Radiation Physics Note 101

Comparison of Bicron Analyst and Eberline Frisker Survey Instruments

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INTRODUCTION

Fermilab policy to allow the off site release of material requires that the net count rate (above background) on contact with any surface be less than or equal to 2000 cpm as measured with a Bicron Analyst scintillator probe (on the X10 scale).[1] This survey instrument uses a 1.5" diameter by 1" long NaI(Tl) scintillation crystal and is highly sensitive to low-levels of residual radioactivity. On the other hand, the determination of low-levels of surface contamination or residual activity on magnetic materials is frequently performed in operational areas at Fermilab by use of the Ludlum Frisker or Eberline E140N survey meter. These devices use a thin 2" diameter end-window Geiger-Muller tube as a probe, and can detect radioactivity at levels of about 0.3 nCi per 100 cm^2 wipe.

This note presents the results of a comparison of the response of the Bicron Analyst and the generic Frisker probe to accelerator radioactivated material. At the same time the response of both instruments to slightly contaminated wipes and small radioactive sources is discussed as well. Previous studies that compare Thyac or Bicron probes with the Elron survey meter have been reported.[2]

PROCEDURE

The measurements were performed in the Accelerator Division ES&H office and the small second floor room at Site 68. Data were obtained for both instruments for various materials on contact, and, at least in some cases, at distances of 1,2,3,4,5,10,20, and 30 cm between the material and the detectors at a height above the floor of 73 cm. Results are presented in Table 1.

RESULTS

1. Accelerator Activated Bulk Material

Five different materials, activated in beamline enclosures at the Fermilab Tevatron accelerator, were studied. The relative net (background subtracted counting rates) response for both the Bicron and the Frisker are shown in Fig. 1. These were obtained from the data at different distances (see Table 2). For each material the net counting rates were normalized so that the Bicron read 10000 cpm on contact with the surface. These data taken together as a sample were fit with a straight-line as shown in the bottom part of Fig. 1. From the slope of this curve,* a net counting rate of 2000 cpm on the Bicron is found to be equivalent to an average net Frisker counting rate of 66 cpm.

The sensitivity of each detector can be defined as the (net counting rate/background counting rate). The relative sensitivity of the Frisker versus the Bicron is shown in Fig. 2. For each material, the sensitivity (see Table 2) was normalized so that the values for the Bicron were set equal to 10 on contact with the surface. All of these data taken together were fit with a straight-line as shown on the bottom part of Fig. 2. The slope* leads to a relative sensitivity of the Frisker equal to 1.25 that of the Bicron. For example, if the net counting rate on a Bicron is equal to twice the background rate, the net rate with the Frisker will be equal to 2.5 times the Frisker background counting rate.

In Table 3 we compare relative contact readings for both instruments for the various accelerator activated materials. The average relative contact reading sensitivity at 1.29 is closely equal to the value from the straight-line fit of Fig. 2; and the average Frisker net count rate of 68 cpm that corresponds to 2000 cpm on the Bicron is in agreement with the value of 66 cpm found in the straight line fit to the data of Fig. 1.

Table 4 and Fig. 3 show the relative Frisker-to-Bicron sensitivities (ratio of Frisker-to-Bicron) as a function of distance between detector and activated material. A quantitative understanding of the observed dependence of the Frisker-to-Bicron ratio depends on the specific beta and gamma-ray energies of the isotopes produced by activation in the materials, and the detection efficiencies for these quantities, and is beyond the scope of the current report.

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* The equation for the straight line is given on the Figures.

2. Wipes

The two sets of wipes shown in Table 1 were obtained by smearing an area of 100 cm^2 of slightly contaminated items in Research Division areas by use of cloth material cut in the shape of 2" diameter disks. Such a procedure is inherently non-reproducible since there are many variables, such as differences in the self-absorption of beta particles in any two material wipes, that can affect the detection of radiation, particularly with the Frisker. Thus, correspondence between Bicron and Frisker readings cannot be quantified as done in the previous section. For example, for the two wipes shown in Table 1, 2000 cpm net on the Bicron is equivalent to both 462 cpm and 1420 cpm on the Frisker.

3. Sources

Figure 4 shows the background subtracted response of both the Bicron and the Frisker to ^{60}Co and ^{137}Cs radioactive sources as a function of distance. In order to display the relative fall-off with distance both detectors were normalized individually to 1000 cpm on contact.

^{60}Co and ^{137}Cs are beta-emitters (followed by gamma decay), with endpoints at 0.314 and 0.514 MeV, respectively, for the major beta branches of each isotope. The Frisker has a moderately high efficiency for detection of β's and an almost negligibly small response to gamma rays. It is expected therefore that its response will fall more steeply with distance than that of the Bicron, whose efficiency for beta-ray detection is negligible because of the wall thickness of the NaI probe. It is expected furthermore that room scattering of gamma rays will enhance the Bicron response at the larger separations.

It has been found[3] empirically that an incident beam of beta particles with a continuous energy spectrum up to a maximum kinetic energy E_m are transmitted through matter exponentially (i.e., $e^{-\mu t}$, where t is the absorber thickness) with a mass absorption coefficient given as μ (cm^2/g) $= 17 \text{ X } E_m^{-1.14}$, where E_m is the spectrum endpoint energy in MeV. For air with a density of $1.293 \text{ X } 10^{-3}$ g/cm^3, the solid curve in Fig. 4 represents this empirical fall off for both ^{60}Co and ^{137}Cs sources. Clearly the measured results fall off significantly faster. It is not understood at present why the empirical relation does not seem to work for an air absorber, but the ^{137}Cs and ^{60}Co sources used in this work are extended disk sources and, therefore, do not represent a true incident beta particle beam.

Figure 5 shows the response (normalized as for Fig. 4) of the Bicron to the ^{137}Cs source, where the data have been corrected for room scattering.** The solid curve represents a calculation by standard techniques[4] of the efficiency of a 1 1/2" by 1" NaI scintillator for the 662 keV gamma ray from ^{137}Cs. The efficiency has been normalized to the corrected data, and, as seen, the measured energy dependence is in agreement with that calculated.

SUMMARY

From an operational point of view, the main conclusion from this study is the result that 65-75 cpm above background as measured with the Frisker corresponds to 2000 cpm net with the Bicron Analyst. Further, a reading of twice background with the Frisker corresponds to about 1.75 times background with the Bicron, so that the detectability, or sensitivity, of the Frisker is somewhat better than the Bicron for typical accelerator produced materials. One might argue, however, that it is visually easier to accurately delineate 2000 cpm above background with the Bicron than 65-75 cpm net on the Frisker. At any rate, both survey meters clearly represent sensitive detectors of low-levels of radiation typical of accelerator produced activation.

REFERENCES

1. J.D. Cossairt and A.J. Elwyn, "Response of 1 1/2" by 1" NaI(Tl) with Respect to a Release Criterion," Rad. Phys. Note #87, Fermilab (Rev. October 1991).

2. J.D. Cossairt, "Thyac vs. Elron: Detection of Low-Levels of Radioactivity," Rad. Phys. Note #27, Fermilab (November 7, 1980); A.J. Elwyn and W.S. Freeman, "Detection of Low-Levels of Radioactivity," Rad. Phys. Note #39, Fermilab (August 30, 1983).

3. N. Tsoulfanidis, Measurement and Detection of Radiation, p. 133, McGraw-Hill, NY (1983).

4. S.H. Vegors, Jr., L.L. Marsden, and R.L. Heath, "Calculated Efficiencies of Cylindrical Radiation Detectors," Report IDO-16370, Phillips Petroleum Co., Idaho (September 1, 1958).

** The room scattered contribution to the Bicron response was determined by fitting the data at distances 4-30 cm to $R = S/r^2 + B$, where R is the measured response, S is the direct source contribution, and B is the assumed constant room scattered component.

TABLE CAPTIONS

1. The raw data for the Bicron-Analyst and Frisker survey meters.

2. Net counting rates (background subtracted) and relative detectability (sensitivity) for Bicron Analyst and Frisker meters.

3. Various quantities determined from contact readings for accelerator activated materials.

4. The ratio of relative detectability (sensitivity) of Frisker to Bicron Analyst as a function of distance for the various materials investigated.

FIGURE CAPTIONS

1. Relative response in net counts per minute of Frisker and Bicron Analyst survey meters for accelerator-activated material. The solid curve in the bottom half represents a linear least-squares fit (as given by the equation) to all of the data.

2. Relative sensitivity as defined in the test of Frisker and Bicron survey meters for accelerator-activated material. The solid line in the bottom half represents a least-square fit (as given by the equation) to all of the data taken together.

3. The ratio of Frisker-to-Bicron sensitivity, as defined in the text, as a function of distance between the item and detector for accelerator-activated material.

4. Net counts per minute of Bicron and Frisker to ^{137}Cs and ^{60}Co radioactive sources as a function of distance. The solid line represents the prediction of a "Rule" given in Ref. 3 and discussed in the text.

5. Counts per minute corrected for room scattering of the Bicron survey meter plotted as a function of distance between the ^{137}Cs source and the detector. The uncorrected data were normalized to 1000 cpm. The solid line represents the shape of the efficiency of a 1 1/2" by 1" NaTi(Tl) scintillator.

Table 1
The Raw Data for the Bicron-Analyst and Frisker Survey Meters

Detector	Source	Counts and Counting times (min) at indicated Distances (cm) to Front Surface of Detector.																			
		Bkgnd	Time	Contact	Time	1	Time	2	Time	3	Time	4	Time	5	Time	10	Time	20	Time	30	Time
Analyst	22(-2.1)-1	13774	10	13719	10																
	55(-1.6)-1	13774	10	13527	10																
	60(-1.1)-2	41398	30	26672	10	23417	10	20039	10	18239	10	17151	10	16416	10	15147	10	14663	10	14759	10
	137(-2.1)-1	13466	10	2079	1	2013	1	1756	1	19534	3	4702	3	6227	4	4199	3	4111	3	13691	10
	RD wipes	41398	30	27252	10																
	RD Wipe	41398	30	20035	10																
	Copper Buss	10493	10	12051	1	10160	1	7968	1	6317	1	10616	2	9151	2	8283	3	17439	10	14616	10
	Alum. Ring	10894	10	10722	2	9584	2	12797	3	13884	4	27012	10	24389	10	18440	10	14467	10	12702	10
	Stnlss Steel	10493	10	23003	0.1	21986	0.1	18863	0.1	16382	0.1	13612	0.1	11733	0.1	63389	1	26371	1	14833	1
	Loss Monitor	10894	10	27650	1	24303	1	20628	1	18167	1	15770	1	14030	1	17571	2	9659	2	10158	3
	Ceram. Insul.	10493	10	32429	1	25795	1	19758	1	15978	1	12606	1	10355	1	15550	3	25879	10	18452	10
Frisker	22(-2.1)-1	750	27.42	1012	12.54	1000	17.57	1000	22.51	1000	25.77	1000	28.1								
	55(-1.6)-1	750	27.42	1000	10.77	1000	18.76	1000	23.58												
	60(-1.1)-2	1000	37.45	1000	0.84	1000	1.05	1000	1.65	1000	2.58	1000	3.56	1000	5.19	1000	15.91	1000	32.06	500	16.85
	137(-2.1)-1	1000	38.08	10000	1.98	2000	0.62	2000	1.14	2000	1.75	2000	2.55	2000	3.93	1000	5.75	1000	18.48	1000	27.33
	RD wipes	1000	37.45	1000	2.96																
	RD Wipe	1000	37.45	1000	2.13																
	Copper Buss	601	20.09	1000	1.76	1000	2.43	1000	3.2	1000	4.07	1000	4.9	1000	6.54	1000	12.35	500	10.28	500	14.65
	Alum. Ring	400	15.88	1000	7.47	1000	7.53	1000	9.15	1000	9.91	1000	11.39	1000	12.52	1000	18.89	1000	27.04		
	Stnlss Steel	601	20.09	5000	0.83	5000	0.92	5000	1.05	5000	1.2	5000	1.4	5000	1.51	2000	1.12	1000	1.33	1000	2.44
	Loss Monitor	400	15.88	1000	0.96	1000	1.12	1000	1.55	1000	1.62	1000	1.94	1000	2.07	1000	3.78	1000	7.14	1000	10.04
	Ceram. Insul.	601	20.09	1000	1.02	1000	1.2	1000	1.67	1000	2.25	1000	2.87	1000	3.57	1000	7.62	602	10.63	500	12.15

Table 2

Net Counting Rates (Background Subtracted) and Relative Detectability (Sensitivity) for Bicron Analyst and Frisker Meters

Net Counting Rates

Instrument	Material	Bkgnd. CR	Net Counting Rate (CPM) at Indicated Distance (cm)								
			Contact	1	2	3	4	5	10	20	30
Analyst	60(-1.1)-2	1379.9	1287.3	961.77	623.97	443.97	335.17	261.67	134.77	86.367	95.967
Frisker	60(-1.1)-2	26.702	1163.8	925.68	579.36	360.89	254.2	165.98	36.151	4.4892	2.9713
Analyst	137(-2.1)-1	1346.6	732.4	666.4	409.4	292.4	220.7	210.2	53.1	23.7	22.5
Frisker	137(-2.1)-1	26.261	5024.2	3199.5	1728.1	1116.6	758.05	482.65	147.65	27.852	10.329
Analyst	Copper Buss	1049.3	11001.7	9110.7	6918.7	5267.7	4258.7	3526.2	1711.7	694.6	412.3
Frisker	Copper Buss	29.915	538.27	381.6	282.6	215.8	174.2	123.0	51.1	18.7	4.2
Analyst	Alum. Ring	1089.4	4271.6	3702.6	3176.3	2381.6	1611.8	1349.5	754.6	357.3	2296.6
Frisker	Alum. Ring	25.189	108.68	107.6	84.1	75.7	62.6	54.7	27.7	11.8	#NUM!
Analyst	Stnlss Steel	1049.3	228980.7	218810.7	187580.7	162770.7	135070.7	116280.7	62339.7	25321.7	13784
Frisker	Stnlss Steel	29.915	5994.2	5404.9	4732.0	4136.8	3541.5	3281.3	1755.8	722.0	379.9
Analyst	Loss Monitor	1089.4	26560.6	23213.6	19538.6	17077.6	14680.6	12940.6	7696.1	3740.1	2296.6
Frisker	Loss Monitor	25.189	1016.5	867.7	620.0	592.1	490.3	457.9	239.4	114.9	74.4
Analyst	Ceram. Insul	1049.3	31379.7	24745.7	18708.7	14928.7	11556.7	9305.7	4134.0	1538.6	795.9
Frisker	Ceram. Insul	29.915	950.48	803.42	568.89	414.53	318.52	250.2	101.32	26.717	11.237
Analyst	RD wipes	1379.9	1345.3								
Frisker	RD wipe	26.702	311.1								
Analyst	RD wipes	1379.9	623.6								
Frisker	RD wipe	26.702	442.8								

Sensitivity

Material	Instru ment	(net CR/Background) at Indicated Distance (cm)								
		Contact	1	2	3	4	5	10	20	30
60(-1.1)-2	Analyst	0.933	0.697	0.452	0.322	0.243	0.190	0.098	0.063	0.070
	Frisker	43.583	34.667	21.697	13.516	9.520	6.216	1.354	0.168	0.111
137(-2.1)-1	Analyst	0.544	0.495	0.304	0.217	0.164	0.156	0.039	0.018	0.017
	Frisker	191.32	121.84	65.807	42.520	28.867	18.379	5.623	1.061	0.393
Copper Buss	Analyst	10.485	8.683	6.594	5.020	4.059	3.361	1.631	0.662	0.393
	Frisker	17.993	12.756	9.446	7.213	5.822	4.111	1.707	0.626	0.141
Alum. Ring	Analyst	3.921	3.399	2.916	2.186	1.480	1.239	0.693	0.328	2.108
	Frisker	4.315	4.272	3.339	3.006	2.486	2.171	1.102	0.468	
Stnlss Steel	Analyst	218.222	208.530	178.767	155.123	128.725	110.817	59.411	24.132	13.136
	Frisker	200.371	180.672	158.179	138.282	118.384	109.687	58.692	24.134	12.700
Loss Monitor	Analyst	24.381	21.309	17.935	15.676	13.476	11.879	7.065	3.433	2.108
	Frisker	40.354	34.446	24.613	23.506	19.464	18.179	9.503	4.560	2.954
Ceramic Insul	Analyst	29.905	23.583	17.830	14.227	11.014	8.868	3.940	1.466	0.759
	Frisker	31.772	26.856	19.017	13.857	10.647	8.363	3.387	0.893	0.376
RD wipes	Analyst	0.975								
	Frisker	11.652								
RD wipes	Analyst	0.452								
	Frisker	16.582								

Table 3
Various Quantities Determined from Contact Readings for Accelerator Activated Materials

MATERIAL	RATIO:FRISKER TO BICRON Sensitivity	RATIO:FRISKER TO BICRON Net CPM	FRISKER NET CPM FOR 2000 NET CPM ON BICRON
Cu Buss	1.72	0.049	98
Al Ring	1.1	0.025	50
St Steel	0.92	0.026	52
Loss Mon	1.66	0.038	77
Ceramic Ins	1.06	0.03	61
Average	1.29 +- 0.37	0.034 +- 0.010	68 +- 20

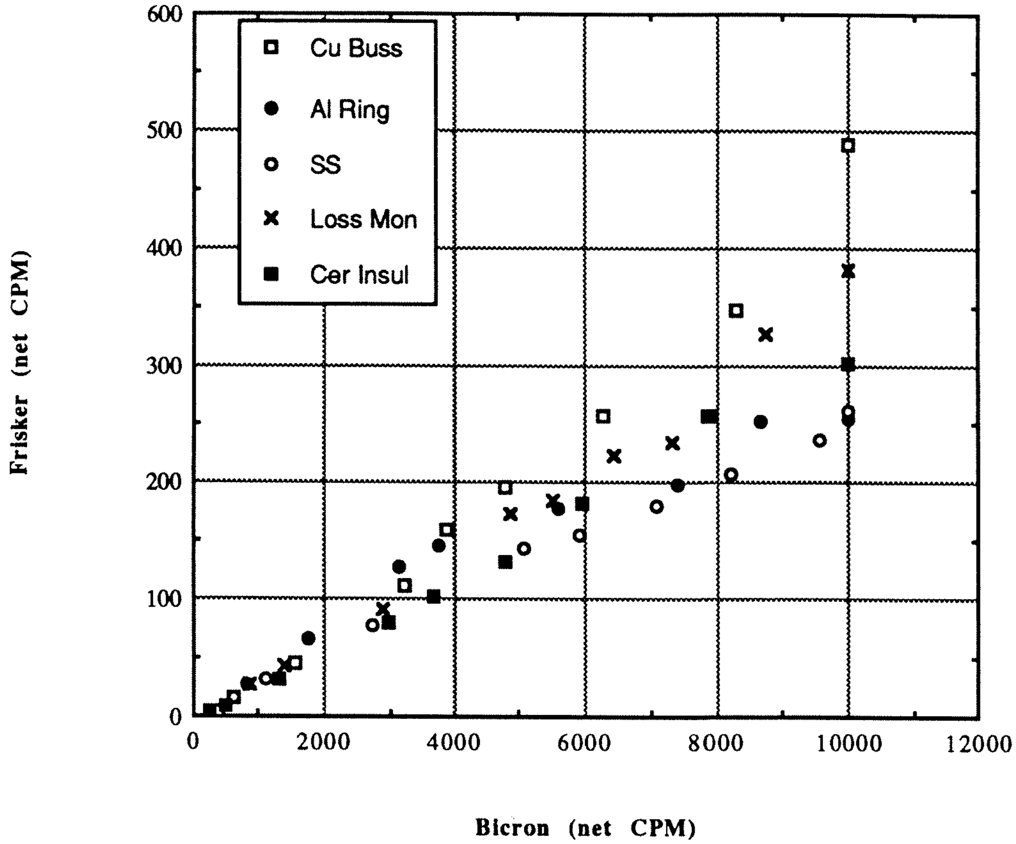
Table 4
The Ratio of Relative Detectability (Sensitivity) of Frisker to Bicron Analyst as a Function of Distance for the Various Materials Investigated

Relative Sensitivity Ratio Frisker/Bicron (Frisker netCPM/bkgnd)/(Bicron netCPM/bkgnd)

Material	Relative Frisker/Bicron at Indicated Distance (cm)								
	Contact	1	2	3	4	5	10	20	30
60(-1.1)-2	46.721	49.739	47.984	42.009	39.194	32.780	13.863	2.686	1.600
137(-2.1)-1	351.769	246.200	216.453	195.819	176.130	117.742	142.588	60.262	23.541
Copper Buss	1.716	1.469	1.433	1.437	1.434	1.223	1.046	0.945	0.359
Alum. Ring	1.100	1.257	1.145	1.375	1.680	1.753	1.590	1.428	0.000
Stnlss Steel	0.918	0.866	0.885	0.891	0.920	0.990	0.988	1.000	0.967
Loss Monitor	1.655	1.617	1.372	1.499	1.444	1.530	1.345	1.328	1.401
Ceramic Insul	1.062	1.139	1.067	0.974	0.967	0.943	0.860	0.609	0.495
RD wipes	11.952								
RD wipe	36.696								

Figure 1

ACCELERATOR ACTIVATED MATERIALS



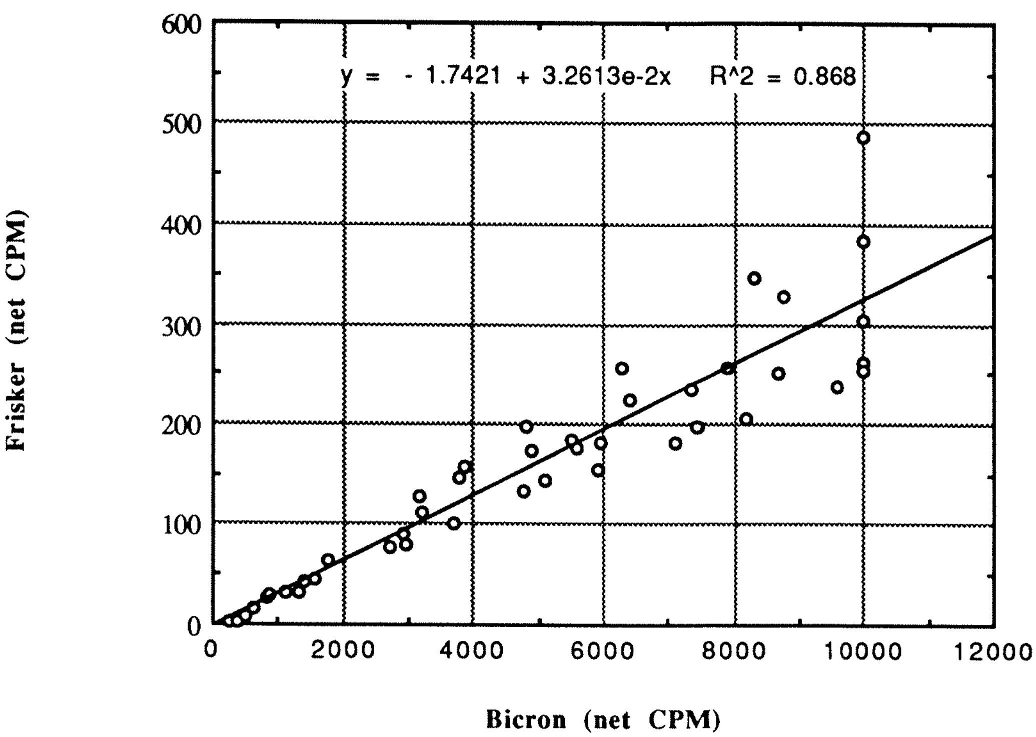
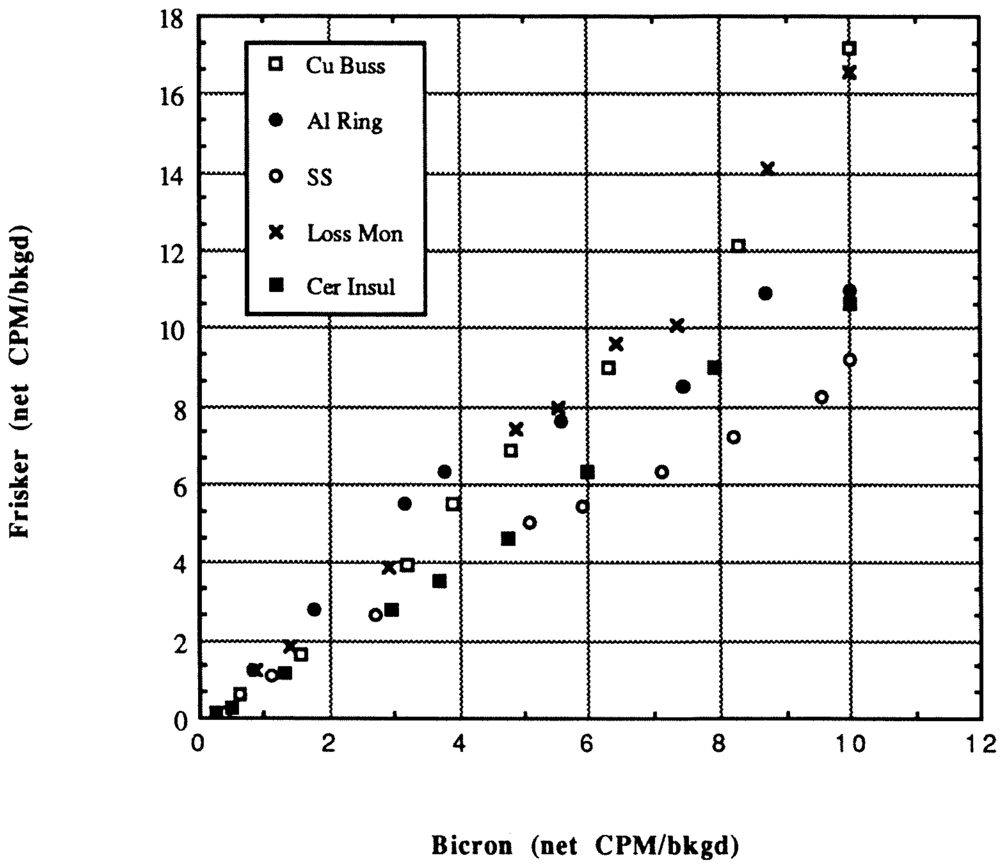


Figure 2

Accelerator Activated Material



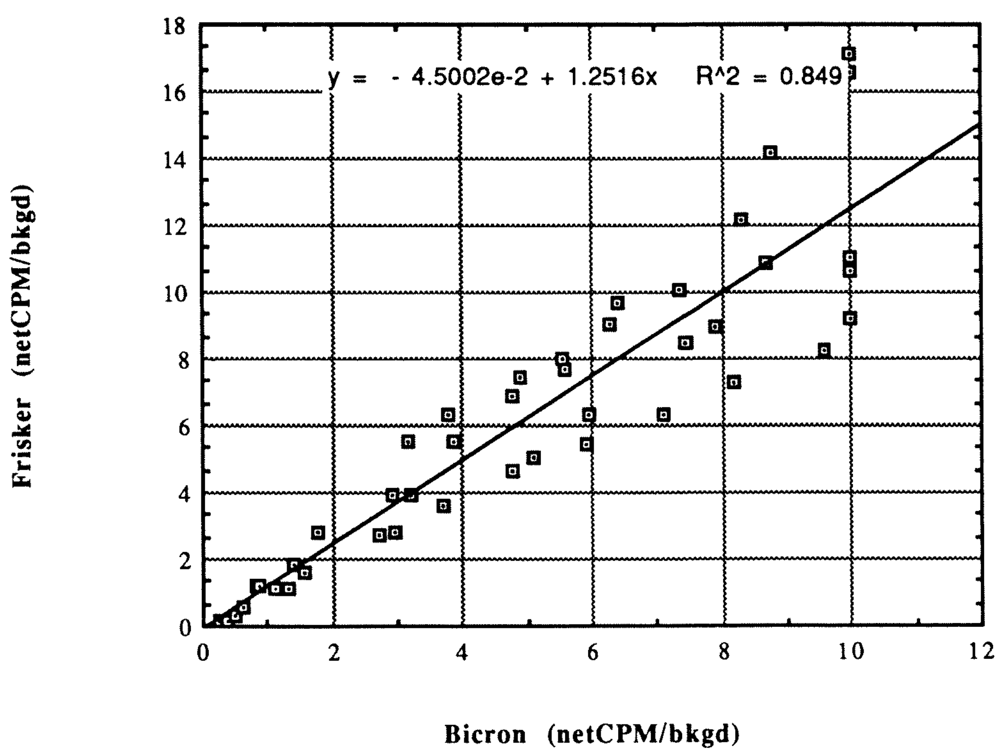
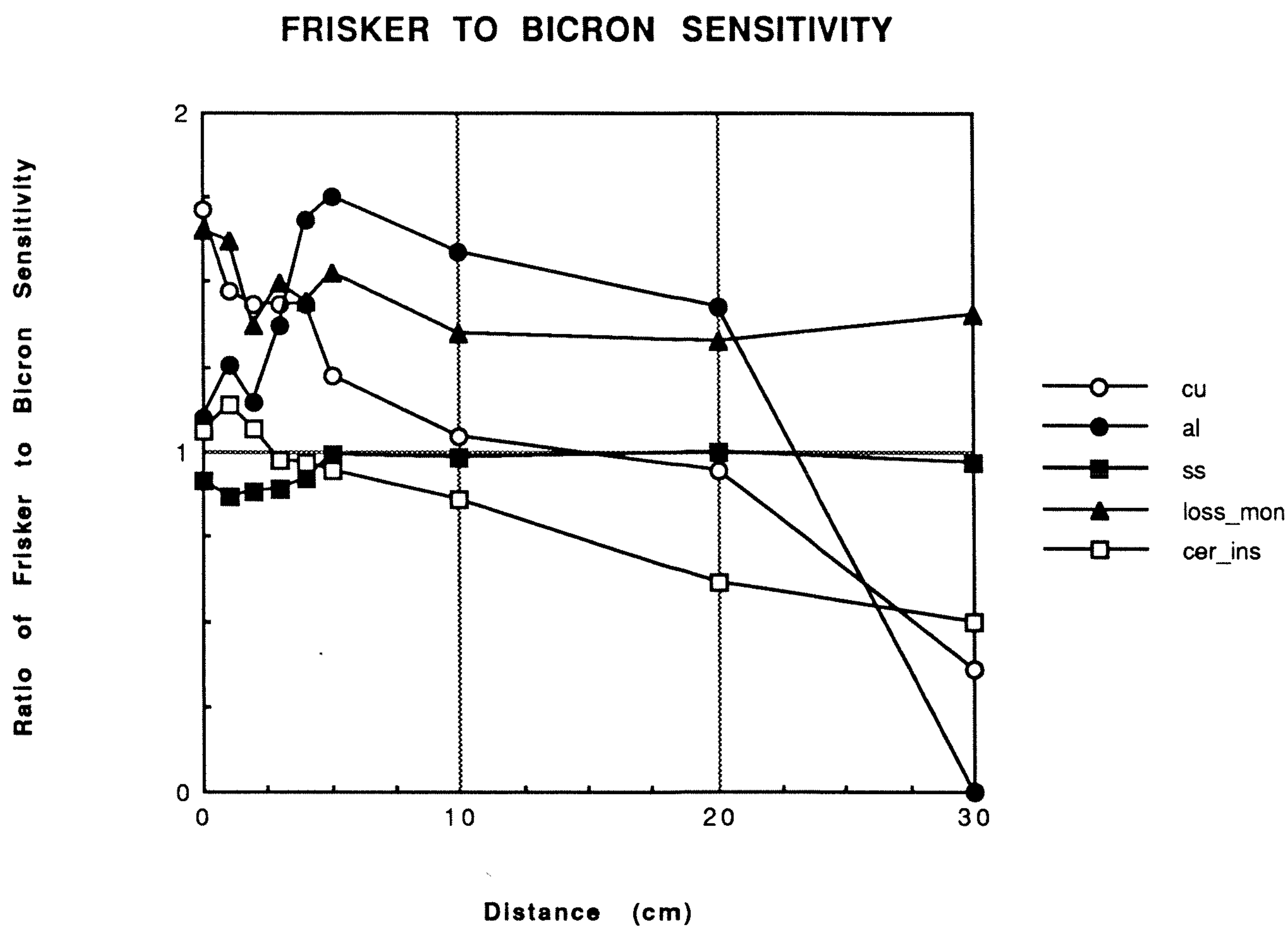


Figure 3


FRISKER TO BICRON SENSITIVITY
2
1
0
0
10
20
30
Ratio of Frisker to Bicron Sensitivity
Distance (cm)
cu
al
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loss_mon
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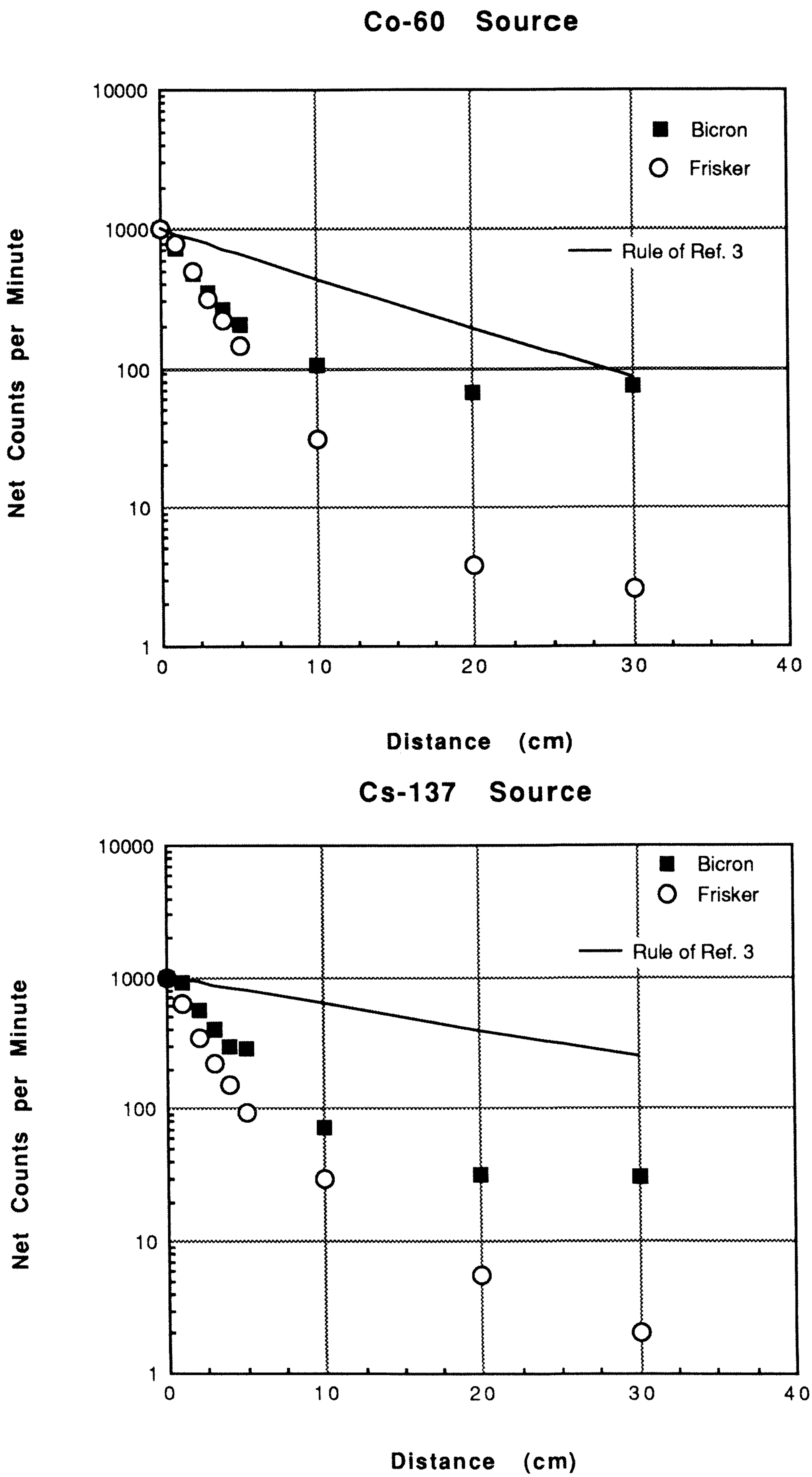
Figure 4


Co-60 Source
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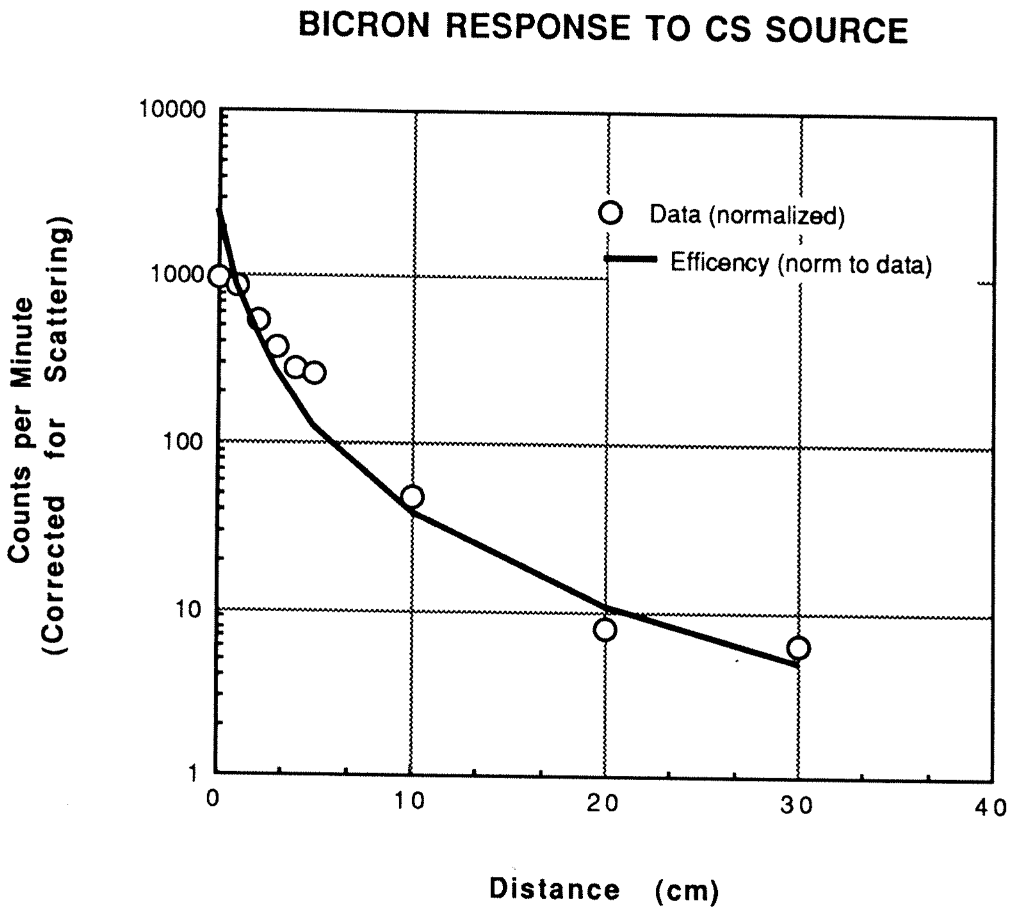
1000
100
10
1
Net Counts per Minute
0
10
20
30
40
Distance (cm)
Bicron
Frisker
Rule of Ref. 3
Cs-137 Source
10000
1000
100
10
1
Net Counts per Minute
0
10
20
30
40
Distance (cm)
Bicron
Frisker
Rule of Ref. 3

Figure 5


BICRON RESPONSE TO CS SOURCE
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1000
100
10
1
0
10
20
30
40
Counts per Minute
(Corrected for Scattering)
Data (normalized)
Efficency (norm to data)
Distance (cm)