape without giving up most of their energy to the system, a detector like plutonium will be rather insensitive to shifts in spectrum.

As will be noted in Table 2, the gamma ray dose to neutron dose ratio varies widely over the different exposures. This means that even a good determination of neutron dose cannot be used to predict the gamma dose. For many experiments in which total gamma dose is the important consideration direct measurement at the point of interest is necessary.

From Table 3 it will be noted that the thermal neutron flux is quite different than one would predict from in-air measurements. The variation from prediction is more at the near positions than at more distant positions. This is because room return from wall scatter in the Kiva has more weight in the production of thermal neutrons than nearby experimental objects as the position approaches large scattering masses. Actually, thermal neutron fluxes of these magnitudes are generally of no interest in radiation effects studies. However, since many gamma dose measuring devices have significant thermal neutron response (of the order of 10^{-9} rad/n/cm²), the presence of significant thermal flux should not be ignored.

CHAPTER 4

CONCLUSIONS

These measurements made under the conditions noted lead to several conclusions of importance in radiation effects studies using Godiva as a source.

1. Local environmental perturbations produced by the experimental objects themselves modify both fast neutron and gamma ray doses at the points of interest.

2. The use of a monitor such as temperature rise in the assembly cannot be used to give an accurate index of either flux or dose at the position of some experimental object.

3. The use of sulfur as a flux or dose monitor cannot be used to give an accurate estimate of total flux or total dose at the position of some experimental object.

4. Plutonium surrounded by B^{10} can be used to give a reasonably accurate estimate of total fast flux and total fast neutron dose (accuracy better than 20%) at the position of an experimental object under the usual conditions of the experiment. If the leakage spectrum is

highly modified by the use of low Z interposed materials, plutonium in itself is unsatisfactory.

5. Gamma ray total dose cannot be predicted from a total neutron dose measurement in radiation effects experiments to better than a factor of three to four.

6. Thermal neutron fluxes are not predictable and (if of any importance) must be measured.

7. Gamma ray dose measuring devices should be thermal neutron insensitive because, generally, the presence of perturbing materials tends to raise the thermal neutron flux background and many standard gamma dose detectors have a high sensitivity (on a rad for rad basis) to thermal neutrons.

TABLE 1. SUMMARY OF FOIL AND GAMMA DOSE DATA

Identity of Burst	Position*	Flux above Threshold				Au Flux		Rad γ
		> 4 Kev	> 750 Kev	> 1.5 Mev	> 2.5 Mev	$\bar{s}$ Cd	$\bar{c}$ Cd	
1335 hrs 27 August $\Delta t = 64.4^\circ\text{C}$	28 " - 71 cm	3.16×10^{11}	2.60×10^{11}	1.15×10^{11}	3.72×10^{10}	1.52×10^{10}	0.90×10^{10}	58.5
	110 " - 279 cm	2.98×10^{10}	2.16×10^{10}	9.64×10^9	4.00×10^9	4.89×10^9	1.93×10^9	12.3
1535 hrs 27 August $\Delta t = 70.7^\circ\text{C}$	18 " - 46 cm	7.38×10^{11}	6.02×10^{11}	2.62×10^{11}	1.56×10^{11}	3.09×10^{10}	1.96×10^{10}	220
	61 " - 155 cm	5.92×10^{10}	4.18×10^{10}	1.84×10^{10}	8.49×10^9	7.25×10^9	3.03×10^9	20.8
0935 hrs 28 August $\Delta t = 71.5^\circ\text{C}$	44.5" - 113 cm	1.65×10^{11}	1.39×10^{11}	5.63×10^{10}	2.24×10^{10}	1.70×10^{10}	0.56×10^{10}	41.0
	56.5" - 144 cm	3.80×10^{10}	2.34×10^{10}	1.14×10^{10}	3.93×10^9	9.96×10^9	3.39×10^9	20.6
1150 hrs 28 August $\Delta t = 83.3^\circ\text{C}$	9.5" - 24 cm	1.98×10^{12}	1.76×10^{12}	7.48×10^{11}	4.78×10^{11}	5.78×10^{10}	4.05×10^{10}	856
	35.5" - 90 cm	1.16×10^{11}	8.42×10^{10}	3.38×10^{10}	2.38×10^{10}	1.35×10^{10}	0.62×10^{10}	46.0
1400 hrs 28 August $\Delta t = 80.1^\circ\text{C}$	9.5" - 24 cm	2.55×10^{12}	2.14×10^{12}	9.32×10^{11}	5.55×10^{11}	5.74×10^{10}	4.20×10^{10}	566
	38.5" - 98 cm	1.44×10^{11}	1.15×10^{11}	4.95×10^{10}	2.17×10^{10}	1.59×10^{10}	0.72×10^{10}	36.5
1545 hrs 28 August $\Delta t = 74.0^\circ\text{C}$	13.5" - 34 cm	1.62×10^{12}	1.34×10^{12}	5.80×10^{11}	2.62×10^{11}	4.44×10^{10}	2.03×10^{10}	600
	26 " - 66 cm	3.66×10^{11}	3.22×10^{11}	1.26×10^{11}	3.44×10^{10}	1.44×10^{10}	0.85×10^{10}	27.5

*Detector position with respect to the center of Godiva in terms of radial distance.

TABLE 2. DOSE MEASUREMENTS AND ESTIMATES

Burst Identity	Position*	γ Dose (rads)	Measured Neutron Dose (rads)	Estimated Neutron Dose from Pu Flux Measurement	Estimated Neutron Dose from S Flux Measurement	Measured γ Dose to Neutron Dose Ratio
1335 hrs 27 August $\Delta t = 64.4^{\circ}\text{C}$	28 "	58.5	755	768	502	0.077
	110 "	12.3	67	72	54	0.184
1535 hrs 27 August $\Delta t = 70.7^{\circ}\text{C}$	18 "	220	1822	1793	2106	0.121
	61 "	20.8	131	144	114	0.159
0935 hrs 28 August $\Delta t = 71.5^{\circ}\text{C}$	44.5"	41.0	399	401	302	0.103
	56.5"	20.6	78	92	53	0.264
1150 hrs 28 August $\Delta t = 83.3^{\circ}\text{C}$	9.5"	856	5094	4811	6453	0.168
	35.5"	46.0	263	282	321	0.175
1400 hrs 28 August $\Delta t = 80.1^{\circ}\text{C}$	9.5"	566	6330	6197	7492	0.089
	38.5"	36.5	339	350	293	0.108
1545 hrs 28 August $\Delta t = 74.0^{\circ}\text{C}$	13.5"	600	3924	3937	3537	0.153
	26 "	27.5	896	889	464	0.031

*Detector position with respect to the center of Godiva in terms of radial distance.

TABLE 3. SUMMARY OF FLUX RATIOS

Burst Identity	Position*	Measured Thermal/ >4 Kev	In Air Thermal/ >4 Kev	$\frac{>750 \text{ Kev}}{>4 \text{ Kev}}$	$\frac{>1.5 \text{ Mev}}{>4 \text{ Kev}}$	$\frac{>2.5 \text{ Mev}}{>4 \text{ Kev}}$
1335 hrs 27 August $\Delta t = 64.4^\circ\text{C}$	28 " 110 "	0.020 0.099	0.009 0.116	0.82 0.72	0.36 0.32	0.12 0.13
1535 hrs 27 August $\Delta t = 70.7^\circ\text{C}$	18 " 61 "	0.015 0.071	0.004 0.061	0.82 0.71	0.36 0.31	0.21 0.14
0935 hrs 28 August $\Delta t = 71.5^\circ\text{C}$	44.5" 56.5"	0.069 0.173	0.021 0.094	0.84 0.62	0.34 0.30	0.14 0.10
1150 hrs 28 August $\Delta t = 83.3^\circ\text{C}$	9.5" 35.5"	0.009 0.063	0.001 0.033	0.89 0.72	0.38 0.29	0.24 0.20
1400 hrs 28 August $\Delta t = 80.1^\circ\text{C}$	9.5" 38.5"	0.006 0.060	0.001 0.026	0.84 0.80	0.36 0.34	0.22 0.15
1545 hrs 28 August $\Delta t = 74.0^\circ\text{C}$	13.5" 26 "	0.015 0.016	0.002 0.009	0.83 0.88	0.36 0.34	0.16 0.09
In Air		-	-	0.85	0.41	0.18

*Position of detector with respect to center of Godiva in terms of radial distance.