ATTACHMENT A

MAINE YANKEE ENGINEERING	CALCULATION COVER SHEET	CALC NO. 004-04(MY) REV. NO. 0 PAGE 1 OF ~~8~~ 29 (29 Pages total) TECH. FILE NO. 17.12 DR1-15-1

TITLE: Exploranium GR-130 Minimum Detectable Concentration (MDC) of CS-137 and Co-60 in Surface Soil

SOURCE DOCUMENT: LTP, Rev. 3 ID NO. N/A
(i.e. EDCR, TE, PROC, WO, SDCM, SPEC)

PLANT SYSTEM: N/A SYSTEM CODE: N/A

PLANT COMPONENT: N/A I.D. NO. N/A SAFETY CLASS N/A

TYPE OF CALC: ☐ Stress ☐ Thermal ☐ Hydraulic ☐ Capacity X Other Radiological-FSS

DISCIPLINE: ☐ Electrical ☐ I & C ☐ Mechanical ☐ Civil X Other Rad Engineering-FSS

PURPOSE AND METHODOLOGY: To develop a means to utilize the quantitative potential of the GR-130 to investigate scan alarms to determine whether the alarm is related to plant derived activity in surface soils (to a depth of 15cm). In order to do this, the MDC for a variety of counting intervals must be determined. This calculation documents the soil MDC associated with the site's most significant gamma-emitting isotopes (Cs-137 and Co-60). successful

SOURCES OF DATA:
Experiments of 09-04-04 and 10-06-04 (Att. 1)

SOURCES OF FORMULAE AND REFERENCES:
1. GR-130 miniSPEC User Manual ReV 14 January 30, 2001
2. Maine Yankee DI-164 Operation of the Exploranium GR-130.
3. G. F. Knoll, Radiation Detection and Measurement, Second Edition, Wiley, New York (1989)
4. NUREG-1507, USNRC, December 1997
5. D.C. Kocher, Radioactive Decay Data Tables, ORNL, US Department of Energy, 1981.

Preliminary ☐ Final Calc X Supersedes Calc NoRev. No. 0

Other Calculations Requiring Revision none

Prepared by: D. B. Randall, Jr. Date: 12-29-04

Reviewed by: W S Cooper Date: 1/17/05

Senior Engineer (or above): W. Henries Date: 1/18/05

The attached calculation shall include (as a minimum): (1) appropriate design input values, (2) assumptions, with justifications, (3) computations with explanatory text, figures and tables, and (4) summary of results and conclusions.

DR 1-17-05

Executive Summary

The Exploranium GR-130 MiniSPEC (GR-130) is a portable, battery powered, hand held instrument with an internal 4.5 cubic inch NaI(Tl) gamma scintillator probe. It uses a 256-channel pulse height analyzer that provides nuclide identification capabilities from a limited nuclide identification suite. The detector can be used to evaluate Cesium–137 and Co-60 concentrations in soil media.

Testing was performed to determine the Minimum Detectable Concentration (MDC) of Cs-137 and Co-60 in surface soil. These MDCs were calculated for spectra collected in 10, 20 and 30-minute count intervals by downloading the data, and evaluating it using an Excel spreadsheet (Attachment 1).

Inputs

1. Experiment data of 09-04-04, and subsequent analyses to support the CS-137 soil MDC (Attachment 1)
2. Experiment data of 10-06-04 and subsequent analyses to develop the Co-60 in soil MDC (Attachment 1)
3. Source Certificates (Attachment 2)
4. DI-164, Rev B

Assumptions

1. The MDCs determined apply to downloaded data that has been reviewed by an analyst. This should be done in accordance with the method described on page 16 of Attachment 1. (The instrument based quantitative analysis output may be adequate, but the associated algorithms are not documented in the user's manual, and the output was not sufficiently tested by this exercise to be considered reliable for the purposes of this calculation.)

2. Background spectra (channel by channel) will not be subtracted when data is analyzed. (The instruments amplifier has exhibited some drift over typical count intervals, making background subtraction inappropriate[1]).

3. Surface soil is defined as the top 15 cm of the soil media being measured.

4. The barrel geometry as described on the source certificate, (Attachment 2) is appropriately representative of contaminated soils. (Smaller surface area geometries would have higher MDCs)

[1] It is considered inappropriate to subtract one spectrum from another directly. However, the subtracting of a background result from a sample result may be appropriate, based on professional judgment.

5. The GR-130 will be used in the horizontal position (display facing up), with the internal probe located above the center on the area being analyzed. DR 1-17-05

Computation

The Cs-137 MDC was determined by direct measurement from a homogenous, NIST traceable soil standard. The MDC for Co-60 was then estimated, based on the Cesium MDCs. This was done by comparing the relative gamma efficiencies for both cobalt and cesium NIST traceable button sources counted separately for 20 minutes in identical geometries. Additional computational details are provided below.

CS-137 MDC determination

Testing was performed to determine the Minimum Detectable Concentration of Cs-137 in soil for downloaded spectra collected in 10, 20 and 30-minute count intervals. The data was then evaluated to determine the instrument's MDC by downloading the data, and performing an evaluation using an Excel spreadsheet (Attachment 1, pp. 4-15). The review of this calculation has verified the accuracy of the spreadsheet analyses.

GR-130 spectra were collected first on a blank. This was done for 600, 1200 and 1800 second count intervals. These blank counts were used to determine whether any ambient background Cs-137 could be detected. No activity was detected in the blanks. (Had any been detected, it would have been accounted for as necessary.) The soil source was also counted for 600, 1200 and 1800 second counts using an identical geometry. The source used was a NIST traceable homogenized soil source in a volumetric geometry with a nominal specific activity of 3.0 pCi/g Cs-137 (the source certificate is included in Attachment 2). The detector was placed with its center of detection over the source center, oriented such that it sat on the horizontal with the display facing up.

Table 1 is a summary of the source activity calculation

Table 1
Cs-137 Soil Source Information

Source No.	62994-60
Activity (dps)	6.147E+03
Sand Weight	56.95 kg
Calculated Activity (pCi/g) $= 6.147E03(dps) \times \frac{60dpm}{dps} \times \frac{1pCi}{2.22dpm} \times \frac{1}{56.95kg} \times \frac{1kg}{1{,}000g}$	2.92
Assay Date	01-29-02
Experiment date	09-04-04
Activity on Experiment date (pCi/g) $A = A_0 e^{-\lambda t}$, Where A_0 = initial activity, $\lambda = (\ln(2)/T_{1/2})$, $T_{1/2}$= 30.17y (Ref 5) t = elapsed time =2.6y	2.75

Analysis

The background data (Att. 1) was reviewed to determine whether detectable levels of ambient Cs-137 background were present at the test location. No discernable Cs-137 peaks were present in background counts as observed by the GR-130 analyses, or by the analyst's review of the downloaded data.

The GR-130 screen output results indicated that Cs-137 was present in each of the runs conducted with the source present. This was also the case for the analyzed data. The Cs-137 soil MDC was determined by subtracting the Compton continuum from the 662 keV photopeak, in accordance with the method described in Knoll (Reference 3). Photo-peak Regions Of Interest (ROI) are determined by the analyst, as is indicated by the hatch marks on the spreadsheet data of Att.1. As stipulated in the Assumptions, the MDC result cited is valid only for situations where the data is downloaded, and evaluated by a trained analyst, since the algorithm used by the GR-130 is not known. However, GR-130 screen results do compare well with the analyses performed and are presented for informational purposes. The experimental results are summarized in Table 2. The supporting data is located in Att. 1.

Table 2
CS-137 MDC Experimental Results

Spectrum. #	16	17	18
Count Time (s)	600	1200	1800
Calculated values (from analyses of downloaded data)			
Cs-137ROI Gross (counts)	2,192	5,102	7119
Cs-137 BKGD/Ch (counts/channel)	143	299	414
Cs-137 Bkg. Integral (counts)	1,573	3887	4968
Cs-137 Net counts	619	1215	2151
Full Width at Half the Maximum (FWHM) (channels, estimated)	5.5	5.5	8.0
Efficiency (counts/pCi/g)	225	442	782
Efficiency (cpm/pCi/g)	22.509	22.091	26.073
Cs-137 MDC (pCi/g) (Ref 4) $MDC = \frac{3+4.65\sqrt{background(counts)}}{Efficency(counts/pCi/g)}$	**0.833**	**0.663**	**0.423**
Reported Results (from GR-130 instrument screen output)			
Cs-137 Gross (counts)	N/A	N/A	N/A
Cs-137 BKGD/Ch (counts/channel)	N/A	N/A	N/A
Cs-137 Bkg. Integral (counts)	N/A	N/A	N/A
Cs-137 detected (Yes/No)	Yes	Yes	Yes
Cs-137 Net counts	675	1,467	2,376
FWHM (GR-130)	5.2	6.0	5.7
Efficiency (counts/pCi/g)	245.5	533.5	864.0

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Efficiency (cpm/pCi/g)	24.55	26.7	28.8
Time weighted average Efficiency (cpm/pCi/g) $Eff_{tot} = \frac{Eff_{600}*600+Eff_{1200}*1200+Eff_{1800}*1800}{3600}$	24.15		
Cs-137 MDC (pCi/g)	N/A	N/A	N/A
Variance (Calculated vs. GR-130) = (Eff.-GR-130eff)/24.15			
Efficiency Variance (Calculated vs. GR-130)	-8.45%	-19.08%	-11.29%

Co-60 MDC Determination

Ideally, a homogeneous Co-60 soil source would be used to determine the instrument's MDC, as was done for Cs-137. Since such a source was unavailable the Cobalt MDC was conservatively estimated. First, the ratio of Cobalt-60 efficiency to Cesium-137 efficiency for a point source was determined. This ratio was then multiplied by the Cs-137 soil MDC to determine the Co-60 MDC.

The method described is conservative since the lower energy (662 keV) Cs-137 direct[2] gammas are more attenuated when homogeneously mixed into a soil matrix than the higher energy (1173 and 1332 keV) emissions for Co-60.

To determine the point source efficiency ratio, two NIST traceable button sources of 1 μCi nominal activity were selected and counted in a uniform geometry, with the source centered at 12 inches from the face of the detector. Source information is included in Table 3. The analysis results determining the Co-60 MDC are included as Table 4. The 1332 keV cobalt line was selected for analysis due to the fact that unlike the 1173 line (the only alternative), its background is less affected by the scattered photons from more energetic emissions originating from the source itself.

A background run was performed prior to doing the individual source counts. No discernable source related photo-peaks were present in background counts as observed by the GR-130 analyses, or by an analyst's review of the downloaded data.

[2] In this context, direct gamma means those gammas that emanate out of the soil matrix, with no interactions with matter within the source matrix.

Table 3
Cs-137 and Cobalt-60 button Source Information

Isotope	Cs-137	Co-60
Half life (years) (Ref.5)	30.17	5.271
Source No.	93CS2502228	59436A-60
Activity (μCi)	0.923	1.036
Geometry	Button	Button
Assay Date	08-12-1993	04-06-2000
Experiment date	10-06-2004	10-06-2004
Activity on Experiment date (μCi) $A = A_0 e^{-\lambda t}$	0.713	0.573
Gamma Yield (Ref.5)	85 %	100 %
4 Pi Gamma emission rate (gps)	2.24E4	2.12E4

Table 4
Cs-137 and Cobalt-60 button Source Information

Spectrum #	20 (Att.1, pp.4-14)	21 (Att.1, pp.4-14)
Count Time (s)	1200	1200
Isotope	Cs-137	Co-60
Calculated values (from analyses of downloaded data)		
Gross (counts) in peak ROI	8906	3456
BKGD/Ch (counts/channel) in ROI	137.00	65.00
Bkg. Integral (counts) in ROI	2466	1235
Net counts	6440	2221
FWHM (channels, estimated)	8	10
Efficiency (net counts/gps) = (net counts/ 4pi emmison rate)	0.288	0.105
Efficiency Ratio (Co-60 counts/gps per Cs-137 counts/gps)		0.364
Co-60 Estimated Efficiency CPM/pCi/g (0.364 x Efficiency_{Cs})		8.84

Estimated Co-60 MDC (pCi/g) [$MDC_{Cobalt} = MDC_{Cesium}$ x Efficiency Ratio (0.364)]			
Count time	**600 s**	**1,200 s**	**1,800 s**
Co-60 MDC (pCi/g)	**2.29**	**1.82**	**1.16**

Conclusion

The GR-130's MDC for cesium-137 and cobalt-60 in soil have been established as shown by the values listed in Tables 2 and 4. The GR-130 can easily detect CS-137 activity at or below the soil DCGls (typically 2.39 pCi/g). The MDC values for Co-60 are typically greater than the DCGLs (typically 0.86 pCi/g) for the nominal count times used. Where quantitative assessment is required, it is recommended that the data be downloaded as to permit analytical evaluation. Calibration factors may be determined from the efficiency values provided.

References

1. GR-130 miniSPEC user manual –REV 14 (January 30, 2001).
2. DI-164 Operation of the Exploranium GR-130.
3. G. F. Knoll, Radiation Detection and Measurement, Second Edition, Wiley, New York (1989), p. 323.
4. NUREG-1507 "Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions", Washington, D.C., Nuclear Regulatory Commission. December 1997.
5. D.C. Kocher, Radioactive Decay Data Tables, Office of Scientific and Technical Information, Oak Ridge National Laboratory, US Department of Energy, 1981.

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Att 1.	17 pages
Att 2.	4 pages
Total Pages	29

Attachment 1

Experimental Data & Equations

GR-130 Data Page

Item/Area Surveyed:
Sand 1/4 Drum / Cs-137 Sand Source 3pci/gram 1/4 Drum

Reason for Survey:
JFS

Survey Date:	9/9/04
Time:	0630

Survey Team	
Sarah Hickey	
Steve White	

Instrument	Instrument S/N	Cal Due	Detector	Detector S/N	Cal Due
GR-130	9955	~~12/09/03~~ 9/1/04	N/A	N/A	N/A
		12/19/04			
		N/A			

STABILIZATION

Time	OK? (Y/N)	Peak Ch	FWHM %	Gain
0720	Y	110.0	7.1	120
0756	Y	110.1	7.0	119
0823	Y	109.9	7.0	119
1003	Y	110.5	7.0	121
1019	Y	110.2	6.9	123
1047	Y	110.2	6.8	123

BACKGROUND

Count Time	Peak kev	ID	Peak kev	ID	Peak kev	ID
		N				
			A			

Survey Location	Count Time (min)	Peak keV	ID	Peak keV	ID	Peak keV	ID	Comments
Sand Spec. #13	10	94	N.I.					
Sand Spec. #14	20	92	N.I.					
Sand Spec. #15	30	89	N.I.					
Cs-137 Sand Source Spec. #16	10	92	N.I.	658	Cs-137	1493	K-40	
Cs-137 Sand Source Spec. #17	20	93	N.I.	659	Cs-137			
Cs-137 Sand Source Spec. #18	30	92	N.I.	659	Cs-137			

Comments

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GR-130 Data Page

Item/Area Surveyed:
2 Button Sources + Bkg for 20min (12") dist

Reason for Survey:
OFS

Survey Date:	10-6-04
Time:	14:45

Survey Team	
Bruce Long	
Paul MacDonald	

Instrument	Instrument S/N	Cal Due	Detector	Detector S/N	Cal Due
GR-130	9955	~~12/09/03~~ 12-17-04 (DR 10-6-04)	N/A	N/A	N/A

STABILIZATION

Time	OK? (Y/N)	Peak Ch	FWHM %	Gain
14:45	Y	109.2	6.9	122

BACKGROUND

Count Time	Peak kev N/A	ID	Peak kev	ID	Peak kev	ID
1200						

Spectrum	Survey Location	Count Time ~~(min)~~ SEC	Peak keV	ID	Peak keV	ID	Peak keV	ID	Comments
	Trailer (FSS North end)	1200							#19 Background
20	TRLR (FSS NORTH END)	1200							DIST-12" CS-137
21	TRLR (FSS NORTH END)	1200							DIST-12" CO-60

ID list

Comments
Probably

Techfile 19.20.8.3

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
4	Time (s)	600	1200	1800	1200	1200	600	1200	1800	1200
5	1	9	18	27	18	18	9	18	27	18
6	2	23	52	75	36	36	25	46	63	20
7	3	504	1014	1557	734	702	439	950	1401	500
8	4	655	1280	1902	1230	910	553	1122	1701	714
9	5	776	1600	2424	1810	1254	703	1426	2112	920
10	6	828	1638	2454	1384	1276	768	1518	2196	850
11	7	897	1796	2622	1424	1404	792	1582	2439	1018
12	8	1058	1992	2937	1676	1688	917	1910	2868	1326
13	9	1320	2478	3600	2100	2012	1118	2296	3450	1656
14	10	1618	3088	4578	2544	2530	1398	2942	4530	2066
15	11	1952	3932	5754	2950	2922	1793	3698	5562	2484
16	12	2562	4818	7329	3404	3382	2109	4438	6885	2804
17	13	2911	5682	8568	3730	3620	2542	5310	8007	3270
18	14	2860	5726	8628	3822	3744	2612	5376	8052	3384
19	15	2955	5752	8721	3864	3752	2612	5310	7953	3360
20	16	2887	5856	8661	3804	3888	2742	5312	7920	3472
21	17	2853	5604	8418	3612	3728	2544	5276	7680	3214
22	18	2894	5638	8478	3578	3614	2561	5162	7776	3298
23	19	2745	5536	8460	3458	3642	2465	5076	7800	3168
24	20	2866	5472	8289	3568	3436	2537	5048	7413	3102
25	21	2782	5438	8244	3422	3468	2534	4968	7380	2938
26	22	2695	5496	8076	3172	3418	2488	4802	7371	2878
27	23	2562	5214	7626	3028	3192	2325	4732	6876	2748
28	24	2520	4904	7599	3058	3120	2312	4536	6720	2596
29	25	2406	4990	7185	2888	2994	2140	4488	6312	2448
30	26	2244	4642	6921	2722	2784	2118	4068	6219	2336
31	27	2156	4452	6573	2604	2704	2037	3948	6009	2154
32	28	2042	4264	6291	2496	2528	1914	3870	5580	2004

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
33	29	2003	4036	6042	2396	2354	1844	3528	5289	1926
34	30	1896	3962	5835	2356	2304	1668	3454	5196	1844
35	31	1831	3758	5634	2342	2254	1700	3284	4998	1808
36	32	1800	3682	5496	2176	2070	1555	3208	4752	1622
37	33	1712	3470	5262	2020	2092	1548	3052	4593	1538
38	34	1663	3302	4974	2018	1978	1421	2948	4395	1476
39	35	1604	3236	4650	1908	1866	1430	2772	4122	1322
40	36	1533	3124	4560	1698	1896	1405	2658	4056	1312
41	37	1375	2812	4314	1616	1862	1266	2490	3846	1304
42	38	1432	2842	4230	1604	1830	1245	2406	3768	1206
43	39	1492	2790	4275	1516	1756	1259	2554	3762	1218
44	40	1413	2870	4323	1488	1684	1276	2504	3768	1166
45	41	1366	2826	4134	1402	1528	1217	2346	3717	1050
46	42	1264	2616	3753	1244	1478	1146	2214	3315	950
47	43	1043	2308	3240	1258	1320	1002	1922	2817	874
48	44	964	2004	2994	1180	1240	904	1670	2550	860
49	45	908	1832	2748	1036	1196	803	1596	2292	784
50	46	853	1694	2607	990	1144	781	1476	2187	726
51	47	906	1628	2463	970	1070	693	1442	2079	684
52	48	756	1632	2436	894	1072	700	1402	2046	650
53	49	779	1598	2256	884	964	668	1376	2007	630
54	50	746	1464	2190	860	910	682	1246	1941	620
55	51	708	1466	2091	812	858	601	1216	1755	524
56	52	691	1362	2070	780	906	609	1132	1638	516
57	53	628	1240	1896	760	834	550	1056	1533	550
58	54	585	1226	1875	714	800	512	1022	1548	476
59	55	583	1196	1686	696	756	439	1018	1524	484
60	56	599	1176	1713	764	704	476	1008	1524	454
61	57	614	1130	1737	674	694	526	1018	1506	418

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
62	58	550	1194	1662	648	746	495	962	1464	428
63	59	565	1074	1638	660	684	507	958	1317	376
64	60	516	1116	1611	570	622	467	880	1413	386
65	61	488	1000	1464	564	626	442	864	1218	338
66	62	479	874	1356	582	600	442	748	1134	336
67	63	409	848	1284	544	576	350	656	1011	318
68	64	391	816	1206	534	548	336	650	912	294
69	65	379	716	1131	480	530	319	614	936	278
70	66	378	718	1104	516	526	293	580	864	276
71	67	320	728	999	462	514	334	580	879	260
72	68	339	650	987	500	502	269	570	819	262
73	69	301	670	939	460	462	271	494	780	250
74	70	298	592	882	432	456	255	534	753	210
75	71	325	598	870	470	444	230	500	750	228
76	72	294	622	837	438	462	218	466	702	226
77	73	274	588	870	426	404	226	428	690	210
78	74	280	612	822	432	448	240	442	657	218
79	75	271	510	789	400	420	214	456	618	228
80	76	280	490	744	400	420	204	438	696	224
81	77	274	528	753	332	450	214	430	648	198
82	78	262	518	738	322	450	229	412	618	202
83	79	248	480	714	328	404	198	420	621	196
84	80	221	480	639	304	384	162	372	585	196
85	81	240	458	690	312	410	175	414	591	182
86	82	227	446	681	304	398	187	380	624	180
87	83	201	498	744	258	362	199	430	603	192
88	84	240	450	726	256	396	183	396	624	168
89	85	220	392	723	228	340	202	420	609	164
90	86	230	458	705	242	376	219	400	588	190

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Rev 0
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	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
91	87	214	440	657	218	366	180	390	513	178
92	88	181	440	633	228	340	223	380	561	182
93	89	189	410	582	224	376	159	352	477	170
94	90	185	356	561	174	322	156	314	459	132
95	91	166	356	525	188	288	142	340	483	162
96	92	171	330	492	194	302	134	320	438	164
97	93	192	348	513	168	350	172	322	411	154
98	94	167	334	528	198	296	148	320	495	128
99	95	186	376	537	190	308	150	326	468	108
100	96	178	392	570	194	326	164	340	516	126
101	97	197	412	582	184	284	164	354	546	124
102	98	204	388	597	176	318	195	316	615	128
103	99	213	398	678	218	330	172	370	561	136
104	100	218	412	609	202	296	201	356	510	152
105	101	191	410	633	190	282	156	380	516	130
106	102	190	376	582	216	304	169	334	480	132
107	103	172	380	582	304	310	179	324	459	150
108	104	185	380	534	402	290	148	282	429	122
109	105	184	390	564	430	302	128	272	435	106
110	106	192	394	594	624	280	139	272	426	100
111	107	197	414	618	766	264	137	272	390	92
112	108	242	458	705	908	258	135	298	414	92
113	109	242	452	750	960	276	138	278	411	116
114	110	282	500	762	926	256	136	244	420	104
115	111	234	494	744	832	272	127	262	381	98
116	112	201	454	660	680	246	150	248	351	80
117	113	208	404	600	530	262	142	238	327	92
118	114	152	368	570	420	252	113	184	285	94
119	115	137	290	423	280	244	101	182	312	86

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
120	116	105	262	354	218	272	72	178	249	80
121	117	102	222	339	160	262	97	168	255	88
122	118	103	218	264	134	226	78	182	237	76
123	119	97	178	282	116	234	106	182	237	86
124	120	107	168	264	84	252	75	172	240	84
125	121	89	178	261	92	232	76	144	237	74
126	122	76	162	210	66	272	69	136	255	80
127	123	93	156	246	76	232	67	164	216	76
128	124	76	144	210	66	252	74	142	198	70
129	125	65	148	234	80	238	84	126	222	76
130	126	70	110	192	68	220	67	146	207	92
131	127	68	162	225	78	232	75	104	216	70
132	128	73	150	198	64	252	76	140	219	72
133	129	66	136	231	58	232	73	134	201	82
134	130	77	142	207	66	262	66	144	204	76
135	131	74	122	192	56	260	81	154	195	70
136	132	77	122	192	76	268	74	118	201	76
137	133	65	122	180	66	258	57	132	183	56
138	134	51	132	189	46	268	67	122	201	64
139	135	61	116	171	66	228	60	114	174	70
140	136	60	118	171	68	264	50	104	168	70
141	137	50	126	174	64	250	50	140	189	50
142	138	55	108	186	66	272	59	108	165	56
143	139	62	102	177	60	236	61	102	144	48
144	140	53	106	183	58	258	56	112	138	64
145	141	61	130	171	72	262	59	96	159	56
146	142	61	108	183	60	244	45	98	156	62
147	143	55	142	189	54	228	60	116	156	50
148	144	57	112	210	68	242	61	124	165	58

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	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
149	145	47	104	150	54	240	63	124	201	56
150	146	50	124	195	66	262	55	118	174	64
151	147	59	126	198	70	258	81	138	171	64
152	148	69	136	186	44	272	60	128	195	44
153	149	72	120	192	70	258	63	134	168	70
154	150	56	130	210	82	238	70	116	186	66
155	151	58	136	222	56	268	91	146	162	64
156	152	69	138	195	62	216	62	142	195	60
157	153	56	128	183	60	252	54	122	198	54
158	154	76	148	162	70	250	69	132	168	46
159	155	73	120	186	64	222	68	130	192	44
160	156	55	144	177	60	208	54	128	186	60
161	157	63	140	159	44	188	57	134	186	60
162	158	43	104	183	46	198	57	112	168	52
163	159	55	116	192	62	216	76	114	168	64
164	160	54	114	198	52	202	58	96	162	48
165	161	50	124	168	60	192	54	122	159	50
166	162	49	106	156	42	182	49	88	141	50
167	163	40	108	144	54	178	45	116	147	44
168	164	35	74	138	56	160	54	84	111	46
169	165	40	98	144	44	178	37	78	105	60
170	166	38	92	111	36	190	46	80	93	46
171	167	32	66	93	48	178	42	76	105	40
172	168	34	84	117	50	142	38	74	117	32
173	169	35	82	96	46	162	37	70	102	44
174	170	30	72	96	44	164	44	68	93	54
175	171	32	60	105	40	146	30	76	108	36
176	172	36	64	105	42	146	28	54	102	32
177	173	31	68	102	30	160	30	66	84	44

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
178	174	41	60	99	44	138	44	70	111	36
179	175	30	80	105	42	164	34	66	108	40
180	176	37	64	117	46	144	33	60	90	38
181	177	39	74	114	40	142	36	80	123	38
182	178	36	74	87	36	106	24	80	108	44
183	179	37	66	105	42	116	27	68	93	40
184	180	42	60	117	50	128	33	64	114	40
185	181	32	68	132	40	126	37	82	108	50
186	182	28	84	120	40	144	22	70	96	44
187	183	42	72	129	46	140	37	80	102	40
188	184	40	82	126	36	176	48	82	108	44
189	185	30	70	99	46	208	40	62	105	38
190	186	31	70	99	48	270	26	70	99	44
191	187	27	66	105	46	280	32	82	111	36
192	188	39	60	102	44	316	26	68	93	46
193	189	35	56	96	52	350	40	70	84	38
194	190	33	54	93	40	382	40	58	81	40
195	191	33	62	117	38	384	34	52	66	30
196	192	26	62	93	32	350	26	56	78	38
197	193	31	66	84	36	308	28	44	87	36
198	194	18	56	87	50	306	25	48	81	38
199	195	23	68	90	36	252	25	50	78	44
200	196	20	64	84	44	238	33	54	66	36
201	197	29	46	78	36	162	17	46	72	30
202	198	29	64	72	26	168	29	60	84	40
203	199	18	50	81	32	106	23	44	72	24
204	200	34	60	96	26	92	30	70	81	24
205	201	25	56	81	24	74	19	60	90	32
206	202	28	70	87	36	62	31	56	60	26

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
207	203	27	48	78	32	66	29	44	78	32
208	204	29	56	57	26	48	34	50	63	30
209	205	27	56	84	18	64	41	60	81	26
210	206	33	50	75	30	64	29	54	81	18
211	207	26	56	78	22	90	17	42	84	14
212	208	17	54	81	20	100	25	46	72	24
213	209	19	38	84	16	114	23	56	78	20
214	210	29	56	69	18	164	31	36	63	22
215	211	22	48	84	16	190	22	42	54	28
216	212	23	36	63	24	218	29	44	54	18
217	213	22	36	54	18	272	14	50	57	22
218	214	19	44	72	18	292	20	40	48	16
219	215	12	44	66	18	244	20	44	51	32
220	216	16	30	33	18	282	18	32	69	16
221	217	12	40	78	22	276	18	34	42	18
222	218	21	40	51	16	264	22	40	36	16
223	219	15	28	60	12	208	14	38	48	22
224	220	16	40	51	22	188	20	30	48	16
225	221	20	28	42	12	174	17	32	57	22
226	222	16	42	48	18	132	13	40	54	20
227	223	12	38	72	14	112	20	32	48	12
228	224	18	30	60	22	72	15	38	57	18
229	225	29	40	57	30	66	15	32	69	26
230	226	22	44	66	22	70	22	44	63	18
231	227	18	46	63	34	64	15	38	75	28
232	228	27	56	72	44	48	22	36	72	30
233	229	32	48	66	44	44	16	32	90	30
234	230	31	50	75	46	52	16	50	96	48
235	231	30	50	84	46	60	19	60	84	36

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS-137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
236	232	27	68	108	50	56	21	50	84	56
237	233	29	60	90	70	60	21	52	108	70
238	234	43	62	111	70	54	25	60	105	64
239	235	47	62	87	60	50	29	70	114	84
240	236	39	62	102	52	60	33	76	102	54
241	237	31	74	87	48	56	39	64	93	54
242	238	23	70	108	46	56	33	66	81	64
243	239	36	70	84	32	40	41	54	81	54
244	240	32	74	105	26	48	23	58	84	34
245	241	19	50	60	30	36	26	54	60	42
246	242	22	54	66	26	26	35	40	57	28
247	243	17	40	63	24	20	29	44	54	40
248	244	19	40	57	18	20	17	40	48	18
249	245	16	38	54	16	22	19	30	45	22
250	246	17	20	42	12	26	15	22	45	20
251	247	13	24	36	8	8	16	30	39	18
252	248	9	30	45	8	16	15	24	45	18
253	249	23	24	42	14	12	11	24	48	18
254	250	16	28	51	14	4	18	24	33	14
255	251	9	30	45	16	16	16	30	45	12
256	252	15	28	45	10	6	16	40	30	10
257	253	0	0	0	0	0	0	0	0	0
258	254	0	0	0	0	0	0	0	0	0
259	Sum (counts, whole spectra)	109098	218826	326328	141182	159442	97151	193998	289695	106682
260	Spec. #	16	17	18	20	21	13	14	15	19
261	ROI Gross (counts)	2192	5102	7119	8906	3456	N/A	N/A	N/A	N/A
262	ROI BKGD/Ch (counts/channel)	143.00	299.00	414.00	137.00	65.00	N/A	N/A	N/A	N/A
263	ROI Bkgd Integral (counts)	1573	3887	4968	2466	1235	N/A	N/A	N/A	N/A
264	ROI Net counts	619	1215	2151	6440	2221	N/A	N/A	N/A	N/A

	A	B	C	D	E	F	G	H	I	J
1		Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	Co-60 MDC	Co-60 MDC	Cs-137 MDC	Cs-137 MDC	Cs-137 MDC	button test BKG
2	Spectrum Number	16	17	18	20	21	13	14	15	19
3	Spectrum Channel	600s CS-137	1200s CS 137	1800s CS-137	CS-137 button	Co-60 button	Background (info only)	Background (info only)	Background (info only)	(Info only)
265	**Cesium MDC Calculations**									
266	Efficiency (counts/pCi/g)	225	442	782						
267	Efficiency (cpm/pCi/g)	22.509	22.091	26.073	24.1515					
268	**Cs-137 MDC (pCi/g)**	**0.833**	**0.663**	**0.423**						
269	**Cobalt MDC Calculations**									
270	Spec. #	20	21							
271	Souce Activity for 662 or 1332 line in (gps)	2.24E+04	2.12E+04							
272	Efficiency Counts/gps	0.288	0.105							
273	Efficiency ratio (Co 60 gps/ Cs-137 gps)	0.364								
274	**Estimated Co-60 MDC (pCi/g)(10,20&30 min)**	**2.29**	**1.82**	**1.16**						

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	A	B	C
1		Cs-137 MDC	Cs-137 MDC
2	Spectrum Number	16	17
3	Spectrum Channel	600s CS-137	1200s CS-137
260	Spec. #	16	17
261	ROI Gross (counts)	=SUM(B110:B120)	=SUM(C109:C121)
262	ROI BKGD/Ch (counts/channel)	=(B109+B121)/2	=(C108+C122)/2
263	ROI Bkgd Integral (counts)	=B262*COUNT(B110:B120)	=C262*COUNT(C109:C121)
264	ROI Net counts	=(B261-B263)	=(C261-C263)
265	**Cesium MDC Calculations**		
266	Efficiency (counts/pCi/g)	=B264/2.75	=C264/2.75
267	Efficiency (cpm/pCi/g)	=60*B266/B4	=60*C266/C4
268	**Cs-137 MDC (pCi/g)**	**=((3+(4.65*(SQRT(B263))))/B266)**	**=((3+(4.65*(SQRT(C263))))/C266)**
269	**Cobalt MDC Calculations**		
270	Spec. #	20	21
271	Souce Activity for 662 or 1332 line in (gps)	22400	21200
272	Efficiency Counts/gps	=E264/B271	=F264/C271
273	Efficiency ratio (Co-60 gps/ Cs-137 gps)	=C272/B272	
274	**Estimated Co-60 MDC (pCi/g)(10,20&30 min)**	**=B268/$B$273**	**=C268/$B$273**

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	D	E	F
1	Cs-137 MDC	Co-60 MDC	Co-60 MDC
2	18	20	21
3	1800s CS-137	CS-137 button	Co-60 button
260	18	20	21
261	=SUM(D110:D121)	=SUM(E106:E123)	=SUM(F210:F228)
262	=(D109+D122)/2	=(E105+E124)/2	=(F209+F229)/2
263	=D262*COUNT(D110:D121)	=E262*(18)	=F262*(19)
264	=(D261-D263)	=(E261-E263)	=(F261-F263)
265			
266	=D264/2.75		
267	=60*D266/D4	=(1*B267+2*C267+3*D267)/6	
268	**=((3+(4.65*(SQRT(D263))))/D266)**		
269			
270			
271			
272			
273			
274	**=D268/$B$273**		

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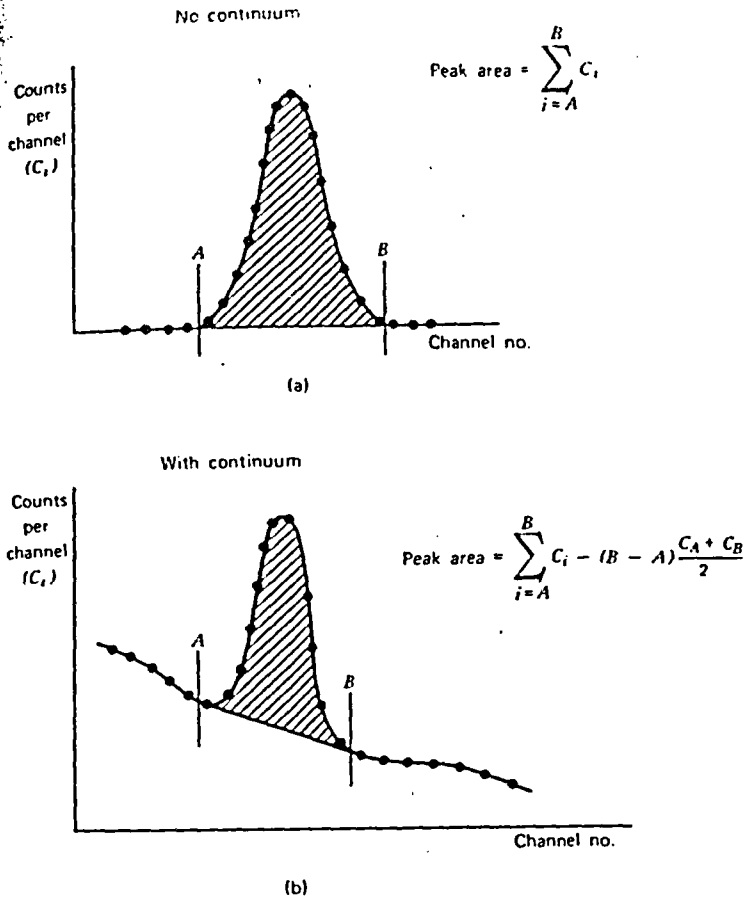

Figure 10-26 Methods of obtaining peak areas from multichannel spectra.

If the peak were a simple isolated one without any superimposed continuum, as shown in Fig. 10-26a, its area could be determined by simple integration between the limits shown. When the spectrum is recorded in a multichannel analyzer, the equivalent process is a simple addition of the content of each channel between the indicated limits. If a continuum is also present, as in Fig. 10-26b, some additional unwanted counts are included in this process and must be subtracted. Some shape must therefore be assumed for the continuum within the region under the peak, and a number of fitting procedures of varying degrees of complexity can be applied. A linear interpolation between the continuum values on either side of the peak is the easiest approach and will give sufficient accuracy for many purposes.

At times, closely spaced or overlapping peaks do not allow the straightforward summation method to be applied. More complex methods must then be used to separate the individual contributions of each of the closely lying peaks. These methods normally involve fitting an analytic shape to that portion of the peak which can be clearly resolved, and assuming that the remainder of the peak is described by the fitted function. A Gaussian curve fitted to the points that lie within one standard deviation on either side of

Table 3.1 MDC Results for Data Obtained From Gas Proportional Detector Using Various MDC Expressions

MDC Expression[a,b]	MDC Result[c] (dpm/100 cm²)	Reference
$2.71 + 4.65\sqrt{B}$	210	NCRP 58 EPA 1980
$2.71 + 4.65\,\sigma_B$	204	Currie 1968
$2.71 + 3.29\,\sigma_B$	146	Currie 1968
$3 + 4.65\sqrt{B}$	211	Brodsky & Gallaghar 1991
$\dfrac{3 + 3.29\sqrt{R_b\, t_g\,(1 + \frac{t_g}{t_b})}}{(Efficiency)(t_g)}$ [d]	211	Strom & Stansbury 1992

[a]The data used in each MDC expression were obtained from a 43-68 gas proportional detector and SrY-90 source. Average background counts (B) of 354 in 1 minute, standard deviation of 18, probe area correction for 126-cm² detector, and detector efficiency of 0.34 count per disintegration were obtained.
[b]Each MDC expression is written using symbols that may be different from the ones that were presented in their respective references. However, the meaning of each has been preserved.
[c]Each MDC result was presented in terms of dpm/100 cm² to facilitate comparison of the different MDC expressions. This involved correcting the MDC expression for probe area and detector efficiency.
[d]The terms R_b, t_g, and t_b refer to the background counting rate, gross count time, and background counting time, respectively. Using t_g equal to t_b (1 minute), resulted in the same expression as that of Brodsky and Gallaghar (1991).

Attachment 2

Source Certificates

Calc No. 004-04 (MY)
Rev. 0
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ANALYTICS
1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318 · U.S.A.
Phone (404) 352-8677
Fax (404) 352-2837

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

62994-60

Cs-137 Sand in Short Steel Drum Filled to Top

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated in an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked using a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1

ISOTOPE:	Cs-137
ACTIVITY (dps):	6.147 E3 2.92 pCi/g
HALF-LIFE:	3.007 E1 years
CALIBRATION DATE:	January 29, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% confidence level.

Impurities: γ-impurities <0.1%

39 L / 56.95 kg of sand.

P O NUMBER 02-00007, Item 1

SOURCE PREPARED BY: M. D. Currie
M. D. Currie, Radiochemist

Q A APPROVED: 2-4-02

Calc. No. 004-04 (MY)
Rev 0
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THE SOURCE INC.

Radiation standards and check sources
2810 Siler Lane, Santa Fe, NM 87501
(505)473-9538 FAX(505)473-5805

Ref. PO#_____

Certificate of Calibration
(Gamma Source)

COPY

The Cesium 137 gamma ray emission rate was compared with NIST referenced source 4200B-134. The comparison was completed using a Sodium Iodide or GeLi gamma detector.

The activity of the source on 08-12-93 1200 EST was 0.923uCi.

The uncertainty of the measurement and the activity of the source is 10.0% which is the sum of the uncertainty of the NIST standard and the random error of counting at the 99.0% confidence interval.

Serial NO. 93CS2502228 Cover_____
Active Diameter(or/area) ¼" Mounting Material Plastic
Total Diameter(or/area) 1" Thickness 1/8"

Michael A. Ortiz — Calibration Manager
Michael A. Ortiz

Charles L. Gonzales — Q.A. Manager
Charles L. Gonzales

The source was leak tested and was found to have <0.005uCi removeable activity.

GC007-93

Calc NO. 004-04
Rev 0
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ANALYTICS

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318 · U.S.A.

Phone (404) 352-8677
Fax (404) 352-2837

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

COPY

BEST AVAILABLE COPY

59436A-60

Co-60 1 Inch x 1/4 Inch Button Source

This standard radionuclide source was prepared using an aliquot measured gravimetrically from a calibrated master liquid radionuclide solution source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked using a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Co-60
ACTIVITY (dps):	3.835 E4
HALF-LIFE:	5.2714 years
CALIBRATION DATE:	April 6, 2000 12:00 EST
TOTAL UNCERTAINTY*:	4.8%
SYSTEMATIC:	4.5%
RANDOM:	0.3%

*99% Confidence Level

Impurities: γ-impurities <0.1%

P O NUMBER 08196-RP-00-0011-742 REV. 1, Item 1

SOURCE PREPARED BY: M. D. Currie
M. D. Currie, Radiochemist

Q A APPROVED: 4/6/00

entered in inventory 4-10-00 by D. Pankhart