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Operation

ROLLER COASTER

PROJECT OFFICERS REPORT—PROJECT 5.1b

STICKY WIRE EVALUATION (U)

A. L. Baietti, Project Officer

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Richmond, California 94804

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DEPARTMENT OF DEFENSE
Washington, D.C. 20301

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Washington, D.C. 20545

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ABSTRACT

Evaluation of data obtained by catching particles from a radioactive cloud on sticky wires is presented. This technique was used successfully in Operation Roller Coaster. Wire preparation and handling, activity measurement, data analysis, and preparation of activity contours for the clouds are discussed.

Results of a laboratory program to determine the correlation between ionization chamber measurements of the wires and the mass of plutonium deposited on them by the cloud are presented; conversion factors obtained by both radiochemical analysis and wipe data compared well.

The effect of altitude on air-ionization measurements is investigated both theoretically and experimentally.

Methods of using sticky wires to obtain more detailed information from radioactive clouds are discussed. Such information would include absolute variations in activity levels of the cloud as a function of the environmental conditions existing at its formation and during its subsequent movement. A laboratory-based developmental program that would investigate such areas as activity capture under

different environments, particle fractionation on the wires, and improved measuring equipment would be necessary.

Use of sticky wires in the areas of air pollution, pesticide dispersal, or simulated fallout are other possible applications.

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CHAPTER 1

INTRODUCTION

This report describes the evaluation of data obtained by suspending sticky wires in a balloon-supported array through which a radioactive cloud passed. The technique was used in Operation Roller Coaster, a joint US-UK program to determine the effects of non-nuclear explosions of plutonium-bearing devices.

One of the objectives of Roller Coaster was to determine activity profiles of clouds produced by the test explosions. In the past, fallout prediction models have generally made assumptions as to cloud uniformity and effects of the environment through which the cloud passes. It was hoped that data collection with sticky wires would test these assumptions, as well as answer other basic questions, such as particle size and distribution as a function of location.

A balloon-supported array of sticky wires and other types of air samplers was established for each test. After the cloud from the explosion had passed through the array, the wires were recovered and the collected radioactivity measured with an air ionization chamber. The information obtained by this operation was only crude data; a correlation between air-ionization currents in μμa and mass of plutonium deposited on the wires in μg had to be established. Also, accuracy and reproducibility of field data had to be determined to assure that the fallout contours did in fact properly identify the cloud profile. One serious question about the accuracy of the data centered about the fact that one ionization chamber consistently read lower than the other by a factor of 2 when exposed to the same Co-60 check source. The cause of this discrepancy, as well as the effect of such factors as temperature, altitude, humidity, and natural airborne radioactivity on the accuracy of the field measurements, had to be determined before maximum use of the field data could be made.

These problems resolved themselves into five objectives:

1. To determine the reason for the difference in readings from the two ionization chambers.
2. To evaluate the effect of such environmental factors as temperature, humidity, and altitude on the data.
3. To determine the response characteristics of the two ionization chambers used in the field.
4. To obtain a conversion factor between the ionization readings and the amount of plutonium deposited on the wires.
5. To prepare a fallout cloud profile for each test.

A laboratory program was undertaken to achieve these objectives. After the wires were recovered, most of them were measured in the ion chamber. Of those measured, some were wiped until they were activity-free and the wipes sent to various laboratories for analyses of Pu content. Others were retained and shipped to the Tracerlab/Richmond laboratory for further study. Theoretical calculations were made to determine the effects of the altitude difference between Tonopah and Richmond on ionization readings; local experiments were made to confirm these calculations. Finally, the conversion factor was checked by remeasuring wires in Richmond.

Standard wires, with a known amount of Pu on them, were then prepared and measured to obtain a rough correlation between ionization-chamber readings and μg Pu deposited on the wires. Wipe data were used to obtain the final μμa/μg Pu conversion factor. Finally, cloud contours were prepared for Double Tracks and Clean Slate I and II.

CHAPTER 2

PROCEDURES

2.1 WIRE PREPARATION AND ARRAYS

The wires were 22 inches long, approximately 1/16th inch in diameter, and made of brass. They were fastened to vertical lines of the balloon arrays with clips (see Figure 2.1). They were made sticky by application of a mixture of Vaseline and benzol.

There were 24 sticky wires per balloon line and 30 active [1] balloon lines per Arc B balloon curtain.

2.2 FIELD HISTORY AND DATA

Operation Roller Coaster was conducted on a portion of the Las Vegas Bombing and Gunnery Range and Sandia's Tonopah Test Range in southwestern Nevada. There were four tests in the series: Double Tracks and Clean Slate I, II and III.

Double Tracks. This event was fired at 02:55 PDT, May 15, 1963. There were two balloon arrays: one, on Arc B, Station 060, had 30 active lines, each of which supported 24 sticky wires. The array on Arc J had individual balloons located at Stations 034, 040, 052, 058, 064,

[1] An active line is one with samples on it. Though the curtain had 31 lines, only 30 were used to hold samplers.

070, and 076. Each balloon was rigged with 20 sticky wires located 50 feet apart along the balloon suspension cable. The measurements from these two arrays are shown in Tables A.1 and A.2, respectively, of Appendix A.

Clean Slate I. Clean Slate I was fired at 04:16 PDT, May 25, 1963. The Arc B balloon curtain was centered on Station 026. No other balloons were used. Clean Slate I. measurements are shown in Table A.3 of Appendix A.

Clean Slate II. This event was fired at 03:47 PDT, May 31, 1963. The Arc B balloon curtain was centered at Station 044. About 13 sticky wires were lost when the catenary cable broke. The results for the Arc B balloon curtain are shown in Table A.4, Appendix A. Data from three balloons that were located near ground zero are shown in Table A.5.

Clean Slate III. Clean Slate III was fired at 03:30 PDT, June 9, 1963. The Arc B curtain became inoperative before the test and could not be used. The data from two Arc J balloons are included in Table A.6, Appendix A. Data from two balloons that were located near ground zero are shown in Table A.7.

2.3 WIRE RECOVERY AND MEASUREMENT

At the end of each test the wires were unclipped from the curtain and placed in specially prepared sample-transport containers (see Figure 2.1). The containers were then placed in clean plastic bags for delivery to the Sample Processing Facility.

Upon receipt of the samples at the Receiving Dock of the Sample Processing Facility, a Sample Handling Record (SHR) was prepared (see Figure 2.2) with the balloon number and line and position location during the test noted. The outer bag was monitored with a portable alpha counter (PAC) to determine whether it was grossly contaminated. This was done to prevent gross contamination of the Receiving Room hoods and pass-through boxes and the subsequent cross-contamination of samples. Plastic bags reading more than 500 cpm were discarded and the samples placed in a clean plastic bag before being put into the pass-through boxes. The exterior contamination value was noted both on the Sample Handling Record form and on the bag itself for use in case cross contamination of samples in transport was later suspected. There was no reason to believe that this occurred.

The Sample Handling Record (SHR) number was marked on the clean outer bag and the sample container placed in a Receiving Room hood pass-through box. Personnel inside the Receiving Room removed the sample container from the hood's pass-through box.

The outer bag was then removed and the sample container placed in one of the two Receiving Room glove boxes.

The sample container was then passed into a glove box in the Sample Processing Section of the trailer.

The desired wire was removed from the box and labeled as to line number, position, and test, and then passed into the next glove box.

The sample was held in the gloved left hand and cut with snips to prevent the glove box from becoming contaminated. A plastic bag was located below the left hand to catch the wire when it was cut. In handling the wires, it was found advisable to have a tissue between the wire and the glove to reduce contamination and replacement of gloves. One end of the wire was snipped just above the 90° angle and the insulation removed. The other end was then snipped just below the 90° angle and its insulation removed. This resulted in one straight end and one bent end. The wire was then placed on the holding jig and monitored with a PAC.

The monitoring results were recorded on a Counting Data Sheet and the sample passed into the next glove box for measurement in the ionization chamber.

The straight end of the wire was placed in the anode clip of the ionization chamber and the bent end in the holder at the cap end. The cap was screwed on the unit and the instrument switched to the appropriate scale setting. Figure 2.3 shows a disassembled air ionization chamber. No measurements were recorded until the unit came to equilibrium. The micromicroampere ($\mu\mu a$) readings, date read, counter, etc., were recorded on the Counting Data Sheet.

Thirty of the wires with high activity levels were retained for future studies. The bent end of each of these wires was cut off and a cork stuck onto the ends. The corked wires were then put into cardboard mailing tubes and the tubes sealed with tape. The SHR number, the line and position location were marked on the outside of the tube. All of the tubes from a test were gathered and placed in a labeled plastic bag. The plastic bags were then placed in cardboard boxes for storage.

Fifty-six other wires were wiped with filter paper until there was only an insignificant amount of activity left on the wire. The wipes were then placed in dissolvable cellulose acetate envelopes and sealed with pre-numbered labels, showing wipe number, balloon line, and position. All the wipe samples from an individual test were then gathered together and placed in a labeled cardboard box for storage.

All other wires were discarded.

2.4 TRANSFER OF SAMPLES

The sticky wires saved from the field and the wipe samples were sent to the Naval Weapons Station in Concord, California, and from there to Tracerlab's Richmond (California) laboratory in the mailing tubes in which they had been stored. After the wires were remeasured at Tracerlab (see Section 2.5.4), they were repackaged in their same tubes to assure that if any activity fell off the wire in transit, either from the field to storage or from Tracerlab/West to the recipient, that the activity could be recovered and the total amount of activity that was trapped by the wire determined. These tubes were then sealed in plastic bags and placed in cartons with absorbent material to minimize shock and the resultant loss of activity from the wires.

The wipe samples in their labeled plastic bags were removed from their storage cartons and placed in shipping cartons for transfer to the laboratories performing the radiochemical analyses. Sample Description Forms (Figure 2.4) with sample location and test number accompanied these samples.

2.5 LABORATORY PROCEDURES

2.5.1 Ion Chamber Comparison. To resolve the difference in field readings between the two ion chambers, they were checked at the Richmond Laboratory. They were compared first with a Co-60 source and then with sticky wires (both field samples and standards).

The readings with the Co-60 source were made through a sheet of Plexiglas of the same thickness (3/16 inch) as the window of the glove box used in the field. All other field parameters were duplicated.

The wires were measured first in one chamber and then immediately transferred to the other and measured again.

This procedure minimized any potential effects resulting from changes in the environment, since the total time between measurements was only minutes.

2.5.2 Altitude Effect on Ion Chamber Operation. As a check on the theoretical calculations of the altitude dependence of the ion-chamber readings (see Appendix B), ion-chamber measurements were made on Mount Diablo (California) and Echo Summit (California). The ion chambers and sticky wire standards were placed in a car and driven up and down the mountains with measurements made at various altitudes. The test altimeter was referenced to local airport barometer readings. Altitude bench markers were used to confirm altimeter readings.

2.5.3 Sticky Wire Standards. To obtain a rough correlation between ion chamber readings and the amount of plutonium deposited on the wires, three types of sticky wire standards were prepared.

Electroplated Standards. Standard-length wires were placed into a plutonium-239 solution and an electric current applied. The plutonium was plated on the wire, which served as the cell anode.

Stippled Standard. Standard-length wires were heated, and predetermined amounts of plutonium-239, from a standard solution, uniformly deposited along the wire. The heat boiled off the carrier solution so that the plutonium adhered to the wire. Tapping and gentle wipe tests were made to determine the amount of plutonium that might come off the wire through normal and rough handling.

Dust Standards. Standard-length sticky wires were mounted in a box into which Monterey sand mixed with known amounts of plutonium was added. The box was shaken to uniformly distribute the contaminated sand over the wire. The standard was removed and the box washed down to recover the plutonium that had not adhered to the wires. Comparison of radiochemical analytical results of the initial solution and the residual activity determined the amount of activity deposited on the wire.

After the study was completed, representative wires were analyzed radiochemically and these results compared with the estimated wire activity levels.

2.5.4 Remeasurement of Sticky Wires. The tape covering one end of the shipping tubes was removed. The open end of the tube was then inserted in a glove box port and the sticky wire removed. Gloves were worn while holding the wires and strips of tissue paper used to minimize contamination of gloves and cross-contamination of wires. A background measurement using an uncontaminated wire was made in each chamber. The sticky wire was then placed in the chamber, measured, removed from the chamber, and a background measurement again made. Three measurements were made on each wire. The wire was then returned to its shipping tube, taken to the other glove box (where the second ion chamber was set up), and similar measurements made.

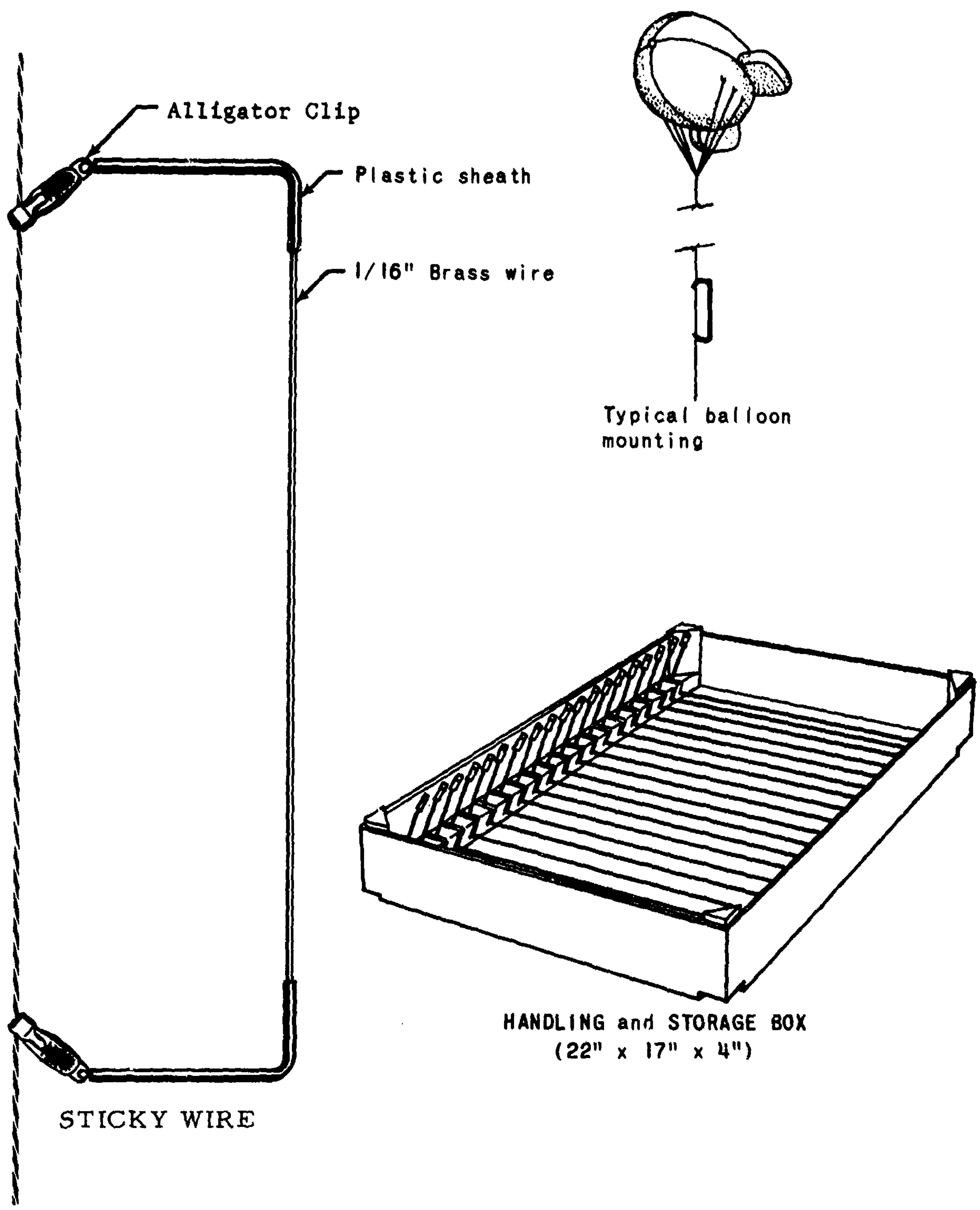

Figure 2.1 Sticky wire air sampler.

SAMPLE HANDLING RECORD

Date ______________ Sample No. 010155

Submitted by (Company Name) ______________
(Project Officer's Name) ______________ Project No. ______
Initiators Sample No. ______________

SAMPLE HISTORY

1. Type ______________
2. Original Location ______________
3. Test No. ______________

ACCEPTED FOR PROJECT 8.1A

WORK TO BE PERFORMED

INITIAL AND DATE WHEN EACH STEP IS COMPLETED

A. Receiving Room (SEE DIRECTION SHEET ______) NO ☐ YES ☐
 1. Normal Processing of Sample
 2. Sample Holder
  a. Discard ☐
  b. Decontaminate for Re-use ☐
  c. Wipe Test Result ______________
  d. Return to: Name ______________
   Location ______________
 3. Special Instructions ______________

B. Sample Handling Area (SEE DIRECTION SHEET ______) NO ☐ YES ☐
 1. Normal Processing of Sample
 2. Count ☐
  Monitoring Check ☐ Results ______________
 3. Special Instructions ______________
 4. Next Station
  High-Level Counting Room ☐ Low-Level Counting Room ☐
  Shipping Room ☐

C. High-Level Counting Room ☐ D. Low-Level Counting Room ☐
 1. Alphas Only ☐ Results ______ dpm
 2. ______ ☐ Results ______ dpm
 3. Counting Time ______________
 4. Accuracy Desired ______________
 5. Special Instructions ______________

E. Shipping Instructions
 1. Samples
  a. Method
   Normal Freight ☐ Air Express ☐ Special Delivery ☐ ☐
  b. Persons Name ______________
  c. Company Name and Address ______________
 2. Data
  a. Persons Name ______________
  b. Company Name and Address ______________
 3. Special Instructions ______________

General Comments ______________

Figure 2.2 Sample handling record.

Figure 2.3 Disassembled air-ionization chamber. (DASA-139-01-TTR-63)

SAMPLE DESCRIPTION FORM

Sample Handling Record ____________________

Sample Type: ________________ Test No. ____________________

Stage No: __________ Sample Location:

Arc _______

Station _______

Estimate of Sample Activity
(as measured in the field)

☐ 0-1 d/m

☐ 1-10 d/m ☐ 10^3-10^4 d/m

☐ 10-100 d/m ☐ 10^4-10^5 d/m

☐ 100-10^3 d/m ☐ $>10^5$ d/m

____
Project 5.1A
(Initial & Date)

Comments: ____

____

____

____

Figure 2.4 Sample description form.

CHAPTER 3

RESULTS

3.1 ION CHAMBER COMPARISON

Two ion chambers were used, both in the field and laboratory, for measuring the activity deposited on the sticky wires. One chamber constantly read about twice as high as the other during the field operations. The difference in the field readings was found to be caused by one chamber's being farther away from the check source than the other. Figure 3.1 shows that the center of the ion chamber is not in the middle of the supporting base. In the field the chambers were set up so that the center of one chamber was 2-1/2 inches from the window and the center of the other was 1-1/2 inches from the window (i.e., one chamber was oriented at 180° with respect to the other). When either chamber was set up so that its centerline was 2-1/2 inches from the Plexiglas, it read 22 μμa when exposed to the check source. When the chambers were turned 180°, both read 36 μμa. These differences correspond to those observed at Tonopah (14 and 25 μμa).

The discrepancy in ion chamber readings observed in the field was not present in laboratory measurements. Although there were minor differences (about 5%) between chamber readings made on the stippled wire standards, no clear pattern was visible (see Table 3.1).

3.2 ALTITUDE EFFECT ON ION CHAMBER OPERATION

The details of the theoretical analysis of altitude effects on the ion chamber readings are present in Appendix B. The calculated (theoretical) ratio of readings at Richmond to readings at Tonopah was 1.23.

To check the calculations in the theoretical study, empirical measurements were made with an ion chamber and stippled wire standards at various altitudes in the vicinity of Richmond. One series of measurements was made on Mount Diablo, the other on Echo Summit, California. Some measurements were also made at intermediate locations. Altitude measurements were combined with sea-level barometric pressures and corrected for local temperatures and humidity to obtain the local density of air in mg/cm^3. Figure 3.2 is a plot of ionization chamber readings for two stippled wire standards versus air density obtained in the experimental study. The altitudes at which the measurements were made are also shown in the figure. The empirically determined ratios are:

Sample S540: Richmond/Tonopah ratio = 245/208 = 1.18

Sample S536: Richmond/Tonopah ratio = 13.05/11.5 = 1.14

The value obtained from Sample S536 is not as accurate as from Sample S540 due to the lower count rate, i.e., the greater effect of background on the measurements used to obtain it.

Both the theoretical and experimental values are in good agreement with those obtained by remeasuring field samples in Richmond (see Section 3.4 and Table 3.3).

3.3 STICKY WIRE STANDARDS

Of the three types of samples prepared (electroplated, stippled, and dust-type), only the dust-type gave truly accurate data in the sense of showing the effects of particle size and particle distribution on the measurements. The electroplated standards were unacceptable. The stippled standards provided qualitative data; also, they were much easier and safer to handle than the dust-type standards.

3.3.1 Electroplated Standards. Electroplating is the standard method for producing stable plutonium standards; however, the wire standards produced by this method were unacceptable as the activity deposited on them was orders of magnitude below that needed for this experiment. Presumably, the electroplating process was not correctly performed.

3.3.2 Stippled Standards. One of the first questions to be resolved regarding stippled standards was the adherability of the Pu to the wires. Two tests were conducted: A stippled wire with 1.2×10^6 dpm Pu deposited on it was tapped five times vertically on a piece of filter paper to simulate actual handling. No alpha activity was detected on the paper. The wire was remeasured in an ion chamber; there had been no change in its activity. This proved that normal handling of the stippled standards would not dislodge the Pu, thereby changing the activity level of the standard.

The second test was made by placing a piece of filter paper loosely around a 1.2×10^6 dpm Pu wire standard and running it down the wire. The wire was then rotated 180° and the wipe made in the upward direction. The filter paper when counted had removed 110 dpm or 0.01% of the activity with this most vigorous (and unrealistic) handling. The wire was remeasured in ion chambers and showed no change in reading. It was therefore decided that the proposed (and even more severe) handling of the stippled standard would not affect the deposited activity.

Six stippled standards were prepared to cover the complete range of field readings. The characteristics of these wires are shown in Table 3.1.

Environmental factors such as temperature and humidity were not considered and may have played a role in the variation of the chamber readings. It is our opinion that human factors (who read the instrument, how long they waited for equilibrium and whether or not they remembered their previous reading) had a greater effect. These factors were especially significant for the lower level samples since the meter needle deflections were so erratic that interpolation between the maximum and minimum deflection was necessary in most cases.

3.3.3 Dust-Type Standards. The dust-type standards clearly pointed up the effect of particle distribution on the wire measurement. Standard 570, which had agglomerated particles, had a conversion factor (dpm/$\mu\mu$a) 2-1/2 times higher than Standard 572 (see Table 3.2), on which the activity was uniformly dispersed and on which there was little self-shielding. As the purpose of this test was only to verify this effect, no other experiments were conducted on this phenomenon.

3.4 REMEASUREMENT OF STICKY WIRES

The results of remeasuring thirty sticky wires saved from the field phase of the operation are shown in Table 3.3.

Twenty-nine of the thirty sticky wires remeasured at Richmond had a reading close to what would be expected on the basis of the Tonopah readings and the Richmond-to-Tonopah conversion factor. It is our opinion that the sample with the anomalous reading (the wire in Line 12, Position 18, Table 3.3 was labeled 120 μμc at Tonopah but read 33 μμa in Richmond) was mislabeled in the field. This opinion is based chiefly on the fact that the high reading is not consistent with neighboring measurements. In fact, the reading may be discarded on the basis of either of two statistical criteria applicable if normally distributed readings are assumed. According to the gross error test (Reference 1) the value may be discarded at the 1-percent significance level. In addition, the deviation of the value from the sample mean (here assumed equivalent to the true mean) is more than four standard deviations so that there is less than 0.02 percent chance that the point is actually part of the population (Reference 2). In these calculations the ratios obtained from the measurements of all sets of wires have been considered as belonging to a single population, because the ratios should depend only upon atmospheric conditions, and not upon the origin of the wires.

When the ratio obtained for Line 12 Position 18 is ignored, the average ratio is 1.15, with a standard deviation of 0.18. This value is in good agreement with the theoretical value of 1.23 and the experimentally determined value of 1.18 (see Section 3.2). This good agreement shows that there was little, if any, activity lost from the wires during their movement from the field to storage and thence to recounting.

3.5 RADIOCHEMICAL ANALYSIS OF STICKY WIRES

Only 10 of the 30 sticky wires saved from the field and remeasured have been analyzed radiochemically to this time. An additional 12 wires have been provided to the UK for study and analysis,but results on these samples have not yet been received. The results of the analysis are shown in Table 3.4 and summarized in Table 3.5.

Because of the small number of samples analyzed, a statistical analysis of the data is not very fruitful, in particular since some question may be raised whether the data belong to the same population.

3.6 STICKY WIRE WIPE RESULTS

The results from the radiochemical analyses of the sticky wire wipes are shown in Table 3.6 and summarized in Table 3.7.

3.6.1 Double Tracks Arc B Balloon. In analyzing the Arc B balloon data in Table 3.6, there is no apparent trend in the conversion factors (dpm/$\mu\mu$a) when the radiochemically determined activity level is above 5×10^4 dpm. The average conversion factor for the 15 samples with greater than 5×10^4 dpm of activity is 1.2×10^4 dpm/$\mu\mu$a with a standard deviation of 0.4×10^4 dpm/$\mu\mu$a. Whether the data from L1P1 and L1P18 (which have radiochemically determined activities below 5×10^4 dpm) must be discarded is difficult to decide. Application of the gross error test allows them to be discarded at the 1% significance level as not belonging to the same population as the rest of the data.

3.6.2 Double Tracks Arc J Balloon. In reviewing the Double Tracks Arc J data in Table 3.6, the radiochemistry data show low activities. It was indicated in the discussion of the Double Tracks Arc B data that the accuracy of the field measurements at these low activity levels was rather poor. It is, therefore, not too surprising that the conversion factors vary considerably. The lowest field reading of 0.2 $\mu\mu$a is only about two to three times a quite variable background, so that the conversion factors for Line 1 Positions 17, 18, and 19 are quite unrealistic. The average value of the remaining conversion factors is 0.76×10^4 with a standard deviation of 0.52×10^4. Clearly the mean is not significantly different from that found in the Arc B data.

A review of a plot of the field measurements (see Figure 3.3) shows that the hottest portion of the cloud either missed the curtain completely or else just passed through Line 1 on the right side. Though a progressive increase of readings is visible through the figure, no overall pattern is discernible.

3.6.3 Clean Slate I Arc B Balloon. In evaluating the Clean Slate I Arc B balloon data (see Table 3.6) it is heartening to note that the mean and median conversion factors are both 1.0×10^4 dpm/μμa with a standard deviation of 0.2×10^4; this indicates that the data are symmetrically distributed about the mean, which is one requirement for the normal distribution that has been assumed all along. It is to be noted that (1) none of the measurements (μμa) of the wires were so low that background effects were a major problem, and (2) the balloon curtain was positioned so that the most active portion of the cloud was being sampled.

3.6.4 Clean Slate II Arc B Balloon. In evaluating the Clean Slate II data, two points that must be remembered are that (1) only 7 wires were wiped, and (2) the highest field measurement on these wires was less than the lowest one from Clean Slate I. This low measurement is due to the fact that the most active portion of the cloud missed the curtain. With the wires reading closer to background, minor instrument fluctuations become more significant. The mean and median of the data were both 1.5×10^4 dpm/μμa with a standard deviation of 0.6×10^4. Although it may appear a correlation exists between the activity levels and the conversion factors, the data are insufficient to either prove or disprove it. In view of the large variations in the conversion factor obtained from the data discussed above and the lack of correlation, we are inclined to assume that the apparent possible correlation here is accidental.

3.6.5 Clean Slate III Arc J Balloon. The number of wipes analyzed from the Arc J balloons used during Clean Slate III is insufficient for drawing any conclusions. However, to give some indication of the amount of deposited Pu we have used a mean conversion factor of 2.4×10^4 dpm/μμa.

3.7 CONVERSION OF FIELD MEASUREMENTS

Field measurements of the sticky wires for Double Tracks Arc B and Arc J, Clean Slate I Arc B and Clean Slate II Arc B balloon curtains are shown in Tables A.1 through A.4 of Appendix A. Also shown are the field measurements for the British balloons at ground zero for Clean Slate II and III and the Arc J balloons for Clean Slate III (Tables A.5 through A.7). The field measurements have been converted to μg Pu by multiplying by the appropriate conversion factor, namely the experimental dpm/μμa times the constant 15 μg Pu/μc divided by the constant 2.2×10^6 dpm/μc. A conversion factor of 8.2×10^{-2} μg Pu/μμa (1.2×10^4 dpm/μμa) was used for all Arc B data. Conversion factors of 17×10^{-2} μg Pu/μμa (2.4×10^4 dpm/μμa) and 5.6×10^{-2} μg Pu/μμa (0.8×10^4 dpm/μμa) were used for the Clean Slate II Arc J and Double Tracks Arc J data, respectively. For the British balloons at ground zero (Clean Slate II and III) μg Pu data based on radiochemical analysis of dust Standard 570 was used. This factor was 0.48 μg Pu/$\mu\mu a$ (7.0 x 10^4 dpm/$\mu\mu a$). This factor was used because it was felt that at ground zero the particles could be large with considerable self-shielding; Standard 570 duplicated this condition.

3.8 ACTIVITY CONTOURS

Activity contours for Double Tracks, Clean Slate I and Clean Slate II Arc B sticky wire arrays are shown in Figures 3.4 through 3.6. The profile contours were chosen to emphasize the significant changes in observed Pu deposited on the sticky wires.

For Double Tracks Arc B data, shown in Figure 3.4, three distinct areas can be defined: (1) 0.1 to 0.9 μg Pu, (2) 1.0 to 9.9 μg Pu, and (3) 10 to 22 μg Pu (the highest value observed). It might also be surmised that a sizable portion of the cloud may have missed the balloon curtain. At least the profile shown in Figure 3.4 indicates that some portion of the cloud passed to the left (viewed from GZ) of the array. Careful examination of Table A.1 will show that more detail can be given on the variation of concentrations within the cloud, as well as where the actual outer profile of the cloud should be drawn. The data also indicates that there may be isolated patches of activity, particularly on the upper portions of Lines 17 and 18. However, in the interest of clarity of presentation, these details were not shown. Figure 3.4 and the data in Table A.1 clearly illustrate the amount of detail on a cloud profile that can be obtained using the sticky wire sample array.

For Clean Slate I, Figure 3.5 illustrates very dramatically the difference in cloud shape and activity distribution that can be obtained. Here again, three levels of concentration were defined: (1) 0.1 to 0.9 μg Pu, (2) 1.0 to 9.9 μg Pu, and (3) 10 to 13 μg Pu (the highest value observed). The data in Table A.3 provides more detail on the concentration distribution. It is interesting to note that the highest concentration observed in Clean Slate I is much less than for Double Tracks and the size of this hot patch is indeed much smaller. Certainly any fallout prediction model would have to accept the difference in activity concentration distribution that is shown in Figures 3.4 and 3.5 if reliable fallout contours are to be defined. Figure 3.5 also illustrates that the Arc B array was positioned so as to intercept the entire radioactive cloud (a direct hit).

The data from the Arc B array of sticky wires for Clean Slate II is not very good. In general, the levels observed were much lower than for Double Tracks and Clean Slate I. It seemed practical to only show two areas of activity concentration: (1) 0.01 to 0.09 μg Pu, and (2) 0.1 to 0.4 μg Pu (highest value observed). Here, isolated patches are clearly shown. The data in Table A.4 clearly shows this to be the case. It would appear that the array only intercepted the very outer edge of the radioactive cloud. Even so, Figure 3.6 does again illustrate the preciseness of profile definition that can be made using the sticky wire array.

TABLE 3.1 ION CHAMBER COMPARISON

Standard No.	Prepared dpm	Measurement** Chamber No. 1 (μμa)	Chamber No. 2 (μμa)	Deviation* (%)	Conversion Factor $\frac{dpm}{(av)\mu\mu a} \times 10^3$
Bkg		0.05	0.05	100	
1	1.45×10^2	0.045	0.06	30-50	2.9***
2	1.45×10^3	0.20	0.25	30	7.0
3	2.9×10^4	4.1	3.95	3	7.1
4	1.16×10^5	14	13.75	3	8.6
5	1.2×10^6	245	245	2	4.8
6	1.3×10^7	2180	2160	2	5.9
					6.1
				Mean	6.7

* Variation in readings observed as compared to the average measurement recorded in Cols. 3 & 4.

** Corrected for background

*** Variations in background and the small current generated by the sample make this value less accurate than the others; consequently it is not included in computing the mean value.

TABLE 3.2 ANALYSIS OF STANDARDS

	Standard No.	Prepared dpm	Analyzed dpm	Difference	Conversion Factor (10^4 dpm/μμa)
Stippled	517	2.9×10^4	2.8×10^4	-4%	0.7
	537	1.3×10^7	1.4×10^7	+7%	0.6
Dust Type	570	1.1×10^6	8.11×10^5	-26%	7.0
	572	1.75×10^6	4.11×10^5	-77%	3.0

TABLE 3.3 STICKY WIRE MEASUREMENTS

Sticky Wire Location		Richmond Measurements $(\mu\mu a)$			Field Measurements $(\mu\mu a)$		Average Ratio
		Chamber #1	#2	Avg	Chamber #1	#2	
Double Tracks Arc B Balloon							
Line	Pos.						
4	8	140	140	140	115		1.22
4	9	262	272	267	205		1.30
4	11	291	300	296	230		1.29
4	15	152	165	159	140		1.14
5	7	97	105	101	85		1.19
5	10	234	250	242	190		1.27
5	13	201	200	200	170		1.18
6	10	295	295	295	270		1.09
7	13	116	115	116	105		1.10
7	14	182	175	179	155		1.15
12	18	33	33	33		120	0.275**
12	20	66	66	66		65	1.02
14	20	47	44	45		38	1.18
18	23	31	31	31	30		1.03
21	23	26	23	24	21		1.14
4	9*	266	260	263	205		1.28
Double Tracks Arc J Balloon							
Line	Pos.						
1	11	28	27	27.5	23		1.19
1	13	40.5	40	40	35		1.14
3	14	40	38	39	36		1.08
4	15	11	10.5	10.75		8.5	1.27
Clean Slate I Arc B Balloon							
Line	Pos.						
10	7	49	49	49		42	1.17
11	7	34	35	35	35		1.00
12	6	42	42	42		38	1.11
13	5	59	60	60	60		1.00
13	6	92	100	96	94		1.02
14	6	132	145	138		125	1.10
17	6	140	149	145		140	1.04
18	6	165	172	169	150		1.13
19	5	158	160	159		135	1.18
19	7	160	166	163		140	1.31
20	70	180	200	190	155		1.23

* Results of recheck at end (first and last sample counted)

** For a discussion of this anamolous value see Section 3.4.

TABLE 3.4 REMEASURED STICKY WIRE RADIOCHEMICAL ANALYTICAL RESULTS

Test	Location*	Radiochemistry Results (10^5 cpm)	Field Count (μμa)	Conversion Factor ($10^4 \frac{dpm}{\mu\mu a}$)
Double Tracks Arc B Balloon	L12P20	6.81	65	1.05
	L7P13	11.2	105	1.07
	L4P8	7.62	115	0.66
	L4P9	12.7	205	0.62
	L5P7	7.50	85	0.87
Double Tracks Arc J Balloon	L1P13	2.87	35	0.82
	L4P13	0.99	8.5	1.16
Clean Slate I Arc B Balloon	L13P5	5.58	60	0.93
	L13P6	11.5	140	0.82
	L19P5	14.6	135	1.08

* Line No. Position No.

TABLE 3.5 SUMMARY OF RADIOCHEMICAL ANALYTICAL RESULTS

Test and Location	No. of wires Analyzed	Mean (10^4 dpm/μμa)	Range (10^4 dpm/μμa)
Double Tracks Arc B Balloon	5	0.85	0.62 - 1.07
Double Tracks Arc J Balloon	2	0.99	0.82 - 1.16
Clean Slate I Arc B Balloon	3	0.94	0.82 - 1.08
TOTAL	10	0.91	0.62 - 1.16

TABLE 3.6 STICKY WIRE WIPE DATA

Test		Sample Handling Record Number	Radiochemistry (10^4 α dpm)	Field Measurement (μμa)	Conversion Factor (10^4 dpm/μμa)
Double Tracks Arc B Balloon					
Line	Pos.				
1	1	5320	3.6	0.6	6.0
1	4	5320	22	19	1.2
1	5	5320	115	115	1.0
1	6	5320	176	160	1.1
1	7	5320	140	66	2.1
1	11	5320	280	320	0.9
1	16	5320	40	30	1.3
1	18	5320	5	1	5.0
3	6	2475	12	7.2	1.7
3	7	2475	56	70	0.8
3	8	2475	106	100	1.1
3	9	2475	190	200	1.0
3	15	2475	59	43	1.4
3	20	2475	16	9.2	1.7
12	19	2121	104	100	1.0
14	21	2122	71	60	1.2
18	24	2123	12	12	1.0
Double Tracks Arc J Balloon					
Line	Pos.				
1	12	5306	8.5	28	0.3
1	15	5306	10	40	0.3
4	12	5335	0.7	8.2	0.09
5	1	5338	0.1	0.2	0.5
5	2	5338	0.6	1.2	0.5
5	3	5338	3.5	2.5	1.4
5	4	5338	6.8	5.0	1.4
5	5	5338	5.1	4.4	1.2
5	7	5338	2.8	2.4	1.2
5	10	5338	0.2	0.3	0.7
5	17	5338	0.0015	0.4	0.004*
5	18	5338	0.0018	0.2	0.009*
5	19	5338	0.0030	2.6	0.001*

* The great disparity between these values and the rest of the balloon wipe data, as well as their low field measurement, makes their accuracy and validity suspect.

TABLE 3.6 (Continued)

Test		Sample Handling Record Number	Radiochemistry (10^4 ε dpm)	Field Measurement (μμa)	Conversion Factor (10^4 dpm/μμa)
Clean Slate I Arc B Balloon					
Line	Pos.				
11	6	5294	32	34	1.0
11	22	5294	3	3.1	1.0
12	5	5284	4.1	7	0.6
12	7	5284	61	60	1.0
12	9	5284	27	23	1.2
12	19	5284	4.7	5	1.0
13	9	5298	59	54	1.1
14	18	5297	13	10	1.3
15	5	5296	97	76	1.3
15	6	5296	1.1	120	0.9
15	7	5296	64	90	0.7
17	5	5299	31	42	0.7
19	6	5342	260	180	1.4
20	6	5341	190	160	1.2
20	15	5341	26.5	30	0.9
23	6	5301	180	150	1.2
Clean Slate II Arc B Balloon					
Line	Pos.				
3	22	5318	0.56	0.9	0.6
4	9	5317	2.5	1.7	1.5
4	22	5317	2.1	1.1	2.0
5	11	5316	2.6	2.4	1.1
5	24	5316	5.1	2.2	2.3
6	11	5315	1.9	1.5	1.3
6	12	5315	3.7	2.0	1.9
Clean Slate III British Balloon					
Line	Pos.				
3	1	5370	13	4	3.2
3	2	5370	1.1	0.7	1.7
3	13	5370	2.1	1	2.2

TABLE 3.7 SUMMARY OF STICKY WIRE WIPE DATA

Test	Double Tracks		Clean Slate I	Clean Slate II	Clean Slate III
Location	Arc B Balloon	Arc J Balloon	Arc B Balloon	Arc B Balloon	Arc J Balloon
No. of Wires Analyzed	17	13	16	7	3
Mean (10^4 dpm/μμa)	1.7 1.2*	0.59 0.8*	1.0	1.5	2.4
Median (10^4 dpm/μμa)	1.2	0.7	1.0	1.5	2.2
Range (10^4 dpm/μμa)	0.8 to 6.0	0.001 to 1.4	0.6 to 1.4	0.6 to 2.3	1.7 to 3.2

* Obtained by excluding the questionable data.

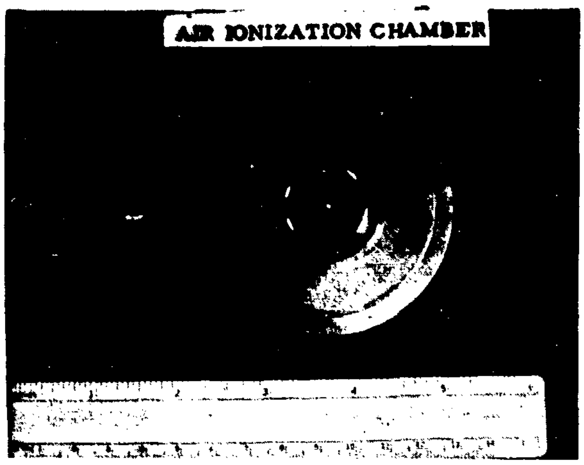

Figure 3.1 Air-ionization chamber.
(Tracerlab photo)

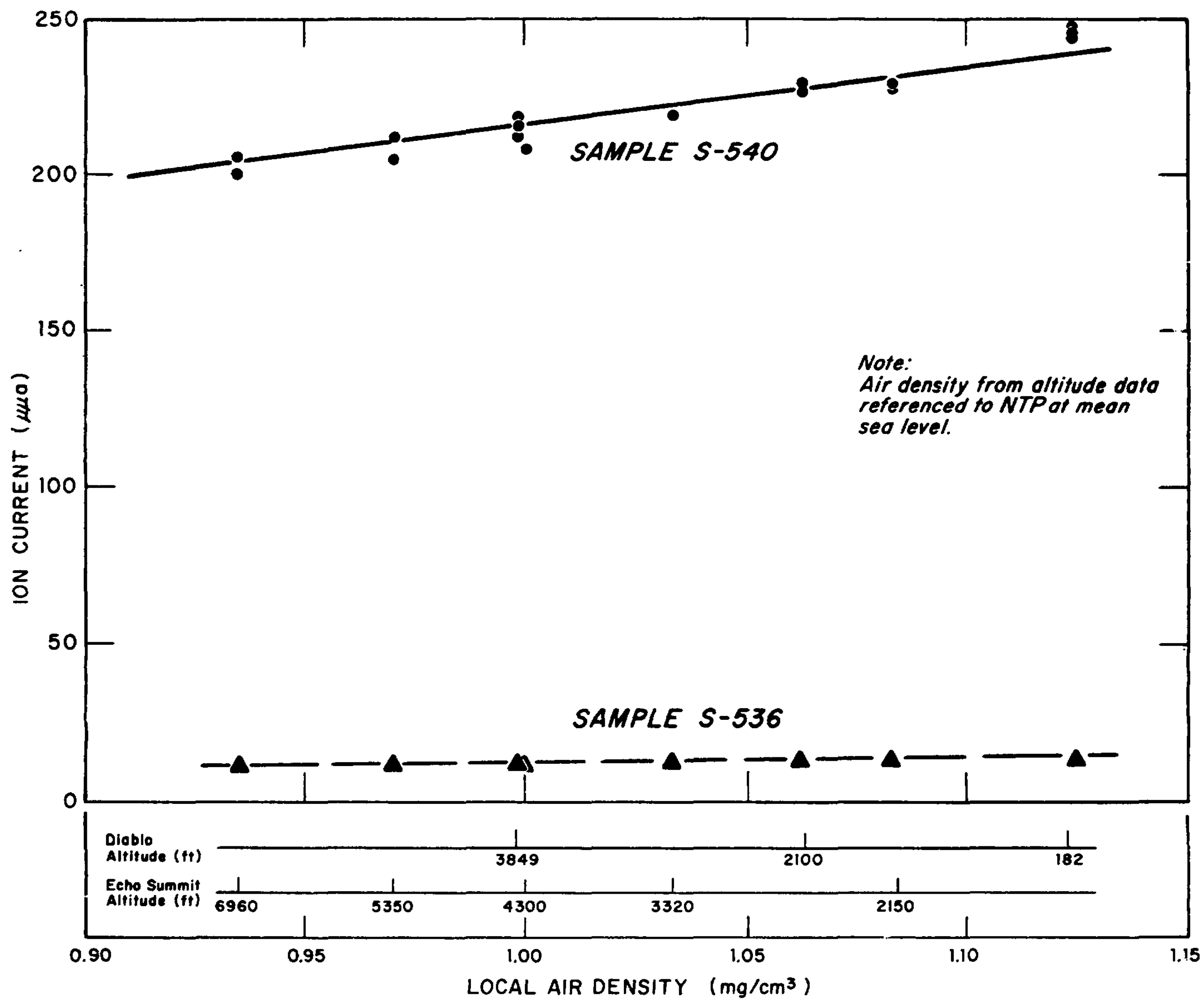

Figure 3.2 Ion chamber current versus air density.

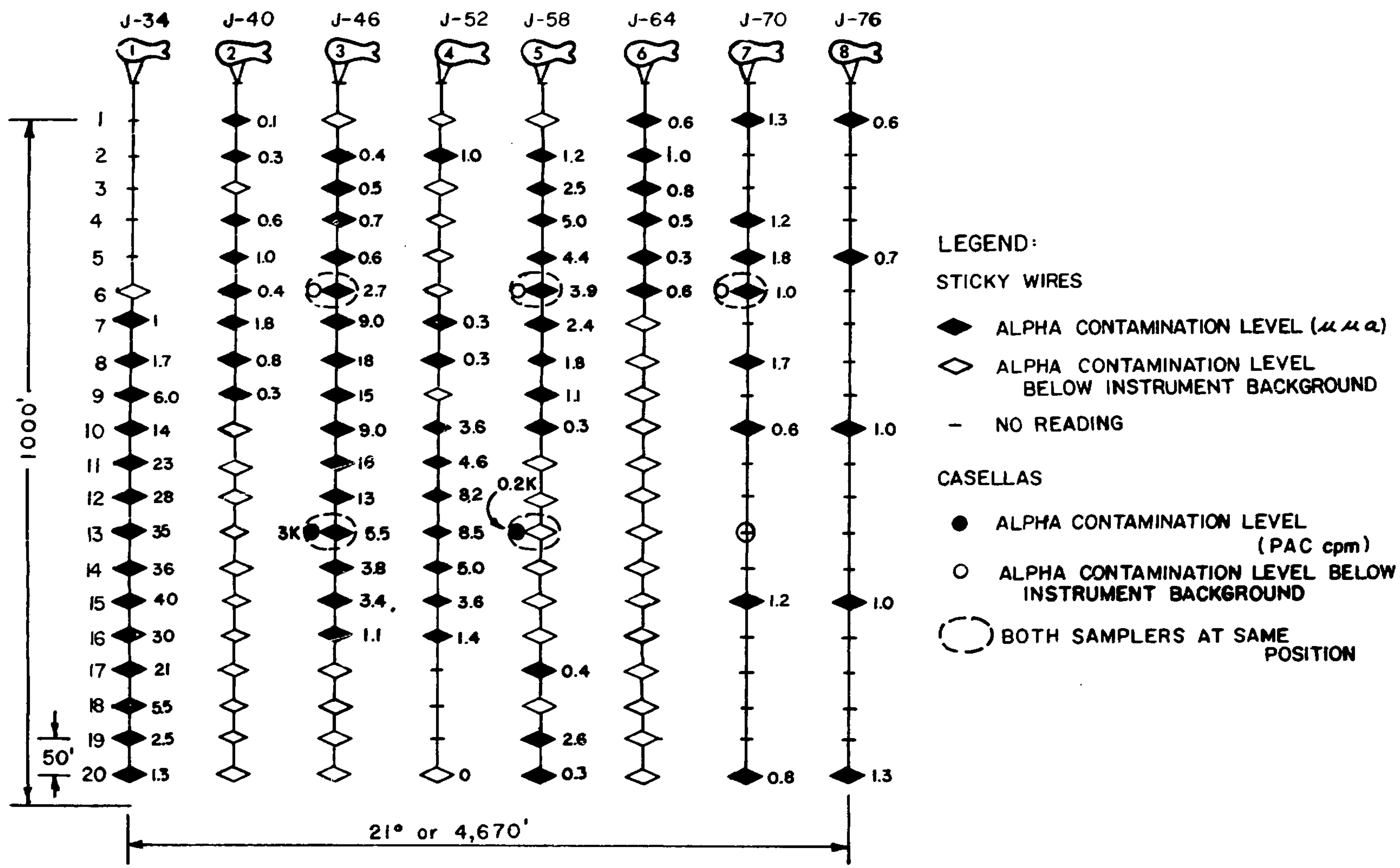

Figure 3.3 Double Tracks monitoring results on UK balloons.

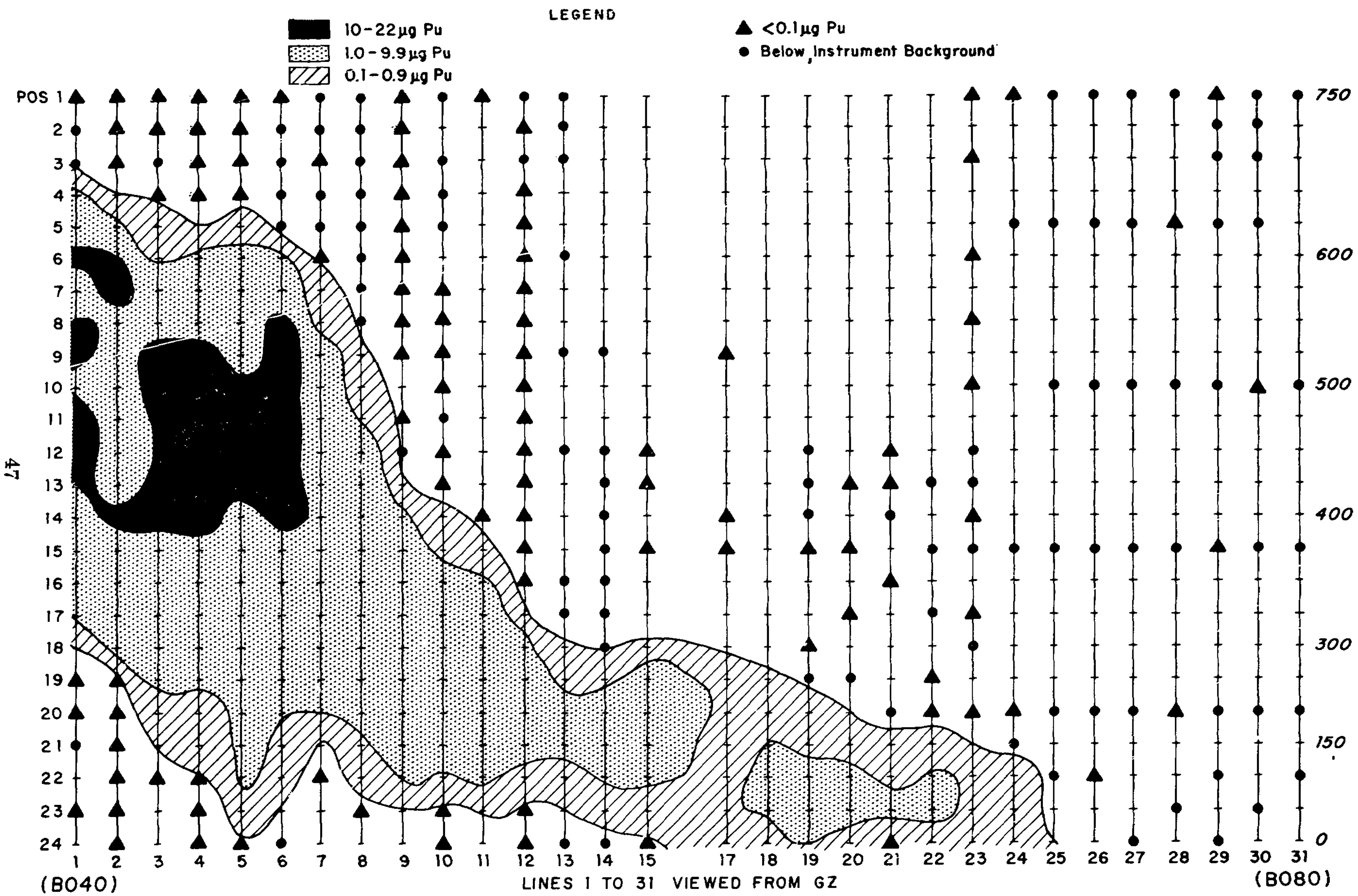

Figure 3.4 Profile of Double Tracks cloud.

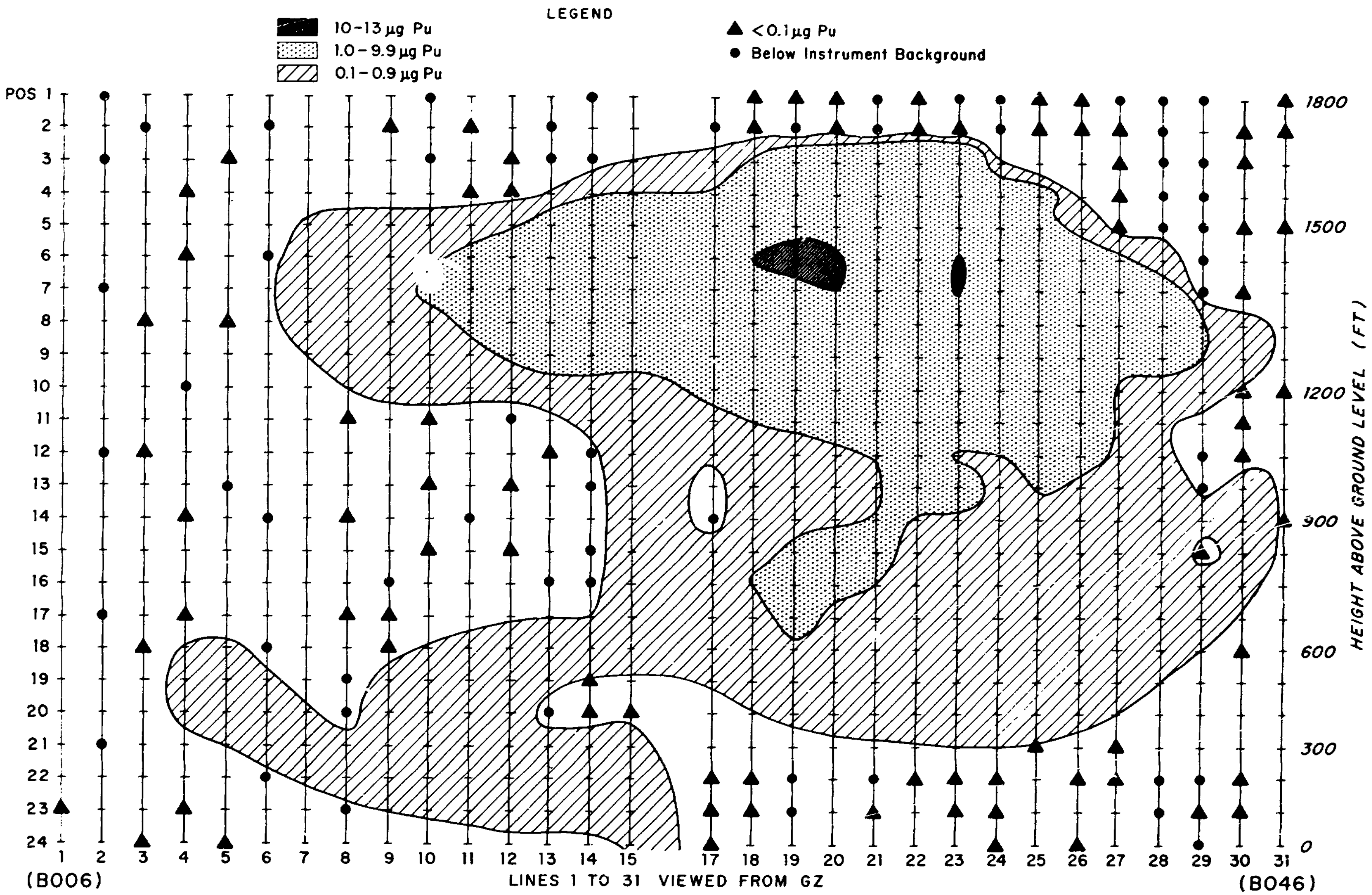

Figure 3.5 Profile of Clean Slate I cloud.

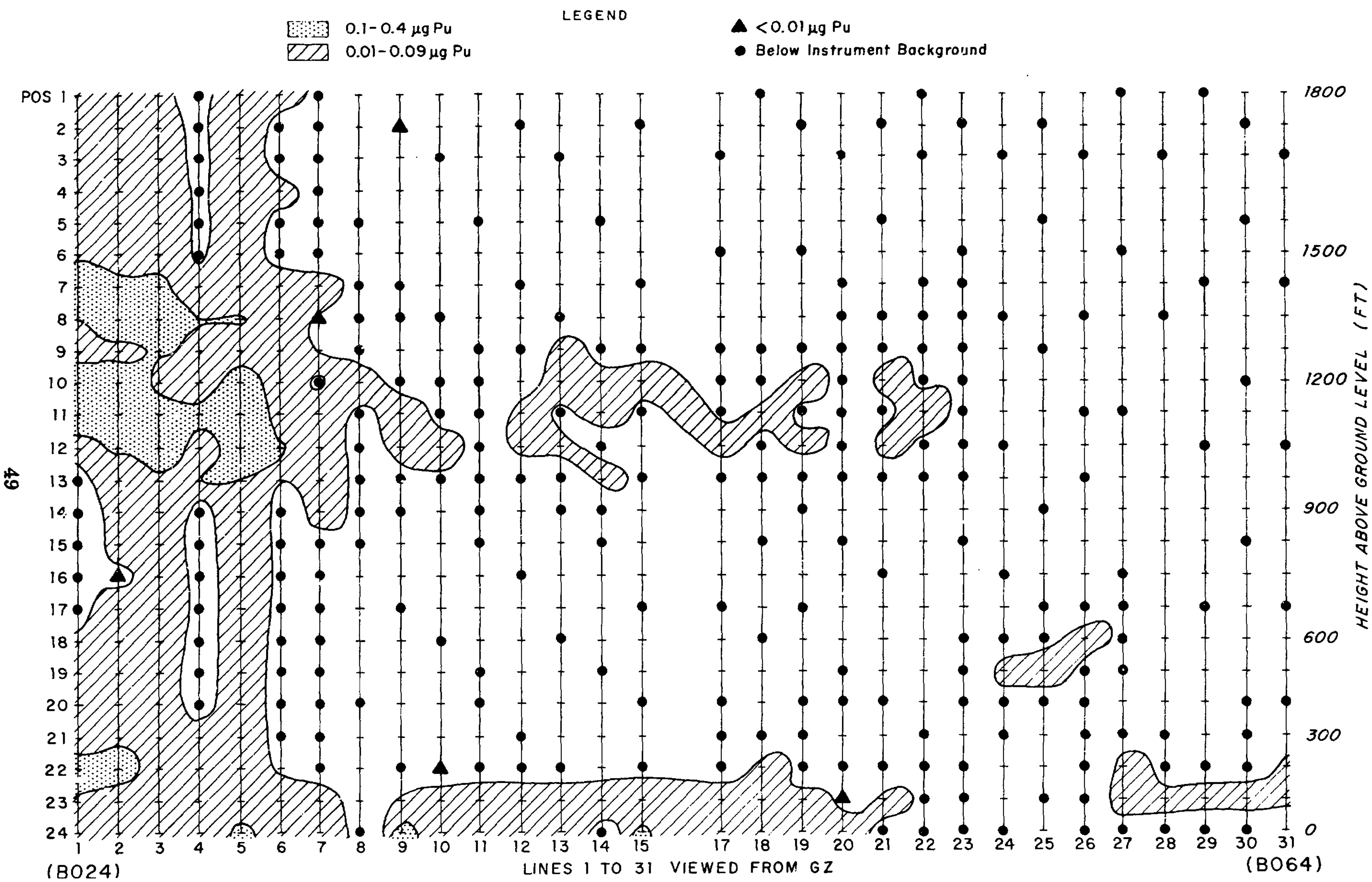

Figure 3.6 Profile of Clean Slate II cloud.

CHAPTER 4

DISCUSSION

4.1 ALTITUDE EFFECT ON ION CHAMBER OPERATION

The conversion factor obtained from the theoretical study compares favorably with the empirical one. Results of this study, shown in Appendix B, show conclusively that air ionization data from any location can be converted to standard air density data and compared with data taken under other conditions by simply multiplying by the correct conversion factor. This value will be ~±10% from the true value. Figure 3.2 shows the relationship between ion chamber current and air density obtained in this study.

The two standards used were selected to represent the higher and lower ion chamber readings encountered in the field. The purpose of the test was to verify that conversion of field data to standard conditions was possible over a broad range of instrument response, though obviously the accuracy would not be as good when samples approached instrument background.

4.2 CONVERSION FACTOR

We have more confidence in the radiochemical data from wipes than from complete wire dissolution because (1) there was a greater number of samples, and (2) the results were from four different laboratories rather than from one. For these reasons, the wipe data for the Arc B arrays in Double

Tracks and Clean Slate I and II were chosen as the basis for the conversion factor.

There is a question as to whether these three sets of conversion factors belong to the same population. Statistical tests applied to the means and to the standard deviations do not reject such a hypothesis, but a statistical test does not unequivocally state that a hypothesis is definitely true. In view of the relatively large variations in the conversion factors and the resulting large standard deviations the sets of results overlap, and we have therefore assumed that the three sets belong to the same population. Recalculation on this basis yields a mean conversion factor 1.2×10^4 dpm/μμa with a standard deviation of 0.4×10^4 dpm/μμa. This is the value of the conversion factor we have used.

4.3 DATA EVALUATION

In evaluating the Roller Coaster sticky wire data as a whole, the following general observations can be made:

(1) The data have proved that fallout clouds are not uniform but have regions of high and low concentrations of activity (see Figures 3.4, 3.5, and 3.6).

(2) Contamination variations of 1000 and more occurred across the cloud profile.

(3) Except for near background samples (less than 1 μμa), reproducibility of readings is ±10%.

(4) Field measurements of 0.1 to 0.5 μμa above background should be viewed with caution due to variations

in instrument background.

(5) The number of cloud profiles that can be drawn from the field data is limited only by the precision of the measurements. The contours that were drawn are only intended to show orders-of-magnitude difference and the non-uniformity of the cloud.

Based on the sticky wire wipe data and the radiochemical analysis of the 10 remeasured wires, the field data can be converted to activity levels to within a factor of two. The portion of the error due to chemistry and that due to wire measurement cannot be assessed with certainty at this time. The radiochemical data from wipes are probably correct to within ±5%. The major portion of the variability is probably caused by variations in the particle size distributions and particle loadings on the wires coupled with the short range of alpha particles in solids.

It should be pointed out that the sticky wire array is a tool to obtain data on the details of fallout clouds. To obtain truly significant cloud data, the variation in activity concentration in the cloud, particle size and distribution, and how all these characteristics vary in time and space must be known. Since many of these factors are almost completely uncertain (perhaps even by orders of magnitude), it is highly inconsistent to attempt a high degree of refinement of sticky wire results. Certainly statistically treatments can be made. Precision and accuracy of data can be assessed. However, if we concentrate on this aspect of the tool, we may lose sight of more important factors that are less well known. After all, the final result of fallout cloud studies is to be able to make accurate forecasts of where fallout will go and what, if any, will be the hazard to man. The sticky wire is a new and important tool that can be used in the study of how we can best achieve this end result. However, the sticky wire is not an end unto itself. Therefore, the data it collects must be kept in perspective with the final results to be achieved.

4.4 STICKY WIRES AS AN ANALYTICAL TOOL

In this section we discuss sticky wires as an analytical tool using Roller Coaster experience to highlight key points. In discussing sticky wires, one must consider the wire's preparation, placement, handling and measurement, the measuring system, and the data produced.

4.4.1 Sample Preparation. The adhesive formulation (benzol and Vaseline) has been chosen for maximum collection efficiency. It must be remembered that this efficiency is a function of the environment (temperature, humidity, etc.) and that an adhesive designed for a warm, dry climate might be totally inadequate for a cold, humid location. The distribution of the adhesive on the wire and between wires must be approximately uniform or the adhesive characteristics will vary (i.e., the quantity deposited on the wire will be dependent on the amount of adhesive and not the activity in the air).

4.4.2 Pretest Handling. The wires must be handled with care before the test or the wires might be bared (adhesive removed); become loaded with dust or dirt and efficiency reduced; or if improperly attached, fall off during the test.

4.4.3 Location of the Array. Unless the array has been properly positioned before the test, the data collected may be of little value. The Arc B balloon curtain used during Double Tracks and Clean Slate I provided much more information in comparison with the Clean Slate II array. The Clean Slate I array in particular was positioned so that the hottest portion of the cloud passed through the center of the curtain (an ideal situation).

4.4.4 Local Environmental Conditions. Since balloon curtains can cover a relatively large area, care must be exercised that the horizontal flow across the curtain is comparatively uniform (little or no streaming). If not, the deposition rate could vary by a considerable amount. Topographical conditions that could cause an extremely rapid or turbulent air stream must also be watched for.

4.4.5 Posttest Sample Handling. Sticky-wire samples are delicate. The value of the samples can be completely destroyed and considerable money needlessly expended if they are carelessly handled following the test. Three potential posttest periods will exist when the samples could be lost (ruined) or cross-contaminated. These are when they are (1) removed from their test support structure, (2) transported to a processing facility, and (3) processed (measured, wiped, packaged, etc.).

4.4.6 Field Measurements. Field measurements of sticky wires assume great importance since most of these samples will not undergo additional analysis. Extreme care must be exercised in recording the right data for the right sample since it is impossible to remeasure a sample that has been discarded.

In selecting the number and types of samples to be analyzed radiochemically, the following bases should be used: (1) sufficient number from a statistical point of view, (2) representative selection of the sample population measured (i.e., some of each range: high, medium, and low), and (3) that the samples selected be in some geometric pattern so that conclusions on the entire cloud shape and size can be drawn. A sample selection pattern centered at the highest levels observed would be meaningful. In addition, representative low-level samples from other locations should also be selected to see how their conversion factor agrees with the results of the hot line samples. For an experiment as large as Roller Coaster, with 720 sticky wires per array, approximately 10% should be analyzed (wiped) if the cloud passed through the center of the curtain (i.e., Clean Slate I) and about 5% if only the outer fringe of the cloud passed through the curtain (i.e., Clean Slate II).

As experience is gained, the number of samples that must be analyzed radiochemically to assure valid results might be reduced.

4.4.7 The Measurement System. In evaluating ion chambers, their use as a field and as a laboratory instrument must be considered separately.

Field Instrument. Air ionization chambers were used to measure ~2800 sticky wires in the field. In evaluating their field use we must consider the measurement process and the data produced. A field measurement instrument should be simple to operate, supply data in a minimum of time, and be reusable immediately (able to be used on the next sample without delay for cleanup, etc.). The chambers used in Roller Coaster had faults in each of these areas. It was difficult to get the instrument to reach equilibrium; any movement within 3 feet of the apparatus sent the meter needle in all directions. Background measurement checks to verify that the unit hadn't become contaminated were especially sensitive to the environment. The unscrewing and screwing together of the unit and the subsequent determination that the wire was making good contact wasted many hours. On several occasions it was necessary to decontaminate the ion chamber to reduce the instrument background to an acceptable level. This decontamination was difficult to accomplish, time consuming, and often had to be repeated two or three times to return the chamber to its initial background reading.

The actual accuracy and reproducibility of the field data cannot be known since only one measurement was made on each wire.

It is our conclusion that air ionization chambers should not be used for future field studies, since they are not suitable, and that a new instrument that is comparatively stable to external effects, provides rapid readings, and is easily decontaminable, be used. If investigation reveals that no presently available instrument has these characteristics, a new unit should be designed and built.

Laboratory Instrument. The same ionization chambers used in the field were used for remeasuring the 30 wires saved for laboratory study and the various standards prepared at Tracerlab/West. The greatest problem in using these chambers as laboratory instruments was their extreme sensitivity to physical vibration. During the laboratory portion of the study a considerable amount of time was spent studying chamber reproducibility for background and standard measurements. In general the background was 0.05 μμa ± 100% with readings as high as 0.4 μμa observed during measurement of the standards when no contamination had occurred. (Note: Higher backgrounds were sometimes obtained after remeasuring one of the samples, but this was from chamber contamination, and decontamination always reduced it.) In reviewing the data, it is obvious that the measurement problems were a direct function of the activity of the sample being measured, i.e., the more activity on the sample, the faster equilibrium was reached. The lower the activity on the sample, the longer it took to reach equilibrium and the greater the variance in the data obtained.

In summary, it is our opinion that ionization chambers can be used for laboratory measurement; however, a simpler and more stable system could likely be devised. This new system should be as stable at background levels as the present system is at high current levels (more than 50 $\mu\mu a$).

4.4.8 Data Produced

Sample Collection. Unlike high-velocity air samplers, which may remove all of the airborne activity from the immediate environment, a sticky wire only removes a portion of the activity with which it comes in contact. Some of the particles do not adhere to the wire. This is caused by several factors: (a) particles that follow the air flow will not impinge on wire, especially very small particles; (b) the adhesive may be completely loaded; (c) the particle may be moving so fast that it does not remain in contact with the adhesive long enough to adhere; (c) the particle may drop off for various reasons after it has adhered (e.g., gusts of wind, too large a particle, not enough surface being held, rough handling in removing the sampler, etc.). For these reasons the results directly obtained from sticky wires can only be qualitative in nature. To make the data quantitative, (1) some of the wires must be analyzed and an instrument conversion factor (i.e., dpm/μμa) determined, the measurement data must then be converted to activity (μg Pu) on the wires, and (2) the activity values determined from the field measurement and radiochemical analyses must be converted to airborne activity as a function of the local environmental conditions existing at the time of the test. To do this, calibration curves based on the test site environmental conditions (wind velocity, dust loading, particle size, etc.) must be prepared.

The above discussion is not meant to imply that the data directly available do not have value; quite the contrary: they are extremely valuable but not quantitative in nature. For many applications the qualitative data would be more than adequate and no additional work beyond contour plotting would be necessary. For other applications, quantitative data will be required and the studies mentioned above will have to be carried out before quantitative results are obtained.

Sample Selection (for additional analysis). For the sticky wire wipes to provide a true conversion value for the field measurement, sufficient wires must be analyzed radiochemically. The exact number is a function of the test being monitored and the location of the sticky wire array in relationship to the cloud. The number of samples to be selected is based on knowledge of the overall cloud pattern (i.e., all of the wires measured and the results plotted). By making a field plot of the data as it accumulates, a pattern for selection of wires to be wiped can be determined. In addition, appropriate samples can be retained (based on measured activity and position in the array) for particle size analyses and detailed radiochemical analyses.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

All of the desired objectives of this study were achieved.

The factor-of-two difference in current readings between the two ionization chambers when exposed to a cobalt-60 check source was due to a geometry variation caused by the chamber not being mounted at the center of the support base. When similar geometries were used, similar results were obtained.

The response characteristics of the two ionization chambers used to measure the sticky wires in the field were studied using specially prepared standards and sticky wires saved from the field. The reproducibility of chamber readings above 1 μμa was ±10% or better. Below this value, reproducibility was considerably poorer.

Environmental factors such as temperature, altitude, and humidity were shown to follow expected theoretical principles with the experimental Richmond/Tonopah ratio being less than 5% from the theoretical estimate. It is therefore possible to perform measurements under varying sets of environmental conditions and to correct the data to a desired set of standard conditions.

The conversion of all field measurements to estimates of deposited μg of Pu is listed in Appendix A.

Fallout cloud profiles for the arc B balloon curtains used during Double Tracks, Clean Slate I and Clean Slate II were prepared (see Figures 3.4, 3.5, and 3.6.)

5.2 RECOMMENDATIONS

Maximum use of the sticky wire analytical technique will only be possible after additional studies have been performed. These studies would permit conversion of qualitative deposited activity data to activity concentration inside the cloud as a function of the environmental conditions existing at the cloud's formation and movement through the area. The studies that need to be performed include:

(a) Collection efficiency study: This would study collection efficiency as a function of particle density and size, wire diameter, and wind velocity as well as environmental factors such as temperature and pressure which affect the viscosity of the air. The effects of some of these variables are indicated in Reference 3. Such a study will enable us to optimize wire design according to the intended application.

(b) Adhesives (capture) study: This would study the capture characteristics of possible adhesives as a function of environmental conditions such as temperature and humidity.

(c) Sticky wire measuring system study: Presently available field and laboratory measuring systems should be investigated as the present ionization chamber system does not have the desired characteristics (especially for field measurements). If no presently available measuring system has the desired characteristics, then a new one needs to be designed.

The sticky wire analytical technique has applications in addition to measuring clouds containing radioactivity. Non-radioactive tracers can be combined with this technique to study the problems of air pollution, simulated fallout from weapons and Plowshare type tests, pesticide dispersal from aerial crop dusting, and seed and pollen dispersion. The only thing that can prevent the logarithmic growth of this technique is the qualitativeness of the data produced to date.

APPENDIX A

FIELD MEASUREMENTS

TABLE A.1 FIELD MEASUREMENTS OF STICKY WIRES FROM DOUBLE TRACKS ARC B BALLOON

Line / Position	1		2		3		4		5		6	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	0.6	0.05	0.1	0.008	0.2	0.02	0.1	0.008	0.4	0.03	0.1	0.008
2	BG	-	0.2	0.02	0.2	0.02	0.4	0.03	0.5	0.04	BG	-
3	BG	-	0.1	0.008	BG	-	0.9	0.07	0.9	0.07	BG	-
4	19	1.6	0.4	0.03	0.3	0.02	0.4	0.03	0.4	0.03	BG	-
5	115	9.4	17	1.4	1.5	0.12	0.3	0.02	2.7	0.22	BG	-
6	160	13	150	12	7.2	0.59	18.5	1.5	40	3.3	20	1.6
7	66	5.4	160	13	70	5.7	*	-	85	7.0	56	4.6
8	150	12	12	9.8	100	8.2	115	9.4	80	6.6	220	18
9	160	13	130	11	200	16	205	17	125	10	215	18
10	130	11	50	4.1	210	17	70	5.7	190	16	270	22
11	320	26	70	5.7	190	16	230	19	230	19	235	19
12	180	15	110	9.0	180	15	32	2.6	240	20	270	22
13	150	12	70	5.7	200	16	60	4.9	170	14	230	19
14	78	6.4	190	16	220	18	195	16	90	7.4	230	19
15	19	1.6	100	8.2	43	3.5	140	11	105	8.6	125	10
16	30	2.5	0.1	0.008	120	9.8	85	7.0	18	1.5	70	5.7
17	15	1.2	40	3.3	92	7.5	65	5.3	90	7.4	105	8.6
18	1	0.08	40	3.3	92	7.5	96	7.9	125	10	105	8.6
19	0.5	0.04	0.1	0.008	41	3.4	52	4.3	95	7.8	60	4.9
20	0.5	0.04	0.2	0.02	9.2	0.75	3	0.25	50	4.1	11	0.90
21	BG	-	0.1	0.008	1.5	0.12	2.5	0.21	48	3.9	5	0.41
22	*	-	0.5	0.04	0.1	0.008	0.2	0.02	28	2.3	2.7	0.22
23	0.2	0.02	0.5	0.04	*	-	0.5	0.04	4.4	0.36	*	-
24	0.7	0.06	0.1	0.008	*	-	0.4	0.03	0.4	0.03	BG	-

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A. 1 (Cont'd)

Line / Position	7		8		9		10		11		12	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	BG	-	BG	-	0.3	0.02	BG	-	0.9	0.07	BG	-
2	BG	-	BG	-	0.5	0.4	1.2	0.10	4.2	0.34	0.2	0.02
3	0.2	0.02	BG	-	0.2	0.02	BG	-	3	0.25	BG	-
4	4	0.33	BG	-	0.9	0.07	BG	-	3.2	0.26	0.3	0.02
5	BG	-	BG	-	0.4	0.03	BG	-	2.8	0.23	0.8	0.07
6	0.5	0.04	BG	-	0.9	0.07	2.6	0.21	1	0.08	0.7	0.06
7	1.3	0.11	BG	-	0.9	0.07	0.3	0.02	3	0.25	0.1	0.008
8	7	0.57	BG	-	0.9	0.07	0.5	0.04	3.2	0.26	0.4	0.03
9	40	3.3	1.0	0.08	0.3	0.02	0.3	0.02	2.1	0.17	0.1	0.008
10	80	6.6	3	0.25	2.1	0.17	0.2	0.02	1	0.08	0.3	0.02
11	105	8.6	5.8	0.48	0.7	0.06	BG	-	4.1	0.34	0.1	0.008
12	135	11	32	2.6	BG	-	0.3	0.02	1	0.08	0.1	0.008
13	105	8.6	42	3.4	0.7	0.06	0.2	0.02	1	0.08	0.1	0.008
14	155	13	74	6.1	17	1.4	8.2	0.67	0.8	0.07	0.4	0.03
15	50	4.1	63	5.2	35	2.9	11	0.90	3.5	0.29	0.2	0.02
16	21	1.7	52	4.3	37	3.0	23	1.9	19	1.6	0.1	0.008
17	19	1.6	55	4.5	22	1.8	42	3.4	23	1.9	0.4	0.03
18	45	3.7	42	3.4	66	5.4	46	3.8	42	3.4	120	9.8
19	50	4.1	59	4.8	66	5.4	60	4.9	62	5.1	100	8.2
20	14	1.1	68	5.6	46	3.8	54	4.4	56	4.6	65	5.3
21	BG	-	*	-	33	2.7	12	0.98	36	3.0	32	2.6
22	0.8	0.07	8	0.66	1	0.08	11	0.90	17	1.4	6	0.49
23	*	-	0.4	0.03	1.1	0.09	0.5	0.04	9	0.74	0.4	0.03
24	*	-	*	-	*	-	0.1	0.008	1.2	0.10	0.2	0.02

Line / Position	13		14		15		17		18		19	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	BG	-	*	-	*	-	*	-	1.0	0.08	*	-
2	BG	-	*	-	*	-	*	-	*	-	*	-
3	BG	-	*	-	*	-	*	-	4	0.33	*	-
4	*	-	*	-	*	-	*	-	*	-	*	-
5	*	-	*	-	*	-	*	-	*	-	*	-
6	BG	-	BG	-	*	-	1.3	0.11	3.4	0.28	*	-
7	*	-	*	-	*	-	*	-	*	-	*	-
8	*	-	*	-	*	-	*	-	*	-	*	-
9	BG	-	-	-	*	-	0.9	0.07	1.1	0.09	*	-
10	*	-	*	-	*	-	*	-	*	-	*	-
11	*	-	*	-	*	-	*	-	*	-	*	-
12	BG	-	BG	-	0.5	0.04	1.3	0.11	3.4	0.28	BG	-
13	6	0.49	BG	-	0.4	0.03	4.6	0.38	0.8	0.07	BG	-
14	4.8	0.39	BG	-	1.1	0.09	0.5	0.04	3.2	0.26	BG	-
15	5	0.41	BG	-	0.5	0.04	0.8	0.07	3.6	0.30	0.3	0.02
16	BG	-	BG	-	4	0.33	1.4	0.11	1.1	0.09	*	-
17	BG	-	BG	-	1.0	0.08	5.6	0.46	3	0.25	*	-
18	2.5	0.21	BG	-	8	0.66	6.2	0.51	4.4	0.36	0.3	0.02
19	2.2	0.18	11	0.90	40	3.3	6	0.49	6	0.49	BG	-
20	55	4.5	38	3.1	46	3.8	12	0.98	8	0.66	2.4	0.20
21	22	1.8	60	4.9	22	1.8	3.6	0.30	15	1.2	12	0.98
22	7	0.57	44	3.6	40	3.3	4.1	0.34	28	2.3	17	1.4
23	4.6	0.38	7.2	5.9	1.2	0.10	9	0.74	30	2.5	25	2.1
24	BG	-	BG	-	0.9	0.07	3.5	0.29	12	0.98	171.4	1.4

[1] Ion Chamber Reading

[2] Deposited Plutonium

Legend: * - Sample not measured

BG - Sample at or below instrument background

TABLE A.1 (Cont'd)

Line / Position	20 ICR[1] (μμa)	20 DP[2] (μg Pu)	21 ICR (μμa)	21 DP (μg Pu)	22 ICR (μμa)	22 DP (μg Pu)	23 ICR (μμa)	23 DP (μg Pu)	24 ICR (μμa)	24 DP (μg Pu)	25 ICR (μμa)	25 DP (μg Pu)
1	*	-	*	-	*	-	0.4	0.03	0.7	0.06	BG	-
2	*	-	*	-	*	-	*	-	*	-	*	-
3	*	-	*	-	*	-	0.6	0.05	*	-	*	-
4	*	-	*	-	*	-	*	-	*	-	*	-
5	*	-	*	-	*	-	*	-	BG	-	BG	-
6	*	-	*	-	*	-	0.5	0.04	*	-	*	-
7	*	-	*	-	*	-	*	-	*	-	*	-
8	*	-	*	-	*	-	0.7	0.06	*	-	*	-
9	*	-	*	-	*	-	*	-	*	-	*	-
10	*	-	*	-	*	-	0.2	0.02	BG	-	BG	-
11	*	-	*	-	*	-	*	-	*	-	*	-
12	*	-	0.7	0.06	*	-	BG	-	*	-	*	-
13	0.1	0.08	0.6	0.05	BG	-	1.2	0.10	*	-	*	-
14	*	-	BG	BG	*	-	0.2	0.02	*	-	*	-
15	0.3	0.02	*	-	BG	-	BG	-	BG	-	BG	-
16	*	-	0.5	0.04	*	-	0.9	0.07	*	-	*	-
17	0.3	0.02	*	-	BG	-	0.5	0.04	*	-	*	-
18	*	-	*	-	*	-	BG	-	*	-	*	-
19	BG	-	*	-	0.1	0.008	*	-	*	-	*	-
20	0.7	0.06	BG	-	0.2	0.02	0.4	0.03	0.5	0.04	BG	-
21	4.5	0.37	1.4	0.11	1.3	0.11	0.7	0.06	BG	-	*	-
22	23	1.9	7	0.57	18	1.5	6.5	0.53	1	0.08	BG	-
23	27	2.2	21	1.7	30	2.5	5.6	0.46	4	0.33	*	-
24	4.5	0.37	0.9	0.07	2.2	0.18	*	-	*	-	*	-

Line / Position	26 ICR[1] (μμa)	26 DP[2] (μg Pu)	27 ICR (μμa)	27 DP (μg Pu)	28 ICR (μμa)	28 DP (μg Pu)	29 ICR (μμa)	29 DP (μg Pu)	30 ICR (μμa)	30 DP (μg Pu)	31 ICR (μμa)	31 DP (μg Pu)
1	BG	-	BG	-	BG	-	0.6	0.05	BG	-	BG	-
2	*	-	*	-	*	-	BG	-	BG	-	*	-
3	*	-	*	-	*	-	BG	-	BG	-	*	-
4	*	-	*	-	*	-	BG	-	BG	-	*	-
5	BG	-	BG	-	0.4	0.03	BG	-	BG	-	BG	-
6	*	-	*	-	*	-	*	-	*	-	*	-
7	*	-	*	-	*	-	*	-	*	-	*	-
8	*	-	*	-	*	-	*	-	*	-	*	-
9	*	-	*	-	*	-	*	-	*	-	*	-
10	BG	-	BG	-	BG	-	BG	-	0.3	0.02	BG	-
11	*	-	*	-	*	-	*	-	*	-	*	-
12	*	-	*	-	*	-	*	-	*	-	*	-
13	*	-	*	-	*	-	*	-	*	-	*	-
14	*	-	*	-	*	-	*	-	*	-	*	-
15	BG	-	BG	-	BG	-	0.3	0.02	BG	-	BG	-
16	*	-	*	-	*	-	*	-	*	-	*	-
17	*	-	*	-	*	-	*	-	*	-	*	-
18	*	-	*	-	*	-	*	-	*	-	*	-
19	*	-	*	-	*	-	*	-	*	-	*	-
20	BG	-	BG	-	0.5	0.04	BG	-	BG	-	BG	-
21	BG	-	*	-	*	-	*	-	*	-	*	-
22	0.3	0.02	*	-	*	-	BG	-	*	-	BG	-
23	*	-	*	-	BG	-	*	-	BG	-	*	-
24	*	-	BG	-	*	-	BG	-	*	-	*	-

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A.2 FIELD MEASUREMENTS OF STICKY WIRES FROM DOUBLE TRACKS ARC J BALLOON

Line / Position	1 (J-34)		2 (J-40)		3 (J-46)		4 (J-52)		5 (J-58)		6 (J-64)		7 (J-70)		8 (J-76)	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	*	-	0.1	0.006	BG	-	BG	-	BG	-	0.6	0.033	1.3	0.071	0.6	0.033
2	*	-	0.3	0.017	0.4	0.022	1.0	0.055	1.2	0.066	1.0	0.055	*	-	*	-
3	*	-	BG	-	0.5	0.027	BG	-	2.5	0.14	0.8	0.044	*	-	*	-
4	*	-	0.6	0.033	0.7	0.038	BG	-	5.0	0.27	0.5	0.027	1.2	0.066	*	-
5	*	-	1.0	0.055	0.6	0.033	BG	-	4.4	0.24	0.3	0.017	1.8	0.10	0.7	0.038
6	BG	-	0.4	0.022	2.7	0.15	BG	-	3.9	0.21	0.6	0.033	1.0	0.055	*	-
7	1.0	0.055	1.8	0.10	9.0	0.50	0.3	0.017	2.4	0.13	BG	-	*	-	*	-
8	1.7	0.093	0.8	0.044	18	1.0	0.3	0.017	1.8	0.10	BG	-	1.7	0.093	*	-
9	6.0	0.33	0.3	0.017	15	0.82	BG	-	1.1	0.060	BG	-	*	-	*	-
10	14	0.077	BG	-	9.0	0.50	3.6	0.20	0.3	0.017	BG	-	0.6	0.033	1.0	0.055
11	23	1.3	BG	-	16	0.88	4.6	0.25	BG	-	BG	-	*	-	*	-
12	28	1.5	BG	-	13	0.71	8.2	0.47	BG	-	BG	-	*	-	*	-
13	35	1.9	BG	-	5.5	0.30	8.5	0.47	BG	-	BG	-	*	-	*	-
14	36	2.0	BG	-	3.8	0.21	5.0	0.27	BG	-	BG	-	*	-	*	-
15	40	2.2	BG	-	3.4	0.19	3.6	0.20	BG	-	BG	-	1.2	0.066	1.0	0.055
16	30	1.6	BG	-	1.1	0.060	1.4	0.077	BG	-	BG	-	*	-	*	-
17	21	1.2	BG	-	BG	-	*	-	0.4	0.022	BG	-	*	-	*	-
18	5.5	0.30	BG	-	BG	-	*	-	BG	-	BG	-	*	-	*	-
19	2.5	0.14	BG	-	BG	-	*	-	2.6	0.14	BG	-	*	-	*	-
20	1.3	0.071	BG	-	BG	-	BG	-	0.3	0.017	BG	-	0.8	0.044	1.3	0.071

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A.3 FIELD MEASUREMENTS OF STICKY WIRES FROM CLEAN SLATE I ARC B BALLOON

Line / Position	1		2		3		4		5		6	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	1.6	0.13	BG	-	*	-	0.7	0.06	*	-	*	-
2	*	-	*	-	1.0	0.08	*	-	*	-	BG	-
3	*	-	BG	-	*	-	*	-	0.9	0.07	*	-
4	*	-	*	-	*	-	0.7	0.06	*	-	*	-
5	1.3	0.11	*	-	*	-	*	-	*	-	*	-
6	*	-	*	-	*	-	0.9	0.07	*	-	BG	-
7	*	-	BG	-	*	-	*	-	*	-	*	-
8	*	-	*	-	0.6	0.05	*	-	0.8	0.07	*	-
9	*	-	*	-	*	-	*	-	*	-	*	-
10	1.3	0.11	*	-	*	-	BG	-	*	-	BG	-
11	*	-	*	-	*	-	*	-	*	-	*	-
12	*	-	BG	-	0.6	0.05	*	-	*	-	*	-
13	*	-	*	-	*	-	*	-	BG	-	*	-
14	*	-	*	-	*	-	0.8	0.07	*	-	BG	-
15	2.1	0.17	*	-	*	-	*	-	*	-	*	-
16	*	-	*	-	*	-	*	-	*	-	*	-
17	*	-	BG	-	*	-	0.5	0.04	*	-	*	-
18	*	-	*	-	0.9	0.07	*	-	1.2	0.10	BG	-
19	*	-	*	-	*	-	*	-	*	-	*	-
20	1.9	0.16	*	-	*	-	1.0	0.08	*	-	*	-
21	*	-	BG	-	*	-	*	-	*	-	*	-
22	*	-	*	-	*	-	*	-	*	-	BG	-
23	0.5	0.04	*	-	*	-	0.9	0.07	*	-	*	-
24	*	-	*	-	0.6	0.05	*	-	0.7	0.06	*	-

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A.3 (Cont'd)

Position \ Line	7 ICR[1] (μμa)	7 DP[2] (μg Pu)	8 ICR (μμa)	8 DP (μg Pu)	9 ICR (μμa)	9 DP (μg Pu)	10 ICR (μμa)	10 DP (μg Pu)	11 ICR (μμa)	11 DP (μg Pu)	12 ICR (μμa)	12 DP (μg Pu)
1	0.8	0.07	*	-	*	-	BG	-	*	-	1.4	0.[illegible]1
2	*	-	*	-	0.8	0.07	*	-	0.6	0.05	*	-
3	*	-	*	-	*	-	BG	-	*	-	0.8	0.07
4	*	-	*	-	*	-	*	-	0.5	0.04	0.6	0.05
5	1.0	0.08	*	-	1.3	0.11	BG	-	1.7	0.14	7	0.57
6	*	-	*	-	*	-	1.5	0.12	34	2.8	38	3.1
7	*	-	*	-	*	-	42	3.4	35	2.9	60	4.9
8	*	-	*	-	*	-	0.2	0.02	30	2.5	52	4.3
9	1.0	0.08	*	-	1.7	0.14	*	-	1.2	0.10	23	1.9
10	*	-	*	-	*	-	*	-	1.5	0.12	1.7	0.14
11	*	-	0.2	0.02	*	-	0.8	0.07	*	-	BG	-
12	*	-	*	-	1.2	0.10	*	-	*	-	*	-
13	*	-	*	-	*	-	0.2	0.02	*	-	0.4	0.03
14	*	-	0.2	0.02	*	-	*	-	BG	-	*	-
15	*	-	*	-	*	-	0.3	0.02	*	-	0.9	0.07
16	0.7	0.06	*	-	BG	-	*	-	*	-	*	-
17	*	-	0.1	0.008	0.8	0.07	*	-	1.0	0.08	1.3	0.11
18	*	-	*	-	0.8	0.07	0.2	0.02	2.3	0.19	7	0.57
19	*	-	BG	-	2.7	0.22	3.2	0.26	5.4	0.44	5	0.41
20	1.1	0.09	BG	-	1.6	0.13	1.8	0.15	2.5	0.21	2.1	0.17
21	*	-	0.9	0.07	3.8	0.31	5	0.41	6	0.49	5.9	0.48
22	*	-	0.9	0.07	2.4	0.20	2.8	0.23	3.1	0.25	5	0.41
23	1.3	0.11	BG	-	1.7	0.14	0.8	0.07	2.6	0.21	1.1	0.09
24	*	-	*	-	0.8	0.07	0.3	0.02	1.6	0.13	1.0	0.08

Position \ Line	13 ICR[1] (μμa)	13 DP[2] (μg Pu)	14 ICR (μμa)	14 DP (μg Pu)	15 ICR (μμa)	15 DP (μg Pu)	17 ICR (μμa)	17 DP (μg Pu)	18 ICR (μμa)	18 DP (μg Pu)	19 ICR (μμa)	19 DP (μg Pu)
1	*	-	BG	-	*	-	*	-	0.5	0.04	0.8	0.07
2	BG	-	*	-	2.8	0.23	BG	-	0.5	0.04	BG	-
3	BG	-	BG	-	1.3	0.11	6.4	0.52	19	1.6	44	3.6
4	1.0	0.08	9	0.74	20	1.6	17	1.4	36	3.0	6.2	0.51
5	60	4.9	75	6.2	76	6.2	42	3.4	54	4.4	135	11
6	94	7.7	125	10	120	9.8	140	11	150	12	180	15
7	60	4.9	90	7.4	90	7.4	70	5.7	86	7.1	140	11
8	66	5.4	55	4.5	62	5.1	48	3.9	68	5.6	120	9.8
9	54	4.4	50	4.1	31	2.5	44	3.6	38	3.1	35	2.9
10	0.2	0.02	BG	-	1.9	0.16	32	2.6	46	3.8	45	3.7
11	0.1	0.008	6.4	0.52	1.1	0.09	3	0.25	18	1.5	8.2	0.67
12	0.1	0.008	BG	-	*	-	1.2	0.10	3.2	0.26	11.5	0.94
13	*	-	BG	-	*	-	0.4	0.03	3.2	0.26	7.2	0.59
14	*	-	*	-	1.7	0.14	BG	-	0.9	0.07	7	0.57
15	*	-	BG	-	2.6	0.21	1.6	0.13	8.8	0.72	22	1.8
16	BG	-	BG	-	5.6	0.46	4.2	0.34	17	1.4	24	2.0
17	*	-	0.6	0.05	8.6	0.71	3.8	0.31	2.4	0.20	34	2.8
18	*	-	10	0.82	5.5	0.45	6.8	0.56	5.5	0.45	6.8	0.56
19	*	-	0.4	0.03	2.1	0.17	0.9	0.07	2.4	0.20	5	0.41
20	BG	-	0.3	0.02	0.6	0.05	0.7	0.06	3.2	0.26	2.7	0.22
21	3.2	0.26	1.7	0.14	1.2	0.10	0.9	0.07	2.3	0.19	1	0.08
22	4.2	0.34	2.7	0.22	1.5	0.12	0.3	0.02	0.5	0.04	BG	-
23	3	0.25	2.2	0.18	1.6	0.13	0.7	0.06	0.3	0.02	BG	-
24	BG	-	0.9	0.07	2.9	0.24	0.5	0.04	*	-	*	-

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A. 3 (Cont'd)

Line / Position	20		21		22		23		24		25	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	0.6	0.05	BG	-	0.6	0.05	1.3	0.11	BG	-	0.9	0.07
2	0.8	0.07	BG	-	0.9	0.07	0.5	0.04	BG	-	0.9	0.07
3	56	4.6	65	5.3	45	3.7	53	4.3	0.3	0.02	1.1	0.09
4	90	7.4	110	9.0	72	5.9	68	5.6	33	2.7	29	2.4
5	*	-	85	7.0	56	4.6	70	5.7	85	7.0	15	1.2
6	160	13	120	9.8	110	9.0	140	12	72	5.9	46	3.8
7	155	13	100	8.2	125	10	160	13	90	7.4	82	6.7
8	110	9.0	100	8.2	110	9.0	110	9.0	58	4.8	73	6.0
9	60	4.9	100	8.2	92	7.5	90	7.4	95	7.8	60	4.9
10	15	1.2	32	2.6	52	4.3	5	0.41	90	7.4	96	7.9
11	16	1.3	13	1.1	37	3.0	78	6.4	56	4.6	63	5.2
12	14	1.1	15	1.2	75	6.2	4.2	0.34	14	1.1	26	2.1
13	8	0.66	3.6	0.30	80	6.6	80	6.6	4.6	0.38	16	.3
14	10	0.82	16	1.3	6.2	0.51	3.4	0.28	2.2	0.18	10	0.82
15	30	2.5	24	2.0	11	0.90	15	1.2	2.7	0.22	4.8	0.39
16	26	2.1	15	1.2	11	0.90	12	0.98	8.8	0.72	8.8	0.72
17	6.2	0.51	15	1.2	13	1.1	13	1.1	7.2	0.59	4.6	0.38
18	4	0.33	3.2	0.26	15	1.2	1.0	0.08	6.8	0.56	5.1	0.42
19	1.8	0.15	3	0.25	10	0.82	7.6	0.62	6	0.49	5.7	0.47
20	2.6	0.21	1.1	0.09	4.9	0.40	4.6	0.38	*	-	5.8	0.48
21	0.9	0.07	BG	-	1.2	0.10	4.2	0.34	*	-	0.5	0.04
22	1.2	0.10	BG	-	0.9	0.07	0.8	0.07	0.2	0.02	1.0	0.08
23	1.2	0.10	0.1	0.008	1.0	0.08	0.9	0.07	0.2	0.02	1.2	0.10
24	*	-	*	-	*	-	*	-	0.1	0.008	0.8	0.07

Line / Position	26		27		28		29		30		31	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	0.7	0.06	BG	-	BG	-	BG	-	*	-	0.3	0.02
2	0.4	0.03	0.2	0.02	BG	-	*	-	0.3	0.02	0.6	0.05
3	1.1	0.09	0.4	0.03	BG	-	BG	-	0.4	0.03	*	-
4	1.1	0.09	0.8	0.07	BG	-	BG	-	BG	-	*	-
5	1.5	0.12	0.1	0.008	BG	-	BG	-	0.7	0.06	0.8	0.07
6	36	3.0	25	2.1	2.8	0.23	BG	-	1.0	0.08	*	-
7	70	5.7	42	3.4	44	3.6	BG	-	0.7	0.06	*	-
8	94	7.7	38	3.1	46	3.8	18	1.5	1.1	0.09	*	-
9	110	9.0	38	3.1	42	3.4	17	1.4	1.8	0.15	*	-
10	110	9.0	3.2	0.26	3.2	0.26	2.4	0.20	0.6	0.05	0.6	0.05
11	110	9.0	4.2	0.34	1.0	0.08	BG	-	0.8	0.07	*	-
12	29	2.4	10	0.82	2.3	0.19	BG	-	0.6	0.05	*	-
13	9.2	0.75	13	1.1	16	1.3	BG	-	1.5	0.12	*	-
14	13	1.1	10	0.82	5.5	0.45	19	1.6	8.4	0.69	0.3	0.04
15	2.7	0.22	3.8	0.31	6.8	0.56	0.5	0.04	3.5	0.29	*	-
16	10	0.82	7.4	0.61	9	0.74	4.8	0.39	2.1	0.17	1.3	0.11
17	8	0.66	1.2	0.10	2.3	0.19	2.8	0.23	1.7	0.14	*	-
18	2.3	0.19	6.0	0.49	8	0.66	0.9	0.07	0.3	0.02	*	-
19	5.6	0.46	4.0	0.33	1.5	0.12	0.3	0.02	4.8	0.39	10	0.08
20	4.4	0.36	1.0	0.08	0.2	0.02	8.4	0.69	4	0.33	*	-
21	1.1	0.09	0.1	0.008	0.2	0.02	4.4	0.36	BG	-	*	-
22	0.6	0.05	0.1	0.008	BG	-	BG	-	0.9	0.07	*	-
23	1.1	0.09	*	-	BG	-	0.2	0.02	0.9	0.07	1.2	0.10
24	0.9	0.07	*	-	BG	-	BG	-	1.1	0.09	*	-

[1] Ion Chamber Reading

[2] Deposited Plutonium

Legend: * - Sample not measured

BG - Sample at or below instrument background

TABLE A.4 FIELD MEASUREMENTS OF STICKY WIRES FROM CLEAN SLATE II ARC B BALLOON

Line / Position	1		2		3		4		5		6	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	*	-	0.2	0.02	0.6	0.05	BG	-	0.5	0.04	0.2	0.02
2	0.9	0.07	0.4	0.03	0.3	0.02	BG	-	0.7	0.06	BG	-
3	1.2	0.10	0.4	0.03	0.7	0.06	BG	-	1.0	0.08	BG	-
4	1.5	0.12	0.5	0.04	0.9	0.07	BG	-	0.6	0.05	0.2	0.02
5	0.4	0.03	0.5	0.04	0.5	0.04	BG	-	1.0	0.08	BG	-
6	1.6	0.13	0.9	0.07	1.8	0.15	BG	-	0.7	0.06	BG	-
7	3.6	0.30	2.5	0.21	2.0	0.16	0.8	0.07	1.4	0.11	0.7	0.06
8	1.8	0.15	3.2	0.26	2.9	0.24	1.9	0.15	2.0	0.16	0.5	0.04
9	0.8	0.07	1.3	0.11	2.0	0.16	1.7	0.14	1.5	0.12	0.5	0.04
10	2.9	0.24	3.8	0.31	1.4	0.11	1.5	0.12	2.3	0.19	0.5	0.04
11	2.3	0.19	4.2	0.34	3.6	0.30	2.2	0.18	2.4	0.20	1.5	0.12
12	1.4	0.11	2.0	0.16	3.4	0.28	1.3	0.11	2.7	0.22	2.0	0.16
13	BG	-	0.5	0.04	1.3	0.11	1.9	0.16	1.9	0.16	0.2	0.02
14	BG	-	0.8	0.07	0.6	0.05	BG	-	1.2	0.10	0.1	0.008
15	BG	-	1.0	0.08	0.6	0.05	BG	-	1.5	0.12	BG	-
16	BG	-	0.1	0.008	0.5	0.04	BG	-	1.4	0.11	BG	-
17	BG	-	0.5	0.04	0.5	0.04	BG	-	1.1	0.09	BG	-
18	0.4	0.03	0.5	0.04	0.4	0.03	BG	-	1.8	0.15	BG	-
19	0.8	0.07	0.5	0.04	0.6	0.05	BG	-	1.2	0.10	BG	-
20	1.0	0.08	1.0	0.08	0.5	0.04	BG	-	1.1	0.09	BG	-
21	1.5	0.12	1.7	0.14	1.0	0.08	0.7	0.06	1.8	0.15	BG	-
22	2.2	0.18	3.2	0.26	0.9	0.07	1.1	0.09	1.0	0.08	0.1	0.008
23	*	-	*	-	1.6	0.13	1.6	0.13	1.7	0.14	0.4	0.03
24	*	-	*	-	0.5	0.04	0.2	0.02	2.2	0.18	1.0	0.08

Line / Position	7		8		9		10		11		12	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	BG	-	0.3	0.02	*	-	*	-	BG	-	*	-
2	BG	-	*	-	0.1	0.008	*	-	*	-	BG	-
3	BG	-	*	-	*	-	BG	-	*	-	*	-
4	BG	-	*	-	*	-	*	-	*	-	*	-
5	BG	-	BG	-	*	-	*	-	BG	-	*	-
6	BG	-	*	-	*	-	*	-	*	-	*	-
7	0.5	0.04	BG	-	BG	-	*	-	*	-	BG	-
8	0.1	0.008	BG	-	BG	-	BG	-	*	-	*	-
9	0.2	0.02	BG	-	*	-	*	-	BG	-	BG	-
10	0.1	0.008	0.3	0.02	BG	-	BG	-	BG	-	0.1	0.008
11	0.2	0.02	BG	-	0.5	0.04	BG	-	BG	-	0.8	0.07
12	0.3	0.02	BG	-	1.3	0.11	0.7	0.06	BG	-	0.7	0.06
13	1.3	0.11	BG	-	BG	-	BG	-	BG	-	BG	-
14	0.3	0.02	BG	-	BG	-	*	-	BG	-	*	-
15	BG	-	BG	-	*	-	*	-	BG	-	*	-
16	BG	-	*	-	*	-	*	-	*	-	BG	-
17	BG	-	*	-	BG	-	*	-	*	-	*	-
18	BG	-	*	-	*	-	BG	-	*	-	*	-
19	BG	-	*	-	*	-	*	-	BG	-	*	-
20	BG	-	BG	-	*	-	*	-	BG	-	*	-
21	BG	-	*	-	*	-	*	-	*	-	BG	-
22	BG	-	*	-	BG	-	0.1	0.008	BG	-	BG	-
23	0.7	0.06	*	-	1.6	0.13	1.5	0.12	0.6	0.05	1.8	0.15
24	1.8	0.15	BG	-	2.0	0.16	0.3	0.02	2.3	0.19	1.4	0.11

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A. 4 (Cont'd)

Line / Position	13		14		15		17		18		19	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	*	-	BG	-	*	-	*	-	BG	-	*	-
2	*	-	*	-	BG	-	*	-	*	-	BG	-
3	BG	-	*	-	*	-	BG	-	*	-	*	-
4	*	-	*	-	*	-	*	-	BG	-	*	-
5	*	-	BG	-	*	-	*	-	*	-	*	-
6	*	-	*	-	*	-	BG	-	*	-	BG	-
7	*	-	*	-	BG	-	*	-	*	-	*	-
8	BG	-	*	-	*	-	*	-	BG	-	*	-
9	0. 3	0. 02	BG	-	BG	-	BG	-	BG	-	BG	-
10	0. 6	0. 05	0. 9	0. 07	0. 2	0. 02	BG	-	BG	-	0. 3	0. 02
11	BG	-	1. 0	0. 08	BG	-	BG	-	0. 3	0. 02	BG	-
12	0. 5	0. 04	BG	-	BG	-	0. 9	0. 07	BG	-	0. 4	0. 03
13	BG	-	0. 4	0. 03	BG	-	BG	-	BG	-	BG	-
14	BG	-	BG	-	BG	-	*	-	*	-	BG	-
15	*	-	BG	-	*	-	*	-	BG	-	*	-
16	*	-	*	-	*	-	*	-	*	-	*	-
17	*	-	*	-	BG	-	BG	-	*	-	BG	-
18	BG	-	*	-	*	-	*	-	BG	-	*	-
19	*	-	BG	-	*	-	*	-	*	-	*	-
20	*	-	*	-	BG	-	BG	-	*	-	BG	-
21	*	-	*	-	*	-	BG	-	BG	-	BG	-
22	BG	-	BG	-	BG	-	BG	-	0. 4	0. 03	BG	-
23	0. 9	0. 07	1. 4	0. 11	0. 5	0. 04	0. 8	0. 07	1. 5	0. 12	0. 3	0. 02
24	0. 4	0. 03	BG	-	2. 0	0. 16	*	-	*	-	0. 7	0. 06

Line / Position	20		21		22		23		24		25	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	*	-	*	-	BG	-	*	-	*	-	*	-
2	*	-	BG	-	*	-	BG	-	*	-	BG	-
3	BG	-	*	-	BG	-	*	-	BG	-	*	-
4	*	-	*	-	*	-	*	-	*	-	*	-
5	*	-	BG	-	*	-	*	-	*	-	BG	-
6	*	-	*	-	*	-	BG	-	*	-	*	-
7	BG	-	*	-	BG	-	BG	-	*	-	*	-
8	BG	-	BG	-	BG	-	BG	-	BG	-	*	-
9	BG	-	BG	-	BG	-	BG	-	*	-	BG	-
10	BG	-	0. 3	0. 02	BG	-	BG	-	*	-	*	-
11	BG	-	BG	-	0. 2	0. 02	BG	-	*	-	*	-
12	BG	-	0. 4	0. 03	BG	-	BG	-	BG	-	*	-
13	BG	-	BG	-	BG	-	BG	-	*	-	*	-
14	*	-	*	-	*	-	*	-	*	-	BG	-
15	BG	-	*	-	*	-	BG	-	*	-	*	-
16	*	-	BG	-	*	-	*	-	BG	-	*	-
17	*	-	*	-	BG	-	*	-	*	-	BG	-
18	*	-	*	-	*	-	BG	-	BG	-	BG	-
19	BG	-	*	-	*	-	BG	-	0. 2	0. 02	0. 3	0. 02
20	BG	-	BG	-	*	-	BG	-	BG	-	BG	-
21	*	-	*	-	BG	-	*	-	BG	-	*	-
22	BG	-	BG	-	BG	-	BG	-	*	-	*	-
23	0. 1	0. 008	0. 5	0. 04	BG	-	BG	-	*	-	BG	-
24	0. 6	0. 05	BG	-	BG	-	BG	-	BG	-	*	-

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A. 4 (Cont'd)

Line / Position	26		27		28		29		30		31	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	*	-	BG	-	*	-	BG	-	*	-	*	-
2	*	-	*	-	*	-	*	-	BG	-	*	-
3	BG	-	*	-	BG	-	*	-	*	-	BG	-
4	*	-	*	-	*	-	*	-	*	-	*	-
5	*	-	*	-	*	-	*	-	BG	-	*	-
6	*	-	BG	-	*	-	*	-	*	-	*	-
7	*	-	*	-	*	-	BG	-	*	-	BG	-
8	BG	-	*	-	BG	-	*	-	*	-	*	-
9	*	-	*	-	*	-	*	-	*	-	*	-
10	*	-	*	-	*	-	*	-	BG	-	*	-
11	BG	-	BG	-	*	-	*	-	*	-	*	-
12	*	-	*	-	*	-	BG	-	*	-	BG	-
13	BG	-	*	-	*	-	*	-	*	-	*	-
14	*	-	*	-	*	-	*	-	*	-	*	-
15	*	-	*	-	*	-	*	-	BG	-	*	-
16	*	-	BG	-	*	-	*	-	*	-	*	-
17	BG	-	BG	-	*	-	BG	-	*	-	BG	-
18	0. 3	0. 02	BG	-	*	-	*	-	*	-	*	-
19	BG	-	BG	-	*	-	*	-	*	-	*	-
20	BG	-	*	-	*	-	*	-	BG	-	BG	-
21	BG	-	BG	-	BG	-	*	-	BG	-	*	-
22	BG	-	0. 3	0. 02	BG	-	BG	-	BG	-	0. 6	0. 05
23	BG	-	0. 3	0. 02	0. 5	0. 04	0. 4	0. 03	0. 4	0. 03	*	-
24	BG	-	BG	-	BG	-	BG	-	BG	-	*	-

[1] Ion Chamber Reading
[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A.5 FIELD MEASUREMENTS OF STICKY WIRES FROM CLEAN SLATE II BRITISH BALLOONS AT GROUND ZERO

Position	Balloon 1		Balloon 2		Balloon 3	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)	ICR (μμa)	DP (μg Pu)
1	0.1	0.048	*	-	*	-
2	1.4	0.67	BG	-	BG	-
3	2.1	1.0	*	-	*	-
4	2.0	0.96	0.5	0.24	BG	-
5	3.3	1.6	*	-	*	-
6	1.2	0.58	BG	-	BG	-
7	2.1	1.0	*	-	*	-
8	2.4	1.2	BG	-	BG	-
9	2.1	1.0	*	-	*	-
10	0.2	0.096	BG	-	BG	-
11	1.5	0.72	*	-	*	-
12	1.0	0.48	0.3	0.14	0.5	0.24
13	1.0	0.48	*	-	*	-
14	0.5	0.24	0.7	0.34	1.1	0.53
15	BG	-	*	-	*	-

[1] Ion Chamber Reading

[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

μg Pu data based on radiochemical results on dust Standard 570 which had a conversion factor of 7.0×10^4 dpm/μμa (0.48 μg Pu/μμa). This number was selected because it was felt that at Ground Zero the particles would be large with considerable self-shielding occurring; this was the situation with Standard 570.

TABLE A.6 FIELD MEASUREMENTS OF STICKY WIRES FROM CLEAN SLATE III ARC J BALLOONS

Position	Balloon 1		Balloon 2	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)
1	4	0.64	BG	-
2	0.7	0.11	*	-
3	BG	-	BG	-
4	*	-	*	-
5	0.6	0.096	0.1	0.016
6	0.2	0.032	*	-
7	*	-	BG	-
8	BG	-	*	-
9	0.3	0.048	BG	-
10	0.4	0.064	*	-
11	0.5	0.08	BG	-
12	0.2	0.032	*	-
13	1	0.16	BG	-
14	0.7	0.11	*	-

[1] Ion Chamber Reading

[2] Deposited Plutonium

Legend: * - Sample not measured
BG - Sample at or below instrument background

TABLE A.7 FIELD MEASUREMENTS OF STICKY WIRES FROM CLEAN SLATE III BRITISH BALLOONS AT GROUND ZERO

Position	Balloon 1		Balloon 2	
	ICR[1] (μμa)	DP[2] (μg Pu)	ICR (μμa)	DP (μg Pu)
1	4	1.9	BG	-
2	0.7	0.34	*	-
3	BG	-	BG	-
4	*	-	*	-
5	0.6	0.29	0.1	0.048
6	0.2	0.096	*	-
7	*	-	BG	-
8	BG	-	*	-
9	0.3	0.14	BG	-
10	0.4	0.19	*	-
11	0.5	0.24	BG	-
12	0.2	0.096	*	-
13	1	0.48	BG	-
14	0.7	0.34	*	-

[1] Ion Chamber Reading

[2] Deposited Plutonium

μg Pu data based on radiochemical results on dust Standard 570 which had a conversion factor of 7.0×10^4 dpm/μμa (0.48 μg Pu/μμa). This number was selected because it was felt that at Ground Zero the particles would be large with considerable self-shielding; this was the situation with Standard 570.

Legend: * - Sample not measured

BG - Sample at or below instrument background

APPENDIX B

STANDARDIZATION OF ION CHAMBER READINGS FROM DIFFERENT ENVIRONMENTS

Theory

The current generated by an alpha emitter (Pu-239) deposit on the central sticky wire in an ionization chamber depends on the rate of energy dissipation in the chamber gas and the amount of energy required to generate an ion pair.

The latter quality is a constant for a particular gas and has the value of 35.5 ev per ion pair in air (Reference 4). It does not depend significantly on the energy of the radiation or on the gas density.

The rate of energy dissipation, however, depends on the range of the emitted alphas, their location and direction of emission, and the internal geometry of the chamber. In particular, since the range of Pu-239 alphas exceeds the chamber radius, variation in gas density will significantly affect the fraction of the energy of the alpha which is dissipated in the chamber gas. Hence, measurements taken on a sample at Tonopah, Nevada (5500 feet in altitude), will be different from the same measurements taken at Richmond, California (essentially sea-level).

In order to correlate data from these two locations, the expected response for the two locations was calculated and the results compared with some empirical measurements made at various altitudes in the Richmond vicinity.

Calculation of Expected Response at Richmond

The chamber gas is taken to be air at normal temperature and pressure (NTP) (15°C and 760 mm Hg). The alpha emitter is considered to be entirely Pu-239 with an alpha energy of 5.16 Mev. The range of these alphas in air at NTP is 3.70 cm (Reference 5).

The alpha-active deposit is on the central wire of the ionization chamber. The wire has a diameter of 1/16 inch and an active length of 12 inches, and is mounted concentrically in a cylinder of 2-inch internal diameter and an overall length of 16 inches. The alphas are assumed to be emitted isotropically in solid angle and to traverse the chamber gas in straight lines until they either strike the outer cylindrical wall or completely expend their range within the chamber. In the former case, the amount of energy dissipated in the gas at NTP is determined by reference to a range-energy curve for alphas (Reference 5).

Due to the non-linear behavior of the range-energy curve at low energy, the total solid angle, measured concentrically with the central wire so that 0° is perpendicular to the wire and 90° is parallel to the wire, was broken up into several regions corresponding to path-length intervals in which the energy-loss was constant. These intervals ranged from a minimum value (emission normal to the wire) equivalent to the chamber radius of 2.46 cm, out to 3.70 cm (complete expenditure of range within the chamber). An average path-length was determined in each region and converted to an equivalent energy loss of the alphas. This was weighted by the included solid angle of the region and summed over all regions to give the average energy loss per emitted alpha from the central wire. This average energy loss is dependent on gas density, since a lower gas density reduces the energy loss in each path-length interval.

This value of average-energy-loss divided by the energy required to form an ion pair gives the number of ion pairs produced per emitted alpha. If care is taken to ensure essentially 100% collection of the ion pairs (i.e., sufficiently high voltage to reach a plateau in collected current), a collected current can be directly related to an alpha emission rate.

Since the regions are determined by choosing maximum and minimum values of path-length, calculations of included solid angle and average path-length must be in terms of these or related parameters. If R is the radial distance (2.46 cm) from central wire to outer wall, and ϕ is the angle of emission with respect to the radial direction, then the corresponding path-length at ϕ is:

$$R_i = R \sec \phi \quad \text{or} \quad \phi = \arccos \left(\frac{R}{R_i}\right)$$

The cylindrical symmetry and small size of the central wire makes consideration of the azimuthal angle unnecessary. The included solid angle in each region (including both hemispheres, i. e. the elemental solid angle on both sides of the normal to the wire) is then:

$$\Omega = 2 \int_{\phi^i \min}^{\phi^i \max} 2\pi \cos \phi \, d\phi = 4\pi (\sin \phi^i{}_{\max} - \sin \phi^i{}_{\min})$$

The average path-length in the ith region is:

$$\bar{R}_i = \frac{R \int_{\phi^i \min}^{\phi^i \max} R_i \cos \phi \, d\phi}{\int_{\phi^i \min}^{\phi^i \max} \cos \phi \, d\phi} = R \left[\frac{\phi^i \max - \phi^i \min}{\sin \phi^i{}_{\max} - \sin \phi^i{}_{\min}} \right]$$

Table B. 1 has the results for NTP air (i. e., Richmond data). The average energy loss per emitted alpha is 3. 81 Mev which is 74% of the energy of the emitted alpha (5. 15 Mev).

Assuming that the Pu-239 is deposited on the central wire in a very thin and uniform layer, then the short range of the alphas in the wire (4. 5 mg/cm^2) implies that the available solid angle for emission into the ion chamber gas is about 2π steradians. The effect of alphas backscattering from the wire into the gas is assumed to roughly compensate for some self-absorption by the wire due to surface roughness and thickness. Although this estimate is crude, it affects only the absolute calculation of ion chamber current and not the relative (i. e., ratio of) currents obtained for the same sample at both Richmond and Tonopah.

If N is the alpha emission (Pu-239) rate on the central wire in disintegrations per second, the resulting generation of ion pairs is:

$$J = \frac{N \text{ alphas/sec}}{2} \times \frac{(3.81 \times 10^6 \text{ ev/alpha})}{(35.5 \text{ ev/ion pair})} =$$

$$(5.37 \times 10^4 N) \text{ ion-pairs/sec}$$

If these ions are collected with 100% efficiency, the resulting current is:

$$I = (5.37 \times 10^4 N) \text{ ion pairs/sec } (1.603 \times 10^{-19}) \frac{\text{amp-sec}}{\text{ion pair}} =$$

$$(8.60 \times 10^{-15} N) \text{ amps}$$

or

$$N = (1.16 \times 10^{14}) \text{ dps of Pu-239},$$

where I is the collected current in amperes.

Calculations of Expected Response at Tonopah

The raw data from the altitude tests are shown in Table B.2 The altitude at Tonopah is 5,500 feet. Reference 6 gives 621 mm Hg as the summer pressure at this elevation. This is a pressure increase factor of 1.22 from Tonopah to NTP (Richmond) and extends the 5.15 Mev alpha range to 4.52 cm. This assumes room temperature, dry air in both cases, and neglects the effects of local barometric fluctuations which may amount to ±3% in each case.

A similar calculation of ion chamber current was then performed for a pressure of 621 mm Hg, with the only difference being that the average path-lengths had to be converted into equivalent path-lengths for NTP air in order to use the specified range-energy tables.

The results are contained in Table B. 3. The average energy loss per emitted alpha is 3. 10 Mev, which gives a relative ratio of 1. 23 for Richmond as compared to Tonopah data.

The collected current (in amps) is:

$$I = \frac{N}{2} \frac{(3.10 \times 10^6)}{35.5} (1.602 \times 10^{-19}) = (7.00 \times 10^{-15} N) \text{ amp}$$

or

$$N = (1.43 \times 10^{14} I) \text{ dps of Pu-239}$$

Calculated Weights of Pu-239

A conversion factor for Pu-239 between dps and milligrams is 2.31×10^6 alphas emitted per second per mg of Pu-239 (Reference 5). This gives the following relationships:

$$\text{mg of Pu-239} = \begin{cases} 5.04 \times 10^7 \, I \text{ for NTP air (Richmond)} \\ 6.19 \times 10^7 \, I \text{ for 621 mm Hg (Tonopah)} \end{cases}$$

Conclusions

The calculated conversion factor for collected current from Tonopah to Richmond is:

$$(\text{Richmond}) = \frac{6.19 \times 10^7}{5.04 \times 10^7} (\text{Tonopah}) = 1.23 \, (\text{Tonopah})$$

As previously noted, the pressure factor from Tonopah to Richmond is 1. 22 while the collected current is increased by a factor of 1. 23. Hence the collected current is closely proportional to the local barometric pressure over this limited range, in spite of the possible non-linear effects associated with the wide angles of emission and the variation of de/dx with energy. These effects will eventually destroy close proportionality as the pressure (or density) interval is increased.

TABLE B.1 CALCULATION OF AVERAGE ENERGY LOSS PER EMITTED ALPHA IN THE ION CHAMBER FOR NTP AIR

Region	1	2	3	4	5	6
Smallest path-length (cm)	2.46	2.70	2.95	3.20	3.45	3.70
Largest path-length (cm)	2.70	2.95	3.20	3.45	3.70	-
Smallest angle (degrees)	0	24.2	33.5	39.8	44.5	48.4
Largest angle (degrees)	24.2	33.5	39.8	44.5	48.4	90
Percent solid angle (%)	41.0	14.1	8.90	6.0	4.7	25.3
Average path length (cm)	2.54	2.82	3.04	3.32	3.60	3.70
Residual range (cm)	1.16	0.88	0.66	0.38	0.10	0
Residual energy (Mev)	2.25	1.80	1.33	0.70	0.10	0
Energy loss (Mev)	2.90	3.35	3.82	4.45	5.05	5.15
Weighted energy loss (Mev)	1.19	0.472	0.340	0.267	0.237	1.30

Sum of weighted energy losses is 3.806 Mev

TABLE B.2 ALTITUDE STUDY DATA

	Environmental Conditions					Measurements				Altimeter Correction Factor		
	Altimeter Reading (ft)	Altitude Marker (ft)	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Relative Humidity (%)	Avg Reading Standard #540 (μμa)	Bkg (μμa)	Avg Reading Standard #536 (μμa)	Bkg (μμa)			
A. Mount Diablo												
Instrument Check												
Altimeter set at 30.04 inches Hg at local airport	3670	3849	87	66	31	214	0.043	12.0	0.046			
	2062	2100	88	65	27	227	0.040	12.8	0.042			
	182		92	72	37	245	0.039	13.0	0.040			
B. Echo Summit										Marker (ft)	Altimeter Reading at 1028 mB (ft)	Altimeter Reading to get Marker Value (ft)
Instrument Check												
Altimeter set at 1028 mB	626[illegible]		51	40	76							
(30.13 inches Hg) at local airport	7000		81	55	14	203	0.04	11.0	0.04	7000	7036	
	5424		88	65	27	207	0.04	11.5	0.06	6000	6054	1027
	4442		93	65	19	208	0.04	12.0	0.04	5000	5080	1026
	3470		92	66	23	219		12.5	0.06	4000	4170	1025
	2345		90	65	24	229	<0.1	13.0		3000	3145	1021
C. Tracerlab												
Instrument set at 30.08 inches Hg	0		72	62	57	243	0.050	13.5	0.055			

TABLE B. 3 CALCULATION OF AVERAGE ENERGY LOSS PER EMITTED ALPHA IN THE ION CHAMBER FOR DRY AIR AT 621 mm Hg

Region	1	2	3	4	5
Smallest path-length (cm)	2.46	3.00	3.50	4.00	4.50
Largest path-length (cm)	3.00	3.50	4.00	4.50	
Smallest angle (degrees)	0	35.0	45.4	52.0	56.8
Largest angle (degrees)	35.0	45.4	52.0	56.8	90
Percent solid angle (%)	57.4	13.7	7.8	4.8	16.3
Average path length (cm)	2.62	3.25	3.62	4.30	4.52
NTP equivalent path length (cm)	2.14	2.66	2.96	3.52	3.70
Residual NTP range (cm)	1.56	1.04	0.74	0.18	0
Residual energy (Mev)	2.85	2.06	1.50	0.25	0
Energy loss (Mev)	2.30	3.09	3.65	4.90	5.15
Weighted energy loss (Mev)	1.32	0.424	0.285	0.235	0.840

Sum of weighted energy losses is 3.104 Mev

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TRC 30 September 1997

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER
ATTENTION: OMI/Mr. William Bush

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The Defense Special Weapons Agency Security Office (OPSSI) has reviewed and approved the following reports for public release:

AD-840378L POR-2512
OPERATION ROLLER COASTER, Project 4.1, Plutonium Uptake by Animals Exposed to a Non-Nuclear Detonation of a Plutonium Bearing Weapon Simulant, Project Officers Report, dated 26 September 1968, R. H. Wilson, the author.

AD-482576 POR-2514
OPERATION ROLLER COASTER, Project 5.1B, Sticky Wire Evaluation, Project Officers Report, dated 23 May 1966, A. Zirkes, the author.

Distribution statement **"A"** now applies to both reports.

Ardith Jarrett

ARDITH JARRETT
Chief, Technical Resource Center