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Thoughts on VCD-145 Detector Calibration

W. V. Morgan

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Walter V. Morgan
Lawrence Livermore National Laboratory

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A. Objectives and Sources

In 1980, Don Smith requested that the EG&G Detector Group in North Las Vegas provide a summary of calibrated sensitivities for the VCD-145 detector. The desired information was provided in a memorandum from Sam Egdorf (Reference 1). A memo from Brent Davis issued a week later described the effect on VCD-145 detector sensitivity that resulted from changing the thickness of the stainless steel entrance window (Reference 2). This memo is intended first to effectively archive those two references, and second to record thoughts about the significance of their contents.

Reference 1 lists a total of 118 calibrated values for 80 different VCD-145 detectors, from 1977 to 1980. With only four exceptions, all of the serial numbers from V004 to V087 were included. The earlier calibrations were for detectors with 1-mil entrance windows, and the later ones were for detectors with 2-mil entrance windows.[1] Three of the earlier units were calibrated at both thicknesses by temporarily placing an extra 1-mil sheet of stainless steel across the window. Altogether six different collimator diameters were used, from 60 mm to 95 mm. Some units were calibrated for more than one collimator diameter, and 14 were at some point designated as backup detectors for a second event.

Reference 2 describes the effect of window thickness on calibrated sensitivity. Quoting that reference:

> *To demonstrate that the sensitivity decrease is solely a function of the window thickness, a standard VCD-145 detector with a 0.001-inch thick window was calibrated with the ^{60}Co source. Then without changing detector or geometry, a 0.001-inch thick stainless steel foil (same material as that of the window) was placed directly in front of the detector window, effectively making a 0.002-inch thick entrance window. The detector was again calibrated. This technique was repeated until the detector had an entrance window equivalent to 0.010-inches thick.*

[1] The change from 1-mil to 2-mil stainless steel entrance window was made for cost and reliability purposes. The 1-mil thickness was difficult to weld, and more likely to fail in the field. Both were very thin compared to the entrance windows of earlier model vacuum Compton detectors: the VCD-125, VCD-127 and VCD-129 all used 60-mil thick silver entrance windows. With the new, thin windows, it was necessary to provide magnets on either side of the beam, between the collimator exit and the detector, to eliminate charged particles.

B. The Data

Reference 1. The data given in Reference 1 were entered into an Excel spreadsheet, and sorted by chronologic sequence and by collimator diameter. The results were saved as two spreadsheets, References 3 and 4, respectively, and either of those can be used to do further sorting. A three-page image of Reference 3 is included here as Table I. A three-page image of Reference 4 is included here as Table II. Both tables include averages for various subsets of the data, and at the end of Table II is a statistical summary of trends due to collimator diameter and entrance window thickness. The sensitivity values are all presented with 1.0 E-22 C/G-MeV suppressed, and that same convention will be used in the discussion that follows. A sensitivity given as 2.95, for example, implies an actual sensitivity of 2.95 E-22 C/G-MeV.

Reference 2 presented data in the form of a hand-drawn plot. The ten data points from that plot have now been extracted for presentation in Figure 1. The smooth curve is a fourth-order fit to the data, an approximation of the hand-drawn curve in the plot of Reference 2.

C. Observations – Collimator Diameter

Referring to the tabulations at the end of Table II, it is not apparent that there is a trend in sensitivity due to changing diameter (for either window thickness): the standard deviations are rather large compared to the differences. A somewhat different picture emerges when comparisons are made for the 20 individual detectors that were calibrated at both 60-mm and 80-mm diameters. Subtracting the sensitivity at 60-mm from that at 80-mm for the 20 individual detectors, the following changes are found:

0.01 decrease	four detectors
0.00 change	one detector
0.01 increase	nine detectors
0.02 increase	six detectors
0.04 increase	one detector

Note that 0.01 sensitivity unit is of the order of one part in 300, since the sensitivities are about 3. One detector, V022, was calibrated at both diameters in both 1979 and 1980, leading to a total of 21 comparison pairs.

From this histogram-type comparison, it is reasonable to infer that sensitivity at 80 mm is something more than 0.01 unit greater than at 60 mm, or perhaps one-half percent.

D. Observations – Window Thickness

From Figure 1, data obtained using one specific detector, we find that the sensitivity with a 2-mil window was 91.6% of that with a 1-mil window. (Some small uncertainty must be associated with that value because of the limited precision with which calibrated sensitivity is reported. Using the values for the 4^{th} order fit at 1-mil and 2-mil, the ratio becomes 91.9%.) A summary at the end of Table II shows that for the data from Reference 1, 2-mil sensitivity is about 90% to 93% of the 1-mil sensitivity, perhaps depending somewhat on the collimated diameter. This is completely consistent with the data from Reference 2 (Figure 1). (Reference 2 did not state what collimator diameter was used in obtaining that data, but it would certainly have been at least 80 mm.)

E. A Window-current/Emitter-current Model

In the calibration procedure using the ^{60}Co source, currents of opposite polarity are produced by photons incident on the window and on the emitter. Since the emitter (3/16-inch aluminum) is much thicker, it produces the much larger current. As the window thickness is increased, the emitter current remains essentially constant, but the window current increases, so the calibrated sensitivity – the difference in the window and emitter currents – decreases. This explanation is completely consistent with the data presented in Reference 2. The same trend is also evident in Reference 1 data.

For the VCD-145 detector, the spacing from the window to the center of the emitter is 74 mm, or about 1/4 nanosecond at the speed of light. Thus, it would be expected that the negative current from the front window would be produced about one-quarter nanosecond before the emitter current, and, indeed, transforms obtained with the Santa Barbara linear accelerator show that a negative precursor is present at about that relative time. The static and dynamic situations are both fully consistent with the concept of detector currents of opposite polarity from the front window and emitter.

The window current is electrons leaving the window and hitting the emitter. Other electrons leaving the window may miss the emitter, but they don't count because they must then somehow be intercepted by the detector case – which is electrically identical to the window. As collimator diameter is reduced, both emitter and window currents will decrease, but the efficiency of the window current will increase because the solid angle presented by the emitter to the window is increased. Thus, for smaller collimator diameters the calibrated sensitivity would be expected to decrease. This is consistent with the observations in Section C above.

In the dynamic case, a larger window current – relative to the emitter current – will mean a larger negative precursor. Whereas a smaller collimator or thicker window will statically reduce the detector sensitivity, the dynamic consequence of increased negative precursor accompanying the same changes is much more serious.

F. Calibration Repeatability

It has normally been assumed that detector calibrations are repeatable to +/- 0.01 sensitivity units, which is also the precision used in reporting. To test that, data from Reference 1 were searched for calibrations repeated for a given detector at a given collimation. Seven pairs were found for six different detectors, with the repeat calibrations following by six to nine months. The windows for all of these were the 1-mil thickness. The changes found:

0.05 decrease	one measurement pair (80 mm collimation)
0.02 decrease*	one measurement pair (80 mm collimation)
0.01 decrease	one measurement pair (80 mm collimation)
0.01 increase*	two measurement pairs (both 60 mm collimation)
0.02 increase	two measurement pairs (both 80 mm collimation)

This is a very small statistical sample, but my initial inference is that it implies that the calibrated sensitivity has a one-sigma uncertainty of about 0.02 units. If a much more comprehensive experiment were performed (and it is possible that this has already been done), almost certainly the standard deviation would be at least 0.01 units, for the precision is 0.01, and in the limited sample here, none of the pairs gave a zero change.

Differences obtained for the calibrated sensitivity for a given detector must be due either to changes in the detector or to random errors associated with the calibration process. If a detector were to be calibrated 10 times in a given day, we would certainly not expect the simple, passive detector to have changed, and differences would be considered a measure of the accuracy of the calibration process. If the detector were to be calibrated once in each of 10 successive months, it still seems unlikely that the simple, passive detector has changed, so differences would still likely be assigned to the calibration process – but indicating long-term drift-type problems instead of short-term problems.

Further evidence of the randomness of the sample above is the fact that the detector that was given repeat calibrations at two diameters (V022) fell in the two groups above that are starred: the 0.02 decrease and the 0.01 increase.

G. Unit-to-unit Sensitivity Differences

It had long puzzled me why the calibrated sensitivities within a set of presumably identical, simple, passive vacuum Compton detectors were not all the same, even though different units were calibrated at the same collimation. Since it has been observed that there is a pronounced change in sensitivity with window thickness, a plausible answer might be found there. Brent Davis has informed me that the stainless steel windows for these detectors did not have a thickness specification; only a nominal 1-mil or 2-mil thickness requirement was given to the vendor. It is plausible, then, that the actual thickness used could be different from the nominal by perhaps 5%, and that value will be used for purposes of a simple trend calculation. The mean sensitivity for 1-mil and 2-mil windows (from Reference 2) is 2.98 (the sensitivity multiplier of 1.0 E-22 C/G-MeV will continue to be understood), and the slope is negative 0.26 per mil, or

$$\text{Sensitivity} = -0.26\ dT + 2.98$$

where dT is the change, in mils, from the mean window thickness of 1.5 mils (0.0015 inch).

Letting dT be +/- 0.5 mils gives just the reported sensitivities of 3.11 (1-mil window) and 2.85 (2-mil window). A 5% variation in nominal thickness would lead to dT of -0.45 to -0.55 mils for the nominal 1-mil window, and +0.4 to +0.6 mils for the nominal 2-mil window. Using the equation above for sensitivity versus change in window thickness, the resulting plausible sensitivity ranges are:

1-mil windows:	3.097 to 3.123	or 3.11 +/- 0.013	[or +/- 0.42%]
2-mil windows:	2.876 to 2.824	or 2.85 +/- 0.026	[or +/- 0.91%]

Using the data at the end of Table II for window and collimator diameter combinations that have 10 or more samples, the standard deviations were found to range from 0.017 to 0.043. These values are reasonably consistent with the simple numerical analysis above that looks at the trend of sensitivity with window thickness. The assumption of a possible 5% variation in thickness was rather arbitrary. No information is available as to actual window thickness variations.

It is concluded that the minor sensitivity variations reported for various units of a given type of vacuum Compton detector should be considered to be meaningful. However, it is possible that window thickness variation is no more significant than the variation due to calibration uncertainty, as discussed in Section F.

H. Conclusions

There are multiple reasons to suspect that the accuracy of the sensitivity reported for a vacuum Compton detector is uncertain by one-half percent or so. Differences in collimated diameter, variations in window thickness, and unknown errors in the calibration procedures all seem to have some small uncertainty. If one looks at the situation from another angle, this can be considered good news – because there are no indications of uncertainties at the one percent level. Having studied the data from References 1 and 2 in depth, it is my opinion that an experimenter can be confident that the calibrated sensitivity reported for a vacuum Compton detector is accurate to one percent or better. This may not be the smallest error in a reaction history measurement, and it may not be negligible, but realistically it is not often a concern. The uncertainty in knowledge of energy transmission through several mean free paths of attenuating material will almost certainly be several times larger than the uncertainty in detector sensitivity.

It is believed that there is a trend for the VCD-145 sensitivity to decrease as the collimator diameter is reduced. Since this likely aggravates the problem of the negative precursor, it is recommended that when detector time response is important, the detector should only be used with a collimator that is close to the largest allowed.

I. Addendum -- The VCD-146 Detector

Within a few years after References 1 and 2 were written, a new, smaller, faster version of the VCD-145 detector became available, and it was designated the VCD-146. The VCD-145 was compatible with collimators as large as 100-mm diameter; the VCD-146 was designed for collimators no larger than 50-mm diameter. A goal with this entire series of detectors, beginning at least with the VCD-129, was to maintain 50 ohms impedance through the detector. Perhaps the VCD-146 did this somewhat better than the others, but it is believed that its smaller size and thinner entrance window were more important. The 1-mil stainless steel window, desirable because a smaller negative precursor would result, was found to be sufficiently reliable for the VCD-146 detector because of its much smaller span. The smaller diameter also meant a tighter geometric distribution of photon/electron events on the emitter, resulting in a tighter distribution of travel times to a common point on the coaxial jumper cable.

References:

1. EG&G/LVO memo RES 11; S. Egdorf to D. E. Smith; 12 June 1980.
2. EG&G/LVO Technical Bulletin DESSD-E-017; B. A. Davis, 18 June 1980.
3. Excel worksheet VCD145_Sensitivity_Chrono; W. Morgan; 31 January 2005
4. Excel worksheet VCD145_Sensitivity_Coll; W. Morgan; 31 January 2005

TABLE I (page 1 of 3)
VCD-145 Calibration Data – Sorted Chronologically

Memo entry sequence	Event name	Month	Year	Type name (as in memo)	Serial Number	Collimator diameter (mm)	Sensitivity 1-mil (e-22)	Sensitivity 2-mil (e-22)	Avg sens. 1-mil	Avg. sens. 2-mil	NOTE
1	FARALLONES	12	1977	VCD-145M	V004	75	3.26				
2	FARALLONES	12	1977	VCD-145M	V005	75	3.24				
3	FARALLONES	12	1977	VCD-145M	V005	75	2.81				*1
4	FARALLONES	12	1977	VCD-145M	V006	75	3.24				
5	FARALLONES	12	1977	VCD-145M	V007	75	3.24		[redacted]		
6	FARALLONES	12	1977	VCD-145M	V008	75	3.26		3.2543		*3
7	FARALLONES	12	1977	VCD-145M	V009	75	3.28				
8	FARALLONES	12	1977	VCD-145M	V010	75	3.26				
9	REBLOCHON	3	1978	VCD-145M	V011	75	3.28				
10	REBLOCHON	3	1978	VCD-145M	V012	75	3.28		3.280		
11	REBLOCHON	3	1978	VCD-145M	V013	75	3.28				
12	CAMPOS	3	1978	VCD-145M	V009	80	3.25				
13	CAMPOS	3	1978	VCD-145M	V010	80	3.24		3.2433		
14	CAMPOS	3	1978	VCD-145M	V014	80	3.24				
15	PANIR	9	1978	VCD-145M	V014	60	3.18				
16	PANIR	9	1978	VCD-145M	V014	80	3.19				
17	PANIR	9	1978	VCD-145M	V015	60	3.14				
18	PANIR	9	1978	VCD-145M	V015	80	3.16				
19	PANIR	9	1978	VCD-145M	V016	60	3.18				
20	PANIR	9	1978	VCD-145M	V016	80	3.19				
21	PANIR	9	1978	VCD-145M	V017	60	3.18				
22	PANIR	9	1978	VCD-145M	V017	80	3.19				
23	PANIR	9	1978	VCD-145M	V018	60	3.18				
24	PANIR	9	1978	VCD-145M	V018	80	3.19		3.2042		
25	PANIR	9	1978	VCD-145M	V019	60	3.18				
26	PANIR	9	1978	VCD-145M	V019	80	3.19				
27	PANIR	9	1978	VCD-145M	V023	60	3.18				
28	PANIR	9	1978	VCD-145M	V023	80	3.19				
29	PANIR	9	1978	VCD-145M	V024	60	3.27				
30	PANIR	9	1978	VCD-145M	V024	80	3.26				
31	PANIR	9	1978	VCD-145M	V027	80	3.24				
32	PANIR	9	1978	VCD-145M	V028	80	3.22				
33	PANIR	9	1978	VCD-145M	V029	80	3.21				
34	PANIR	9	1978	VCD-145M	V030	80	3.22				
35	PANIR	9	1978	VCD-145M	V031	80	3.22				
36	PANIR	9	1978	VCD-145M	V032	80	3.22				
37	PANIR	9	1978	VCD-145M	V033	80	3.22				
38	PANIR	9	1978	VCD-145M	V034	80	3.30				
39	DIABLO HAWK	10	1978	VCD-145M	V020	60	3.22				
40	DIABLO HAWK	10	1978	VCD-145M	V020	80	3.21				
41	DIABLO HAWK	10	1978	VCD-145M	V022	60	3.22				
42	DIABLO HAWK	10	1978	VCD-145M	V022	80	3.24		3.2175		
43	DIABLO HAWK	10	1978	VCD-145M	V025	60	3.20				
44	DIABLO HAWK	10	1978	VCD-145M	V025	80	3.21				
45	DIABLO HAWK	10	1978	VCD-145M	V026	60	3.22				
46	DIABLO HAWK	10	1978	VCD-145M	V026	80	3.22				

TABLE I (page 2 of 3)

VCD-145 Calibration Data – Sorted Chronologically

Memo	Event name	Month	Year	Type	Serial	Collimator	Sensitivity		Avg	Avg.	NOTE
entry				name	Number	diameter	1-mil	2-mil	sens.	sens.	
sequence				(as in memo)		(mm)	(e-22)	(e-22)	1-mil	2-mil	
47	QUARGEL	11	1978	VCD-145M	V035	80	3.18				
48	QUARGEL	11	1978	VCD-145M	V036	80	3.22				
49	QUARGEL	11	1978	VCD-145M	V037	80	3.20		3.180		*1
50	QUARGEL	11	1978	VCD-145M	V038	80	3.18		3.196		
51	QUARGEL	11	1978	VCD-145M	V039	80	3.20				[redacted]
52	QUARGEL	11	1978	VCD-145M	V039	90	3.10				*3
53	FARM	12	1978	VCD-145M	V040	80	3.18				
54	FARM	12	1978	VCD-145M	V041	80	3.15				
55	FARM	12	1978	VCD-145M	V042	80	3.18				
56	FARM	12	1978	VCD-145M	V043	80	3.20				
57	FARM	12	1978	VCD-145M	V044	80	3.16		3.172		
58	FARM	12	1978	VCD-145M	V045	80	3.20				
59	FARM	12	1978	VCD-145M	V046	80	3.16				
60	FARM	12	1978	VCD-145M	V047	80	3.16				
61	FARM	12	1978	VCD-145M	V048	80	3.16				
62	KLOSTER	2	1979	VCD-145M	V050	60	3.14				
63	KLOSTER	2	1979	VCD-145M	V050	80	3.13				
64	KLOSTER	2	1979	VCD-145M	V051	60	3.11				
65	KLOSTER	2	1979	VCD-145M	V051	80	3.13		3.140		
66	KLOSTER	2	1979	VCD-145M	V052	60	3.13				
67	KLOSTER	2	1979	VCD-145M	V052	80	3.14				
68	KLOSTER	2	1979	VCD-145M	V053	60	3.16				
69	KLOSTER	2	1979	VCD-145M	V053	80	3.18				
70	PEPATO	6	1979	VCD-145M	V022	80	3.22				
71	PEPATO	6	1979	VCD-145M	V022	60	3.23		3.233		
72	PEPATO	6	1979	VCD-145M	V024	60	3.28				
73	PEPATO	6	1979	VCD-145M	V025	80	3.20				
74	BURZET	8	1979	VCD-145M	V042	80	3.20				
75	BURZET	8	1979	VCD-145M	V055	80	3.20		3.197		
76	BURZET	8	1979	VCD-145M	V056	80	3.19				
77	PERA	9	1979	VCD-145M-1	V053	80	3.20		3.20		
78	NESSEL	9	1979	VCD-145-2M	V060	80		2.88			
79	NESSEL	9	1979	VCD-145-2M	V061	80		2.90			
80	NESSEL	9	1979	VCD-145-2M	V062	80		2.89			
81	NESSEL	9	1979	VCD-145-2M	V063	80		2.88		2.914	
82	NESSEL	9	1979	VCD-145-2M	V064	80		2.97			
83	NESSEL	9	1979	VCD-145-2M	V065	80		2.95			
84	NESSEL	9	1979	VCD-145-2M	V066	80		2.93			
85	AZUL	12	1979	VCD-145-2M	V058	90		2.85			
86	AZUL	12	1979	VCD-145-2M	V059	90		2.85			
87	TARKO	2	1980	VCD-145-2M	V068	80		2.95			
88	TARKO	2	1980	VCD-145-2M	V071	80		2.95		2.940	
89	TARKO	2	1980	VCD-145-2M	V072	80		2.93			
90	TARKO	2	1980	VCD-145-2M	V074	80		2.93			
91	NORBO	3	1980	VCD-145-2M	V013	60		2.90			
92	NORBO	3	1980	VCD-145-2M	V017	60		2.88			

TABLE I (page 3 of 3)

VCD-145 Calibration Data – Sorted Chronologically

Memo entry sequence	Event name	Month	Year	Type name (as in memo)	Serial Number	Collimator diameter (mm)	Sensitivity 1-mil (e-22)	Sensitivity 2-mil (e-22)	Avg sens. 1-mil	Avg. sens. 2-mil	NOTE
93	NORBO	3	1980	VCD-145-2M	V021	60		2.97			
94	NORBO	3	1980	VCD-145-1M	V056	60	3.17		3.17		
95	NORBO	3	1980	VCD-145-2M	V069	80		2.95			
96	NORBO	3	1980	VCD-145-2M	V070	80		2.95			
97	NORBO	3	1980	VCD-145-2M	V073	60		2.94			
98	NORBO	3	1980	VCD-145-2M	V075	60		2.90		2.912	
99	NORBO	3	1980	VCD-145-2M	V075	80		2.91			
100	NORBO	3	1980	VCD-145-2M	V076	80		2.93			
101	NORBO	3	1980	VCD-145-2M	V078	60		2.87			
102	NORBO	3	1980	VCD-145-2M	V079	60		2.83			
103	COLWICK	4	1980	VCD-145M	V059	60		2.85			
104	COLWICK	4	1980	VCD-145M	V081	80		2.90			
105	COLWICK	4	1980	VCD-145M	V082	60		2.86			
106	COLWICK	4	1980	VCD-145M	V082	80		2.88			
107	COLWICK	4	1980	VCD-145M	V083	60		2.86		2.885	
108	COLWICK	4	1980	VCD-145M	V084	80		2.90			
109	COLWICK	4	1980	VCD-145M	V085	80		2.90			
110	COLWICK	4	1980	VCD-145M	V086	80		2.90			
111	COLWICK	4	1980	VCD-145M	V087	60		2.88			
112	COLWICK	4	1980	VCD-145M	V087	80		2.92			
113	LIPTAUER	4	1980	VCD-145-2M	V015	95		2.96			
114	LIPTAUER	4	1980	VCD-145-2M	V020	95		3.00		2.953	
115	LIPTAUER	4	1980	VCD-145-1M	V049	85	3.14				
116	LIPTAUER	4	1980	VCD-145-1M	V049	90	3.12		3.130		
117	LIPTAUER	4	1980	VCD-145-2M	V062	85		2.89			
118	LIPTAUER	4	1980	VCD-145-2M	V067	90		2.96			

COMMENT All sensitivity values have multiplier 1E-22 (C/G-MeV) suppressed.
Average sensitivities shown for 1-mil and 2-mil windows are for the individual events.
This is then a way of looking for a trend in calendar time.

NOTE *1: The second FARALLONES calibration of V005 did not use magnets.
NOTE *2: This FARALLONES average includes all eight calibrations
NOTE *3: This FARALLONES average does not include the calibration of V005 without magnets.

Comments by Brent Davis, Sept 4, 2003:

Four detector 'type names' appear, but there are probably only two types in the usual sense: 1-mil or 2-mil window.
The presence of four names is probably the result of an irregularity in the transition of names when 2-mil windows began to be used

Thus: VCD-145M-1, VCD-145-1M, and all of the VCD-145M before NESSEL are probably all of the same type;
VCD-145-2M and all of the VCD-145M for COLWICK are probably the second type.

Detectors in general were not reworked, so the appearance of a given serial number with both 1-mil and 2-mil windows probably means that the 2-mil version simply used an extra 1-mil sheet placed in front of the original vacuum window. The detectors shown with both windows are serial numbers:
V013, V015, V017, V020

TABLE II (page 1 of 3)

VCD-145 Calibration Data – Sorted by Collimator Diameter

Memo	Event name	Month	Year	Type	Serial	Collimator	Sensitivity		
entry				name	Number	diameter	1-mil	2-mil	Average
sequence				(as in memo)		(mm)	(e-22)	(e-22)	
3	FARALLONES	12	1977	VCD-145M	V005	75	2.81		NOTE*1
15	PANIR	9	1978	VCD-145M	V014	60	3.18		
17	PANIR	9	1978	VCD-145M	V015	60	3.14		
19	PANIR	9	1978	VCD-145M	V016	60	3.18		
21	PANIR	9	1978	VCD-145M	V017	60	3.18		
23	PANIR	9	1978	VCD-145M	V018	60	3.18		
25	PANIR	9	1978	VCD-145M	V019	60	3.18		
27	PANIR	9	1978	VCD-145M	V023	60	3.18		
29	PANIR	9	1978	VCD-145M	V024	60	3.27		
39	DIABLO HAWK	10	1978	VCD-145M	V020	60	3.22		
41	DIABLO HAWK	10	1978	VCD-145M	V022	60	3.22		3.19
43	DIABLO HAWK	10	1978	VCD-145M	V025	60	3.20		(60-mm)
45	DIABLO HAWK	10	1978	VCD-145M	V026	60	3.22		
62	KLOSTER	2	1979	VCD-145M	V050	60	3.14		
64	KLOSTER	2	1979	VCD-145M	V051	60	3.11		
66	KLOSTER	2	1979	VCD-145M	V052	60	3.13		
68	KLOSTER	2	1979	VCD-145M	V053	60	3.16		
71	PEPATO	6	1979	VCD-145M	V022	60	3.23		
72	PEPATO	6	1979	VCD-145M	V024	60	3.28		
94	NORBO	3	1980	VCD-145-1M	V056	60	3.17		
1	FARALLONES	12	1977	VCD-145M	V004	75	3.26		
2	FARALLONES	12	1977	VCD-145M	V005	75	3.24		
4	FARALLONES	12	1977	VCD-145M	V006	75	3.24		
5	FARALLONES	12	1977	VCD-145M	V007	75	3.24		
6	FARALLONES	12	1977	VCD-145M	V008	75	3.26		
7	FARALLONES	12	1977	VCD-145M	V009	75	3.28		3.26
8	FARALLONES	12	1977	VCD-145M	V010	75	3.26		(75-mm)
9	REBLOCHON	3	1978	VCD-145M	V011	75	3.28		
10	REBLOCHON	3	1978	VCD-145M	V012	75	3.28		
11	REBLOCHON	3	1978	VCD-145M	V013	75	3.28		
12	CAMPOS	3	1978	VCD-145M	V009	80	3.25		
13	CAMPOS	3	1978	VCD-145M	V010	80	3.24		
14	CAMPOS	3	1978	VCD-145M	V014	80	3.24		
16	PANIR	9	1978	VCD-145M	V014	80	3.19		
18	PANIR	9	1978	VCD-145M	V015	80	3.16		
20	PANIR	9	1978	VCD-145M	V016	80	3.19		
22	PANIR	9	1978	VCD-145M	V017	80	3.19		
24	PANIR	9	1978	VCD-145M	V018	80	3.19		
26	PANIR	9	1978	VCD-145M	V019	80	3.19		
28	PANIR	9	1978	VCD-145M	V023	80	3.19		
30	PANIR	9	1978	VCD-145M	V024	80	3.26		
31	PANIR	9	1978	VCD-145M	V027	80	3.24		
32	PANIR	9	1978	VCD-145M	V028	80	3.22		
33	PANIR	9	1978	VCD-145M	V029	80	3.21		
34	PANIR	9	1978	VCD-145M	V030	80	3.22		
35	PANIR	9	1978	VCD-145M	V031	80	3.22		
36	PANIR	9	1978	VCD-145M	V032	80	3.22		
37	PANIR	9	1978	VCD-145M	V033	80	3.22		
38	PANIR	9	1978	VCD-145M	V034	80	3.30		

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VCD-145 Calibration Data – Sorted by Collimator Diameter

Memo entry sequence	Event name	Month	Year	Type name (as in memo)	Serial Number	Collimator diameter (mm)	Sensitivity 1-mil (e-22)	Sensitivity 2-mil (e-22)	Average
40	DIABLO HAWK	10	1978	VCD-145M	V020	80	3.21		
42	DIABLO HAWK	10	1978	VCD-145M	V022	80	3.24		
44	DIABLO HAWK	10	1978	VCD-145M	V025	80	3.21		
46	DIABLO HAWK	10	1978	VCD-145M	V026	80	3.22		
47	QUARGEL	11	1978	VCD-145M	V035	80	3.18		
48	QUARGEL	11	1978	VCD-145M	V036	80	3.22		
49	QUARGEL	11	1978	VCD-145M	V037	80	3.20		
50	QUARGEL	11	1978	VCD-145M	V038	80	3.18		
51	QUARGEL	11	1978	VCD-145M	V039	80	3.20		
53	FARM	12	1978	VCD-145M	V040	80	3.18		
54	FARM	12	1978	VCD-145M	V041	80	3.15		
55	FARM	12	1978	VCD-145M	V042	80	3.18		3.20
56	FARM	12	1978	VCD-145M	V043	80	3.20		(80-mm)
57	FARM	12	1978	VCD-145M	V044	80	3.16		
58	FARM	12	1978	VCD-145M	V045	80	3.20		
59	FARM	12	1978	VCD-145M	V046	80	3.16		
60	FARM	12	1978	VCD-145M	V047	80	3.16		
61	FARM	12	1978	VCD-145M	V048	80	3.16		
63	KLOSTER	2	1979	VCD-145M	V050	80	3.13		
65	KLOSTER	2	1979	VCD-145M	V051	80	3.13		
67	KLOSTER	2	1979	VCD-145M	V052	80	3.14		
69	KLOSTER	2	1979	VCD-145M	V053	80	3.18		
70	PEPATO	6	1979	VCD-145M	V022	80	3.22		
73	PEPATO	6	1979	VCD-145M	V025	80	3.20		
74	BURZET	8	1979	VCD-145M	V042	80	3.20		
75	BURZET	8	1979	VCD-145M	V055	80	3.20		
76	BURZET	8	1979	VCD-145M	V056	80	3.19		
77	PERA	9	1979	VCD-145M-1	V053	80	3.20		
115	LIPTAUER	4	1980	VCD-145-1M	V049	85	3.14		3.14
52	QUARGEL	11	1978	VCD-145M	V039	90	3.10		
116	LIPTAUER	4	1980	VCD-145-1M	V049	90	3.12		3.11
91	NORBO	3	1980	VCD-145-2M	V013	60		2.90	
92	NORBO	3	1980	VCD-145-2M	V017	60		2.88	
93	NORBO	3	1980	VCD-145-2M	V021	60		2.97	
97	NORBO	3	1980	VCD-145-2M	V073	60		2.94	
98	NORBO	3	1980	VCD-145-2M	V075	60		2.90	
101	NORBO	3	1980	VCD-145-2M	V078	60		2.87	2.89
102	NORBO	3	1980	VCD-145-2M	V079	60		2.83	(60-mm)
103	COLWICK	4	1980	VCD-145M	V059	60		2.85	
105	COLWICK	4	1980	VCD-145M	V082	60		2.86	
107	COLWICK	4	1980	VCD-145M	V083	60		2.86	
111	COLWICK	4	1980	VCD-145M	V087	60		2.88	
78	NESSEL	9	1979	VCD-145-2M	V060	80		2.88	
79	NESSEL	9	1979	VCD-145-2M	V061	80		2.90	
80	NESSEL	9	1979	VCD-145-2M	V062	80		2.89	
81	NESSEL	9	1979	VCD-145-2M	V063	80		2.88	
82	NESSEL	9	1979	VCD-145-2M	V064	80		2.97	
83	NESSEL	9	1979	VCD-145-2M	V065	80		2.95	
84	NESSEL	9	1979	VCD-145-2M	V066	80		2.93	

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VCD-145 Calibration Data – Sorted by Collimator Diameter

Memo entry sequence	Event name	Month	Year	Type name (as in memo)	Serial Number	Collimator diameter (mm)	Sensitivity 1-mil (e-22)	Sensitivity 2-mil (e-22)	Average
87	TARKO	2	1980	VCD-145-2M	V068	80		2.95	
88	TARKO	2	1980	VCD-145-2M	V071	80		2.95	
89	TARKO	2	1980	VCD-145-2M	V072	80		2.93	
90	TARKO	2	1980	VCD-145-2M	V074	80		2.93	2.92
95	NORBO	3	1980	VCD-145-2M	V069	80		2.95	(80-mm)
96	NORBO	3	1980	VCD-145-2M	V070	80		2.95	
99	NORBO	3	1980	VCD-145-2M	V075	80		2.91	
100	NORBO	3	1980	VCD-145-2M	V076	80		2.93	
104	COLWICK	4	1980	VCD-145M	V081	80		2.90	
106	COLWICK	4	1980	VCD-145M	V082	80		2.88	
108	COLWICK	4	1980	VCD-145M	V084	80		2.90	
109	COLWICK	4	1980	VCD-145M	V085	80		2.90	
110	COLWICK	4	1980	VCD-145M	V086	80		2.90	
112	COLWICK	4	1980	VCD-145M	V087	80		2.92	
117	LIPTAUER	4	1980	VCD-145-2M	V062	85		2.89	2.89
85	AZUL	12	1979	VCD-145-2M	V058	90		2.85	
86	AZUL	12	1979	VCD-145-2M	V059	90		2.85	2.89
118	LIPTAUER	4	1980	VCD-145-2M	V067	90		2.96	
113	LIPTAUER	4	1980	VCD-145-2M	V015	95		2.96	
114	LIPTAUER	4	1980	VCD-145-2M	V020	95		3.00	2.98

NOTE *1: This calibration did not use magnets, and it is not included in the averages below.

Comments by Brent Davis, Sept 4, 2003:

Four detector 'type names' appear, but there are probably only two types in the usual sense: 1-mil or 2-mil window. There was probably an irregularity in the transition of names used.

Detectors in general were not reworked, so the appearance of a given serial number with both 1-mil and 2-mil windows probably means that the 2-mil version simply used an extra 1-mil sheet placed in front of the original vacuum window.

Mean sensitivities:

1-mil windows: Collimation	#	Average	std. Dev.	2-mil windows: Coll.	#	Average	std. Dev.
60-mm	19	3.19	0.043	60-mm	11	2.89	0.039
75-mm	10	3.26	0.017	80-mm	21	2.92	0.023
80-mm	47	3.20	0.033	85-mm	1	2.89	0
85-mm	1	3.14	0	90-mm	3	2.89	0.052
90-mm	2	3.11	0.010	95-mm	2	2.98	0.020

RATIO: 2-mil to 1-mil (same diameter)

60-mm dia	0.905
80-mm dia	0.913
90-mm	0.928

1.0E-22 is suppressed in all sensitivity values reported.

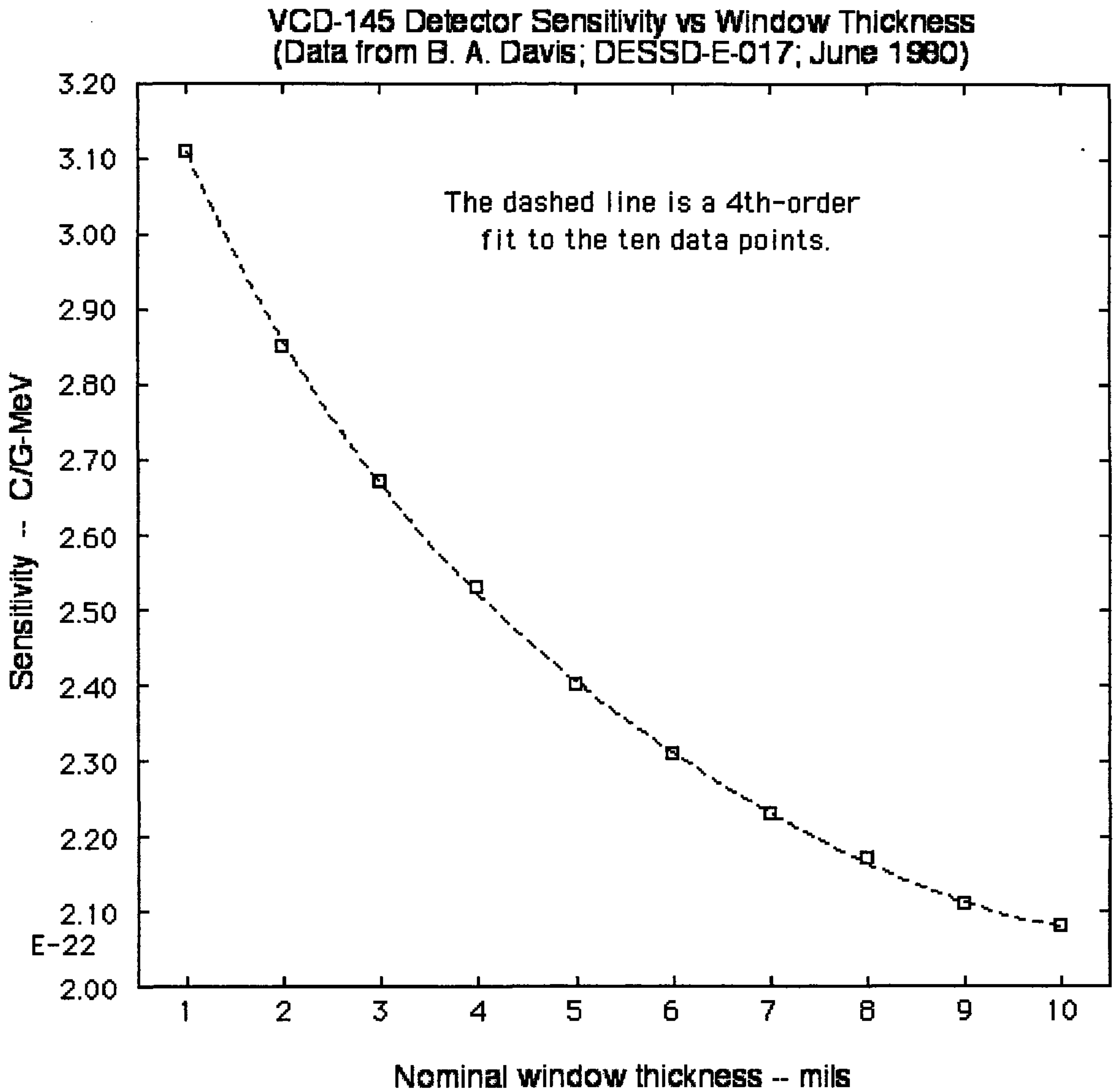

Figure 1. Variation of detector sensitivity with window thickness.