ORNL/MD/LTR-246

CCCTF Trap Table Calibration Curves for Krypton-85 Activity Determination

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June 2003

Fissile Materials Disposition Program

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CCCTF Trap Table Calibration Curves for Krypton-85 Activity Determination

The enclosed document describes a series of calibration measurements performed on the CCCTF trap table that is used to determine the ^{85}Kr inventories within and hence the fission gas release fractions for the MOX test capsules. This effort was sponsored by the Fissile Materials Disposition Program (FMDP). The work was carried out at the Irradiated Fuels Examination Laboratory by the Metals and Ceramics Division of the Oak Ridge National Laboratory during the period from November 2002 though May 2003.

This is a Level-2 document as defined in the Fissile Materials Disposition Program Light-Water Reactor Mixed-Oxide Fuel Irradiation Test Project Plan, ORNL/MD/LTR-78.

Sincerely,

Robert N. Morris
Fissile Materials Disposition Program

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ORNL/MD/LTR-246

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Oak Ridge National Laboratory

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ACRONYMS

CCCTF	Core Conduction Cooldown Test Facility
CPS	Counts per Second
DPS	Disintegrations per Second
FMDP	Fissile Materials Disposition Program
INEEL	Idaho National Engineering and Environmental Laboratory
LN_2	Liquid Nitrogen
LWR	Light Water Reactor
MOX	Mixed Oxide
ORNL	Oak Ridge National Laboratory
PIE	Post Irradiation Examination

ABSTRACT

This report summarizes a series of calibration measurements performed on the CCCTF trap table at ORNL Building 3525 during the November 2002 through May 2003 timeframe. These traps are used to measure the ^{85}Kr activity in the gas collected from coated particle fuel, test capsule volumes, and fuel pin plenums. The purposes of these measurements were twofold. The first goal was to check and update the calibration curve of the traps. The second goal was to modify the detector mounts so that the distance between the traps and the detectors could be varied in proportion to the activity level so as to increase the range of trap inventories that can be measured.

1. INTRODUCTION

1.1 General

The CCCTF trap table consists of 1) two charcoal traps cooled by liquid nitrogen in partially shielded enclosures with detectors facing the traps, 2) a cooled copper turnings-filled trap to collect moisture upstream of the charcoal traps, 3) a vacuum system to support the needs of the vacuum insulation around the traps, 4) a temperature control system, and 5) a valve panel to allow switching traps into and out of the flow path. See Figure 1 for a schematic of the system.

The system functions by flowing helium through the experiment under study, into the valve panel and through the selected trap(s). The helium sweeps the released gases from the test apparatus into the trap system. The helium flow is continuous and a time period of 5 to 30 minutes is usually required to transport all of the released ^{85}Kr into the trap system. The flow rate is usually between 400 and 1000 cm^3 per minute. Generally, a series of counts is taken over a period of ½ to 2 hours to insure that all the ^{85}Kr has been swept into the active trap.

A simple on/off control arrangement is used to control trap temperatures. The charcoal traps operate at about -190ºC. A thermocouple at the cooling vent of the trap monitors the upper trap temperature (nitrogen boil off) and allows liquid nitrogen in when it reaches –180ºC and stops flow when it has decreased to -185ºC. Experience has demonstrated that these settings will maintain the proper temperatures at the trap internals.

The moisture trap operates at about -80ºC. This trap also has a thermocouple at the cooling vent of the trap that monitors the temperature. Liquid nitrogen is introduced when this thermocouple reads –95ºC and flow is stopped at -105ºC (this trap is really cooled by cold gas rather than liquid).

The purpose of the moisture trap is to purge the incoming gas stream of any moisture that may freeze up and block the flow in the relatively small passages of the charcoal traps. In practice it has been observed that very small amounts of water can cause problems with these trapping systems, that water is almost always present in a system that has been exposed to the air, and that the moisture must be dealt with to have a reliable system. Other water purging options include chemical desiccants, but the associated chemical handling and waste issues make the cryogenic option more attractive.

The moisture trap has little impact on the krypton flow through the system; it primarily introduces a small time delay in the transfer of krypton from the test apparatus to the charcoal traps. Krypton has a boiling point of -152˚C and the copper turnings do not absorb the gas as does charcoal. The moisture trap will also slow down the transfer of CO_2 (sublimes at about -78˚C) and Xe (boiling point -107˚C).

A cross section of the trap system is shown in Figure 2. The vacuum region surrounding the trap provides insulation and the cooled charcoal medium absorbs the krypton. In principal, the traps can be operated somewhat above the freezing point of krypton, at about -140˚C (krypton freezes

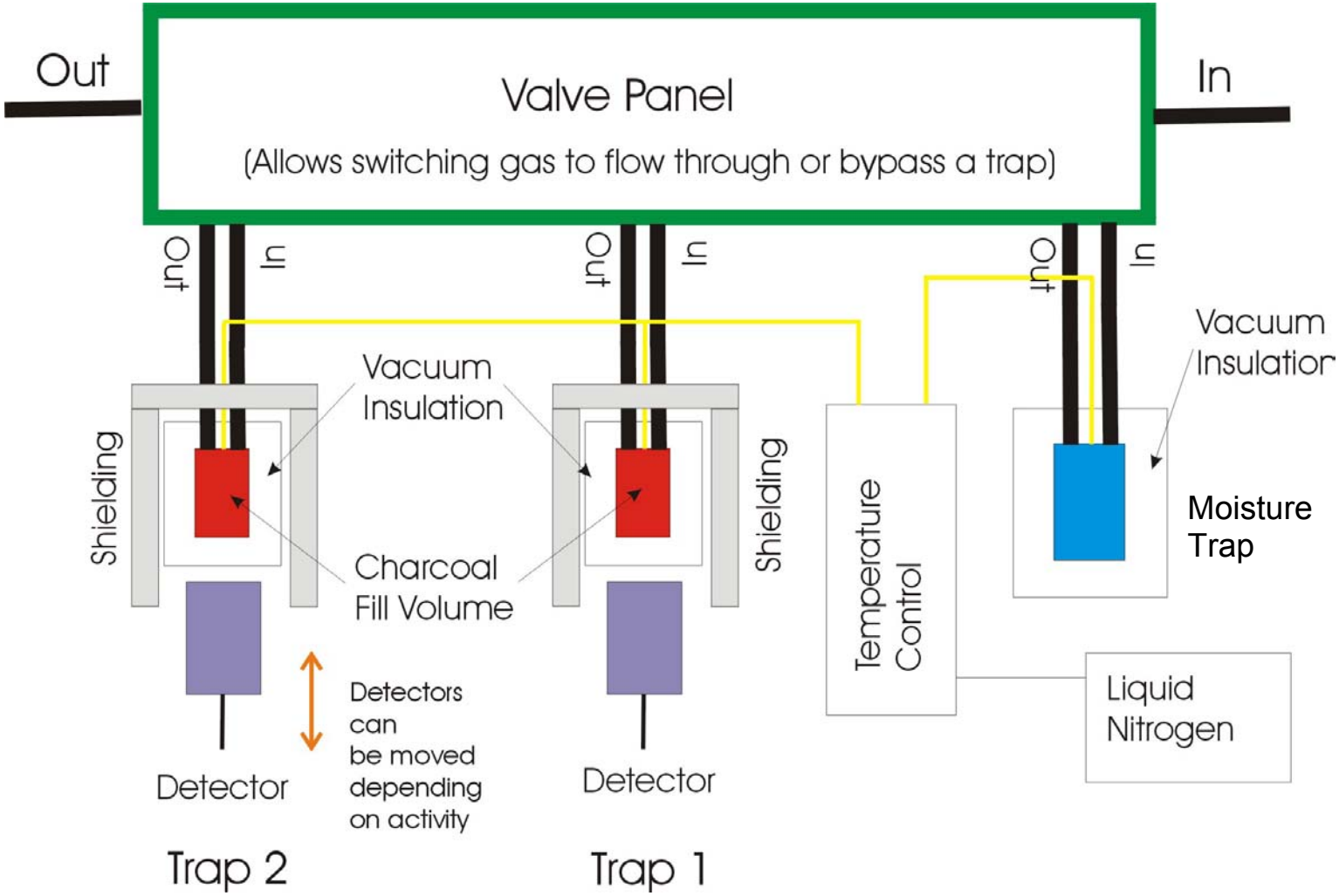

Figure 1. Schematic view of the CCCTF Trap Table.

at -157˚C), but testing has shown that the vapor pressure of the gas is high enough that migration up the charcoal column occurs over a time period of several hours, perhaps aided by the continuous flow of helium. The material is stable in the traps at a temperature just below the freezing point of krypton. The lower temperature of -190ºC was chosen for operation, as it was conservative and is convenient to obtain with liquid nitrogen (LN_2).

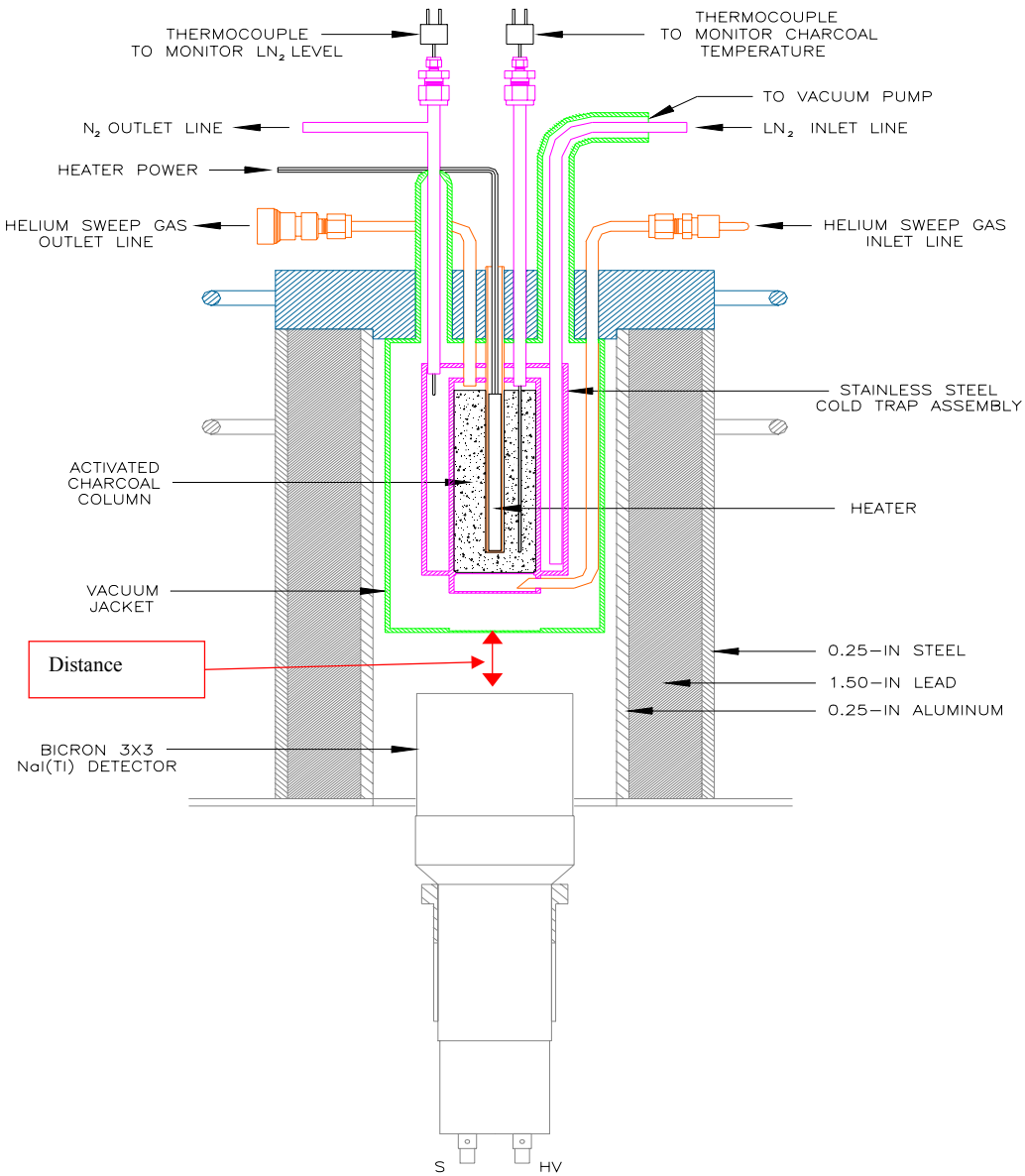

Figure 2. Cut away view of the coldtrap and detector. The distance between the bottom of the trap vacuum jacket and the top of the detector determines the spacing..

The sensitivity of the measurement can be changed by moving the detector closer to or farther from the trap. Closer to the trap increases the sensitivity of the system, but limits the maximum inventory because of the threat of detector overload. Farther away increases the allowable inventory at the expense of the minimum detectable activity. The detector can be moved during a test, so it is possible to compensate as necessary for unanticipated factors. Three distances were chosen for calibration purposes: 1/2", 5", and 14".

The calibration is conducted by introducing a known amount of ^{85}Kr into the system by purging it out of a specially prepared glass sphere with helium gas at a modest flow rate (~400 cm^3 per minute). Figure 3 is a schematic of the test equipment setup.

At the conclusion of the test, the krypton is released from the traps by warming them with an internal heater with the helium sweep flow on. This means can also be used to transfer krypton from Trap 1 to Trap 2. Trap 2 is cooled down and Trap 1 is heated up, releasing the krypton to the helium sweep gas. The gas then flows into the cooled Trap 2 that then collects the krypton. This method was used during the conduct of this test so that the same quantity of krypton could be measured in both traps.

One shortcoming of the system is the additional uncertainty (estimated to be 1-5%) introduced by the specific location of the collected krypton in the charcoal column. The geometry of the counting system is changed slightly depending on exactly where the krypton freezes out in the charcoal column. This is most important for the close geometry (1/2") and least important for the far (14") geometry.

1.2 Reference ^{22}Na Checks

To provide a long-term relativity simple calibration check capability for the traps, a ^{22}Na source (roughly 10μCi) is used to simulate an ^{85}Kr inventory. The sodium has a photopeak at 511 keV that is a good match to the ^{85}Kr peak at 514 keV.

This check capability is achieved as follows. First a ^{22}Na source is either placed into a special tube that runs down the center of the traps (for the warm up heater) or the trap itself is removed and replaced by a dummy trap containing a ^{22}Na source. The detector response to this source is recorded for each trap at the detector locations of interest (3 locations in our case).

When the trap calibration is again being checked at some later time, the ^{22}Na source is placed back into the respective trap and the detector response measured. The old and the new values are expected to agree within some counting tolerance (<3%) to insure that the system has not changed in some unexpected fashion.

Generally, only one location needs to be checked for day-to-day operation; after a long period of inactivity it is wise to check all three locations to insure that no mechanical changes to the detector mounts have occurred.

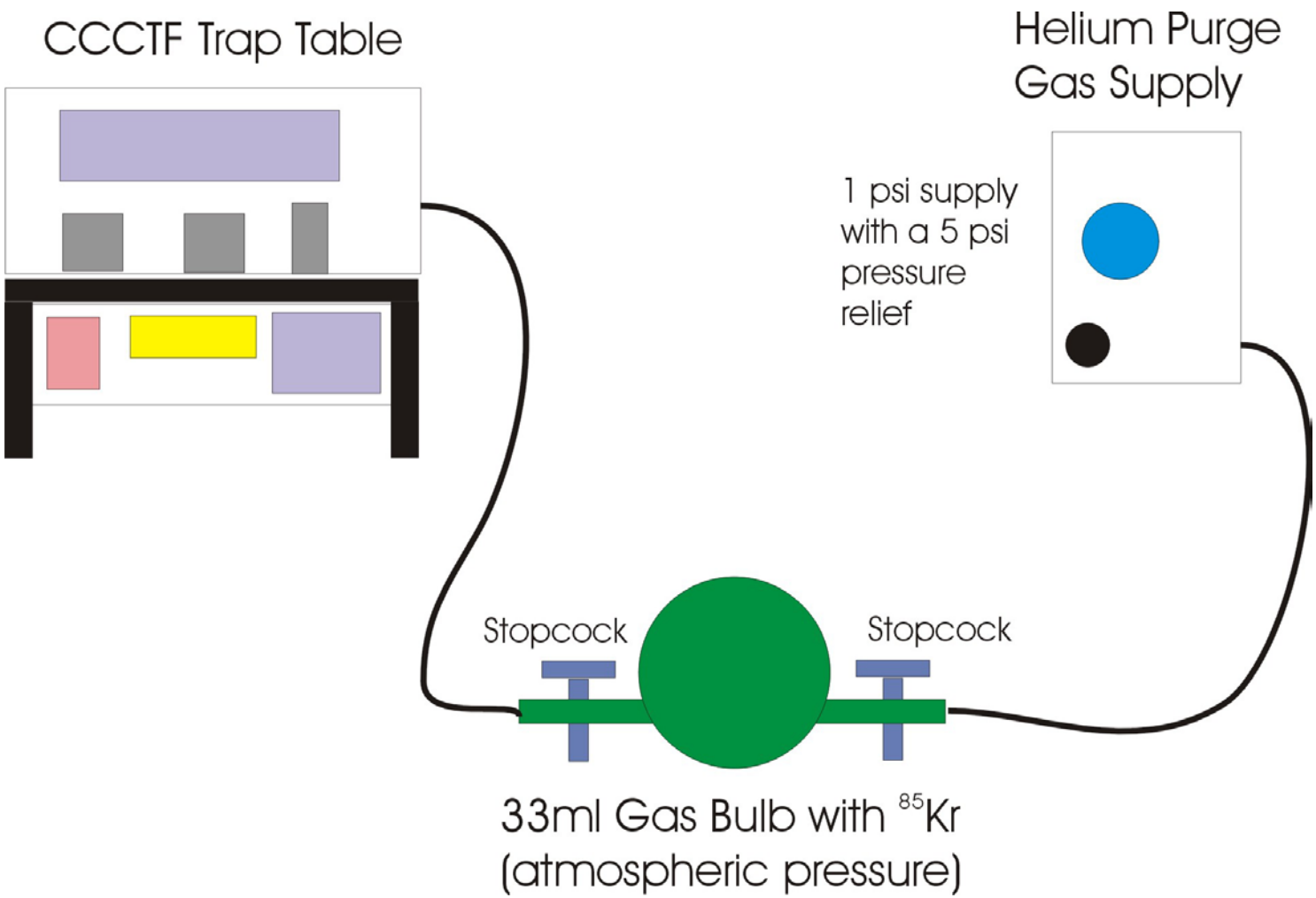

Figure 3. Schematic of test set up showing how the known quantity of ^{85}Kr is introduced in the trap system

2. RESULTS OF THE CALIBRATION MEASUREMENTS

2.1 Sources Used

Nine ^{85}Kr sources in 33 ml glass spheres with in/out stopcocks were procured from ANALYTICS. These are detailed in Table 1 and the associated certification sheets are contained in Appendix A. In addition, one source was locally prepared and used (2.89 µCi).

Table 1. ANALYTICS Reference Sources.

^{85}Kr Amount (µCi)	Reference Number	Activity (DPS)	Date of Calibration	Uncertainty (%)
9.554	65032-198	3.535×10^5	11 Dec 2002	5.0
32.97	65033-198	1.220×10^6	11 Dec 2002	5.0
94.37	65034-198	3.492×10^6	11 Dec 2002	5.0
331.6	65035-198	1.227×10^7	11 Dec 2002	5.0
1,015	65036-198	3.754×10^7	11 Dec 2002	5.0
3,197	65037-198	1.183×10^8	11 Dec 2002	5.0
4,214	65671-198	1.559×10^8	10 Mar 2003	5.0
5,870	65672-198	2.172×10^8	10 Mar 2003	5.0
10,222	65038-198	3.782×10^8	11 Dec 2002	5.0

2.2 Historical Data

Some historical calibration data was available for the trap system. This consists of six calibration points for the two traps. More data is available for Trap 2 than Trap 1 because the original Trap 1 was contaminated with cesium and was replaced.

This historical data is of interest for three reasons:

1. This data connects the present calibration with past calibration work.
2. Two different agents measured the krypton quantities – a commercial vendor (recent) and the local laboratory (past).
3. The conditions of the two calibrations were somewhat different. The past calibration work was conducted at a higher purge gas flow rate, about 800 cm^3 per minute versus the 400 cm^3 per minute used for this test, and the introduction of the krypton was different. In the present test, the flow to the traps was stopped, the glass sphere containing the krypton inserted into the line, and the flow reestablished. In the past calibration, the krypton was contained in small glass ampoules and placed in a larger loose fitting rubber tube inserted into the flow path. Gas flow was established and the sweep gas flowed past the ampoule. The ampoule was then crushed and the krypton released into the faster, already flowing gas stream. The importance of this lies in the way the krypton freezes out in the traps. If the freeze out position in the charcoal column is sensitive to the flow

rate and flow concentration, the two methods would produce different results. Fortunately, the results obtained with the two different methods agree rather well.

2.3 Calibration Test Results

The results of the calibration tests are shown in Figures 4 through 9 for the two traps at 3 different detector spacings along with individual curve fits. In the past, a linear detector response function (inventory versus CPS at ½" spacing) has been used for computing the ^{85}Kr inventory (mostly in the range of 3-100 μCi); however, the current tests demonstrate that the response significantly deviates from a simple linear approximation over the full inventory range and either a more complex calibration function should be used or an average value computed over the narrow range of interest. Tables 2 through 4 tabulate the results for each calibration source and detector spacing.

At the ½" detector spacing, the highest source was sufficient to drive the detectors past their linear limit and into saturation, at least for the detector at Trap 1. Both Figures 4 and 5 show a fit to the "knee" region of the curve (above 10,000 CPS), but this is only for completeness and readings with ^{85}Kr activities in this region are not recommended.

The historical data follows the generated calibration data well, with an average deviation from the fitted curves of less than 3%. Only one past data point has an error of greater than 5% (112 μCi point with a difference of 8.5% as indicated in Figure 5). This may be due to calibration uncertainties or the way the material froze out on the trap.

Third order polynomial fits were determined for each trap for the 3 test distances. These are shown in Table 5. The curve fit reproduced the data to better than 3.2% (in most cases better than 2%), excluding the "knee" in the ½" spacing tests. The coefficients were determined by minimizing the fractional error at the measured points. The fit at ½" does not use the last two data points to avoid the inconsistencies introduced by detector overload.

If these curve fits are insufficient for the application of interest, the values in the tables can be used to generate a more appropriate fit for a specific need.

The uncertainty of the curve fit may be estimated as follows:

Sample uncertainty	*5%*
Counting statistics	*3%*
Curve fit / Freeze out uncertainty	*5% (Rough estimate based on past data plus curve fitting)*

A sum of squares approximation gives an uncertainty estimate of about 8%. To do better would require that the reproducibility of the system be examined in greater detail. Data collected from the ^{22}Na tests indicate a long-term detector reproducibility of better than 3%. Since the current uncertainties are acceptable, an extensive effort to better determine the ^{85}Kr freeze out behavior on the charcoal is not warranted.

Table 2. Results with the detectors at ½".

Calibration Source Description	Source Activity (µCi)	Source Reference Date	Test Date	Activity at Test Time (µCi)	Trap 1 CPS	Dead Time (%)	Trap 2 CPS	Dead Time (%)
KR-11	2.89	1/21/2003	1/24/2003	2.88	12.97	0	10.76	0
SRS 65032-198	9.55	12/11/2002	1/30/2003	9.47	46.77	0	37.68	0
SRS 65033-198	32.97	12/11/2002	1/31/2003	32.67	167.30	1	135.00	1
SRS 65034-198	94.37	12/11/2002	2/3/2003	93.47	453.90	2	393.20	1
SRS 65035-198	331.60	12/11/2002	2/4/2003	328.39	1559.00	6	1356.00	5
SRS 65036-198	1015.00	12/11/2002	2/6/2003	1004.82	4602.00	17	4089.00	14
SRS 65037-198	3197.00	12/11/2002	2/11/2003	3162.14	11320.00	39	10840.00	37
SRS 65671-198	4214.00	3/10/2003	4/30/2003	4176.16	13360.00	50	12520.00	43
SRS 65672-198	5870.00	3/10/2003	5/1/2003	5816.26	14810.00	53	14630.00	50
SRS 65038-198	10222.00	12/11/2002	2/12/2003	10108.74	13310.00	66	15560.00	63

Notes: CPS – Counts per second after background subtraction as they relate to Test Activity. Dead Time – the percentage of time that the detector is effectively off due to count "pile up".

Table 3. Results with the detectors at 5".

Calibration Source Description	Source Activity (µCi)	Source Reference Date	Test Date	Activity at Test Time (µCi)	Trap 1 CPS	Dead Time (%)	Trap 2 CPS	Dead Time (%)
SRS 65032-198	9.55	12/11/2002	1/30/2003	9.47	7.599	0	7.035	0
SRS 65033-198	32.97	12/11/2002	1/31/2003	32.67	28.41	0	25.20	0
SRS 65034-198	94.37	12/11/2002	2/3/2003	93.47	79.29	0	73.74	0
SRS 65035-198	331.60	12/11/2002	2/4/2003	328.39	280.60	1	264.30	1
SRS 65036-198	1015.00	12/11/2002	2/6/2003	1004.82	871.50	3	809.70	3
SRS 65037-198	3197.00	12/11/2002	2/11/2003	3162.14	2725.00	10	2590.00	9
SRS 65671-198	4214.00	3/10/2003	4/30/2003	4176.16	3526.00	14	3303.00	12
SRS 65672-198	5870.00	3/10/2003	5/1/2003	5816.26	4587.00	17	4416.00	16
SRS 65038-198	10222.00	12/11/2002	2/12/2003	10108.74	7549.00	27	7296.00	25

Table 4. Results with the detectors at 14".

Calibration Source Description	Source Activity (µCi)	Source Reference Date	Test Date	Activity at Test Time (µCi)	Trap 1 CPS	Dead Time (%)	Trap 2 CPS	Dead Time (%)
SRS 65034-198	94.37	12/11/2002	2/3/2003	93.47	15.430	0	14.430	0
SRS 65035-198	331.60	12/11/2002	2/4/2003	328.39	57.280	0	53.270	0
SRS 65036-198	1015.00	12/11/2002	2/6/2003	1004.82	181.500	1	173.500	1
SRS 65037-198	3197.00	12/11/2002	2/11/2003	3162.14	589.800	2	564.200	2
SRS 65671-198	4214.00	3/10/2003	4/30/2003	4176.16	771.700	3	732.800	3
SRS 65672-198	5870.00	3/10/2003	5/1/2003	5816.26	1036.000	3	1007.000	4
SRS 65038-198	10222.00	12/11/2002	2/12/2003	10108.74	1839.000	7	1777.000	6

Notes: CPS – Counts per second after background subtraction as they relate to Test Activity. Dead Time – the percentage of time that the detector is effectively off due to count "pile up".

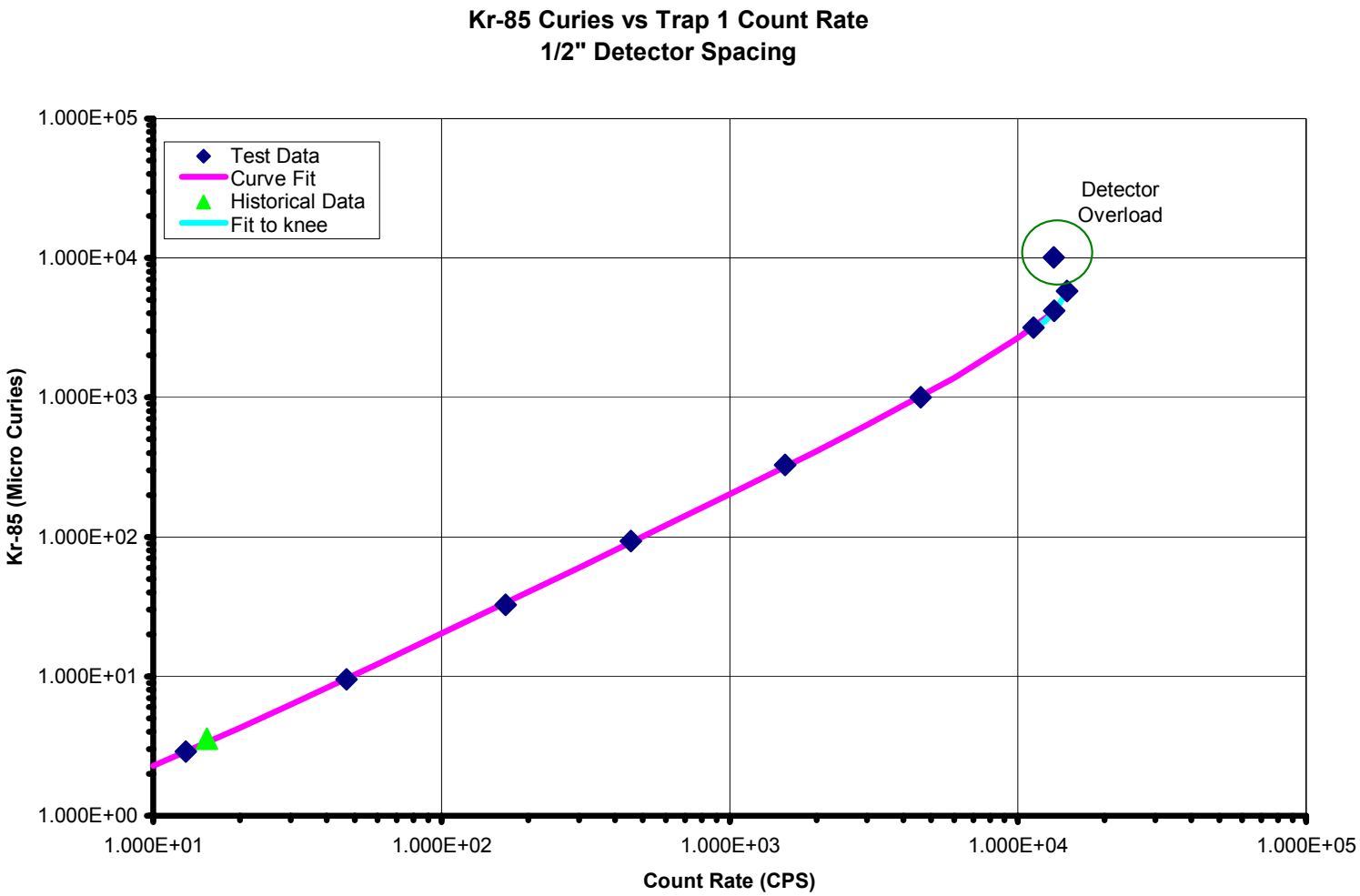

Figure 4. Detector 1 response at ½" spacing.

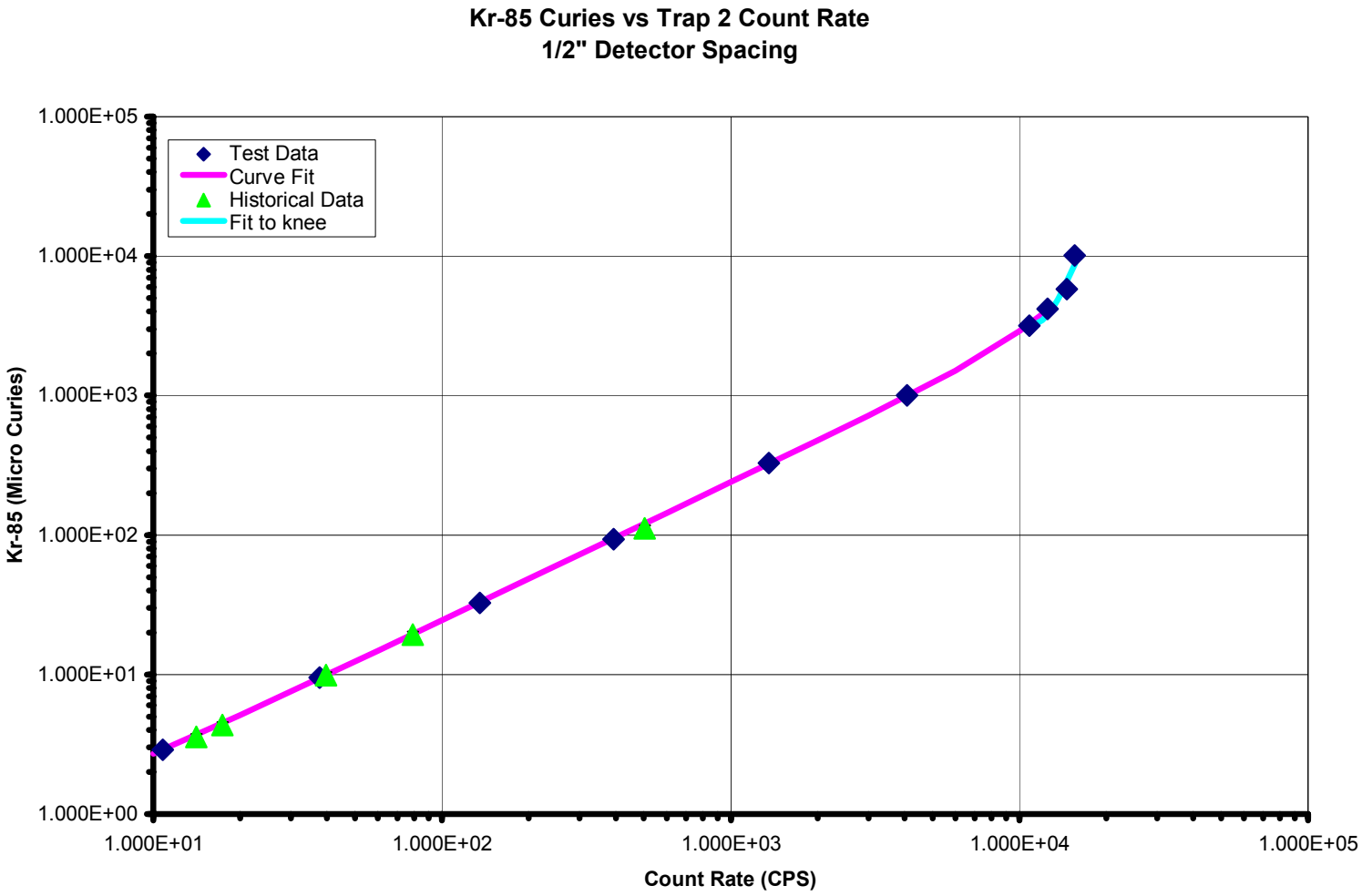

Figure 5. Detector 2 response at ½" spacing.

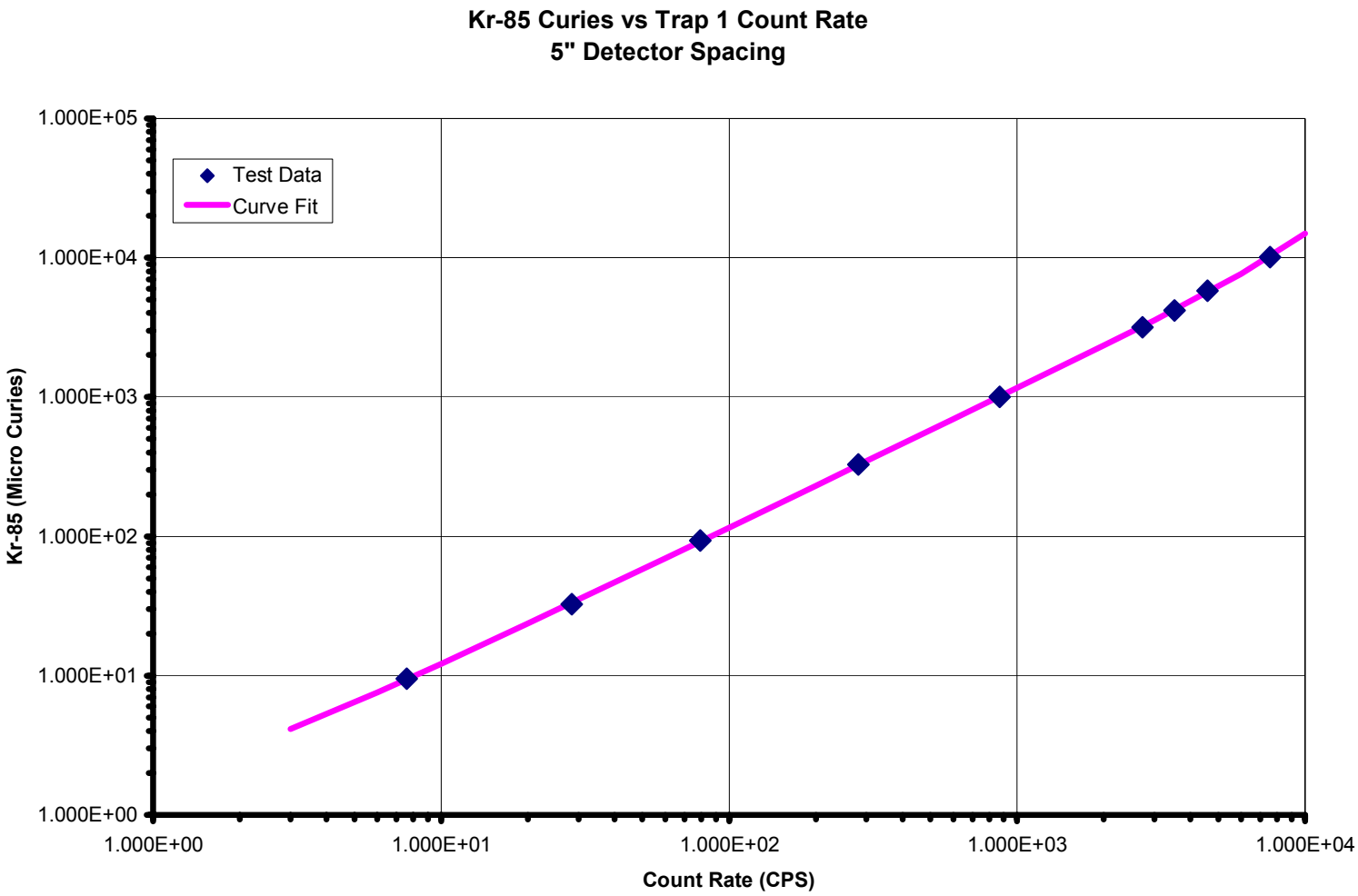

Figure 6. Detector 1 response at 5" spacing.

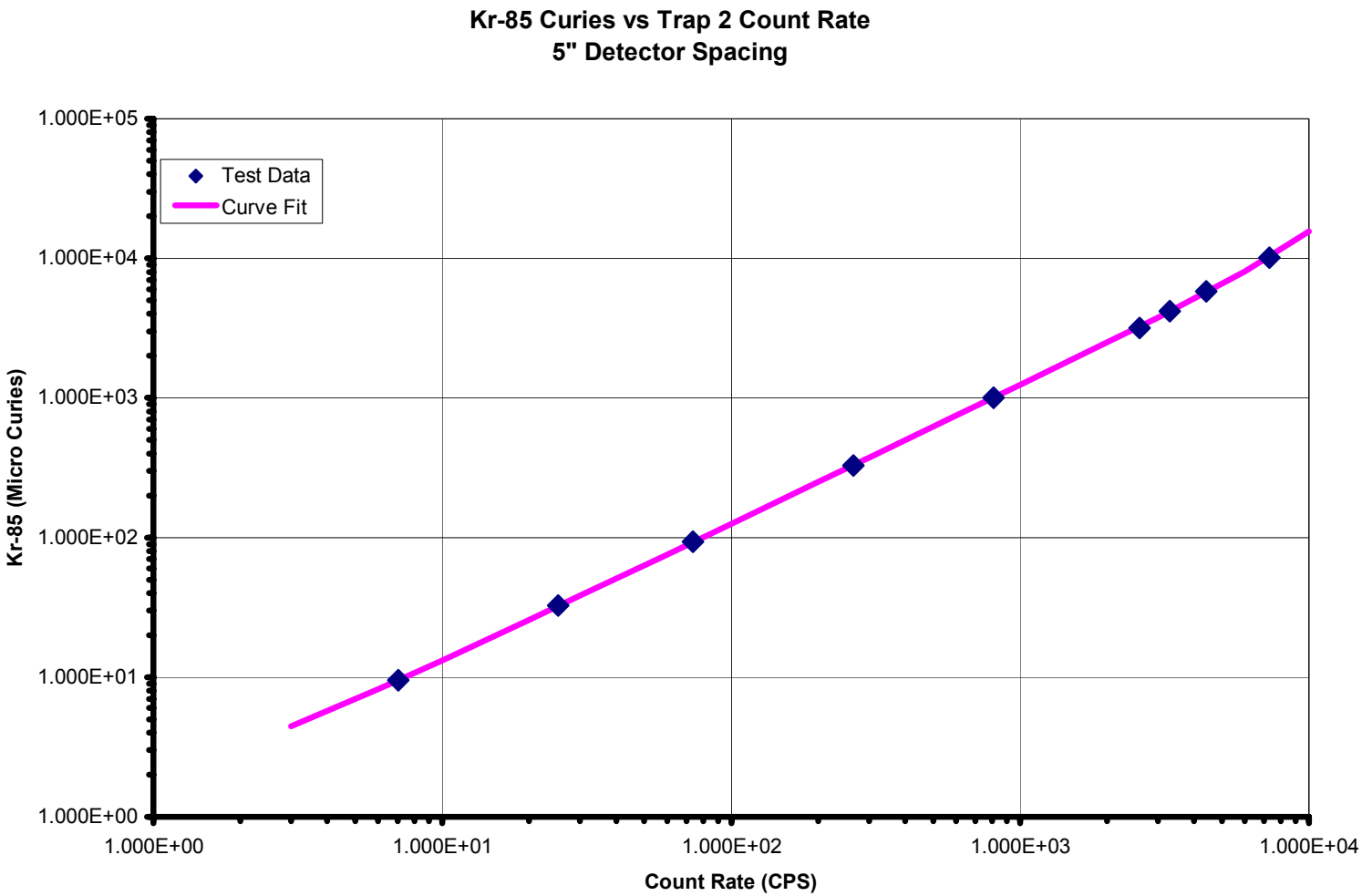

Figure 7. Detector 2 response at 5" spacing.

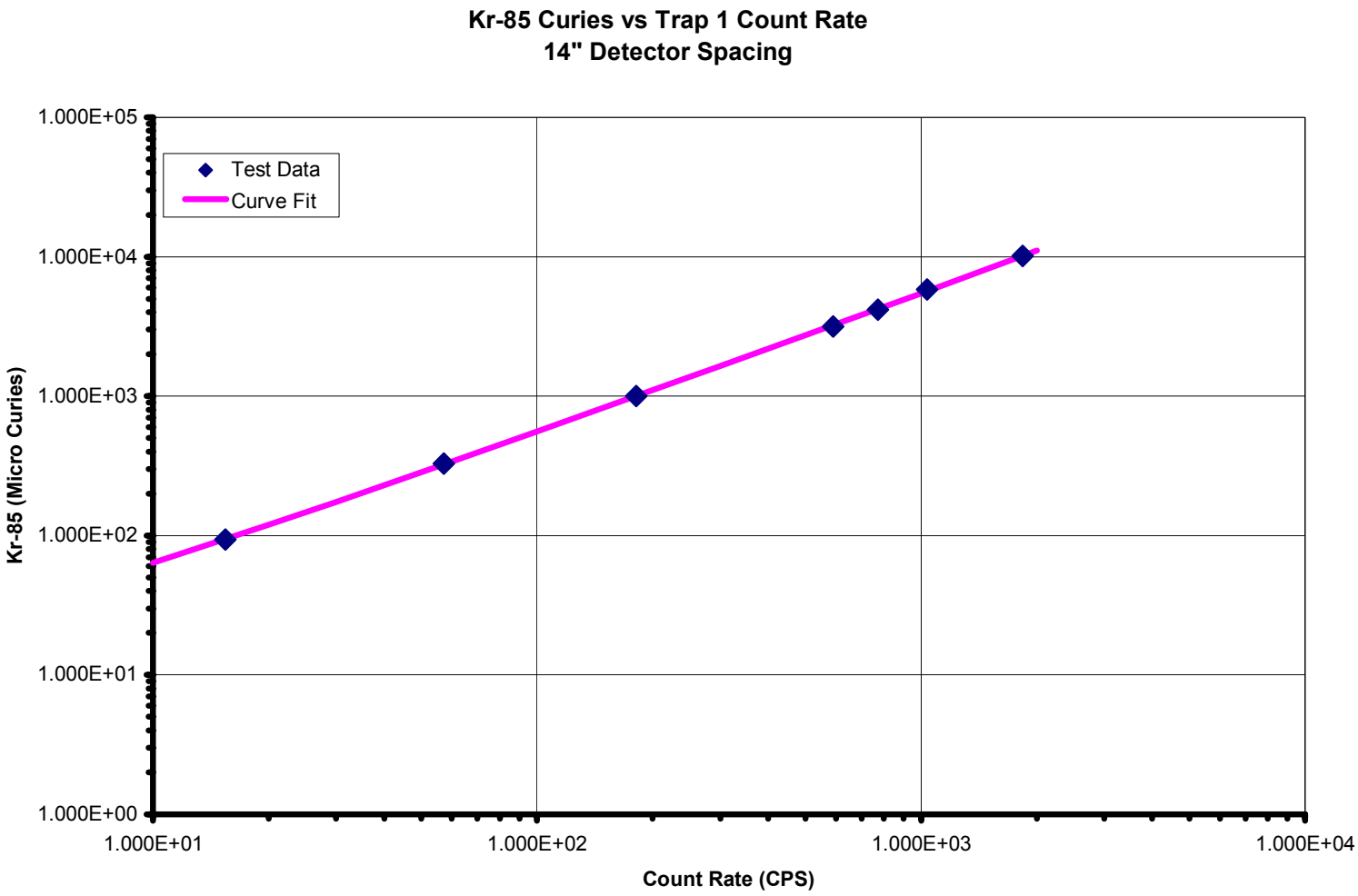

Figure 8. Detector 1 response at 14" spacing.

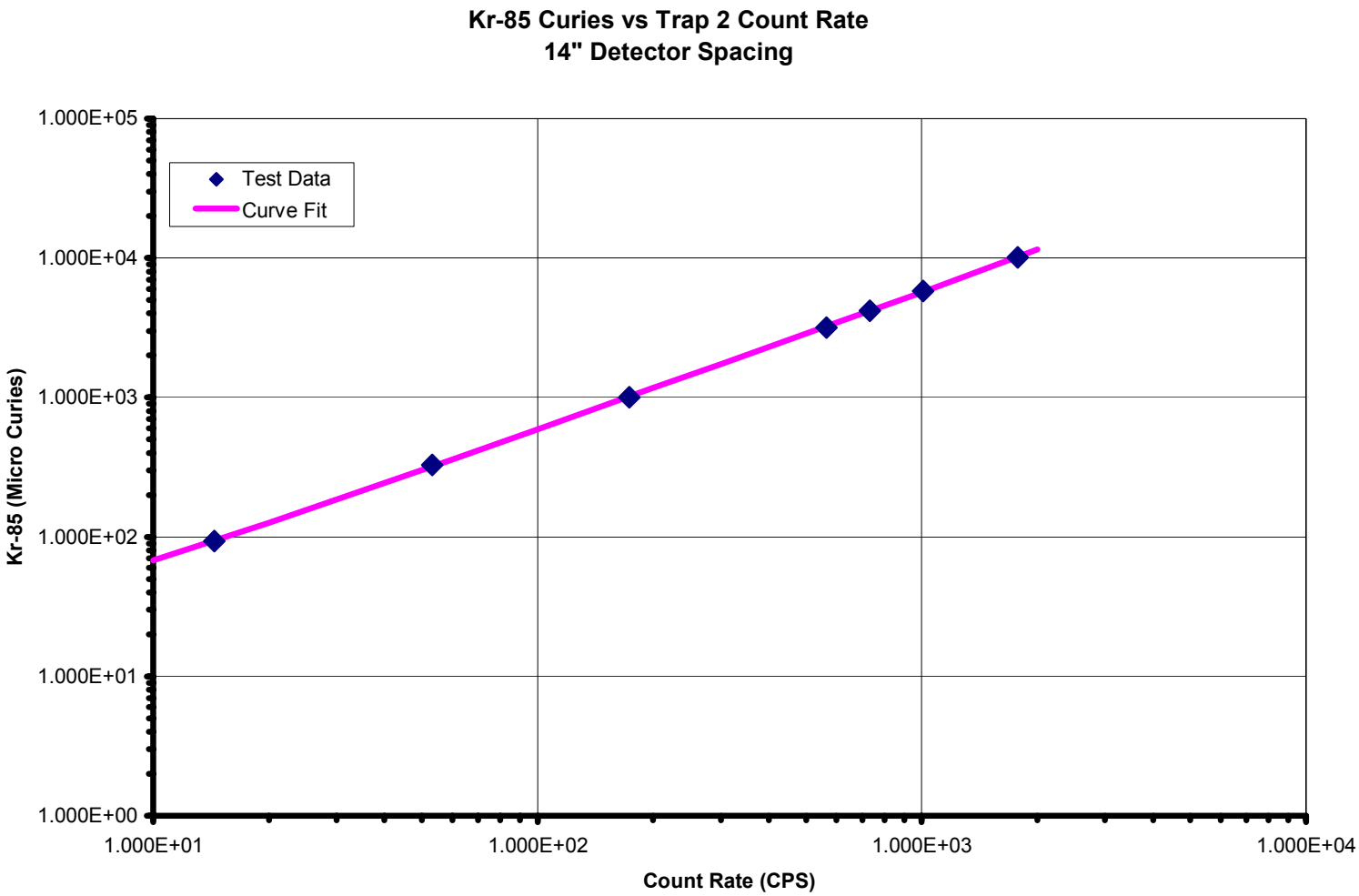

Figure 9. Detector 2 response at 14" spacing.

Table 5. CPS Fit Coefficients.

$$^{85}Kr[\mu Ci] = A + Bx + Cx^2 + Dx^3 \qquad x = CPS/1000$$

Detector 1					
Spacing (inches)	CPS Range	A	B	C	D
½	0<CPS<13,400	2.8319e-01	1.9912e+02	2.7262e+00	4.1222e-01
5	7.5<CPS<7600	6.7327e-01	1.1519e+03	2.0305e+00	3.1690e+00
14	15<CPS<1900	8.6474e+00	5.5184e+03	-1.5084e+02	8.2019e+01
Detector 2					
Spacing (inches)	CPS Range	A	B	C	D
½	0<CPS<12,600	2.8975e-01	2.4156e+02	-2.7245e+00	7.5289e-01
5	7<CPS<7300	7.1307e-01	1.2507e+03	-1.0840e+01	4.1868e+00
14	14<CPS<1800	9.3596e+00	5.8674e+03	-3.7554e+02	1.6069e+02

2.4 Detector Efficiency

Often the parameter of interest is not the relationship between counts per second and source activity, but rather the detector efficiency. The detector efficiency is the number of photons captured in the detector divided by the number of photons emitted by the specimen. For our purposes, it is generally in the range of 0.1 to 3%. The reason for the interest is that the software that operates the detector systems often is calibrated by the use of an efficiency factor rather than counts per second versus activity. The efficiency is generally assumed to be a function of photon energy, but not photon intensity as has been observed in the current calibration check.

The practical implications of this is that one either uses the CPS measured by the detectors and applies the curve fits or one generates an average efficiency to use over some restricted activity range and inputs this to the software. The analyst can determine the best approach. The former method is used for the MOX test capsules. Since the CPS are collected and stored for each test, the approaches are not mutually exclusive; one can always compute the measured activity based on CPS and compare this result with the values obtained via the efficiency method.

Tables 6 through 8 show the collected efficiency data (processed by system software) and figures 10 through 12 show the detector efficiency as a function of krypton trap loading. Table 9 details the curve fit coefficients.

These results reflect those observed in the previous section. In particular, the overload at the higher activity at the ½" spacing is manifested as a drop off in efficiency.

Table 6. Efficiency results with the detectors at ½".

Calibration Source Description	Source Activity (µCi)	Source Reference Date	Test Date	Activity at Test Time (µCi)	Trap 1 Efficiency (%)	Dead Time (%)	Trap 2 Efficiency (%)	Dead Time (%)
KR-11	2.89	1/21/2003	1/24/2003	2.88	2.8080	0	2.3310	0
SRS 65032-198	9.55	12/11/2002	1/30/2003	9.47	3.0820	0	2.4300	0
SRS 65033-198	32.97	12/11/2002	1/31/2003	32.67	3.1960	1	2.5790	1
SRS 65034-198	94.37	12/11/2002	2/3/2003	93.47	3.0310	2	2.6250	1
SRS 65035-198	331.60	12/11/2002	2/4/2003	328.39	2.9620	6	2.5770	5
SRS 65036-198	1015.00	12/11/2002	2/6/2003	1004.82	2.8600	17	2.5410	14
SRS 65037-198	3197.00	12/11/2002	2/11/2003	3162.14	2.2340	39	2.1400	37
SRS 65671-198	4214.00	3/10/2003	4/30/2003	4176.16	1.9970	50	1.8720	43
SRS 65672-198	5870.00	3/10/2003	5/1/2003	5816.26	1.5890	53	1.5690	50
SRS 65038-198	10222.00	12/11/2002	2/12/2003	10108.74	0.8219	66	0.9611	63

Notes: Dead Time – the percentage of time that the detector is effectively off due to count "pile up".

Table 7. Efficiency results with the detectors at 5".

Calibration Source Description	Source Activity (µCi)	Source Reference Date	Test Date	Activity at Test Time (µCi)	Trap 1 Efficiency (%)	Dead Time (%)	Trap 2 Efficiency (%)	Dead Time (%)
SRS 65032-198	9.55	12/11/2002	1/30/2003	9.47	0.5007	0	0.4636	0
SRS 65033-198	32.97	12/11/2002	1/31/2003	32.67	0.5426	0	0.4813	0
SRS 65034-198	94.37	12/11/2002	2/3/2003	93.47	0.5294	0	0.4924	0
SRS 65035-198	331.60	12/11/2002	2/4/2003	328.39	0.5333	1	0.5024	1
SRS 65036-198	1015.00	12/11/2002	2/6/2003	1004.82	0.5415	3	0.5032	3
SRS 65037-198	3197.00	12/11/2002	2/11/2003	3162.14	0.5379	10	0.5113	9
SRS 65671-198	4214.00	3/10/2003	4/30/2003	4176.16	0.5271	14	0.4937	12
SRS 65672-198	5870.00	3/10/2003	5/1/2003	5816.26	0.4922	17	0.4738	16
SRS 65038-198	10222.00	12/11/2002	2/12/2003	10108.74	0.4661	27	0.4505	25

Table 8. Efficiency results with the detectors at 14".

Calibration Source Description	Source Activity (µCi)	Source Reference Date	Test Date	Activity at Test Time (µCi)	Trap 1 Efficiency (%)	Dead Time (%)	Trap 2 Efficiency (%)	Dead Time (%)
SRS 65034-198	94.37	12/11/2002	2/3/2003	93.47	0.1030	0	0.0963	0
SRS 65035-198	331.60	12/11/2002	2/4/2003	328.39	0.1089	0	0.1012	0
SRS 65036-198	1015.00	12/11/2002	2/6/2003	1004.82	0.1128	1	0.1078	1
SRS 65037-198	3197.00	12/11/2002	2/11/2003	3162.14	0.1164	2	0.1114	2
SRS 65671-198	4214.00	3/10/2003	4/30/2003	4176.16	0.1154	3	0.1096	3
SRS 65672-198	5870.00	3/10/2003	5/1/2003	5816.26	0.1112	3	0.1080	4
SRS 65038-198	10222.00	12/11/2002	2/12/2003	10108.74	0.1136	7	0.1097	6

Notes: Dead Time – the percentage of time that the detector is effectively off due to count "pile up".

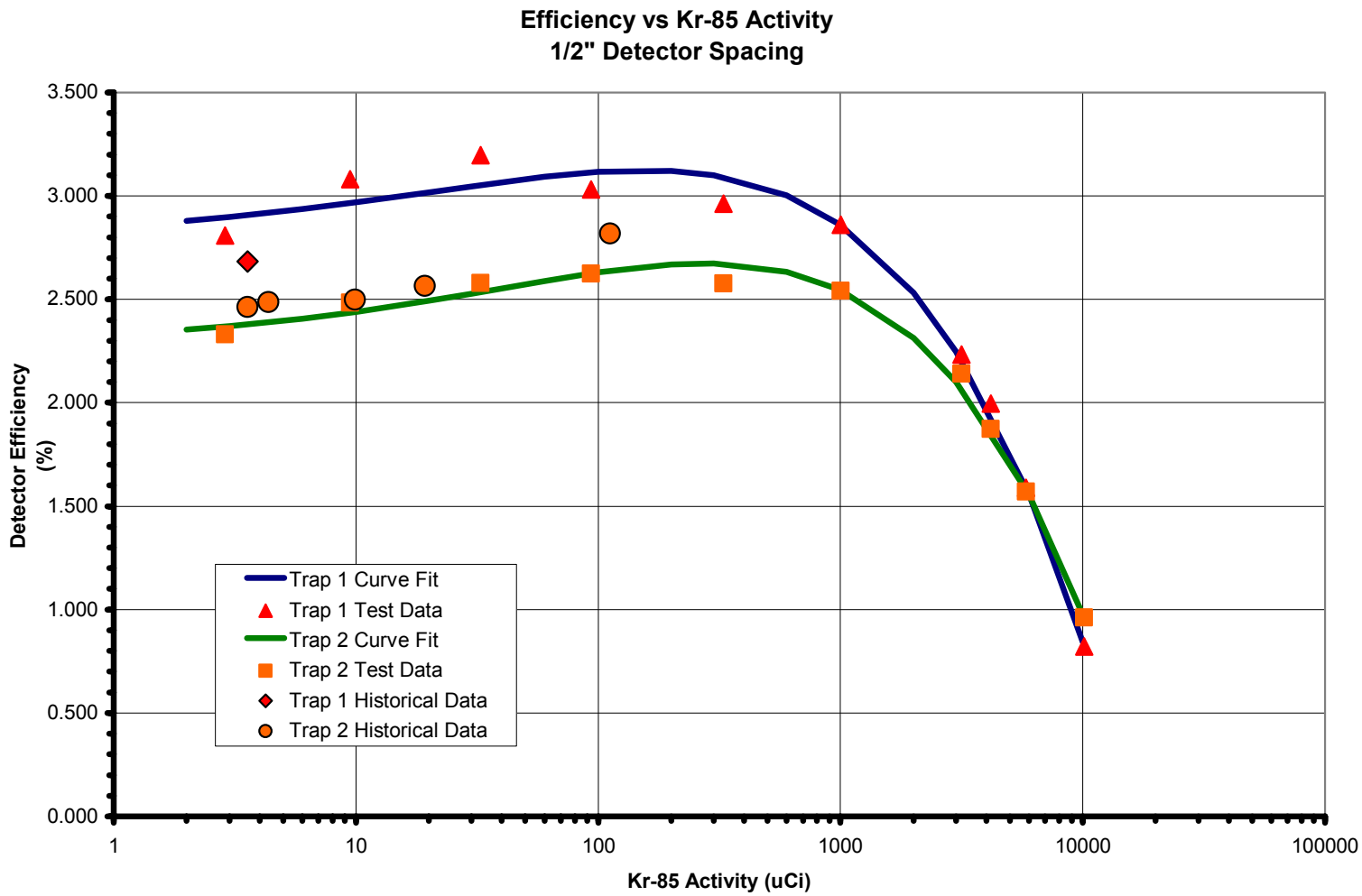

Figure 10. Detector efficiency at ½" spacing.

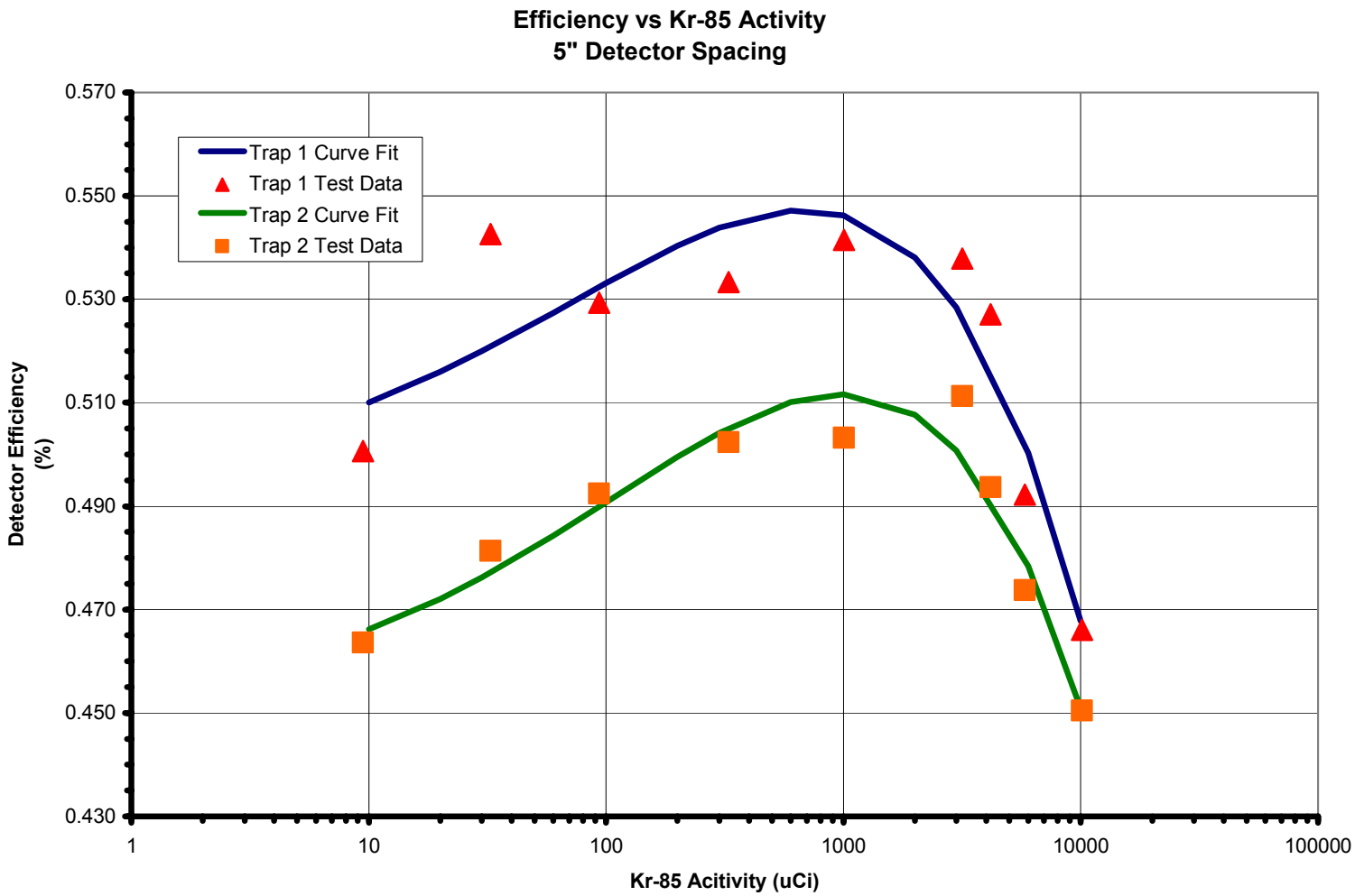

Figure 11. Detector efficiency at 5" spacing.

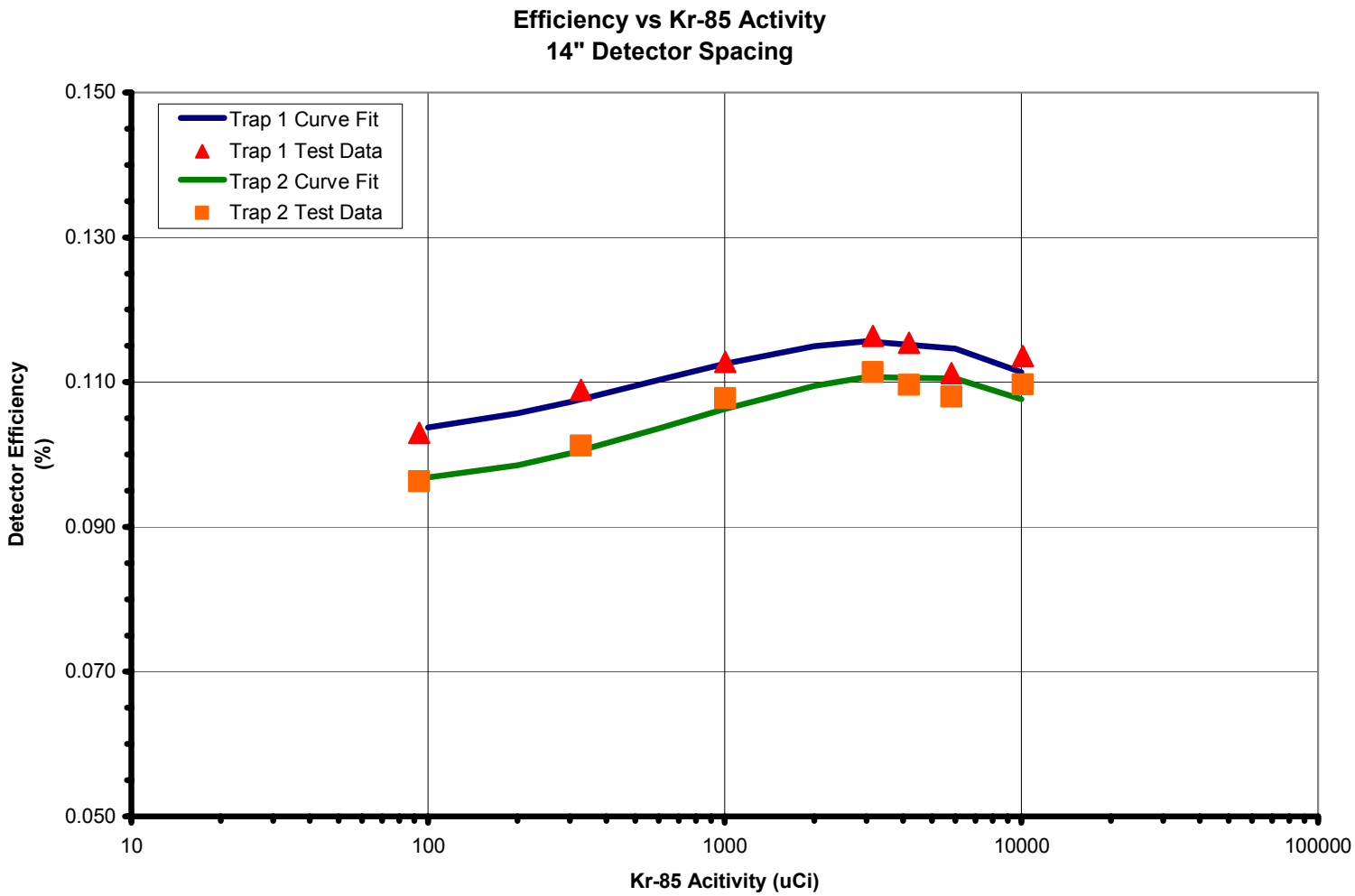

Figure 12. Detector efficiency at 14" spacing.

Table 9. Efficiency Fit Coefficients.

$$\eta = A + Bx + Cx^3 + Dx^5 \qquad x = \log\left({}^{85}Kr[\mu Ci]\right)$$

Detector 1					
Spacing (inches)	^{85}Kr Range	A	B	C	D
½	3<^{85}Kr <10,000 μCi	2.8488e+00	9.9688e-02	2.3921e-02	-3.8428e-03
5	10<^{85}Kr <10,000 μCi	4.9735e-01	9.9575e-03	3.0049e-03	-2.5560e-04
14	100<^{85}Kr <10,000 μCi	1.1974e-01	-1.5691e-02	2.2814e-03	-8.9490e-05
Detector 2					
Spacing (inches)	^{85}Kr Range	A	B	C	D
½	3<^{85}Kr <10,000 μCi	2.3268e+00	8.5953e-02	3.0726e-02	-3.5747e-03
5	10<^{85}Kr <10,000 μCi	4.5512e-01	7.8405e-03	3.5089e-03	-2.5406e-04
14	100<^{85}Kr <10,000 μCi	1.2253e-01	-2.2553e-02	2.8397e-03	-1.0392e-04

2.5 Dead Time

Finally, the detector dead times are shown in Figures 13 and 14 for each of the three detector spacings. The dead time is the percent of the total time that the detector is effectively off, advancing neither counts nor elapsed time. It is an electronically tallied quantity. If the dead time were 50%, then one hour of counting time would require two hours of elapsed time.

The curves shown in Figures 13 and 14 have the shapes that one would expect, with the higher activities and closer detector spacings resulting in greater dead time. When these curves are compared with those discussed in the previous section, one can clearly recognize the drop off in efficiency with increased dead time.

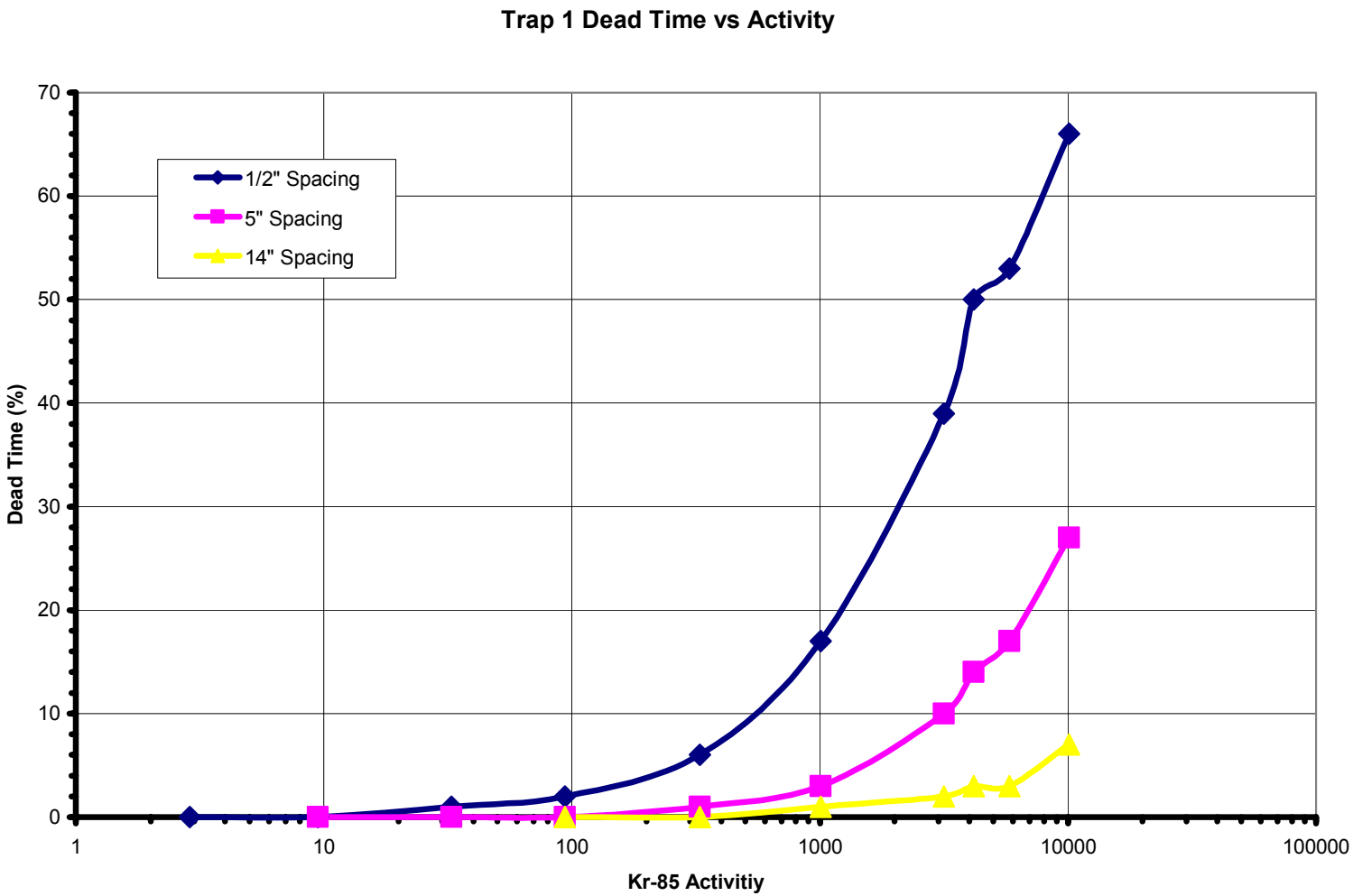

Figure 13. Detector 1 Dead Time.

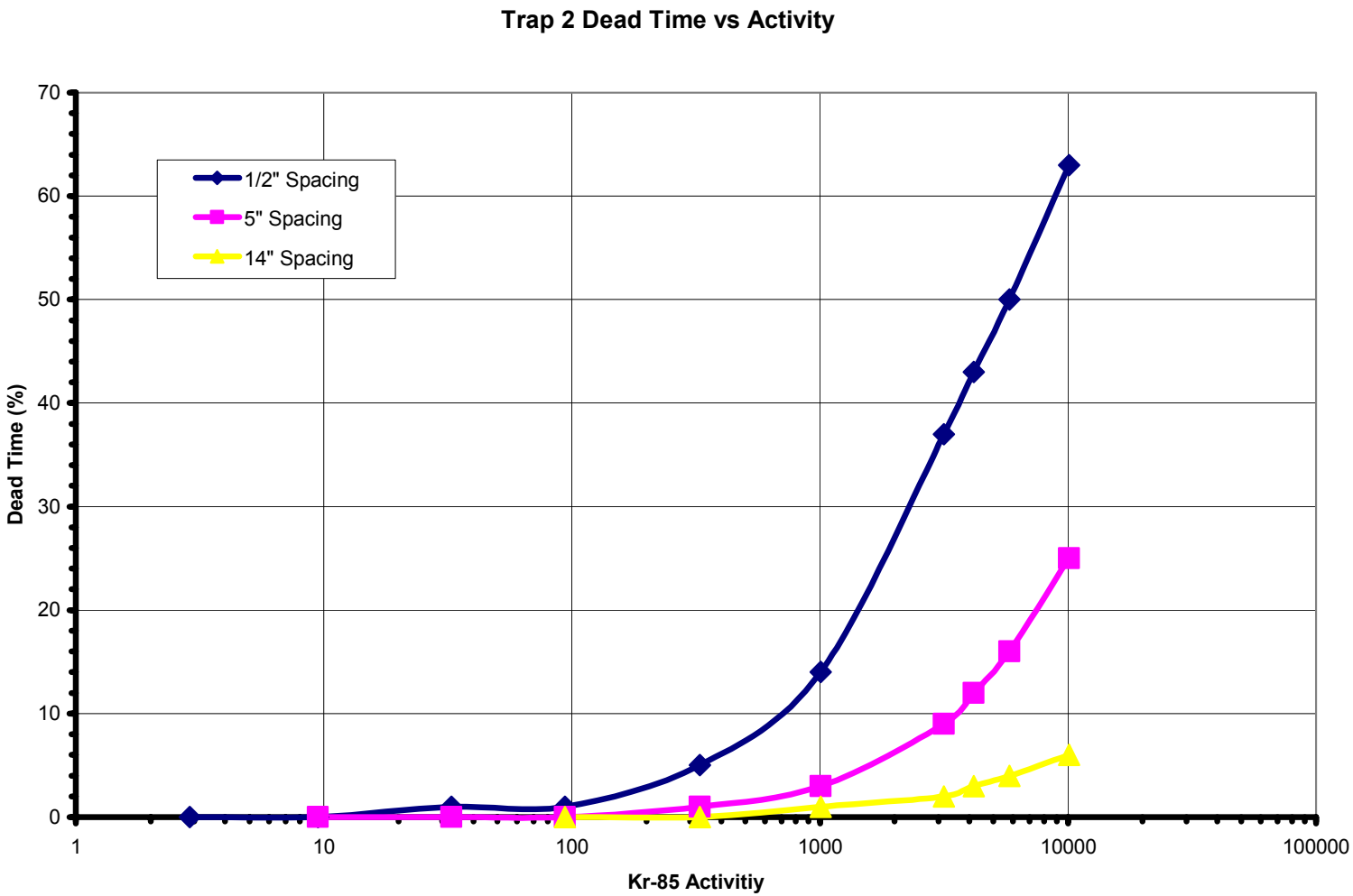

Figure 14. Detector 2 Dead Time.

3. SUMMARY

The CCCTF Trap System was calibrated with 10 sources ranging from approximately 3 to 10,000 μCi. The detectors responses were obtained at 3 different spacings from the traps so that a wide range of trap activities could be examined. A calibration curve was generated for each trap spacing and although each detector response curve is roughly linear, deviations from linearity are great enough to warrant a 3rd order polynomial fit. The range of sources was large enough to define and examine the count rate at which the detector response curve "knees" over for the ½" detector spacing.

With use of the calibration curves, highly accurate ^{85}Kr activity measurements can be obtained. It is recommended that the use of the ½" detector spacing be limited to a maximum trap loading of 1000 μCi and that the 5 and 14" spacings be routinely employed for general purpose work.

This data will be used in future testing and to reevaluate ^{85}Kr values obtained for the MOX test capsules in previous PIEs.

4. ACKNOWLEDGEMENTS

The authors would like to thank the staff at Building 3525 for their help and support during this test, the assigned radiation protection technicians for radiological safety support, and the ORNL FMDP management for their review and editing support of this document.

5. DISTRIBUTION

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Appendix A Certificates of Calibration for the ^{85}Kr Sources

ANALYTICS

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

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

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65032-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was prepared using an aliquot measured volumetrically from a calibrated master gaseous radionuclide source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

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

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	3.535 E5
HALF-LIFE:	10.77 years
CALIBRATION DATE:	December 11, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2788 including septum side arm is 32.79 cc.

PO NUMBER 4000019770, Item 1

SOURCE PREPARED BY: _____
R. C. McFarland, President

Q A APPROVED: _____ 12-12-02

ANALYTICS

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

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

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65033-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was prepared using an aliquot measured volumetrically from a calibrated master gaseous radionuclide source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

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

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	1.220 E6
HALF-LIFE:	10.77 years
CALIBRATION DATE:	December 11, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2787 including septum side arm is 30.43 cc.

PO NUMBER 4000019770, Item 2

SOURCE PREPARED BY: RCMcF
R. C. McFarland, President

Q A APPROVED: 12-12-02

ANALYTICS

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

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65034-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was prepared using an aliquot measured volumetrically from a calibrated master gaseous radionuclide source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

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

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	3.492 E6
HALF-LIFE:	10.77 years
CALIBRATION DATE:	December 11, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2785 including septum side arm is 32.93 cc.

PO NUMBER 4000019770, Item 3

SOURCE PREPARED BY: R C McF
R. C. McFarland, President

Q A APPROVED: D.M. [signature] 12-12-02

ANALYTICS

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

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65035-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was prepared using an aliquot measured volumetrically from a calibrated master gaseous radionuclide source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

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

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	1.227 E7
HALF-LIFE:	10.77 years
CALIBRATION DATE:	December 11, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2786 including septum side arm is 32.91 cc.

PO NUMBER 4000019770, Item 4

SOURCE PREPARED BY: _____
R. C. McFarland, President

Q A APPROVED: _____ 12-12-02

ANALYTICS

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

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65036-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was prepared using an aliquot measured volumetrically from a calibrated master gaseous radionuclide source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

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

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	3.754 E7
HALF-LIFE:	10.77 years
CALIBRATION DATE:	December 11, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2782 including septum side arm is 32.49 cc.

PO NUMBER 4000019770, Item 5

SOURCE PREPARED BY: _____
R. C. McFarland, President

Q A APPROVED: _____ 12-12-02

ANALYTICS

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Fax (404) 352-2837

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65037-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was prepared using an aliquot measured volumetrically from a calibrated master gaseous radionuclide source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

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

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	1.183 E8
HALF-LIFE:	10.77 years
CALIBRATION DATE:	December 11, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2759 including septum side arm is 33.44 cc.

PO NUMBER 4000019770, Item 6

SOURCE PREPARED BY: _____
R. C. McFarland, President

Q A APPROVED: _____ 12-12-02

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

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65671-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was calibrated in an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	1.559 E8
HALF-LIFE:	10.77 years
CALIBRATION DATE:	March 10, 2003 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2801 including septum side arm is 32.30 cc.

P O NUMBER 4000021585, Item 1

SOURCE PREPARED BY: _____
R. C. McFarland, President

Q A APPROVED: _____ 3-11-03

ANALYTICS

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

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

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65672-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was calibrated in an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	2.172 E8
HALF-LIFE:	10.77 years
CALIBRATION DATE:	March 10, 2003 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2802 including septum side arm is 34.95 cc.

P O NUMBER 4000021585, Item 2

SOURCE PREPARED BY: R. C. McFarland, President

Q A APPROVED: 3-11-03

ANALYTICS

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CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

65038-198

Kr-85 Gas Standard in Glass Sphere

This standard radionuclide source was prepared using an aliquot measured volumetrically from a calibrated master gaseous radionuclide source. The master source was calibrated in an ion chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards. ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

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

U.S. Patent 4,456,823; U.K. Patent GB2,149,102B; CA. Patent 1,205,210.

ISOTOPE:	Kr-85
ACTIVITY (dps):	3.782 E8
HALF-LIFE:	10.77 years
CALIBRATION DATE:	December 11, 2002 12:00 EST
TOTAL UNCERTAINTY*:	5.0%
SYSTEMATIC:	4.7%
RANDOM:	0.3%

*99% Confidence Level

Total volume of sphere 2758 including septum side arm is 33.92 cc.

PO NUMBER 4000019770, Item 7

SOURCE PREPARED BY: RCMcFarland
R. C. McFarland, President

Q A APPROVED: 12-12-02