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Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Beta and Gamma Correction Factors for the Eberline RO-20 Ionization Chamber Survey Instrument

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Prepared for the Lockheed Martin Services, Inc.
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INTRODUCTION

This technical document provides details of derived correction factors for the Eberline RO-20 (1995) survey meter, which uses an ionization chamber to measure ambient exposure rates. A thin end window allows the instrument to measure exposure rates from non-penetrating radiation (i.e., beta radiation).

Correction factors are provided for contact measurements with beta and gamma disk sources, gamma beams and, finally, general area beta fields. Beta correction factors are based on the instrument's response to ^{204}Tl, selected as the most conservative isotope for beta correction factors, as indicated in previous studies of similar instruments using ^{204}Tl, ^{147}Pm, and ^{90}Sr(Y) isotopes (Hankins 1982). Gamma correction factors are based on ^{137}Cs, considered the predominant source of gamma radiation on the Hanford Site.

SUMMARY

Correction factors developed for the Eberline RO-20 are summarized in the following tables. Each correction factor type (disk source, beam source, or general area beta) is detailed in the following sections. Gamma disk source correction factors adjust the instrument's response to the true dose rate at the surface of (on contact with) the source. The beta disk source correction factors adjust the instrument's response to the true dose rate either at the source surface or at 1/8 inch from the source surface. Both beam and general area beta correction factors correct the instrument's response to the true dose rate at the center of the instrument's ion chamber.

The correction factor calculated for general area beta exposure rates is two (2) rad/h per R/h. Tables 1 and 2 summarize the correction factors for disk and beam sources.

Table 1. Eberline RO-20 Gamma and Beta Disk Source Correction Factors

Disc Diameter	Correction Factor for Contact Measurements[1]		
	For exposure rate on contact with source		For exposure rate at 1/8 inch from source
	Beta[2] (rad/h / R/h ± 1σ)	Gamma[3] (R/h / R/h ± 1σ)	Beta[4] (rad/h / R/h ± 1σ)
0.5 in	250 ± 40	54 ± 1	180 ± 9
1 in	46 ± 4	26 ± 3	55 ± 13
2 in	15 ± 12	8 ± 1	13 ± 2
3 in	6 ± 2	5 ± 2	6 ± 1

(1) Correction factor is the ratio of the true dose rate (at the point the dose rate was measured) to the instrument's response rate.

(2) Instrument response rate is measured with the source's surface on the same plane as the rails that hold the instrument's beta window (~10 mm (3/8 inches) from instrument window). Dose rate is measured at the surface of (in contact with) the source. Beta correction factors are based on ^{204}Tl.

(3) Gamma correction factors are based on ^{137}Cs; the source is in contact with the beta shield.

(4) Instrument response rate is measured with the source surface on the same plane as the rails that hold the instrument's beta window. Dose rate is measured 1/8 inch from the surface of the source.

Table 2. Eberline RO-20 Beam Correction Factors

Beam Diameter, inches	Gamma Beams (R/h / R/h) [1]	
	Beam perpendicular to chamber	Beam coaxial with chamber
< 0.50	97	129
0.50	24	32
0.75	11	14
1.00	6	8
1.50	3	4
2.00	2	2
≥ 3.00	1	1

1. Instrument window is closed; correction factor corrects instrument's response to true exposure rate at the center of the chamber. Gamma beam correction factors are calculated as the ratio of the chamber volume to the ionization volume.

INSTRUMENT DESCRIPTION

An Eberline RO-20 ionization chamber, a box-shaped ion chamber used to measure exposure rates in air, was the instrument tested. The ionization chamber measures 2.84 inches in diameter by 2.14 inches in height for a total volume of 13.5 in^3. The chamber has a sidewall aerial density of 1,000 mg/cm^2. The thin beta window is composed of two layers of aluminized polycarbonate and has a total aerial density of 7 mg/cm^2.

DEFINITION OF "CORRECTION FACTOR"

Correction factors provided in this report adjust the instrument response to the true exposure rate, either:

- On contact with the source (for beta and gamma disk sources), at 1/8 inch from the source (for beta disk sources only), or
- At the center of the ion chamber (for beam measurements and for general area beta measurements).

- Beta correction factors for contact measurements with disk sources correct the instrument's response with the window 10 mm from the source to the true exposure rate on contact with the source or at 1/8 inch from the source.

- Beta correction factors for general area beta measurements correct the instrument's response to the true exposure rate at the center of the ion chamber.

- Gamma correction factors for contact measurements with disk sources correct the instrument's response with the beta shield in contact with the source (i.e., the window closed and in contact with the source surface) to the true exposure rate on contact with the source.

- Gamma beam correction factors correct the instrument's response to the true exposure rate at the center of the ion chamber.

Previously developed correction factors for contact measurements with the Eberline RO-3B (1984) corrected the instrument's response to the true exposure rate at the window of the instrument. When the instrument is in contact with the source, the window is at some, albeit small, distance from the source.

Eberline RO-20 beta correction factors are larger than the previously reported Eberline RO-3B correction factors, despite the fact that the RO-20 chamber is smaller than the RO-3B chamber. The reason for higher correction factors is that contact correction factors are based on the contact dose rate with the source. Previous correction factors were based on the exposure rate at some distance from the source (such as at the instrument's window). In addition, the beta isotope, upon which previously reported RO-3B beta correction factors are based, is not known and may have been $^{90}Sr(Y)$. Beta correction factors in this report are based on ^{204}Tl, which emits a lower energy beta.

DISK SOURCE CORRECTION FACTORS

Correction factors were developed for thick-windowed ^{137}Cs disk sources and thin-windowed ^{204}Tl disk sources. The ^{137}Cs sources provide gamma geometry correction factors; the ^{204}Tl disk sources provided a basis for beta geometry correction factors.

The correction factors adjust the instrument's response in R/h to the true exposure rate in R/h for gamma sources, or the true shallow dose rate in tissue in rad/h for beta sources (i.e., the correction factor units are R/h per R/h or are rad/h per R/h).

The first step in developing the disk source correction factors was measuring the true exposure or dose rate from each disk source. The second step was to measure the Eberline RO-20's response to each source. Finally, a correction factor was calculated using the ratio of the true exposure or dose rate to the instrument's response.

Rather than model the disk sources as a series of point sources, ^{137}Cs and ^{204}Tl disk sources were purchased that had physical dimensions matching the disk sources of interest to this project. The disk sources, purchased from Amersham(1), had active areas with 12 mm, 25 mm, 50 mm, and 75 mm diameters. All sources had nominal activity of 150 kBq (4 μCi). Actual activities varied from 147 kBq to 153 kBq. Thin, chipstrate thermoluminescent dosimeters (TLD's) were used to measure the exposure or dose rate from each disk source.

Measuring the Exposure Rate from ^{137}Cs Disk Sources

The true exposure rate produced by each gamma disk source was determined using chipstrate TLDs mounted in 7 mg/cm^2 covers. The chipstrates were placed on polyethylene blocks measuring approximately 4 inches high by 3.5 inches wide by 1 inch thick. The polyethylene block with TLD's mounted to its front face was placed at some measured distance from the source surface. Total exposure time, typically greater than 4 hours, was recorded. Background TLD's were processed along with the exposed TLDs. Total exposure recorded by background TLD's was subtracted from the total exposure recorded on exposed TLDs. The chipstrate reader was calibrated using chipstrates mounted on identical phantoms and exposed to 1 R ^{137}Cs at a distance of one meter. The chip readings in units of R were taken to be a measure of the true exposure rate. Because only gamma radiation was involved, corrections for angular dependence were assumed negligible.

Measuring the Shallow Dose Rate from ^{204}Tl Disk Sources

The true shallow dose rate produced by each beta disk source in the specified geometry was determined using chipstrate TLDs mounted on polyethylene blocks as described above and the reader was calibrated as described above. For the purpose of converting from TLD units of exposure to TLD units of absorbed dose in tissue, a conversion factor of 1 R = 1 rad was used.

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(1) Nycomed Amersham, United Kingdom

This is not unreasonable given that the Cx factors between 0.98 and 1.03 are given for ^{137}Cs in the performance test standards used for extremity and whole body dosimetry at DOE facilities (DOE 1986, HPS 1995).

Beta Correction Factors for ^{204}Tl Chipstrate Exposures

The ^{204}Tl chip results were corrected for beta energy dependence. Correction factors were estimated using VARSKIN MOD2®[2], a computer program that calculates shallow dose rates in tissue due to beta sources.

All Amersham sources used for irradiation had frontal areas greater than 10 times the frontal area of the TLD chip (0.1 cm^2), and appeared much like infinite sources to the TLD chip when in close proximity. Consequently, when using VARSKIN MOD2® to estimate the appropriate ^{204}Tl beta correction factor for use with the chipstrate in contact geometry, a disk source of large dimensions (11.28 cm diameter) relative to the chip (0.32 cm x 0.32 cm x 0.015 cm) was chosen as the model. The assumption that the source appeared as an infinite slab was confirmed by repeated calculations using the actual source sizes.

The computer code VARSKIN MOD2® was used to calculate the volume averaged dose to a volume of skin with a frontal area 0.1 cm^2 and lying at depths between 6.9 and 7.1 mg/cm^2 and to a volume of TLD material having a frontal area of 0.1 cm^2 and lying between 7.0 and 47.0 mg/cm^2 depths. The source was modeled as a two dimensional ^{204}Tl disk source 100 cm^2 in area (11.28 cm dia.) with no covering. The distance between the source and targets was given as 0.1 mm (contact). The chip's beta correction factor was calculated as the volume averaged dose to the chip divided by the volume averaged dose to a patch of skin of the same frontal area. This correction factor includes the geometry effects from beta particles striking at an angle from the source's periphery. At a distance of 0.1 mm (contact), the results show that the volume averaged dose received by the skin at the same location and with the same area as the chip, is 1.98 times the volume averaged dose received by the chip.

The total correction factor by which chip readings in R were multiplied to get actual shallow dose in rad from disk sources was rounded to 2.0.

Measuring the RO-20 Response to the Disk Sources

Once the true exposure or dose rate from each source was known, the next step was to determine the response of the instruments to each of the disk sources. To allow a more accurate measurement of the instrument response, an electrometer was placed in-line with the meter circuit to measure the current delivered to the meter. This eliminated errors associated with reading the instrument's analog display.

The correlation between meter current and exposure rate was determined by repeating the

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(b) VARSKIN MOD2® was developed by JS Durham at Pacific Northwest National Laboratory and documented in NUREG/CR-5873 (PNL 7913).

measurements in known radiation fields. Two points on each range of the instrument were measured using ^{137}Cs calibration fields. Each data point represents an average of 20 separate electrometer readings.

The RO-20's response was measured with disk sources as close as possible to the detector. For the RO-20 beta source measurements, the actual source to window distance was limited by the rails used to guide the beta shield, (~ 10 mm). For gamma source measurements, the RO-20 window was closed and the gamma sources were in contact with the beta shield (~ 10 mm from the beta window).

To compare the methodology used in this report for calculating correction factors with the methodology used in previous years at the Hanford Site, instrument response data was also collected for the Eberline RO-3B. This allowed the author to compare newly calculated correction factors for the Eberline RO-3B with correction factors developed many years ago. Eberline RO-3B beta source measurements were made with beta source on the same plane as the retaining ring that holds the thin beta window (source was approximately 2.4 mm from the beta window). Gamma source measurements were also made with the instrument window closed and the source in contact with the beta filter.

Calculation of Correction Factor for Disk Sources

Once the true exposure rate and instrument response for each source was known, the correction factor was calculated as a ratio of the true exposure rate (R/h or rad/h) to the instrument's response rate (R/h).

Error bars for the beta correction factors were likely due to non-uniformities in the distribution of the source activity. Multiple measurements of each source, with the TLD in contact with the source, resulted in wide and varied estimates of contact dose rates.   More consistent data with smaller error bars was obtained with TLD's at 1/8 inch from the surface of the source.

Consequently, two sets of correction factors are presented for the beta sources. One set corrects the RO-20 response to the true dose rate on contact with (physically touching) the surface of the source. The second set corrects the RO-20 response to the true dose rate 1/8 inch from the surface of the source. In both cases, the RO-20 to source geometry is identical (i.e., the source is on the same plane as the rails that hold the RO-20 beta shield).

A summary of the TLD results, and instrument response data, is provided in Attachment 1, along with calculated correction factors reiterated in Table 1.

Table 1. Gamma and Beta Disk Source Correction Factors for the Eberline RO-20.

Disc Diameter	Correction Factor for Contact Measurements[1]		
	For exposure rate on contact with source		For exposure rate at 1/8 inch from source
	Beta [2] (rad/h / R/h ± 1σ)	Gamma [3] (R/h / R/h ± 1σ)	Beta [4] (rad/h / R/h ± 1σ)
0.5 in	250 ± 40	54 ± 1	180 ± 9
1.0 in	46 ± 4	26 ± 3	55 ± 13
2.0 in	15 ± 12	8 ± 1	13 ± 2
3.0 in	6 ± 2	5 ± 2	6 ± 1

(1) Correction factor is the ratio of the true dose rate (at the point the dose rate was measured) to the instrument's response.

(2) Instrument response is measured with the source surface on same plane as rails that hold the instrument beta window (~10 mm (3/8 inches) from instrument window). Dose rate is measured at the surface of (in contact with) the source. Beta correction factors based on ^{204}Tl.

(3) Gamma correction factors based on ^{137}Cs; source is in contact with the beta shield.

(4) Instrument response is measured with the source surface on same plane as rails that hold the instrument beta window. Dose rate is measured 1/8 inch from the surface of the source.

GAMMA BEAMS

An ionization chamber's response to a beam of gamma radiation must be corrected to account for the partial ionization of the chamber. The correction factor is calculated as the ratio of the total ionization chamber volume to the irradiated volume. The ionization chamber is essentially a right cylinder, the volume of which is readily calculated. The beam is assumed to vertically intersect the axis of the chamber. For the purposes of this report, the beam is assumed to irradiate an area within the chamber that can be represented by a right cylinder. This is not entirely accurate as the ends of the cylinder are curved (to match the curvature of the chamber sidewall) but is sufficiently accurate for this purpose.

The calculated beam correction factors are listed in Table 2; a copy of the spreadsheet is provided in Attachment 2. Beam correction factors were calculated for beams perpendicular to the chamber and for beams coaxial with the chamber. The axis of beams perpendicular to the chamber must intersect the axis of the chamber.

Table 2. Eberline RO-20 Beam Correction Factors

Beam Diameter, inches	Gamma Beams (R/h / R/h)[1]	
	Beam perpendicular to chamber	Beam coaxial with chamber
< 0.50	97	129
0.50	24	32
0.75	11	14
1.00	6	8
1.50	3	4
2.00	2	2
≥ 3.00	1	1

(1) Instrument window is closed; correction factor corrects instrument's response to true exposure rate at the center of the chamber. Gamma beam correction factors are calculated as the ratio of the chamber volume to the ionization volume.

GENERAL BETA FIELDS

The Eberline RO-20 correction factor for uniform beta fields was estimated using a ^{204}Tl point source. The center of the RO-20 ion chamber was placed 35 cm from the source. At this distance, the ^{204}Tl source appears as a uniform field to the instrument. The response of the RO-20 was 700 mrad/h with an actual dose rate (measured with an extrapolation chamber) measuring 1.34 R/h. This yields a correction factor of 1.9, which for the purposes of this study was rounded to 2 rad/h per R/h.

Similarly, the Eberline RO-20 response was measured for a uniform ^{90}Sr(Y) field by placing the center of the RO-20 30 cm from a 50 mCi ^{90}Sr(Y) point source. The delivered shallow dose rate was 20 rad/h. The instrument response was 19 R/h, yielding a correction factor of approximately one rad/h per R/h.

REFERENCES

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Hankins, D.E. 1982. *Beta-Energy Response of the Eberline RO-7 Survey Instrument.* Lawrence Livermore National Laboratory, Livermore, CA.

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Attachment 1

Data Sheets for Calculating Disk Source Correction Factors

Isotope: 204Tl Beta

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	**Numbers in this column appear in Rpt. Correction Factor**
D13837	Background TLD		NA	NA	NA		0			
D15413	Background TLD				NA		-4			
D12947	Background TLD				NA		-1			
D19219	Background TLD				NA		2			
D11309	Background TLD				NA		0			
D16623	Background TLD		NA	NA	NA		16			
D15746	Background TLD		NA	NA	NA		2			
D14271	Tl-204 SN FN 411	0	0	20	20	20 min	7288	43381		
D19586	12 mm diameter	0			20	20 min	3947	23494		
D10047	149 kBq	0			20	20 min	5091	30304		
D12833		0			20		2771	16494		
							Average	28418	104	**273**
							Std. Dev	11458	error +/-	**110**
D15284	Tl-204 SN FN 411	0			10		2315	27560		
D15408	12 mm diameter	0			10		2937	34964		
D25256	149 kBq	0			10		2546	30310		
D13052		0			10.06667		2137	25272		
D23165		0			10		2065	24583		
D13180		0			11		2157	23344		
D13006		0			10		2180	25952		
D13514		0			10		1753	20869		
D15280		0			10		2008	23905		
D26047		0			10		1825	21726		
D14107		0			10		2151	25607		
D10237		0			10.05	20 min	2215	26238		
							Average	25861	104	**249**
							Std. Dev	3813	error +/-	**37**
D12243	12 mm	CP Window (0.1)			21	20 min	4344	24626		
D19494	12 mm	CP Window (0.1)			24	20 min	4244	21052		
D11048	12 mm	CP Window (0.1)			20.4	20 min	3558	20763		
							Average	22147	104	**213**
							Std. Dev	2152	error +/-	**21**

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	**Isotope: 204Tl Beta** TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	**Numbers in this column appear in Rpt. Correction Factor**
D16414	12 mm	0.125			20	20 min	3032	18048		
D12329	12 mm	0.125			22.5	20 min	3551	18788		
D17825	12 mm	0.125			20	20 min	3332	19833		
							Average	18890	104	**182**
							Std. Dev	897	error +/-	**9**
D20754	12 mm	0.25			20	20 min	1341	7982		
D11146	12 mm	0.25			20	20 min	1434	8536		
D12765	12 mm	0.25			20	20 min	1463	8708		
							Average	8409	104	**81**
							Std. Dev	379	error +/-	**4**
D13955	12 mm	0.5	0	30	30	30 min	681	2702	104	**26**
									error +/-	
D21555	12 mm	1	2	0.5	120.5	2 hr	677	669	104	**6**
									error +/-	
D10718	12 mm	1.5	4	30	270	4.5 hr	686	188	104	**2**
									error +/-	
D14178	Tl-204 SN FN 412	0	0	20	20	20 min	135	804		
D11532	25 mm diameter	0			20	20 min	269	1601		
D15178	151 kBq	0			20	20 min	399	2375		
D13988		0			20	20 min	199	1185		
D10939		0		40	40		676	2012		
D25463		0		40	40		4031	11997		
D19527		0		41	41		1726	5012		
D25523		0		65	65		6045	11071		
D16329		0		60	60		5854	11615		
D10048		0			114		11624	12139	(this set not used)	
							Average	5981	104	**58**
							Std. Dev.	5060	error +/-	**49**
D18209	Tl-204 SN FN 412	0			20		876	5214		
D10221	25 mm diameter	0			20		834	4964		
D17285	151 kBq	0			20		700	4167		
D18087		0			20		773	4601		
							Average	4737	104	**46**
							Std. Dev.	456	error +/-	**4**

Isotope: 204Tl Beta

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	Numbers in this column appear in Rpt. **Correction Factor**
D11364	Tl-204 SN FN 412	0.125			60	45 min	2401	4764		
D16143	25 mm diameter	0.125			22	20 min	987	5341		
D18237	151 kBq	0.125			32	20 min	2063	7675		
D12064		0.125			32	20 min	1392	5179		
							Average	5740	104	**55**
							Std. Dev.	1313	error +/-	**13**
D14635	Tl-204 SN FN 412	0.5			45	45 min	703	1860		
D22726	25 mm diameter	0.5			20	20 min	305	1815		
D10395	151 kBq	0.5			20	20 min	332	1976		
D12371		0.5			20	20 min	326	1940		
							Average	1898	104	**18**
							Std. Dev.	73	error +/-	**1**
D22717	25 mm	1			122	2 hr	845	825		
D12312	25 mm	1.5			270	4.5 hr	662	181		
D16183	Tl-204 SN FN 413	0			30	30 min	819	3250		
D25560	50 mm diameter	0			30	30 min	480	1905		
D14360	147 kBq	0			30		564	2238		
D19173		0			34		761	2665		
D11172		0			34		26	91		
D13945		0			34		132	462		
D25422		0			31		29	111		
D19394		0			31		135	518		
D19247		0			31		225	864		
D25972		0			28		26	111		
D19572		0			28		581	2470		
D12450		0			28	30 min	409	1739		
							Average	1369	94	**15**
							Std. Dev.	1136	error +/-	**12**
D16015	Tl-204 SN FN 413	0.125			32	80 min	335	1246		
D12015	50 mm diameter	0.125			32	80 min	256	952		
D12146	147 kBq	0.125			32		406	1510		
D11765		0.125			31		293	1125		
D13933		0.125			31		307	1179		
						80 min				
							Average	1203	94	**13**
							Std. Dev.	204	error +/-	**2**

Isotope: 204Tl Beta

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	Numbers in this column appear in Rpt. Correction Factor
D15988	50 mm	0.5			82	80 min	610	886		
D13232		0.5			82	80 min	641	931		
D12050		0.5			82	80 min	482	700		
							Average	839	94	**9**
							Std. Dev.	122	error +/-	**1**
D20747	50 mm	1			180	3 hr	566	374		
D15977		1			180	3 hr	545	360		
D12560		1			180	3 hr	526	348		
							Average	361	94	**4**
							Std. Dev.	13	error +/-	**0**
D16533	50 mm	1.5			280	4.5 hr	639	168		
D13667		1.5			280	4.5 hr	508	134		
D22821		1.5			280	4.5 hr	592	156		
							Average	153	94	**2**
							Std. Dev.	17	error +/-	**0**
D12605	Tl-204 SN FN 414	0			61	1 hour	345	673		
D15720	75 mm diameter	0			61	1 hour	199	388		
D10800	146 kBq	0			61	1 hour	153	299		
D14070		0			61	1 hour	246	480		
D25776		0			61	1 hour	207	404		
							Average	449	80	**6**
							Std. Dev.	141	error +/-	**2**
D19562	Tl-204 SN FN 414	0.125			50	4.5 hr	195	464		
D22846	75 mm diameter	0.125			50		236	562		
D18202	146 kBq	0.125			50		251	598		
D11071		0.125			50		227	540		
D15700		0.125			50		171	407		
D18973		0.125			50		216	514		
D18192		0.125			50		189	450		
D10844		0.125			45		179	474		
D15722		0.125			45		160	423		
D11053		0.125			45		194	513		
D10701		0.125			45		202	534		
D19699		0.125			45		199	526		
D11917		0.125			54		242	534		
D23104		0.125			54		226	498		
D18233		0.125			54		210	463		

Isotope: 204Tl Beta

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	Correction Factor (Numbers in this column appear in Rpt.)
D19542		0.125			54		205	452		
D16666		0.125			54		219	483		
D23101		0.125			54	4.5 hr	289	637		
						4.5 hr				
							Average	504	80	**6**
							Std. Dev.	59	error +/-	**0.74**
D22878	Tl-204 SN FN 414	0.5			120	2 hr	321	318		
D15913	75 mm diameter	0.5			120	2 hr	415	412		
D12469	146 kBq	0.5			120	2 hr	248	246		
D12417		0.5			120	2 hr	265	263		
D19528		0.5			120	2 hr	326	323		
							Average	313	80	**4**
							Std. Dev.	65	error +/-	**1**
D15613	Tl-204 SN FN 414	1			180	3 hr	280	185		
D16679	75 mm diameter	1			180	3 hr	413	273		
D15407	146 kBq	1			180	3 hr	296	196		
D18199		1			180	3 hr	280	185		
D15019		1			180	3 hr	241	159		
							Average	200	80	**2**
							Std. Dev.	43	error +/-	**1**
D13162	Tl-204 SN FN 414	1.5			300	5 hr	309	76		
D18805	75 mm diameter	1.5			300	5 hr	431	106		
D20478	146 kBq	1.5			300	5 hr	310	76		
D16067		1.5			300	5 hr	319	78		
D16569		1.5			300	5 hr	314	77		
							Average	83	80	**1**
							Std. Dev.	13	error +/-	**0**

NOTES 1. Dose rate is the total dose divided by the exposure time (in hours) and multiplied by the correction factor.

RO-20 Correction Factor Study

Data sheet for measuring dose rate from disk sources **with beta shield**

Isotope: Cesium-137 Gamma

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	Total Time, min	Minimum Total Time	TLD Exposure mR	Exposure Rate mR/h	RO-20 Response mR/h	Correction Factor
D20661	Background TLD		NA	NA	NA		14			
D11558	Background TLD		NA	NA	NA					

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	<u>**Isotope: 204Tl Beta**</u> TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	**Numbers in this column appear in Rpt.** **Correction Factor**
D17688	Background TLD		NA	NA	NA		-2			
D12291	Background TLD		NA	NA	NA		6			
D16263	Background TLD		NA	NA	NA		3			
D17354	Background TLD		NA	NA	NA		-3			
D12734	Background TLD		NA	NA	NA		-1			
	Background TLD		NA	NA	NA					
D21524	Cs-137 SN FN 407	0	4		240	4 hr	185	46		
D18814	12 mm diameter	0	114	17	6857	48 hrs	5182	45		
	149 kBq						Average	46	0.85	**54**
							Std. Dev	1	error +/-	**1**
D15494	Cs-137 SN FN 408	0	4		240	4 hr	95	24		
D13772	25 mm diameter	0	113	59	6839	48 hrs	2358	21		
	148 kBq						Average	22	0.85	**26**
							Std. Dev	2	error +/-	**3**
D12486	25 mm	0.5	4	6	246	4 hr	33	8		
D18138	25 mm	1	4	5	245	4 hr	11	3		
D18991	25 mm	1.5	14	41	881	4 hr	37	3		
D22866	50 mm	0.5	4		240	4 hr	13	3		
D25597	50 mm	1	5	20	320	4 hr	20	4		
D15031	50 mm	1.5	4		240	4 hr	4	1		
D20464	50 mm diameter	0	4	9	249	4 hr	27	7		
D25816	153 kBq	0	4	9	249	4 hr	25	6		
D16348		0	113	53	6833	48 hrs	890	8		
D10975		0	113	53	6833	48 hrs	696	6		
D14294		0	113	53	6833	48 hrs	812	7		
							Average	7	0.87	**8**

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	**Isotope: 204Tl Beta** TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	**Numbers in this column appear in Rpt. Correction Factor**
D10572	50 mm	0.5	4	0	240	4 hr	21	5		
D20606	50 mm	0.5	4	0	240	4 hr	18	5		
D12506	50 mm	0.5	4	0	240	4 hr	17	4		
							Average	5		
D18360	50 mm	1	5	6	306	4 hr	9	2		
D17738	50 mm	1	5	6	306	4 hr	9	2		
D17561	50 mm	1	5	6	306	4 hr	17	3		
							Average	2		
D25783	50 mm	1.5	4	0	240	4 hr	6	2		
D20770	50 mm	1.5	4	0	240	4 hr	1	0		
D22825	50 mm	1.5	4	0	240	4 hr	6	2		
							Average	1		
D15018	Cs-137 SN FN 410	0	4	5	245	4 hr	35	9		
D13382	75 mm diameter	0	4	5	245	4 hr	13	3		
D16157	150 kBq	0	4	5	245	4 hr	12	3		
D20700		0	4	5	245	4 hr	12	3		
D10128		0	4	5	245	4 hr	11	3		
D10985		0	113	50	6830	96 hrs	561	5		
D13291		0	113	50	6830	96 hrs	634	6		
D12490		0	113	50	6830	96 hrs	363	3		
D15297		0	113	50	6830	96 hrs	439	4		
D11119		0	113	50	6830	96 hrs	428	4		
							Average	4	0.78	**5**
D22815	75 mm	0.5	4		240	4 hr	11	3		
D20483	75 mm	0.5	4		240	4 hr	4	1		
D18155	75 mm	0.5	4		240	4 hr	5	1		
D11380	75 mm	0.5	4		240	4 hr	11	3		
D25481	75 mm	0.5	4		240	4 hr	4	1		
							Average	2		
D25310	75 mm	1	4	1	241	4 hr	4	1		
D19531	75 mm	1	4	1	241	4 hr	5	1		
D12466	75 mm	1	4	1	241	4 hr	5	1		
D15991	75 mm	1	4	1	241	4 hr	11	3		
D18187	75 mm	1	4	1	241	4 hr	5	1		
							Average	1		
D13567	75 mm	1.5	14	37	877	4 hr	16	1		
D11013	75 mm	1.5	14	37	877	4 hr	17	1		

TLD #	Source SN, Diameter, and isotope	Dist. to Src. (in.)	Exposure Time Hour	Min	TLD Exposure Time, min	Minimum Total Time	Isotope: 204Tl Beta TLD Exposure mR	Dose Rate mrad/h (1)	RO-20 Response mR/h	**Numbers in this column appear in Rpt.** **Correction Factor**
D10911	75 mm	1.5	14	37	877	4 hr	25	2		
D11923	75 mm	1.5	14	37	877	4 hr	18	1		
D15065	75 mm	1.5	14	37	877	4 hr	11	1		
							Average	1		

Attachment 2

Calculation of Gamma Beam Correction Factor

INSTRUMENT DIMENSIONS

Eberline Ion chamber Model	Distance Source to Window, mm	Volume in3	Volume cm3	Diameter, inches	Chamber Depth, in	Chamber x-section in2
RO-20	10.0	13.5	222	2.84	2.14	6.33
RO-3B	2.4	29.4	482	3.00	4.16	7.07

Notes:
Diameter and depth verified with physical measurements for both instruments

CALCULATION OF BEAM CORRECTION FACTORS

Beam diameter inches	Beam X-section inches-sq	RO-20 Beam volume perpen.	RO-3B Beam volume perpen.	RO-20 Corr. factor perpen.	RO-20 Corr. factor coaxial	RO-3B Corr. factor perpen.	RO-3B Corr. factor coaxial
0.25	0.05	0.14	0.15	97	129	200	144
0.50	0.20	0.56	0.59	24	32	50	36
0.75	0.44	1.25	1.33	11	14	22	16
1.00	0.79	2.23	2.36	6	8	12	9
1.50	1.77	5.02	5.30	3	4	6	4
2.00	3.14	8.92	9.42	2	2	3	2
2.50	4.91	13.94	14.73	1	1	2	1
3.00	7.07	20.07	21.21	1	1	1	1
3.50	9.62	27.32	28.86	1	1	1	1
4.00	12.57	35.69	37.70	1	1	1	1