WSRC-TR-2003-00444
Revision 0

Determination of Co-60 in Cobalt Slugs and Slabs and Radionuclides in Curium Sampler Slugs in L-Reactor Disassembly Basin

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December 10, 2003

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ABSTRACT

Using a sodium iodide detector and multichannel analyzer system and an underwater collimator assembly, Co-60 concentrations were determined for 548 L-Reactor Disassembly Basin cobalt slugs and slabs and 18 curium sampler slugs. The total activity of all of the assayed slugs summed to 31,783 curies. From the Co-60 concentrations of the curium sampler slugs, the irradiation flux was determined for the known irradiation time. The amounts of Pu-238,239,240,241,242; Am-241,243; and Cm-242,244 produced were then obtained based on the original amount of Pu-239 irradiated.

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Determination of Co-60 in Cobalt Slugs and Slabs and Radionuclides in Curium Sampler Slugs in L-Reactor Disassembly Basin

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1. INTRODUCTION

Co-60 was historically produced in the SRS reactors for private vendors and the United States military. Cobalt slugs were irradiated in the early 1970s. Post-production, remaining cobalt slugs (including slab form) were consolidated for storage in L-Basin. There are approximately nine hundred cobalt slugs currently stored in L-Basin awaiting final disposition. These slugs had historically incomplete documentation for activity rates; therefore, assaying was required in order to determine their activity levels.

Since the gamma dose rate from these slugs is extremely high, the most cost effective way to shield a source of this magnitude from personnel and the radiation detector was to use the basin water in which the slugs are stored as the shield. A sodium iodide gamma detector was placed above a specially designed air collimator assembly, so that slug was at least eight feet from the detector and was shielded by the basin water.

The assaying took part in two phases. The first phase was in 1999. Assays were taken as slugs were being consolidated from K-Basin to L-Basin and also for a portion of the slugs already stored in L-Basin.[1-3] As these slugs were assayed, they were placed in tag-holders, then into labeled buckets for storage. The second phase of assaying has just been completed for the remainder of slugs that were stored in L-Basin prior to 1999, as part of the current disposal effort. The slugs that were recently assayed in the second phase were placed in numbered bins with procedurally specified activity ranges.

Seventy-two cobalt slugs were originally stored at Savannah River Technology Center (SRTC) irradiation facility with a decay-corrected activity of 36,000 curies. These slugs were recently transferred to L-Basin in an 8-Ton Cask as part of the disposition effort, and were the only slugs with documentation of original activity rates.[4]

All of the slugs previously stored in the basin and the SRTC slugs are to be disposed of as “low-level waste” at the Solid Waste facilities. In order to permanently minimize radiation exposure from this intense Co-60 source, an obsolete Paducah Demonstration Cask (also slated for waste disposal) will be utilized to provide shielding via depleted uranium layers within the cask.

In addition to the cobalt slugs, there are 18 curium sampler slugs[5] (also called Pu monitor pins) that were used to produce Cm-244 from Pu-239; these slugs will be disposed of with the Co-60. Very little information exists on the isotopic content of these slugs. Therefore, in addition to the Co-60 assay, the sampler slugs were also analyzed with a High Purity Germanium (HPGE) detector in an attempt to identify any additional radioactive nuclides in them.

2. EXPERIMENTAL

Instrument Setup for Cobalt Slugs and Slabs

An air filled collimator had been designed to allow a small pencil of gamma radiation from the slug to reach the detector, a 2"x 2" NaI crystal.[2] Eleven feet of basin water provided the gamma ray shielding. Figure 1 is a sketch of the collimator used in data acquisition. The collimator consists of a tray to hold the slug that was placed below the lower end of the collimator, a 48"x 3/4" pipe, a 1 1/4" x 48"aperture holder containing five 15/16" x 1/8" aperture pieces and a packet of BBs that disperse the Co-60 gamma rays.

Two measurement systems were used for determining the quantity of Co-60 in the cobalt slugs and slabs and the curium sampler slugs.[6] For most of the slug and slab measurements, analyses were performed with a portable multichannel analyzer (MCA) EG&G Dart system, containing a laptop computer with GammaVision software. Since the EG&G Dart system became inoperable in the very hot and humid environment, it was replaced with another system that consisted of a portable computer with a Canberra NaI+ card installed and Genie 2000 software. This card converts the PC to a full function MCA and contains the ancillary electronics, high voltage power supply and amplifier, required for data acquisition. A 2" x 2" NaI detector was used and data were stored on floppy disks for subsequent review and analysis and retention. The spectra were acquired in the energy range 0 – 2MeV with an ADC gain of 512 channels and with the detector high voltage set to +800V. Pictures of the NaI detector arrangement and underwater cobalt assay assembly are shown in Figures 2 and 3.

For analysis of the curium sampler slugs, the analysis system consisted of a portable high purity germanium detector, a personal computer with a Canberra Accuspec card and Genie 2000 software, a high voltage power supply, an analog-to-digital converter, and an amplifier.

The gamma ray spectrum from Co-60 consists of two gamma rays, one at 1.17 MeV and the other at 1.33 MeV. A "region of interest" (ROI) was defined around these two gamma rays in the spectrum, and the number of counts in this region summed by the MCA software. This provided the data necessary to assay the slugs. A background spectrum and a cobalt standard spectrum are shown in Figure 4. The two prominent Co-60 peaks can be seen with the ROI markers around them, and a Cs-137 peak from the basin water is also seen.

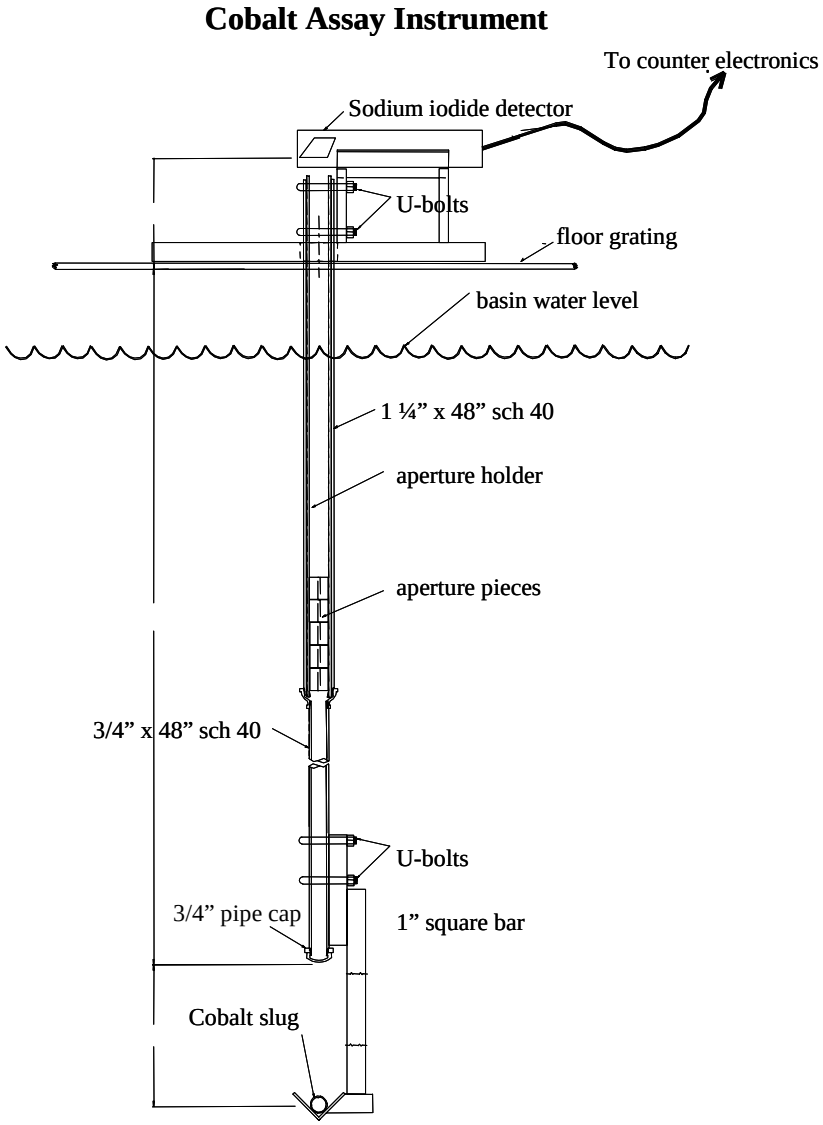


Figure 1. Sketch of the L-Area cobalt assay instrument assembly with NaI detector.

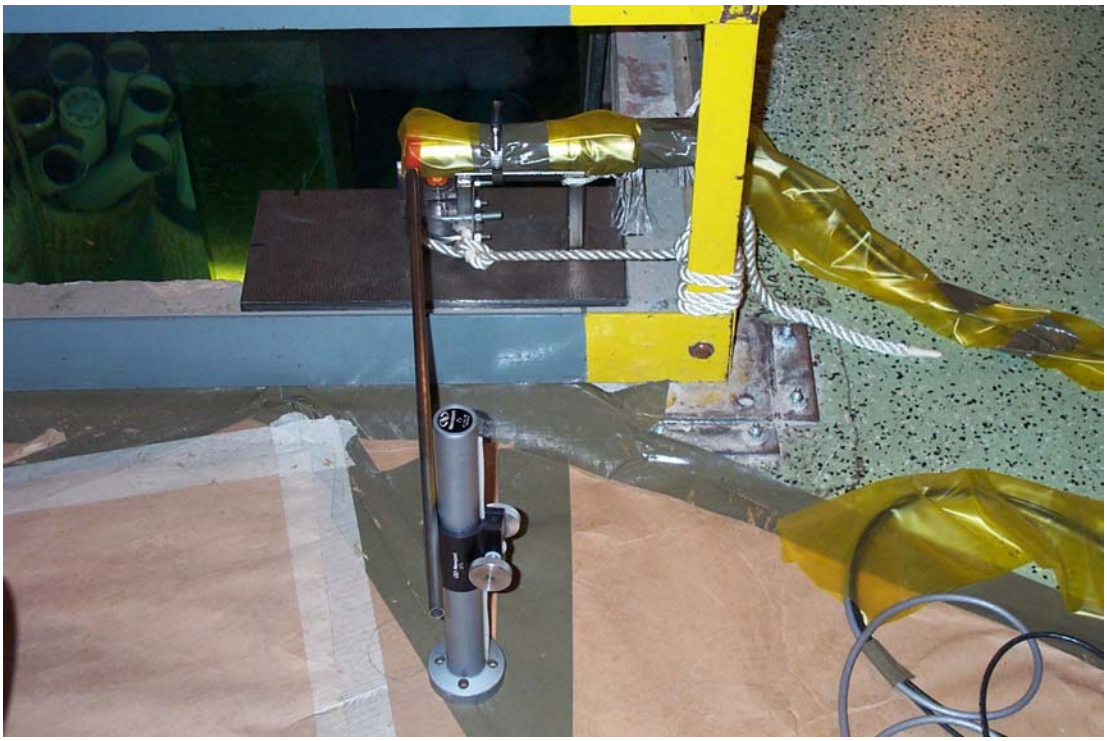


Figure 2. NaI detector arrangement for counting standard Co-60 standard source.

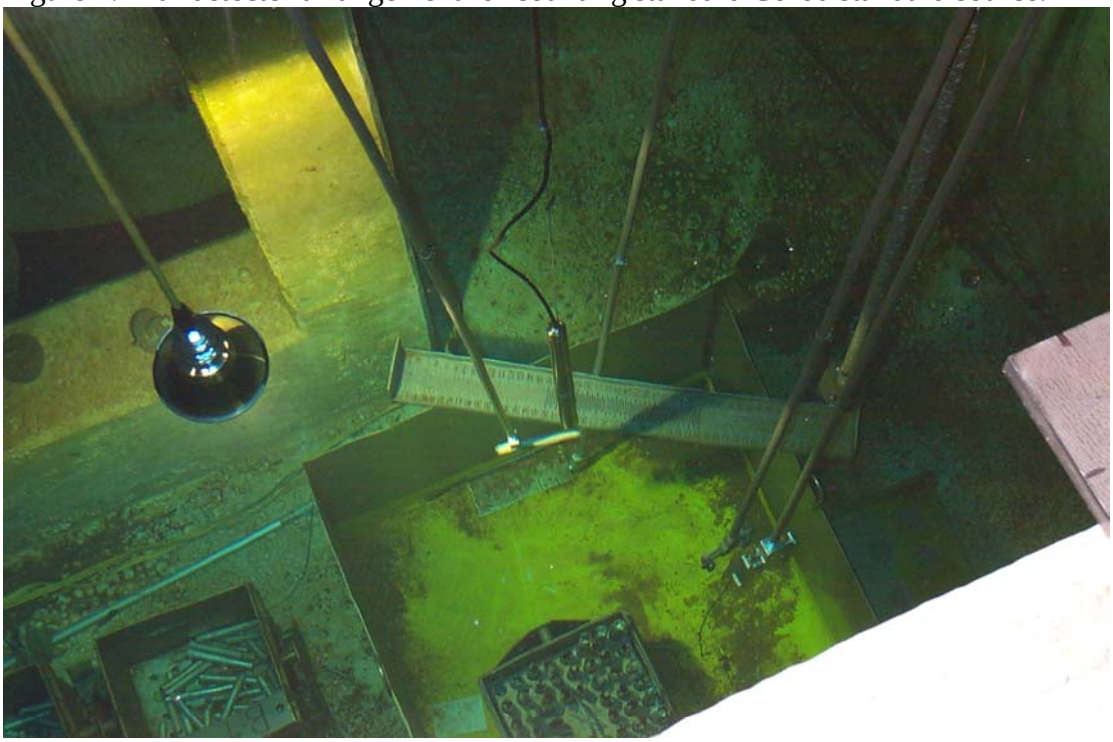


Figure 3. Underwater cobalt assay assembly showing measurement platform, RO7 monitor and slug bins.

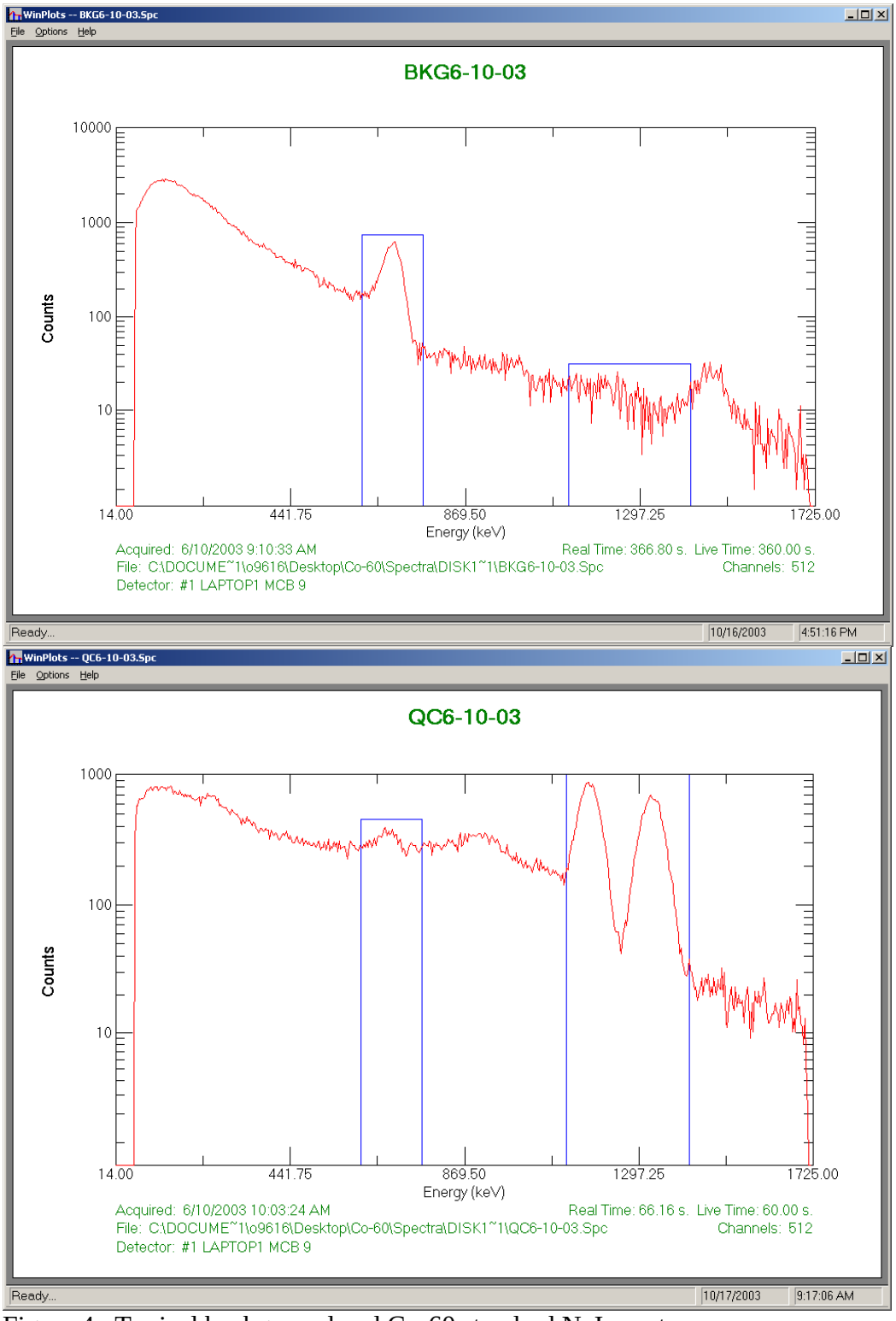


Figure 4. Typical background and Co-60 standard NaI spectra.

In addition to the cobalt assays, dose measurements were performed, per procedure SOP-DHS-121-L, Assay of Cobalt Slugs,[6] and results were recorded with the assay results. The length of each slug was measured before assays were performed, as shown in Figure 3.

Instrument Setup for Curium Sampler Slugs

In order to increase the sensitivity of the measurement, the sample holder was removed from the water and the slug tray relocated from a distance of 12" to 2 3/4" from the base of the collimator. The small collimators and collimator tube were removed and only the collimator pipe was used.

The 18 Curium pins were removed one at a time from the basket and assayed with the sodium idodide detector. The Co-60 in the pin was produced by irradiating a 1/16" x 1/16" piece of cobalt wire used as a neutron monitor. Since it was very difficult to position the pin properly for this measurement, the Co-60 was also obtained from RO7 dose readings of the pins by calibrating the RO7 versus assay results from previously assayed materials.

After all 18 slugs had been assayed with the NaI detector, this detector was replaced with a high-resolution HPGE detector, and the pins were assayed with this detector to determine what isotopes, if any, could be identified in the slugs other than Co-60.

Calibration:

The same calibration was used as in the K Reactor assay, described in SRT-ADS-0327, and previous Co-60 slug measurements described in SRT-ADS-99-0391. For this calibration, four slugs were chosen to have different nominal values in an effort to obtain a linear relationship between Co-60 counts and activity. Analysis of the data showed that this was not possible, so the data were averaged. The basin background count rate in the ROI was subtracted from the average count and this divided by the average number of Curies/slug to obtain the conversion factor of 189 counts/two minutes/Ci for a 2" x 2" sodium iodide detector. The uncertainty in this value was determined to be $\pm$ 25%. and this uncertainty had to be added in quadrature to the other measurement uncertainties, including counting statistics.

The slugs in L Reactor Basin are assumed to be essentially identical to those in K Reactor basin. The gamma rays seen by the detector have come from various points within the slug. Therefore, the attenuation of the gamma rays from the various portions of the slug will differ because of the differing distances traveled in the slug. Since attenuation depends upon the composition and density of the slug, if the slugs in L Basin are not identical to those in K Basin, the calibration will be in error by an unknown amount.

Both slugs and slabs were analyzed. The slugs have cobalt contained between two D-bar (half-round) pieces of aluminum, while the slabs are pieces (may be rectangular) of cobalt with cladding. Since the gamma rays from Co-60 (1.17 MeV and 1.33 MeV) are very high energy, the difference in sample attenuation is considered well within the overall uncertainties reported.

Since the calibration is for a certain length slug (nominally 8") and since we are only measuring gamma rays from a small portion of the sample, a correction was made for samples of length that differ from the calibration length. The slug tray distance was reduced from 12" to 2 ¾" and the collimation was changed for assays of the curium sampler slugs; therefore, the same slugs were assayed at both configurations to recalibrate the system for the new distance and collimation.

Since RO7 contact measurements are more sensitive for detecting Co-60 than the assay detectors located more than eight feet from the slug, the RO7 was calibrated from previously assayed slugs for low activity measurements. The curium sampler slugs are composed primarily of aluminum by weight, as compared to the cobalt slugs that are about 48% aluminum and 52% cobalt by weight and the curium sampler slugs are contained in ~1/16" aluminum sleeves. Also, the cobalt was distributed uniformly throughout the slugs and the pins only contained a 1/16" x 1/16" wire (neutron monitor). Therefore, dose measurements were adjusted to account for the difference in compositions and cobalt distribution.

System Quality Assurance/Quality Control:

A background analysis was performed each day prior to sample analysis to show that essentially no Co-60 was present. A Co-60 gamma source was counted in a known geometry, as shown in Figure 2, prior to and after analysis completion to ensure that the energy calibration had not changed significantly and to verify that the counts in a designated peak agree to within the control chart limits (3-sigma).

All of the data were collected from 6/11/03 to 8/20/03. Data were kept in a logbook and spectra, representing the official data, were stored on 3 1/2" floppy disks. Over this period, fifty-three Co-60 quality control checks were performed for the NaI assay systems, and four were performed for the HPGe assay system. A control chart for these checks is given in Figure 5. The last four determinations listed were for the HPGe system. Using the standard positioner shown in Figure 2, the average count (2 minutes) and standard deviation for the NaI QC checks were 17,440 $\pm$ 230, while corresponding values of 5,860 $\pm$ 170 were obtained for the HPGe QC checks. All QC checks were within the designated 3-sigma control limits.

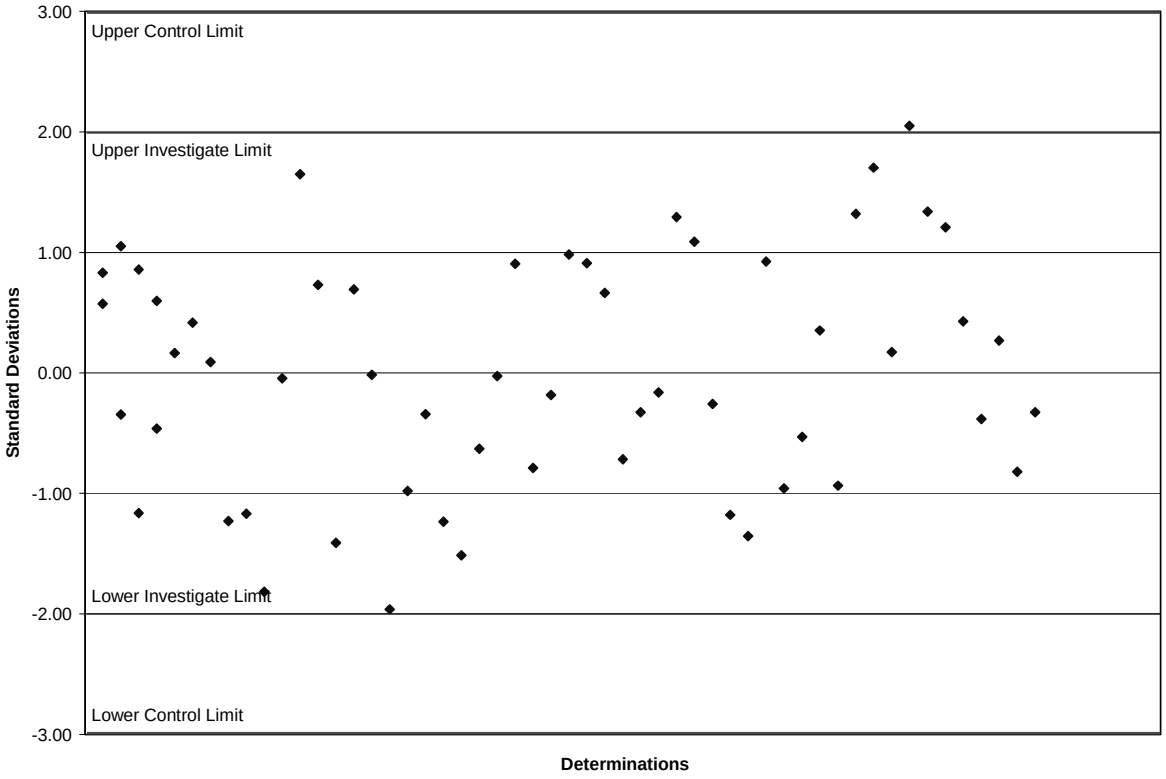


Figure 5. Control chart for Co-60 Standard Check Source (6/11/03 – 8/20/03)

3. ANALYSIS AND RESULTS

Cobalt Slug and Slab Analysis and Results

In order to ensure that the results from this campaign are consistent with previous measurements, nine previously analyzed slugs were reanalyzed to confirm that the present measurements are comparable to those previously done. After correcting for Co-60 decay and any differences in geometry, the total counts for the nine previously analyzed slugs was about 8% higher than expected from the results obtained in 1999. This was considered acceptable because, as stated previously, the calibration uncertainty was $\pm$ 25%. The calibration uncertainty had to be added in quadrature to the other measurement uncertainties, primarily counting statistics for the slug measurements. For the present slug measurements with appreciable Co-60 activities, the counting statistics uncertainties were less than 5% and did not make an appreciable contribution to the overall uncertainty.

A typical spectrum for the cobalt slugs and slabs is shown in Figure 6. The first region of interest is from Cs-137 in the L-Basin, while the second region of interest is from the two Co-60 gamma rays at 1.17 and 1.33 MeV. The Co-60 activity in this slug was determined to be 72 curies.

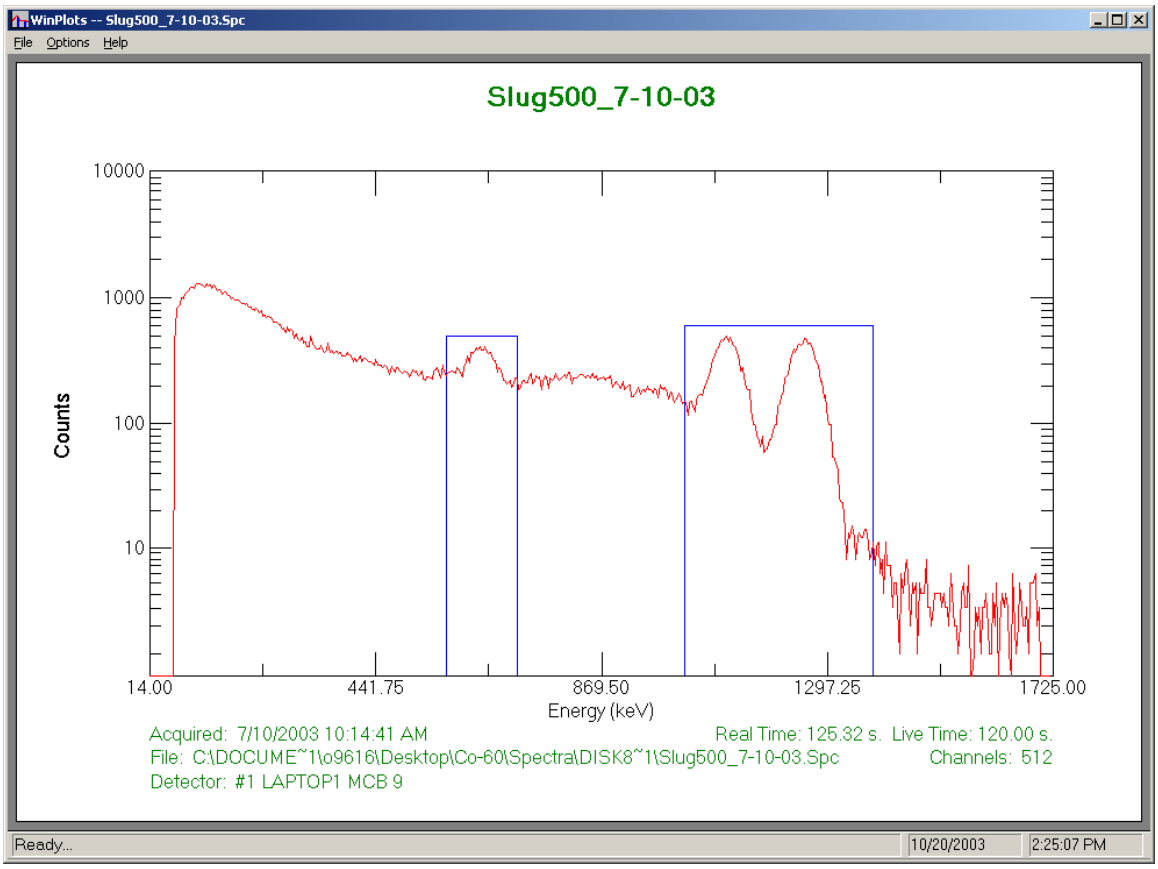


Figure 6. Typical slug spectrum with regions of interest for Cs-137 and Co-60.

All of the assay results were independently technically reviewed before the data were released. These results are compiled in Table 1. As previously mentioned, the basin background count rate in the ROI was subtracted from the average count and this divided by the conversion factor of 189 counts/two minutes/Ci for a 2" x 2" sodium iodide detector. Analysis of 548 slugs and slabs resulted in 31,783 curies of Co-60. Each slug or slab was placed in a bin depending upon the number of curies of Co-60 measured for that item. The Co-60 curie range per bin were Bin 1(0 curies); Bin 2 (0 – 50 curies); Bin 3 (50 – 100 curies); Bin 4 (100 – 150 curies); Bin 5 (150 -200 curies); Bin 6 (200 – 500 curies) and Bin 7 (>500 curies). In some cases, based on preliminary results, items outside these ranges were placed in the bin.

As shown in Table 1, the number of slugs and slabs (items) and the curies of Co-60 for each bin were: Bin 1 = 156 items, 0 curies; Bin 2 = 181 items, 3957 curies; Bin 3 = 108 items, 7901 curies; Bin 4 = 32 items, 3959 curies; Bin 5 = 39 items, 6885 curies; Bin 6 = 31 items, 8387 curies and Bin7 = 1 item, 694 curies. It is interesting to note that bins 3 through 7 contain 211 slugs representing 88% (27,826 curies) of the Co-60 activity, while essentially all of the remaining activity (3,957 curies) is contained in the 181 slugs in bin 2. The total activity of all 548 assayed items summed to 31,783 curies.

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
1	372	Slug	8	48.2	694	7	**694**	**1**
2	135	Slug	8	77	410	6		
3	2	Slug	8.25	35	344	6		
4	313	Slug	6	5.6	339	6		
5	284	Slug	6	43.4	338	6		
6	154	Slug	8.5	57.5	324	6		
7	544	Slug	7.5	39.5	311	6		
8	6	Slug	8	35.4	293	6		
9	520	Slug	5.5	17	292	6		
10	5	Slug	8	35.7	290	6		
11	325	Slug	6	5	284	6		
12	330	Slug	6	5.1	270	6		
13	9	Slug	8.5	28.3	270	6		
14	341	Slug	6	5.5	269	6		
15	344	Slug	6	5.6	262	6		
16	283	Slug	6	33.4	262	6		
17	394	Slug	8.5	53	261	6		
18	339	Slug	6	5.6	260	6		
19	274	Slug	8.5	57.2	254	6		
20	7	Slug	8.75	34.3	254	6		
21	282	Slug	6	31.6	245	6		
22	286	Slug	6	38.4	243	6		
23	517	Slug	5.5	22.2	242	6		
24	543	Slug	9	23.7	242	6		
25	542	Slug	9	20.1	242	6		
26	303	Slug	6	5.6	242	6		
27	504	Slug	8.5	27.4	240	6		
28	519	Slug	5.5	23.8	233	6		
29	438	Slug	8	32.5	230	6		
30	3	Slug	8.5	27.6	217	6		
31	305	Slug	6	5.4	213	6		
32	324	Slug	6	4.5	212	6	**8387**	**31**
33	528	Slug	8	24.4	200	5		
34	312	Slug	6	4.9	195	5		
35	70	Slug	8	29.0	194	5		
36	311	Slug	6	6	193	5		
37	321	Slug	6	5.2	193	5		
38	333	Slug	6	5.2	192	5		
39	309	Slug	6	5.8	192	5		
40	524	Slug	8		188	5		
41	349	Slug	5.5	4.1	187	5		
42	449	Slug	8	25.6	186	5		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
43	231	Slug	8	37.8	186	5		
44	257	Slug	8	41.8	186	5		
45	343	Slug	6	5.2	185	5		
46	300	Slug	6	4.9	184	5		
47	315	Slug	5.5	6.4	184	5		
48	522	Slug	5.5	18.5	183	5		
49	336	Slug	8	3.5	183	5		
50	376	Slug	8	14.6	178	5		
51	151	Slug	8	30	177	5		
52	301	Slug	6	5.8	177	5		
53	470	Slug	8	23.7	177	5		
54	331	Slug	6	4.8	176	5		
55	393	Slug	8	52.8	176	5		
56	319	Slug	6	6.1	175	5		
57	277	Slug	8.5	38.3	175	5		
58	334	Slug	6	5	173	5		
59	425	Slug	8	25.6	169	5		
60	307	Slug	5.5	6.3	169	5		
61	25	Slug	9	25.3	168	5		
62	348	Slug	6	5.3	164	5		
63	472	Slug	8	25	162	5		
64	488	Slug	8	18.3	161	5		
65	365	Slug	8	9	161	5		
66	347	Slug	6	5.6	160	5		
67	338	Slug	6	5.6	160	5		
68	362	Slug	6	6.6	158	5		
69	546	Slug	8	18.5	154	5		
70	521	Slug	5.5	14.4	153	5		
71	345	Slug	6	4.6	152	5	**6885**	**39**
72	346	Slug	5.5	4.5	149	4		
73	508	Slug	8	18.5	148	4		
74	131	Slug	8	29.8	148	4		
75	323	Slug	6	6.7	144	4		
76	456	Slug	8	22	142	4		
77	320	Slug	6	4.2	142	4		
78	15	Slug	8.75	13.4	141	4		
79	310	Slug	6	5.5	131	4		
80	340	Slug	6	4.4	131	4		
81	281	Slug	6	19.4	130	4		
82	302	Slug	6	4.5	129	4		
83	335	Slug	5.5	4.4	126	4		
84	304	Slug	6	5	126	4		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
85	308	Slug	6	3	125	4		
86	486	Slug	8	17	124	4		
87	249	Slug	8	26	124	4		
88	489	Slug	8	16.1	124	4		
89	48	Slug	8	23.9	122	4		
90	487	Slug	8	14.7	120	4		
91	317	Slug	6	4.1	119	4		
92	318	Slug	6	3.6	118	4		
93	493	Slug	8	15.6	115	4		
94	195	Slug	8	30.8	114	4		
95	228	Slug	8	21.5	113	4		
96	342	Slug	6	4.9	111	4		
97	267	Slug	8.5	18.7	109	4		
98	136	Slug	9	21.6	108	4		
99	138	Slug	8	17.6	107	4		
100	133	Slug	8	27.9	107	4		
101	306	Slug	5.5	4	106	4		
102	506	Slug	8	12.5	104	4		
103	316	Slug	6	5.3	103	4	**3959**	**32**
104	263	Slug	8.5	32.4	187	3		
105	516	Slab	13	8.1	114	3		
106	329	Slug	8	3.4	101	3		
107	505	Slug	10	10.9	100	3		
108	197	Slug	8	23.7	100	3		
109	374	Slug	8	6.8	99	3		
110	395	Slug	8.5	30.5	98	3		
111	295	Slug	6	4.7	97	3		
112	383	Slug	8	43.8	97	3		
113	4	Slug	9	12.4	96	3		
114	370	Slug	9	6.6	96	3		
115	314	Slug	6	3.7	95	3		
116	218	Slug	8	18.2	94	3		
117	29	Slug	8.5	10.8	94	3		
118	380	Slug	8	10.3	93	3		
119	261	Slug	8	23	93	3		
120	459	Slug	8.5	12.7	91	3		
121	357	Slug	8	4.3	90	3		
122	384	Slug	8	19.3	90	3		
123	392	Slug	8	25	89	3		
124	256	Slug	8	20.4	89	3		
125	424	Slug	8.5	14	89	3		
126	369	Slug	8	7.4	89	3		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
127	387	Slug	8	19.1	88	3		
128	469	Slug	8	13.1	87	3		
129	137	Slug	8	19.1	87	3		
130	47	Slug	8	12.8	85	3		
131	124	Slug	8	17.9	85	3		
132	100	Slab	13	8.2	84	3		
133	397	Slug	8	12	83	3		
134	1	Slab	13	5.2	83	3		
135	460	Slug	8	10.2	83	3		
136	360	Slug	8	2.9	82	3		
137	39	Slug	8.5	10.3	82	3		
138	368	Slug	8	6.3	82	3		
139	16	Slug	9	9	80	3		
140	382	Slug	8	19.6	79	3		
141	414	Slug	8	10	78	3		
142	240	Slug	8	14	77	3		
143	80	Slab	13	6.3	76	3		
144	381	Slug	8	18.2	76	3		
145	500	Slug	8	9.4	74	3		
146	386	Slug	8	14.4	72	3		
147	292	Slug	8	2.6	72	3		
148	11	Slab	13	4.7	72	3		
149	62	Slab	13	6.2	72	3		
150	77	Slab	13	6.6	72	3		
151	114	Slab	13	7	71	3		
152	12	Slug	9	8.2	71	3		
153	153	Slug	8	13	71	3		
154	95	Slab	13	6.6	70	3		
155	145	Slug	8.5	12.9	70	3		
156	96	Slab	13	7.2	70	3		
157	290	Slug	8	2.1	70	3		
158	87	Slab	13	5.9	69	3		
159	436	Slug	8	12.7	69	3		
160	252	Slug	8	17.3	68	3		
161	158	Slug	8	16.3	68	3		
162	157	Slug	8.5	19	68	3		
163	155	Slug	8	15.2	68	3		
164	88	Slab	13	8.4	68	3		
165	140	Slug	8.5	13.2	67	3		
166	53	Slab	13	5.4	66	3		
167	90	Slab	13	5.7	64	3		
168	337	Slug	6	4	64	3		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
169	65	Slug	8	12.5	64	3		
170	165	Slug	8.5	14.7	64	3		
171	171	Slug	8	17	63	3		
172	37	Slug	9	8.5	63	3		
173	52	Slab	13	6.2	63	3		
174	78	Slab	13	6.3	62	3		
175	81	Slab	13	5.4	62	3		
176	112	Slab	13	6	62	3		
177	91	Slab	13	5.4	61	3		
178	107	Slab	13	6.3	61	3		
179	86	Slab	13	7	61	3		
180	224	Slug	8	11.9	61	3		
181	84	Slab	12	6.5	61	3		
182	109	Slab	13	6.7	61	3		
183	119	Slab	13	7.4	60	3		
184	113	Slab	13	6.6	60	3		
185	68	Slug	8	9.0	60	3		
186	105	Slab	13	7.1	60	3		
187	101	Slab	13	8	60	3		
188	430	Slug	8	8.6	60	3		
189	204	Slug	8	17	60	3		
190	547	Slug	12	4.2	59	3		
191	350	Slug	8	2.5	58	3		
192	115	Slab	13	6.7	58	3		
193	260	Slug	8	12.9	58	3		
194	144	Slug	8.5	10.8	58	3		
195	111	Slab	13	6.6	58	3		
196	149	Slug	8	9	56	3		
197	515	Slug	8	8.6	55	3		
198	391	Slug	8	15.3	55	3		
199	103	Slab	13	5.1	55	3		
200	82	Slab	13	5.4	54	3		
201	378	Slug	8	6	54	3		
202	99	Slab	13	5.6	54	3		
203	170	Slug	8.5	12.1	54	3		
204	85	Slab	13	6.4	54	3		
205	110	Slab	13	7.2	53	3		
206	94	Slab	13	5	53	3		
207	417	Slug	8	8.6	53	3		
208	117	Slab	13	5.6	53	3		
209	106	Slab	13	6.3	52	3		
210	396	Slug	8	15.5	41	3		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
211	518	Slug	12.5	4.8	37	3	**7901**	**108**
212	116	Slab	13	5.6	51	2		
213	121	Slab	13	7	51	2		
214	354	Slug	8	2.3	51	2		
215	98	Slab	13	6.1	50	2		
216	102	Slab	13	4.8	50	2		
217	108	Slab	13	6	49	2		
218	398	Slug	8	7.3	49	2		
219	19	Slug	9	8.7	49	2		
220	352	Slug	8	2.2	49	2		
221	175	Slug	8	14	49	2		
222	379	Slug	8	6	48	2		
223	451	Slug	8	6.8	48	2		
224	33	Slug	9	9.2	47	2		
225	147	Slug	8.5	12	47	2		
226	192	Slug	8	0	47	2		
227	371	Slug	8	3.4	47	2		
228	359	Slug	8	4.4	47	2		
229	20	Slug	9	7	47	2		
230	289	Slug	8	1.4	47	2		
231	74	Slug	8.5	9.7	46	2		
232	390	Slug	8	11.5	45	2		
233	14	Slug	9	5.4	45	2		
234	21	Slug	8.5	7.7	45	2		
235	373	Slug	8	4.1	45	2		
236	76	Slug	8.5	7.7	43	2		
237	457	Slug	8	6.1	41	2		
238	445	Slug	8	5.8	40	2		
239	410	Slug	8	5.8	40	2		
240	83	Slab	13	4.3	40	2		
241	97	Slab	13	6.2	40	2		
242	494	Slug	8	6.7	40	2		
243	161	Slug	9	8.6	39	2		
244	159	Slug	8	9	39	2		
245	71	Slug	9	5.5	39	2		
246	276	Slug	8	9.1	38	2		
247	167	Slug	8.5	9.1	38	2		
248	166	Slug	8	9.9	37	2		
249	134	Slug	8.5	6	37	2		
250	389	Slug	8	8.1	37	2		
251	271	Slug	8.25	6.2	36	2		
252	89	Slab	13	6.5	36	2		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
253	8	Slug	13	4.3	36	2		
254	238	Slug	8	8	36	2		
255	26	Slug	9	5.3	35	2		
256	128	Slug	8	6.6	35	2		
257	150	Slug	8	5.9	34	2		
258	13	Slug	9	4.3	34	2		
259	120	Slab	13	6	34	2		
260	458	Slug	8	5.5	34	2		
261	258	Slug	8	7	34	2		
262	441	Slug	8	5.1	34	2		
263	351	Slug	8	1.5	34	2		
264	225	Slug	8	6.3	33	2		
265	215	Slug	8	8.6	32	2		
266	375	Slug	8	3.5	32	2		
267	239	Slug	8	6.4	32	2		
268	184	Slug	8	9.8	32	2		
269	423	Slug	8.5	5.5	31	2		
270	44	Slug	8	0.5	31	2		
271	22	Slug	8	5.3	31	2		
272	287	Slug	7	7.5	29	2		
273	364	Slug	8	2.2	28	2		
274	122	Slug	8.5	4.7	28	2		
275	461	Slug	8	4.1	28	2		
276	356	Slug	8	1.3	28	2		
277	118	Slab	13	5.9	28	2		
278	194	Slug	8.5	6.5	27	2		
279	477	Slug	8	4.3	27	2		
280	328	Slug	9	1	27	2		
281	196	Slug	8	7.4	26	2		
282	208	Slug	8	9.3	26	2		
283	285	Slug	7	7.3	26	2		
284	139	Slug	8	4.4	26	2		
285	327	Slug	8	0.9	24	2		
286	181	Slug	8.5	4.3	24	2		
287	174	Slug	8	5.4	23	2		
288	178	Slug	8	5.4	23	2		
289	169	Slug	8	4.1	22	2		
290	126	Slug	8.5	4	22	2		
291	17	Slug	13	3.2	22	2		
292	428	Slug	8	3.8	21	2		
293	388	Slug	8	3.4	21	2		
294	200	Slug	8	5.8	21	2		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
295	255	Slug	8	5.2	20	2		
296	501	Slug	8	2.3	20	2		
297	10	Slab	13	4.9	20	2		
298	254	Slug	8	4.9	20	2		
299	55	Slug	8	2.4	19	2		
300	160	Slug	8	4.3	19	2		
301	234	Slug	8	3.8	19	2		
302	186	Slug	8	4.7	19	2		
303	447	Slug	8	3.0	19	2		
304	146	Slug	8	3.9	18	2		
305	473	Slug	8	3.3	18	2		
306	377	Slug	8	1.5	18	2		
307	272	Slug	8	3.2	18	2		
308	385	Slug	8	2	18	2		
309	429	Slug	8	3.4	17	2		
310	132	Slug	8	2.5	16	2		
311	61	Slug	8	2.4	16	2		
312	245	Slug	8	3.6	16	2		
313	237	Slug	8	3.75	16	2		
314	130	Slug	8	2.9	15	2		
315	497	Slug	8	4	15	2		
316	361	Slug	8	1.1	15	2		
317	523	Slug	2	2	15	2		
318	180	Slug	8	0	15	2		
319	444	Slug	8	2.8	15	2		
320	172	Slug	8	3.3	15	2		
321	93	Slab	13	6	15	2		
322	75	Slug	8	3	15	2		
323	296	Slug	8.5	0.5	15	2		
324	434	Slug	8	2.8	15	2		
325	437	Slug	8	2.4	14	2		
326	125	Slug	8.5	2.6	14	2		
327	211	Slug	8	4.6	13	2		
328	162	Slug	8	2.6	13	2		
329	168	Slug	8.5	3	13	2		
330	72	Slug	8	1.5	13	2		
331	220	Slug	8	2.4	13	2		
332	298	Slug	8	0.4	13	2		
333	439	Slug	8.5	2.7	13	2		
334	42	Slug	8	2.6	12	2		
335	529	Slug	13	1.3	12	2		
336	279	Slug	8.25	3	11	2		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
337	35	Slug	8	1.7	11	2		
338	253	Slug	8	1.9	9	2		
339	104	Slab	13	7	9	2		
340	545	Slug	7.5	0.2	9	2		
341	431	Slug	8	1.8	9	2		
342	471	Slug	8	2.2	9	2		
343	450	Slug	8	2	9	2		
344	467	Slug	8	1.8	9	2		
345	152	Slug	8	1.4	8	2		
346	454	Slug	8	2.1	8	2		
347	142	Slug	8	1.2	8	2		
348	60	Slug	8	1.2	8	2		
349	455	Slug	8	1.9	8	2		
350	266	Slug	8.5	1.4	8	2		
351	511	Slug	8	1.3	8	2		
352	297	Slug	8	0.2	7	2		
353	244	Slug	8	1.6	7	2		
354	248	Slug	8	1.8	7	2		
355	164	Slug	8	1.2	7	2		
356	24	Slug	8	1.3	7	2		
357	221	Slug	8	1.6	7	2		
358	427	Slug	8	1.7	7	2		
359	38	Slug	8.5	1	6	2		
360	420	Slug	8	1.7	6	2		
361	191	Slug	8	1.4	6	2		
362	188	Slug	8	1.2	6	2		
363	31	Slug	8	1.1	6	2		
364	355	Slug	8	0.3	5	2		
365	478	Slug	8	1.5	5	2		
366	163	Slug	8	1.3	5	2		
367	490	Slug	8	2	5	2		
368	498	Slug	8	2	4	2		
369	141	Slug	8	0.5	4	2		
370	251	Slug	8	0.9	4	2		
371	57	Slug	8	0.3	3	2		
372	183	Slug	8	0.5	3	2		
373	45	Slug	8	0.5	3	2		
374	411	Slug	8	1.2	3	2		
375	479	Slug	8	1.3	3	2		
376	79	Slug	8	0.4	2	2		
377	59	Slug	8	0.5	2	2		
378	322	Slug	6	0.1	2	2		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
379	408	Slug	8	1	2	2		
380	433	Slug	8	1.2	2	2		
381	227	Slug	8	0.7	2	2		
382	216	Slug	8	1	1	2		
383	40	Slug	8	0	1	2		
384	226	Slug	8	0.4	1	2		
385	299	Slug	8	0.1	1	2		
386	210	Slug	8	0.3	1	2		
387	485	Slug	8	1.5	1	2		
388	435	Slug	8	1.3	0.5	2		
389	482	Slug	8	1.5	0.3	2		
390	69	Slug	8	0.1	0.2	2		
391	422	Slug	8	0.7	0.1	2		
392	43	Slug	8.5	0	0.1	2	3957	181
393	413	Slug	8	0.7	0	1		
394	18	Slug	8.5	0.02	0	1		
395	23	Slug	8.5	0	0	1		
396	27	Slug	8.75	0	0	1		
397	28	Slug	9	0.2	0	1		
398	30	Slug	8	0	0	1		
399	32	Slug	8	0	0	1		
400	34	Slug	8.5	0.1	0	1		
401	36	Slug	8	0	0	1		
402	41	Slug	8	0.01	0	1		
403	46	Slug	9	0	0	1		
404	49	Slug	8	0.0	0	1		
405	50	Slug	8	0.0	0	1		
406	51	Slug	8	0.0	0	1		
407	54	Slug	8	0.0	0	1		
408	56	Slug	8	0.2	0	1		
409	58	Slug	8	0.1	0	1		
410	63	Slug	8	0.0	0	1		
411	64	Slug	8	0.0	0	1		
412	66	Slug	8	0.1	0	1		
413	67	Slug	9	0.1	0	1		
414	73	Slug	8	0.0	0	1		
415	92	Slug	8	0	0	1		
416	123	Slug	8.5	0.1	0	1		
417	127	Slug	9	0.1	0	1		
418	129	Slug	8	0.1	0	1		
419	143	Slug	8.5	0.2	0	1		
420	148	Slug	8.5	0.1	0	1		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
421	156	Slug	8	0.2	0	1		
422	173	Slug	8	0	0	1		
423	176	Slug	8	0	0	1		
424	177	Slug	8	0.1	0	1		
425	179	Slug	8	0	0	1		
426	182	Slug	8	0	0	1		
427	185	Slug	8	0	0	1		
428	187	Slug	8	0	0	1		
429	189	Slug	8	0	0	1		
430	190	Slug	8	0	0	1		
431	193	Slug	8	0	0	1		
432	198	Slug	8.5	0	0	1		
433	199	Slug	8	0.1	0	1		
434	201	Slug	8.5	0	0	1		
435	202	Slug	8	0	0	1		
436	203	Slug	8.5	0	0	1		
437	205	Slug	8	0	0	1		
438	206	Slug	8	0.3	0	1		
439	207	Slug	8	0.1	0	1		
440	209	Slug	8	0	0	1		
441	212	Slug	8	0	0	1		
442	213	Slug	8	0	0	1		
443	214	Slug	9	0	0	1		
444	217	Slug	8	0.1	0	1		
445	219	Slug	8	0.1	0	1		
446	222	Slug	8	0	0	1		
447	223	Slug	8	0.4	0	1		
448	229	Slug	8	0	0	1		
449	230	Slug	8	0	0	1		
450	232	Slug	8	0	0	1		
451	233	Slug	8	0	0	1		
452	235	Slug	8	0	0	1		
453	236	Slug	8	0.2	0	1		
454	241	Slug	8	0	0	1		
455	242	Slug	8	0	0	1		
456	243	Slug	8	0	0	1		
457	246	Slug	8	0	0	1		
458	247	Slug	8	0	0	1		
459	250	Slug	8	0	0	1		
460	259	Slug	8	0	0	1		
461	262	Slug	8	0	0	1		
462	264	Slug	8.25	0	0	1		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
463	265	Slug	8.25	0	0	1		
464	268	Slug	8.25	0	0	1		
465	269	Slug	8.25	0.1	0	1		
466	270	Slug	8.25	0.1	0	1		
467	273	Slug	8.25	0.1	0	1		
468	275	Slug	8.25	0.1	0	1		
469	278	Slug	8.25	0.1	0	1		
470	280	Slug	8.25	0.1	0	1		
471	288	Slug	8	0.1	0	1		
472	291	Slug	8	0	0	1		
473	293	Slug	8	0	0	1		
474	294	Slug	8	0	0	1		
475	326	Slug	8	0	0	1		
476	332	Slug	8.5	0.1	0	1		
477	353	Slug	8.5	0.1	0	1		
478	358	Slug	6	0.1	0	1		
479	363	Slug	8	0.1	0	1		
480	366	Slug	8	0.2	0	1		
481	367	Slug	8	1.5	0	1		
482	399	Slug	8	0.6	0	1		
483	400	Slug	8	0.5	0	1		
484	401	Slug	8.5	0.5	0	1		
485	402	Slug	8.5	0.6	0	1		
486	403	Slug	8	0.6	0	1		
487	404	Slug	8	0.6	0	1		
488	405	Slug	8	0.6	0	1		
489	406	Slug	8	0.7	0	1		
490	407	Slug	8	0.7	0	1		
491	409	Slug	8	0.7	0	1		
492	412	Slug	8	0.7	0	1		
493	415	Slug	8.5	0.7	0	1		
494	416	Slug	8	0.7	0	1		
495	418	Slug	8	0.8	0	1		
496	419	Slug	8.5	0.8	0	1		
497	421	Slug	8	0.7	0	1		
498	426	Slug	8.5	0.8	0	1		
499	432	Slug	8	1	0	1		
500	440	Slug	8	0.9	0	1		
501	442	Slug	8	0.8	0	1		
502	443	Slug	8	0.9	0	1		
503	446	Slug	8	0.8	0	1		
504	448	Slug	8	0.9	0	1		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
505	452	Slug	8	0.5	0	1		
506	453	Slug	8	1	0	1		
507	462	Slug	8.5	0.8	0	1		
508	463	Slug	8	0.9	0	1		
509	464	Slug	8.5	0.9	0	1		
510	465	Slug	8	0.9	0	1		
511	466	Slug	8	0.9	0	1		
512	468	Slug	8	0.9	0	1		
513	474	Slug	8	0.9	0	1		
514	475	Slug	8	0.9	0	1		
515	476	Slug	8	0.8	0	1		
516	480	Slug	8	1	0	1		
517	481	Slug	8	0.9	0	1		
518	483	Slug	8	1.3	0	1		
519	484	Slug	8	1.4	0	1		
520	491	Slug	8	1.4	0	1		
521	492	Slug	8	1.5	0	1		
522	495	Slug	8	1.5	0	1		
523	496	Slug	8	1.5	0	1		
524	499	Slug	8	0.1	0	1		
525	502	Slug	8	0	0	1		
526	503	Slug	8	0	0	1		
527	507	Slug	8	0.1	0	1		
528	509	Slug	8	0	0	1		
529	510	Slug	8	0	0	1		
530	512	Slug	8	0.1	0	1		
531	513	Slug	8	0.2	0	1		
532	514	Slug	8	0.1	0	1		
533	525	Slug	7.5	0.2	0	1		
534	526	Slug	11	0.2	0	1		
535	527	Slug	11.5	0.2	0	1		
536	530	Slug	12	0	0	1		
537	531	Slug	12	0	0	1		
538	532	Slug	6	0	0	1		
539	533	Slug	1	0	0	1		
540	534	Slug	1	0	0	1		
541	535	Slug	2	0	0	1		
542	536	Slug	1	0	0	1		
543	537	Slug	1	0	0	1		
544	538	Slug	2	0.1	0	1		
545	539	Slug	1	0	0	1		
546	540	Slug	3	0	0	1		

Table 1. Curies of Co-60 in L-Area Basin Cobalt Slugs and Slabs (continued)

Item #	Analysis Sequence #	Slug/Slab	Length (inches)	R07 (R/hr) (@ 24")	Ci(Co-60) curies	Bin#	Ci/Bin	Items/bin
547	541	Slug	3	0	0	1		
548	548	Slug	4	0	0	1	**0**	**156**
				TOTAL =	**31783**		**31783**	**548**

Curium Sampler Slug Analysis and Results (NaI detector/RO7 Monitor)

The curium sampler slugs have been stored in the basin for over thirty years. They originally contained a small piece of cobalt wire (1/16" x 1/16") to act as a neutron monitor,[5] and 100 milligrams of Pu-239 to convert to Cm-244. When the slugs were irradiated, the neutron flux converted some of the cobalt into Co-60, which has decayed since the irradiation. By determining the amount of Co-60 produced for a known irradiation time, the neutron flux was determined and the amount of original Pu-239 remaining was determined.[7]

After the slug tray was moved from 12" to 2 ¾" and the collimators were removed, routine NaI assays (2-min counts) were done on all the curium sampler slugs, and a 50,000-second count was done on selected slug #0654. Figure 7 shows the spectrum of the 50,000-second count. Except for Cs-137 from the basin water and a detectable peak for Co-60, no other peaks were detected above background.

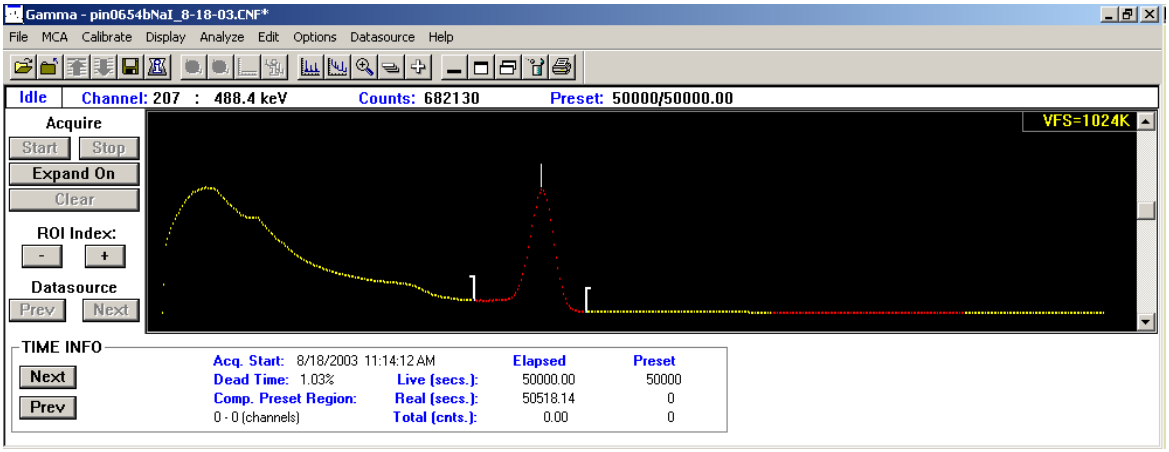


Figure 7. NaI count (50,000 sec) at collimator tray distance of 2 ¾" with collimators removed.

Since the RO7 dose monitor (on contact) was the most sensitive instrument, it was calibrated with a previously analyzed cobalt slug and used for the Co-60 determination (described below).[8]

1. System Calibration for Movement of Slug Tray from 12" to 2 3/4" and remove collimators

NaI Assay - Slugs w/ collimators and tray @ 12"

Slug	Counts	time (s)
Cal #3	7259	600

NaI Assay - Slugs w/o collimators and tray @ 2 3/4"

Slug	Counts	time (s)
Cal #3	394230	120

Geometry Correction = (394230/120) / (7259/600) = 272

Geometry Correction = 272 (used to measure cobalt below in different geometry)
(The distance correction of moving the tray without moving the collimators was determined to be 5.8; therefore, the correction for removing the collimators is calculated to be (272/5.8) = **47**.)

2. Calibration of RO7 Radiation Monitor for Contact Measurements

Slug	NaI Counts (Co-60)	Length (inches)	RO7 (R/Hr) contact	Measured Ci(Co-60)	**(R/Hr)/Ci**
cal#2	72252	8	74.4	1.405	**53**

3. Measured values in R/hr of Co-60 per Curium Sampler Slug (Pin) on contact

PIN #	**(R/Hr)**
632	2.6
615	2.1
633	2.6
640	2.4
625	2.2
641	2.5
636	2.5
618	2.3
639	2.4
616	2.5
601	2.3
650	2.3

637 2.4
635 2.5
653 2.6
648 2.6
621 2.6

AVE = 2.4 R/Hr

4. Determination of Curium Sampler Slug (pin) R07 detection efficiency versus Cobalt Slug detector efficiency[9]

Microshield Slug Det Eff		Corrected Water Att Slug value		Microshield Corr Slug Det Eff	Microshield Pin Det Eff	Eff. Ratio (Pin Det Eff / Slug Det Eff)
3.19E+05	X	0.95	=	3.03E+05	1.09E+06	**3.60E+00**

5. Determination of the average curies of Co-60 per Curium Sampler Slug (pin)

Ci Co-60/pin (8/4/2003) = (Pin R/Hr) / ((Slug R/Hr / Eff. Ratio))

Pin (R/Hr)	R/Hr/Ci (slug)	Eff. Ratio	**Ci Co-60/pin (8/4/2003)**
2.4	53	3.60E+00	**0.0126**

6. Cobalt Produced in PIN Irradiation

Volume of wire = π x r^2 x L ; where r = radius, L = length
Volume of wire (cm^3) = 3.1416 x $(1/32)^2$ in^2 x (1/16) in x (2.54)3 cm^3/in^3
Volume of wire (cm3) = 3.14E-03

Target Nuclei = V x ρ x N_{Av} / A ; where ρ = density, N_{Av} = Avagadro's Number, A = atomic wt
Target Nuclei = (3.14E-03 cm^3 x 8.9 g/cm^3 x 6.02E+23 atoms) / 58.93 g
Target Nuclei (N) = 2.86E+20

Ci (assay) = **2.02 Ci produced on 12/19/1964** (0.0126 Ci 8/4/03)

7. Per report TC 1-1361, the curium sampler slugs were irradiated for 0.55 years and the flux is calculated as follows:

Co-60 activity = (σ x N x ϕ / 3.7E+10) (1 - $e^{-\lambda t}$) ; where σ = thermal neutron cross section, ϕ = thermal neutron flux, λ = Co-60 decay constant

2.02 = (37E-24 cm^{-1} x 2.86E+20 nuclei x ϕ $n/cm^2/sec$ / 3.7E+10 dps/Ci) (1 - $e^{(-0.693 \times 0.55/5.27)}$)

flux = 1.01E+14 n/cm2/sec

8. From this flux and using the graphs in report TA 1-1361, the activities obtained for the 18 pins (total grams Pu-239 = 0.1 grams/pin x 18 pins) are given in Table 2.

Table 2. Activities produced from irradiation of 18 curium sampler slugs.

Nuclide	g/g Pu-239	gPu-239	half-life (yr)	decay factor	grams 8/4/03	**Ci 8/4/03**
Pu-238	5.0E-06	1.8E+00	8.775E+01	7.37E-01	6.6E-06	**1.1E-04**
Pu-239	2.7E-01	1.8E+00	2.413E+04	9.99E-01	4.9E-01	**3.0E-02**
Pu-240	2.2E-01	1.8E+00	6.569E+03	9.96E-0	3.9E-01	**8.9E-02**
Pu-241	6.0E-02	1.8E+0	1.44E+01	1.56E-01	1.7E-02	**1.7E+00**
Pu-242	2.0E-02	1.8E+00	3.758E+05	1.00E+00	3.6E-02	**1.4E-04**
Am-241	4.5E-04	1.8E+00	4.322E+02	9.40E-01	7.6E-04	**2.6E-03**
Am-243	1.3E-03	1.8E+00	7.380E+03	9.96E-01	2.3E-03	**4.6E-04**
Cm-242	2.5E-04	1.8E+00	4.468E-01	9.55E-27	4.3E-30	**8.6E-27**
Cm-244	1.1E-04	1.8E+00	1.811E+01	2.28E-01	4.5E-05	**3.7E-01**

Measurement Uncertainty = slug calibration uncertainty + RO7 calibration uncertainty + geometry correction

Measurement Uncertainty = 100 * SQRT $((0.25)^2 + (0.20)^2 + (0.15)^2)$ = **35%**

Curium Sampler Slug Analysis and Results (HPGe detector)

Since a high purity germanium (HPGe) detector has much better resolution than a NaI detector, 2-min counts were done on all the curium sampler slugs with the HPGe detector at a collimator tray distance of 2 ¾" with the collimators removed. No nuclides except Cs-137 from the basin water were detected. A 50,000 sec count was done on sampler slug labeled 0618 (spectrum shown in Figure 8) and in addition to Cs-137 a very small Co-60 peak was detected. Although some Co-60 was detected, it was impossible to position the curium slug in the collimator tray such that the exact position of the 1/16" x 1/16" cobalt wire was known. The wire was known to be approximately in the center of the slug, but its position within the slug, which affects the attenuation, also was not known. Therefore, this arrangement was not deemed to be reliable for the Co-60 measurement.

The primary reason that this detector system was used was to look for any nuclides present. No other nuclides were detected below the Cs-137 (661.65 keV) peak shown because of the high Compton background. In addition to Cs-137, the only other discernable peaks detected were for the nuclides Eu-154 (723.4; 873.5; 1004.9;1274.3 keV), Co-60 (1173.2; 1332.5 keV) and K-40 (1460.6 keV).

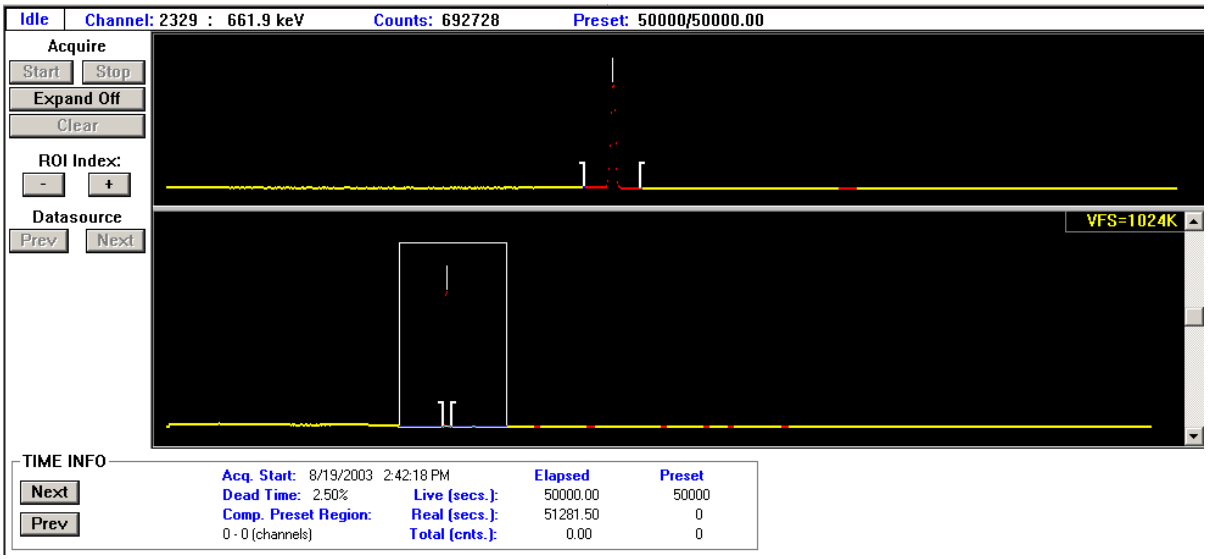


Figure 8. HPGe 50,000 sec count of curium sampler slug 0618; Cs-137 peak seen in top window.

CONCLUSIONS

Using a sodium iodide detector and multichannel analyzer system and an underwater collimator assembly, the Co-60 concentrations were determined for 548 L-Reactor Disassembly Basin cobalt slugs and slabs and 18 curium sampler slugs. The total activity of all of the 548 assayed slugs and slabs (items) summed to 31,783 curies. No Co-60 was detected for 156 items, while 180 had 0 – 50 curies; 108 had 50 – 100 curies; 32 had 100 – 150 curies; 40 had 150 – 200 curies; 31 had 200 – 500 curies, and 1 had greater than 500 curies.

The amount of Co-60 in the curium sampler slugs was determined by calibrating an RO7 dose monitor with a slug of known activity. A geometry correction was made for the curium sampler slug cobalt distribution (1/16” x 1/16’ wire) compared to the cobalt slug geometry (8” rod). From the Co-60 of the curium sampler slugs, the irradiation flux was determined for the known irradiation time. The amounts of Pu-238,239,240,241,242; Am-241,243; and Cm-242,244 produced were then obtained based on the original amount of Pu-239 irradiated. The curium sampler slugs were analyzed with a high purity germanium detector (overnight count). In addition to Cs-137 from the basin water, the only other discernable peaks were for Co-60, Eu-154 and K-40.

6. REFERENCES

1. F. S. Moore and Saleem Salaymeh, SRT-ADS-99-0327, Co-60 *Assay Values of Co-60 Slugs in K Reactor Disassembly Basin*, 8/10/99.

2. Frank Moore and Saleem Salaymeh, SRT-ADS-99-0391, *Co-60 Assay Values of Co-60 Slugs in L Reactor Disassembly Area*, 9/13/99.

3. Frank Moore and Saleem Salaymeh, SRT-ADS-99-0453, *Assay of Miscellaneous Slugs in L Reactor Storage Basin*, 11/3/99.

4. SOP-DHS-117-L, Rev. 0, *Receipt of Cobalt in 8-Ton SRL Cask-Disassembly*, 6/03.

5. Hilley, J.R., Smith, J.A., Nelson, E.C., *Curium-244 Production Program*, TA 1-1361, 4/21/64.

6. SOP-DHS-121-L, Rev. 0, *Assay of Cobalt Slugs*, 6/03.

7. MacLeod, S.M., *Curium-244 Production Program*, TC 1-1361, 10/25/65.

8. Casella, V.R., *Determinations of Radionuclides in L-Area Curium Sampler Slugs (Pins)*, G-GLC-A-00116, 9/16/03.

9. Microshield v5.03 (5.03-00075), Grove Engineering, Rockville, Maryland, 10/96.

Appendix 1. Qualification Plan for Characterizing Cobalt Slugs in L-Basin

Qualification Plan for Characterizing Cobalt Slugs in L-Basin (SRT-ADS-2003-0-303)

1. **Purpose:**

This methodology provides the requirements for analysis and reporting of Co-60 concentrations in SRS L-Basin cobalt slugs.

These slugs were stored in the basin for many years. They were the input slugs for various irradiation campaigns, fuel assembly spacers, and the irradiated slugs resulting from various campaigns. The Co slugs were irradiated in the early 1970s to an activity of up to approximately 50-60,000 Ci/slug. Decay corrected to the present time, this yields potentially up to 1 KCi/slug. The most cost effective way to shield a source of this magnitude is to use the basin water in which the slugs are stored as the shield, while keeping the gamma detector above the water. Very little information exists on the isotopic content of the slugs.

2. **Scope:**

This task is part of the SRTC/ADS support being provided to Special Nuclear Fuels to develop and implement a non-destructive analysis (NDA) method that can be used to measure the Co-60 in SRS L-Basin cobalt slugs.

3. **Responsibilities:**

a. Task Manager: the task manager is responsible for ensuring that the task activities are adequately controlled and documented.

b. Task Leader (CTF): the task CTF is responsible for ensuring that the requirements of this methodology are followed and complied with. The task CTF may verbally delegate activities to team members.

c. Task Scientist: task scientists are responsible to follow the requirements of this methodology.

Procedure:

a. Instrument Setup:

i. An air filled collimator has been designed, as described in SRT-ADS-99-0327, to allow a small pencil of gamma radiation from the slug to reach the detector, a 2”x 2” NaI crystal. Eleven feet of basin water provided the gamma ray shielding. A tray to hold the slug was placed below the lower end of the collimator.

ii. A portable multichannel analyzer (MCA) and associated electronics will be used for data acquisition and analysis. Data will be stored on floppy disks for subsequent review and analysis and permanent retention.

ii. The gamma ray spectrum from Co-60 consists of two gamma rays, one at 1.17 MeV and the other at 1.33 MeV. A "region of interest" (ROI) will be defined around these two gamma rays in the spectrum, and the number of counts in this region summed by the MCA software. This provided the data necessary to assay the slugs. A typical gamma ray spectrum is shown in SRT-ADS-99-0391. The two prominent Co-60 peaks can be seen with the ROI markers around them, and a small Cs-137 peak is also seen in the basin water.

iii. Per procedure SOP-DHS-121-L, Assay of Cobalt Slugs, RO-7 readings will be taken of the slug and recorded.

b. Calibration:

i. The same calibration will be used as in the K Reactor assay, described in SRT-ADS-0327, and previous Co-60 slug measurements described in SRT-ADS-99-0391. Four slugs were chosen to have different nominal values in an effort to obtain a linear relationship between counts and activity. Analysis of the data showed that this was not possible, so the data were averaged. The basin background count rate in the ROI was subtracted from the average count and this divided by the average number of Curies/slug to obtain the conversion factor of 189089 counts/two minutes/ KCi. The uncertainty in this value is +/- 25% and this uncertainty must be added in quadrature to the other measurement uncertainties, including counting statistics.

The slugs in L Basin are assumed to be essentially identical to those in K Reactor basin. The gamma rays seen by the detector have come from various points within the slug. Therefore the attenuation of the gamma rays from the various portions of the slug will differ because of the differing distances traveled in the slug. Since attenuation depends upon the composition and density of the slug, if the slugs in L Basin are not identical to those in K Basin, the calibration will be in error by an unknown amount.

ii. The Task CTF and Task Manager will review all NDA results and reports to verify that there are no features present that will make the slugs unsuitable for analysis. The task CTF and Task Manager will initial and date the NDA reports to indicate acceptance of the NDA results.

c. System Quality Assurance/Quality Control:

i. A background analysis will be performed each day prior to sample analysis and approved by the Task CTF or Task Manager or Task Scientist.

ii. A gamma source will be counted in a known geometry prior to analysis and after analysis completion to ensure that the energy calibration has not changed significantly and to verify that the counts in a designated peak agree to within the previously determined control chart limits (3-sigma). This source check must be approved by the Task CTF or Task Manager or Task Scientist. If the source checks

are not within the control chart limits, the samples must be re-assayed or a reason that the sample(s) are not re-assayed must be documented in a final report.

iii. All data will be kept in a notebook and spectra will be stored on 31/2" floppy disks.

iv. Both slugs and slabs will be analyzed. The slugs have cobalt contained between two D-bar (half-round) pieces of metal (may be aluminum), while the slabs are pieces (may be rectangular) of cobalt with cladding. Since the gamma rays from Co-60 (1.17 MeV and 1.33 MeV) are very high energy, the difference in sample attenuation is considered well within the overall uncertainties reported.

v. Since the calibration is for a certain length slug (nominally 8") and since we are only measuring gamma rays from a portion of the sample, a correction must be made for samples of length that differ from the calibration length.

vi. In order to ensure that the results from this campaign are consistent with previous measurements, previously analyzed slugs will be reanalyzed to confirm that the present measurements are comparable to those previously done.

5. **Final Report:**

a. The results and conclusions of this investigation will be documented by a final report that will be prepared by the Task Manager. The report will be peer reviewed by the task team members and/or designated subject matter experts and will be approved by the task manager prior to issue.

b. The report will be provided to the L-Area Project Manager as part of the SRTC supporting work to this task.

6. **References:**

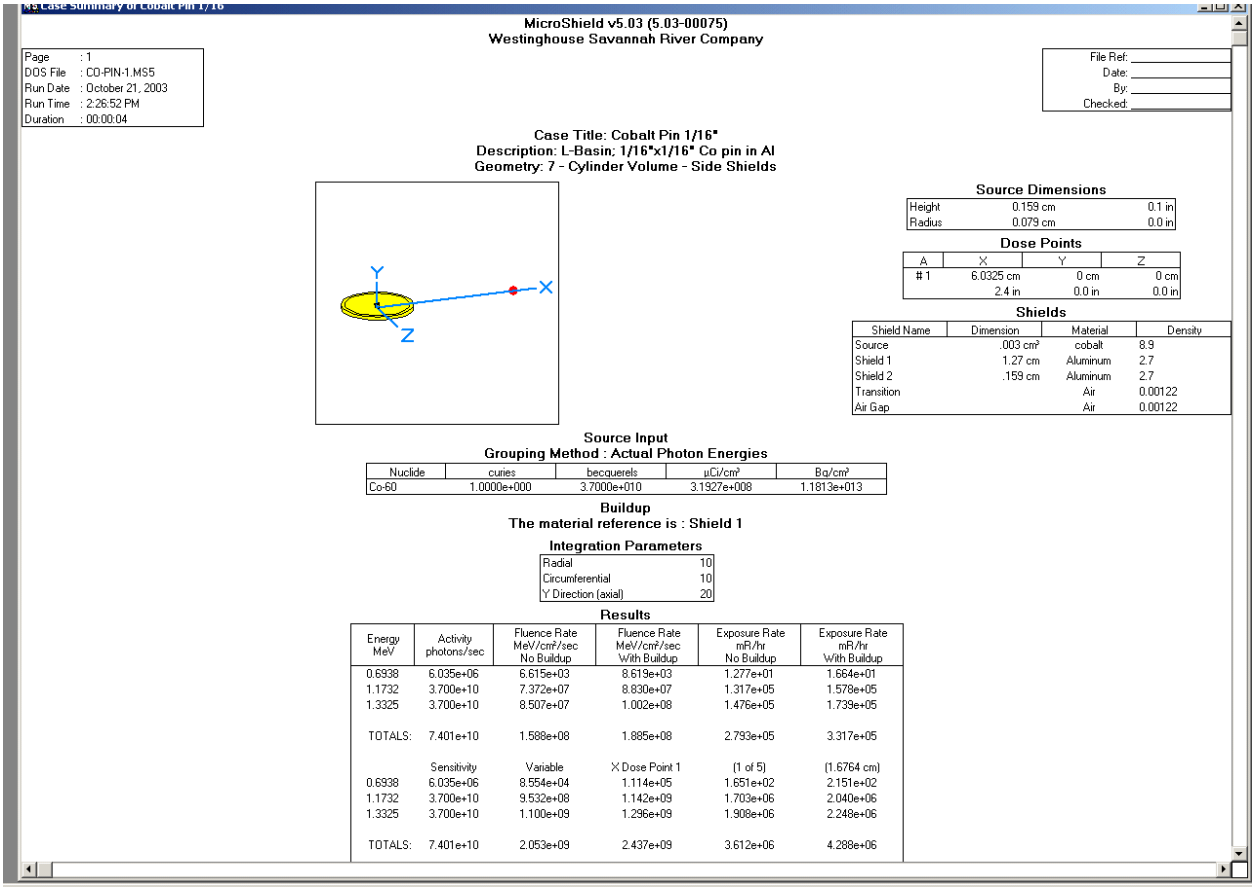
SRT-ADS-99-0327 Co-60 Assay Values of Co-60 Slugs in K Reactor Disassembly Basin, F. S. Moore and Saleem Salaymeh, Aug.10, 1999.

SRT-ADS-99-0391 Co-60 Assay Values of Co-60 Slugs in L Reactor Disassembly Area, Frank Moore and Saleem Salaymeh, Sep.13, 1999.

SRT-ADS-99-0453 Assay of Miscellaneous Slugs in L Reactor Storage Basin, Frank Moore and Saleem Salaymeh, Nov.3, 1999.

SOP-DHS-121-L Assay of Cobalt Slugs, June, 2003.

Appendix 2. Microshield calculation for curium sampler slug geometry correction.



MS Case Summary of Cobalt Pin 1/16

MicroShield v5.03 (5.03-00075)
Westinghouse Savannah River Company

Page	: 1
DOS File	: CO-PIN-1.MS5
Run Date	: October 21, 2003
Run Time	: 2:26:52 PM
Duration	: 00:00:04

File Ref:
Date:
By:
Checked:

Case Title: Cobalt Pin 1/16"
Description: L-Basin; 1/16"x1/16" Co pin in Al
Geometry: 7 - Cylinder Volume - Side Shields

Source Dimensions

Height	0.159 cm	0.1 in
Radius	0.079 cm	0.0 in

Dose Points

A	X	Y	Z
# 1	6.0325 cm	0 cm	0 cm
	2.4 in	0.0 in	0.0 in

Shields

Shield Name	Dimension	Material	Density
Source	.003 cm	cobalt	8.9
Shield 1	1.27 cm	Aluminum	2.7
Shield 2	.159 cm	Aluminum	2.7
Transition		Air	0.00122
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	μCi/cm³	Bq/cm³
Co-60	1.0000e+000	3.7000e+010	3.1927e+008	1.1813e+013

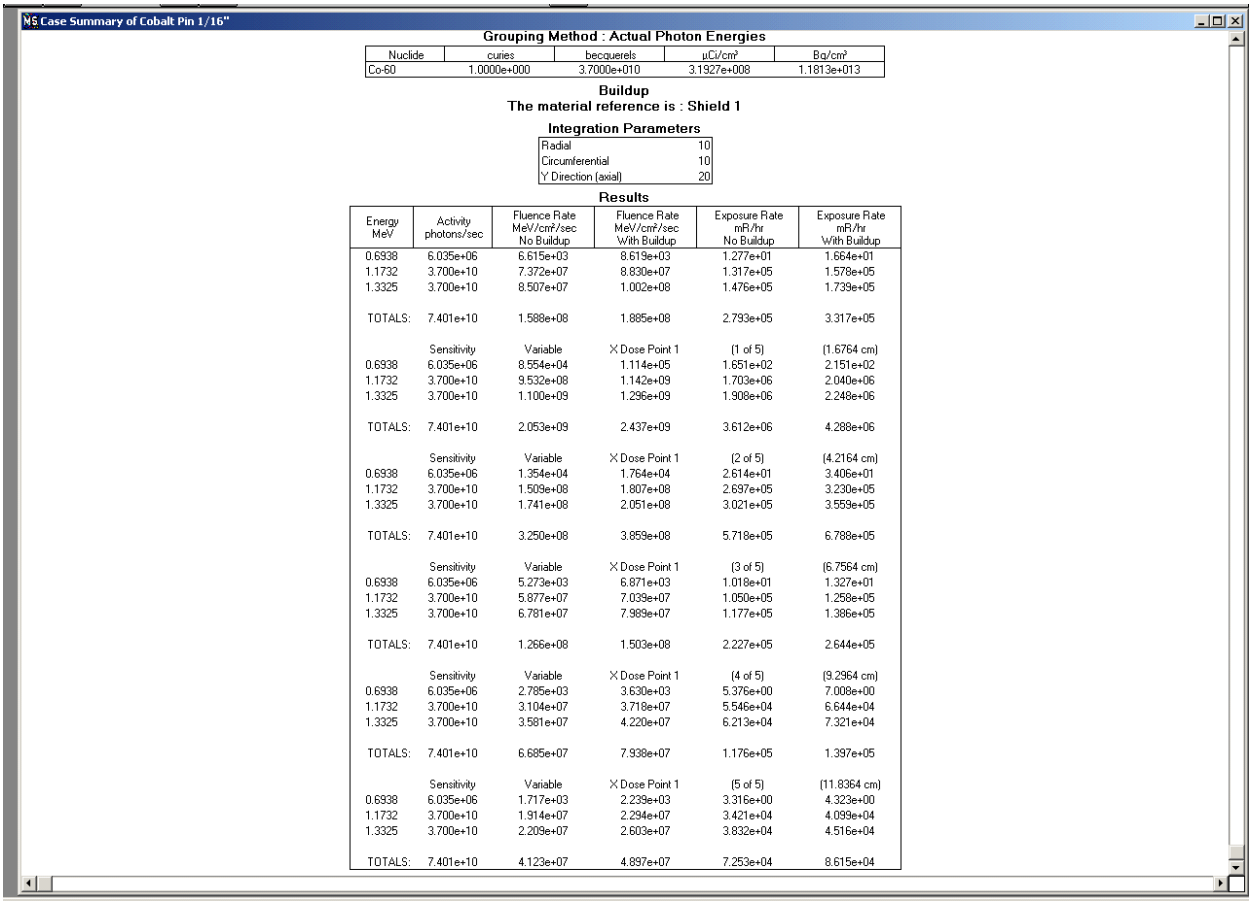
Buildup
The material reference is : Shield 1

Integration Parameters

Radial	10
Circumferential	10
Y Direction (axial)	20

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.6938	6.035e+06	6.615e+03	8.619e+03	1.277e+01	1.664e+01
1.1732	3.700e+10	7.372e+07	8.830e+07	1.317e+05	1.578e+05
1.3325	3.700e+10	8.507e+07	1.002e+08	1.476e+05	1.739e+05
TOTALS:	7.401e+10	1.588e+08	1.885e+08	2.793e+05	3.317e+05
	Sensitivity	Variable	X Dose Point 1	(1 of 5)	(1.6764 cm)
0.6938	6.035e+06	8.554e+04	1.114e+05	1.651e+02	2.151e+02
1.1732	3.700e+10	9.532e+08	1.142e+09	1.703e+06	2.040e+06
1.3325	3.700e+10	1.100e+09	1.296e+09	1.908e+06	2.248e+06
TOTALS:	7.401e+10	2.053e+09	2.437e+09	3.612e+06	4.288e+06



MS Case Summary of Cobalt Pin 1/16"

Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm²	Bq/cm²
Co-60	1.0000e+000	3.7000e+010	3.1927e+008	1.1813e+013

Buildup
The material reference is : Shield 1

Integration Parameters

Radial	10
Circumferential	10
Y Direction (axial)	20

Results

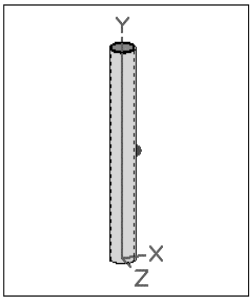
Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.6938	6.035e+06	6.615e+03	8.619e+03	1.277e+01	1.664e+01
1.1732	3.700e+10	7.372e+07	8.830e+07	1.317e+05	1.578e+05
1.3325	3.700e+10	8.507e+07	1.002e+08	1.476e+05	1.739e+05
TOTALS:	7.401e+10	1.588e+08	1.885e+08	2.793e+05	3.317e+05
	Sensitivity	Variable	X Dose Point 1	(1 of 5)	(1.6764 cm)
0.6938	6.035e+06	8.554e+04	1.114e+05	1.651e+02	2.151e+02
1.1732	3.700e+10	9.532e+08	1.142e+09	1.703e+06	2.040e+06
1.3325	3.700e+10	1.100e+09	1.296e+09	1.908e+06	2.248e+06
TOTALS:	7.401e+10	2.053e+09	2.437e+09	3.612e+06	4.288e+06
	Sensitivity	Variable	X Dose Point 1	(2 of 5)	(4.2164 cm)
0.6938	6.035e+06	1.354e+04	1.764e+04	2.614e+01	3.406e+01
1.1732	3.700e+10	1.509e+08	1.807e+08	2.697e+05	3.230e+05
1.3325	3.700e+10	1.741e+08	2.051e+08	3.021e+05	3.559e+05
TOTALS:	7.401e+10	3.250e+08	3.859e+08	5.718e+05	6.788e+05
	Sensitivity	Variable	X Dose Point 1	(3 of 5)	(6.7564 cm)
0.6938	6.035e+06	5.273e+03	6.871e+03	1.018e+01	1.327e+01
1.1732	3.700e+10	5.877e+07	7.039e+07	1.050e+05	1.258e+05
1.3325	3.700e+10	6.781e+07	7.989e+07	1.177e+05	1.386e+05
TOTALS:	7.401e+10	1.266e+08	1.503e+08	2.227e+05	2.644e+05
	Sensitivity	Variable	X Dose Point 1	(4 of 5)	(9.2964 cm)
0.6938	6.035e+06	2.785e+03	3.630e+03	5.376e+00	7.008e+00
1.1732	3.700e+10	3.104e+07	3.718e+07	5.546e+04	6.644e+04
1.3325	3.700e+10	3.581e+07	4.220e+07	6.213e+04	7.321e+04
TOTALS:	7.401e+10	6.685e+07	7.938e+07	1.176e+05	1.397e+05
	Sensitivity	Variable	X Dose Point 1	(5 of 5)	(11.8364 cm)
0.6938	6.035e+06	1.717e+03	2.239e+03	3.316e+00	4.323e+00
1.1732	3.700e+10	1.914e+07	2.294e+07	3.421e+04	4.099e+04
1.3325	3.700e+10	2.209e+07	2.603e+07	3.832e+04	4.516e+04
TOTALS:	7.401e+10	4.123e+07	4.897e+07	7.253e+04	8.615e+04

MicroShield v5.03 (5.03-00075)
Westinghouse Savannah River Company

Page	: 1
DOS File	: CO-PIN-2.MS5
Run Date	: October 24, 2003
Run Time	: 1:24:32 PM
Duration	: 00:00:04

File Ref: _____
Date: _____
By: _____
Checked: _____

Case Title: Co-Al Pin 8"
Description: L-Basin; 8"x1" Co-Al pin in Al
Geometry: 7 - Cylinder Volume - Side Shields



Source Dimensions

Height	20.32 cm	8.0 in
Radius	1.27 cm	0.5 in

Dose Points

A	X	Y	Z
# 1	1.6764 cm	10.16 cm	0 cm
	0.7 in	4.0 in	0.0 in

Shields

Shield Name	Dimension	Material	Density
Source	102.963 cm³	Cobalt/Aluminum	5.8
Shield 1	.159 cm	Aluminum	2.7
Transition		Air	0.00122
Air Gap		Air	0.00122

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm³	Bq/cm³
Co-60	1.0000e+000	3.7000e+010	9.7122e+003	3.5935e+008

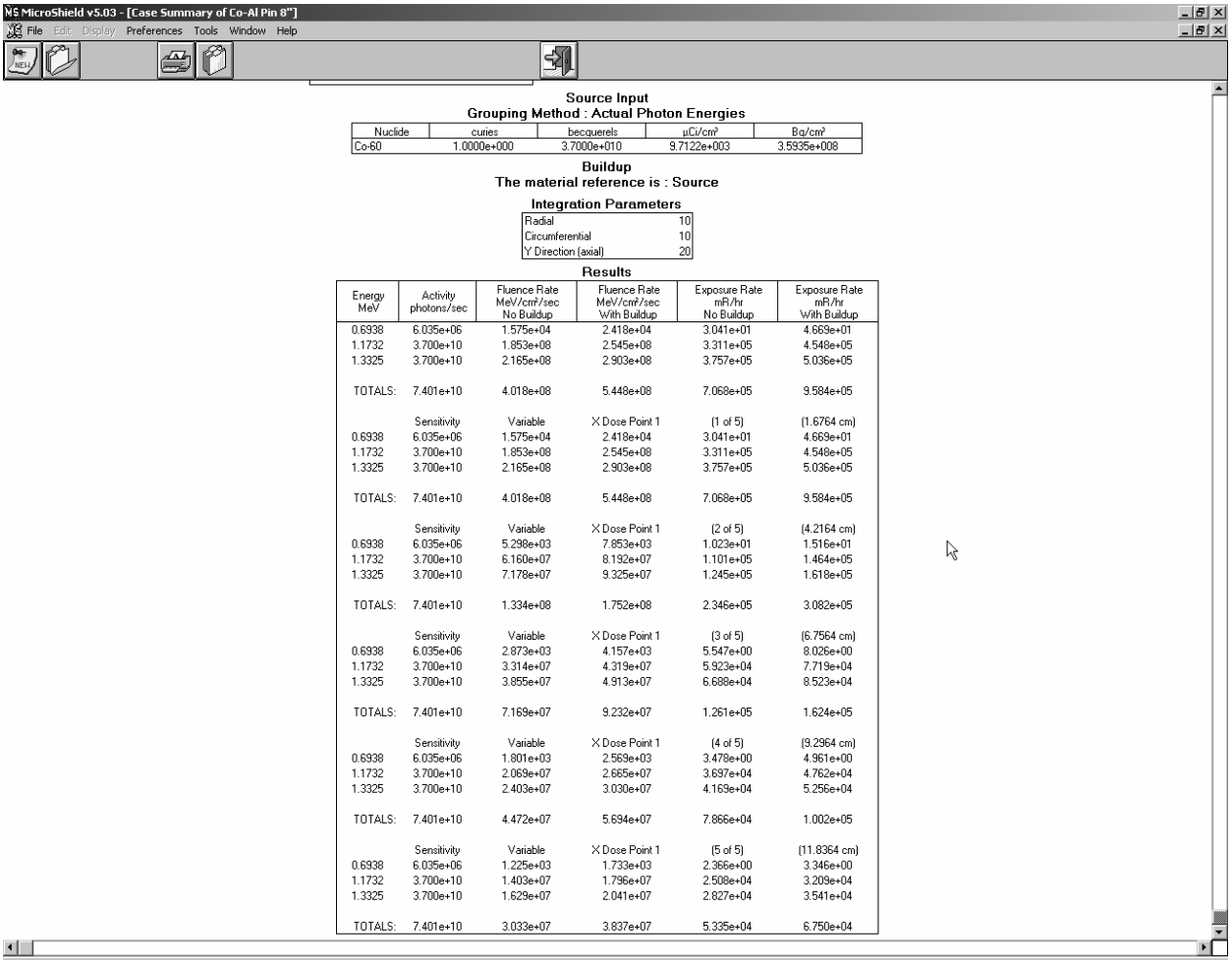
Buildup
The material reference is : Source

Integration Parameters

Radial	10
Circumferential	10
Y Direction (axial)	20

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.6938	6.035e+06	1.575e+04	2.418e+04	3.041e+01	4.669e+01
1.1732	3.700e+10	1.853e+08	2.545e+08	3.311e+05	4.548e+05
1.3325	3.700e+10	2.165e+08	2.903e+08	3.757e+05	5.036e+05
TOTALS:	7.401e+10	4.018e+08	5.448e+08	7.068e+05	9.584e+05
	Sensitivity	Variable	X Dose Point 1	(1 of 5)	(1.6764 cm)
0.6938	6.035e+06	1.575e+04	2.418e+04	3.041e+01	4.669e+01
1.1732	3.700e+10	1.853e+08	2.545e+08	3.311e+05	4.548e+05
1.3325	3.700e+10	2.165e+08	2.903e+08	3.757e+05	5.036e+05
TOTALS:	7.401e+10	4.018e+08	5.448e+08	7.068e+05	9.584e+05
	Sensitivity	Variable	X Dose Point 1	(2 of 5)	(4.2164 cm)
0.6938	6.035e+06	5.298e+03	7.853e+03	1.023e+01	1.516e+01



MicroShield v5.03 - [Case Summary of Co-Al Pin 8"]

File Edit Display Preferences Tools Window Help

Source Input
Grouping Method : Actual Photon Energies

Nuclide	curies	becquerels	µCi/cm²	Bq/cm²
Co-60	1.0000e+000	3.7000e+010	9.7122e+003	3.5935e+008

Buildup
The material reference is : Source

Integration Parameters

Radial	10
Circumferential	10
Y Direction (axial)	20

Results

Energy MeV	Activity photons/sec	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/hr No Buildup	Exposure Rate mR/hr With Buildup
0.6938	6.035e+06	1.575e+04	2.418e+04	3.041e+01	4.669e+01
1.1732	3.700e+10	1.853e+08	2.545e+08	3.311e+05	4.548e+05
1.3325	3.700e+10	2.165e+08	2.903e+08	3.757e+05	5.036e+05
TOTALS:	7.401e+10	4.018e+08	5.448e+08	7.068e+05	9.584e+05
	Sensitivity	Variable	X Dose Point 1	(1 of 5)	(1.6764 cm)
0.6938	6.035e+06	1.575e+04	2.418e+04	3.041e+01	4.669e+01
1.1732	3.700e+10	1.853e+08	2.545e+08	3.311e+05	4.548e+05
1.3325	3.700e+10	2.165e+08	2.903e+08	3.757e+05	5.036e+05
TOTALS:	7.401e+10	4.018e+08	5.448e+08	7.068e+05	9.584e+05
	Sensitivity	Variable	X Dose Point 1	(2 of 5)	(4.2164 cm)
0.6938	6.035e+06	5.298e+03	7.853e+03	1.023e+01	1.516e+01
1.1732	3.700e+10	6.160e+07	8.192e+07	1.101e+05	1.464e+05
1.3325	3.700e+10	7.178e+07	9.325e+07	1.245e+05	1.618e+05
TOTALS:	7.401e+10	1.334e+08	1.752e+08	2.346e+05	3.082e+05
	Sensitivity	Variable	X Dose Point 1	(3 of 5)	(6.7564 cm)
0.6938	6.035e+06	2.873e+03	4.157e+03	5.547e+00	8.026e+00
1.1732	3.700e+10	3.314e+07	4.319e+07	5.923e+04	7.719e+04
1.3325	3.700e+10	3.855e+07	4.913e+07	6.688e+04	8.523e+04
TOTALS:	7.401e+10	7.169e+07	9.232e+07	1.261e+05	1.624e+05
	Sensitivity	Variable	X Dose Point 1	(4 of 5)	(9.2964 cm)
0.6938	6.035e+06	1.801e+03	2.569e+03	3.478e+00	4.961e+00
1.1732	3.700e+10	2.069e+07	2.665e+07	3.697e+04	4.762e+04
1.3325	3.700e+10	2.403e+07	3.030e+07	4.169e+04	5.256e+04
TOTALS:	7.401e+10	4.472e+07	5.694e+07	7.866e+04	1.002e+05
	Sensitivity	Variable	X Dose Point 1	(5 of 5)	(11.8364 cm)
0.6938	6.035e+06	1.225e+03	1.733e+03	2.366e+00	3.346e+00
1.1732	3.700e+10	1.403e+07	1.796e+07	2.508e+04	3.209e+04
1.3325	3.700e+10	1.629e+07	2.041e+07	2.827e+04	3.541e+04
TOTALS:	7.401e+10	3.033e+07	3.837e+07	5.335e+04	6.750e+04

Total exposure rate for 8” cobalt slug = 3.19E5 mR/hr

Total exposure rate for curium sampler slug containing 1/16” x 1/16” cobalt wire = 1.09E6 mR/hr

Ratio geometry correction factor (air) = 1.09E6 / 3.19E5 = 3.42

Correction for Basin Water Absorption = 3.42 / 0.95 = 3.60