To the Graduate Council:

I am submitting herewith a thesis written by Richard D. Korynta entitled "Analysis of a Radiological Box Monitor for Source Segregation." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

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ANALYSIS OF A RADIOLOGICAL BOX MONITOR FOR SOURCE SEGREGATION

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Richard D. Korynta

May, 1995

DEDICATION

This thesis is dedicated to my wife

Dr. Carol Senger Korynta

for all her support and encouragement along the way.

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ABSTRACT

This study assesses the use of a Radiological Box Monitor (RBM) for source segregation of radioactively contaminated and uncontaminated solid waste generated at the Oak Ridge Y-12 site. The RBM is a monitoring device designed to screen bulky items such as trash bags for radioactive contamination. Prior studies of potentially radioactive waste in dumpsters revealed that 90% of the waste could be disposed of in the Y-12 sanitary landfill. Thus, waste segregation ranks high in the Y-12 waste minimization policy, and this is why Y-12 chose to investigate the use of RBMs for source segregation. The objectives of this study are to: (1) optimize counting times for maximum throughput and (2) determine lower limits of detection for various waste forms and source locations within the waste matrix.

An evaluation to establish optimal counting times was performed using a 4 by 4 matrix of background and sample count times ranging from 30 to 120 seconds. Thirty data points were collected for each of the 16 combinations of counting times. Results of the data collected to determine optimal counting times indicated that equal 60 second background and sample count times have the lowest standard deviation of all combinations tried.

Performance of the instrument relative to waste composition and source location was evaluated by using five depleted uranium sources ranging in mass from 0.5 to 10 grams placed at nine locations in four waste matrices. The term "waste matrix" as used in this document refers to the composition of the waste form being examined. These waste forms include empty beverage cans, paper, machine turnings, and an aggregate of trash. Data were obtained over a three week period in August of 1991 by randomly placing each of the sources, as well as a blank, in all nine positions of the waste matrices.

Evaluation of data collected on performance of the instrument indicated that the RBM has lower limits of detection for depleted uranium below the existing action value of 35 pCi/g for all positions in the cavity and for all waste matrices studied. However, analysis of variance results suggest significant problems with the instruments reliability. If reliability of the instrument can be improved, it is expected that the Radiological Box Monitor will perform adequately on waste with minimal radioactive contamination.

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LIST OF ACRONYMS

Cathode Ray Tube	CRT
Lower Limit of Detection	LLD
Radiological Box Monitor	RBM
Trash Monitoring Station	TMS
Upper Level Discriminator	ULD

1. INTRODUCTION

1.1 Background

Until recently, there was not much concern with costs resulting from waste generation. Opportunities to reduce waste at the source were often not realized because existing regulations and resources required for compliance focused on treatment and disposal rather than source reduction. Regulations have not emphasized multimedia waste management. Technical assistance and information has been necessary to overcome institutional barriers for source reduction adoption and implementation.[1]

Prior to 1985, the Y-12 Plant relied primarily on administrative controls and some surface measurements to separate radioactive from non-radioactive solid waste. The non-radioactive solid waste has been and continues to be disposed of in an onsite State permitted landfill while the radioactive portion was disposed in shallow-land burial trenches which were not permitted. Due to changes in regulatory requirements and enforcement agreements, the existing facilities for radioactive waste disposal have been closed, and the waste is being placed in interim storage pending development of new radioactive solid waste management facilities.[2]

Over a period of several years after 1985, Y-12 implemented the use of instrumentation for detection of depleted uranium concentrations in dumpsters. This system is called the Trash Monitoring Station (TMS). It uses thallium activated sodium iodide crystal detectors to pick up the 0.765 and 1.001 MeV gamma rays from an intermediate daughter-product protactinium (Pa-234m), in the decay chain of U-238. Dumpsters are now routinely monitored at the Trash Monitoring Station for depleted uranium contamination.[2]

Based on fiscal year 1989 data, approximately 30% of the Y-12 waste monitored at the TMS was labeled as being contaminated and could not be disposed of in the Y-12 sanitary landfill. Dissection

of waste in a dumpster which was labeled contaminated after monitoring at the TMS revealed that less than 10% of the waste in the dumpster was contaminated.[2] Therefore it is likely that the relative volume of uranium-contaminated solid waste generated as a result of mixing contaminated and uncontaminated waste can be significantly reduced by monitoring and segregating at the source.[8] For this reason waste segregation ranks high in the Y-12 waste minimization policy and is why Y-12 chose to investigate the use of Radiological Box Monitors (RBM) for source segregation. It is expected that segregation of low level contaminated waste from uncontaminated waste can be enhanced with the addition of monitoring instrumentation at the waste generator level in centralized locations.

1.2 Objectives

The purpose of this study is to assess the use of a TSA Model BM-285 Bag/Box Monitor for segregation of radioactively contaminated and uncontaminated solid waste generated at Alpha 5 on the Oak Ridge Y-12 site. This radiological box monitor was manufactured by TSA Systems, Ltd. located in Longmont, Colorado and was purchased to demonstrate the application of source segregation at Y-12. The objectives of this study are to: (1) optimize counting times for maximum throughput and (2) determine the lower limits of detection for various waste forms and source locations.

Typically the radiological box monitor will be placed in a location near an exit that is normally used by plant personnel in the handling of waste. Heavy plastic bags, which are the standard solid waste containers, will be placed in the monitor on the way to the dumpsters. Operation of the monitor will require a personnel identification code and a waste description. After this information is entered, the monitor will obtain a sample count and indicate whether the trash is contaminated or uncontaminated based on a preset alarm level. The trash will then be placed in separate dumpsters for contaminated and uncontaminated readings and subsequently monitored at the Trash Monitoring Station.

The central freight elevator in the Alpha 5 building was chosen as one of the locations to introduce the RBM into the waste flow stream at the generator level. Alpha 5 encompasses a wide variety of activities ranging from office use to machining. Consequently there is great diversity in the component make-up of the solid waste generated. Trash to be monitored may contain waste components including paper, glass, rags, metal cans, floor sweepings, and machine turnings. The principle contaminant is depleted uranium with a nominal specific activity of 450 nCi/g.

2. RBM DESCRIPTION

2.1 Physical Description

The TSA Bag/Box Monitor, Model BM-285, is a large box monitoring device (i.e. radiological box monitor) designed to screen bulky items of up to 400 pounds for radioactive contamination. The units dimensions are 56" high x 40" wide x 43" deep weighing 9,500 pounds with 1.75" of lead shielding. The internal cavity is 29" high x 27" wide x 24" deep.[3]

The Monitor uses six plastic scintillation detectors, one each on the top, bottom, back, left and right sides of the chamber, plus one in the door. The detectors are 12" x 19" x 1.5" and are coupled to Photo-Multiplier tubes via light pipes. Sensitivity is stated as 0.5 + or - 0.25 gram depleted Uranium (in a 60 second count time) in a 2mR/hr background. Sample scan time can be programmed by the user for 1 to 1,000 seconds. Background count time can be programmed by the user for 10 to 1,000 seconds.[3]

The unit will scan samples weighing 10 to 400 pounds.[3] A sliding scale platform can be pulled out of the cavity in a cantilevered position to facilitate placing large objects into the cavity. Figure 1 shows the monitor with the scale platform in the cantilevered position.

The scale platform rests on four strain gauge load cells coupled to individual scale amplifier modules that feed the controller module for weight detection. The load cells utilize a resistive bridge so that changes in load produce a differential DC voltage output. The load cell output is amplified and buffered by differential amplifier circuits. The buffered output is then applied to a voltage-to-frequency converter and from there to counters in the controller module.[3]

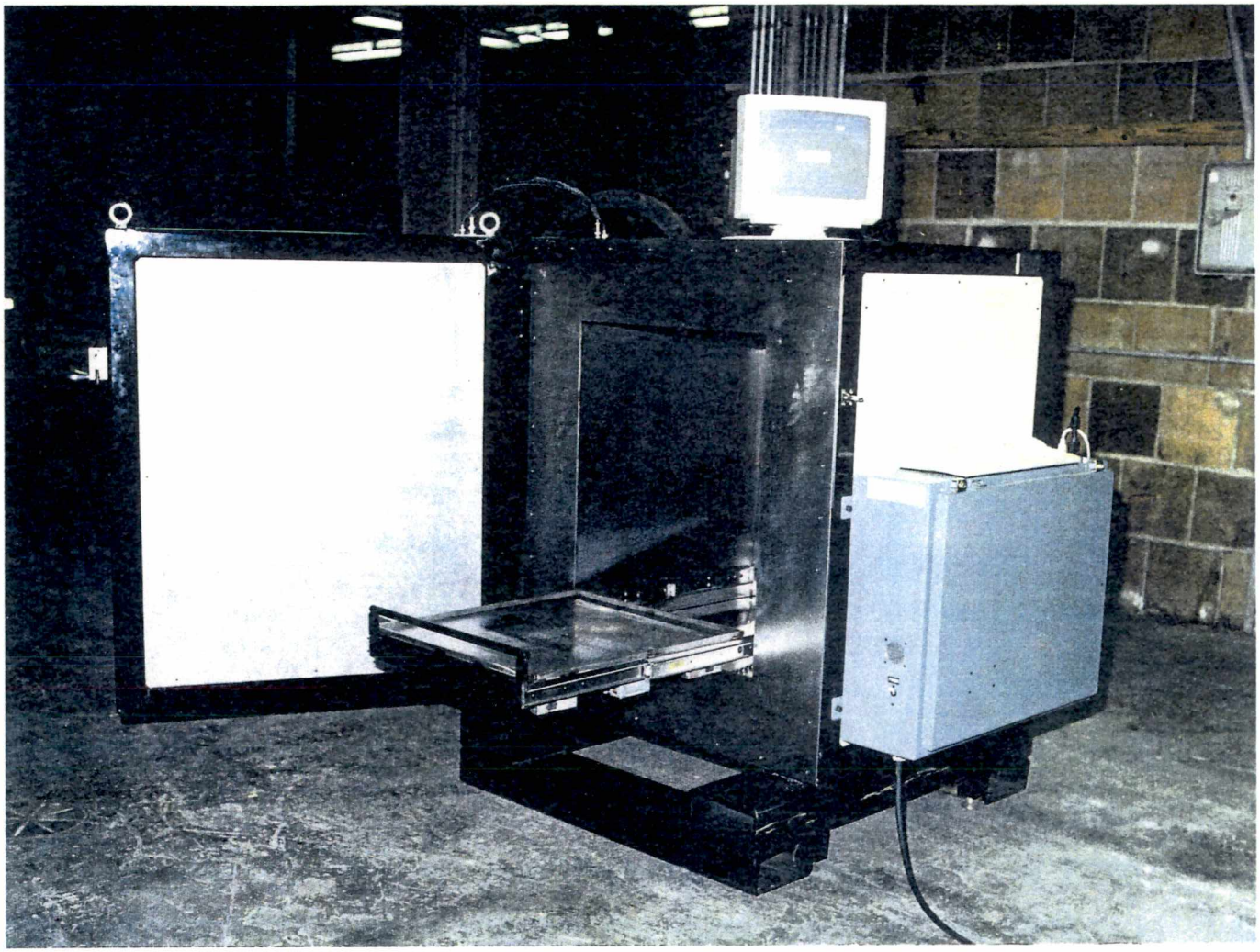

Figure 1. Photograph of Radiological Box Monitor

2.2 Operation

Operation of the instrument is controlled from an external computer keyboard and Cathode Ray Tube (CRT) monitor screen. All access is controlled by user assigned password protection. An external printer can provide report generation or the printing of container labels.[3]

The instrument performs a self-test and acquires a new background count each time it is powered up. It also monitors its own operation during normal use and indicates any failures. It runs continuously, updating backgrounds whenever no weight is detected inside the chamber on the scale platform. A new sample count is initiated after a door open/close sequence when weight is detected on the scale platform.[3]

Most of the operating parameters are adjusted via access to the computer's setup mode. The setup mode is password protected, with two levels of user access provided. Access level 1 users are only permitted to display operating parameters, run variance checks, and set the time and date on the real time clock. Users with 0 level access may change operating parameters, run radiometric and weight calibrations, and detector optimization.

The only hardware adjustment required is the Upper Level Discriminator (ULD). The ULD sets the maximum energy level at which the system accepts counts. The maximum adjustment level is approximately 1.5 MeV and can be adjusted by a 10 turn knob located inside the electronics enclosure mounted on the side of the instrument.[3] The ULD was adjusted to it's maximum level for this experiment, as the primary source of background counts was assumed to be U-238 and initial adjustments had no effect on the efficiency of the instrument.

When the instrument is turned on, the computer performs a self test at the end of which the monitor displays a background collection screen with the message "GETTING INITIAL BACKGROUND". The background count time is established by the operator in the set-up menu. When the background

count is completed a green "READY" window lights up and background counts per second or total counts are displayed depending on which mode has been chosen.

After the initial background collection, the background is continually updated (until a sample scan is initiated) using a rolling method. The rolling background updates occur ten times during the background count time. Therefore, if the background count time is set for 60 seconds, the background is updated every 6 seconds. This means that the "oldest" 6 seconds of background counts are subtracted from the total background counts and the most recent 6 seconds of background counts are added on. In the counts per second mode the background counts displayed are the total counts (updated) divided by the total background count time.

A sample scan is initiated by opening the door, placing a bag of trash on the scale platform and closing the door. When the door is closed, the detector display turns green and a grey pop-up window asks for a waste I.D. Once the waste I.D. is entered, the sample count is initiated for the duration that has been entered in the set-up menu. When the sample count is completed, the counts are displayed as counts per second (including background) or total net counts (with the background count subtracted) again depending on which mode has been chosen. The choice of display mode establishes how both the sample and background counts are displayed, i.e., background and sample counts are always displayed in the same mode.

3. THEORY

3.1 Optimization of Count Times

A comparative analysis to optimize count times is based on the statistical uncertainty associated with varying background and sample count times as well as empirical determination. The statistical uncertainty is a function of the number of counts that are collected in a given count time,[4] whereas the empirical determination is simply what length of time can reasonably be taken in using the instrument for practical application.

The difference in population variability associated with changing count times is a function of the number of counts accumulated.[4] The fewer counts accumulated the greater relative contribution to the variance. Therefore as count times are increased (all other factors being held constant) the sample variance will decrease because of the relatively smaller contribution from each count. Following this logic, sample variance will continue to decrease as counting times are increased.

The operative assumption that all other factors are constant can not be used in a field environment. There are many variables in the field environment which can influence the variability of sample counts. One example is short term variability in background counts due to movement of radioactive material. The movement of radioactive material closer to or farther from the counting instrument will cause fluctuations in the background. Fluctuation in the background during the background counting cycle could be one factor that would act to prevent increased background count times from reducing variability.

The same logic can be used when considering an optimal sample count time. Variation in the level of background during the sample counting cycle will increase the variability of the sample counts. Since the level of radioactivity in a sample will be determined using gross sample minus background counts, the variability in both factors must be considered. One method of doing this is to

collect a sufficient number of samples using varying background and sample count times to approximate a normal distribution.

It is generally accepted that the normal approximation of a population distribution is good if the sample size is greater than or equal to 30. This result is an immediate consequence of the Central Limit Theorem which states: If $\bar{x}$ is the mean of a random sample size n taken from a population with mean μ and finite variance σ^2, then the limiting form of the distribution of

$$Z = \frac{\bar{x} - \mu}{\sigma/\sqrt{n}}$$

as n approaches infinity, is the standard normal distribution n(0,1).[4]

The standard deviation is an indicator of variability in a sample and hence provides a measure of uncertainty. The standard deviation is defined as "The positive square root of the variance of the random variable." The sample variance is defined by the statistic

$$S^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1} \quad .$$

Thus a comparison of standard deviations from sample populations provides a measure of comparative uncertainty in the sample populations.[4]

3.2 Lower Limit of Detection

A comparative analysis of the RBM performance at various locations in the cavity and with different waste matrices is based upon the lower limits of the measurement process. This lower limit is referred to as the "Lower Limit of Detection" (LLD).[5]

The LLD is defined as the smallest concentration of radioactive material in a sample that will yield a net count above background, with at least 95% probability, and with no greater than 5% probability of concluding that a background observation represents radioactivity in the sample. The standard deviation is multiplied by two times the factor for a 95% confidence level to compensate for the two

possible types of error.[5] In addition, a multiplying factor to compensate for systematic (non-random) error is introduced. The LLD for the background spectrum at the 95% confidence level is defined by Pasternack and Harley[6] as,

$$LLD = 2 * 1.645 * \sqrt{2} * S$$

where, S is the standard deviation of the background. The standard deviation of the background is the square root of the mean number of counts for the region of interest and the counting time is assumed to have no associated measurement error.

Incorporating factors for the sample size, overall counting efficiency, and conversion from disintegrations per second (dps) to pCi/, LLD for the background spectrum calculation of interest is calculated using the following equation[7]:

$$LLD = \frac{4.66 * \sqrt{B}}{0.037\ (t*\varepsilon*W)}$$

where:

B = Mean Background Count

t = Counting Time

ε = Detector Efficiency

W = Weight of Sample

0.037 = dps per pCi

This equation indicates that the LLD is directly proportional to the square root of the background counts and is inversely proportional to the livetime and efficiency. Therefore, increasing the counting time results in an improvement of the measurement sensitivity. However, an increase in the counting time sufficient enough to realize an increase in the sensitivity may not be practical for efficient use of a monitoring device and may be outweighed by influence of other factors such as increased variation in background counts.

3.3 Analysis of Variance

One very common procedure to deal with testing population means is called the analysis of variance. The term analysis of variance describes a technique whereby the total variation is being analyzed or divided into meaningful components. The procedure separates total variability into two components:

1. Variability, measuring systematic and random variation.

2. Variability, measuring only random variation.

Determining if component 1 is significantly larger than component 2 is the essence of the analysis [4].

In the case where the distribution can be assumed to be approximately bell shaped, confidence intervals can be computed using the t-distribution with relatively good results. The use of the t-distribution is based on the premise that the sample is from a normal distribution. Statisticians recommend that when normality cannot be assumed, a sample size of ≥ 30 should be used. This is based on the presumption that with a sample size as large as 30 the Central Limit Theorem prevails[4].

In addition to determining confidence intervals it is often desirable to predict the probable response of a system based on actual observed experimental values. A common method used for prediction is called a regression equation. Linear regression implies that a predicted mean value of y is linearly related to x by the fitted regression line

$$\hat{y} = a + bx,$$

where the estimates a and b represent the y intercept and slope, respectively. The symbol $\hat{y}$ is used to distinguish between the estimated or predicted value given by the sample regression line and an actual observed experimental value y for some value of x. Here again the agreement between the sample line and the unknown hypothetical line will improve as the amount of data available increases.[4]

The values of a and b may be estimated using the Method of Least Squares. The method of least squares is based on the premise that each pair of observations satisfies the relation [4]

$$y_i = a + b\,x_i + e_i \ ,$$

where $e_i = y_i - \hat{y}$ is called the residual and describes the difference between the fit of the model at the ith data point. The equations used to find a and b such that the sum of squares of the residuals is a minimum follow [4]:

$$a = \frac{\sum_{i=1}^{n} y_i - b \sum_{i=1}^{n} x_i}{n}$$

$$b = \frac{n \sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n \sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}$$

A confidence interval for the mean response $\mu_{y|x_0}$ is then given by [4],

$$\hat{y}_0 - t_{\alpha/2} S\sqrt{1/n + \frac{(x_0-\bar{x})^2}{S_{xx}}} < \mu_{y|x_0} < \hat{y}_0 + t_{\alpha/2} S \sqrt{1/n + \frac{(x_0-\bar{x})^2}{S_{xx}}} \ ,$$

where:

$\mu_{y|x_0}$ = the mean response of y evaluated at x_0

$\hat{y}_0$ = the predicted single value y_0 for a given value x_0

$t_{\alpha/2}$ = the value of the t-distribution with n-2 degrees of freedom and a $(1 - \alpha)$ 100% level of confidence

n = the number of data points

S = an unbiased estimate of the standard deviation given by $S = \sqrt{\frac{S_{yy} - bS_{xy}}{n-2}}$

$$S_{xx} = \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2$$

$$S_{yy} = \sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2$$

$$S_{xy} = \sum_{i=1}^{n} x_i y_i - \frac{\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n}$$

$\bar{x}$ = the mean value of x

The linear regression line provides an indication of how well actual observed responses "fit" an expected linear relation between a given value of x and an estimated value of $\hat{y}$. The confidence interval provides an indication of the variability of the actual observed responses for a given value of x.

4. EXPERIMENTAL

4.1 Test Instrument

A test device was developed to allow positioning of a source in each corner of the RBM cavity as well as in the center of the cavity. The device was a heavy cardboard box made to within 1/2 inch of the RBM cavity dimensions. Figure 2 shows the box in the RBM cavity. Vertical compartments 2 and 1/2 inches square were located in the corners and center of the box. Figure 3 shows a top view of the vertical compartments when the box was filled with beverage cans. Pedestals made out of layered cardboard slats allowed positioning of a point source at the top, bottom, or center of each compartment. Figure 4 shows the cardboard pedestal being positioned. For the beverage can waste matrix, aluminum cans were used as the pedestals in a similar manner to the cardboard slats. For the machine turnings waste matrix, the aluminum can pedestals were filled with machine turnings. In this way the sensitivity of the monitor could be examined using a point source located at any of the corner or center positions.

The box was removed from the cavity each time a point source was positioned. Figure 5 shows the box on the scale platform cantilevered on rails outside of the cavity. The box was removed from the platform and placed on a table to position the sources. This allowed an updated background reading to be taken before each measurement. Because the box was made to within 1/2 inch of the RBM cavity dimensions and because it was always positioned in the same orientation there was little variation in the positioning of the point source at a given location from one test to another.

4.2 Counting Time Matrix

Initially a series of tests were performed using a 4 by 4 matrix of background and sample count times. Thirty data points were collected for each of the 16 combinations of background and sample count times in the 4 by 4 matrix. The count times used were 30, 60, 90, and 120 seconds (see

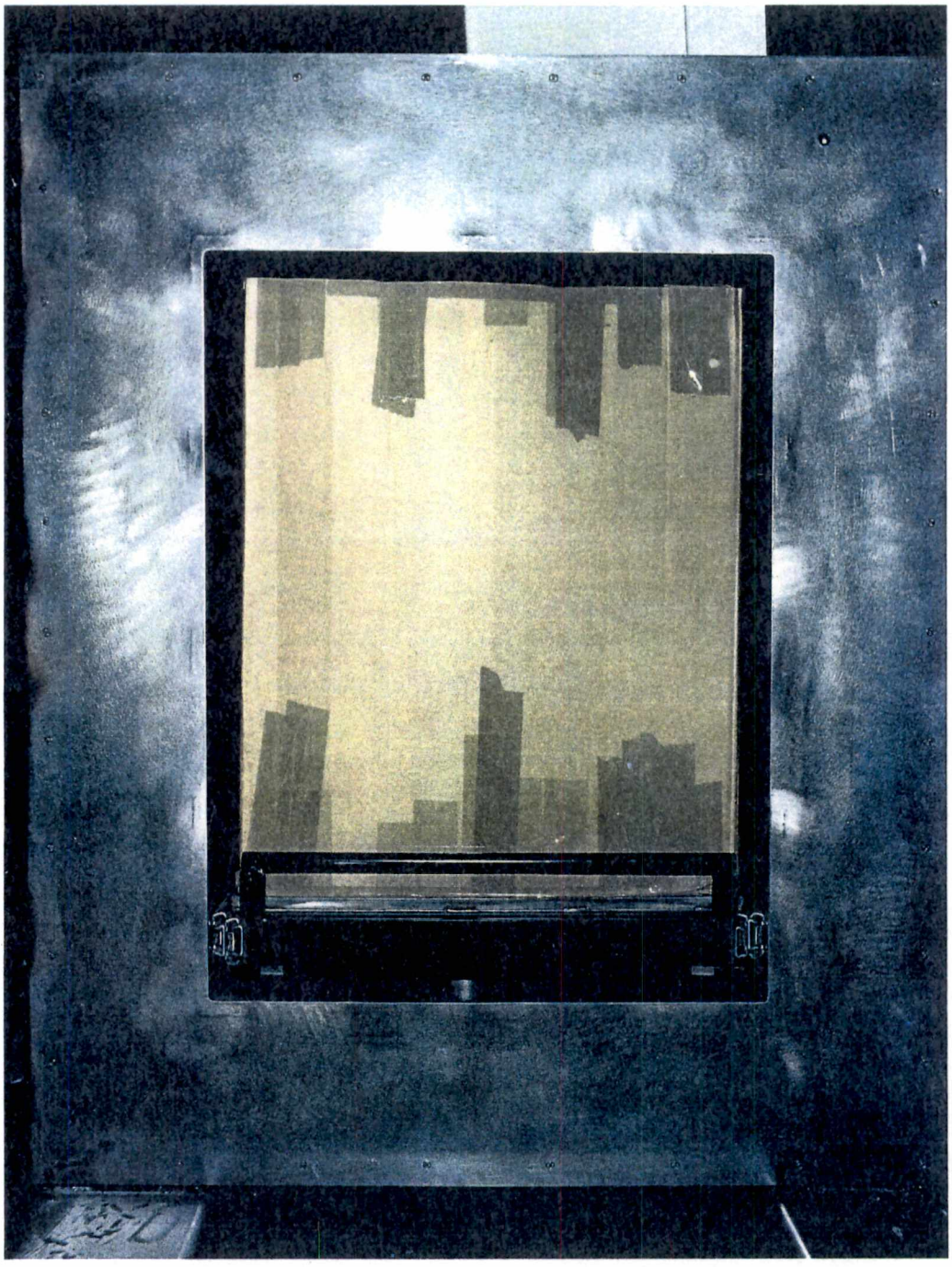

Figure 2. Photograph of Test Device in RBM Cavity

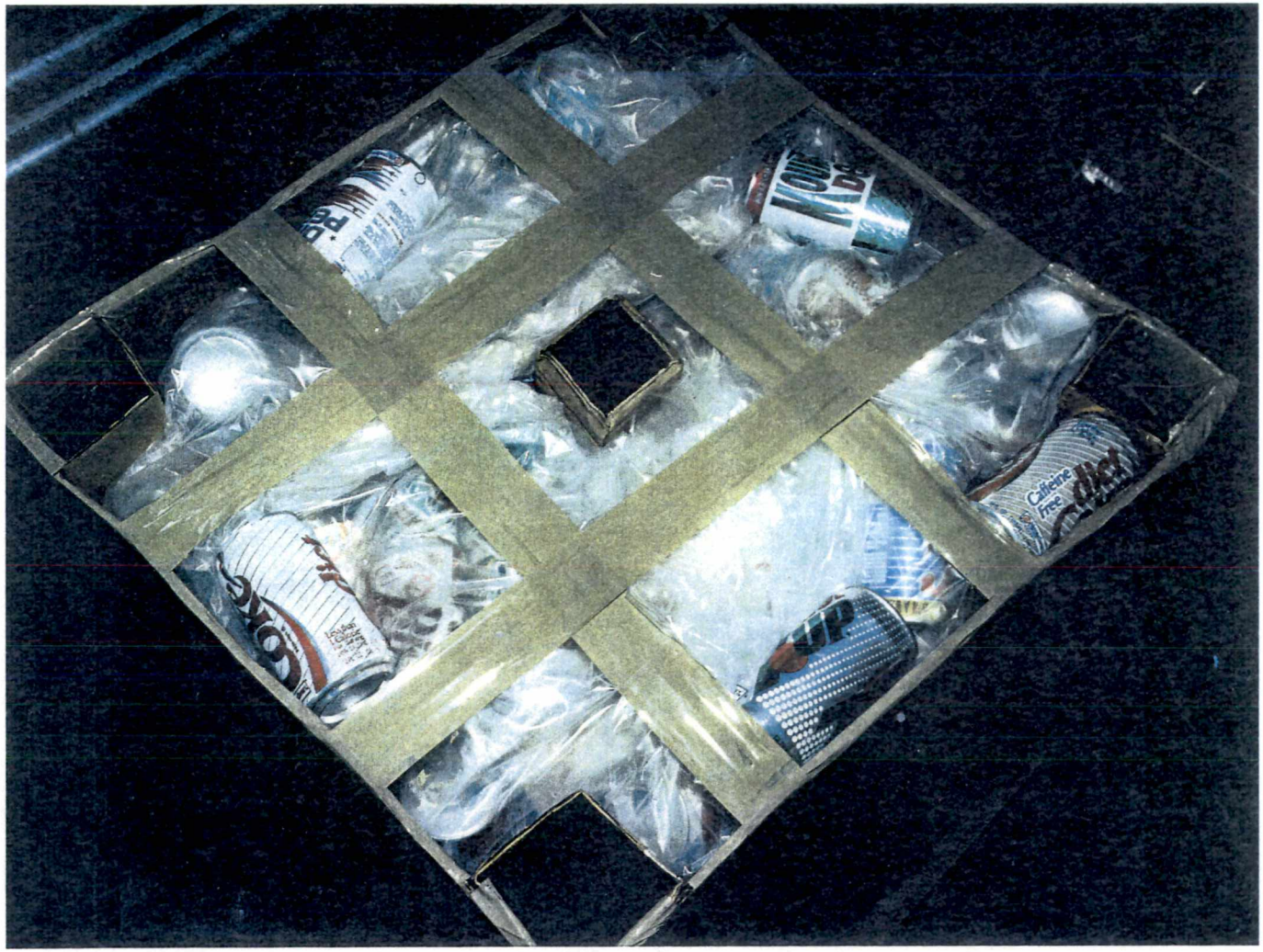

Figure 3. Photograph Showing Vertical Compartments in Test Device



Figure 4. Photograph of Cardboard Pedestal for Positioning Sources

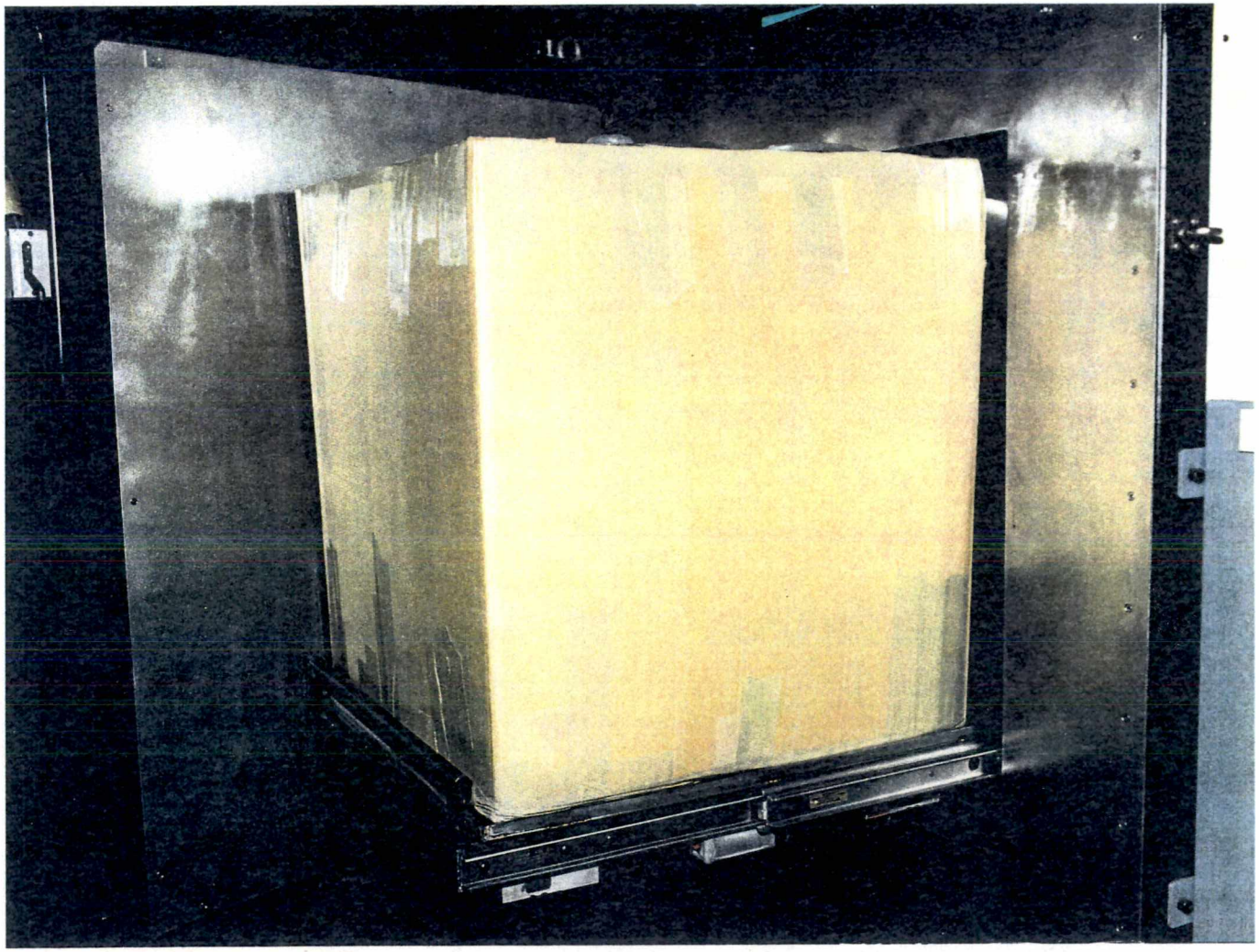

Figure 5. Photograph of Test Device on Cantilevered Scale Platform

Appendix A). These times were chosen based on the manufacturer's suggested counting times and practical application of the monitor.[9]

The box was filled with an aggregate of trash from an uncontaminated area. A 5 gram depleted uranium source was placed in the center of the box using the center compartment and appropriate cardboard pedestals. The total weight of the filled box was 33 kg. This ratio of total weight to source weight was used to replicate a container contaminated at the plant action value of specific activity (74 pCi/g).

4.3 RBM Performance Test

Testing the effects of waste composition and source position on the sensitivity of the instrument was performed using 5 depleted uranium sources ranging in mass from 0.5 to 10 grams. Counts were taken with each of the 5 sources at each corner and in the center of the RBM cavity (9 locations). In addition, sample counts with no source were taken to baseline the analysis. The sources were randomly selected by drawing them out of a container used to mix them up before each test. Using four waste types and repeating each test, a total of 432 sample counts were taken. The data collected is shown in Appendix B and compiled in Table 1.

4.3.1 Waste Composition

Four different waste matrices were used in the performance test. The four matrices used were empty beverage cans, paper, machine turnings, and an aggregate of random trash.

The beverage can waste type was soda cans retrieved from aluminum can collection barrels. The test instrument box was completely filled with the cans except for the center and corner compartments. The total weight of the filled box was 11 kg.

The paper waste type included a mixture of stacked sheet paper, bound paper, and loose crushed paper. The paper was placed in the box with alternate layers of the less dense crushed paper and

Table 1. Sample Count Matrix

Waste Matrix (wt)	Source Weight (g)	Net Sample Counts/sec by Source Position *								
		1	2	3	4	5	6	7	8	9
Aggregate / (33 kg)	0.5	26.33	17.63	34.77	32.73	16.40	36.38	25.57	26.73	27.37
	1	46.23	45.38	60.67	73.15	46.92	42.03	39.17	43.72	77.82
	2	101.83	87.50	100.18	90.95	67.17	63.93	85.35	93.73	134.48
	5	267.75	200.17	238.48	250.47	170.92	194.52	177.40	184.65	294.23
	10	395.68	312.30	366.28	442.70	259.77	293.32	337.07	316.73	506.72
Cans / (11 kg)	0.5	34.72	9.93	15.90	27.80	10.38	17.48	23.67	8.52	29.58
	1	31.33	32.13	43.13	47.08	22.32	42.70	48.03	52.98	70.15
	2	81.87	70.13	91.92	103.02	64.33	82.17	83.75	97.43	65.22
	5	226.00	167.82	237.00	257.42	180.53	158.97	202.67	186.62	296.78
	10	363.82	298.15	387.22	530.57	307.65	278.52	332.85	362.87	515.18
Paper / (49 kg)	0.5	142.85	23.17	31.32	39.63	6.63	50.07	22.32	32.32	41.45
	1	64.65	53.42	67.77	66.12	52.33	46.07	43.07	56.35	69.77
	2	96.97	73.23	101.23	115.63	51.28	79.12	98.58	88.05	115.98
	5	232.25	174.00	221.97	257.80	148.40	186.35	203.43	194.47	277.40
	10	408.48	257.78	404.88	427.15	240.22	312.28	314.67	330.05	473.65
Turnings / (36 kg)	0.5	0	0	0	0	0	0	0	0	0
	1	0	0	0	2.73	0	0	6.97	0	18.95
	2	42.75	43.73	52.58	44.12	18.92	22.83	32.25	33.93	61.93
	5	169.32	181.65	189.65	193.57	114.98	115.37	123.93	136.48	213.33
	10	298.72	279.17	356.98	386.68	223.53	200.27	284.85	240.20	409.18

*1. Back of cavity in upper left corner
2. Back of cavity in upper right corner
3. Back of cavity in lower left corner
4. Back of cavity in lower right corner
5. Next to door in upper left corner
6. Next to door in uper right corner
7. Next to door in lower left corner
8. Next to door in lower right corner
9. Center of cavity

more dense stacked and bound paper. Once again the box was completely filled except for the center and corner compartments. The total weight of the filled box was 49 kg.

The machine turnings waste type was a random collection of various alloys including brass, aluminum, and steel. The majority of the turnings were loosely twisted ribbons resembling a stretched cork screw or spring. A relatively small portion of the turnings were small tightly wound pieces which settled to the bottom of the test instrument box. Again the box was completely filled except for the center and corner compartments with a total weight of 38 kg.

The aggregate trash waste type was a mixture of trash collected out of office trash cans. It included all kinds of paper, bottles, styrofoam coffee cups, cigarette butts, and orange peels plus other miscellaneous items. It was dumped in the box randomly. Once again the box was completely filled with a total weight of 33 kg.

4.3.2 Depleted Uranium Sources

Five sources were used in the RBM performance test. The mass of each of the five sources was 0.500, 1.006, 2.027, 5.067, and 10.181 grams with corresponding measured activity of 202, 407, 820, 2050, and 4119 nCi.

4.3.3 Source Positioning

For the paper and aggregate trash waste types, the sources were positioned in the corner and center compartments of the test instrument box using pedestals made out of layered cardboard slats cut to the correct height for positioning the source. The source was held in place by means of a plastic garbage bag with a rubber band holding the bag securely to the pedestal. Figure 6 shows a source being positioned at the bottom of the cardboard pedestal. For positioning a source in the center of a compartment, cardboard slates were placed both above and below the source. In this way the source could be securely placed at the top, bottom, or center of a compartment in the box. For the beverage

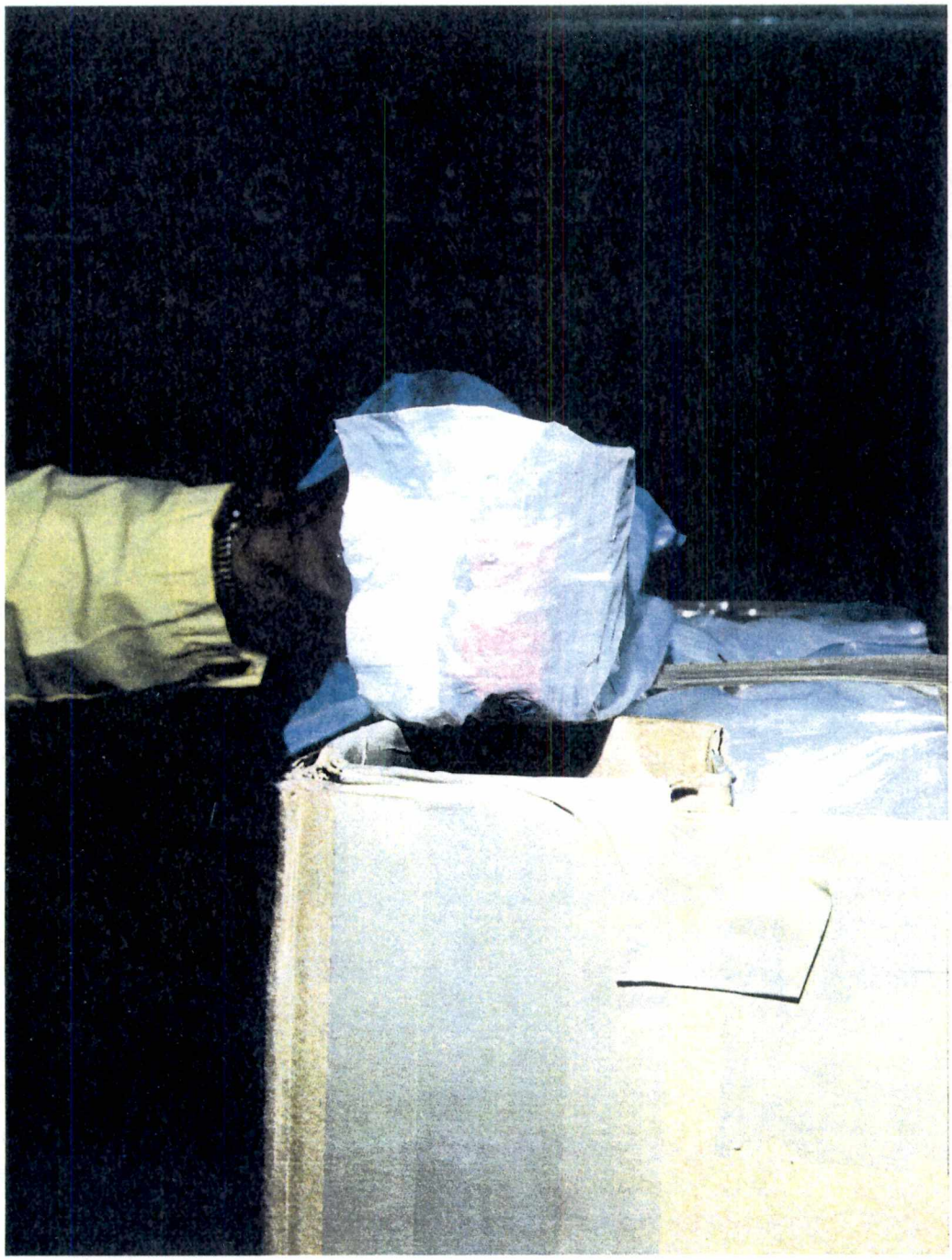

Figure 6. Photograph of Source Positioning

can waste matrix, aluminum cans were used as the pedestals in a similar manner to the cardboard slats. Figure 7 shows the aluminum cans being placed into a vertical compartment. A plastic bag was used to secure the source to the cans but was not used in this photograph so that the cans were more visible. For the machine turnings waste type the aluminum can pedestals were filled with machine turnings.

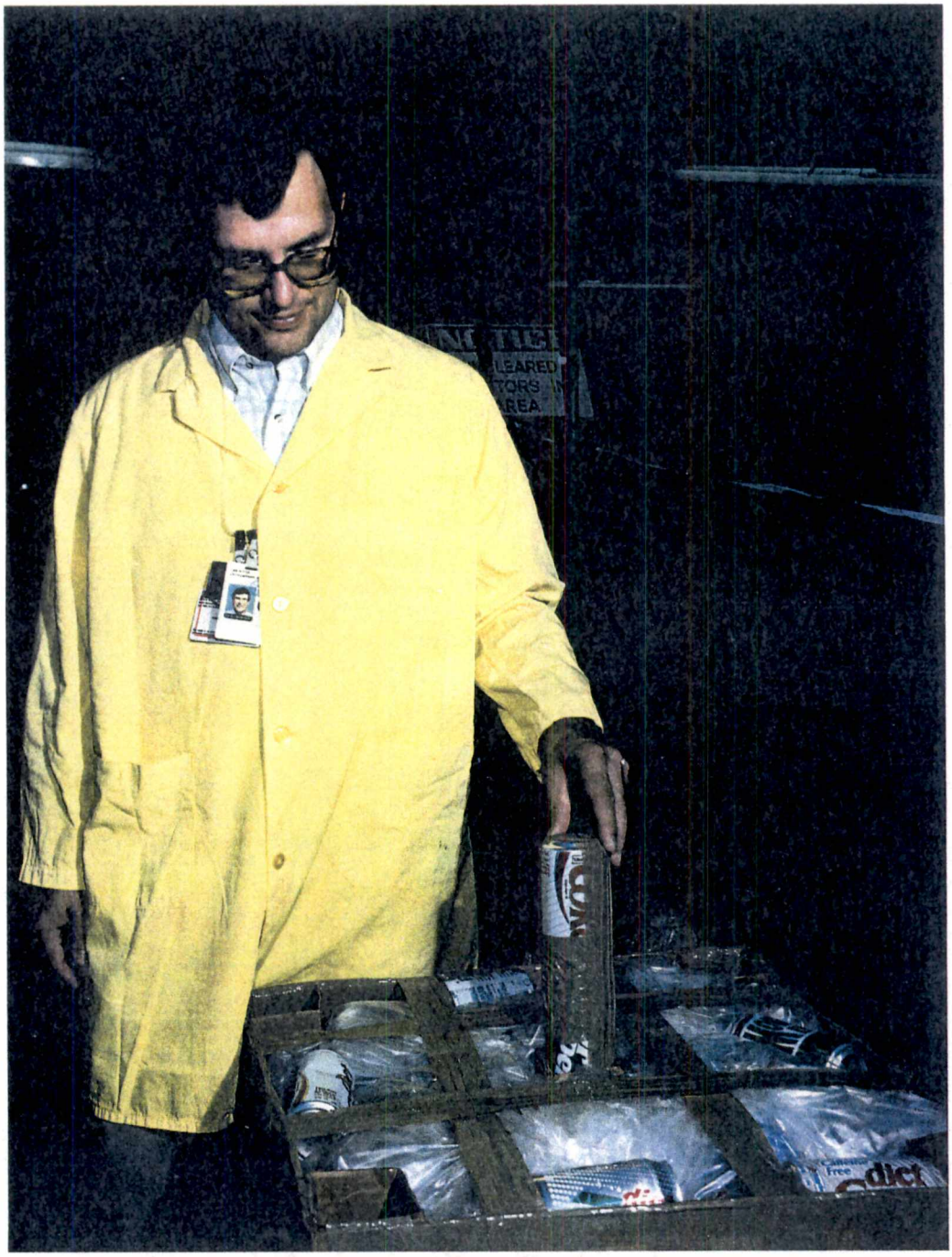

Figure 7. Photograph Showing Aluminum Can Pedestal

5. DATA AND ANALYSIS

5.1 Counting Time

Data were collected over a period of four days from 8:00 a.m. to 7:00 p.m. Activities in the area around the monitor varied from no activity to movement of containerized waste with a fork lift out of the building. Weather conditions varied from dry to rain which significantly affected the humidity of the air where the RBM was located because of the close proximity to an open doorway.

Data were collected in a 4x4 matrix of 30, 60, 90, and 120 seconds for both the sample and background count times (see Appendix A). Both sample and background counts per second were recorded for each cell in the matrix. The process used for recording data was to randomly collect data for all the cells in one matrix and then begin the next. The test device was removed from the monitor cavity and a background count was obtained prior to taking the sample count. Each combination of background and sample count times in the matrix was repeated 30 times, i.e., 30 matrices were completed.

All data points collected were used to calculate the standard deviation for each of the matrix cells. The standard deviation of each sample count time in the matrix was derived using net sample counts (gross sample count minus the background count) with the formula [4],

$$S = \sqrt{\frac{(\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \quad .$$

As expected the standard deviation tended to decrease as counting times were increased. However, the combinations with a shorter background count time than the sample count time tended to have consistently higher standard deviations. The highest standard deviation of 274 was with the combination of a 30 second background count time and a 120 second sample count time. This combination had a mean of 337 counts per second.

The lowest standard deviation for all combinations was 7 which corresponded to equal 60 second background and sample count times. Six of the sixteen combinations had a standard deviation of less than 12. All six of these had background and sample count times equal to or greater than 60 seconds. Mean counts per second ranged from 379 to 386. A summary of all standard deviations is provided in Table 2 and a graph for comparison is provided in Figure 8.

Table 2. Counting Time Matrix
Standard Deviation and Mean

Background Count Times (Sec)	Sample Count Times (sec)			
	30	60	90	120
30	74.13 374.4	156.1 345.4	42.61 379.2	274.0 337.1
60	18.81 381.9	7.33 386.0	19.16 384.9	70.16 373.0
90	15.29 385.5	11.74 379.7	9.20 384.3	32.09 379.3
120	66.01 375.3	10.71 384.8	8.54 386.07	11.89 381.2

* Recorded from top to bottom in each cell:

- Standard Deviation of Net Sample Counts/Second
- Mean of Net Sample Counts/Second

The combination of equal 60 second background and sample count times was chosen as the optimal combination because of having the lowest standard deviation and because of the practical benefits of using shorter count times. The difference between standard deviations for all six of the combinations which had a standard deviation below 12 are not significant, however the practical benefit of using the shorter count times would outweigh any slight benefit in standard deviation from using longer count times.

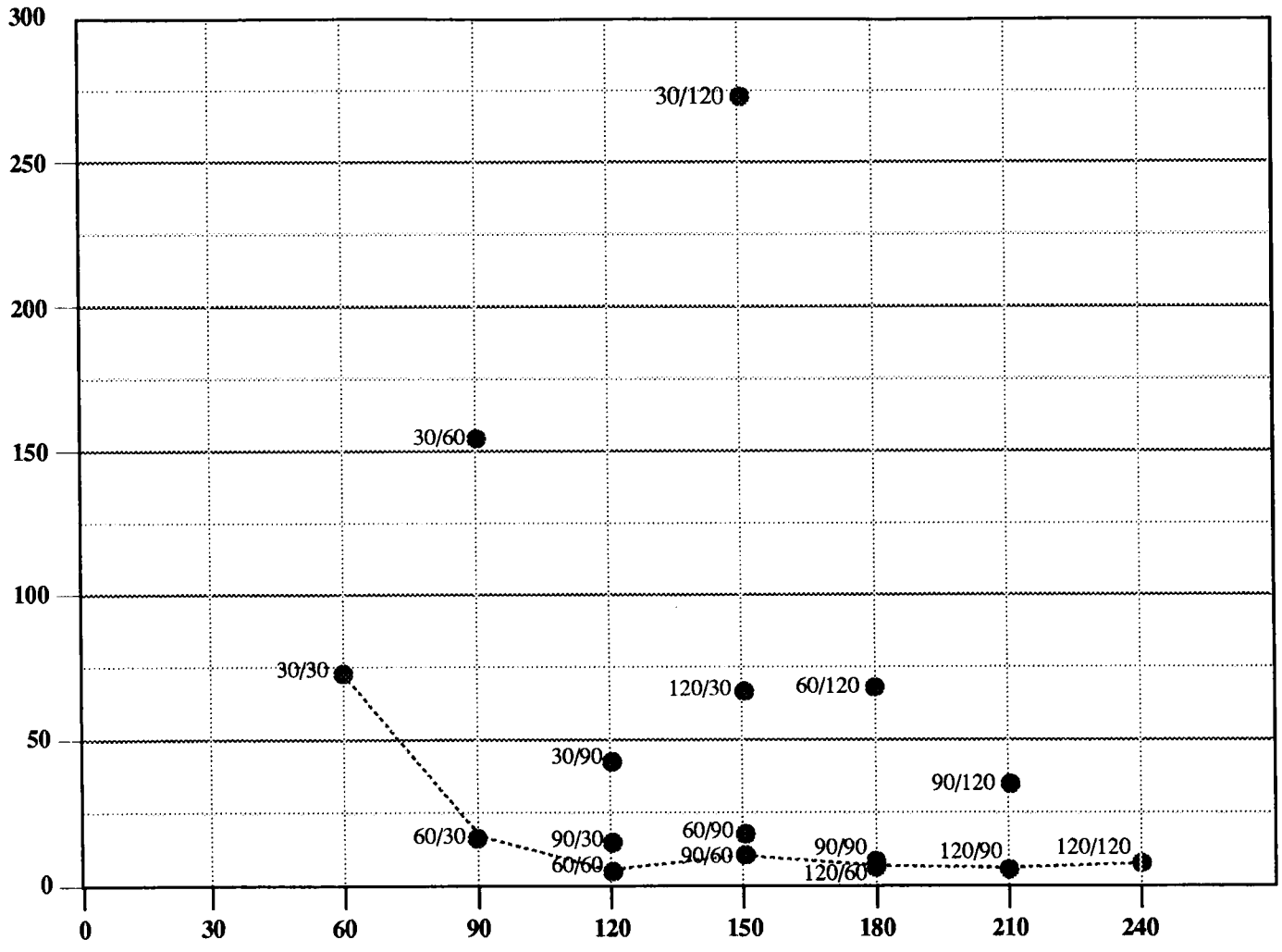

Figure 8. Counting Time Matrix Standard Deviations

Two effects can inject errors into the process when measuring background. The first is statistical counting errors, and the second is changes in background between the time the background is counted and the time the sample is counted. In this case both effects are likely to have contributed to the variability of the data. For example, take the effect of a 1% increase (actual change in background over all recorded data was approximately 3%) in background between the time background is counted and the time the sample is counted. Using the mean background of all the recorded data, a 1% increase in background would result in 813 additional background counts over a 60 second period or 13.6 counts per second. The mean of net sample counts per second recorded in the counting time evaluation was 376.1 counts per second. Therefore, a 1% increase in background during the sample count period would result in a 3% increase in the net sample counts per second.

Movement of radioactive material by the RBM did occur while samples were being tested. As radioactive material was moved by the RBM, short term spikes in background radiation were counted as source radiation. This is one reason for the high variability in combinations of shorter background than sample count times.

5.2 Radiological Box Monitor Performance

Data were collected over a period of 10 days in a similar time frame and with similar activities as for the experiment to establish counting times. The sequence of source selection was randomized by placing the sources in a box, shaking the box and then drawing a source from the box. In this way the sequence of readings was random. Data were recorded for all five sources and for no source at one of the nine positions in the box (see Table 1). Then the sources were mixed again to repeat the process for another position. A piece of folded red duct tape was used as a blank so that the readings taken with no source were also random.

A total of 432 sample counts were taken over the 10 day period (see Appendix B). There were two counts taken for each source, position, and waste matrix combination. A background count was

taken between data being collected for each combination, however the second reading was taken without obtaining a new background count. That is to say, there were 216 background counts taken.

Table 1 illustrates the results of the data collection. Data collected using the blank for both the Aggregate and Paper waste matrices indicated that the blank or null readings were consistently above background due to naturally occurring radiation. Therefore the information recorded in Table 1 has been scaled by subtracting out the mean of the null readings.

5.2.1 Lower Limit of Detection (LLD)

The calculated LLD for each position by waste matrix is shown in Table 3. The LLD was derived using the calculated efficiency (Table 4) at each position. The efficiency was calculated by adding total net sample counts from each source (Table 1) obtained for a given position and dividing by the sum of known activity from the five sources. It should be noted that if the weight of the waste matrices were all the same there would be a direct inverse relationship between efficiency and LLD. However, this was not the case due to a fixed volume and varying mass of the waste matrices.

This is particularly evident in comparison of results of mean LLD for soda cans and machine turnings. The RBM efficiency for the machine turnings was significantly less than for the soda cans. This would be expected due to the higher density materials in the machine turnings waste matrix. However the mean LLD for the turnings was significantly better than for the cans.

From examination of the two variables in the LLD equation (weight and efficiency), it is readily apparent why the calculations turned out that way. The weight of turnings, being over three times that of the cans, more than offset the higher efficiencies of the cans matrix. One explanation for this is that because of the turning's spring-like nature, large voids in the matrix resulted in less radiation being shielded from the detectors.

Table 3. Lower Limit of Detection Matrix

Waste Matrix	Lower Limit of Detection by Source Position * (pCi/g)									Mean for Matrix
	1	2	3	4	5	6	7	8	9	
Aggregate	6.71	8.63	6.97	6.97	10.07	9.06	8.63	8.63	5.49	7.91
Cans	22.65	28.61	21.74	17.53	28.61	28.61	24.71	23.63	17.53	23.74
Paper	4.69	6.42	4.69	4.21	7.63	5.55	5.55	5.55	3.94	5.36
Turnings	10.38	10.38	8.74	8.30	15.10	15.10	11.86	12.78	7.55	11.13
Mean for Position	11.11	13.51	10.49	9.25	15.35	14.58	12.69	12.65	8.63	12.03

* 1. Back of cavity in upper left corner
2. Back of cavity in upper right corner
3. Back of cavity in lower left corner
4. Back of cavity in lower right corner
5. Next to door in upper left corner
6. Next to door in uper right corner
7. Next to door in lower left corner
8. Next to door in lower right corner
9. Center of cavity

Table 4. Efficiency Matrix

Waste Matrix	Efficiency by Position*									Mean for Matrix
	1	2	3	4	5	6	7	8	9	
Aggregate	0.0027	0.0021	0.0026	0.0026	0.0018	0.0020	0.0021	0.0021	0.0033	0.0024
Cans	0.0024	0.0019	0.0025	0.0031	0.0019	0.0019	0.0022	0.0022	0.0031	0.0024
Paper	0.0026	0.0019	0.0026	0.0029	0.0016	0.0022	0.0022	0.0022	0.0031	0.0024
Turnings	0.0016	0.0016	0.0019	0.0020	0.0011	0.0011	0.0014	0.0013	0.0022	0.0016
Mean for Position	0.0023	0.0019	0.0024	0.0027	0.0016	0.0018	0.0020	0.0020	0.0029	0.0022

* 1. Back of cavity in upper left corner
2. Back of cavity in upper right corner
3. Back of cavity in lower left corner
4. Back of cavity in lower right corner
5. Next to door in upper left corner
6. Next to door in uper right corner
7. Next to door in lower left corner
8. Next to door in lower right corner
9. Center of cavity

Figure 9 illustrates the difference between mean LLD for the four waste matrices. Except for the LLD for cans being much higher than that for turnings the results are as expected. Figures 10 through 14 show the variation in LLD by source position. It is evident that there is greater sensitivity to source radiation at the center of the cavity than at any of the extremes. However, the overall performance of the RBM was not significantly affected by position of the source in the cavity.

On the basis of LLD figures 9 through 14 show that the RBM will perform adequately at the existing action value for depleted uranium detection (35 pCi/g) regardless of source position or waste matrix. (Note, that at the inception of work on this paper the radioactive contamination level at which trash could be disposed of in the Y-12 sanitary land fill was 74 pCi/g. A subsequent agreement with the State of Tennessee has lowered that limit to 35 pCi/g.)

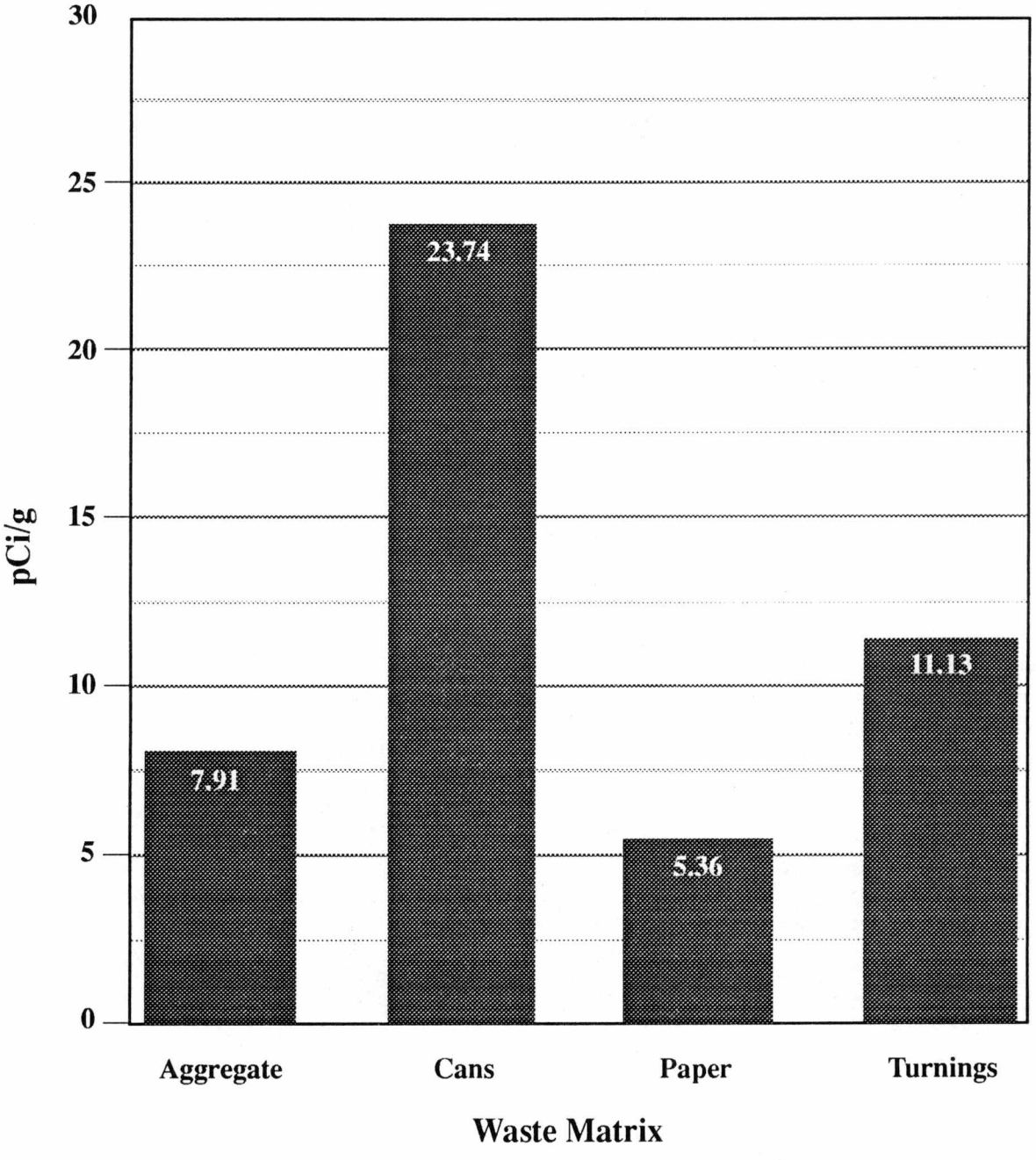

Figure 9. Comparison of Mean LLD by Waste Matrix

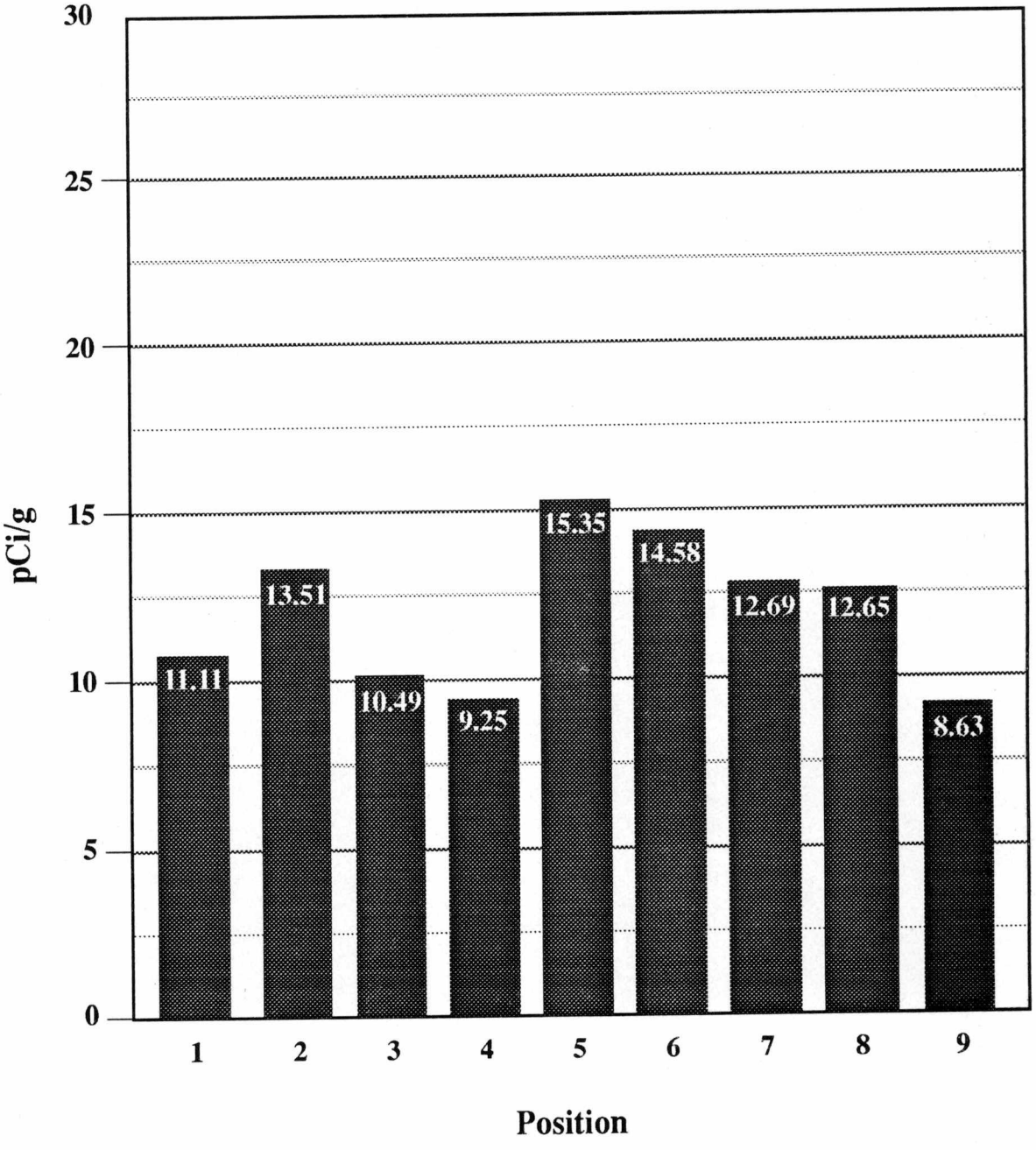

Figure 10. Comparison of Mean LLD by Source Position

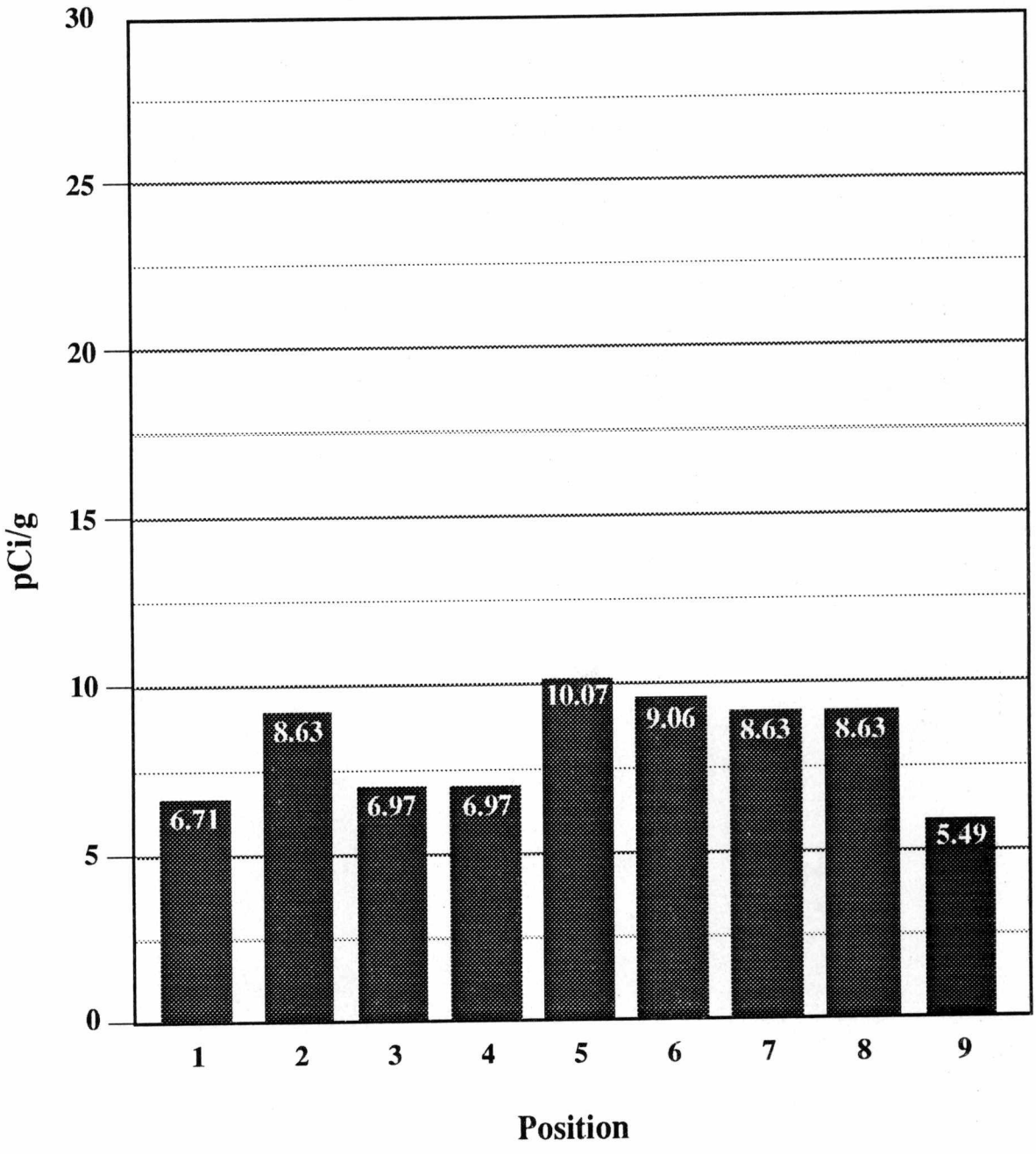

Figure 11. LLD for Aggregate Matrix by Position in Cavity

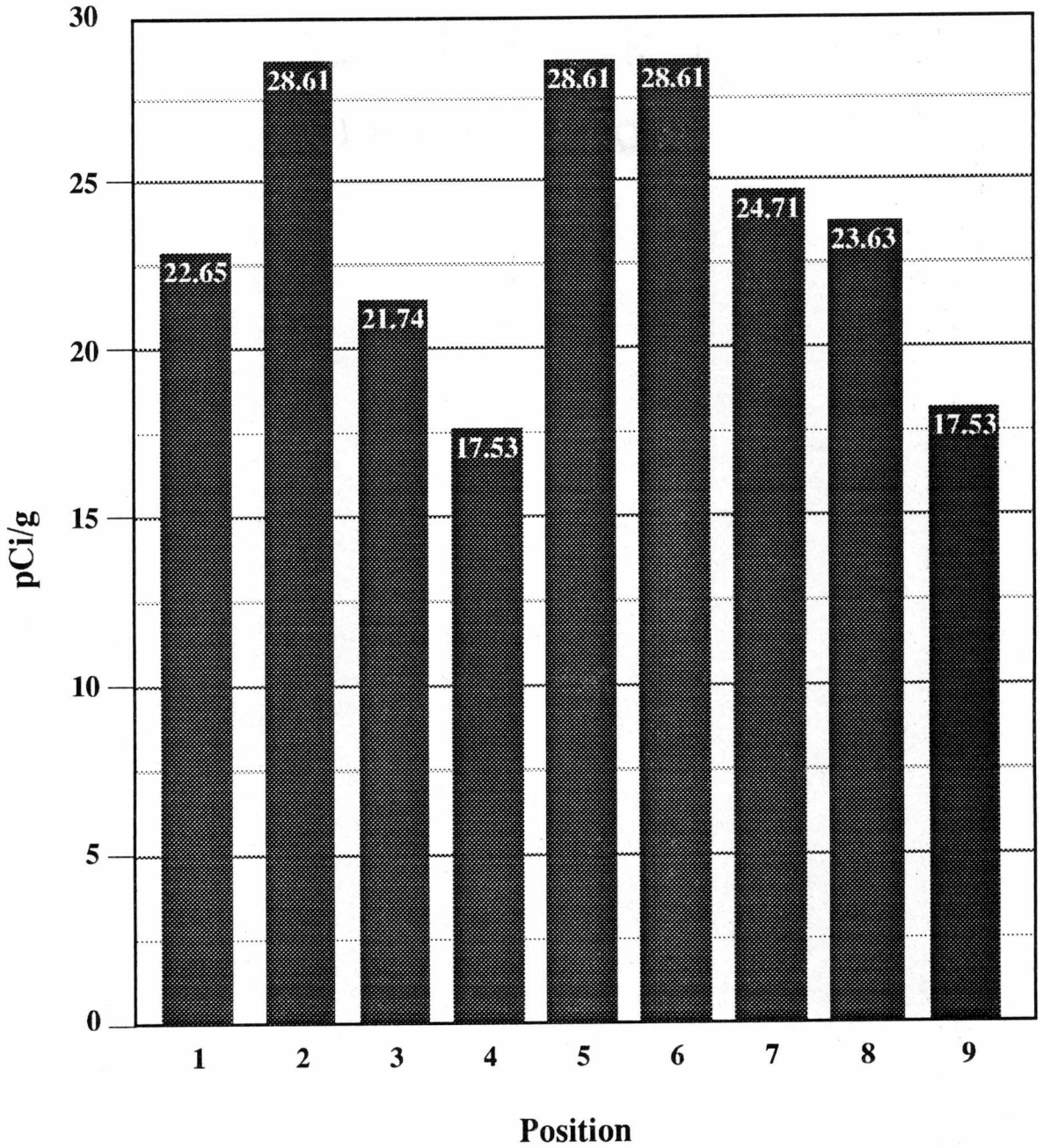

Figure 12. LLD for Cans Matrix by Position in Cavity

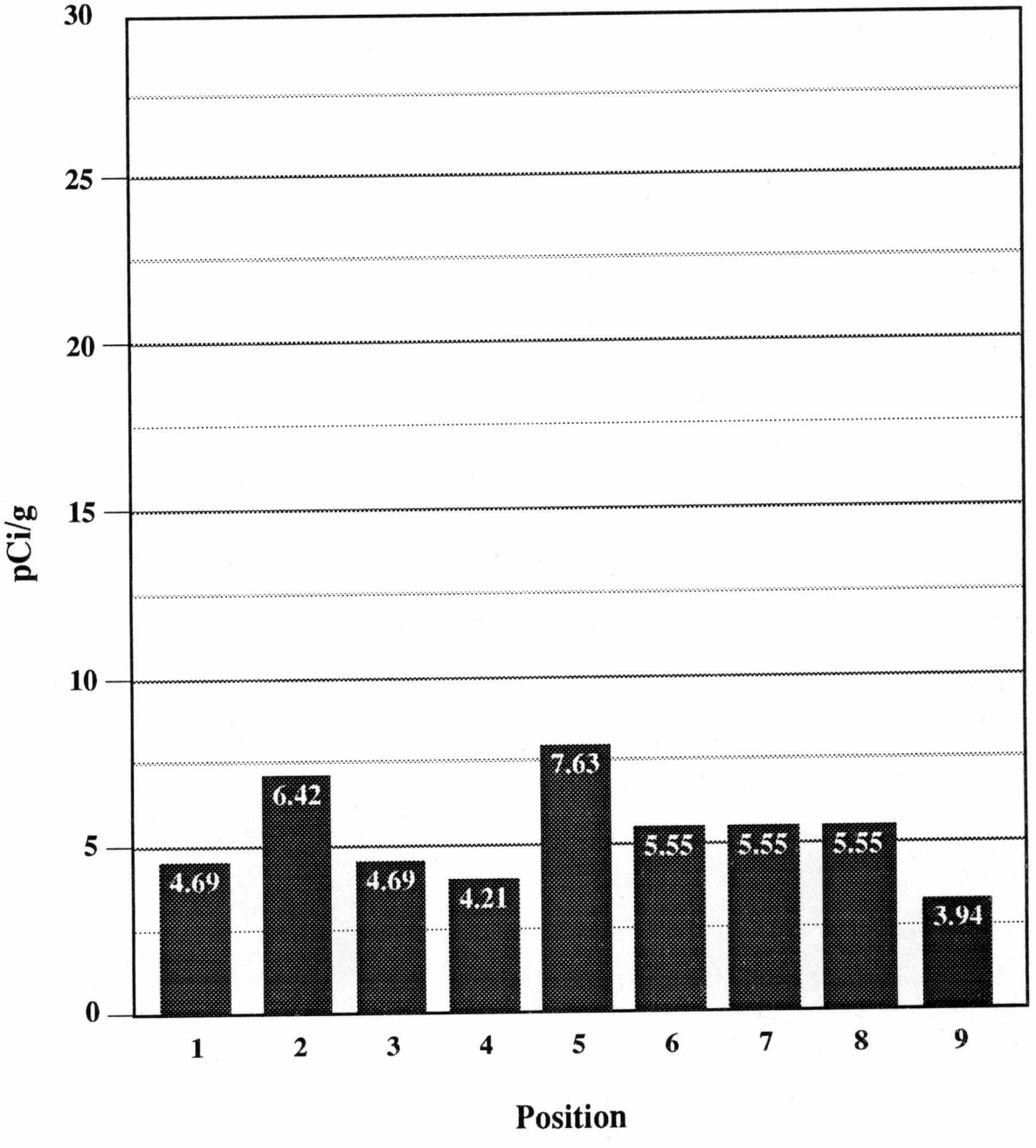

Figure 13. LLD for Paper Matrix by Position in Cavity

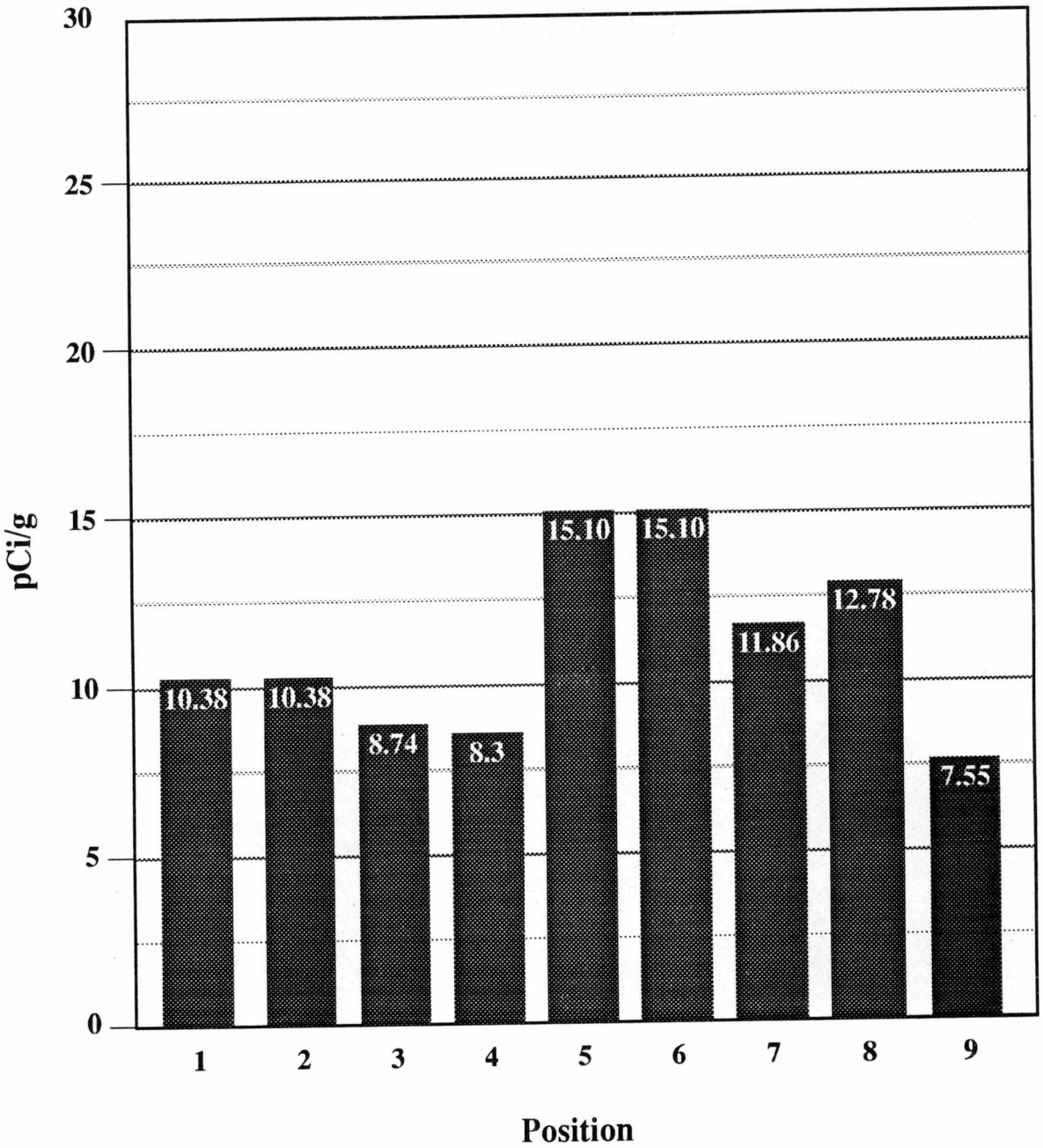

Figure 14. LLD for Turnings Matrix by Position in Cavity

5.2.2 Analysis of Variance

Figures 15 through 18 show the data plotted for each waste matrix with the calculated linear regression lines. The linear regression equations were calculated using the formulas presented in section 3.2. Derived equations for the four matrices are:

Aggregate	$y = 20.6 + 35.0\ x$
Cans	$y = 5.1 + 38.3\ x$
Paper	$y = 29.6 + 32.8\ x$
Turnings	$y = -20.3 + 32.5\ x.$

Values in the equations are expressed in counts per second.

To the first order of magnitude the slope of the regression equations is remarkably consistent across the matrices. Large values for the intercept calculated for the Aggregate and Paper matrices are the result of an apparent reduced efficiency in detection as source sizes increased due to self shielding by the source. This was apparent for all matrices and flattened the slope of the regression lines.

For the Cans and Turnings matrices the flatter slope was countered by zero readings for the small sources. Therefore the regression lines were shifted downward decreasing the intercept value. This is particularly apparent for the Turnings matrix where there were no readings above background for the 0.5 gram source and only very limited detection of the 1.0 gram source.

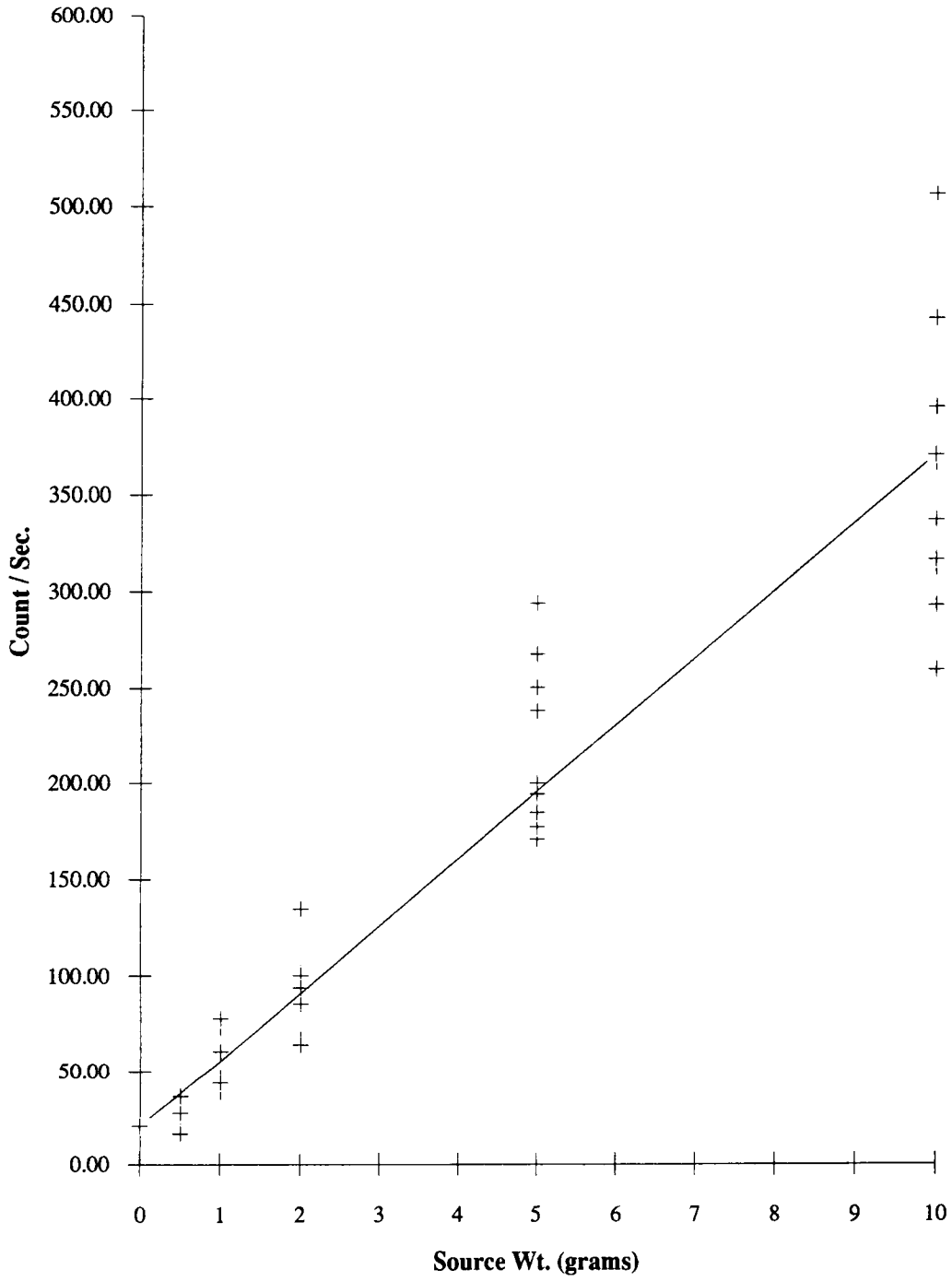

Figure 15. Linear Regression Line for Aggregate Matrix for Nine Source Locations

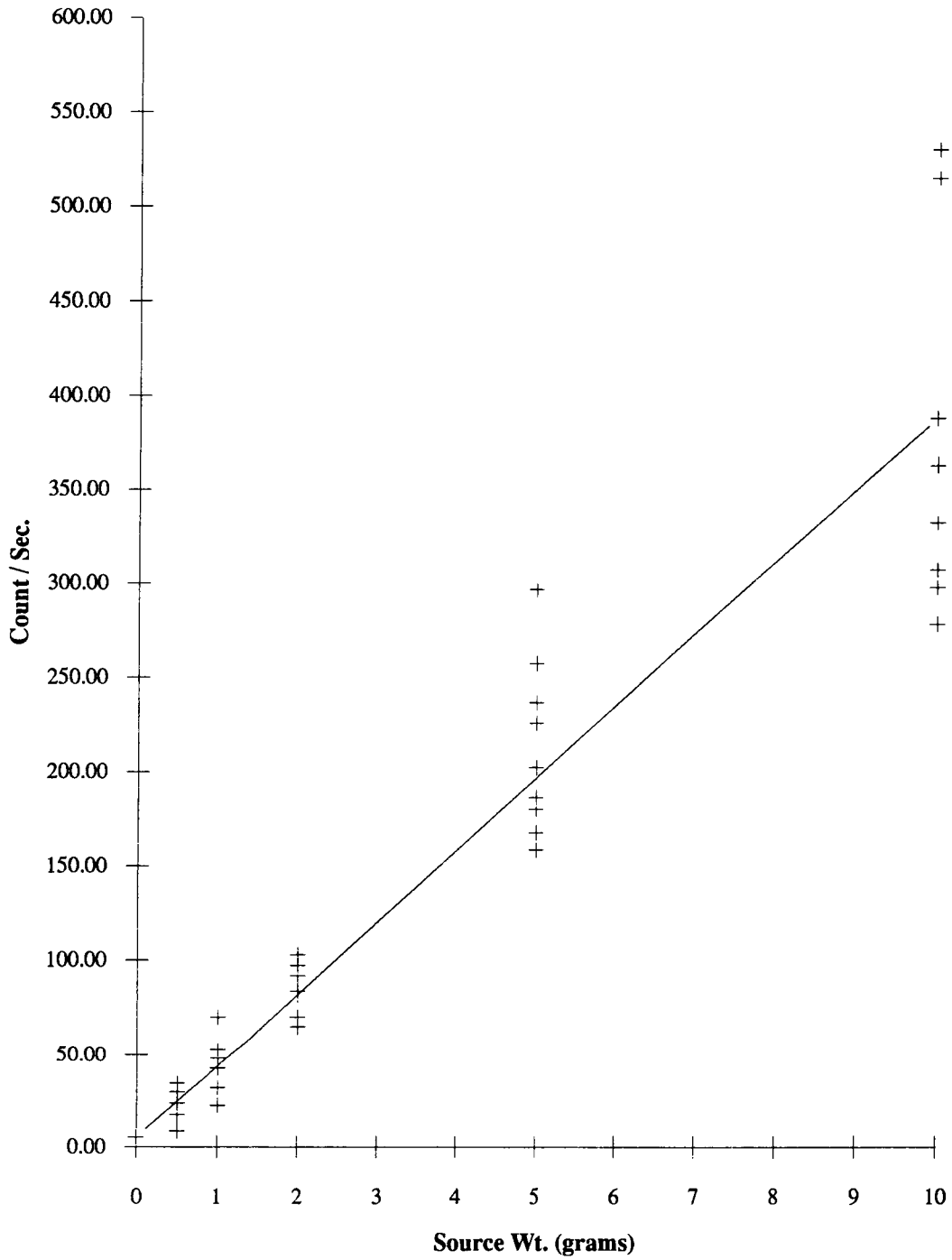

Figure 16. Linear Regression Line for Cans Matrix for Nine Source Locations

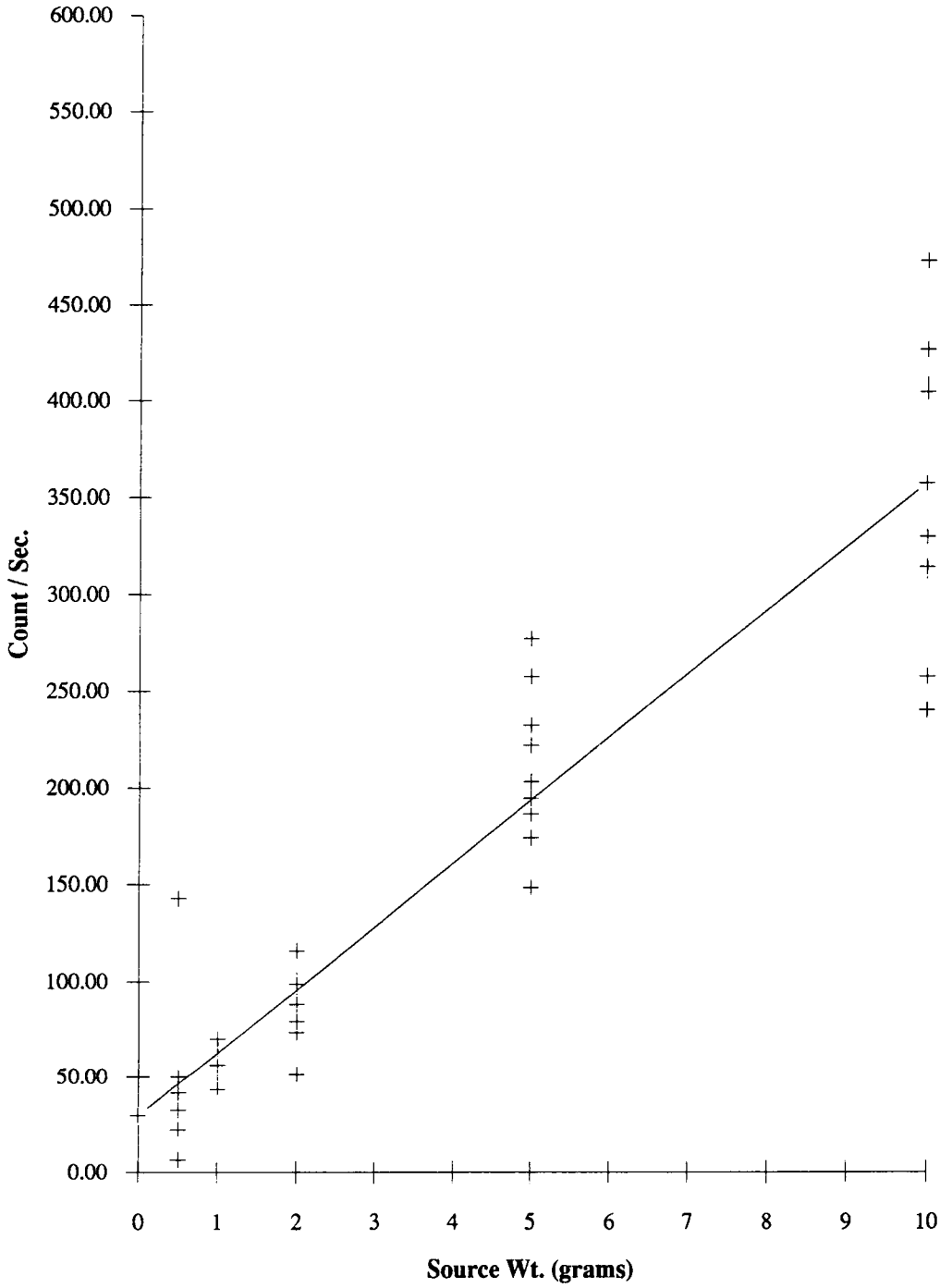

Figure 17. Linear Regression Line for Paper Matrix for Nine Source Locations

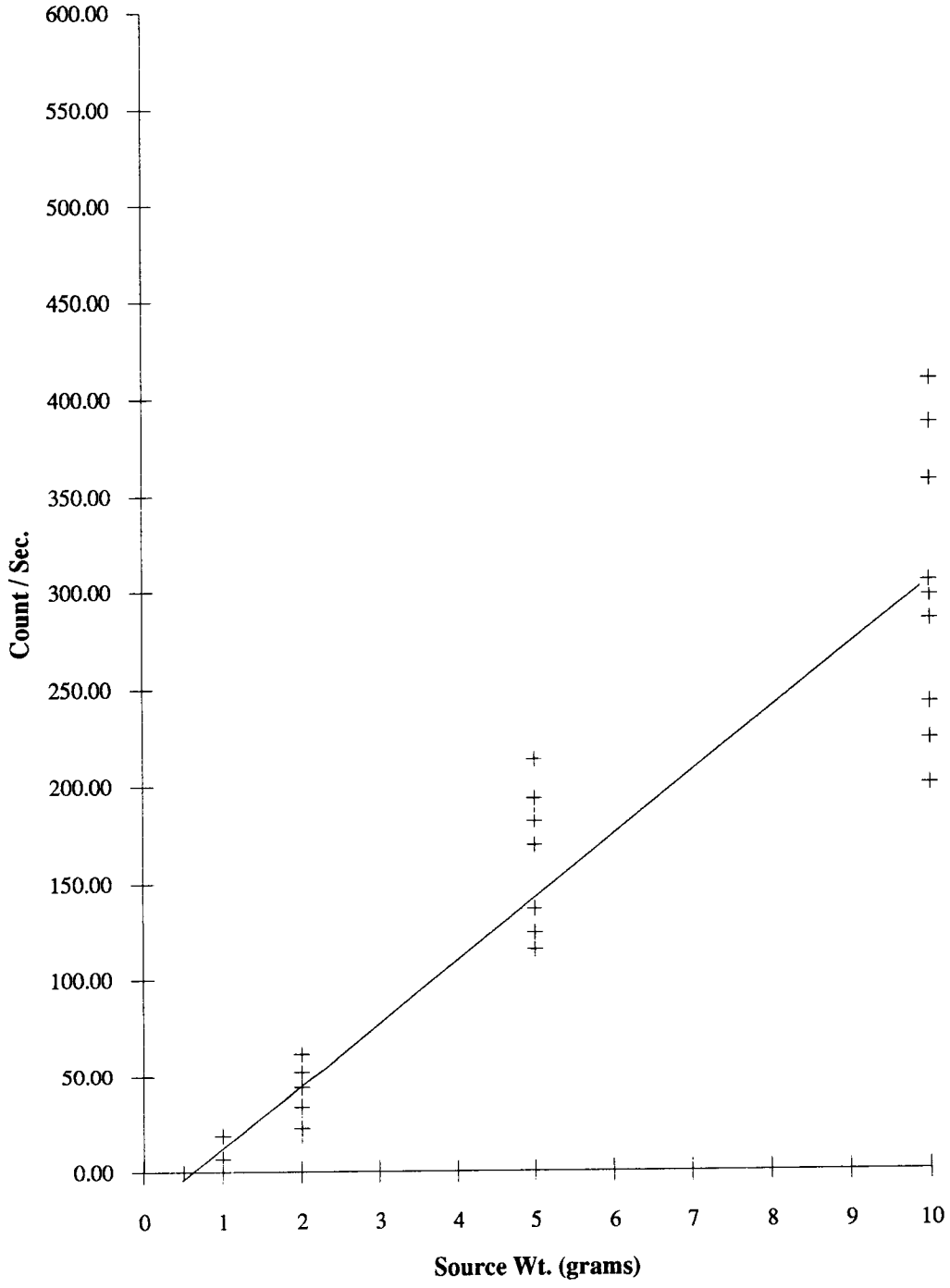

Figure 18. Linear Regression Line for Turnings Matrix for Nine Source Locations

Confidence intervals for each waste matrix in pCi/g follow using the formulas presented in section 3.3:

Aggregate	$-126 < \mu_{y\|_{x=74}} < 274$
Cans	$-401 < \mu_{y\|_{x=74}} < 549$
Paper	$-158 < \mu_{y\|_{x=74}} < 306$
Turnings	$-103 < \mu_{y\|_{x=74}} < 251.$

There appear to be several elements contributing to the wide spread in the confidence intervals. It is readily apparent from the distribution of data for each of the waste matrices (Figures 15 - 18) that as source size increases the variability of the data increases and the response of the detectors is not linear. In addition, wide variation in the data exists which can not be attributed to random variability, indicating instrument reliability problems.

Likely influences causing the non-linear response are shielding by the source and waste matrix. Thus, the number of particles incident on the detectors decreases with increased shielding, and the overall variability in counts detected is increased by the probability associated with the shielding.

The reliability of the instrument may be affected by both hardware and software problems. All of the counting functions and many of the hardware systems (e.g. voltage applied to the photo-multiplier tubes) are software dependent. Hardware problems are likely to be related to the stability of the electronics. Fluctuations in power supply voltage affecting the lower level discriminator could have a significant impact on the instrument's performance. Other factors contributing to stress placed on the electronic circuits are opening and closing of the door as well as movement of the scale platform. In addition, noticeable gaps between the closed door and main body of the instrument result in lower detection efficiency at locations next to the door. This is substantiated by consistently higher LLDs for positions 5 through 8 (positions next to the door) as shown in Figures 10 through 14.

The high degree of variability shown in the confidence intervals raises serious questions about the instruments reliability. Based on the LLDs the instrument has the capability to perform adequately. However, the reliability of the instrument must be improved before it's performance will be considered acceptable.

6. CONCLUSIONS

This study indicated that equal counting times of 60 seconds for obtaining background and sample counts had the least variability of the options examined (30, 60, 90, & 120 seconds). As expected from theory, combinations of background and sample count times with the greatest difference showed greater variability than those where the background and sample count times were equal. This was particularly apparent when the background count time was significantly less than the sample count time.

Data generated from performance testing of the RBM had both positive and negative results. From evaluation of performance on the basis of LLD, the RBM will be able to perform adequately at the existing action value for depleted uranium detection (35 pCi/g) regardless of source position or waste matrix. (Note, that at the inception of work on this paper the radioactive contamination level at which trash could be disposed of in the sanitary land fill was 74 pCi/g. A subsequent agreement with the State of Tennessee has lowered that limit to 35 pCi/g.) However, analysis of variance results produced confidence intervals varying from $\pm$ 177 pCi/g to $\pm$ 475 pCi/g. This appears to be the result of reliability problems with the instrument. The variability of the data raises serious questions about the instruments performance. However, if the reliability can be improved, it is expected that the Radiological Box Monitor will perform adequately on waste with minimal radioactive contamination.

7. RECOMMENDATIONS

Subsequent work on analyzing performance of the RBM should look at how to deal with the issues of source shelf shielding, waste matrix effects, and instrument reliability concerns. It is recommended that further studies on this instrument be performed to investigate these effects. In other experiments similar monitors have been tested using samples made up of rags saturated with liquid containing appropriate isotopes and methods have been studied to compensate for matrix effects.[10]

The reliability of the instrument may be affected by both hardware and software problems. It is recommended that a thorough analysis on both the hardware and software systems be performed to determine the nature of the reliability problems. In addition, remounting of the door on the RBM used for this study is suggested to reduce the gap between the closed door and main body of the instrument.

A process that has been used to increase confidence in the measurements of very low levels of radioactivity is Bayesian analyses of the data.[11] This process provides methods for dealing with negative net rates when it is known that they should be positive. Using Bayes Theorem and available computer programs[12], it is possible to establish an acceptable confidence interval a priori, and continue to count until that level of confidence is obtained. It is recommended that a Bayesian analysis method be explored for real-time evaluation of the RBM's performance.

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[10] "Segregation of Uncontaminated Dry Active Waste." EPRI NP-3299. Palo Alto, California: Electrical Power Research Institute, November 1983.

[11] Little, R.J.A. "The Statistical Analysis of Low-Level Radioactivity in the Presence of Background Counts." In *Health Physics* Vol 43, 693-703, 1982.

[12] Personal conversation with Dr. Peter Groer.

APPENDICES

APPENDIX A

COUNTING TIME MATRIX DATA

Page # A-1

Date: 8-19-91

Start time: 9:55 Stop time: 11:20

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1765	1778	1759	1768
	2.	1380	1385	1381	1366
	3.	385	393	378	402
60	1.	1778	1772	1769	1770
	2.	1377	1373	1371	1374
	3.	401	399	398	396
90	1.	1768	1761	1762	1766
	2.	1422	1377	1367	1377
	3.	346	384	395	389
120	1.	1745	1770	1755	1765
	2.	1662	1370	1373	1372
	3.	83	400	382	393

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-2

Date: 8-19-91

Start time: 11:20 Stop time: 12:39

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1766	1761	1762	1763
	2.	1362	1368	1363	1370
	3.	404	393	399	393
60	1.	1773	1757	1766	1766
	2.	1368	1369	1431	1365
	3.	405	388	335	401
90	1.	1747	1767	1758	1761
	2.	1373	1369	1373	1378
	3.	374	398	385	383
120	1.	1772	1766	1762	1770
	2.	1340	1369	1397	1368
	3.	432	397	365	402

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-3

Date: 8-19-91

Start time: 12:43 Stop time: 2:23

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1768	1751	1757	1768
	2.	1360	1364	1380	1372
	3.	408	387	377	396
60	1.	1768	1763	1762	1760
	2.	1457	1371	1371	1367
	3.	311	392	391	393
90	1.	1752	1763	1762	1752
	2.	1372	1370	1363	1374
	3.	380	393	399	378
120	1.	1746	1750	1751	1751
	2.	1362	1372	1370	1366
	3.	384	378	381	385

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-4

Date: 8-19-91

Start time: 2:24 Stop time: 3:30

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1765	1747	1760	1755
	2.	1374	1373	1376	1366
	3.	391	374	384	389
60	1.	1755	1760	1753	1762
	2.	1372	1372	1373	1380
	3.	383	388	380	382
90	1.	1767	1762	1754	1746
	2.	1373	1377	1367	1371
	3.	394	385	387	375
120	1.	1738	1756	1760	1758
	2.	1365	1363	1367	1373
	3.	373	393	393	385

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-5

Date: 8-19-91

Start time: 3:30 Stop time: 4:40

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1764	1763	1755	1758
	2.	1373	1363	1380	1375
	3.	391	400	375	383
60	1.	1770	1770	1764	1761
	2.	1370	1374	1435	1380
	3.	400	396	329	381
90	1.	1748	1737	1767	1762
	2.	1371	1372	1375	1379
	3.	377	365	392	383
120	1.	1749	1761	1763	1766
	2.	1370	1373	1372	1418
	3.	379	388	391	348

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-6

Date: 8-19-91

Start time: 4:40 Stop time: 5:45

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1761	1761	1755	1759
	2.	1367	1391	1369	1384
	3.	394	370	386	375
60	1.	1757	1762	1761	1757
	2.	1376	1376	1370	1370
	3.	381	386	391	387
90	1.	1768	1760	1765	1765
	2.	1373	1375	1375	1420
	3.	395	385	390	345
120	1.	1775	1769	1762	1756
	2.	1374	1380	1369	1379
	3.	401	389	393	377

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-7

Date: 8-19-91

Start time: 5:50 Stop time: 7:10

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1773	1755	1757	1762
	2.	1371	1360	1375	1380
	3.	402	395	382	382
60	1.	1767	1760	1757	1765
	2.	1368	1382	1377	1370
	3.	399	378	380	395
90	1.	1772	1756	1765	1757
	2.	1327	1373	1375	1370
	3.	445	383	390	387
120	1.	1758	1778	1765	1751
	2.	1483	1373	1369	1366
	3.	275	405	396	385

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-8

Date: 8-20-91

Start time: 8:30 Stop time: 9:35

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1761	1761	1761	1765
	2.	1369	1361	1362	1369
	3.	392	400	399	396
60	1.	1756	1766	1768	1763
	2.	1364	1370	1367	1375
	3.	392	396	401	388
90	1.	1752	1764	1736	1756
	2.	1369	1414	1370	1319
	3.	383	350	366	437
120	1.	1744	1756	1757	1749
	2.	1370	1369	1373	1367
	3.	374	387	384	382

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-9

Date: 8-20-91

Start time: 9:35 Stop time: 10:45

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1751	1752	1756	1749
	2.	1367	1356	1344	1362
	3.	384	396	412	387
60	1.	1735	1750	1750	1751
	2.	1369	1361	1361	1361
	3.	366	389	389	390
90	1.	1755	1751	1739	1753
	2.	1359	1364	1361	1357
	3.	396	387	378	396
120	1.	1753	1756	1751	1750
	2.	1361	1367	1365	1365
	3.	392	389	386	385

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-10

Date: 8-20-91

Start time: 10:45 Stop time: 11:50

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1753	1743	1750	1755
	2.	1363	1357	1376	1366
	3.	390	386	374	389
60	1.	1738	1749	1754	1755
	2.	1372	1357	1374	1357
	3.	366	392	380	398
90	1.	1741	1746	1750	1751
	2.	1365	1357	1358	1365
	3.	376	389	392	386
120	1.	1753	1751	1754	1750
	2.	1361	1365	1361	1363
	3.	392	386	393	387

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-11

Date: 8-20-91

Start time: 11:50 Stop time: 12:55

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1745	1750	1746	1747
	2.	1360	1349	1361	1372
	3.	385	401	385	375
60	1.	1761	1748	1746	1755
	2.	1357	1361	1362	1363
	3.	404	387	384	392
90	1.	1742	1741	1750	1750
	2.	1364	1363	1364	1364
	3.	378	378	386	386
120	1.	1755	1742	1759	1750
	2.	1363	1362	1355	1365
	3.	392	380	404	385

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A-12

Date: 8-20-91

Start time: 1:35 Stop time: 2:45

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1753	1750	1740	1751
	2.	1365	1370	1365	1358
	3.	385	380	375	393
60	1.	1739	1750	1747	1742
	2.	1360	1367	1361	1368
	3.	379	383	386	374
90	1.	1753	1751	1724	1742
	2.	1362	1359	1351	1364
	3.	391	392	373	378
120	1.	1743	1743	1745	1739
	2.	1366	1360	1369	1361
	3.	377	383	376	378

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -13

Date: 8-20-91

Start time: 2:50 Stop time: 3:55

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1742	1738	1744	1753
	2.	1350	1356	1360	1369
	3.	392	382	384	384
60	1.	1751	1738	1741	1743
	2.	1360	1364	1359	1356
	3.	391	374	382	387
90	1.	1751	1739	1757	1748
	2.	1369	1365	1362	1369
	3.	382	374	395	379
120	1.	1736	1743	1741	1737
	2.	1359	1362	1365	1358
	3.	377	381	376	379

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -14

Date: 8-20-91

Start time: 3:55 Stop time: 5:00

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1746	1748	1746	1749
	2.	1365	1377	1357	1366
	3.	381	371	389	383
60	1.	1751	1745	1743	1749
	2.	1360	1365	1361	1359
	3.	391	380	382	390
90	1.	1753	1750	1746	1748
	2.	1361	1368	1363	1361
	3.	392	382	383	387
120	1.	1737	1744	1743	1735
	2.	1370	1359	1362	1361
	3.	367	385	381	374

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -15

Date: 8-20-91

Start time: 5:20 Stop time: 6:30

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1746	1754	1743	1749
	2.	1367	1370	1365	1374
	3.	379	384	378	375
60	1.	1746	1746	1753	1751
	2.	1376	1359	1359	1372
	3.	370	387	394	379
90	1.	1739	1744	1746	1743
	2.	1365	1363	1361	1361
	3.	374	381	385	382
120	1.	1797	1757	1752	1752
	2.	1366	1366	1368	1359
	3.	431	391	384	393

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -16

Date: 8-21-91

Start time: 8:00 Stop time: 9:20

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1745	1760	1750	1751
	2.	1363	1370	1361	1369
	3.	382	390	389	382
60	1.	1763	1757	1746	1742
	2.	1363	1361	1362	1369
	3.	400	396	384	373
90	1.	1755	1755	1738	1750
	2.	1367	1376	1364	1379
	3.	388	379	374	371
120	1.	1752	1745	1759	1758
	2.	1366	1371	1357	1373
	3.	386	374	402	385

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -17

Date: 8-21-91

Start time: 9:30 Stop time: 10:35

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1756	1746	1751	1748
	2.	1367	1361	1359	1365
	3.	389	385	392	383
60	1.	1752	1758	1752	1745
	2.	1365	1371	1360	1373
	3.	387	387	392	372
90	1.	1740	1743	1745	1750
	2.	1370	1368	1366	1369
	3.	370	375	379	381
120	1.	1747	1745	1760	1747
	2.	1370	1365	1362	1374
	3.	377	380	398	374

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -18

Date: 8-21-91

Start time: 10:35 Stop time: 11:35

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1747	1754	1750	1755
	2.	1361	1365	1368	1375
	3.	386	389	382	380
60	1.	1732	1752	1746	1752
	2.	1363	1354	1352	1358
	3.	369	398	394	394
90	1.	1747	1744	1752	1752
	2.	1366	1369	1361	1368
	3.	381	375	391	384
120	1.	1761	1761	1750	1748
	2.	1364	1364	1374	1368
	3.	397	397	376	380

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -19

Date: 8-21-91

Start time: 11:40 Stop time: 12:40

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1764	1756	1750	1748
	2.	1353	1362	1370	1366
	3.	411	394	380	382
60	1.	1752	1747	1754	1746
	2.	1377	1365	1356	1363
	3.	375	382	398	383
90	1.	1751	1745	1744	1742
	2.	1367	1364	1363	1371
	3.	384	381	381	371
120	1.	1752	1747	1745	1750
	2.	1384	1365	1360	1367
	3.	368	382	385	383

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -20

Date: 8-21-91

Start time: 12:40 Stop time: 1:40

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1764	1746	1750	1749
	2.	1373	1353	1349	1360
	3.	391	393	401	389
60	1.	1745	1745	1750	1748
	2.	1365	1372	1366	1344
	3.	380	373	384	404
90	1.	1740	1738	1757	1756
	2.	1370	1371	1357	1370
	3.	370	367	400	386
120	1.	1752	1753	1751	1744
	2.	1357	1389	1370	1366
	3.	395	364	381	378

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -21

Date: 8-21-91

Start time: 2:15 Stop time: 3:15

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1747	1754	1751	1746
	2.	1363	1308	1363	1362
	3.	384	446	388	384
60	1.	1760	1752	1752	1755
	2.	1366	1365	1374	1372
	3.				
90	1.	1745	1747	1755	1756
	2.	1357	1365	1365	1364
	3.	394	382	390	392
120	1.	1754	1748	1739	1743
	2.	1387	1400	1357	1367
	3.	367	348	382	376

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -22

Date: 8-21-91

Start time: 3:20 Stop time: 4:25

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1752	1754	1728	1752
	2.	1371	1357	1369	1465
	3.	381	397	359	287
60	1.	1748	1744	1752	1743
	2.	1362	1363	1371	1367
	3.	386	381	381	376
90	1.	1750	1745	1742	1745
	2.	1358	1366	1370	1368
	3.	392	379	372	377
120	1.	1741	1748	1749	1748
	2.	1364	1362	1369	1360
	3.	377	386	380	388

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -23

Date: 8-21-91

Start time: 4:25 Stop time: 5:25

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1752	1743	1746	1742
	2.	1365	1365	1350	1361
	3.	387	378	396	381
60	1.	1737	1745	1745	1750
	2.	1374	1369	1372	1373
	3.	363	376	373	377
90	1.	1751	1746	1744	1749
	2.	1361	1367	1362	1367
	3.	390	379	382	382
120	1.	1743	1748	1752	1756
	2.	1364	1359	1363	1371
	3.	329	389	389	385

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -24

Date: 8-21-91

Start time: 5:25 Stop time: 6:30

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1742	1740	1754	1756
	2.	1365	1364	1363	1360
	3.	377	376	391	396
60	1.	1744	1741	1744	1744
	2.	1366	1362	1366	1365
	3.	378	379	378	379
90	1.	1761	1749	1745	1725
	2.	1362	1364	1368	1499
	3.	399	385	377	226
120	1.	1743	1746	1748	1741
	2.	1359	1367	1366	1368
	3.	384	379	382	373

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -25

Date: 8-22-91

Start time: 8:20 Stop time: 9:25

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1749	1742	1747	1747
	2.	1362	1371	1349	1355
	3.	387	371	398	392
60	1.	1745	1740	1748	1742
	2.	1367	1357	1355	1362
	3.	378	383	393	380
90	1.	1748	1734	1747	1747
	2.	1351	1364	1363	1356
	3.	397	370	384	391
120	1.	1737	1740	1750	1745
	2.	1358	1356	1355	1359
	3.	379	384	395	386

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -26

Date: 8-22-91

Start time: 9:25 Stop time: 10:30

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1739	1758	1744	1744
	2.	1351	1552	1370	1363
	3.	388	206	374	381
60	1.	1752	1736	1746	1749
	2.	1349	1360	1301	1353
	3.	403	376	445	396
90	1.	1732	1738	1746	1734
	2.	1358	1354	1349	1342
	3.	374	384	397	392
120	1.	1740	1739	1731	1738
	2.	1354	1360	1349	1360
	3.	386	379	382	378

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -27

Date: 8-22-91

Start time: 10:30 Stop time: 11:35

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1741	1747	1738	1732
	2.	1369	1359	1350	1342
	3.	372	388	388	390
60	1.	1734	1741	1739	1740
	2.	1351	1345	1353	1356
	3.	383	396	386	384
90	1.	1723	1737	1735	1742
	2.	1352	1349	1358	1343
	3.	371	388	377	399
120	1.	1725	1744	1737	1742
	2.	1351	1350	1354	1348
	3.	374	394	383	394

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -28

Date: 8-22-91

Start time: 11:35 Stop time: 12:40

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1741	1739	1730	1749
	2.	1365	1366	1343	1343
	3.	376	373	387	406
60	1.	1745	1741	1739	1748
	2.	1354	1357	1345	1353
	3.	391	384	394	395
90	1.	1748	1747	1717	1733
	2.	1355	1351	1352	1351
	3.	393	396	365	382
120	1.	1743	1740	1738	1740
	2.	1355	1353	1345	1351
	3.	388	387	393	389

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

Page # A -29

Date: 8-22-91

Start time: 1:45 Stop time: 2:45

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1734	1730	1744	1740
	2.	1354	1343	1365	1355
	3.	380	387	379	385
60	1.	1729	1739	1738	1734
	2.	1366	1352	1354	1351
	3.	363	387	384	383
90	1.	1737	1727	1735	1739
	2.	1345	1383	1348	1348
	3.	392	344	387	391
120	1.	1746	1738	1748	1739
	2.	1360	1357	1359	1397
	3.	386	381	389	342

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

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Date: 8-22-91

Start time: 2:45 Stop time: 4:00

Background Count Time (sec)		Sample Count Time (sec) 30	60	90	120
30	1.	1728	1730	1747	1742
	2.	1353	1354	1352	1348
	3.	375	376	395	394
60	1.	1727	1741	1738	1730
	2.	1361	1360	1357	1351
	3.	366	381	378	379
90	1.	1743	1736	1728	1741
	2.	1352	1354	1350	1358
	3.	391	382	378	383
120	1.	1737	1737	1736	1746
	2.	1350	1348	1356	1358
	3.	387	389	380	388

Record in Each Cell:

1. Gross Counts/sec = Background + Source
2. Background Counts/sec
3. Net Counts/sec = #1 - #2

APPENDIX B

RBM PERFORMANCE DATA

Format for RBM Performance Data

Position:

1	=	Back Upper Left
2	=	Back Upper Right
3	=	Back Lower Left
4	=	Back Lower Right
5	=	Door Upper Left
6	=	Door Upper Right
7	=	Door Lower Left
8	=	Door Lower Right
9	=	Center

Waste:

1	=	Aggregate (Mixed Trash)
2	=	Alumium Cans
3	=	Paper
4	=	Machine Turnings (Steel, Aluminum, Brass)

Source:

0	=	No source
0.5	=	0.500 gm U-238
1	=	1.006 gm U-238
2	=	2.027 gm U-238
5	=	5.067 gm U-238
10	=	10.181 gm U-238

F Count = First count taken (Net counts in 60 sec.)

S Count = Second count taken using some background reading as the first count.

RBM Performance Data

Position	Waste	Source	FCount	SCount
1	1	0	5571	5550
1	1	0.5	6980	7025
1	1	1	8174	8236
1	1	2	11510	12248
1	1	5	21465	20888
1	1	10	29141	30511
2	1	0	5384	5561
2	1	0.5	6458	5546
2	1	1	8123	15054
2	1	2	10650	9550
2	1	5	17410	17784
2	1	10	24138	25167
3	1	0	6221	6344
3	1	0.5	7486	7770
3	1	1	9040	9101
3	1	2	11411	11348
3	1	5	19709	19374
3	1	10	27377	28209
4	1	0	5494	5178
4	1	0.5	7364	7833
4	1	1	9789	9693
4	1	2	10803	11116
4	1	5	20428	19656
4	1	10	31962	31085
5	1	0	5251	5749
5	1	0.5	6384	6179
5	1	1	8215	6625
5	1	2	9430	9692
5	1	5	15655	15039
5	1	10	20986	20865
6	1	0	4595	4573
6	1	0.5	7583	7290
6	1	1	7922	7770
6	1	2	9236	9840
6	1	5	17071	16453
6	1	10	22999	22556
7	1	0	5475	5082
7	1	0.5	6934	7161
7	1	1	7750	7475
7	1	2	10521	10405
7	1	5	16044	15918
7	1	10	25624	26315
8	1	0	5408	5950
8	1	0.5	7004	6377

RBM Performance Data

Position	Waste	Source	FCount	SCount
8	1	1	8023	7197
8	1	2	11024	10959
8	1	5	16479	15954
8	1	10	24404	25283
9	1	0	5269	5655
9	1	0.5	7042	7426
9	1	1	10069	9850
9	1	2	13469	13042
9	1	5	23054	22409
9	1	10	35803	36108
1	2	0	0	191
1	2	0.5	2083	2157
1	2	1	1880	1917
1	2	2	4912	5345
1	2	5	13560	14588
1	2	10	21829	21837
2	2	0	92	0
2	2	0.5	596	672
2	2	1	1928	2217
2	2	2	4208	4433
2	2	5	10069	10798
2	2	10	17889	18301
3	2	0	0	0
3	2	0.5	954	1488
3	2	1	2588	3010
3	2	2	5515	5715
3	2	5	14220	13647
3	2	10	23233	23008
4	2	0	0	0
4	2	0.5	1668	1519
4	2	1	2825	2881
4	2	2	6181	6790
4	2	5	15445	14657
4	2	10	31834	27501
5	2	0	0	0
5	2	0.5	623	1166
5	2	1	1339	1976
5	2	2	3860	3430
5	2	5	10832	9370
5	2	10	18459	17770
6	2	0	0	0
6	2	0.5	1049	661
6	2	1	2562	2022
6	2	2	4930	3849

RBM Performance Data

Position	Waste	Source	FCount	SCount
6	2	5	9538	9686
6	2	10	16711	16796
7	2	0	0	0
7	2	0.5	1420	1538
7	2	1	2882	2988
7	2	2	5025	5910
7	2	5	12160	12288
7	2	10	19971	20656
8	2	0	0	0
8	2	0.5	511	764
8	2	1	3179	2594
8	2	2	5846	4723
8	2	5	11197	13132
8	2	10	21772	20845
9	2	0	0	0
9	2	0.5	1775	1767
9	2	1	4209	3311
9	2	2	3913	7277
9	2	5	17807	18616
9	2	10	30911	30044
1	3	0	1398	1290
1	3	0.5	10207	3133
1	3	1	5515	4318
1	3	2	7454	8071
1	3	5	15571	16342
1	3	10	26145	25323
2	3	0	1647	2154
2	3	0.5	3026	3231
2	3	1	4841	3888
2	3	2	6030	5454
2	3	5	12076	13204
2	3	10	17103	16875
3	3	0	1212	1624
3	3	0.5	3515	3280
3	3	1	5702	5211
3	3	2	7710	7589
3	3	5	14954	15334
3	3	10	25929	25325
4	3	0	1665	2314
4	3	0.5	4014	3518
4	3	1	5603	5824
4	3	2	8574	8103
4	3	5	17104	17057
4	3	10	27265	27750

RBM Performance Data

Position	Waste	Source	FCount	SCount
5	3	0	1771	1086
5	3	0.5	2034	2823
5	3	1	4776	4344
5	3	2	4713	5016
5	3	5	10540	10834
5	3	10	16049	15921
6	3	0	1644	1449
6	3	0.5	4640	3920
6	3	1	4400	4836
6	3	2	6383	6692
6	3	5	12817	14870
6	3	10	20373	20679
7	3	0	2676	2345
7	3	0.5	2975	4109
7	3	1	4220	4229
7	3	2	7551	7616
7	3	5	13842	13089
7	3	10	20516	20454
8	3	0	1991	2167
8	3	0.5	3575	3577
8	3	1	5017	5093
8	3	2	6919	6682
8	3	5	13304	13187
8	3	10	21439	21521
9	3	0	1723	493
9	3	0.5	4123	4380
9	3	1	5822	5147
9	3	2	8595	9155
9	3	5	18280	18482
9	3	10	30055	29756
1	4	0	0	0
1	4	0.5	0	0
1	4	1	0	0
1	4	2	2565	2620
1	4	5	10159	10093
1	4	10	17923	18033
2	4	0	0	0
2	4	0.5	0	0
2	4	1	0	0
2	4	2	2624	2547
2	4	5	10899	10250
2	4	10	16750	17210
3	4	0	0	0
3	4	0.5	0	0

RBM Performance Data

Position	Waste	Source	FCount	SCount
3	4	1	0	0
3	4	2	3155	2804
3	4	5	11379	11598
3	4	10	21419	21917
4	4	0	0	0
4	4	0.5	0	0
4	4	1	164	272
4	4	2	2647	3531
4	4	5	11614	11923
4	4	10	23201	23095
5	4	0	0	0
5	4	0.5	0	0
5	4	1	0	0
5	4	2	1135	858
5	4	5	6899	6773
5	4	10	13412	13887
6	4	0	0	0
6	4	0.5	0	0
6	4	1	0	0
6	4	2	1370	1565
6	4	5	6922	6962
6	4	10	12016	12271
7	4	0	0	0
7	4	0.5	0	0
7	4	1	418	768
7	4	2	1935	2115
7	4	5	7436	7840
7	4	10	17091	17722
8	4	0	0	0
8	4	0.5	0	0
8	4	1	0	0
8	4	2	2036	1606
8	4	5	8189	7247
8	4	10	14532	14581
9	4	0	0	0
9	4	0.5	0	0
9	4	1	1137	1582
9	4	2	3716	4308
9	4	5	12800	12538
9	4	10	24551	24815

VITA

Richard D. Korynta was born and raised on a farm near Ardoch, North Dakota. His contribution to the family farm was always considered important which early in life instilled a strong sense of responsibility and self worth. To this day he maintains an interest in the farm and is never happier than when working on the land and with the cattle.

He graduated from Midway High School in May of 1971 and attended the University of North Dakota for two years. He then joined the United States Air Force to serve as an electronics technician. Upon receiving an honorable discharge in the fall of 1976, he re-entered the University of North Dakota and graduated in December, 1979, with a Bachelor of Science degree in Business Administration.

In September of 1984, he left a position as Assistant Manager for the Farmers Elevator Company in Forest River, North Dakota to attend the University of New Mexico. He served as an Engineering Technician at the Air Force Weapons Laboratory in Albuquerque and was awarded a Bachelor of Science degree in Electrical Engineering in May of 1987.

Upon completion of a security clearance review by the Department of Energy in August of 1987, he was employed by the Nevada Operations Office in Las Vegas as a General Engineer in the Weapons Testing Program. In the fall of 1988 he was selected for the Management Intern Development Program and assigned to the New Production Reactor Program at the Department of Energy Headquarters in Washington, DC. As part of the Management Intern Development Program, he was given the opportunity to begin a Master of Science Program in Nuclear Engineering at the University of Tennessee a year after his assignment to the Oak Ridge Operations Office Advanced Reactor Program in September of 1989.

His present position is Program Manager in the Waste Management and Technology Development Division for the Department of Energy, Oak Ridge Operations Office.