UCID-19484

UCID--19484

DE83 003108

BETA-ENERGY RESPONSE OF THE
EBERLINE RO-7 SURVEY INSTRUMENT

D. E. Hankins

October 10, 1982

The logo for Lawrence Livermore Laboratory, featuring a stylized 'U' and 'L' symbol to the left of the text 'Lawrence Livermore Laboratory' which is arranged in three lines.

Lawrence
Livermore
Laboratory

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under Contract W-7405-Eng-48.

CONTENTS

Introduction	1
Description of the RO-7 Instrument	1
Gamma Evaluation	2
Beta Evaluation	5
Energy Response to Betas	15
References	25

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe on privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

209

BETA-ENERGY RESPONSE OF THE EBERLINE RO-7 SURVEY INSTRUMENT

INTRODUCTION

We obtained an RO-7 radiation survey instrument from the Eberline Instrument Corporation to use in a study of the beta dose rates from the Godiva IV Critical Assembly at Los Alamos National Laboratory. We have performed a limited evaluation of the instrument and have determined its energy dependence for beta particles.

DESCRIPTION OF THE RO-7 INSTRUMENT

The RO-7 instrument is a hand-held, cutie-pie-style survey meter with a liquid crystal digital readout. The instrument is available with three interchangeable ion chamber probes, although we used only the midrange probe (RO-7-BM) in this study. The midrange probe has a full-scale range of 199.9 R/h and a resolution of 0.1 R/h. The ion chamber has a 1-in.-diameter entry window 2 mils thick ($\sim 7 \text{ mg/cm}^2$) of aluminized mylar. The chamber is lined with phenolic nominally $1/8$ in. thick. The housing is nominally 60 mils thick. The chamber's internal dimensions are 1-in. diameter $\times$ 0.6-in. length (2.5 cm $\times$ 1.5 cm) with a sensitive volume of 7 cm^3 . The beta shield is a plastic cap ($\sim 1000 \text{ mg/cm}^2$) over the beta window and is held in place over the probe by an O-ring. The overall dimensions of the basic probe are 1.5 in. $\times$ 4.2 in. The weight of the instrument with the midrange probe is 3.2 pounds (1.5 kg). The batteries are three 9-V and two 30-V cells with an operating lifetime of 160 hours (for the 9-V cells). The overall unit is 9.5 in. high, 4.25 in. wide and 13.5 in. long when the probe is attached.

One disadvantage of the RO-7 instrument we found in this work was its low sensitivity. The lower detection limit is 0.1 R/h and the display is in units of tenths of R, so a source reading between ~ 0.06 and 0.14 will indicate 0.1 R/h. At the overlap region the instrument will flip back and forth between the two numbers and we found this to be an area where the dose rate could be determined with greater accuracy because the switching occurs over a small region; for example, ~ 0.14 to 0.16 R/h.

GAMMA EVALUATION

The first part of the evaluation was to determine the linearity and the instrument's relative response to ^{60}Co and ^{137}Cs gamma rays. Figure 1 shows the results we obtained on two separate occasions using the sources in our Building 255 calibration facility. The response of the instrument was found to be exceptionally linear over its three-decade range. There is no discernible difference between the ^{60}Co or ^{137}Cs calibrations and the instrument was reading about 15% high. The instrument has since been adjusted to remove the 15%-high reading.

The above results were obtained with the plastic beta shield on the probe. When it is removed, the instrument responds to electrons being ejected from the ^{60}Co and ^{137}Cs source encapsulation (the rabbit tubes) and from the air. Figure 2 shows the increased readings obtained with the beta shield removed from the probe. The increase in readings varies from about 6 to 14% depending on which source is used and the source-to-detector distance. These high readings are not reproducible under different scattering conditions; for example, we found that an aluminum plate (~3 ft in diameter, 1/4 in. thick), which previously had been located just under the source to place dosimeters on during irradiation, increased the instrument reading to ~19% for ^{60}Co and also resulted in a differently shaped curve beyond one meter. For a narrow beam geometry, the effect of these scattered electrons will be negligible and, in addition, the reading of the instrument without the shield will probably be lower than the exposure dose rate value because electron equilibrium has not been established in the RO-7 instrument. The RO-7 window is only 7 mg/cm^2 which is far short of the several hundred mg/cm^2 necessary to establish electron equilibrium for gamma rays from ^{137}Cs or ^{60}Co .

The measured dose rates from isotopes or combinations of isotopes containing high-energy gamma rays would indicate that beta radiation is present and a skin dose is being received, even though no beta decay is occurring. In field work, however, if the beta dose rate is as small as the above contribution by electrons, it is usually not considered to be significant (when compared to the gamma exposures). This effect is not unique to the RO-7 and applies to all instruments with thin windows. The magnitude of the effect may be slightly different for other instruments depending on the window thickness and geometry factors of the probes.

Figure 1. Linear response of RO-7 exposed to ^{60}Co and ^{137}Cs gamma rays (with beta cap on probe).

Figure 2. Response of the RO-7 instrument, with the beta shield removed, to ^{137}Cs and ^{60}Co gamma rays as a function of distance from the source.

The gamma-energy dependence of the instrument is given in the Technical Manual for Model RO-7 provided by Eberline Instrument Corporation.¹

Figure 3 is taken from this report. We did not attempt to repeat or confirm the accuracy of this figure. The curve labeled "Shield on face toward source" is the one that is applicable for most field uses of the instrument. The curve with the "Shield off face toward source" shows the increased reading at 660 keV caused by electrons being ejected from the source encapsulations and the air discussed previously. The curve labeled "Dose equivalent (rem) at 1 cm/Exposure (R)" is the dose curve and is the curve that the RO-7 should follow if it is accurately measuring the dose at the 1-cm tissue depth. Note that the RO-7 with the shield on follows this curve closely. The dose curve peaks around 60 keV at ~1.5, which is caused by backscattering, changes in absorption coefficients, attenuation and other factors in the body. The dose to tissue from gamma rays of ~60 keV is actually 1.5 times the "R" dose and for field work an instrument should have a response with a corresponding high response at 60 keV; otherwise, it would indicate a reading less than the actual tissue dose. A LiF TLD placed on the surface of a phantom responds to backscattered radiation and has an increased reading that is higher by a factor of 1.8 at ~60 keV than the R dose in air.² Readings from an RO-7 should compare favorably with TLD readings.

BETA EVALUATION

To determine the beta response of the RO-7 instrument, it was placed at various distances from the PTB beta sources used with and without their filters or flatteners. All distances were measured from the face of the source to the center of the probe. The PTB filters consist of disks made of thin plastic positioned at 10 cm from the source. These filters flatten the beta beam to permit larger probes to be exposed uniformly (see Ref. 3). These results have been plotted in Figs. 4-7. The results with the large ⁹⁰Sr source (50 mCi) and the small ⁹⁰Sr source (2 mCi) shown in Figs. 4 and 5, respectively, are straight lines and have slopes that are very similar when overlaid. The curve for the flattened beam drops slightly away from the unflattened beam at larger distances. The curves decrease only slightly faster than the inverse square relationship predicts. The ²⁰⁴Tl source

Figure 3. Photon energy response of the RO-7, taken from the Eberline manual.¹

Figure 4. RO-7 instrument readings as a function of distance from the large ^{90}Sr source.

Figure 5. RO-7 instrument readings as a function of distance from the small ^{90}Sr source.

Figure 6. RO-7 instrument readings as a function of distance from the ^{204}Tl source.

Figure 7. RO-7 instrument readings as a function of distance from the ^{147}Pm source.

(14 mCi) results are shown in Fig. 6 and deviate from straight lines at the smaller and larger distances from the source. The curves also are further apart than the curves for the ^{90}Sr sources and decrease significantly faster than inverse square. The curves for the ^{147}Pm source (0.5 mCi) shown in Fig. 7 have no straight-line regions, diverge rapidly from each other and fall more abruptly than was found with the other sources. The differences in shapes of the curves are caused by the beta energies being lower for the ^{204}Tl (0.765 MeV) and the ^{147}Pm sources (0.227 MeV), which result in more attenuation of the betas by the air, probe window and flatteners.

For the ^{204}Tl , ^{147}Pm , and small ^{90}Sr sources the dose rates at the larger distances were so small that accurate readings of the RO-7 could not be obtained. The RO-7 has a liquid crystal display (LCD) readout with the lowest units being tenths of R/h and at lower dose rates the same reading is displayed over a range of distances from the source. For example, in Figs. 6 and 7 we have plotted a bracket at each of these LCD readings.

To help establish the shape of the curves at low dose rates we obtained data with a pancake GM instrument. The window size was reduced by taping an aluminum disk with a 1.0-in.-diameter hole (probe size of RO-7) on the pancake probe. The results are plotted in Figs. 8-10. When overlaid, the shapes and slopes of these curves agree very well with the part of the curve where the RO-7 results overlap. The instruments have slightly different window thicknesses and are different types of instruments; i.e., a GM vs an ion chamber, but the curves shown in the respective figures agree quite well. Since the curves in the overlap region agreed well we used the shape of the curve from the pancake probe results to draw the extrapolated curves shown for the RO-7 instrument in Figs. 5-7. This procedure may not be entirely accurate but is believed to give much better results than would be obtained with a curve drawn using eyeball extrapolation or guesswork.

The calibration points for the PTB sources measured by the PTB or by using an extrapolation chamber at LLNL³ (air dose) have been plotted in Figs. 4-7. (Since these points are only for comparison purposes of the dose vs distance curves, we simply plotted the dose rates in rad/h as R/h using the R/h scale on the abscissa.) For the ^{90}Sr sources, Figs. 4 and 5, the PTB calibration points and our extrapolation chamber measurements follow the inverse square rule closely, but the results obtained with the RO-7 instrument decrease more rapidly. The PTB points for the ^{204}Tl plotted in Fig. 6

Figure 8. Pancake probe readings as a function of distance from the small ^{90}Sr source.

Figure 9. Pancake probe readings as a function of distance from the ^{204}Tl source.

Figure 10. Pancake probe readings as a function of distance from the ^{147}Pm source.

decrease more rapidly than inverse square predicts but the RO-7 values drop even faster.

The reason the RO-7 readings drop more rapidly than the extrapolation chamber readings must be due, in part, to the differences in geometry of the RO-7 and extrapolation chamber. The extrapolation chamber's geometry is essentially 2π for betas while the RO-7 probe is significantly less than 2π and would respond less to air-scattered betas. Also at 11 cm there are some additional geometry factors because the two instruments have greatly differing probe or chamber sizes and shapes. These factors become small at 30 cm and beyond. We conclude that the design and/or energy dependence of the RO-7 instrument results in a response to point beta sources which decreases as a function of increasing source-to-detector distance more rapidly than the dose measured by an extrapolation chamber or a similar instrument with a larger angle of detection. Fortunately, this effect is small (see Table 1) and will normally not affect the field use of the instrument.

ENERGY RESPONSE TO BETAS

To determine the energy response of the RO-7 to betas we compared the PTB calibration values and our extrapolation chamber results with the dose rates taken from the curves in Figs. 4-7 at various distances. These data are shown in Table 1. We have shown three dose rates for the PTB sources: (1) the measured dose in air, and (2 and 3) the calculated doses (using the factors provided by the PTB) in tissue (at 0 depth) and at 7 mg/cm^2 depth in tissue. In the last two columns we have determined the percent deviation of the RO-7 instrument from the tissue and 7 mg/cm^2 depth dose.

Figure 11 shows the relative reading of the RO-7 instrument compared to the air dose as a function of the calculated beta E_{max} . We calculated the E_{max} using the known absorber thicknesses which seal the PTB sources and the absorption by the air and beam flatteners. The thickness of each absorber used in the calculation is given in Table 2. The stopping powers for the betas used in the calculation⁴ are given in Table 3. The calculations are not precise; the largest error is the value of the stopping power for the lower-energy betas where the values are changing rapidly with beta energy.

Table 1. Response of the RO-7 instrument compared with the beta dose rates in air.

Source	Distance	Extrapolation chamber dose rate ^a (rad/h), air	Calculated dose rate (rad/h)		RO-7 dose rate (R/h)	Relative reading of RO-7		
			Tissue	7 mg depth		Air	Tissue	7 mg depth
⁹⁰ Sr large, no flattener	11 cm	176	196	209	210	1.19	1.07	1.00
	30 cm	24.0	26.7	28.5	24	1.00	0.90	0.84
	50 cm	8.59	9.54	10.1	8.0	0.93	0.84	0.79
	1.0 cm	2.04	2.27	2.39	1.7	0.83	0.75	0.71
⁹⁰ Sr small, flattener	30 cm	0.594	0.659	0.686	0.59	0.99	0.90	0.86
	no flattener 11 cm	6.73	7.48	8.00	8.0	1.19	1.07	1.00
	30 cm	0.952	1.06	1.13	0.95	1.00	0.90	0.84
	50 cm	0.335	0.37	0.39	~0.31 ^b	0.93	0.84	0.79
	1 m	0.0768	0.085	0.091	~0.07 ^b	0.91	0.82	0.77
²⁰⁴ Tl, flattener	30 cm	0.0745	0.0849	0.0810	~0.04 ^b	0.54	0.47	0.49
	no flattener 11 cm	1.001	1.140	1.09	0.74	0.74	0.65	0.68
	30 cm	0.117	0.133	0.127	~0.075 ^b	0.64	0.56	0.59
	50 cm	0.032	0.036	0.035	~0.017 ^b	0.53	0.47	0.49
¹⁴⁷ Pm, flattener	20 cm	0.0659	0.0758	0.0152	~0.015 ^b	0.23	0.20	0.99
	no flattener 11 cm	3.41	3.92	0.784	0.73	0.21	0.19	0.93
	20 cm	0.302	0.347	0.0695	~0.065 ^b	0.22	0.19	0.94

^a Values shown are those obtained from the PTE calibrations where applicable or from our extrapolation chamber measurements.

^b Dose rates determined using extrapolated values based on the response of a pancake probe (see text).

Figure 11. Relative response of the RO-7 instrument compared with the air dose in rad/h.

Table 2. The thickness of the absorbers located between the source and the face of the RO-7 probe (including the materials used to seal the source) and the calculated beta energy ($E_{\max}$).

Source	Distance	Theoretical beta energy, $E_{\max}$ (MeV)	Thickness of absorber (mg/cm ²)						Calculated beta energy, $E_{\max}$ (MeV)
			Air	Ag	SS	Flattener	Au	Ni	
⁹⁰ Sr large, no flattener	11 cm	2.27	14.2	50	79				2.06
	30 cm	(⁹⁰ Y)	38.8	50	79				2.02
	50 cm		65	50	79				1.98
	1.0 m		129	50	79				1.87
⁹⁰ Sr small, flattener	30 cm	2.27 (⁹⁰ Y)	38.8	50		68	2.0		2.00
	no flattener		14.2	50			2		2.17
			38.8	50			2		2.13
			65	50			2		2.02
			129	50			2		1.98
²⁰⁴ Tl, flattener	30 cm	0.766	38.8	20		57	2		0.61
	no flattener		14.2	20			2		0.71
			38.8	20			2		0.67
			65	20			2		0.63
¹⁴⁷ Pm, flattener	20 cm	0.224	25.9	5.0		-		0.5	0.148
	no flattener		14.2	5.0				0.5	0.178
			25.9	5.0				0.0	0.148

Table 3. Stopping powers used to calculate the beta energies given in Table 2.

Source	Stopping power of beta (MeV/cm ² /g) ^a					
	Air	Ag	SS ^b	Flattener ^c	Au	Ni
⁹⁰ Sr	1.72	1.40	1.42	1.89	1.33	
²⁰⁴ Tl	1.72	1.28	1.37	1.95	1.149	
¹⁴⁷ Pm	2.6	1.65				1.8

^a From Ref. 3.

^b Stainless steel was not given in tables so Cu was used.

^c Plastic was not given in tables so water was used.

For the purposes of this report, these calculations are considered to be adequate. The points plotted in Fig. 11 at about 2.0 MeV were obtained with the ⁹⁰Sr sources. The two points which lie above the rest of the points were at the 11-cm distance. At this small distance the geometry factors of the two instruments (RO-7 and extrapolation chamber) would cause the RO-7 reading to be high. The same effect was found at the 11-cm distance with the ²⁰⁴Tl source. The curve drawn in this and following figures is based on our evaluation of which of the several points is more accurate.

If the RO-7 instrument were an ideal Bragg-Gray air ionization chamber, the RO-7 should read ~1.15 R when exposed to 1 rad of ⁹⁰Sr - ⁹⁰Y betas. The lower-than-expected readings can be explained by the failure of the RO-7 instrument to meet the requirements for a Bragg-Gray air ionization chamber. This is not surprising since few, if any, instruments meet all the requirements for a Bragg-Gray air ionization chamber. With the RO-7 the number of ergs/g of air in the chamber caused by 1 R of gamma rays is most likely not the theoretical value of 86.9 (it is probably higher). By adjusting the instrument response, the meter can be made to read 1 R for any value of ergs/g. When this instrument is calibrated to indicate 1 R when exposed to 1 R of gamma rays the meter should, in theory, read 1.15 R when exposed to 1 rad of beta ($\frac{100}{86.9}$ ergs/g). The failure of the RO-7 to do so is caused by several factors; among them are (1) the change in the probe caused by removing the beta shield, and (2) the probe is not exposed to 1 rad

because some betas are absorbed in the probe window. It would be difficult to quantitatively evaluate all the factors contributing to this problem and wouldn't be worth the effort. Consequently, the RO-7 instrument, when used to evaluate beta doses, requires a "beta factor" greater than one for all beta energies (see later discussion).

The relative response of the RO-7 to ^{204}Tl (at 600 to 700 keV in Fig. 11) is lower than expected if one considers only the absorption of the betas by the probe window. Obviously other factors are contributing to the low readings.

The response of the instrument, shown in Fig. 11, is zero at 70 keV since all the betas are absorbed in the 7 mg/cm^2 probe window. The ^{147}Pm points at ~ 150 keV may not be precise because there is a small ^{146}Pm contamination in the source. It is unfortunate that we do not have more beta sources on which to base the shape of this and following curves although in field work the exact shape of the curves is not required.

The "air dose" from betas is not normally of interest in health physics work where we are interested in dose to people. What is required is tissue doses either at the surface (0 depth), at 7 mg/cm^2 or some other selected depth in tissue. The PTB source calibrations give conversion factors from "air" to "tissue at 0 depth" of 1.111 for ^{90}Sr , 1.139 for ^{204}Tl and 1.15 for ^{147}Pm . Values of tissue dose rates for the PTB sources are given in column 4 of Table 1. Since the tissue doses are larger than the air doses, the energy response curve of the RO-7 instrument shown in Fig. 12 is correspondingly lower than the one given in Fig. 11. The beta factor curve for the RO-7 instrument was determined using the reciprocal of the curve in Fig. 12 and is shown as the solid line in Fig. 13. The beta factor is used to correct for the energy dependence of the instrument to beta. This figure shows a large beta factor at low beta energies for tissue at 0 depth but for health physics application the tissue at 7 mg/cm^2 depth is the appropriate curve (see later discussion).

Beta readings of the RO-7 instrument (unshielded minus shielded readings) must be multiplied by the beta factor which varies depending on the beta energy. Unfortunately, the beta energy (E_{max}) is not often known. If an average beta factor of 1.5 is used for tissue in air, the corrected values would be between $\pm 20\%$, for beta energies of 0.6 MeV to 2.0 MeV. For beta energies of < 0.6 MeV the corrected reading would be low, significantly if

Figure 12. Relative response of the RO-7 instrument in R/h compared with the tissue dose at 0 depth in rad/h.

Figure 13. Beta factor for the RO-7 instrument as a function of beta energy. See text for a discussion of the shape of the curves at low energy.

very-low-energy betas are being measured. I explain how to determine the beta energy using the RO-7 instrument in another report.⁵

The dose rates of the PTB beta sources at 7 mg/cm^2 depth in tissue are given in Table 1. These were determined by using the values given in the PTB source calibration information for various depths in a phantom. At 7 mg/cm^2 , which is the NRC specified depth of the dead layer of skin, the factors for the large ^{90}Sr source are 1.070 at 11 cm, 1.068 at 30 cm and 1.060 at 50 cm. The small ^{90}Sr source, ^{204}Tl and ^{147}Pm , used with their respective flatteners, have transmission factors at 7 mg/cm^2 of 1.041, 0.955 and 0.20 respectively. At 1 m from the large ^{90}Sr source no factor was given by the PTB so we used a value of 1.05. For the small ^{90}Sr source used without a flattener, the values given above for the large ^{90}Sr source were applied. No information was given by the PTB for the ^{204}Tl and ^{147}Pm sources used without flatteners so we used the same values as those for the flattened source. These values may be slightly high since at 30 cm the flattened and unflattened ^{90}Sr source factors were 1.068 and 1.041 respectively. The error in the unflattened ^{204}Tl and ^{147}Pm is believed to be small, on the basis of the small changes in the ^{90}Sr source and the reasonably good agreement shown as percent deviation in Table 1 for the flattened and unflattened ^{204}Tl and ^{147}Pm sources.

The tissue doses given in Table 1 for the 7 mg/cm^2 depth were compared to the RO-7 readings to obtain the energy dependence curve as shown in Fig. 14. The exact shape of the curve is not known because of the limited number of sources we have to work with, but is probably reasonably accurate. The shape of the curve below about 700 keV is being affected by the beta absorption in the 7 mg/cm^2 probe window which would give an exponential shape to the curve. The 7 mg/cm^2 window causes the curve to go to zero at ~70 keV where complete absorption of betas <70 keV occurs in the window material. But the dead layer of skin also stops all betas with energies <70 keV, so this drop in response is correct for health physics purposes.

The beta factor curve for the RO-7 instrument is shown as the dashed line in Fig. 13. This curve indicates that for beta energies of >140 keV a single value for the beta factor of 1.5 could be used and the evaluated dose would be very close to the $\pm 20\%$ usually required of field survey results. Low readings would be obtained at beta energies of less than 140 keV and would require a beta energy determination to evaluate them properly.

REFERENCES

1. Technical Manual for Model RO-7, Eberline Instrument Corporation, Santa Fe, NM (1979).
2. D. E. Hankins, "The Energy Response of TLD Badges Located on Personnel," Health Physics 28, 80-81 (1975).
3. D. E. Hankins, "Additional Calibrations of the PTB Sources," internal memo, April 23, 1982 (to be published in Hazards Control Department Annual Technology Review 1982, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-50007-82).
4. F. H. Attix and W. C. Rosech, Radiation Dosimetry, Vol. 1 (Academic Press, 1968).
5. D. E. Hankins, "Evaluation of Beta Energy E_{max} and Spectral Type Using Survey Instruments," report in preparation (1982).