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**MONITORING THE MTR CANAL GAMMA SOURCE—
A TREATMENT OF RELIABILITY**

By
J. G. Carroll

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**California Research Corporation
Richmond, California**

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Introduction

Spent fuel elements from nuclear reactors are used extensively as gamma radiation sources. Such a source has been in operation since 1952 at the National Reactor Testing Station in Idaho. Fuel from the Materials Testing Reactor is utilized. These MTR fuel elements are arranged in an angle iron grid work,⁽¹⁾ shown in Figure 1, which is placed under about 18 feet of water in the MTR canal. Cal Research has been exposing samples in this source since 1953. This discussion pertains to exposures made between October 1955 and April 1956.

Generally, each sample container occupies about a third of the horizontal area of one irradiation section in Figure 1. Radiation flux gradients exist in both the horizontal and vertical directions in these irradiation positions. Such gradients pose measuring problems in obtaining reliable values for dosages received by samples. The following paragraphs pertain to a treatment of these problems.

Monitoring

Monitoring was performed routinely by personnel of Phillips Petroleum Company, operators of the MTR. Three recognized techniques were used: (1) reduction of ceric ion⁽²⁾, (2) calorimetry⁽³⁾, and (3) ion chamber methods⁽⁴⁾. The last method is now used more than the others, although the first two methods are retained for correlation and crosschecking purposes. In the Cal Research exposures, the gamma flux in a container position was monitored three times weekly, at the midplane and at 6 inches and 12 inches above and below midplane. Sample containers were positioned so that the materials being irradiated were within the $\pm$ 12-inch vertical dimension. The number of sets of flux points varied with the length of exposure. Typically, two sets of points described an irradiation for 10^8 roentgens (r); and about 80 sets of points were measured for a 5×10^9 r exposure.

The horizontal flux gradient was comparatively small and could be ignored⁽⁵⁾. Also, it was partially averaged in the monitoring operation because the monitoring devices measured the radiation from the significant portion of the approximately 3 x 3-inch horizontal area occupied by the sample. However, the vertical flux gradient would neither be averaged in this manner nor ignored; it posed the principal problem. Figure 2 shows

this vertical pattern. The flux is a maximum at the midplane which is about 22-1/2 inches above the canal floor. It is skewed so that higher levels prevailed below midplane than above midplane.

Data Handling

The flux, or dose rate, values from the MTR for each monitored position were integrated versus time to yield dosage (flux times time) values. Such an integration can be performed graphically by plotting the values for a given monitored position versus time and measuring the area under the curve as shown in Figure 3. The flux-time information cannot simply be treated algebraically; different fuel element cycles are often involved, and the elements decay in radioactivity by the complex rates associated with gross fission products. The information, however, may be satisfactorily handled with a computing machine. At Cal Research, the flux data were numerically integrated on a Datatron computer.

When thus processed, the data were reduced to five dosage values, one value for each of the five points monitored. These dosage values were sufficient to allow assignment by interpolation of dosages to individual portions of the 24-inch high irradiation container.

The procedure described thus far in monitoring and in processing the monitoring data was time consuming. When sufficient data had accrued, they were analyzed (1) to define a general curve showing flux (or dosage) distribution with height in terms of the midplane values and (2) to determine the reliability of the curve for various exposures. With a reliable curve, the sample container need only be monitored at the midplane. From this single value, the general curve would describe the vertical flux (or dosage) distribution. Initially, then it was necessary to determine the variations of the shape of the curve of Figure 2 with exposure period.

Dosage Data Analysis

Table I summarizes pertinent dosage data for various sample containers. Integrated flux values at the container midplane are shown in Column 3. As seen in Figure 2, the flux peaks sharply at or just below the midplane position. In order to reduce the weight given to the midplane point, an arithmetic mean was established from the midplane value and the values 6 inches above and below midplane. This mean is shown in Column 4 of Table I.

Individual dosages for all other positions were then expressed as a percentage of this arithmetic mean. The average of the percentages for each dosage level is shown in Table II, together with the "grand average" of these for each of the five monitored positions. The grand averages, still in terms of per cent of the arithmetic mean of Table I, were weighted for the number of sets of monitoring values from which they were derived. These weighted values were then adjusted to make the midplane value 100%. The curve of Figure 4 is drawn through the adjusted and weighted or final grand averages. The points off the curve show the spread of the data from which the curve was derived.

The final grand averages were then analyzed for standard deviation and confidence limits⁽⁶⁾ as shown in Table III. An average value for a given container monitoring position from Table I is designated as X , and the final grand average as $\bar{X}$. Results of this treatment are shown in Table IV.

Discussion of Errors

The initial flux monitoring values are considered accurate to about $\pm 10\%$ ⁽⁵⁾. Table V notes the type of errors which is included in this limitation. This margin of error is reducing during the integration process in proportion to the number of individual observations. There are introduced other errors in the machine treatment of the data, such as the approximate method of integration used and lack of smoothing of data. As shown in Table IV, the data reduce to about a $\pm 10\%$ absolute error with a 95% reliability. This means that any random set of flux points may be integrated, and the dosage thus obtained will be within $\pm 10\%$ of the values of the standard curve of Figure 5 in 19 cases out of 20. The confidence limits for 90%, 95%, and 99% are shown graphically in Figure 5.

There is a further region of error associated with the fact that MTR gamma fluxes are measured without the sample in place. To obtain a flux reading, the sample is removed, and the ion chamber is placed in the exact position occupied by the sample. The ion chamber is approximately three-fourth inch in diameter by 3 inches long. The sample is 3 inches in diameter and 24 inches long. The types of errors resulting from this procedure include:

- a. Self-absorption in the sample
- b. Absorption in the sample container
- c. Effect of different geometry
- d. The nature of the horizontal flux gradient

Such errors were not included in the treatment of data discussed in this report as they are independent of the method of data expression.

Conclusions

1. The general curve of Figure 5 may be used to indicate the reliability of gamma dosages obtained in the MTR gamma grid. A 95% reliability for an error of about $\pm 10\%$ is shown.
2. With the general curve of Figure 5, a single dosage point, taken at the midplane, is sufficient to determine the dosage received by the exposure container. The dosage thus determined will be accurate within $\pm 10\%$ with a confidence limit of 95%. This accuracy is considered adequate and equal to the accuracy of the initial monitoring measurements.

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* Present position with San Rafael School District.

TABLE I

SUMMARY OF GAMMA DOSAGE VALUES FOR SAMPLE CONTAINERS

Container No.	No. of Sets of Monitoring Values	Midplane Dosage 10 ⁸ r	Arithmetic Mean of +6 inches, Midplane, and -6 inches Position 10 ⁸ r
36E	2	1.74	1.59
36C	2	1.25	1.14
36W	2	0.97	0.86
39E	2	1.75	1.55
39C	2	1.44	1.27
39W	2	0.94	0.92
23	13	6.69	5.94
24	14	9.56	8.45
25	13	7.87	6.89
33	9	7.26	6.38
37E	12	6.12	5.49
37C	12	8.03	7.08
37W	12	7.94	6.82
40E	9	7.64	6.81
40C	9	8.03	7.08
40W	9	5.58	4.90
* 107	7	7.30	6.44
* 108	8	7.30	6.51
* 109	10	7.20	6.38
26	13	14.63	13.0
27	13	14.62	12.8
28	13	14.41	12.7
34	16	13.50	11.9
35	21	13.74	12.2
38E	15	12.12	10.8
38C	15	11.47	10.2
38W	15	12.44	10.9
* 41E	14	11.77	10.5
* 41C	14	11.77	10.4
* 41W	14	8.98	7.9
* 110	20	14.66	13.0
* 111	16	19.15	16.8
* 112	15	18.73	16.5
29	77	72.81	64.5
30	92	86.44	75.9
31	81	67.65	59.6

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*Irradiations conducted on Air Force Contract AF 33(616)-3184

TABLE II

AVERAGE GAMMA DOSAGE
PERCENTAGE OF MIDPLANE VALUE

	No. of Containers	Per Cent of Arithmetic Mean at Position (Inches from Midplane)				
		+12	+6	0	-6	-12
Nominal Midplane Dosage, 10^8 r						
1	6	26.2	70.8	110.0	120.0	73.5
5	13	27.7	77.4	113.0	109.5	69.0
10	14	26.0	73.8	113.3	112.7	74.3
50	3	26.7	74.9	113.5	112.0	70.7
Grand Average		26.6	74.2	112.5	113.5	71.0
Grand Average, Weighted for Sets of Data		26.7	74.7	112.6	112.7	71.9
Final Grand Aver- age (Grand Aver- age: Midplane = 100%)		23.6	66.3	100	100	64

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TABLE III

RELATIONSHIPS USED IN DATA ANALYSIS

1. σ = Standard Deviation = $\sqrt{\frac{(X_i - \bar{X})^2}{N - 1}}$ X_i = individual observation
 $\bar{X}$ = final grand average
2. Confidence Limits = $\bar{X} \pm \sigma t$ t = confidence factor
 N = number of containers monitored

for 90% Reliability, $t = 1.69$

for 95% Reliability, $t = 2.03$

for 99% Reliability, $t = 2.726$

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TABLE IV

SIGNIFICANCE OF DOSAGE VALUES

	Position, Inches from Midplane				
	+12	+6	0	-6	-12
Final Grand Average	23.6	66.3	100	100	64
$\sum (X_i - \bar{X})^2$	336.66	673.53	144.50	863.4	1272.12
N	36	36	36	36	36
σ	3.1	4.27	2.03	4.98	6.03
Confidence Limits, Per Cent of Midplane Dosage					
90	23.6 $\pm$ 5.2	66.3 $\pm$ 7.2	100 $\pm$ 3.4	100 $\pm$ 8.4	64 $\pm$ 10.2
95	23.6 $\pm$ 6.3	66.3 $\pm$ 8.7	100 $\pm$ 4.1	100 $\pm$ 10.1	64 $\pm$ 12.2
99	23.6 $\pm$ 8.5	66.3 $\pm$ 11.6	100 $\pm$ 5.5	100 $\pm$ 13.8	64 $\pm$ 16.7

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TABLE V

ERRORS IN GAMMA FLUX
MEASUREMENTS

1. Instrument

- a. Flatness of the plateau
- b. Wall thickness (volume of cavity)
- c. Air dryness
- d. Pressure and its relationship to gas density
- e. Reliability above 10^7 r
- f. Conversion in terms of ion pairs per Mev
- g. Detection and handling of currents in the range of 0.1 to 1 microamp
- h. Leakage

2. Monitoring

- a. Positioning errors of the instrument
- b. Errors in readings - human and instrument
- c. Errors in calibration

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FIGURE 1
ARRANGEMENT OF FUEL ELEMENTS AND
SAMPLE CONTAINERS IN MTR GAMMA GRID

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FIGURE 2
VERTICAL PROFILE OF GAMMA FLUX
IN M T R CANAL SOURCE

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FIGURE 3
A TYPICAL INTEGRATION OF GAMMA FLUX
SERIES G-21 [CRC 501-28]

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RE 571548

FIGURE 4
 VERTICAL DOSAGE DISTRIBUTION- GENERAL CASE
 FINAL GRAND AVERAGE OF DOSAGE VALUES

TABLE II

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FIGURE 5
VERTICAL DOSAGE DISTRIBUTION-RELIABILITY

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