Beta Dosimetry Study of H.B. Robinson Steam Generators

April 1983

S. A. Browne

I. INTRODUCTION

A. During the three-week steam generator outage at H.B. Robinson during April through May 1983, a beta dosimetry study was conducted. The objectives of the study were to:

1. Characterize the beta spectra in the steam generator in terms of maximum- and average-effective energy.

2. Evaluate the effect of wearing dosimeters inside plastic bags.

3. Evaluate the effect of distance from the source on the beta spectra and the dosimeter response.

4. Evaluate the difference in response between the standard dosimeter and a modified dosimeter which is designed to improve beta dose measurement.

5. Evaluate the TLD badge results of steam generator workers relative to beta dose.

B. Experimental measurements were made using smears, an Eberline RO-7 survey instrument, and TLD badges.

II. MATERIALS

A. Standard TLD Badges (40).

The Panasonic UD-802AQ dosimeter and UD-854A badge hanger is the standard badge used for personnel monitoring at H.B. Robinson.

B. Modified TLD Badges (40).

The Panasonic UD-802AQ dosimeter was modified by removing the plastic filter over Element 2 and by widening the open window in

the UD-854A badge hanger to uncover Element 2. This reduced the filtration over Element 2 from about 350 mg/cm^2 to about 75 mg/cm^2. Table 16 contains further information about the configuration of the standard and modified UD-802 badges.

C. Aluminum Foil.

Ordinary household aluminum foil was used to create filters of various thicknesses. Samples of foil were measured and weighed to determine the density thickness in mg/cm^2 of a single sheet. Multiple sheets were then used to produce filters of various thicknesses.

D. Plastic Bags.

The plastic bags were the type normally used at H.B. Robinson to protect the TLD and SRPD from becoming contaminated. The measured density thickness of the plastic was 5.5 mg/cm^2.

E. Eberline RO-7 Survey Instrument.

The RO-7 instrument is a hand-held survey meter with a digital, liquid crystal display.

The instrument was used with the RO-7-BM midrange ion chamber detector which has a full-scale range of 199.9 R/hr and a resolution of 0.1 R/hr. The ion chamber is approximately 1 inch in diameter and 0.6 inch long with a 7 mg/cm^2 thick aluminized mylar entry window. The plastic beta shield for the probe is 1000 mg/cm^2 thick.

F. Irradiation Stand.

A TLD irradiation stand was constructed using wooden dowels and masonite pegboard. The stand was designed to hold 20 to 40 TLD badges in a horizontal plane above the contaminated surface.

The height of the TLD badges above the surface could be adjusted from contact to about 24 inches.

III. METHODS

A. Smear Methods.

When the steam generator was first opened, ordinary dry smears were taken on the inner surfaces near the manway hole and on the diaphragm. A gamma spectra analysis was performed on each smear using a Ge (Li) detector system. A computer program was run which calculates the average beta and gamma energies per disintegration for the overall spectrum based on the nuclides detected and their relative activities.

B. Survey Methods.

Survey measurements were made at seven locations inside Steam Generator "A" using an Eberline RO-7 ion chamber instrument. At each location, measurements were made at approximately 1 inch and 6 inches from the surface with a bare probe and with the probe covered with three different thicknesses of aluminum foil (5, 34, and 269 mg/cm^2).

A similar series of measurements with the RO-7 were also performed on the Steam Generator "B" hot-leg diaphragm after it had been removed to a low-background area. The measurements were performed at distances of about 1, 6, 12, and 24 inches with bare probe, with probe shielded by three different thicknesses of aluminum foil (5, 34, and 269 mg/cm^2), and with a lucite cover of 1000 mg/cm^2.

C. Thermoluminescent Dosimeter (TLD) Methods.

After removal of the diaphragm plate from Steam Generator "B" hot leg, it was relocated to an area of relatively low

background and a series of measurements were made using TLDs. The diaphragm was a convenient source to work with because of its portability, simple geometry (flat disc), uniform field, and representative spectra.

The diaphragm was placed flat on the floor with the contaminated surface facing upward. The irradiation stand was placed on top of the diaphragm. The TLD badges were clipped to an adjustable platform which allowed the badges to be positioned at various heights above the diaphragm in a plane parallel to the contaminated surface.

Control TLD badges were used to measure the background exposure received by the badges involved in the study.

The standard and modified badges were irradiated in four different configurations as follows:

1. Ten standard and ten modified badges were irradiated together at a distance of 1 inch for 10 minutes.

2. Ten standard and ten modified badges were irradiated together at a distance of 6 inches for 40 minutes.

3. Ten standard badges in hangers with various thicknesses of aluminum filtration added were irradiated at 1 inch for 15 minutes. The filter thicknesses were calculated to approximate different maximum-effective beta energies. Table 1 shows the relationships between maximum-effective energy, range, and added aluminum filter thickness.

4. Ten standard and ten modified badges were irradiated together with a 5.5 mg/cm^2 plastic covering at a distance of 1 inch for 15 minutes. The plastic covering is equivalent to the plastic bag in which TLD badges are normally placed when monitoring personnel within contaminated areas.

In addition to the diaphragm irradiations, the results of TLD badges worn by steam generator workers were reviewed for evidence of beta exposure as indicated by the ratio of E2:E1. A control group of badges investigated by G. Hudson was used to establish the normal E2:E1 ratio.

IV. RESULTS

A. Smear Results.

The results of smears taken in the steam generator and analyzed by Ge (Li) gamma scan techniques are summarized in Table 2.

No direct measurement of beta was performed and no estimate is available for pure beta emitters, such as Sr-Y-90. Based on experience, Sr-Y-90 is not found in significant activities compared to the major activation products.

Short-lived F-18 (110 min. half-life) was present in significant quantities at the time of analysis. Because of the rapid decay of F-18, it should not be a major dose contributor to personnel during steam generator work.

The average beta energy for the steam generator beta spectrum was calculated based on the relative activity and average beta energy/disintegration for each individual nuclide identified in the Ge (Li) scan. The inclusion of F-18 in the calculation, although short-lived, tends to offset the omission of Sr-Y-90. The calculated average beta energy for the overall spectra ranged from 83 to 88 KeV for the smears. San Onofre reported average beta energy spectra results of 89 to 92 KeV for steam generator smears using similar calculational techniques. San Onofre results included Sr-90 but not F-18. The close agreement with San Onofre tends to support the reliability of the HBR smear results.

B. Survey Results.

1. The Diaphragm.

The results of the survey for the diaphragm using the RO-7 are shown in Table 3. An attempt was made to evaluate the maximum-effective beta energy using the multiple absorber method described by Hankins; however, the data was not consistent enough to apply this technique. One problem with the data is that the detector was hand held and the distance from the source was "eyeballed." As a result, the source-to-detector distances for the measurements were not very accurate or consistent. The Hankins technique requires the readings with each absorber to be made at the same source-to-detector distance. This is very critical when working at close range with beta radiation. A second problem with the data is that only one measurement was made with each absorber at a given distance. With a survey instrument, it is probably necessary to make several measurements and average the results in order to obtain good data.

2. Inside the Steam Generator.

The results of RO-7 surveys taken inside the steam generator are summarized in Table 4. The measurements at a distance of 1 inch for Locations 1 through 4 were relatively consistent, and it was felt these results could be averaged for greater accuracy and reliability in the analysis of maximum-effective beta energy. The relative beta response ratios for the various absorbers were calculated as described by Hankins and compared to the curves for determination of beta energy. Hankins' method classifies beta spectra into four types based on shape. The ratios calculated for the steam generator line up very well on

Hankins Type 2 spectra curves with a predicted maximum-effective beta energy of about 0.45 MeV. This is reasonably consistent with the smear results which indicate the highest energy betas among the predominant nuclides are .314 MeV (Co-60) and .635 MeV (F-18). According to Hankins, the average-effective beta energy for a Type 2 spectra can be calculated by multiplying the maximum-effective energy by 0.28. This calculation yields an average energy of about 126 KeV. Because of the short half-life of F-18 (110 min.) and high beta energy, it is not surprising that the survey results give a higher average energy than the smear results which were analyzed at a later time.

The readings reported in Tables 3 and 4 are relative beta responses. To obtain the beta dose rate, the beta readings (bare minus shielded readings) from the RO-7 instrument must be multiplied by a correction factor which varies with the beta energy. Hankins determined the beta energy response of the RO-7 instruments and found that for a maximum beta energy of 0.45 MeV; the beta correction factor is about 2.4 (the beta correction factor increases as the energy decreases). Based on the average RO-7 measurements at 1 inch for Locations 1 through 4, the gamma dose rate was 12 R/hr and the beta dose rate was 31 Rad/hr.

The survey results at 6 inches were analyzed in the same manner as at 1 inch to evaluate the maximum-effective beta energy. The data indicates the spectra has shifted to Type 3 with a maximum energy of about 0.6 through 0.7 MeV for the predominant nuclides. This hardening of the spectra is expected as a result of air attenuation of the lower energy beta particles.

For 0.6 through 0.7 MeV energies, the beta correction factor for the RO-7 is about 1.8. Based on the average RO-7 measurements at 6 inches for Locations 1 through 4, the

gamma dose rate was about 10 R/hr and the beta dose rate was about 10 Rad/hr.

As expected, the ratio of beta:gamma dose decreases rapidly with distance from ~ 3:1 at 1 inch to 1:1 at 6 inches.

C. TLD Results.

The results of TLD measurements using the steam generator diaphragm as a source and using various badge designs, absorber configurations, and distances are discussed below. Since the control badge readings were insignificant compared to the readings of the irradiated badges, no background dose corrections were applied to any of the TLD readings.

1. Gamma Dose Rates.

Table 12 shows a comparison of the gamma dose rates as determined by TLD and RO-7 measurements.

The gamma dose rates agreed reasonably well at 1 and 6 inches, especially considering the distances were measured by eye with the RO-7. The TLDs gave higher dose rate estimates by 18 percent at 1 inch and by 25 percent at 6 inches.

2. Maximum-Effective Beta Energy.

Table 5 shows the results for badges irradiated with various thicknesses of aluminum foil over Element 1. The objective of these measurements was to determine the maximum range and corresponding maximum-effective beta energy for the spectra. Figure 1 is a plot of Element 1 response as a function of absorber thickness. The beta component of the dose extrapolates to zero at an absorber thickness of approximately 100 mg/cm^2 which corresponds to a

maximum-effective energy of about 350 KeV. This is relatively close to the maximum energy estimated using multiple absorbers with the RO-7.

3. Standard Badges.

Tables 6 and 7 show the results for individual TLD badges irradiated at 1 and 6 inches. Table 13 summarizes the average result for each badge element after normalizing the readings to dose rate. For comparison, Table 14 shows the dose rates at 1 and 6 inches from the diaphragm based on the RO-7 measurements.

As expected, E2 of the standard badge showed very little response to the beta radiation because of the relatively thick filtration ~ 300 mg/cm^2 over the element. At 1 inch, E2 was 12 percent higher than E4 which has about 1000 mg/cm^2 filtration. At 6 inches, E2 was 8 percent higher than E4.

Although RO-7 measurements indicated a spectrum change and a higher maximum-effective energy at 6 inches, the ratio of E2:E1 was the same at both 1 and 6 inches. On the standard badge, this ratio does not appear to be a good index of the effective beta energy.

The response of E1 was low by a factor of about 1.8 at both 1 and 6 inches compared to the RO-7 results for beta plus gamma. It is clear from this data that when a significant amount of low energy beta radiation is present, the total skin dose is not accurately measured by E1 without a correction factor.

Although the standard badge cannot be used to estimate effective beta energy, it appears that a good estimate of the total beta dose can be obtained if the approximate beta

energy is known and an appropriate correction factor is applied to the difference of E1 minus E2. A correction factor of 2.2 yields excellent agreement between the standard TLD badge and the RO-7 beta dose rate measurements at both 1 and 6 inches.

4. Modified Badge.

Tables 7 and 8 show the results for the individual modified badges at 1 and 6 inches. The average results for the modified and standard badges after normalization are compared in Table 13.

As expected, the modified badge shows a higher response to beta on E2 as a result of the reduced filtration. In the standard badge the ratio of E2:E1 changes very little with distance, while in the modified badge the ratio E2:E1 changes rapidly with the distance from the source. The change in the ratio of E2:E1 is a result of the effect of air attenuation on the lower energy betas in the spectrum. Since the ratio of E2:E1 is sensitive to changes in the average energy of the spectrum, it can be used as an index of the effective beta energy.

Ishigaro and Takeda have described a technique which uses the ratio of E2:E1 in the modified badge as a beta energy index to determine the maximum-effective beta energy from a source. They also developed curves which relate the beta sensitivity of the badge to the beta energy. These curves can be used to establish beta correction factors (BCF) which allow beta dose to be calculated from the TLD badge results as follows:

$$\text{Beta Dose} = (E1-E4)/BCF$$

The average readings from the modified badges were analyzed by this technique, and the results have been summarized in Table 15.

The beta dose rates estimated by the TLD badges were 54 percent higher at 1 inch and 51 percent higher at 6 inches than the dose rates estimated by the RO-7 instrument. Considering the numerous assumptions, variables, and uncertainties involved in each of these methods, the agreement in dose rate estimates was relatively good. With the RO-7 there were major uncertainties in the distances from the source at which the measurements were made. With the TLD badges, there were uncertainties about the exact thickness of the filtration in the badge. Distance from the source and filter thickness are both critical factors which have significant effects in the beta dose rate estimates when small variations occur.

From these results it appears that the modified badge could be useful when there is little information available about the maximum-effective beta energy from a source; however, the relative beta response as a function of beta energy would need to be determined specifically for the CP&L badge.

5. Badges Covered with Plastic.

Tables 10 and 11 show the results for individual standard and modified badges which were irradiated with a 5.5 mg/cm^2 plastic covering. Table 13 compares the average results for the badges with and without the plastic covering.

On average, the plastic covering reduced the response of E1 by 30 percent at 1 inch. On E2 of the standard badge, the addition of 5.5 mg/cm^2 is insignificant compared to the total filtration of 350 mg/cm^2 which is already present and

no significant reduction was observed. On the modified badge, E2 was reduced by about 10 percent, but this amount is probably not significant since a similar reduction occurred on E4 which had 1000 mg/cm^2 of filtration.

Using either the standard or modified badges, the estimation of beta dose will be affected by the plastic covering when irradiated at small distances. However, the effect should decrease with distance from the source and is probably insignificant at distances greater than 50 cm where the density thickness of air (65 mg/cm^2) is large compared to the thickness of the plastic bag (5.5 mg/cm^2).

6. Results for Steam Generator Jumpers During May 1983.

The average ratio of E2:E1 was .90 for the TLD badge readings of 91 steam generator jumpers during the May 1983 outage as compared with an average of .97 for 4272 routine badge readings investigated by G. Hudson over the period from March 1982 to March 1983. The results for the steam generator jumpers were for TLD badges inside plastic bags which may have reduced the E1 response slightly. The amount by which E1 was reduced is probably much less than the 30 percent observed in this study for badges at 1 inch from the surface of the diaphragm, since the workers on the average are exposed at a much greater distance. As distance increases, the effect of the plastic bag decreases in comparison to the effects of air attenuation on the low energy betas. The density thickness of 24 inches of air is almost five times that of the plastic bag.

In addition, the skin of the worker is covered by protective clothing which probably has a minimum thickness of at least 60 mg/cm^2 (San Onofre estimated the minimum thickness of protective clothing worn by steam generator workers to be 69 mg/cm^2). Since the TLD is worn outside protective

clothing, it will be overestimating the actual beta dose to the skin. Table 5 shows that 60 to 80 mg/cm^2 of aluminum reduced the beta to levels which could not be distinguished from the gamma background. As a result, the actual beta dose to the skin must be negligible in comparison to the gamma dose for steam generator workers.

V. CONCLUSIONS

The conclusions from this study are relatively general concerning the nature of the beta spectra in the steam generator environment at H.B. Robinson and the factors which affect beta dosimetry measurements. No specific correction factors calculated from the data in this study can be recommended for use in the actual dosimetry program because of the unknown accuracy of the beta dose rate measurement and the lack of precision in some distance and absorber thickness measurements. However, this study provided much useful information about relative instrument and dosimeter responses under various conditions. Specifically, this study demonstrated:

A. The beta spectra is produced primarily by a mixture of activation products, rather than fission products. The average beta energy is less than 0.1 MeV and the maximum-effective beta energy is less than 0.5 MeV.

B. The beta spectra shifts toward higher effective beta energies as distance from the source increases due to the attenuation of lower energy betas in the air. This shift affects the beta response of instruments and dosimeters.

C. The beta-to-gamma ratio decreases rapidly with distance from the source so that at distances greater than 6 inches from the surface inside the steam generator the gamma dose is more limiting than the beta dose.

D. The plastic bags used to cover TLD badges during work in contaminated areas reduces the beta response by about 30 percent at a distance of 1 inch from the source. However, the influence of the plastic thickness should decrease with distance from the source and with increasing effective beta energy.

E. For the low energy betas typical of the steam generator spectra, the standard badge provided good agreement with the RO-7 beta dose estimates when correction factors of 2.1 to 2.2 were used. The correction factor varied only slightly between 1 and 6 inches despite the shift in effective beta energy. This indicates that over a relatively narrow range of energies of interest in the plant, a single beta factor might be adequate for the standard badge.

F. The modified badge concept appears to work. Although the dose rates estimated were high compared to the RO-7, the relationship was consistent. The difference could be eliminated by determining the relative beta response versus energy specifically for the CP&L badge, rather than using the values reported by others.

G. The actual beta dose to skin of steam generator workers when protective clothing is taken into account is negligible compared to the gamma dose.

VI. RECOMMENDATIONS

In order to develop accurate beta correction factors for radiation monitoring and personnel dosimetry purposes, the following additional studies should be conducted.

A. Dosimeter and survey instrument measurements should be compared to extrapolation chamber measurements of the true beta dose at various distances and with various attenuator thicknesses corresponding to protective clothing using the steam generator diaphragm plate as a source which is representative of the activity

deposited throughout the primary system during routine (nonfuel-failure) operations.

B. Dosimeter and survey instrument response should be established relative to a series of beta calibration standards covering the range of energies likely to be encountered during both routine and emergency (failed-fuel) conditions.

VII. REFERENCES

A. D. E. Hankins, "Evaluation of Beta Energy (E_{max}) and Spectral Type Using Survey Instruments."

B. D. E. Hankins, "Beta-Energy Response of the Eberline RO-7 Survey Instrument," 1982.

C. H. Ishigaro and S. Takeda, "Development of Personnel Dosimeter Using $Li_2B_4O_7$ (Cu) Elements and Automatic TLD Reader, Part I: Method for Evaluation of Alpha and Beta Doses," Translated from: Hoken Butsuri 16 305-316, 1981.

D. G. Hudson, "Response Interpretation of Panasonic 802 Dosimeter in Use at H.B. Robinson Plant," Internal Memorandum 83-311 (HBR), March 31, 1983.

Table 1

STANDARD BADGES WITH VARIOUS ALUMINUM FILTERS IRRADIATED AT 1 INCH FOR 15 MINUTES

Maximum-Effective Beta Energy, MeV	Beta Range[(1)] mg/cm²	Aluminum Filter [(2)] mg/cm²		TLD Readings, R
0.10	14	0		5.03
0.15	27	13	(12)	2.49
0.20	43	29	(31)	1.33
0.25	60	46	(49)	1.08
0.30	79	65	(67)	0.98
0.35	99	85	(86)	1.03
0.40	120	106	(104)	1.14
0.60	211	197	(196)	1.02
0.80	310	296	(294)	1.09
1.00	412	398	(398)	0.97

(1) Range was calculated based on the following formula from the Radiological Health Handbook:

$$R = 412\ E^{(1.256 - 0.0954 \ln E)}$$

Where: E = Maximum-Effective Energy, MeV
R = Range, mg/cm^2

(2) The badge has a minimum inherent filtration of 14 mg/cm^2 plastic to which the aluminum filter thickness was added. The numbers in parenthesis are the best estimate of the actual thickness of aluminum foil used as compared to the theoretical required thickness.

Table 2

SUMMARY OF S/G SMEAR ANALYSES

Location	Date	Major Nuclides	Average Beta Energy	Average Gamma Energy
S/G "A" Hot Leg Near Manway	5/3/83	Co-58, Co-60 Cr-51, F-18	83 KeV	1.64 MeV
S/G "A" Hot Leg Near Manway	5/3/83	Co-58, Co-60 Cr-51, F-18	87 KeV	1.06 MeV
S/G "A" Cold Leg Near Manway	5/3/83	Co-58, Co-60 Cr-51, F-18	88 KeV	1.13 MeV
S/G "A" Cold Leg Diaphragm	5/3/83	Co-58, Co-60 Cr-51, F-18	85 KeV	1.22 MeV

Table 3

RO-7 SURVEY RESULTS FOR THE DIAPHRAGM

	Relative Readings With Various Absorbers				
Distance	Bare	Plastic 1000 mg/cm^2	Al 5 mg/cm^2	Al 34 mg/cm^2	Al 269 mg/cm^2
1"	14.0	2.8	15.5	4.0	3.0
6"	4.4	0.7	4.4	4.2	0.8
12"	1.3	0.2	1.3	0.6	0.4
24"	0.2	0.1	0.3	0.1	0.1

Table 4

RO-7 SURVEY RESULTS INSIDE STEAM GENERATOR

Probe Filtration	Distance From Surface	Bowl No.1	Divider Plate No. 2	Tube Sheet No. 3	Tube Sheet No. 4	Divider Plate No. 5	Bowl No. 6	General Area[1] No. 7
		Relative Readings at Various Locations						
Bare	1"	23.5	24.7	26.9	23.5	11.5[2]	9.5	11.5
	6"	16.5	15.1	13.6	14.8	11.4[2]	9.1	11.6
Al 5 mg/cm$^{(2)}$	1"	15.0	24.3	22.0	19.1	17.7	9.0	9.3
	6"	12.7	14.1	14.2	13.2	14.9	9.0	9.8
Al 34 mg/cm$^{(2)}$	1"	11.5	15.3	13.3	13.3	13.2	8.0	9.4
	6"	10.6	11.0	11.1	11.2	11.8	8.0	9.6
Al 269 mg/cm$^{(2)}$	1"	9.8	13.7	12.1	12.5	12.3	7.5	9.9
	6"	9.6	10.0	10.4	10.5	10.9	7.5	8.7
Plastic 1000 mg/cm$^{(2)}$								9.6

Notes: (1) Location was in air approximately 1 foot from divider plate, 2 feet from tube sheet, and 3 feet from bowl.

(2) Location was approximately the same as for Location 7, bare probe readings at 1 inch and 6 inches.

Table 5

STANDARD BADGES WITH VARIOUS AL FILTER THICKNESSES OVER ELEMENT 1 IRRADIATED AT 1 INCH FOR 15 MINUTES

Badge No.	Element 1	Element 2	Element 3	Element 4
1347	5.03 R	1.11 R	814 mR	885 mR
1043	2.49 R	1.03 R	823 mR	896 mR
1701	1.33 R	967 mR	787 mR	851 mR
1928	1.08 R	950 mR	752 mR	847 mR
1926	977 mR	894 mR	787 mR	823 mR
1538	1.03 R	934 mR	792 mR	818 mR
1363	1.14 R	1.11 R	867 mR	940 mR
1655	1.02 R	973 mR	822 mR	918 mR
1619	1.09 R	1.02 R	863 mR	871 mR
1702	971 mR	995 mR	809 mR	841 mR
Mean	*	998 mR	812 mR	869 mR
Std. Dev.	*	71 mR	35 mR	40 mR
% Std. Dev.	*	7.1%	4.3%	4.7%

*Each badge had a different density thickness filter over E1. See Table 1 for the specific filter thicknesses used.

Table 6

STANDARD BADGES - IRRADIATED AT 1 INCH FOR 10 MINUTES

Badge No.	Element 1	Element 2	Element 3	Element 4
2384	3.13 R	703 mR	543 mR	580 mR
2264	2.54 R	562 mR	488 mR	564 mR
1632	2.65 R	555 mR	528 mR	545 mR
1983	3.23 R	760 mR	555 mR	610 mR
1424	2.67 R	544 mR	485 mR	537 mR
1554	2.82 R	643 mR	559 mR	515 mR
1292	2.77 R	583 mR	585 mR	555 mR
1160	3.19 R	643 mR	545 mR	556 mR
2212	3.33 R	708 mR	567 mR	638 mR
1869	3.11 R	703 mR	559 mR	610 mR
Mean	2.94 R	640 mR	541 mR	571 mR
Std. Dev.	.28 R	77 mR	33 mR	38 mR
% Std. Dev.	9.6%	12.0%	6.0%	6.7%

Table 7

STANDARD BADGES - IRRADIATED AT 6 INCHES FOR 40 MINUTES

Badge No.	Element 1	Element 2	Element 3	Element 4
1274	3.22 R	652 mR	637 mR	650 mR
1257	3.19 R	618 mR	584 mR	616 mR
1560	2.94 R	670 mR	596 mR	554 mR
1344	3.17 R	679 mR	635 mR	645 mR
1494	2.51 R	530 mR	485 mR	516 mR
1689	2.69 R	616 mR	568 mR	524 mR
1248	2.51 R	610 mR	540 mR	556 mR
1651	2.59 R	593 mR	562 mR	582 mR
2303	2.51 R	600 mR	528 mR	552 mR
1682	2.80 R	666 mR	513 mR	553 mR
Mean	2.81 R	623 mR	565 mR	575 mR
Std. Dev.	.30 R	45 mR	50 mR	47 mR
% Std. Dev.	10.5%	7.2%	8.8%	8.2%

Table 8

MODIFIED BADGES - IRRADIATED AT 1 INCH FOR 10 MINUTES

Badge No.	Element 1	Element 2	Element 3	Element 4
01957	2.75 R	642 mR	511 mR	553 mR
06162	2.76 R	691 mR	522 mR	583 mR
01938	2.64 R	717 mR	560 mR	602 mR
16915	2.70 R	687 mR	514 mR	589 mR
01111	3.35 R	771 mR	571 mR	584 mR
02354	3.06 R	868 mR	602 mR	631 mR
17423	3.15 R	756 mR	573 mR	630 mR
15881	2.70 R	628 mR	505 mR	603 mR
15632	3.13 R	721 mR	563 mR	619 mR
17415	3.09 R	676 mR	610 mR	641 mR
Mean	2.93 R	716 mR	553 mR	604 mR
Std. Dev.	.25 R	70 mR	38 mR	27 mR
% Std. Dev.	8.5%	9.8%	6.9%	4.5%

Table 9

MODIFIED BADGES - IRRADIATED AT 6 INCHES FOR 40 MINUTES

Badge No.	Element 1	Element 2	Element 3	Element 4
17425	3.20 R	955 mR	581 mR	603 mR
15593	3.27 R	1.05 R	595 mR	563 mR
18373	3.47 R	941 mR	593 mR	606 mR
16933	3.40 R	948 mR	569 mR	582 mR
15627	3.64 R	995 mR	626 mR	581 mR
15630	3.39 R	1.03 R	671 mR	622 mR
15851	3.24 R	1.03 R	635 mR	599 mR
17428	3.56 R	1.16 R	631 mR	608 mR
02422	3.51 R	1.12 R	604 mR	536 mR
16966	3.30 R	1.02 R	591 mR	581 mR
Mean	3.40 R	1025 mR	610 mR	588 mR
Std. Dev.	.15 R	72 mR	31 mR	25 mR
% Std. Dev.	43%	7.0%	5.0%	4.3%

Table 10

STANDARD BADGES COVERED WITH 5.5 MG/CM^2 PLASTIC
IRRADIATED AT 1 INCH FOR 15 MINUTES

Badge No.	Element 1	Element 2	Element 3	Element 4
1577	2.93 R	844 mR	754 mR	802 mR
1700	3.57 R	997 mR	790 mR	845 mR
1703	3.55 R	1.06 R	869 mR	887 mR
1698	3.06 R	807 mR	772 mR	782 mR
1532	2.88 R	881 mR	750 mR	870 mR
1523	3.48 R	980 mR	878 mR	933 mR
1697	3.46 R	984 mR	856 mR	841 mR
1727	2.77 R	838 mR	791 mR	819 mR
1464	3.07 R	891 mR	717 mR	809 mR
1325	3.21 R	940 mR	868 mR	922 mR
Mean	3.20 R	922 mR	804 mR	851 mR
Std. Dev.	.30 R	82 mR	59 mR	51 mR
% Std. Dev.	9.3%	8.9%	7.3%	6.0%

Table 11

MODIFIED BADGES COVERED WITH 5.5 MG/CM^2 PLASTIC
IRRADIATED AT 1 INCH FOR 15 MINUTES

Badge No.	Element 1	Element 2	Element 3	Element 4
17418	3.09 R	922 mR	797 mR	839 mR
01186	3.11 R	998 mR	857 mR	835 mR
06717	2.80 R	902 mR	771 mR	862 mR
18157	2.90 R	934 mR	706 mR	784 mR
17405	2.58 R	949 mR	636 mR	746 mR
02481	2.69 R	881 mR	699 mR	690 mR
15564	3.06 R	937 mR	685 mR	776 mR
17406	3.45 R	1.04 R	767 mR	859 mR
16974	2.69 R	1.01 R	862 mR	966 mR
18123	3.65 R	1.05 R	685 mR	805 mR
Mean	3.00 R	969 mR	746 mR	816 mR
Std. Dev.	.34 R	57 mR	77 mR	29 mR
% Std. Dev.	11.5%	5.9%	10.3%	3.5%

Table 12

COMPARISON OF TLD AND RO-7
GAMMA DOSE RATE MEASUREMENTS FOR THE DIAPHRAGM

	Distance	
	1 Inch	6 Inches
TLD (1)	3.3 R/hr	0.873 R/hr
RO-7 (2)	2.8 R/hr	0.7 R/hr

Notes: (1) Average of Elements 3 and 4.

(2) Probe shielded with plastic cap.

Table 13

IRRADIATED BADGE READINGS NORMALIZED TO R/HR

	Standard Badges					Modified Badges				
Distance	E2/E1	E1	E2	E3	E4	E2/E1	E1	E2	E3	E4
1 Inch	.22	17.640	3.840	3.246	3.426	.24	17.580	4.296	3.318	3.624
6 Inches	.22	4.215	0.934	0.848	0.862	.30	5.100	1.538	0.915	0.882
1 Inch*	.28	12.792	3.688	3.216	3.404	.32	12.008	3.876	2.984	3.264

*With Plastic Cover

Table 14

DIAPHRAGM DOSE RATES BASED ON RO-7

Distance	Max. Eff. Beta Energy	RO-7 Beta Correction Factor	Beta Dose Rate Rad/Hr	Gamma Dose Rate R/Hr	Total Dose Rate Rem/Hr
1 Inch	.35 MeV*	2.7	30.2	2.8	33.0
6 Inches	.6 MeV**	1.9	7.0	0.7	7.7

*Based on TLD measurements on diaphragm.

**Based on RO-7 measurements in steam generator.

Table 15

COMPARISON OF MODIFIED TLD AND RO-7 BETA DOSE RATE ESTIMATES

Distance	E2/E1	E1-E4	Max. Eff.[1] Beta Energy MeV	Beta[2] Correction Factor BCF	Beta Dose Rate[3] Estimate by TLD[5]	Beta Dose Rate[4] Estimate by RO-7	TLD/RO-7
1 Inch	0.24	13.956	0.8	.3	46.5	30.2	1.54
6 Inches	0.30	4.218	0.9	.4	10.5	7.0	1.51

(1)As predicted by E2/E1 from Figure 7 of reference paper (3).

(2)The BCF is the inverse of the relative beta sensitivity determined using Figure 6 of reference paper (3).

(3)Beta Dose = (E1-E4)/BCF where E1 and E4 are taken from Table 13.

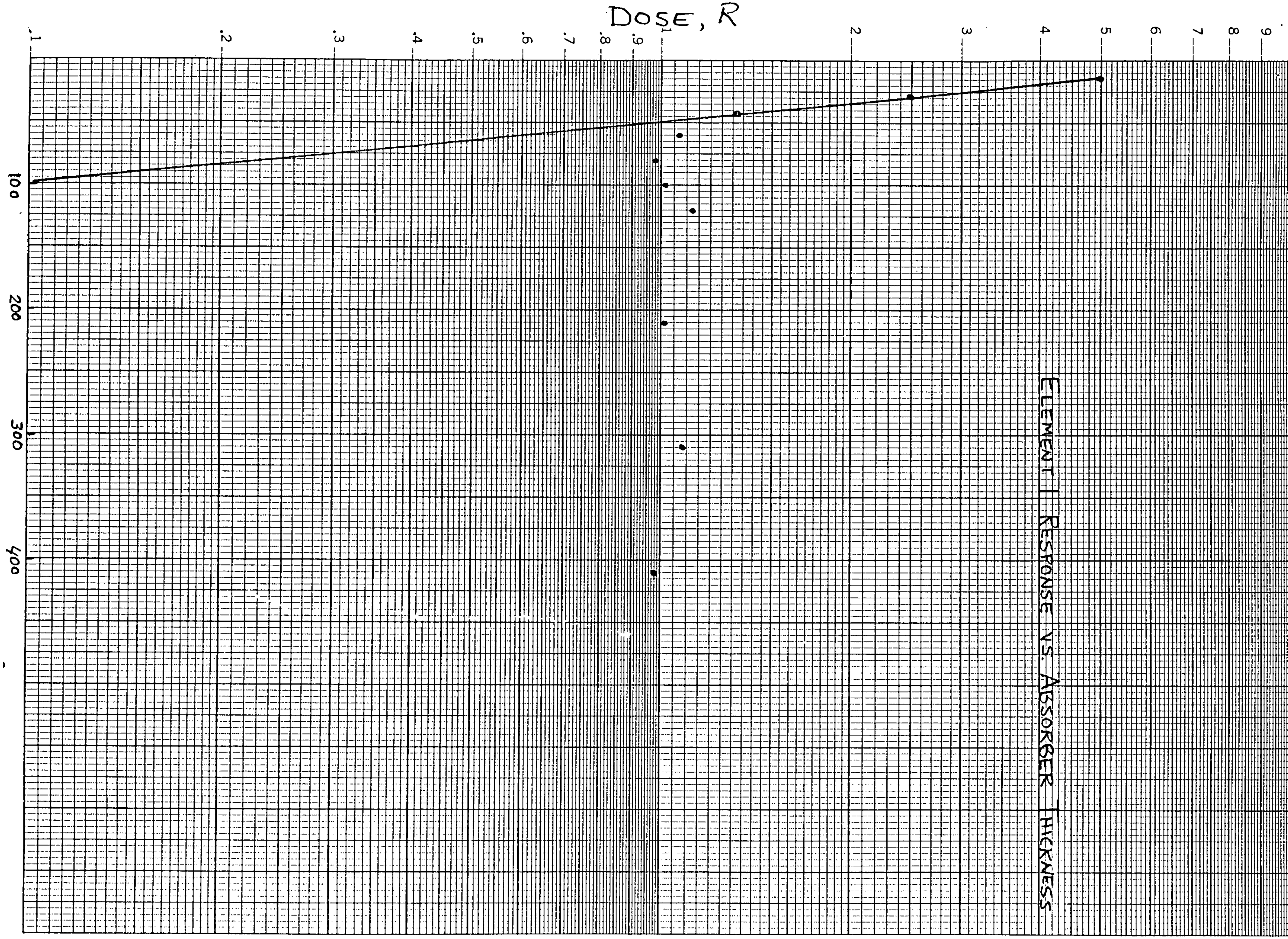
(4)From Table 14.

(5)Modified TLD badge.

Table 16

PANASONIC UD-802AQ TLD BADGE
(WITH UD-854A BADGE HANGER)

Badge Type	Element 1 $Li_2B_4O_7:Cu$	Element 2 $Li_2B_4O_7:Cu$	Element 3 $CaSO_4:Tm$	Element 4 $CaSO_4:Tm$
Standard	14 mg/cm^2 Plastic	350 mg/cm^2 Plastic	350 mg/cm^2 Plastic	1000 mg/cm^2 Plastic + Lead
Modified	14 mg/cm^2 Plastic	75 mg/cm^2 Plastic	350 mg/cm^2 Plastic	1000 mg/cm^2 Plastic + Lead



ELEMENT I RESPONSE VS. ABSORBER THICKNESS

FIGURE 1