REPORT UUT-2
27 JAN 1954

UNIVERSITY OF UTAH
DUGWAY PROJECT
DUGWAY PROVING GROUND
DUGWAY, UTAH

SHIELDING EFFICIENCY OF REMOTE HANDLING CELL AND MONITORING ROOM

by
G. ABEL
K. ANDERSON
E. CAMPAGNA

OPERATED FOR THE
ARMY CHEMICAL CORPS
BY THE
UNIVERSITY OF UTAH
CONTRACT NO. DA-18-108-CML-4753

ACKNOWLEDGEMENTS

Robert Kaneko calibrated the instruments used, and helped to make many of the measurements. Corporal Haller and Corporal Schuma made the drawings in Appendix I. Dr. Marilyn G. Alder was responsible for the method of Appendix IV. Many of the University of Utah group aided in the cell operations.

SHIELDING EFFICIENCY OF REMOTE HANDLING CELL AND MONITORING ROOM

By

G. ABEL
K. ANDERSON
E. CAMPAGNA

Report UUT-2

27 January 1954

UNIVERSITY OF UTAH
DUGWAY PROJECT
DUGWAY PROVING GROUND
DUGWAY, UTAH

CONTENTS

INTRODUCTION

OBJECTIVES

The objectives of this investigation were:

1. To measure the attenuation of gamma rays by the remote handling cell windows and monitoring room windows when filled with (1) water and (2) zinc bromide solution.

2. To measure the quantity of scattered radiation issuing from the remote handling cell door slits.

3. To determine the magnitude of shielding provided by the concrete walls of the remote handling cell and monitoring room, and by the ceiling of the monitoring room.

4. To investigate the possible hazard from access holes and faulty concrete construction.

MATERIALS AND METHODS

The remote handling cell[1] windows were filled with water, and 30 cartridges with a total strength of 237 curies were placed in the cell. Radiation intensities outside the cell and monitoring room were measured at the windows, walls, and door slits, with the MX-5 Geiger counter survey meters.

The 30 cartridges (Table 1) were mounted in a 2-inch thick block, 11 inches long and 9.5 inches wide. The cartridges, about nine inches in length, were supported in an upright position. This cartridge support was placed at one end of a

[1]The remote handling cell is commonly referred to as the "filling cell"; this term is used throughout the report.

filling cell car body; during the course of the investigation it was moved to various known positions, marked by guide and stop strips fastened to the platform. At the opposite end of the car body, a Beckman MX-4 ionization chamber was mounted to measure the strength of the source. This meter was turned on and off with a mechanical hand and its dial read through the filling cell window.

TABLE 1: Activity of Cartridges

CARTRIDGE NUMBER	APPARENT ACTIVITY (curies)	CARTRIDGE NUMBER	APPARENT ACTIVITY (curies)
1	10.00	16	9.16
2	10.00	17	8.27
3	9.45	18	7.98
4	9.16	19	8.27
5	10.30	20	8.27
6	13.00	21	6.50
7	11.80	22	6.50
8	11.50	23	8.86
9	9.75	24	6.50
10	10.90	25	6.50
11	12.10	26	6.20
12	9.33*	27	9.16
13	11.20	28	8.86
14	11.20	29	10.60
15	9.33*	30	9.16

*The value 9.33 curies is an average of the other 28 cartridges. Since the cartridges contained different weights of agent, this is not a true average.

With the source successively located at four positions in the filling cell and at one position in the monitoring room, measurements were made at various locations outside the cell with an MX-5.

The distance between the source and the side walls of the cell was varied by moving the source along the car body with a mechanical hand. The distance between the source and the end walls was varied by moving the car by means of the remote-control, cable-conveyor system.

Because of space limitations on the car body, the Beckman MX-4 was located 4.5 feet above the source level when the two determinations of the effective strength of the cartridge source were made. The difference between the total strength, in curies, determined from the sum of the individual cartridge activities and the total strength obtained from MX-4 readings was caused by self-absorption.

Since the source was unsymmetrical, the effects of self-absorption varied with the location of the measuring instruments. To eliminate this variation, some of the measurements were repeated using a spherical source.

The additional measurements were made at the cell windows with an MX-4 ionization chamber, utilizing a spherical source of approximately 7.18 curies. A mechanical hand was used to hold the source and subsequently to place it in a wooden rack at a known position. This spherical source and the MX-4 ionization chamber were used to take readings at the slit of the opened filling cell doors. The sphere was placed inside the cell in a wooden rack one foot from the wall and directly opposite the door slit. The MX-4 was placed at the same height as the source.

Additional measurements were taken at the slit of the opened filling cell doors with a crystal scintillation counter and a 25-millicurie standard radium source. This radium source was placed in a wooden rack about one foot from the slit on the south side of the opened filling cell door. The counter was placed at the height of the source.

During filling operations for the Walter Kidde Heat Test, measurements were made of the intensity of the gamma radiation outside the zinc bromide-filled windows, through the walls, and through the slit of the closed filling cell doors. The apparent strength of the source used in these tests was 8200 curies.[2] Four agent-filled spheres were immersed in an oil bath on one side of the cell and the other four were placed in the car body on the opposite side. The different locations of the samples made an accurate estimate of the apparent strength impossible; for the calculations, an effective source of 5000 curies was assumed.

Measurements were also made of the shielding provided by the monitoring room windows, walls, and ceiling. Radioactive agent from five of the original shipping containers for the agent used in the heat test comprised the source. Three of the original agent-filled shipping containers were used as a part of this source. The material from the other two containers had previously

---

[2] Measurements of the radiation intensities of the spheres are given in Appendix IV.

been transferred to smaller containers; these smaller containers comprised the remainder of the source. The effective source was about 8000 curies. Measurements made at different locations varied considerably as a result of the shielding provided by the lead barricade and the machinery fixed on the car body. The calculations for these measurements are approximate only, because the position of the car in the monitoring room was not exactly known for this series of measurements.

The rack of eight spheres with an apparent activity of 8200 curies was then used as a source in measuring the shielding provided by the zinc bromide solution in the windows and by the concrete walls and doors. The magnitude of the radiation scattered through the door slits was determined, and the presence of the "geometry effect" observed in the first set of measurements was verified. Each one of the eight spheres used in this test was measured separately using a slit system in which the monitoring room doors were opened about one foot. A wooden rack, built so that the spheres would be off-set vertically, was then loaded with the spheres and the radiation intensity measured through the slit. The source was rotated 90, 180, and 270 degrees and measured in each of these positions. The source thus formed the corners of a tilted cube about nine inches on a side.

Special measurements were made to verify the scattering effect noticed during the first set of measurements when the windows were

filled with water. The test was made by opening the doors which formed the slit at the time the most intense sphere was measured. An MX-5 Geiger counter, MX-4 ionization chamber, and a lab monitor were used for these measurements.

A description of each of the monitoring positions as well as diagrams showing the source locations and monitoring positions may be found in Appendix I.

RESULTS

The complete results are given in Appendix II. The intensity measurements were divided into three classes: (M), where the measured value of intensity is much more than the theoretical value; (S), where the measured value is of the same order of magnitude as the theoretical value; and (L), where the measured value is much less than the theoretical value. A possible reason for the (M) and (L) locations is listed below.

Since a large number of positions were monitored for each source location, and since the description of the positions is rather lengthy, a number was assigned to each position and a letter to each source location. The positions are described briefly in Appendix I; the positions and locations are shown in Appendix I, Figures 1 thru 8. Figure 9 of Appendix I is a photograph of the west wall of the filling cell.

The M and L locations listed below are for water-filled windows and the 30-cartridge source.

M Locations

18	Access hole
19	Access hole
20	Access hole
27	Space between door and wall of cell (slit)
28	Space between door and wall of cell (slit)
29	Space between door and wall of cell (slit)
31	Space between door and wall of cell (slit)
32	Space between door and wall of cell (slit)
33	Space between door and wall of cell (slit)
C-35	Louver and air duct dimensions not accurately known
B-36	Louver and air duct dimensions not accurately known
44	Access hole
49	Space between door and wall of cell
B-55	Irregularity of bottom of water tank spoils calculations
F-56	Irregularity of bottom of water tank spoils calculations
C-56	Irregularity of bottom of water tank spoils calculations
61	Access hole
62	Access hole
64	Access hole
65	Access hole
68	Access hole
69	Access hole
70	Access hole
74	Access hole for Greer Arm
77	Space between door and wall of cell
78	Space between door and wall of cell
79	Space between door and wall of cell
80	Space between door and wall of cell
81	Space between door and wall of cell
83	Space between door and wall of cell
85	Louver and air duct dimensions not accurately known
86	Louver and air duct dimensions not accurately known
88	Access hole
89	Access hole
H-101	Access hole
102	Hole for conduit allows scattered radiation
103	Access hole

104	Access hole
106	Access hole
108	Scattered radiation from ceiling of cell comes through panel
117	Access hole

L Locations

F-36	Completely different from F-86 and similar measurements; probably irregular air duct
H-48	Similar to F-47, B-96, C-97, etc.
F-49	Source was not a point source
G-59	Similar to F-47, B-96, C-97, etc.
F-97	Similar to F-47, B-96, C-97, etc.
H-98	Similar to F-47, B-96, C-97, etc.
H-109	Absorption by filling cell car not considered in the calculation
H-110	Absorption by filling cell car not considered in the calculation
G'-78	Source was not a point source
G'-80	Source was not a point source
G"-(North slit)-	Source was not a point source
G"-(South slit)-	Source was not a point source
Source passing slit-	Source was not a point source

A comparison of the measured and theoretical radiation intensities is not included for the data taken with the scintillation counter and the source of eight spheres, containing 8200 apparent curies. However, the following results were obtained:

M Locations

D- 13	An unplugged access hole
51	Some contamination on floor on west side
54	Some contamination on floor on west side
68	A partially plugged hole
117	An open hole
119	A partially plugged hole
S-409	An open hole

Doors Open

F- 27	Scattering through the open door slit
28	Scattering through the open door slit
29	Scattering through the open door slit
31	Scattering through the open door slit
32	Scattering through the open door slit
33	Scattering through the open door slit
34	Scattering through the open door slit
43	Unknown
44	Unknown
81	Scattering through the open door slit
82	Scattering through the open door slit
83	Scattering through the open door slit
101	Scattered radiation plus partially plugged holes
103	Scattered radiation plus partially plugged holes
105	Scattered radiation plus partially plugged holes

Doors Closed

F- 78	Scattering through slit
82	Scattering through slit

The data in Tables 2 and 3 are a summary of the measurements made to determine the absorption of the filling cell window when it was filled first with water and then with zinc bromide solution. Complete measurements may be found in Appendix II. Sample calculations are in Appendix III.

TABLE 2: Absorption of Water-filled Cell Windows

MEASURING INSTRUMENT LOCATION	SOURCE LOCATION	MEASURED INTENSITY (mr/hr)	CALCULATED INTENSITY (mr/hr)	MEASURED REDUCTION FACTOR	CALCULATED REDUCTION FACTOR
30-cartridge Source					
Cell Window	1 ft from window 6 ft from MX-5	5.5	8.25	8320	5540
Cell Window	5 ft from window 10 ft from MX-5	2.0	2.95	8220	5540
Monitoring Room Window	6 ft from window 8 ft from T-1B	700	1220	36.7	21.1
Single, 7.18-curie, Spherical Source					
Cell Window	1 ft from window 6 ft from MX-4	0.30	0.25	4610	5540
Monitoring Room Window	1 ft from window 4 ft from MX-4	112	145	27.8	21.5

TABLE 3: Absorption of Zinc Bromide-filled Cell Windows

MEASURING INSTRUMENT LOCATION	SOURCE LOCATION	MEASURED INTENSITY (mr/hr)	CALCULATED INTENSITY (mr/hr)	MEASURED REDUCTION FACTOR	CALCULATED REDUCTION FACTOR
Assuming Effective Source of 5000 Curies					
Cell Window	5 ft from window 10 ft from MX-5	0.05	1×10^{-3}	7×10^{6}	3.5×10^{8}
Assuming Effective Source of 8000 Curies					
Monitoring Room Window	8 ft from window 10 ft from MX-5	300	420	1.9×10^{3}	1.3×10^{3}
8-sphere, 8200-curie Source					
Cell Window	5 ft from window 10 ft from MX-5	0.045	1.8×10^{-3}	8×10^{6}	3.5×10^{8}

Figures 1 and 2 show the effects of scattering at the door slits. Using a source of 8200 curies at position F, the maximum radiation measured at the slit was 2.0 mr/hr when the filling cell doors were open, and 1.5 mr/hr when the doors were closed.

Table 4 is a summary of the data taken to determine the shielding of the walls of the filling cell and the walls and ceiling of the monitoring room.

TABLE 4: Absorption of Gamma Radiation by Thick Walls

POSITION	RADIATION INTENSITY		REMARKS
	Measured (mr/hr)	Calculated (mr/hr)	
30-cartridge Source			
B- 5	Bg*	1.4×10^{-4}	Indecisive
11	Bg	4.6×10^{-5}	Indecisive
55	0.06	2.2×10^{-3}	Too high
61	0.20	8.6×10^{-6}	Too high
107	Bg	1.0×10^{-7}	Indecisive
119	Bg	1.5×10^{-4}	Indecisive
C- 6	Bg	1.4×10^{-4}	Indecisive
12	Bg	4.6×10^{-5}	Indecisive
56	0.04	2.1×10^{-3}	Too high
62	0.30	8.6×10^{-6}	Too high
102	0.20	0.02	Too high
107	Bg	4.0×10^{-3}	Indecisive
108	13	1.8	Too high
1 ft below 108	0.40	1.0×10^{-3}	Too high
F- 6	Bg	2.0×10^{-4}	Indecisive
12	Bg	3.6×10^{-5}	Indecisive
56	0.04	2.1×10^{-4}	Too high
62	0.03	3.6×10^{-5}	Too high
107	Bg	2.6×10^{-7}	Indecisive
108	15	4.0	Too high
G- 85	0.7	4.5×10^{-3}	Too high

Continued on page 18

*Bg denotes background

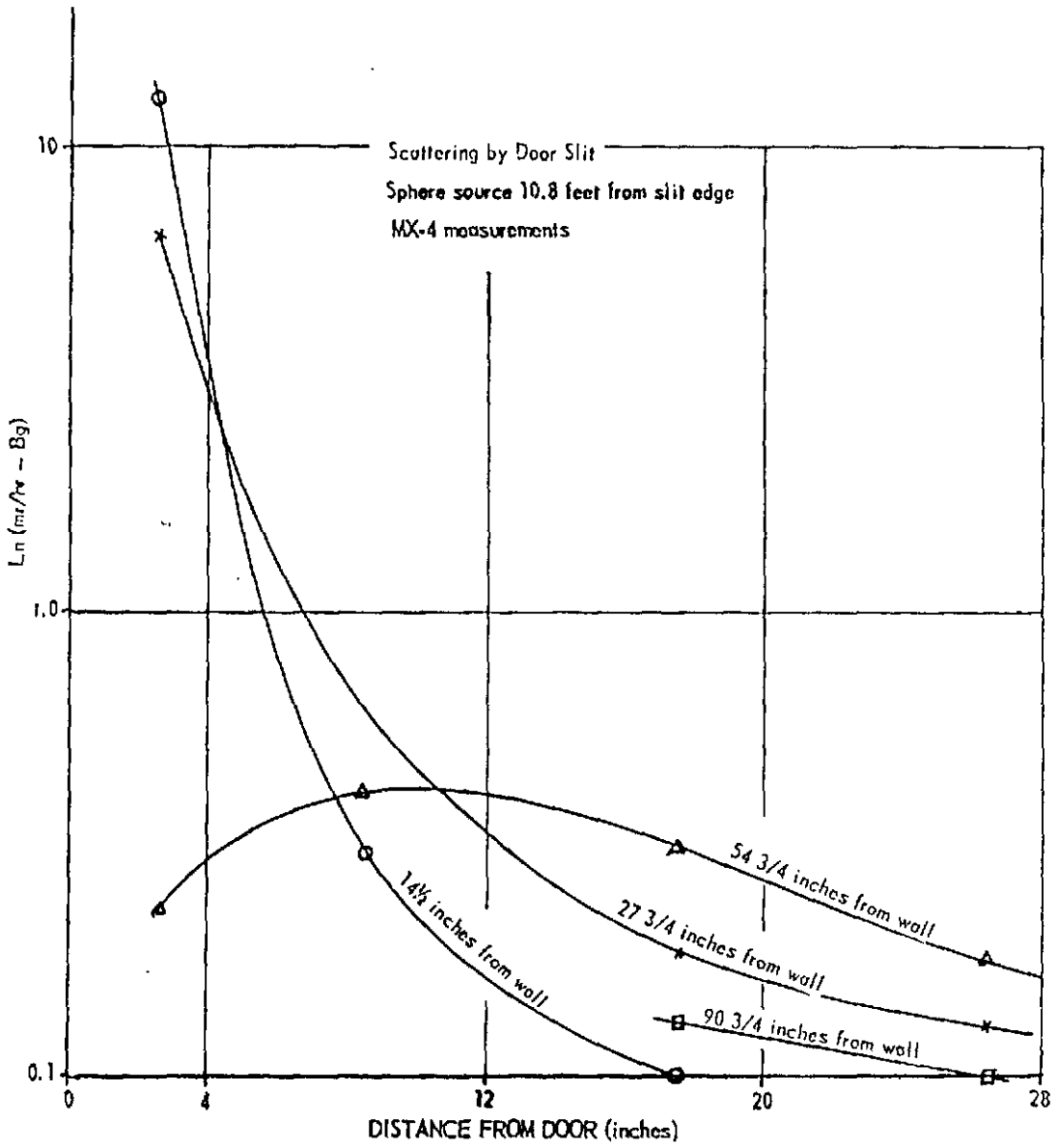

Fig. 1. – Scattering of radiation by door slit.

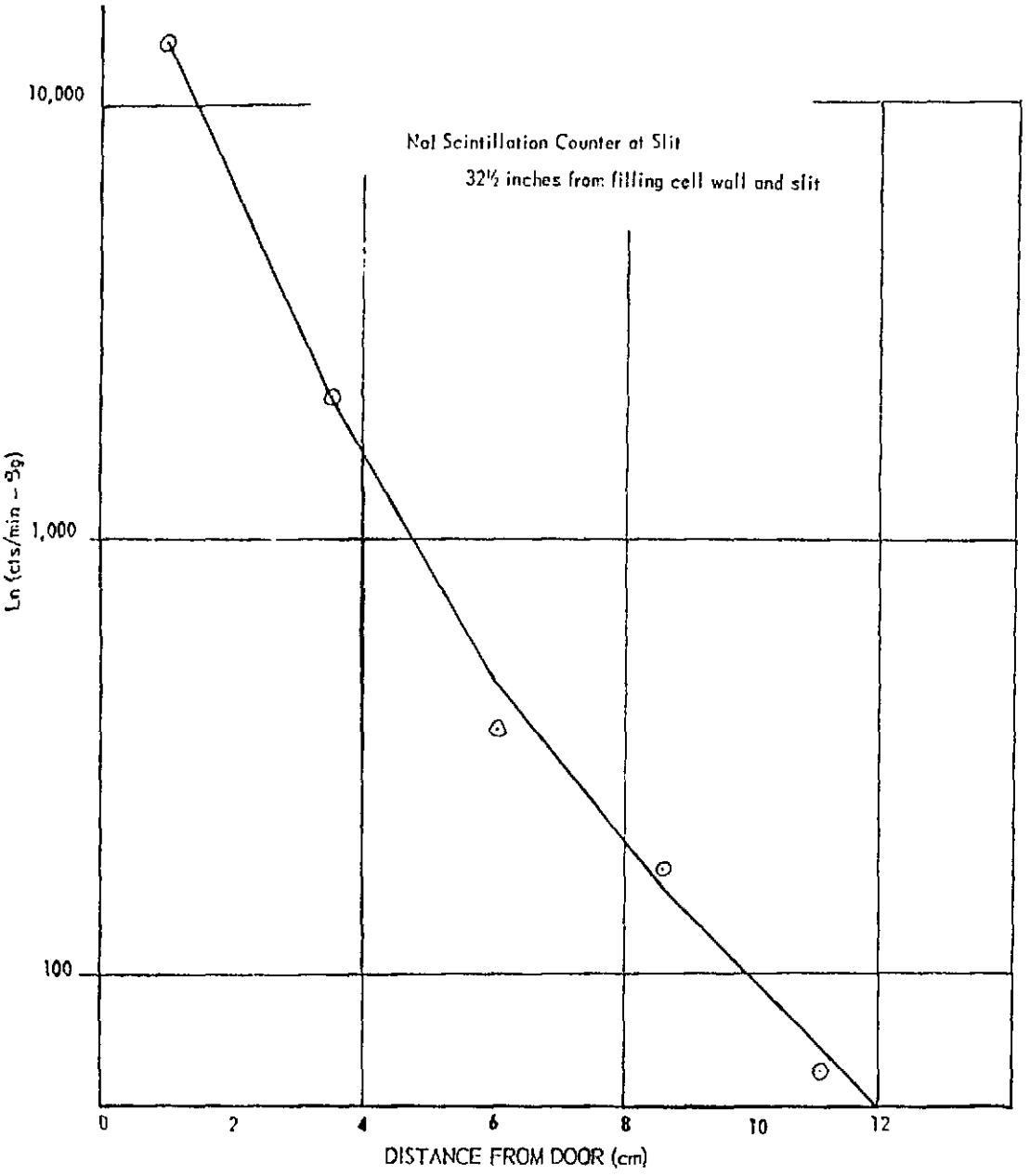

Fig. 2. – NaI scintillation counter at slit.

TABLE 4: Absorption of Gamma Radiation by Thick Walls (Continued)

POSITION	RADIATION INTENSITY		REMARKS
	Measured (mr/hr)	Calculated (mr/hr)	
G- 88	0.05	0.04	All right
89	0.02	0.074	All right
H- 35	40	36.5	All right
43	3.5	1.9	All right
44	0.75	0.26	All right
85	42	36.5	All right
93	5	1.9	All right
94	0.5	0.26	All right
H-101	300	7.8	Too high
102	130	20.8	Too high
103	50	1.9	Too high
104	250	1.9	Too high
Single, 7.18-curie, Spherical Source			
H -156	44	64	All right
Assuming Effective Source of 5000 Curies			
H- 4	0.10	1.1×10^{-3}	Too high
10	Bg	8.2×10^{-4}	Indecisive
107	12	6.7×10^{-6}	Too high
108	1000-2000	0.02	Too high
114	0.04	4.9×10^{-3}	Too high
Assuming Effective Source of 8000 Curies			
H-103	1500	645	All right
6 ft above H-102	120	332	All right
8-sphere, 8200-curie Source			
D- 4	0.06	8.2×10^{-3}	Too high
5	Bg	1.5×10^{-3}	Indecisive
10	0.05	1.2×10^{-3}	Too high
11	0.03	8.4×10^{-7}	Too high
54	0.17	7.8×10^{-3}	Too high
55	0.08	7.7×10^{-3}	Too high
60	0.04	1.2×10^{-3}	Too high
114	0.04	2.5×10^{-3}	Too high
119	0.60	7.8×10^{-3}	Too high

Continued

TABLE 4: Absorption of Gamma Radiation by Thick Walls (Concluded)

POSITION	RADIATION INTENSITY		REMARKS
	Measured (mr/hr)	Calculated (mr/hr)	
F- 6	0.05	8.8×10^{-3}	Too high
36	0.50	0.39	All right
43	1.0	2.0×10^{-3}	Too high
44	1.0	3.3×10^{-3}	Too high
101	17	2.4×10^{-11}	Too high
103	17	4.8×10^{-11}	Too high
105	12	5.1×10^{-5}	Too high
107	10	2.0×10^{-6}	Too high
Doors Closed			
F- 6	0.05	8.2×10^{-3}	Too high
62	0.05	1.2×10^{-3}	Too high

When a source of 8200 curies was located near the unplugged access holes, readings made in line with the holes were:

D- 13	1.0 mr/hr
D-117	26.0
D-S409	60.0

For plugged access holes the readings were:

D-116	0.10 mr/hr
D-S401?	0.08
F-2'	0.06
F-65	Bg

These results show that even the unplugged access holes offer little hazard to personnel since little radiation reaches the work area.

DISCUSSION

Since the order of magnitude of ionization was considered more important than the actual intensity in milliroentgens per hour, the MX-5 Geiger Counter was used, even though it is not recommended for measuring gamma radiation. The radiation intensity measurements of the MX-5 agreed within a factor of two with those of the Beckman MX-4.

An increase in counted radiation outside thick walls, caused by scattering by the walls, has been observed. The scattered radiation must be included when the radiation outside the filling cell and monitoring room is calculated. An empirical equation giving the true radiation intensity is called a "build-up equation." Hirschfelder and Magee[3] obtained the following equations for gamma absorption through thick media at the energy levels indicated:

1 Mev: $I = I_o (1 + 0.487\ D + 0.030\ D^2)e^{-D}$, where $D = \mu x$

3 Mev: $I = I_o (1 + 0.400\ D + 0.0080D^2)e^{-D}$

5 Mev: $I = I_o (1 + 0.33\ D + 0.0040D^2)e^{-D}$

By plotting the coefficients of D against Mev on semilog paper and the coefficients of D^2 against Mev on log-log paper, the coefficients for 1.15 Mev were interpolated. In this manner an equation was derived for the 1.15-Mev source:

$$I = I_o (1 + 0.480\ D + 0.025\ D^2)e^{-D}$$

---

[3]Hirschfelder and Magee. Review of Modern Physics. 1948.20:305

The equation of the curve of the quantity in parenthesis, often called the B or "build-up factor", versus D was then calculated and plotted for use in the calculations (Fig. 3). The equation derived from the equations of Hirschfelder and Magee did not accurately fit this data. Since the build-up factor is a function of several complicated geometry factors; it probably will be unique for each installation and experimental set-up.

An equation which gives a better fit for the conditions at Able Area, Dugway Proving Ground is:

$$I = I_o e^{-\mu x}\left[1 + 0.5\mu x + 0.01(\mu x)^2 + 0.5\times10^{-8}\ (\mu x)^8\right]$$

The data obtained with the 30-cartridge, and 8-sphere sources were used to determine this equation; the equation has not been checked with all the data.

In previous work done at Able Area,[4] the absorption coefficient of zinc bromide solution was determined to be 0.147 cm^{-1}. This value was used in calculations for this work.

CONCLUSIONS

1. The zinc bromide-filled windows offer more shielding than the concrete walls in which they are set.

2. With the zinc bromide solution in the windows, a million curies can be safely handled in the filling cell provided the north light-access panel is avoided.

---

[4]E. A. Campagna. A Determination of the Half-Thickness of Zinc Bromide Solution. UUT-III. University of Utah. Radiological Research, Dugway Project, Dugway Proving Ground, Dugway, Utah. 22 July 1953.

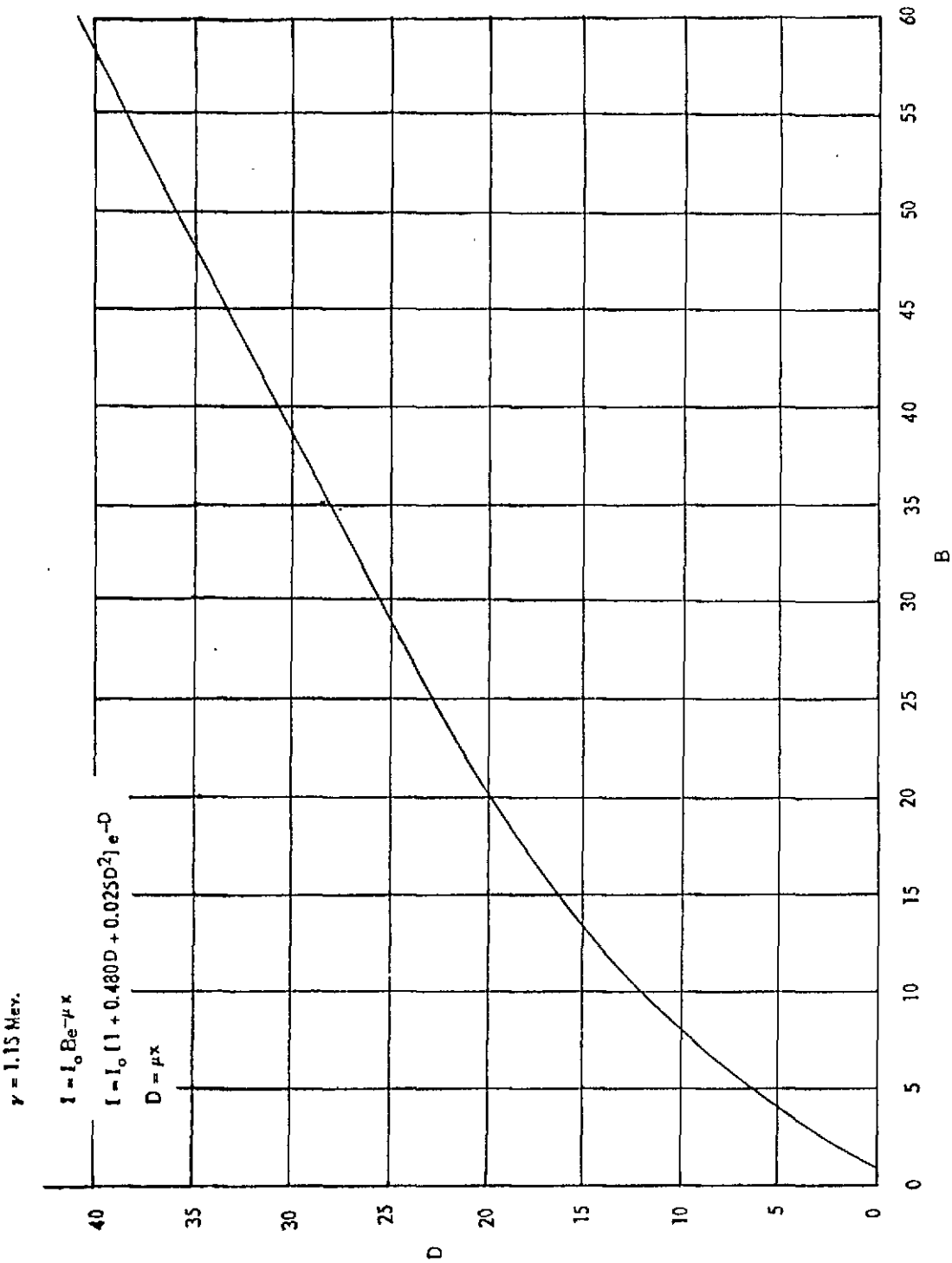

Fig. 3-Gamma absorption for thick walls

3. The light-access panel on the north wall of the filling cell is dangerous when more than 100 curies are exposed in the filling cell.

4. The monitoring room windows, even though filled with zinc bromide solution, provide insufficient shielding if more than 1000 curies are exposed within this room.

5. The walls and roof of the monitoring room should be considered unsafe if more than 1000 curies are exposed in this room or if more than 10,000 curies are exposed in the filling cell and the filling cell doors are left open.

6. There is little danger from scattered radiation coming through the door slits.

7. The access holes of the filling cell, even when completely open, offer no hazard to personnel involved in normal operations around the cell.

8. There may be a few air holes in the concrete, but they offer no serious hazard to personnel.

9. Accurate calculation of radiation intensity can be made for water-filled windows using the Hirschfelder-Magee equation. Calculations using this equation break down when more than three feet of concrete, or zinc bromide solution must be considered. In the filling cell, calculations using the equation are low by a factor of about 25.

APPENDIX I

MONITORING POSITIONS AND SOURCE LOCATIONS

Description of Monitoring Positions

POSITION NUMBER		DESCRIPTION*
East Wall	West Wall	
1	51	Against south window, 6 inches above its bottom
2	52	Against center window, 6 inches above its bottom
3	53	Against north window, 6 inches above its bottom
4	54	Against wall, 1 foot below south window
5	55	Against wall, 1 foot below center window
6	56	Against wall, 1 foot below north window
7	57	4 feet from south window, 5 feet above platform
8	58	4 feet from center window, 5 feet above platform
9	59	4 feet from north window, 5 feet above platform
10	60	Against wall under platform, 5 feet above plug 207
11	61	Against wall under platform, 5 feet above plug 206
12	62	Against wall under platform, 5 feet above plug 205
13	63	Against plug 207
14	64	Against plug 206
15	65	Against plug 205
16	66	Against plug 408
17	67	Against plug 407
18	68	Against plug 406
19	69	Against plug 405
20	70	Against plug 404
21	71	Against plug 509
22	72	Against plug 508
23	73	Against plug 507 (W 507 has Greer Arm)
24	74	Against plug 506 (W 506 has Greer Arm)
25	75	Against plug 505 (W 505 has Greer Arm)
26	76	Against plug 504 (W 504 has Greer Arm)
27	77	Against south side of opened door, 3 feet above platform
28	78	Against north side of opened door over slit, 3 feet above platform
29	79	Against south side of opened door over slit, 3 feet above platform
30	80	Against north side of opened door at door edge (over slit), 3 feet above platform
31	81	South side of opened door, above platform, 5 feet above floor
32	82	North side of opened door, above platform, 5 feet above floor
33	83	South side of opened door, above platform, 5 feet above floor
34	84	North side of opened door, above platform, 5 feet above floor

Continued

*All measurements referring to windows are made with respect to their vertical center lines.

Description of Monitoring Positions (Concluded)

POSITION NUMBER East Wall	POSITION NUMBER West Wall	DESCRIPTION
35	85	Against wall, 2 feet below window
36	86	Against window, 6 inches above its bottom
37	87	Against plug 403
38	88	Against plug 402
39	89	Against plug 401
40	90	Against plug 503
41	91	Against plug 502
42	92	Against plug 501
43	93	Against wall, above 202, 5 feet above floor
44	94	Against plug 203
45	95	On top handrail opposite south window
46	96	On top handrail opposite center window
47	97	On top handrail opposite north window
48	98	On top handrail opposite monitoring room window
49	99	On top handrail opposite south slit
101		Against plug T7 above monitoring room
102		Over hole for electrical lines
103		Against plug T1 above monitoring room
104		Against plug T5 above monitoring room
105		Against plug N602 above monitoring room
106		Against plug N601 above monitoring room
107		Against cell wall halfway between N601 and N602, 5 feet above monitoring room roof
108		Above monitoring room, in center of panel N901
109		At east edge of closed door 2
110		At center edge of closed doors 1 and 2
111		At west edge of closed door 1
112		Against plug S205
113		Against plug S206
114		Against wall, above S205, 5 feet above floor
115		Against plug S403
116		Against plug S406
117		Against plug S408
118		Against plug S501
119		Against wall, below S408, 5 feet above platform
120		On top rail, opposite S408
121		At west edge of filling cell, 9 feet above monitoring room floor
122		In center of filling cell doors, 9 feet above monitoring room floor
123		At east edge of filling cell, on door, 9 feet above monitoring room floor

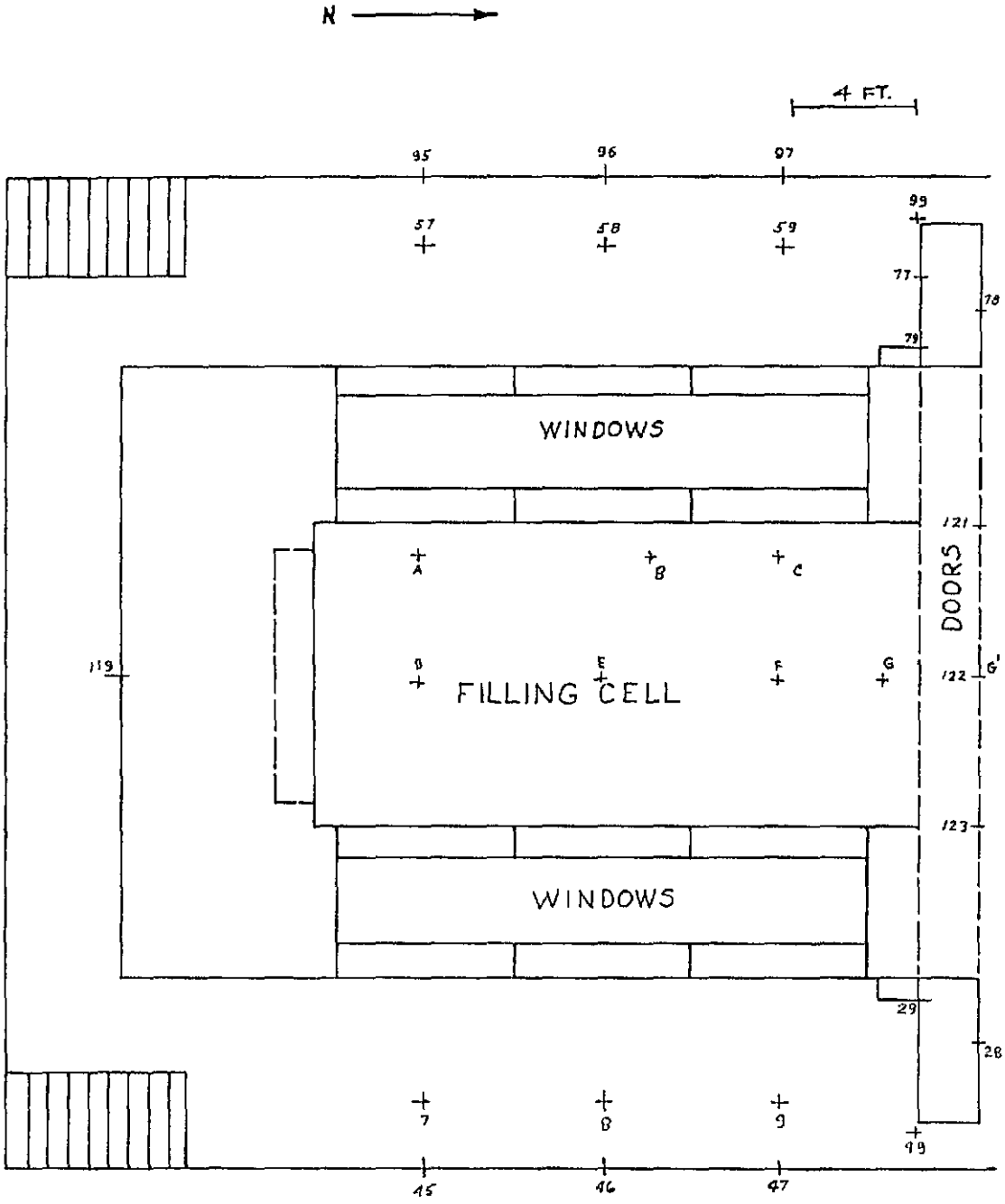

Fig. 1. – Top View of Filling Cell.

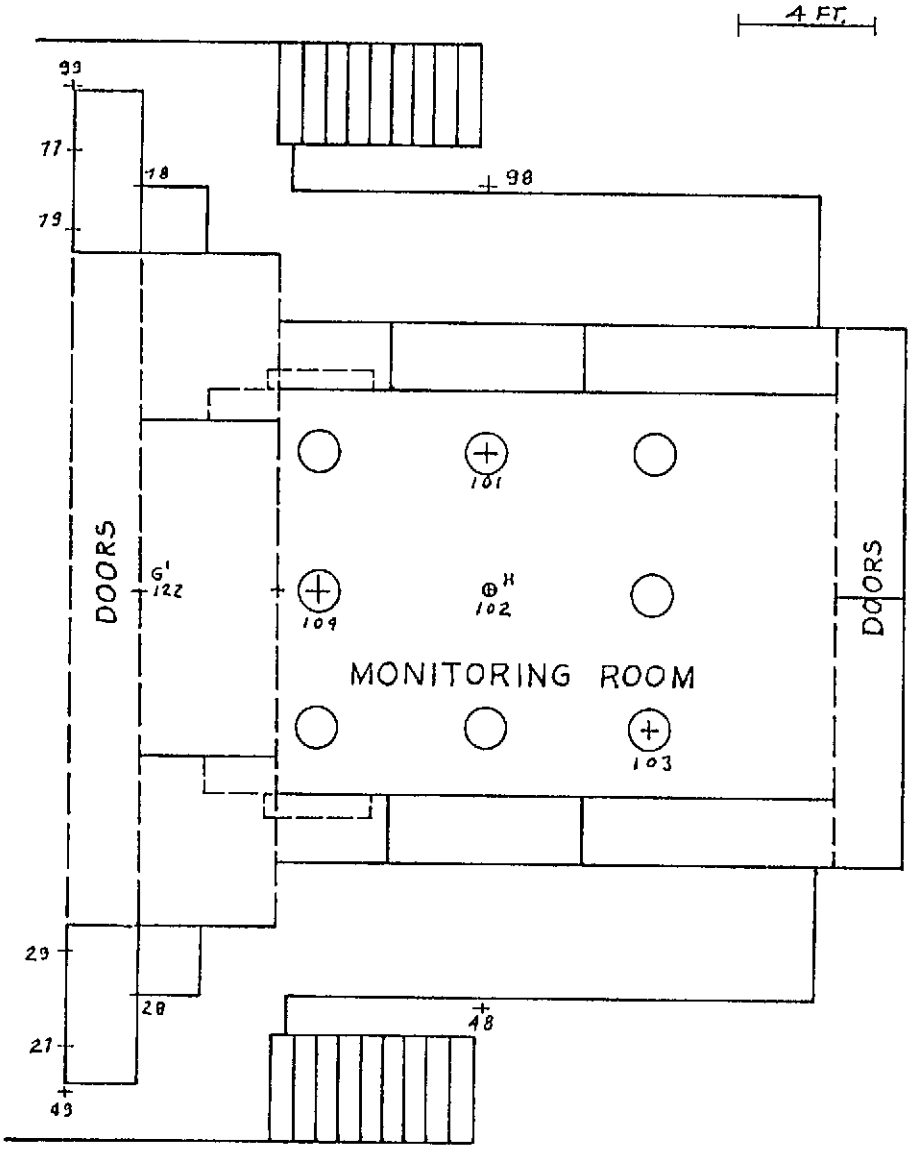

Fig. 2. – Top View of Monitoring Room.

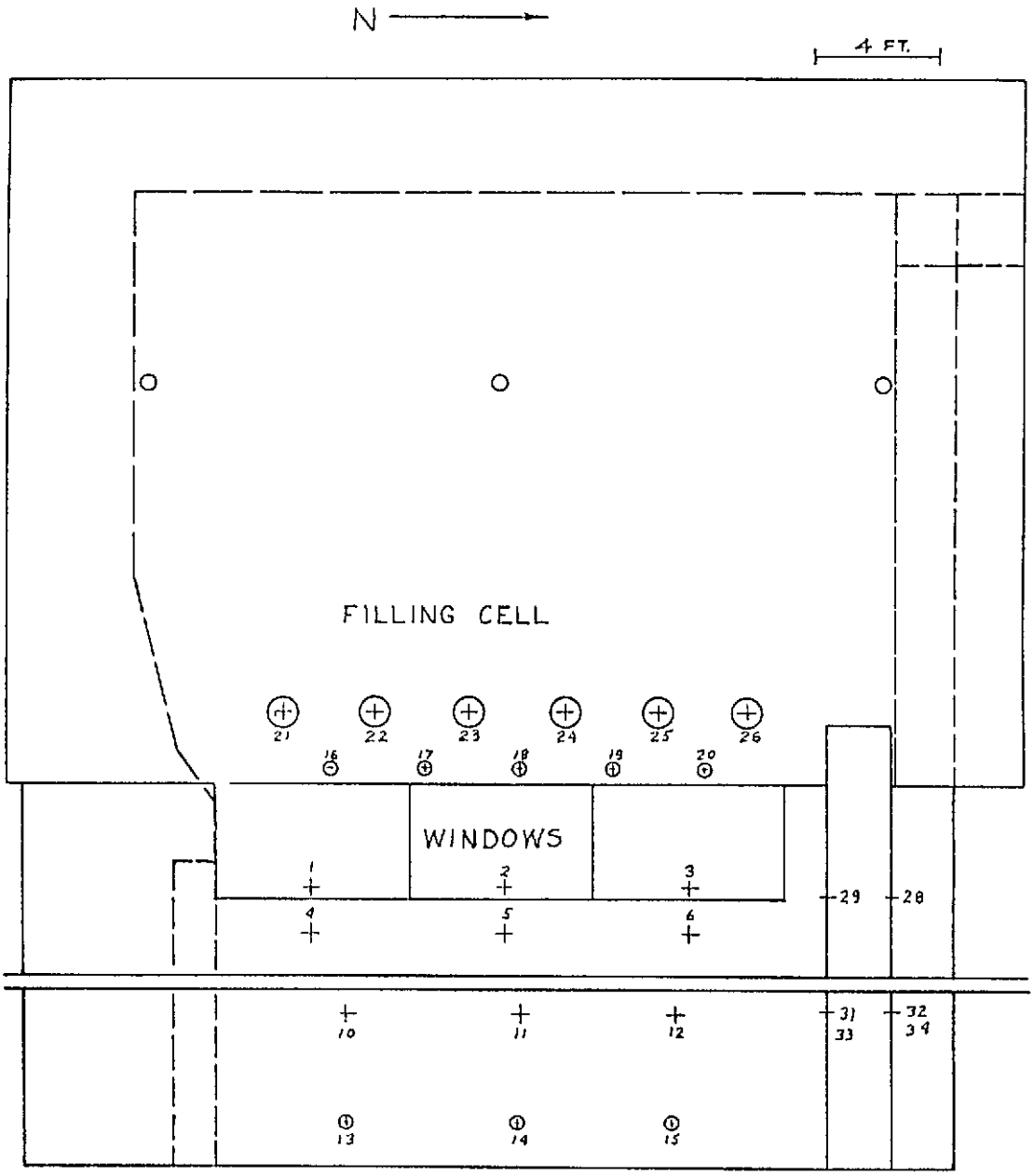

Fig. 3. – East Wall of Filling Cell.

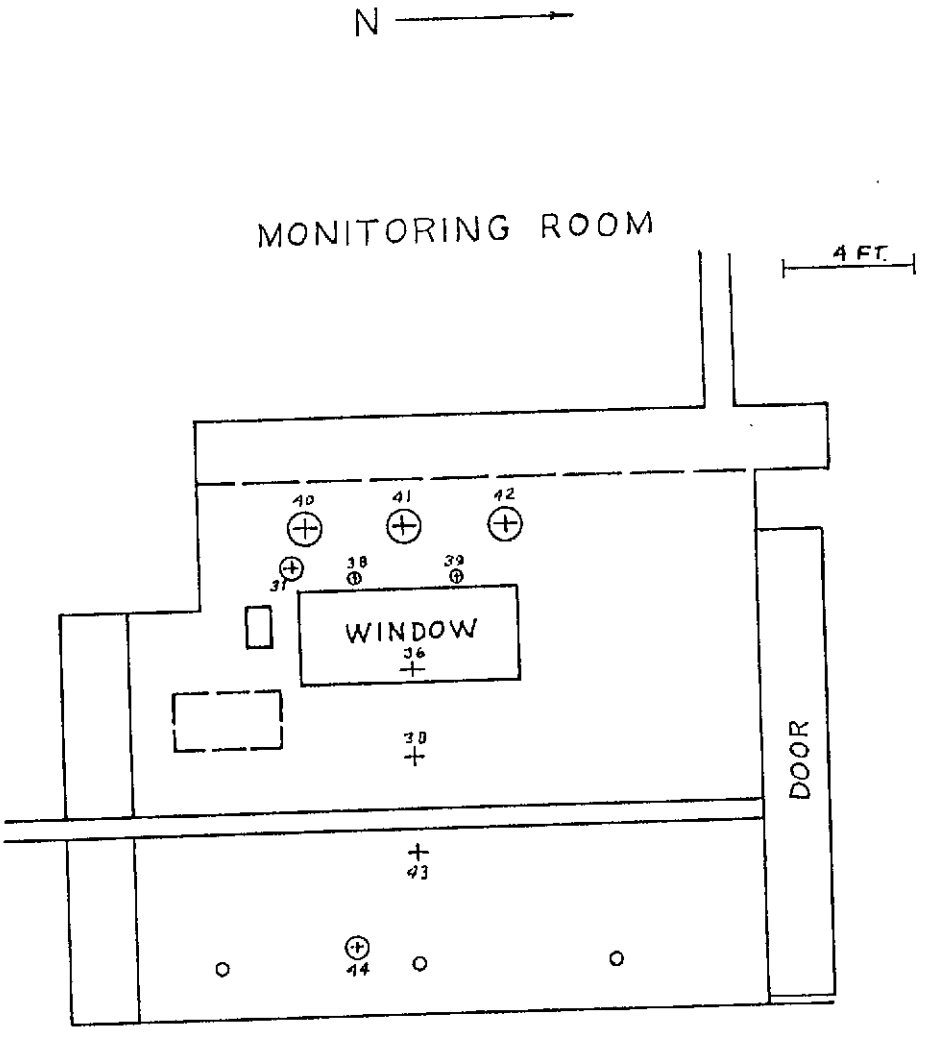

Fig. 4. – East Wall of Monitoring Room.

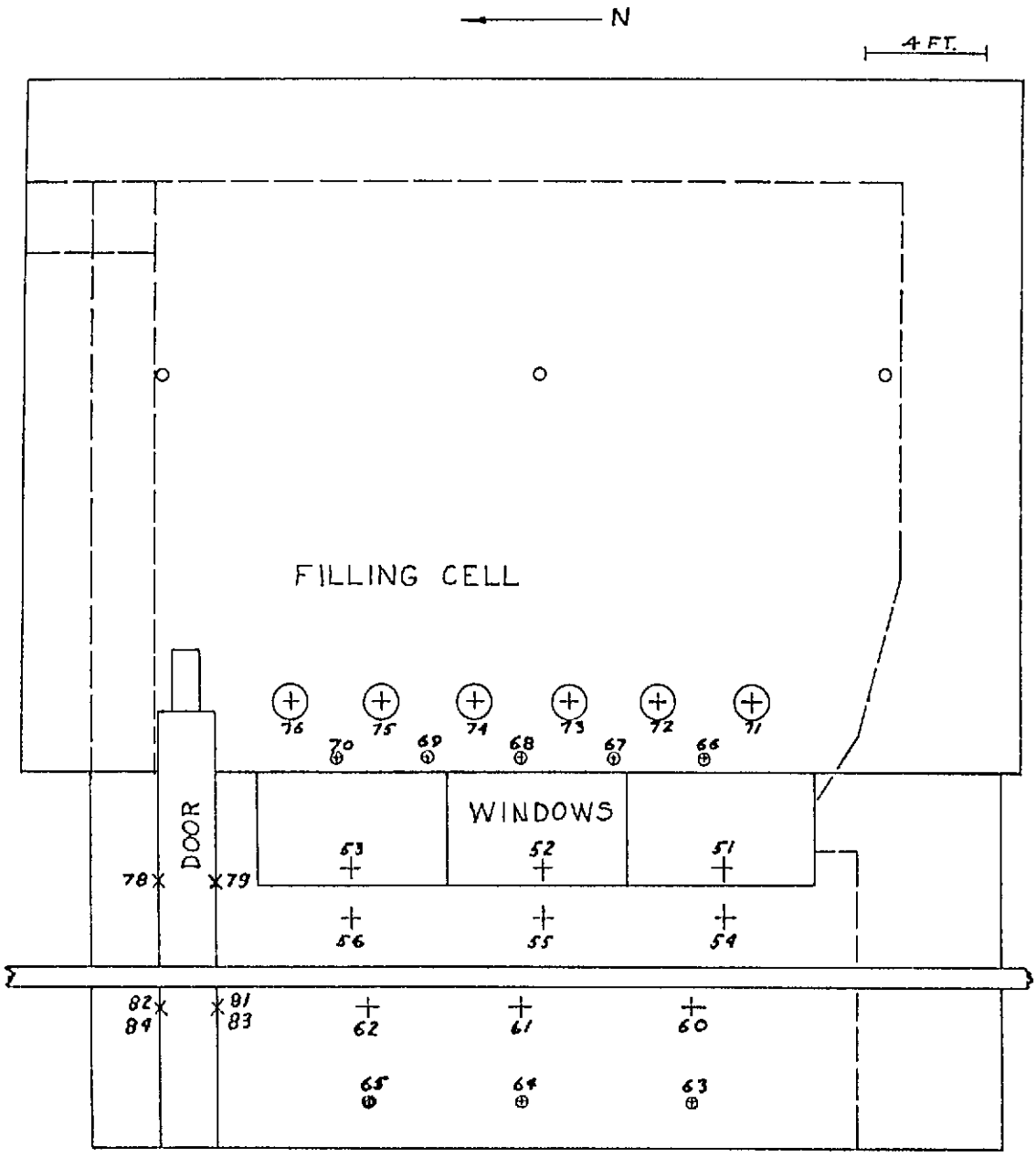

Fig. 5. – West Wall of Filling Cell.

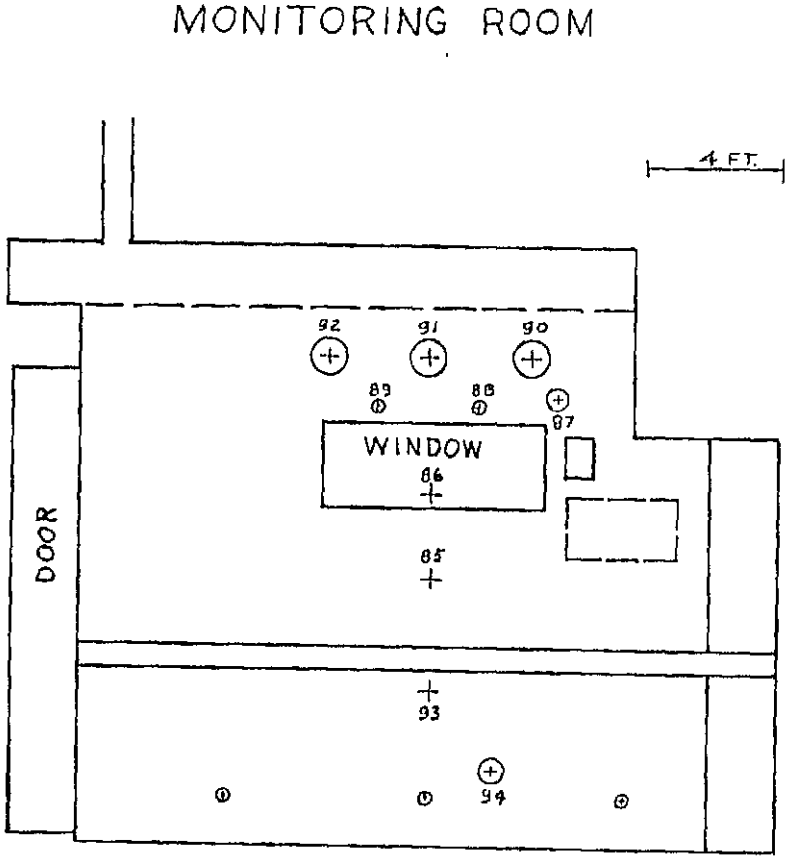

Fig. 6. – West Wall of Monitoring Room.

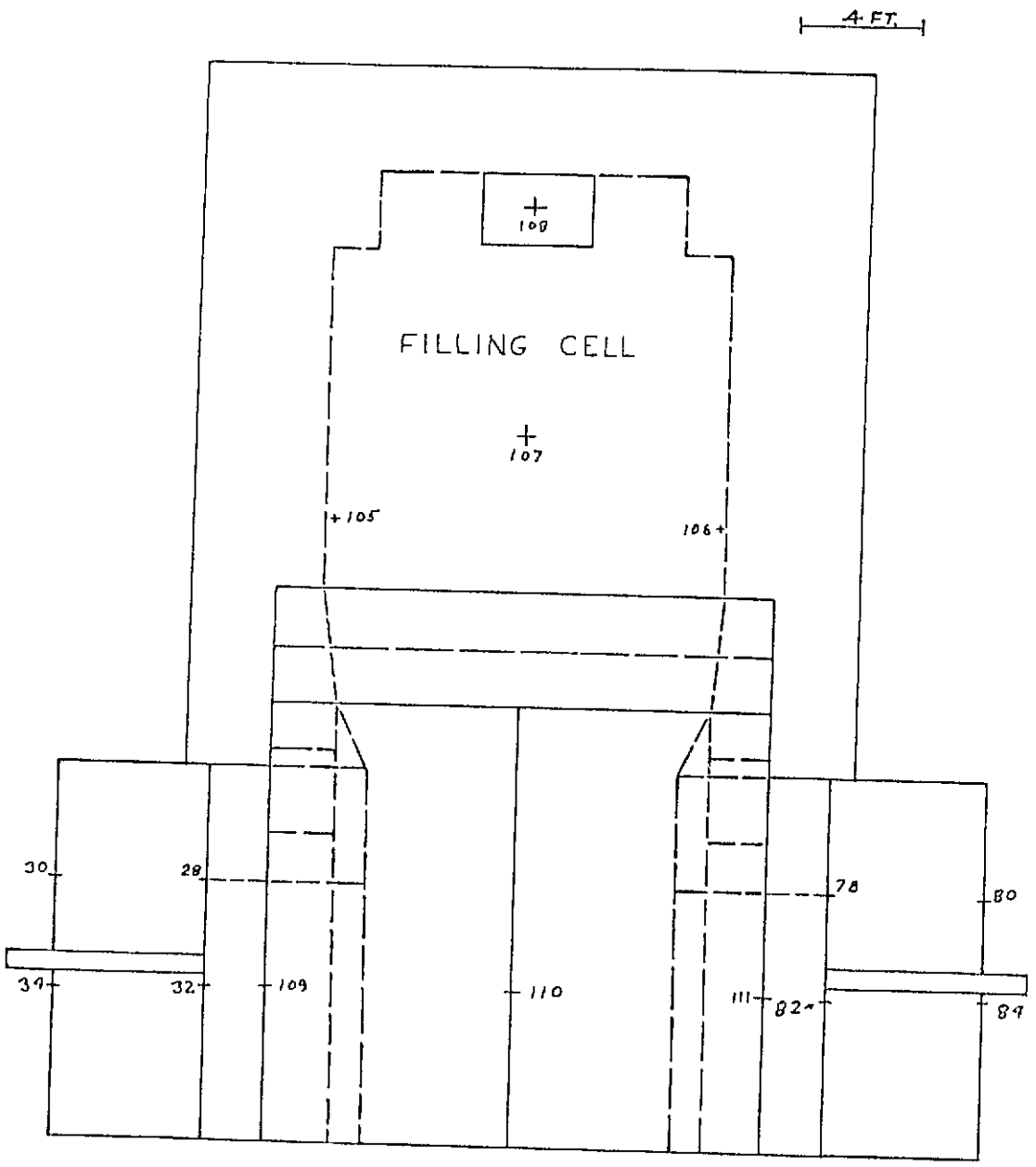

Fig. 7. – South Wall of Filling Cell.

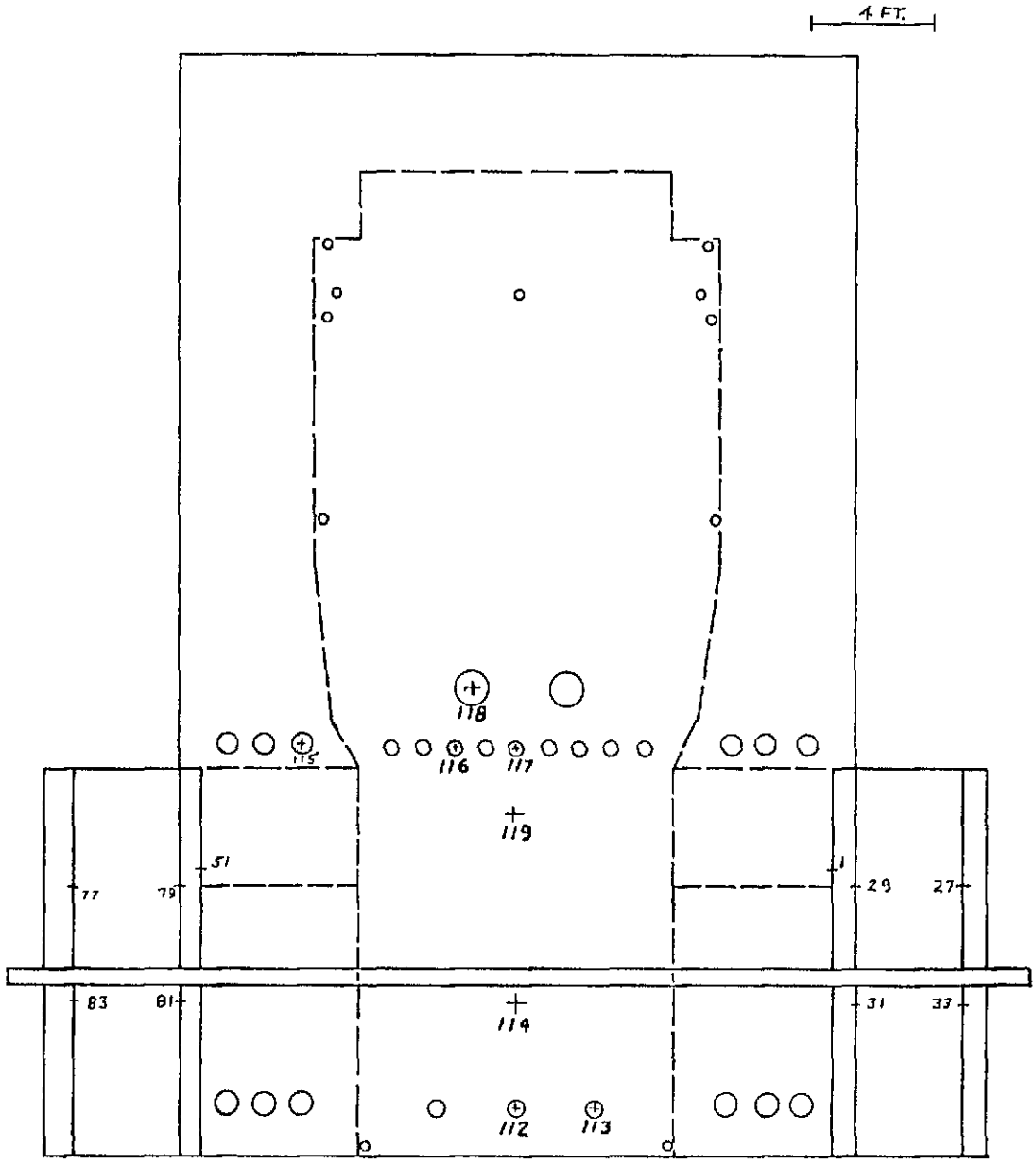

Fig. 8. – North Wall of Filling Cell.

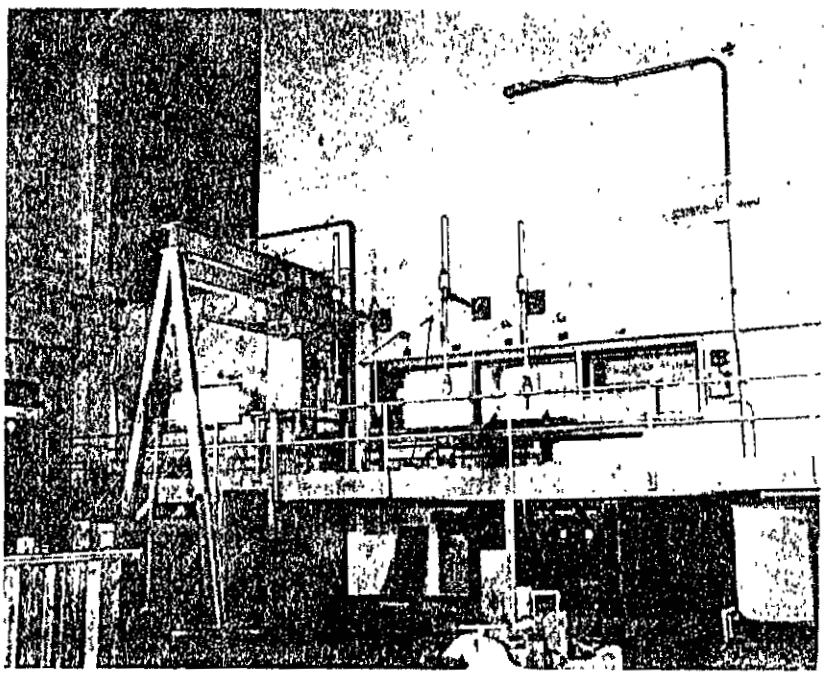

Fig. 9. – Photograph of West Wall of Filling Cell.

APPENDIX II

RADIATION INTENSITY MEASUREMENTS

TABLE 1: Comparison of Calculated and Measured Radiation Intensity With 30-cartridge Source and Water-filled Windows.

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-5 (ft^2)	TOTAL μx	B FACTOR*	RADIATION INTENSITY		CLASS*1
	Water (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)	
B- 2	145	10.2	0	196	10.84	9.2	1.52	1.0	S
5	0	0	152	196	21.1	21.9	1.4×10^{-4}	Bg*2	S
8	145	10.2	0	324	10.84	9.2	0.92	0.35	S
11	0	0	159	213	22.1	23.6	4.6×10^{-5}	Bg	S
14	0	0	174	256	24.2	27.2	5.4×10^{-6}	Bg	S
15	0	0	182	281	25.4	29.4	1.6×10^{-6}	Bg	S
18	95.5	5.1	82.3	235	18.3	18.0	1.4×10^{-3}	0.03	M
19	97.5	5.1	82.5	240	18.5	18.1	1.0×10^{-3}	Bg	S
27	16.3	11.4	0	384	12.2	10.7	0.23	2.0	M
28	56	5.0	198	384	31.8	41.9	2.8×10^{-9}	0.7	M
29	109	6.6	91	292	20.7	21.3	1.2×10^{-4}	1.5	M
35	0	0	82	552	11.4	9.8	0.2	0.2	S
36	202	14.2	0	635	14.97	13.8	0.01	3.5	M
52	145	10.2	0	36	10.84	9.0	8.0	5.5	S
53	183	12.7	0	57.8	13.8	12.45	0.35	0.2	S
55	24.8	2.5	128	384	19.76	19.8	2.2×10^{-3}	0.06	M
58	145	10.2	0	100	10.84	9.2	2.9	1.3	S
61	0	0	183	52.3	25.4	29.4	8.6×10^{-6}	0.2	M
64	0	0	250	96	34.8	48.6	6.4×10^{-10}	0.25	M
65	0	0	315	121	43.8	67.0	8.7×10^{-14}	0.45	M
68	147	5.1	48.8	61	17.1	16.3	0.018	0.3	M
69	157	5.6	52.4	70	18.5	18.2	4.0×10^{-3}	0.35	M
74	107	6.4	109	80	23.0	25.0	5.2×10^{-5}	0.13	M
96	145	10.2	0	156	10.84	9.2	1.9	0.55	S
104	0	0	193	370	26.8	32.0	3.3×10^{-7}	0.04	M
107	0	0	201	424	27.9	34.0	1.0×10^{-7}	Bg	S
108	0	0	131	729	18.2	17.8	5.0×10^{-3}	20	M
117	0	0	15	324	20.8	21.4	1.0×10^{-4}	0.3	M
119	0	0	14.7	324	20.4	20.7	1.5×10^{-4}	Bg	S
C- 2	156	11	0	225	11.65	10.1	0.64	0.4	S
3	145	10.2	0	196	10.84	9.2	1.5	0.9	S
6	0	0	152	196	21.1	21.9	1.4×10^{-4}	Bg	S
9	145	10.2	0	324	10.84	9.2	0.92	0.4	S
12	0	0	159	213	22.1	23.6	4.6×10^{-5}	Bg	S
15	0	0	174	256	24.2	27.2	5.4×10^{-6}	Bg	S

Continued

*See DISCUSSION.

*1See RESULTS.

*2Background.

TABLE 1: Comparison of Calculated and Measured Radiation Intensity With 30-cartridge Source and Water-filled Windows. (continued)

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-5 (ft^2)	TOTAL μx	B FACTOR*	RADIATION INTENSITY		CLASS*[1]
	Water (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)	
G- 19	97.5	5.1	82.5	240	18.5	18.1	1.0×10^{-3}	0.03	M
20	95.5	5.1	82.3	235	18.3	18.0	1.4×10^{-3}	0.04	M
24	0	0	211	266	29.35	36.7	4.0×10^{-8}	Bg	S
25	0	0	201	250	24.95	28.5	2.7×10^{-6}	Bg	S
27	56	5.1	147	324	24.75	28.1	2.6×10^{-6}	1.5	M
29	0	0	235	296	32.7	44.0	1.5×10^{-9}	2.0	M
31	0	0	193	340	27.8	33.8	1.4×10^{-7}	1.1	M
33	0	0	189	247	26.3	32.0	8.0×10^{-7}	1.5	M
35	0	0	107	428	14.9	13.7	0.018	0.3	M
36	97.9	8.9	0	428	7.6	6.2	11.9	7.5	S
44	0	0	111	445	15.47	14.4	0.01	0.4	M
52	196	13.8	0	70.6	14.64	13.5	0.15	0.05	S
53	145	10.2	0	36	10.84	9.0	8.0	5.5	S
55	35	3.6	181	77	27.9	34.0	5.5×10^{-7}	Bg	S
56	24.8	2.5	128	38.4	19.76	19.8	2.1×10^{-3}	0.04	M
59	145	10.2	0	100	10.84	9.2	2.9	1.3	S
62	0	0	183	53.3	25.4	29.4	8.6×10^{-6}	0.3	M
69	157	5.6	52.4	70	18.47	18.2	4.0×10^{-3}	0.04	M
70	147	5.1	48.8	61	17.1	16.3	0.18	0.2	M
86	185	2.5	228	408	44.1	71.4	2.0×10^{-34}	0.2	M
97	145	10.2	0	156	10.84	9.2	1.9	0.5	S
102	0	0	125	369	17.35	16.75	0.02	0.2	M
106	0	0	171	231	23.8	26.5	8.7×10^{-6}	0.05	M
107	0	0	120	400	16.7	15.9	4.0×10^{-3}	Bg	S
108	0	0	66.5	655	9.24	7.65	1.8	13	M
1 ft below 108	0	0	127	600	17.65	17.1	1×10^{-3}	0.4	M
F- 3	145	10.2	0	100	10.8	9.2	2.95	2.0	S
6	0	0	153	100	21.2	22.0	2.2×10^{-4}	Bg	S
9	145	10.2	0	196	10.8	9.2	1.6	0.7	S
12	0	0	165	117	23.0	25.2	3.6×10^{-5}	Bg	S
15	0	0	192	156	26.7	31.9	8.5×10^{-7}	Bg	S
19	125	6.4	62.3	136	17.7	17.2	4.7×10^{-3}	0.05	M
20	123	5.1	61	130	17.2	16.6	7.1×10^{-3}	0.08	M
27	119	5.1	153	199	29.7	37.4	3.9×10^{-8}	1.0	M
28	10.2	2.5	232	188	39.2	58.4	4.9×10^{-13}	2.0	M
29	61	5.2	122	132	21.7	23.0	1.1×10^{-4}	1.5	M
31	0	0	174	144	24.2	27.2	9.6×10^{-6}	1.0	M

Continued

TABLE 1: Comparison of Calculated and Measured Radiation Intensity With 30-cartridge Source and Water-filled Windows. (continued)

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-5 (ft^2)	TOTAL μx	B FACTOR*	RADIATION INTENSITY		CLASS*1
	Water (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)	
F- 32	0	0	252	200	35.0	49.0	2.5×10^{-10}	1.5	M
33	0	0	290	212	40.3	60.5	1.5×10^{-13}	0.5	M
35	0	0	175	350	24.3	27.3	3.6×10^{-9}	0.7	M
36	89	2.5	15.3	350	8.3	6.9	8.1	0.7	M
47	145	10.2	0	262	10.8	9.2	1.2	0.25	S
49	150	10.2	0	240	11.2	9.6	0.9	0.1	L
53	145	10.2	0	100	10.8	9.2	2.95	2.0	S
56	0	0	153	100	21.2	22.0	2.3×10^{-4}	0.04	M
59	145	10.2	0	196	10.8	9.2	1.58	0.7	S
62	0	0	165	117	23.0	25.2	3.6×10^{-5}	0.03	M
65	0	0	192	156	26.7	31.9	8.5×10^{-7}	0.05	M
69	125	6.4	62.2	136	17.6	17.0	4.7×10^{-3}	0.06	M
70	123	5.1	61	130	17.2	16.6	7.1×10^{-3}	Bg	S
76	37.6	5.1	153	146	24.4	27.6	7.9×10^{-6}	Bg	S
77	119	5.1	153	199	29.7	37.4	3.9×10^{-8}	0.6	M
79	61	5.1	122	132	21.7	23.0	1.1×10^{-4}	1.2	M
81	0	0	252	199	35.0	49.0	2.5×10^{-10}	2.0	M
83	0	0	290	212	40.3	60.5	1.5×10^{-12}	0.8	M
86	89	2.5	15.3	350	8.3	6.9	8.1	5.0	S
97	145	10.2	0	262	10.8	9.2	1.2	0.35	S
102	0	0	168	369	23.3	25.6	8.7×10^{-6}	0.2	M
105	0	0	196	276	27.2	32.7	3.0×10^{-7}	Bg	S
106	0	0	196	276	27.2	32.7	3.0×10^{-7}	Bg	S
107	0	0	196	310	27.2	32.7	2.6×10^{-7}	Bg	S
108	0	0	61	600	8.5	7.0	4	15	M
G- 27	0	0	155	185	21.5	22.6	9.2×10^{-5}	18	M
29	0	0	137	102	19.0	18.8	1.7×10^{-3}	15	M
49	0	0	155	272	21.5	22.6	6.2×10^{-5}	0.7	M
52	198	14	0	188	14.9	13.8	0.04	Bg	S
59	147	10.2	0	207	11.4	9.8	0.86	0.2	L
77	0	0	155	185	21.5	22.6	9.2×10^{-5}	80	M
78	0	0	160	108	22.2	23.8	8.2×10^{-5}	7.0	M
80	0	0	244	196	33.9	46.6	7.4×10^{-10}	1.5	M
85	0	0	122	246	17.0	16.2	4.5×10^{-3}	0.7	M
86	120	10	0	263	9.2	7.6	4.75	3.0	S
88	0	0	107	213	14.9	13.8	0.04	0.05	S
89	63.5	2.5	66	315	13.7	12.2	0.074	0.02	S

Continued

TABLE 1: Comparison of Calculated and Measured Radiation Intensity With 30-cartridge Source and Water-filled Windows. (continued)

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-5 (ft^2)	TOTAL μx	B FACTOR[a]	RADIATION INTENSITY		CLASS[b]
	Water (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)	
5 ft south of									
[illegible]	0	0	66	161	9.2	7.6	7.8	0.7	L
[illegible]'-78	0	0	0	108	0	0	$1.52 \times 10^{+4}$	230	L
80	0	0	0	196	0	0	$8.4 \times 10^{+3}$	130	L
[illegible]"-78	0	0	0	111	0	0	$1.49 \times 10^{+4}$	180	L
80	0	0	0	111	0	0	$1.49 \times 10^{+4}$	360	L
Source passing									
78	0	0	0	108	0	0	$1.53 \times 10^{+4}$	280	L
[illegible]- 35	0	0	61	64	8.5	7.0	36.5	40	S
36	56	5.1	0	64	4.3	3.5	$1.20 \times 10^{+3}$	480	S
MAX-36	56	5.1	0	64	4.3	3.5	$1.20 \times 10^{+3}$	600	S
43	0	0	81	112	11.2	9.6	1.93	8.5	S
44	0	0	95	154	13.1	11.8	0.26	0.75	S
48	56	5.1	0	144	4.3	3.5	$5.4 \times 10^{+2}$	60	L
78	0	0	189	256	26.2	30.8	8.2×10^{-7}	0.4	M
80	0	0	91	332	12.7	11.3	0.17	11	M
85	0	0	61	64	8.5	7.0	36.5	42	S
86	56	5.1	0	64	4.3	3.5	$1.22 \times 10^{+3}$	410	S
MAX-86	56	5.1	0	64	4.3	3.5	$1.22 \times 10^{+3}$	700	S
88	0	0	81	112	11.2	9.6	1.9	80	M
89	0	0	81	112	11.2	9.6	1.9	80	M
93	0	0	80	112	11.2	9.6	1.9	5	S
94	0	0	95	154	13.1	11.8	0.26	0.5	S
98	56	5.1	0	144	4.3	3.5	541	60	L
101	0	0	71	86	9.9	8.2	7.8	300	M
102	0	0	65	72	9.0	7.4	20.8	130	M
103	0	0	76	112	10.6	9.0	1.9	50	M
104	0	0	68	97	9.4	7.8	11	250	M
109	0	0	68	146	9.2	7.6	6.5	0.27	L
110	0	0	61	156	8.5	7.0	14.9	1.3	L
5 ft south of									
85	0	0	49	85	6.8	5.6	$1.20 \times 10^{+2}$	190	S

Continued

TABLE 1: Comparison of Calculated and Measured Radiation Intensity With 30-cartridge Source and Water-filled Windows. (concluded)

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-5 (ft^2)	TOTAL μx	B FACTOR*	RADIATION INTENSITY		CLASS*[1]
	Water (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)	
5 ft south of 35	0	0	49	85	6.8	5.6	$1.20 \times 10^{+2}$	110	S
MAX door 1	0	0	61	156	8.5	7.0	14.9	1.3	L
MAX door 2	0	0	61	156	8.5	7.0	14.9	3.0	L

TABLE 2: Comparison of Calculated and Measured Radiation Intensity With 7.18-curie Sphere as Source and Water-filled Windows.

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-4 (ft^2)	TOTAL μx	B FACTOR*	RADIATION INTENSITY		CLASS*[1]
	Water (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)	
C- 3	145	10.2	0	36	10.85	9.2	0.25	0.30	S
Source	56	5.1	0	36	4.34	3.55	64	44	S
1 ft from Monitoring Room Window	56	5.1	0	25	4.34	3.55	93	66	S
	56	5.1	0	16	4.34	3.55	145	112	S

*See DISCUSSION.
*[1] See RESULTS.

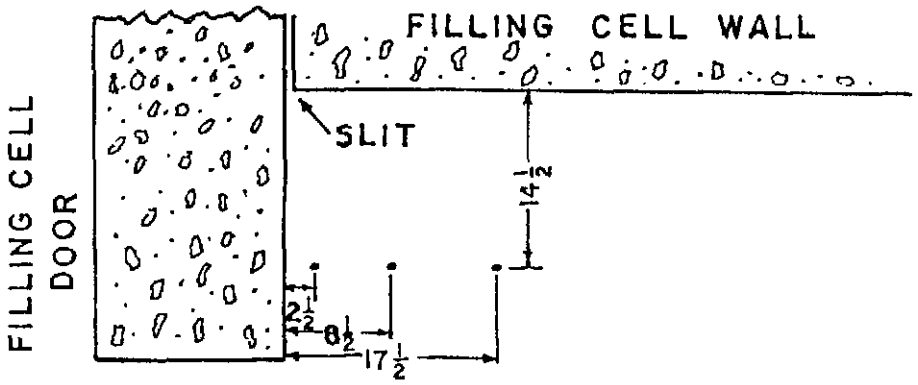

TABLE 3: Radiation Intensities at Filling Cell Door Slit, South Side, 7.18-curie Sphere as Source, MX-4.

DISTANCE FROM WALL (inches)	DISTANCE FROM DOOR (inches)	INTENSITY (mr/hr)	BACKGROUND (mr/hr)	CORRECTED INTENSITY (mr/hr)
14.5	2.5	12.8	0.12	12.7
14.5	8.5	0.42	0.12	0.30
14.5	17.5	0.22	0.12	0.10
27.75	2.5	6.6	0.12	6.5
27.75	8.5	0.72	0.12	0.60
27.75	17.5	0.30	0.12	0.18
27.75	26.5	0.25	0.12	0.13
54.75	25	0.35	0.12	0.23
54.75	8.5	0.53	0.12	0.41
54.75	17.5	0.44	0.12	0.32
54.75	26.5	0.30	0.12	0.18
54.75	35.5	0.12	0.12	0.00

TABLE 4: Radiation Intensity Readings at Filling Cell Door Slits, South Side of Door, 25-millicurie Radium Source, Scintillation Counter.*

DISTANCE FROM DOOR (cm)	INTENSITY (cts/min)	BACKGROUND (cts/min)	CORRECTED INTENSITY (cts/min)
1.00	16,440	2,260	14,180
3.54	4,380	2,260	2,120
6.08	2,627	2,260	367
8.62	2,435	2,260	175
11.05	2,320	2,260	60

*Source was 32.72 inches from filling cell wall and slit. Measurements were made at greater distances from the door; however, the corrected intensity was of the same order as the probable error.

TABLE 5: Radiation Intensities as Determined by the MX-4 and Scintillation Counter.

POSITION	INTENSITY (mr/hr)	(cts/min)	REMARKS
1	0.05	120	
2	0.05	120	
3	0.05	120	
4	0.1	150	
5	0.1	150	
6	0.1	150	
7	0.05	120	
8	0.05	120	
9	0.05	120	
10		100	
11	0.1	150	
13	0.35	800	Open plug.
14	0.1	150	
16	0.1	150	
28	0.05	100	
4 ft from wall opposite slit, 5 ft above platform	0.25	450	
4 ft from wall opposite slit, under platform	0.15	300	
114	0.04		
Against plug S-407	1.0		Conduit through plug
117	15		Open plug
105	2		Scattered through monitor room roof and air duct.
107	12		Scattered through monitor room roof and air duct
108	1000-2000		Air duct and scattering through light panel
36	200-300		Instruments did not agree
38	150-200		Instruments did not agree
103	1500		Instrument would not measure higher - plug not complete
On light-access platform above monitoring room	120		Shielding by platform not considered in calculation

TABLE 6: Comparison of Calculated and Measured Radiation Intensity With Filling Cell Doors Open and 8-sphere, 8,200-curie Source.

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-5 (ft^2)	TOTAL μx	B FACTOR*	RADIATION INTENSITY	
	$ZnBr_2$ (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)
D- 1	145	10.2	0	100	22.7	24.6	1.8×10^{-3}	0.04
2	156	11	0	137	24.5	27.7	2.5×10^{-4}	Bg*1
4	0	0	152	100	21.1	22.0	8.0×10^{-3}	0.06
5	0	0	180	137	25.1	28.8	1.5×10^{-3}	Bg
7	145	10.2	0	196	22.7	24.6	9.3×10^{-4}	0.04
10	0	0	165	117	23.0	25.2	1.2×10^{-3}	0.05
11	0	0	218	182	30.3	38.4	8.4×10^{-7}	0.03
13	0	0	192	156	26.7	31.9	3.0×10^{-5}	1.0
14	0	0	246	217	34.2	46.8	1.7×10^{-8}	0.08
16	123	5.1	61	130	27.3	32.8	2.0×10^{-5}	0.03
17	125	6.4	62.3	136	28.0	34.2	1.0×10^{-6}	0.04
45	145	10.2	0	324	22.7	24.6	5.6×10^{-4}	0.05
51	145	10.2	0	100	22.7	24.6	1.8×10^{-3}	0.09
52	156	11	0	100	24.5	27.7	3.4×10^{-4}	0.06
54	0	0	152	100	21.1	22.4	8.0×10^{-3}	0.17
55	0	0	152	102	21.1	22.4	8.0×10^{-3}	0.08
60	0	0	165	117	23.0	25.2	1.2×10^{-3}	0.04
63	0	0	192	156	26.7	31.9	3.0×10^{-5}	Bg
66	123	5.1	61	130	27.3	37.8	2.0×10^{-5}	0.07
67	125	6.4	62.2	136	28.0	34.2	1.0×10^{-6}	0.08
68	132	5.4	66	154	29.3	36.6	2.6×10^{-6}	0.13
112	0	0	183	144	25.5	29.5	1.0×10^{-4}	Bg
113	0	0	187	150	26.0	30.5	5.8×10^{-5}	Bg
114	0	0	161	100	22.4	24.2	2.5×10^{-3}	0.04
116	0	0	170	114	23.6	26.2	7.3×10^{-4}	0.10
117	0	0	168	110	23.3	25.6	1.0×10^{-3}	26.0
119	0	0	152	85	21.1	22.4	8.0×10^{-3}	0.60
S-409	0	0	170	114	23.6	26.2	7.3×10^{-4}	60.0
S-4012	0	0	180	140	25.1	28.8	1.5×10^{-3}	0.08
F- 3	145	10.5	0	100	22.7	24.6	1.8×10^{-3}	0.05
6	0	0	152	100	21.1	22.4	8.0×10^{-3}	0.05
9	145	10.2	0	196	22.7	24.6	9.3×10^{-4}	0.05
20	123	5.1	61	130	27.3	32.8	2.0×10^{-5}	0.06
27	119	5.1	153	199	39.5	59	1.2×10^{-10}	25.0
28	10.2	2.5	232	188	47.9	84	3.7×10^{-14}	30.0

Continued

*See DISCUSSION.

*1Background.

TABLE 6: Comparison of Calculated and Measured Radiation Intensity With Filling Cell Doors Open and 8-sphere, 8,200-curie Source. (concluded)

POSITION	SHIELDING			SQUARE OF DISTANCE, SOURCE TO MX-5 (ft^2)	TOTAL μx	B FACTOR*	RADIATION INTENSITY	
	$ZnBr_2$ (cm)	Glass (cm)	Concrete (cm)				Calculated (mr/hr)	Measured (mr/hr)
F- 29	61	5.2	122	132	26.7	31.7	2.6×10^{-5}	36
31	0	0	174	144	24.2	27.2	3.3×10^{-4}	1.8
32	0	0	252	200	35.0	49.0	8.8×10^{-9}	2.0
33	0	0	290	212	40.3	60.5	5.4×10^{-11}	2.0
34	49	5.1	275	268	39.7	59.5	7.2×10^{-11}	1.8
35	0	0	120	366	16.7	16.0	0.07	0.7
36	89	2.5	15.3	360	15.6	14.6	0.39	0.5
37	0	0	85	265	11.8	10.2	16.2	0.6
38	0	0	90	312	12.5	10.95	7.4	0.6
39	0	0	161	415	22.4	21.2	5.4×10^{-4}	0.5
43	0	0	152	391	21.1	22.0	2.2×10^{-3}	1.0
44	0	0	146	361	20.3	21.0	3.3×10^{-3}	1.0
62	0	0	165	117	23.0	25.2	1.2×10^{-3}	0.5
65	0	0	192	156	26.7	31.9	3.1×10^{-5}	Bg*1
81	0	0	252	199	35.0	49.0	8.9×10^{-9}	2.0
82	0	0	244	212	33.9	37.9	2.4×10^{-8}	2.0
83	0	0	290	212	40.3	60.5	5.4×10^{-11}	1.8
93	0	0	152	391	21.1	22.0	2.2×10^{-3}	0.7
101	0	0	299	387	40.5	61.5	2.4×10^{-11}	17
103	0	0	283	578	39.3	58.3	4.8×10^{-11}	17
105	0	0	184	252	25.6	29.7	5.1×10^{-5}	12
107	0	0	207	317	28.8	35.6	2.0×10^{-6}	10
109	0	0	61	934	8.48	6.9	88	20
110	0	0	61	870	8.48	6.9	94	60
111	0	0	61	934	8.48	6.9	88	20
In center of lights platform	0	0	204	625	28.4	34.9	1.5×10^{-6}	25
F- 3*2	145	10.5	0	100	22.7	24.6	1.8×10^{-3}	0.5
6*2	0	0	152	100	21.1	22.0	8.0×10^{-3}	0.5
62*2	0	0	165	117	23.0	25.2	1.2×10^{-3}	0.5
78*2	0	0	244	196	34.0	46.7	2.3×10^{-8}	1.5
79*2	61	5.1	122	132	26.6	31.6	3.8×10^{-5}	0.08
81*2	0	0	252	199	35.0	49.0	8.9×10^{-9}	0.08
82*2	0	0	244	212	33.9	37.9	2.4×10^{-8}	1.5

*2In these measurements the filling cell doors were closed.

TABLE 7: Comparison of Measured Intensity With Calculated Intensity.

DISTANCE OF COUNTER FROM WINDOW (inches)	SQUARE OF DISTANCE, SOURCE TO COUNTER (ft^2)	INTENSITY	
		Calculated (mr/hr)	Measured Scintillation Counter (cts/min)
	Source 14 inches from window		
0	39	5.03×10^{-3}	200
12	52.7	3.72×10^{-3}	190
24	68.3	2.87×10^{-3}	205
36	89	2.33×10^{-3}	230
48	105	1.87×10^{-3}	220
60	126.4	1.55×10^{-3}	235
72	150	1.31×10^{-3}	220
96	203	0.965×10^{-3}	240
	Source 43 inches from window		
0	75.2	2.6×10^{-3}	150
12	93.5	2.09×10^{-3}	190
24	114	1.72×10^{-3}	190
36	136	1.44×10^{-3}	210
48	161	1.22×10^{-3}	220
60	186	1.05×10^{-3}	230
	Source 67 inches from window		
0	114	1.72×10^{-3}	130
12	136	1.44×10^{-3}	190
24	161	1.22×10^{-3}	170
36	186	1.05×10^{-3}	200
48	215	0.912×10^{-3}	210
60	245	0.8×10^{-3}	220
	Source 91 inches from window		
0	161	1.2×10^{-3}	130
12	186	1.1×10^{-3}	150
24	215	9.1×10^{-2}	200
36	245	8.0×10^{-2}	200
48	277	7.1×10^{-2}	210

TABLE 8: Comparison of Measured Intensity with Calculated Intensity, Through Monitoring Room Door.

DISTANCE OF COUNTER FROM DOOR (ft)	SQUARE OF DISTANCE, SOURCE TO COUNTER (ft^2)	INTENSITY	
		Calculated (mr/hr)	Measured MX-4 (mr/hr)
0	870	94	60
15	1,980	41	10
30	3,540	23	5
70.5	10,000	8.2	2.2

APPENDIX III

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

Effective source strength from MX-4 measurement[1]

$$\frac{(11.83 \text{ ft})^2 \times 12 \text{ r/hr}}{6.04 \times 1.15 \text{ Mev}} = 242 \text{ curies}$$

$$\frac{(9.75 \text{ ft})^2 \times 17 \text{ r/hr}}{6.04 \times 1.15 \text{ Mev}} = 232 \text{ curies}$$

average = 237 curies

Sample calculation of expected radiation[1]

Position C-53 with cartridges as source

$$I = I_o B e^{-\mu x}$$

$$= \frac{237 \text{ curies} \times 6.04 \times 1.15 \text{ Mev} \times 9.0 \times e^{-10.84}}{36}$$

$$= 45.9 \times 9.0 \times 10^{-5} \times 2$$

$$= 0.00825 \text{ r/hr or } 8.25 \text{ mr/hr}$$

Position C-53 with sphere as source

$$I = \frac{7.18 \times 6.04 \times 1.15 \times 9.0 \times e^{-10.84}}{36}$$

$$= 1.38 \times 9.0 \times 2 \times 10^{-5}$$

$$= 0.00025 \text{ r/hr or } 0.25 \text{ mr/hr}$$

---

[1] Morgan. "Some Practical Considerations on Radiation Shielding". US AEC Isotopes Division Circular B-4. 1948.

Reduction Factor of water-filled windows[2]

Filling cell, with 7.18-curie sphere source

$$\frac{7.18 \times 10^3 \times 6.04 \times 1.15}{(6)^2 \times 0.30} = 4610 \text{ measured value of Reduction Factor}$$

$$\frac{7.18 \times 10^3 \times 6.04 \times 1.15}{(6)^2 \times 0.25} = 5540 \text{ calculated Reduction Factor}$$

Filling cell, with 30-cartridge source

$$\frac{237 \times 10^3 \times 6.04 \times 1.15}{(6)^2 \times 5.5} = 8320 \text{ measured}$$

$$\frac{237 \times 10^3 \times 6.04 \times 1.15}{(6)^2 \times 8.25} = 5540 \text{ calculated}$$

$$\frac{237 \times 10^3 \times 6.04 \times 1.15}{(10)^2 \times 2.0} = 8220 \text{ measured}$$

$$\frac{237 \times 10^3 \times 6.04 \times 1.15}{(10)^2 \times 2.95} = 5540 \text{ calculated}$$

Monitoring Room, with 7.18-curie sphere source

$$\frac{7.18 \times 10^3 \times 6.04 \times 1.15}{(4)^2 \times 112} = 27.8 \text{ measured}$$

$$\frac{7.18 \times 10^3 \times 6.04 \times 1.15}{(4)^2 \times 145} = 21.5 \text{ calculated}$$

Monitoring Room, with 30-cartridge source

$$\frac{237 \times 10^3 \times 6.04 \times 1.15}{(8)^2 \times 700} = 36.7 \text{ measured}$$

$$\frac{237 \times 10^3 \times 6.04 \times 1.15}{(8)^2 \times 1220} = 21.1 \text{ calculated}$$

---

[2]A Reduction Factor is defined as the measured value of unshielded radiation divided by the measured value of the radiation penetrating the shielding.

APPENDIX IV

MEASUREMENT OF INDIVIDUAL CARTRIDGE AND SPHERE ACTIVITIES

MEASUREMENT OF INDIVIDUAL CARTRIDGE AND SPHERE ACTIVITIES

CARTRIDGES

The activity level of each of 30 cartridges was determined by measuring the radiation intensity produced at a distance of 20 feet from each cartridge. A new Beckman MX-4 instrument, calibrated against a standard radium source, was used to make the intensity measurements. Before calibration, the MX-4 was allowed to equilibrate for two hours at the ambient temperature characteristic of the cartridge intensity measurements.

For each cartridge, the radiation intensity measurement was made in the following manner:

(1) The cartridge was placed in a vertical position in a wooden holder located 20 feet from the ionization chamber of the MX-4. The cartridge holder and the ionization chamber were aligned on a concrete slab such that the mid-point of each was 38 inches above the slab. In an effort to minimize scattering from the concrete, a 1/2 x 15 x 36-inch lead strip was positioned on the concrete, midway between the holder and ionization chamber. Removal of the lead strip produced no measurable variation in the intensity readings.

(2) The cartridge holder was mounted so that it could be rotated through 180° about the vertical axis of the cartridge. Since a variation of cartridge position produced but a slight change

in the intensity readings for 12 of the cartridges, the remaining 18 cartridges were measured in only one position.

By use of an appropriate transformation[1], the measured intensity values were converted to apparent millicuries of activity. The pertinent data are listed in the text, Table 1.

SPHERES

The eight spheres which were used in the last part of the investigation were measured through slits formed by the filling cell and monitoring room doors with an MX-4.

Individual spheres:

Sphere Number	mr/hr	curies
1	410	1707
2	250	1041
3	197	820
4	265	1103
5	250	1041
6	205	854
7	195	812
8	200	833
	Total	8211

Whole rack:

Rotated	mr/hr	curies
0°	1820	7577
90°	1770	7309
180°	1550	6453
270°	1550	6453

[1] M. G. Alder, E. R. Campagna, K. P. Anderson. A Method for the Determination of the Apparent Activity of RW Agents. UUT-1. University of Utah, Radiological Research, Dugway Project, Dugway Proving Ground, Dugway, Utah. 22 January 1953. Secret.

DISTRIBUTION

1,2,3,4,5,6	Chief, RW Division, Dugway Proving Ground, Dugway, Utah
7	Chief, Test Design and Evaluation Office, Dugway Proving Ground, Dugway, Utah
8	Scientific Director, Dugway Proving Ground, Dugway, Utah
9,10	Technical Library, Chemical and Radiological Laboratories, Army Chemical Center, Maryland, ATTN: Miss Alice Amoss
11	Technical Library, Dugway Proving Ground, Dugway, Utah
12	Commanding General, Research and Engineering Command, Army Chemical Center, Maryland, ATTN: Chief, Radiological Warfare and Non-toxic Materiel Division
13	Commanding Officer, Chemical and Radiological Laboratories, Army Chemical Center, Maryland, ATTN: Chief, Special Projects Division
14,15	Technical Information Service, U. S. Atomic Energy Commission, Oak Ridge, Tennessee
16	Air Force Special Weapons Project, Kirtland Air Force Base, Albuquerque, New Mexico
17	United States Naval Radiological Defense Laboratory, San Francisco 24, California
18	Editorial Branch, TD&E, Dugway Proving, Dugway, Utah