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VIRGINIA ELECTRIC AND POWER COMPANY

BETA DOSIMETRY REPORT

BY:

CORPORATE HEALTH PHYSICS

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TABLE OF CONTENTS

INTRODUCTION

On April 11, 1983, Virginia Electric and Power Company (Vepco) received a Confirmation of Action Letter (CAL-280/83-01 and CAL-281/83-01) from the Nuclear Regulatory Commission (NRC) pertaining to the Surry Power Station. Item Number 3 stated, "By July 5, 1983, complete an evaluation to resolve the discrepancy between beta radiation dose measurements made with portable survey instruments and measurements made with thermoluminescent dosimeters. Until this evaluation is completed, retain detailed survey records to provide sufficient information to adjust thermoluminescent dosimetry results, should such adjustment become necessary. Also, until the above evaluation is completed, control personnel exposure to beta radiation based on dose rate measurements made with portable survey instruments".

In order to resolve this item, Vepco developed the following action plan:

1. Empirically identify the beta spectral components;

2. Determine the response of the beta survey instrumentation (Eberline Model RO2A) to the identified spectra and determine a correction factor for this instrumentation;

3. Assess the beta dose to the lens of the eye as it relates to whole body dose;

4. Determine if a beta source similar to the identified station beta spectra is available;

5. Review the thermoluminescent dosimetry (TLD) beta dose algorithms with respect to the identified station spectra in order to determine if a correction factor is required;

6. Expose TLD's to a beta slab source at known distances and dose rates to determine a TLD correction factor;

7. Compare the TLD dose algorithm for Strontium/Yttrium-90 to the correction factor determined using the beta slab source.

NOTE: Items 1-3 will be addressed in this report. The remaining items will be addressed in a subsequent report.

Implementation of the action plan was initiated by acquiring swipes from Surry's Unit Number 2 primary system components. A Feather's analysis (Ch67) was performed on each swipe to determine the beta transmission. This procedure was then duplicated using swipes acquired from Unit Number 1.

The data was then analyzed using a method developed by T. Baltakmens (Ba77), as discussed in Appendix II, to determine an effective average and maximum beta energy. From this data an arithmetic average beta energy was calculated to determine which beta emitting standard would best approximate the beta energies characteristic of Surry Power Station.

EQUIPMENT

The equipment used to perform the Feather's analysis was an Eberline Model HP-210T thin window (1.4 - 2.0 mg/cm^2) Gieger Muller (GM) probe, high voltage power supply set for 900 Volts DC, two Eberline Model SH-4A sample holders, and an amplifier-scaler to count the pulses from the probe. The aluminum absorber set used was an Atomic Accessories, Inc. Absorber Set, Model AB-23, Serial Number #7688. This set has 24 aluminum absorbers (3.0 - 1604.2 mg/cm^2) and five lead absorbers (978.1 - 7190.8 mg/cm^2). The sample holders and HP-210T detector were assembled as illustrated in Figure 1. The detector and sample holder assembly were placed inside a shield constructed of lead bricks whose walls were two to four inches in thickness in order to minimize the background contribution to the data. In order to ensure that there were no shifts in the data an electronic stability check was performed using a strontium/yttrium-90 calibration source each day prior to taking data.

PROCEDURE

Prior to any beta analysis each swipe was counted on the GeLi system at the station to determine the isotopic ratios of the nuclides present. The results of these GeLi scans are summarized in Table 1. Examination of Table 1 indicates that cesium and cobalt are the primary beta emitting nuclides found at Surry Power Station. The beta counting apparatus was arranged as illustrated in Figure 2. With an empty stainless steel planchet in place, background counts were taken. Stainless steel planchets were also used for counting the swipes and calibration sources. The counting interval for the initial count, with an empty absorber ring placed above the source, was chosen to obtain at least 10,000 counts. Subsequent counts with absorbers in place were taken to obtain a minimum of 1000 counts. Tables of the data for both swipes and known sources are included as Appendix I. The gross count rates were then corrected for detector dead-time using the following equation:

$$\text{Corrected Count Rate} = (C)\ [1.0/(1.0 - CT)]$$

C = Gross Count Rate in CPS

T = Resolution Time ($50. \times 10^{-6}$ sec for HP210T)

The data was then corrected for the photon contribution. Due to the short range of beta particles, the count rate through 1604.2 mg/cm^2 of aluminum was assumed to be due entirely to photons. Therefore, the count rate due to photons with 0.0 thickness of aluminum can be calculated by using the following equation:

$$I(\emptyset) = I(1604.2)\ \exp\ (\mu_a/\rho * X)$$

where:

$I(1604.2)$ = The photon count rate through 1604.2 mg/cm^2 of aluminum.

$I(\emptyset)$ = The count rate due to photons with 0 mg/cm^2 of aluminum.

μ_a/ρ = Mass attenuation coefficient for the photons in aluminum (cm^2/g).

X = 1604.2 mg/cm^2 of aluminum converted to g/cm^2.

All other values of $I(x)$, where x is some thickness of aluminum absorber, may be calculated using the following equation:

$$I(x) = I(\emptyset) \exp(-\mu_a/\rho * (x)\ mg/cm^2)$$

The mass attenuation coefficient, μ_a/ρ, was taken from NSRDS - NBS29 Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV for the cobalt-60 and cesium-137 calibration sources. For the swipe data and strontium/yttrium-90 calibration source the mass attenuation coefficient was calculated either using the data taken through the lead attenuators or determined by analyzing the photon attenuation between 1200 and 1600 mg/cm^2 of aluminum and assuming that no betas can penetrate that thickness. In order to have a beta contribution to the count rate through 1200 mg/cm^2 of aluminum, the beta must have an energy greater than 2.5 MeV. Isotopic analysis of the swipes did not indicate the presence of any isotopes that emit betas above 2.5 MeV. The photon count rate data between 1200 and 1600 mg/cm^2 was least-squares fitted in order to calculate the mass attenuation coefficient using the equation:

$$Y = a \exp(bx)$$

where:

Y = The count rate.

a = Constant

b = The mass attenuation coefficient, cm^2/mg.

x = Aluminum thickness in mg/cm^2.

The least-squares fitted value of b was then used to calculate the photon count rate for each thickness of aluminum attenuator. The same correction for dead-time was applied to the calculated photon count rate prior to subtraction from the gross count rate.

Subtraction of the photon contribution results in a count rate due only to the beta flux. Figure 3 illustrates the "Beta Transmission versus Attenuator Thickness". Transmission is defined as the beta count rate through the attenuator thickness divided by the beta count rate with no attenuation. Note that almost all of the curves have reached zero by 300 mg/cm^2.

The method used to determine the endpoint and average beta energy assumes that beta absorption is an exponential process and that it is possible to calculate a mass absorption coefficient to describe the beta absorption with distance. A beta mass absorption coefficient was calculated for each of the 10 samples using the following equation:

$$\mu_a/\rho(\text{cm}^2/\text{mg}) = \frac{0.693}{x\ (\text{mg}/\text{cm}^2)}$$

where:

$\mu_a/\rho(\text{cm}^2/\text{mg})$ = Beta mass absorption coefficient

x = The thickness of aluminum that reduces the beta response by 50% (i.e., the first half-value thickness).

The μ_a/ρ value was then used to calculate the endpoint and average beta energy using the power function relationship between beta mass absorption coefficient developed by Mr. Baltakmens (Ba77).

$$\text{Beta Endpoint Energy:}\quad E_m = 6.47\ n^{-0.661}$$

$$\text{Average Beta Energy:}\quad E_{ave} = 2.90\ n^{-0.745}$$

where:

n = The beta mass absorption coefficient.

These beta endpoint and average energy values were then averaged to obtain a representative beta energy value for Surry Power Station.

RESULTS

Figure 3 illustrates that in spite of the varying nuclide distribution, the shift in the beta attenuation spectra is small. Some of the attenuation curves diverge from the classical shape of a beta attenuation range curve. This deviation below 10% transmission is probably due to the bremsstrahlung contributions, photon buildup and scattering, and beta range straggling for which corrections were unable to be made or were inadequate. Therefore, the method outlined by T. Baltakmens (Ba77) was used to determine beta maximum and beta average energies. Mr. Baltakmens' assumption of a power function relationship between the apparent beta mass absorption coefficient and the beta endpoint energy is supported by previous experimental work as reported by Evans (Ev67), Hine (Hi56), and Fitzgerald (Fi67).

The apparent beta mass absorption coefficient was calculated from the thickness of aluminum that was required to reduce by 50% the incident flux of beta reaching the detector. The half-value criteria was taken as a compromise between attempting to minimize the error due to bremsstrahlung and range straggling and wanting to include as much of the attenuation curve as possible in the measurement. The results of this analysis are in Table 2. In compiling Table 2 five smears from each unit were used to determine the average beta maximum energy that would be characteristic of Surry Power Station. Note that the Unit 1 and Unit 2 smears represent mixtures of nuclides that were decayed for different periods of time. Unit 2 smears had decayed approximately 1 week prior to beta counting, whereas Unit 1 smears were allowed to decay about 4 weeks prior to beta counting in order to see how much shift in beta spectra would occur. Also note that the shift in the average beta maximum energy is approximately 100 keV. The resulting beta maximum average value for the week-old fission products is 0.631 MeV and 0.526 MeV for the four-week-old fission products.

Beta spectra from three calibration sources, cobalt-60, cesium-137, and strontium/yttrium-90, were also analyzed concurrently with the swipe spectra to verify the experimental results. Beta E_m and E_{ave} were calculated and compared to the published reference values. The calculated values and the reference values taken from Baltakmens paper are listed in Table 3. The calculated and reference values from the experiment agree to within 12%. Possible differences between the experimental and reference values for the cesium-137 and the strontium/yttrium-90 may be due to interference between the high and low energy betas emitted in the decay scheme of these nuclides.

From the determination of the E_{max} and E_{ave} characteristic of "fresh" (one week old) and "aged" (four weeks old) fission products at Surry Power Station, it was determined that thallium-204 would be the most appropriate calibration source. Mr. Bryce Rich's paper on "Applied Beta Dosimetry" presented at the 1982 Health Physics Society Meeting (Ri82), depicted a comparison between measured and theoretical beta spectra for a thallium-204 point source (Figure 4). The figure illustrates that at 20 cm from the source the measured E_{max} and E_{ave} are very close to Surry's calculated E_{max} and E_{ave} for "fresh" fission products. The comparison is made only with the "fresh" fission products since most of the situations in which workers are exposed to large doses of beta radiation during an outage occur within the first weeks of the unit's shutdown. At 20 cm from a thallium-204 source the Eberline Model R02A portable ionization chamber will only register 55% (see Figure 5) of the total beta dose. This under-response indicates that the beta correction factor should be 1/0.55 or 1.82. This is much less than the correction factor of 4 presently in use at Surry Power Station.

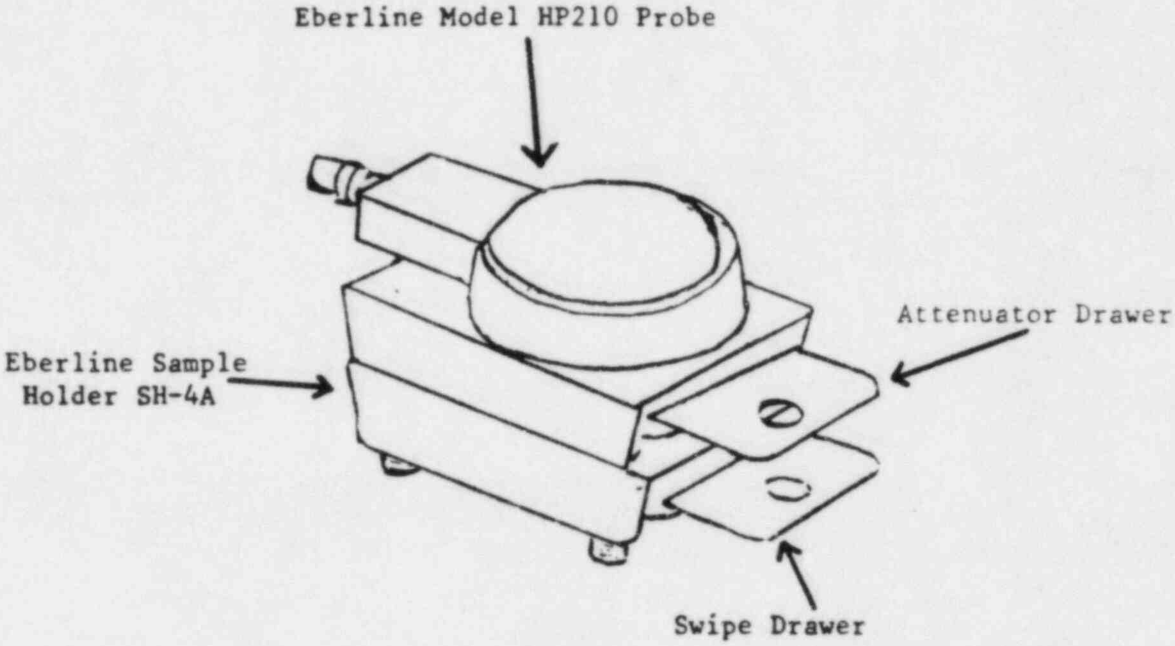
RECOMMENDATIONS AND CONCLUSION

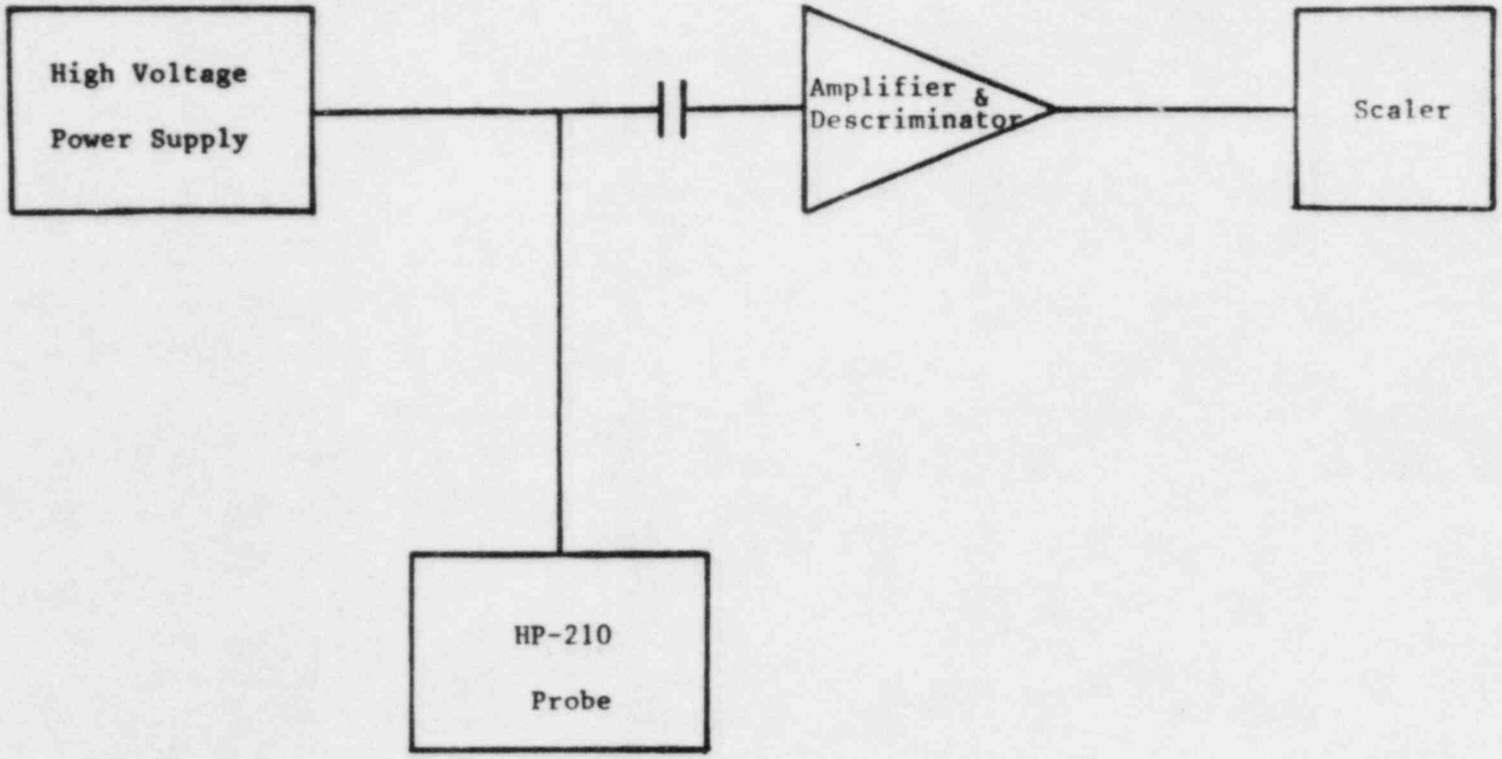
Vepco has empirically identified the beta spectral components as being primarily isotopes of cobalt and cesium. From the analysis of the collected data a beta spectral distribution with a maximum beta energy of 0.631 MeV was determined to be representative of Surry's spectra.

The data analysis discussed in the previous section indicates that the current practice of using a beta correction factor of 4 for the Eberline R02A instruments is overly conservative. It is recommended, based upon the experimental results, that a beta correction factor of 2 be used for all Eberline R02A measurements. Although the experimental results show that the correction factor is actually 1.82, a correction factor of 2 is recommended for ease of use. The use of this correction factor will result in a conservative estimate of the beta dose rates, which should be sufficient to correct for shifts in the beta spectra due to decay.

Form NRC-5, Current Occupational External Radiation Exposure, states that lens of the eye dose is measured at 300 mg/cm^2. Therefore, in order for the betas to contribute to the lens of the eye dose they must have a range greater than 300 mg/cm^2. The "maximum" or extrapolated range of 631 keV betas is approximately 225 mg/cm^2. Comparing this range to the lens of the eye mass density thickness of 300 mg/cm^2 indicates that there is no beta contribution to the lens of the eye dose. The dose to the lens of the eye is solely a function of the photon component of the radiation field.

FIGURE 1


Eberline Model HP210 Probe
Eberline Sample Holder SH-4A
Attenuator Drawer
Swipe Drawer



Equipment Configuration

FIGURE 2

BETA TRANSMISSION VS ATTENUATOR THICKNESS
Surry Power Station Units 1 & 2 Swipe Data

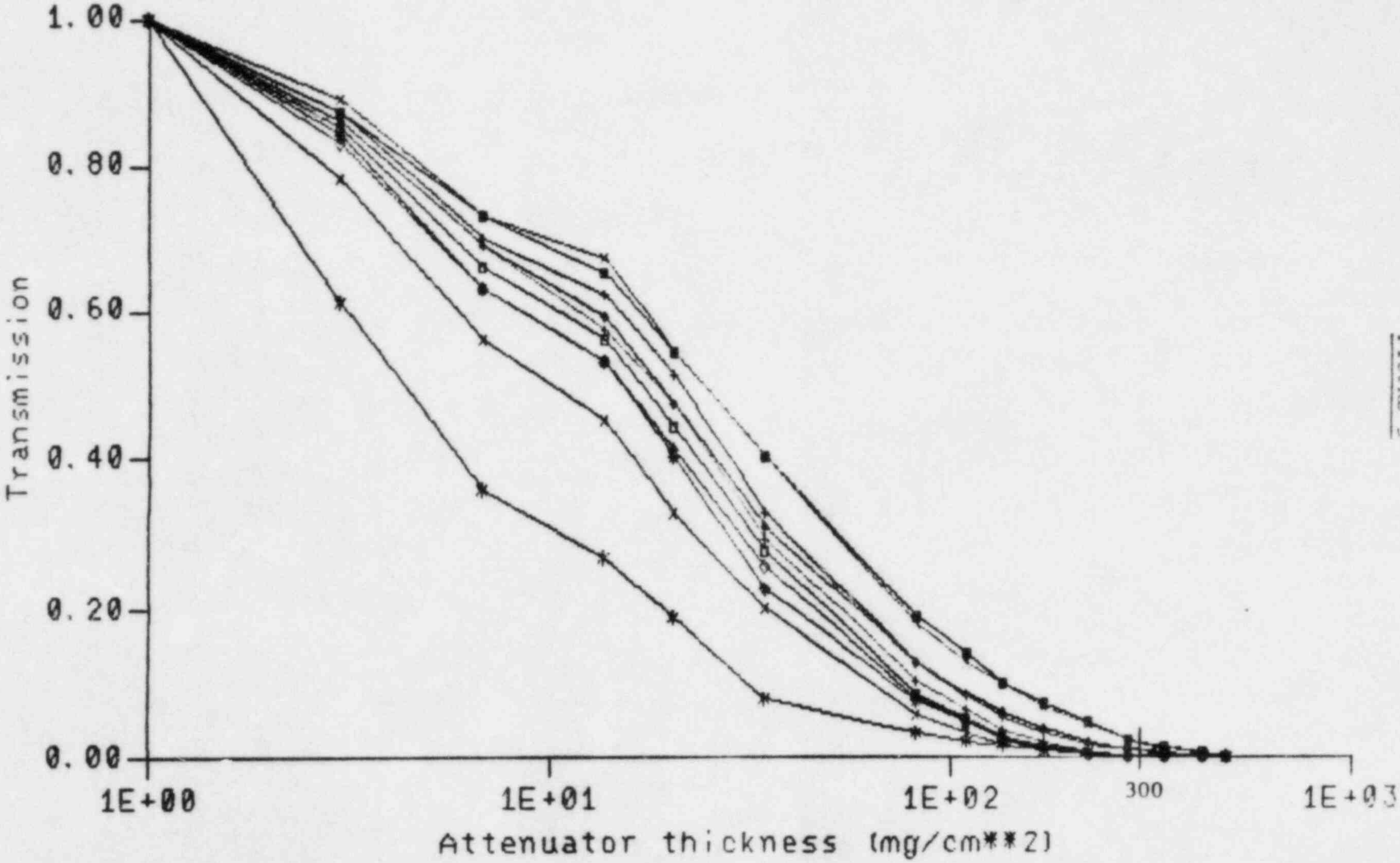
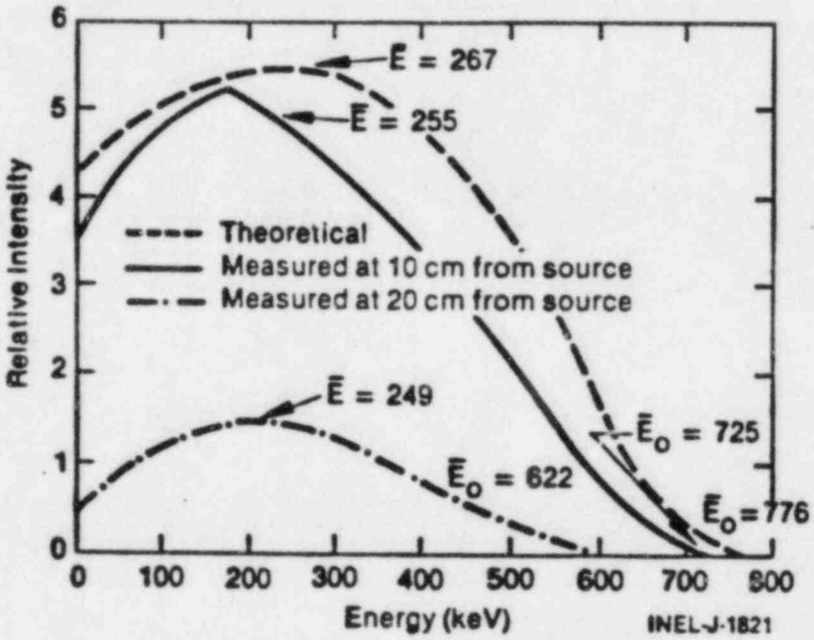


FIGURE 3

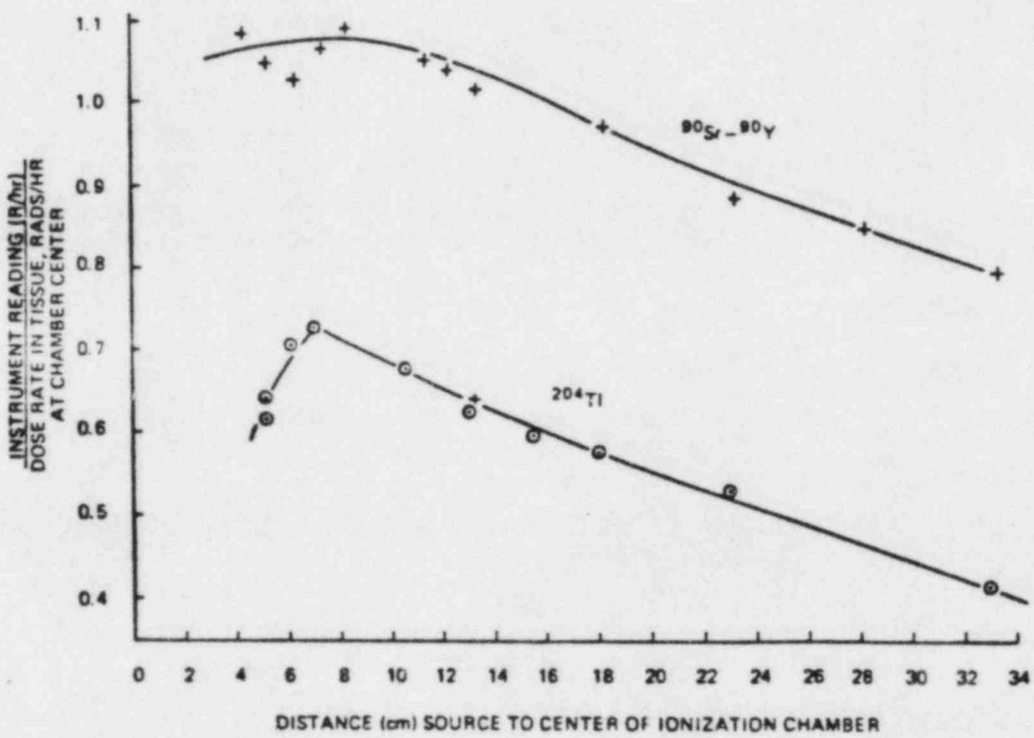
FIGURE 4



Comparison of measured-to-theoretical beta spectra for ^{204}TL

From Rich (Ri82) p. 20

FIGURE 5



TYPICAL BETA RESPONSE OF MODELS RO-2 AND RO-2A

From Eberline Instrument Corporation Product and Services Catalogue, July 1979, (Santa Fe, New Mexico).

TABLE 1

ISOTOPIC ANALYSIS OF SURRY SMEAR DATA
SUMMARY OF DATA

Unit 1 Smears	Range of Percent Composition	Average Composition
Co-58	0.2 - 44.5%	14.1%
Co-60	1.4 - 35.4%	13.2%
Mn-54	0.2 - 6.5%	1.8%
Cs-134	1.4 - 38.4%	26.7%
Cs-137	1.7 - 66.3%	41.9%
Cr-51	Only 1 Smear	-
Fe-59	Only 1 Smear	-

Unit 2 Smears	Range of Percent Composition	Average Composition
Co-58	11.9 - 32.9%	24.7%
Co-60	2.7 - 31.6%	15.1%
Mn-54	0.7 - 2.9%	1.7%
I-131	2.3 - 69.8%	19.0%
I-133	Only 1 Smear	-
Cs-134	7.9 - 21.4%	16.3%
Cs-137	7.2 - 29.4%	21.0%

TABLE 2

Sample #	Half Value Thickness (mg/cm²)	Beta Attenuation Coefficient (cm²/g)	E_{max} (MeV)	E_{ave} (MeV)
Unit 1				
1	10.56	65.6	0.407	0.128
2	18.39	37.7	0.587	0.194
3	16.77	41.3	0.553	0.181
4	15.38	45.1	0.522	0.178
5	17.05	40.7	0.559	0.183
Unit 2				
1	14.99	46.2	0.513	0.167
2	18.73	37.0	0.595	0.197
3	24.46	28.3	0.709	0.240
4	24.46	28.3	0.709	0.240
5	20.40	34.0	0.629	0.210

TABLE 3

Calibration Source	Calculated Values			Reference Values	
	E_{max}	E_{ave}		E_{max}	E_{ave}
Sr/Y-90	2.044	0.791	Y-90	2.27	0.936
			Sr-90	0.546	0.196
Co-60	0.281	0.084		0.319	0.095
Cs-137	0.604	0.200	β_1	1.18	0.390
			β_2	0.514	0.170

APPENDIX I

SWIPE AND SOURCE DATA

CONTAINMENT UNIT 1 RHR FLAT PUMP CASING SWIPE

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	829056	1	829056	2681988	2681880	21516.0	2660364
3.0	763816	1	763816	2101359	2101251	21511.7	2079739
6.8	667276	1	667276	1503088	1502980	21506.2	1481474
13.7	605266	1	605266	1221251	1221143	21496.3	1199646
20.4	512071	1	512071	893239	893131	21486.6	871645
34.6	375186	1	375186	545848	545740	21466.2	524274
82.7	154826	1	154826	177761	177653	21397.1	156256
110.4	105316	1	105316	115448	115340	21357.4	93983
135.8	70155	1	70155	74511	74403	21321.1	53082
171.5	48421	1	48421	50457	50349	21270.2	29079
221.8	32686	1	32686	33601	33493	21198.6	12295
277.5	26421	1	26421	27016	26908	21119.7	5788
342.0	25716	1	25716	26279	26171	21028.6	5143
425.7	23331	1	23331	23794	23686	20911.0	2775
491.5	22441	1	22441	22869	22761	20819.0	1942
547.7	22553	1	22553	22985	22877	20740.8	2136
619.5	21656	1	21656	22054	21946	20641.2	1305
687.3	21591	1	21591	21987	21879	20547.7	1331
857.9	20433	1	20433	20787	20679	20314.1	365
1220.5	19526	1	19526	19849	19741	19826.6	0
1604.2	19323	1	19323	19639	19531	19323.4	208

CONTAINMENT UNIT 1 A CUBICAL FLOOR DRAIN SWIPE

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	71042	1	71042	75512.5	75405.5	1157.00	74248.5
3.0	62026	1	62026	65406.8	65299.8	1156.72	64143.0
6.8	50033	1	50033	52209.8	52102.8	1156.36	50946.5
13.7	42363	1	42363	43913.2	43806.2	1155.72	42650.5
20.4	34919	1	34919	35965.6	35858.6	1155.09	34703.5
34.6	22856	1	22856	23299.8	23192.8	1153.77	22039.0
82.7	8861	1	8861	8926.9	8819.9	1149.29	7670.6
110.4	5956	1	5956	5985.7	5878.7	1146.71	4732.0
135.8	4026	1	4026	4039.6	3932.6	1144.36	2788.2
171.5	2841	1	2841	2847.7	2740.7	1141.06	1599.7
221.8	1753	1	1753	1755.6	1648.6	1136.42	512.1
277.5	1383	1	1383	1384.6	1277.6	1131.32	146.3
342.0	1571	1	1571	1573.1	1466.1	1125.43	340.6
425.7	1301	1	1301	1302.4	1195.4	1117.83	77.6
491.5	1231	1	1231	1232.3	1125.3	1111.90	13.4
547.7	1273	1	1273	1274.4	1167.4	1106.85	60.5
687.3	1193	1	1193	1194.2	1087.2	1094.42	0.0
960.3	1141	1	1141	1142.1	1035.1	1070.52	0.0
1220.5	1113	1	1113	1114.0	1007.0	1048.22	0.0
1604.2	1016	1	1016	1016.9	909.9	1016.18	0.0

CONTAINMENT UNIT 1 CUBICAL SWIPE #1

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	657051	1	657051	1452183	1452080	8630.00	1443450
3.0	603066	1	603066	1212327	1212224	8628.37	1203596
6.8	521722	1	521722	923023	922920	8626.32	914294
13.7	474109	1	474109	783769	783666	8622.58	775043
20.4	403191	1	403191	607209	607106	8618.95	598487
34.6	292111	1	292111	386097	385994	8611.27	377383
82.7	111851	1	111851	123348	123245	8585.30	114660
110.4	73983	1	73983	78844	78741	8570.37	70171
135.8	45401	1	45401	47186	47083	8556.71	38527
171.5	26733	1	26733	27342	27239	8537.55	18702
221.8	14171	1	14171	14340	14237	8510.63	5727
277.5	9710	1	9710	9789	9686	8480.91	1205
342.0	8986	1	8986	9054	8951	8446.62	504
425.7	8656	1	8656	8719	8616	8402.34	214
547.7	8733	1	8733	8797	8694	8338.21	356
687.3	8506	1	8506	8567	8464	8265.43	198
960.3	8413	1	8413	8472	8369	8124.93	244
1220.5	8156	1	8156	8212	8109	7993.25	116
1604.2	7803	1	7803	7854	7751	7802.94	0

CONTAINMENT UNIT 1 CUBICAL SWIPE #2

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	547731	1	547731	1007678	1007575	7254.00	1000321
3.0	500561	1	500561	858793	858690	7252.61	851437
6.8	427960	1	427960	665188	665085	7250.84	657834
13.7	385436	1	385436	567817	567714	7247.64	560466
20.4	324406	1	324406	444598	444495	7244.54	437250
34.6	230833	1	230833	285812	285709	7237.95	278471
82.7	87623	1	87623	94525	94422	7215.71	87206
110.4	56353	1	56353	59130	59027	7202.93	51824
135.8	35971	1	35971	37083	36980	7191.23	29788
171.5	21856	1	21856	22261	22158	7174.82	14984
221.8	11561	1	11561	11673	11570	7151.76	4419
277.5	8001	1	8001	8055	7952	7126.31	825
342.0	7823	1	7823	7874	7771	7096.95	674
425.7	7681	1	7681	7730	7627	7059.03	568
491.5	7491	1	7491	7538	7435	7029.37	406
547.7	7491	1	7491	7538	7435	7004.13	431
687.3	7560	1	7560	7608	7505	6941.83	563
960.3	6673	1	6673	6710	6607	6821.60	0
1220.5	6616	1	6616	6653	6550	6708.94	0
1604.2	6546	1	6546	6582	6479	6546.20	0

CONTAINMENT UNIT 1   CUBICAL SMEAR #3

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	1079116	1	1079116	10712246	10712139	38059.0	10674080
3.0	1014957	1	1014957	6581975	6581868	38051.9	6543816
6.8	914856	1	914856	3850080	3849973	38043.0	3811930
13.7	849056	1	849056	2903219	2903112	38026.7	2865085
20.4	752273	1	752273	2016246	2016139	38011.0	1978128
34.6	508381	1	508381	882071	881964	37977.6	843987
82.7	304336	1	304336	407746	407639	37864.7	369774
110.4	234330	1	234330	291193	291086	37799.8	253286
135.8	179566	1	179566	211164	211057	37740.4	173317
171.5	141371	1	141371	160250	160143	37657.1	122486
221.8	111375	1	111375	122770	122663	37540.0	85123
277.5	92266	1	92266	99951	99844	37410.8	62433
342.0	82713	1	82713	88836	88729	37261.8	51467
425.7	68749	1	68749	72927	72820	37069.2	35751
491.5	61122	1	61122	64402	64295	36918.5	27377
547.7	57316	1	57316	60191	60084	36790.3	23294
619.5	52210	1	52210	54585	54478	36627.2	17851
687.3	49921	1	49921	52088	51981	36473.8	15507
857.9	42481	1	42481	44040	43933	36090.6	7842
960.3	38363	1	38363	39630	39523	35862.6	3660
1084.5	37435	1	37435	38640	38533	35587.9	2945
1220.5	36503	1	36503	37648	37541	35289.6	2252
1372.8	35466	1	35466	36546	36439	34958.5	1481
1491.7	34433	1	34433	35450	35343	34702.1	641
1604.2	34461	1	34461	35480	35373	34461.3	912

CONTAINMENT UNIT 2 RECIRC SPRAY VALVE SWIPE

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	20000	1.09	18348.6	18633.5	18594.8	394.650	18200.1
3.0	20000	1.26	15873.0	16085.8	16047.0	394.566	15652.5
6.8	20000	1.56	12820.5	12959.0	12920.2	394.459	12525.8
13.7	20000	1.82	10989.0	11090.6	11051.8	394.266	10657.6
20.4	20000	2.24	8928.6	8995.5	8956.8	394.078	8562.7
34.6	10000	1.66	6024.1	6054.5	6015.7	393.680	5622.1
55.0	10000	2.43	4115.2	4129.4	4090.6	393.110	3697.5
82.7	10000	3.69	2710.0	2716.2	2677.4	392.336	2285.1
110.4	10000	5.04	1984.1	1987.4	1948.7	391.564	1557.1
135.8	4000	2.60	1538.5	1540.4	1501.7	390.858	1110.8
171.5	4000	3.48	1149.4	1150.5	1111.8	389.867	721.9
221.8	4000	4.77	838.6	839.2	800.4	388.475	411.9
277.5	2000	3.05	655.7	656.1	617.3	386.940	230.4
342.0	2000	3.59	557.1	557.4	518.6	385.169	133.4
425.7	2000	4.48	446.4	446.6	407.8	382.884	25.0
619.5	2000	5.22	383.1	383.3	344.5	377.644	0.0
960.3	1000	2.76	362.3	362.4	323.7	368.604	0.0
1604.2	2000	5.68	352.1	352.2	313.5	352.109	0.0

CONTAINMENT UNIT 2 SEAL TABLE SWIPE

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	10000	0.57	17543.9	17804.2	17767.6	443.880	17323.7
3.0	10000	0.67	14925.4	15113.4	15076.8	443.785	14633.0
6.8	10000	0.88	11363.6	11472.3	11435.7	443.665	10992.0
13.7	10000	1.05	9523.8	9600.0	9563.4	443.448	9120.0
16.7	10000	1.18	8474.6	8534.9	8498.3	443.353	8054.9
20.4	10000	1.36	7352.9	7398.3	7361.7	443.237	6918.4
34.6	10000	2.21	4524.9	4542.0	4505.4	442.789	4062.6
55.0	10000	3.47	2881.8	2888.8	2852.2	442.148	2410.0
82.7	10000	5.53	1808.3	1811.0	1774.4	441.278	1333.2
110.4	4000	2.98	1342.3	1343.8	1307.2	440.409	866.8
135.8	4000	4.14	966.2	967.0	930.4	439.615	490.7
171.5	4000	5.17	773.7	774.2	737.6	438.500	299.1
221.8	2000	3.21	623.1	623.4	586.8	436.935	149.8
277.5	2000	3.69	542.0	542.3	505.7	435.208	70.4
342.0	2000	3.77	530.5	530.7	494.1	433.217	60.9
425.7	2000	4.08	490.2	490.4	453.8	430.646	23.2
619.5	2000	4.36	458.7	458.9	422.3	424.753	0.0
960.3	2000	4.73	422.8	423.0	386.4	414.585	0.0
1604.2	2000	5.05	396.0	396.2	359.6	396.032	0.0

CONTAINMENT UNIT 2   A CUBICAL HOT LEG ROOT VALVE SWIPE

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	40000	1.34	29850.7	30612.2	30569.6	457.470	30112.2
3.0	40000	1.53	26143.8	26726.1	26683.5	457.372	26226.1
6.8	40000	1.82	21978.0	22388.1	22345.5	457.249	21888.2
13.7	40000	2.03	19704.4	20033.4	19990.8	457.025	19533.8
20.4	20000	1.21	16528.9	16759.8	16717.2	456.807	16260.4
34.6	20000	1.62	12345.7	12474.0	12431.4	456.346	11975.1
82.7	20000	3.25	6153.8	6185.6	6143.0	454.788	5688.2
110.4	10000	2.11	4739.3	4758.1	4715.5	453.893	4261.6
135.8	10000	2.79	3584.2	3595.0	3552.4	453.074	3099.3
171.5	10000	3.67	2724.8	2731.0	2688.4	451.926	2236.5
221.8	10000	4.91	2036.7	2040.1	1997.5	450.312	1547.2
277.5	4000	3.06	1307.2	1308.6	1266.0	448.532	817.5
342.0	4000	3.99	1002.5	1003.3	960.7	446.480	514.3
425.7	4000	6.08	657.9	658.3	615.7	443.831	171.8
491.5	2000	3.69	542.0	542.3	499.7	441.760	57.9
547.7	2000	4.16	480.8	481.0	438.4	439.998	0.0
619.5	2000	4.48	446.4	446.6	404.0	437.757	0.0
687.3	2000	4.55	439.6	439.7	397.1	435.652	0.0
1604.2	2000	4.90	408.2	408.3	365.7	408.157	0.0

CONTAINMENT UNIT 2   A CUBICAL DRAIN SWIPE

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	40000	0.20	200000	240000	239954	3163.84	236790
3.0	40000	0.22	181818	214286	214239	3163.17	211076
6.8	40000	0.26	153846	176471	176424	3162.31	173262
13.7	40000	0.28	142857	162162	162116	3160.76	158955
20.4	40000	0.34	117647	130435	130388	3159.25	127229
34.6	40000	0.44	90909	98361	98314	3156.07	95158
82.7	40000	0.90	44444	46154	46107	3145.29	42962
110.4	40000	1.18	33898	34884	34837	3139.10	31698
135.8	40000	1.58	25316	25862	25816	3133.44	22682
171.5	40000	2.12	18868	19169	19123	3125.50	15997
221.8	20000	1.44	13889	14052	14005	3114.34	10891
277.5	20000	2.19	9132	9202	9156	3102.03	6054
342.0	10000	1.48	6757	6795	6749	3087.84	3661
425.7	10000	2.20	4545	4563	4516	3069.51	1447
491.5	10000	2.65	3774	3785	3739	3055.19	684
547.7	10000	2.93	3413	3423	3376	3043.00	333
619.5	10000	2.95	3390	3399	3353	3027.51	326
687.3	10000	3.26	3067	3075	3029	3012.95	16
857.9	10000	3.30	3030	3038	2992	2976.62	15
960.3	10000	3.34	2994	3002	2955	2955.03	0
1084.5	10000	3.42	2924	2931	2885	2929.05	0
1220.5	10000	3.39	2950	2957	2911	2900.86	10
1372.8	10000	3.33	3003	3011	2964	2869.62	95
1491.7	10000	3.65	2740	2746	2700	2845.47	0
1604.2	10000	3.54	2825	2832	2785	2822.80	0

CONTAINMENT UNIT 2   C CUBICAL FLOOR SWIPE

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	20000	1.30	15384.6	15584.4	15550.8	271.130	15279.7
3.0	20000	1.48	13513.5	13667.4	13633.8	271.072	13362.8
6.8	20000	1.84	10869.6	10968.9	10935.3	270.999	10664.3
13.7	10000	1.03	9708.7	9787.9	9754.3	270.866	9483.5
20.4	10000	1.25	8000.0	8053.7	8020.1	270.737	7749.4
34.6	10000	1.86	5376.3	5400.5	5366.9	270.464	5096.5
55.0	10000	2.83	3533.6	3544.0	3510.4	270.072	3240.3
82.7	10000	4.41	2267.6	2271.9	2238.3	269.540	1968.7
110.4	4000	2.53	1581.0	1583.1	1549.5	269.010	1280.5
135.8	4000	3.42	1169.6	1170.7	1137.1	268.525	868.6
171.5	4000	4.77	838.6	839.2	805.6	267.844	537.7
221.8	2000	3.39	590.0	590.3	556.7	266.888	289.8
277.5	2000	4.37	457.7	457.8	424.2	265.833	158.4
342.0	1000	2.49	401.6	401.7	368.1	264.617	103.5
425.7	1000	2.99	334.4	334.5	300.9	263.047	37.9
491.5	1000	3.24	308.6	308.7	275.1	261.819	13.3
547.7	2000	6.36	314.5	314.5	280.9	260.775	20.2
1604.2	2000	7.26	275.5	275.5	241.9	241.904	0.0

CESIUM 137 SOURCE DATA

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	134663	1.00	134663	151685	151659	837.000	150822
3.0	117949	1.00	117949	130806	130780	836.821	129943
6.8	96745	1.00	96745	105229	105202	836.595	104366
9.8	86747	1.00	86747	93507	93480	836.417	92644
13.7	84095	1.00	84095	90432	90406	836.185	89570
16.7	76743	1.00	76743	81986	81960	836.007	81124
20.4	68862	1.00	68862	73054	73028	835.787	72192
34.6	46737	1.00	46737	48631	48605	834.943	47770
55.0	28961	1.00	28961	29677	29651	833.733	28817
82.7	16799	1.00	16799	17038	17011	832.093	16179
110.4	11109	1.00	11109	11213	11187	830.456	10356
135.8	10000	1.46	6849	6889	6862	828.957	6033
171.5	10000	2.55	3922	3934	3908	826.856	3081
191.9	4000	1.58	2532	2537	2511	825.657	1685
221.8	10000	5.83	1715	1718	1691	823.904	868
277.5	4000	4.22	948	949	922	820.648	102
342.0	2000	2.19	913	914	888	816.893	71
425.7	2000	2.27	881	882	855	812.046	43
491.5	2000	2.41	830	830	804	808.256	0
547.7	2000	2.31	866	866	840	805.032	35
960.0	2000	2.38	840	841	815	781.776	33
1604.2	10000	12.94	773	773	747	746.776	0

COBALT 60 SOURCE DATA

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	61300	1.00	61300.0	64600.0	64555.7	2277.70	62278.0
3.0	45769	1.00	45769.0	47583.9	47539.6	2277.33	45262.3
6.8	28773	1.00	28773.0	29479.9	29435.6	2276.86	27158.7
9.8	23036	1.00	23036.0	23486.9	23442.6	2276.49	21166.1
13.7	21240	1.00	21240.0	21622.7	21578.4	2276.01	19302.4
16.7	17374	1.00	17374.0	17629.2	17584.9	2275.64	15309.3
20.4	12953	1.00	12953.0	13094.3	13050.0	2275.18	10774.9
26.8	10000	1.26	7936.5	7989.3	7945.0	2274.39	5670.7
34.6	10000	1.64	6097.6	6128.7	6084.4	2273.42	3811.0
55.0	10000	2.71	3690.0	3701.4	3657.1	2270.91	1386.2
82.7	10000	3.09	3236.2	3245.0	3200.7	2267.49	933.2
110.4	10000	3.37	2967.4	2974.7	2930.4	2264.09	666.3
135.8	10000	3.70	2702.7	2708.8	2664.5	2260.97	403.5
171.5	10000	3.88	2577.3	2582.9	2538.6	2256.59	282.0
221.8	4000	1.64	2439.0	2444.0	2399.7	2250.43	149.3
277.5	4000	1.67	2395.2	2400.0	2355.7	2243.64	112.1
342.0	10000	4.27	2341.9	2346.5	2302.2	2235.79	66.4
547.7	4000	1.71	2339.2	2343.7	2299.4	2210	88.5
687.3	4000	1.77	2259.9	2264.2	2219.9	219[illegible]6	25.6
1220.5	4000	1.85	2162.2	2166.1	2121.8	2131.64	0.0
1604.2	10000	4.79	2087.7	2091.3	2047.0	2087.69	0.0

STRONTIUM/YTTRIUM-90 SOURCE DATA

AL ABSORBER THICKNESS MG/CM2	GROSS CTS	TIME (MIN)	GROSS CPM	DEADTIME CORRECTED (CPM)	BACKROUND CORRECTED (CPM)	PHOTON (CPM)	BETA RAY COUNTRATE (CPM)
0.0	105375	1.00	105375	115519	115473	540.900	114932
3.0	102617	1.00	102617	112213	112166	540.785	111625
6.8	97730	1.00	97730	106395	106348	540.639	105808
9.8	97358	1.00	97358	105954	105908	540.523	105367
13.7	94366	1.00	94366	102420	102374	540.373	101833
20.4	90062	1.00	90062	97370	97323	540.116	96783
26.8	85576	1.00	85576	92147	92101	539.870	91561
34.6	81892	1.00	81892	87890	87843	539.571	87304
55.0	73194	1.00	73194	77948	77902	538.789	77363
82.7	64920	1.00	64920	68633	68587	537.729	68049
110.4	58051	1.00	58051	61002	60956	536.671	60419
135.8	50928	1.00	50928	53185	53139	535.703	52603
171.5	43728	1.00	43728	45382	45335	534.345	44801
221.8	35953	1.00	35953	37063	37017	532.437	36485
277.5	26948	1.00	26948	27567	27521	530.333	26990
342.0	20390	1.00	20390	20742	20696	527.906	20168
376.6	16449	1.00	16449	16678	16631	526.609	16104
425.7	12312	1.00	12312	12440	12393	524.774	11868
491.5	7283	1.00	7283	7327	7281	522.324	6759
547.7	10000	1.66	6024	6054	6008	520.241	5488
619.5	10000	2.82	3546	3557	3510	517.592	2993
687.3	10000	4.22	2370	2374	2328	515.103	1813
857.9	4000	4.60	870	870	824	508.893	315
960.3	2000	3.15	635	635	589	505.201	84
1084.5	2000	3.59	557	557	511	500.760	10
1220.5	2000	3.61	554	554	508	495.941	12
1604.2	10000	20.72	483	483	436	482.594	0

APPENDIX II

BACKGROUND INFORMATION

BACKGROUND INFORMATION

The objective of the data analysis was to determine the "range" and the maximum and average energy of the beta particles emitted from the sources. Since electrons are thought to lose energy more or less continuously as they pass through matter, if given the electron's maximum energy, it should be possible to calculate a definite range. This range is known as the mean range and is denoted in Figure 1 of this Appendix as R_o. However, the energy loss by an electron is only continuous to a first approximation. In fact there are statistical fluctuations causing the distribution of energy loss to be Gaussian. Therefore, the range distribution would also be Gaussian as illustrated by the shape of the curve in Figure 1. The "extrapolated" range (R_e) is the distance that is most often referred to in the literature and in this report as the "absolute" or "maximum" range of a beta particle. "Range straggling" is the term used to describe the difference between R_e and the tail of the range curve and is the direct result of this Gaussion range distribution. The fraction of betas involved in straggling will vary as a function of R_o and the atomic number of the material the beta passes through. A more complete mathematical treatment of range straggling can be found in Kase (K78).

For single nuclides Feather's analysis is a useful method of determining beta particle range and maximum energy. This method compares the attenuation of the sample in aluminum to the attenuation of a known standard. However, the choice of an appropriate standard is difficult since both radionuclides need to have similar beta spectral distribution (i.e., both must be either allowed or forbidden transitions). In nuclear power stations the radionuclide mixtures consist of nuclides which decay by either allowed or forbidden transitions, which makes the application of Feather's method inappropriate for the determination of maximum energy or range of the beta particles. However, Feather's method of recording the beta count rate through a series of aluminum attenuators was performed to generate a series of transmission curves. These curves were used to document the similarity of the beta spectra at the station regardless of the differences in radionuclide composition ratios.

An alternate method of determining the maximum energy or range of a beta particle takes advantage of the fact that to a first approximation beta absorption is exponential. Therefore, an apparent beta mass absorption coefficient can be determined as discussed in the body of the report. From this mass absorption coefficient a maximum beta energy can be calculated using the power function relationship between the maximum beta energy and the apparent mass absorption coefficient.

$$E_m = kn^{-a}$$

where:

E_m = The maximum beta energy.

k & a = Constants.

n = The apparent mass absorption coefficient.

Baltakmens (Ba77) has experimentally calculated values for the constants k and a utilizing data from 21 beta emitting radionuclides including cesium-137, cobalt-60, iodine-131, strontium-90, yttrium-90, and strontium-89. His least squares "best fit" to the data results in the following equations:

$$E_m = 6.47n^{-0.661}$$

$$E_{ave} = 2.90n^{-0.745}$$

where:

E_m = The maximum beta energy (MeV).

E_{ave} = The average beta energy (MeV).

n = The apparent mass absorption coefficient (cm^2/g).

However, these equations for absorption in aluminum will yield slightly different results from the theoretial values calculated using Loevinger's emperical equation for the apparent mass absorption coefficient (ν) for tissue as a function of beta energy.

$$\nu = \frac{18.6}{(E_m - 0.036)^{1.37}} [2 - (E_{ave}/E^*_{ave})]$$

where:

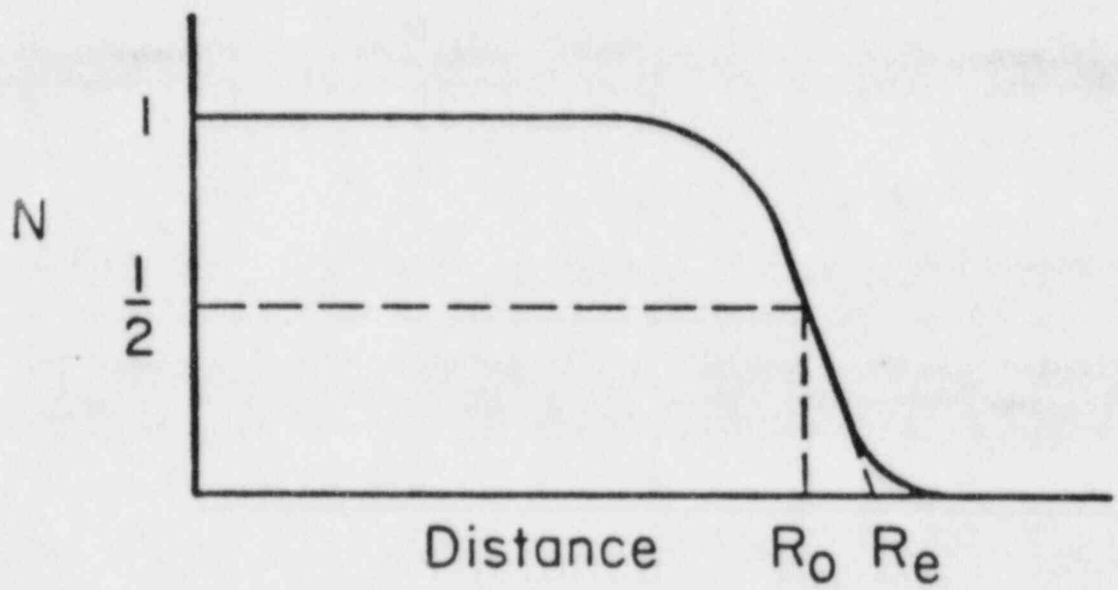
E_m = The maximum beta energy.

(E_{ave}/E^*_{ave}) = The forbidden spectra correction factor, generally considered to be approximately 1.

ν = Loevingers apparent absorption coefficient.

For a beta energy of 631keV, ν has a value of 37.88 cm^2/g which corresponds to the 34.76 cm^2/g absorbtion coefficient calculated from Surry Unit 2 data. If the Z/A correction factor taken from Morgan (Mo73) for tissue and aluminum is applied to the experimental value there would be agreement to within 6%, which denotes "good" agreement.

FIGURE 1



From Kase (K78) page 65

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