

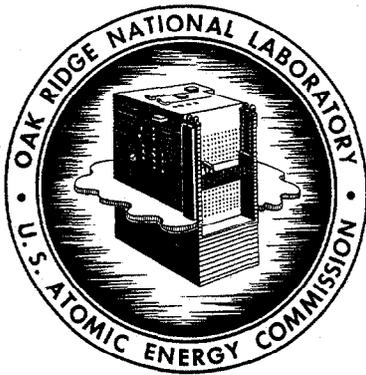
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DECONTAMINATION OF CELLS 6 AND 7,
BUILDING 3019, FOLLOWING
PLUTONIUM-RELEASE INCIDENT

J. R. Parrott



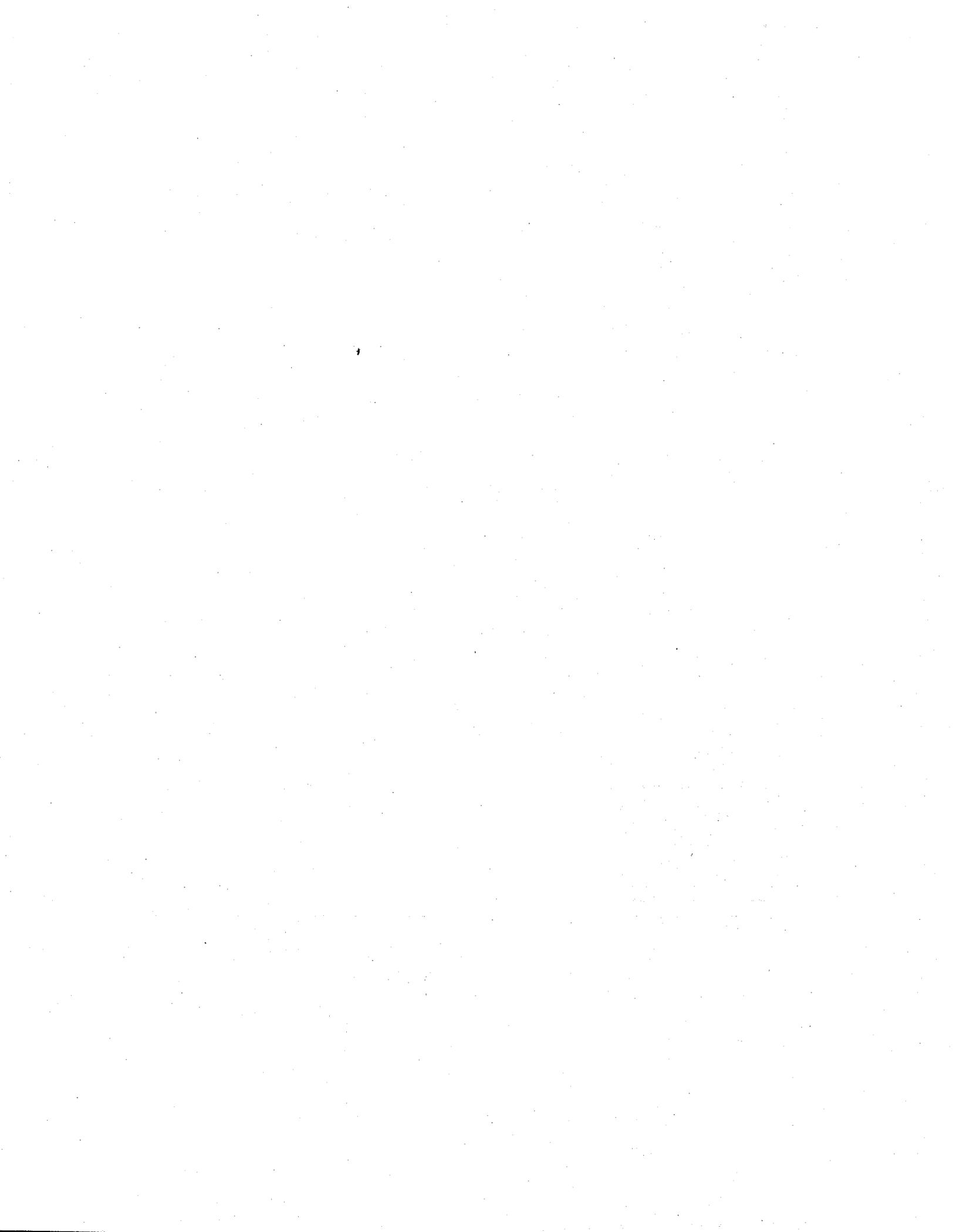
OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION

for the

U.S. ATOMIC ENERGY COMMISSION



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CHEMICAL TECHNOLOGY DIVISION

Pilot Plant Section

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ABSTRACT

As a result of the evaporation explosion in the Radiochemical Processing Pilot Plant on Nov. 20, 1959, two cells were contaminated with plutonium to a transferable level of 10^8 d/m/100 sq cm. The area involved measures 40 by 20 by 27 ft high with a total surface area, including equipment, of 10,000 sq ft. The cells were decontaminated by a factor of 1000 in five months by removing loose equipment, debris, and shielding blocks and flushing with 430,600 liters of various decontaminating reagents. The remaining contamination (10^4 - 10^5 d/m/100 sq cm) was fixed to the surface with three coats of paint. The general beta-gamma radiation background was decreased from 2000 to 30 mr/hr and the long-lived alpha contamination in the air was reduced from 2×10^{-10} to 8×10^{-13} $\mu\text{c}/\text{cc}$. Approximately 141 g of plutonium was flushed from the cell surfaces.

The total direct effort expended was 3000 man-hr including 250 entries into the cell, 175 of which were made in plastic air suits. There were no overexposures from beta-gamma radiation and no detectable increase in the body burden of plutonium of any individual involved.

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1.0 INTRODUCTION

This report summarizes the decontamination of the processing cells (cells 6 and 7) in which an explosion occurred, including removal of debris and miscellaneous material from the cell, the decontaminating solutions used and their application, decontamination factors obtained, and personnel protection during cell entry. Recommendations for future decontamination programs of this sort are included. The explosion occurred on Nov. 20, 1959, at Oak Ridge National Laboratory in an intercycle evaporator that was being decontaminated. As a result the Radiochemical Processing Pilot Plant (Bldg. 3019), the X-10 Graphite Reactor (Bldg. 3001), and nearby streets and building surfaces became contaminated by plutonium. The explosion, its cause, the extent of the contamination, and decontamination of areas outside the processing cells are described elsewhere.*

Acknowledgment is made to A. J. Smith, Health Physics Division for the survey results presented.

2.0 DESCRIPTION OF FACILITY

Building 3019, Oak Ridge National Laboratory, contains seven cells, one 11 by 20 by 27 ft deep and six 20 by 20 by 27 ft deep, each divided into cubicles. Two of the large cells, Nos. 6 and 7, are combined to form a single cell 40 by 20 by 27 ft deep. The intercycle evaporator that ruptured was in a subcell in the northeast corner of cell 6. Figures 2.1 and 2.2 are plan and sectional views of the building and Fig. 2.3 is a plan view of the cells 6 and 7 combination showing the equipment location. Cell 6 is the only cell into which a door opens directly at ground level. The other six cell entrances are 8 ft below level, at the bottom of stairways which make right angles with the entrances.

*L. J. King and W. T. McCarley, ORNL-2989, "Plutonium Release Incident of November 20, 1959" (Feb. 1, 1961).

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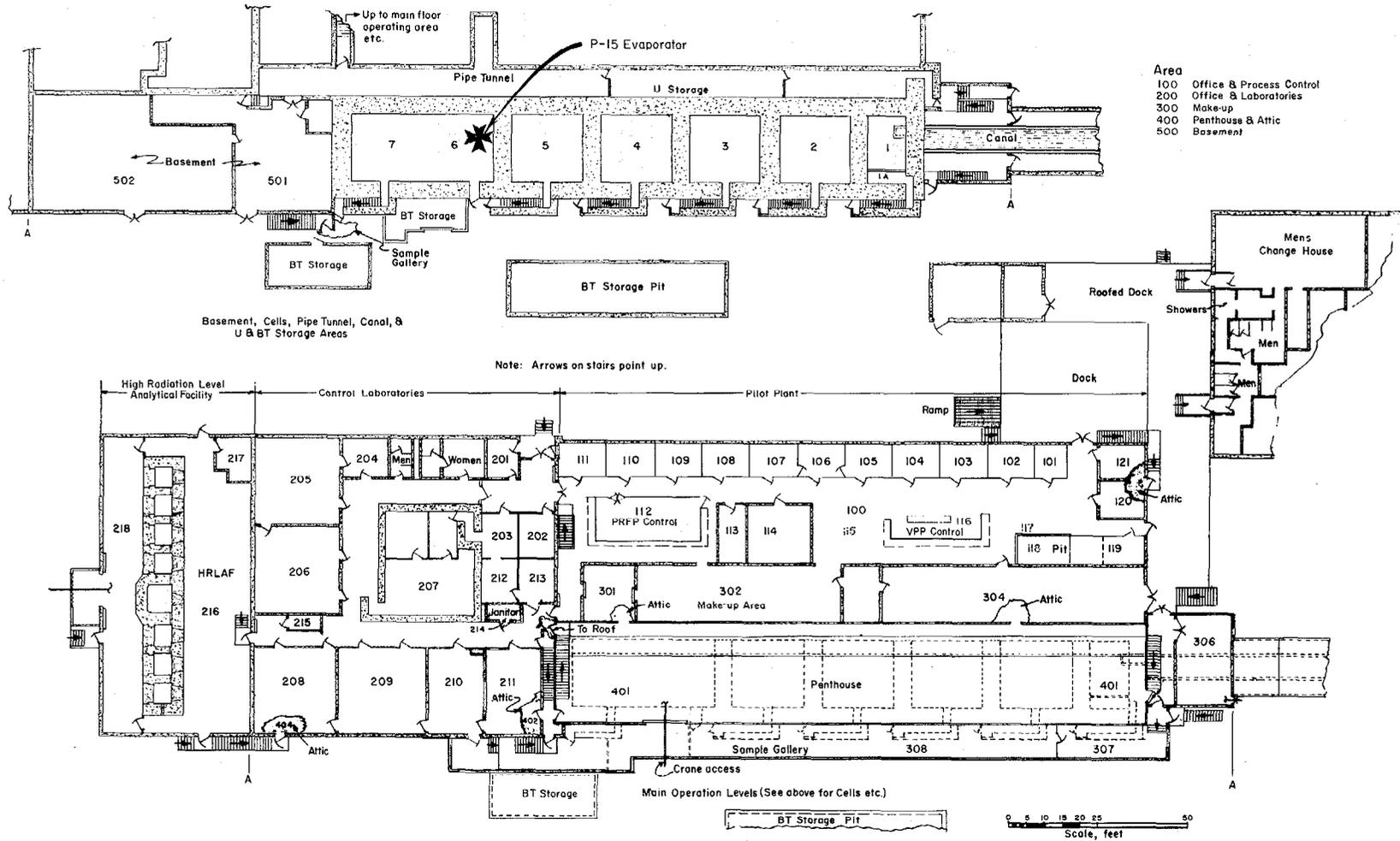


Fig. 2.1. Plan of Radiochemical Processing Pilot Plant.

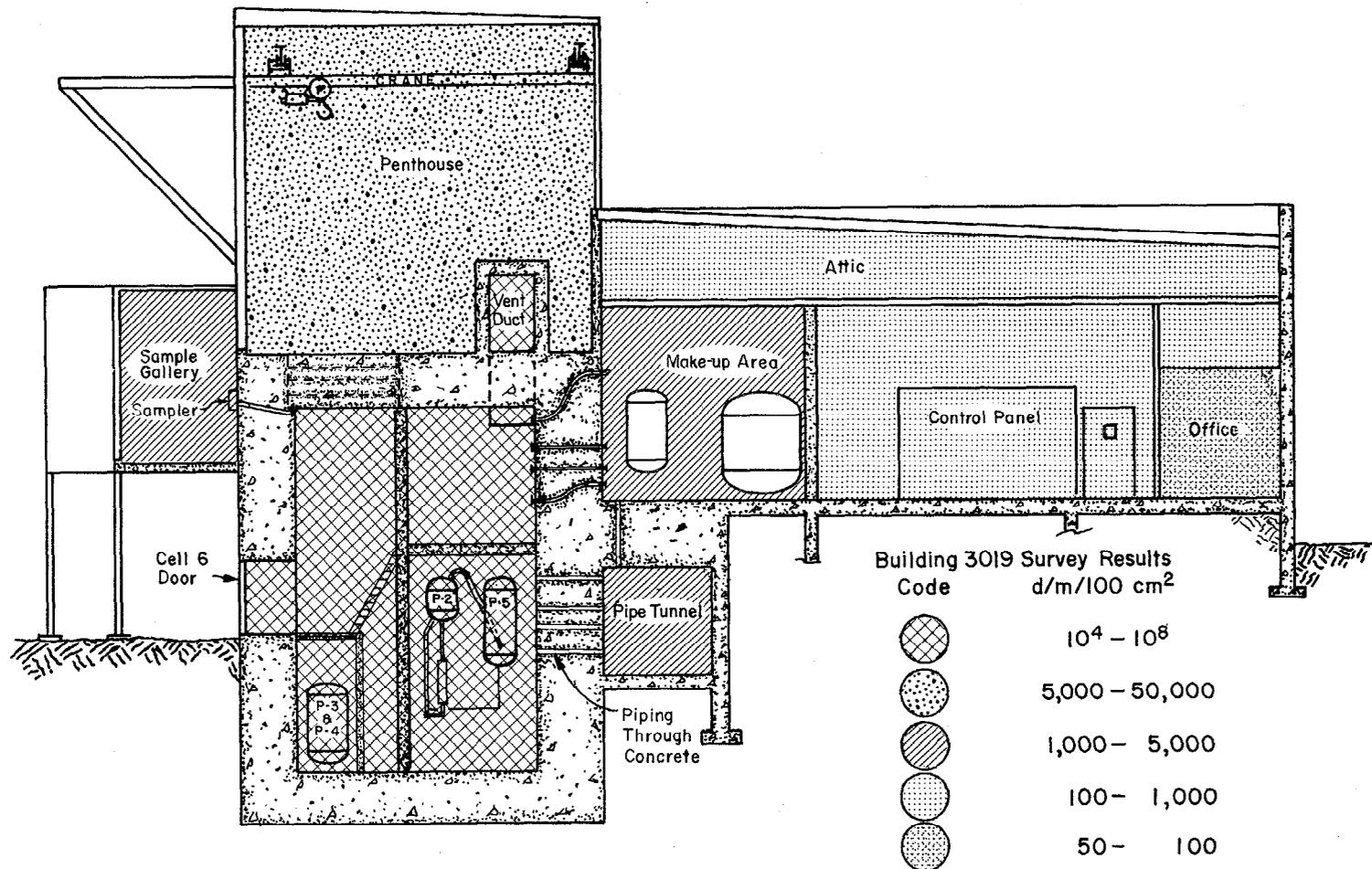


Fig. 2.2. Sectional elevation through cell 6, Radiochemical Processing Pilot Plant, showing inside contamination levels after explosion.

Prior to the start of decontamination, the cell 7 entrance was moved to the basement area and a shower was installed in room 501 to better control cell entrances and exits. The area under the sample gallery was enclosed to serve as a secondary containment area as well as a plenum chamber to provide air for cell ventilation through filters in the cell walls.

A Lucite-plywood box, referred to as the "greenhouse," was installed (Sect. 3.0) through the cell 6 ground level door to serve as an observation point for work in the cells.

3.0 THE "GREENHOUSE"

A cubicle constructed of Lucite and plywood was inserted in the south-east entrance to cell 6, from which initial cell decontamination was carried out and personnel working in the cell could be constantly observed. This "greenhouse" (Figs. 3.1 and 3.2) was installed at the 10-ft level directly opposite the ruptured evaporator.

Initial communication between the observer and the worker was via a sound-powered phone system. Originally the person working in the air suit was equipped with a head set and phone similar to those worn by a telephone operator, but the head set could not be easily kept in place. It was replaced by a speaker hung from the ceiling, which could be withdrawn for repair. With thorough indoctrination of the worker and establishment of a series of hand signals the one-way communication proved satisfactory.

The greenhouse was equipped with a communications system to permit contact with the control room and penthouse to coordinate the more complex operations.

Gloves protruded into the cell from the greenhouse for use in directing spray solution during initial decontamination of the cell. The solution entered the cell from the penthouse via a line along the floor of the greenhouse.



Fig. 3.1. View of greenhouse from plenum chamber.

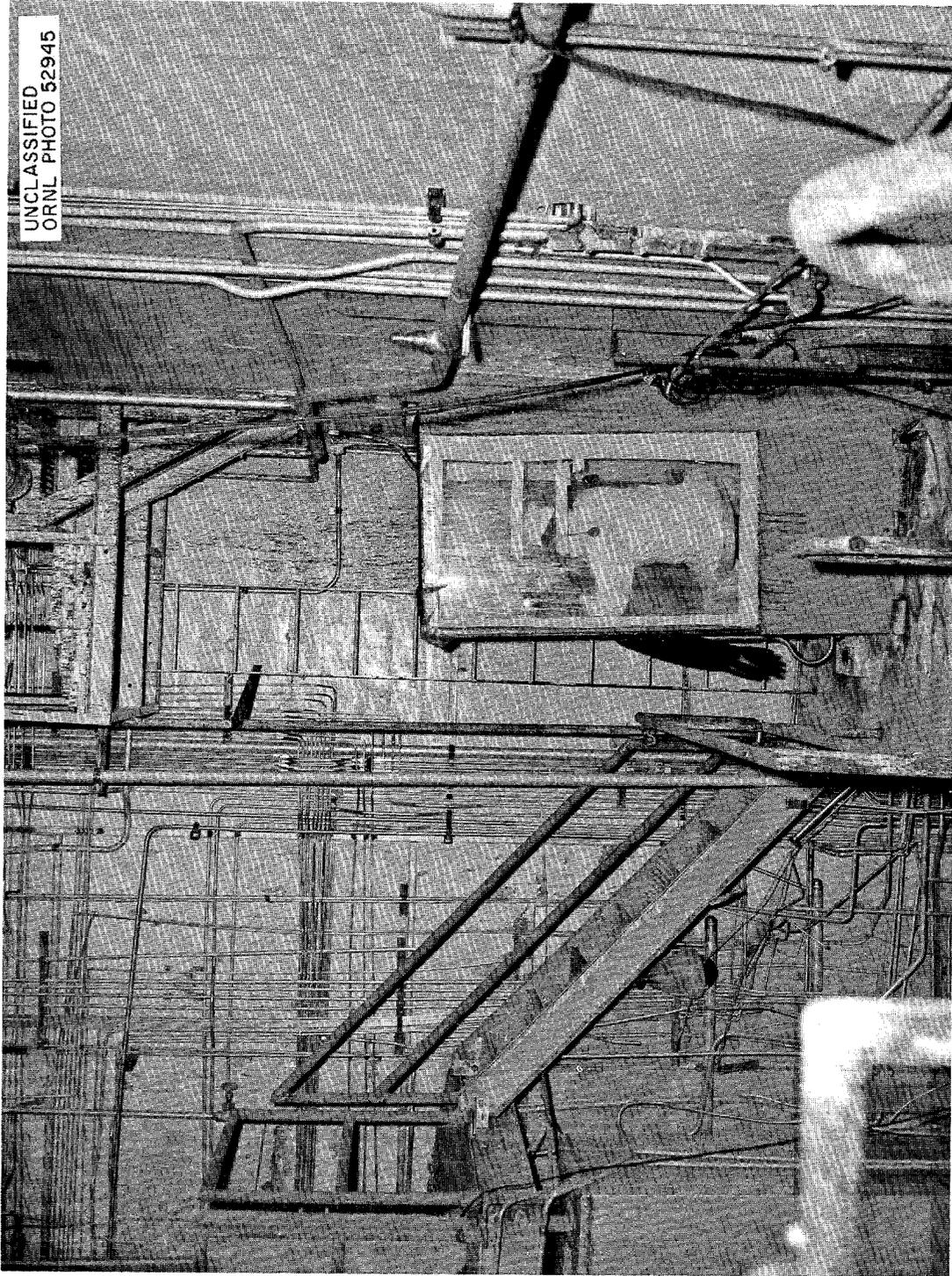


Fig. 3.2. View of greenhouse from upper level of cell 7.

The greenhouse was provided with a constant air purge to prevent possible accumulation of contaminated air in it. A continuous alpha air monitor plotted the contamination in the greenhouse. The cell was kept under ~ 0.5 in. H_2O pressure less than that of the greenhouse, which prevented backflow of contaminated air. The greenhouse was checked daily for transferable as well as direct-reading alpha contamination. The Lucite was cleaned as required and the plywood was repainted on two occasions when the transferable contamination reached 30 d/m/100 sq cm.

4.0 INITIAL DECONTAMINATION

Washing of the cell surfaces with detergent began as soon as the greenhouse was installed. The solution was made up in a tank in the penthouse at a concentration of 0.2 oz/gal, heated to $70^{\circ}C$, and pumped to a wand accessible from the greenhouse (Sect. 6.0). This solution was alternated with a solution of laundry compound (Turco 4324) at a concentration of 3 oz/gal.

The cells were sprayed with 22,000 liters of the above solutions. A sample of the solution from the walls was transferred from the cell sump to the waste catch tank (N-16), acidified, and sampled for plutonium content. A total of 57 g of plutonium was recovered during the initial phase of decontamination. The plutonium concentration in the spent solution varied from 0.007 mg/ml for the initial 1900 liters of solution to 0.001 mg/ml for the final 1900 liters.

Particular emphasis was placed on washing the debris, shielding blocks, and loose equipment, which were removed in a subsequent step.

This phase of the decontamination was accomplished without a cell entry.

5.0 DEBRIS, BLOCK, AND EQUIPMENT REMOVAL

The second phase of the decontamination was removal of debris and approximately 1500 dry-stacked concrete shielding blocks from the cells (Figs. 5.1 and 5.2). In addition to providing a high alpha source in the cell, this material was a source of sand and grit which was detrimental to the sump jets used to transfer solutions and a possible medium for plugging the sump overflow lines to the tank farm. Access to the cell from the penthouse area was through a hinged metal door, which was installed in the cell roof.

On Nov. 3, 1960, the debris, approximately 100 of the blocks which had been blown loose from in front of the evaporator, was removed in eight 50-gal drums. Beta-gamma readings, primarily from the debris itself, were up to 5 r/hr. Two workers and a Health Physics surveyor spent 1 hr in the cell in air suits. The two workers, who handled the contaminated material, received exposures of 230 and 260 mrem, respectively, and the surveyor, who handled the moving equipment, received 115 mrem. The procedure involved two separate operations: (1) packaging of the material in the cell and removal, and (2) repackaging in the penthouse and transferral to a truck and thence to the burial ground for disposal. The material was thoroughly wet prior to removal to decrease air-borne contamination.

The drums in which the material was packaged were of mild steel and had clamp-on lids. Three eyelets equally spaced around the top took the lifting hooks from an overhead crane. The drums were lined with a 42- by 42-in. plastic bag to ensure against leakage of contaminated water. The top of the bag was brought over the rim of the drum and secured with masking tape.

The actual sequence of operations was:

1. One drum was wrapped in plastic and lowered into the cell, by the crane, along with all the drum tops, which were wrapped individually with plastic and all placed in one plastic bag. The bands that snapped the tops to the drums were kept in the penthouse area.

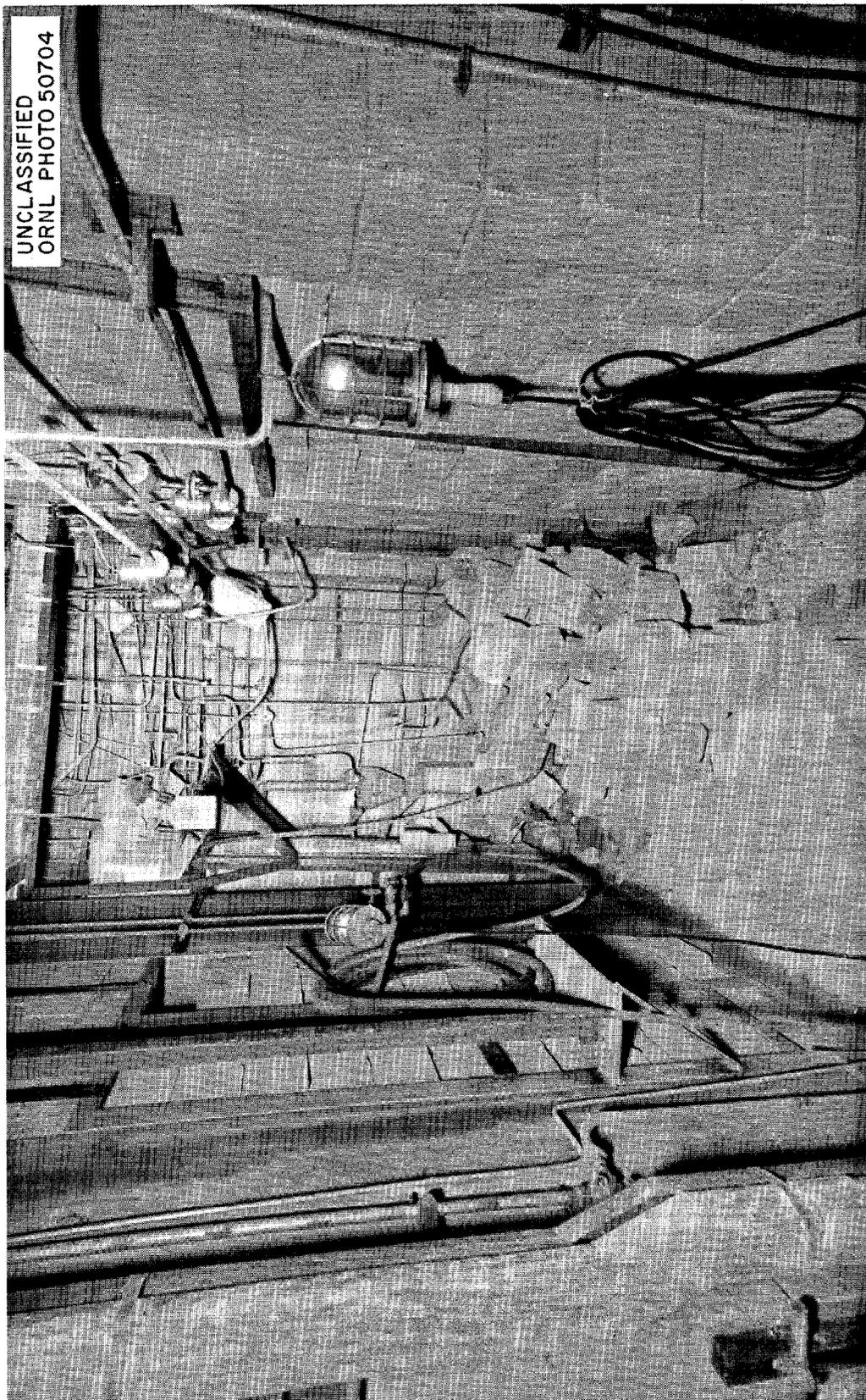


Fig. 5.1. View of cell 6 lower level prior to block and debris removal.

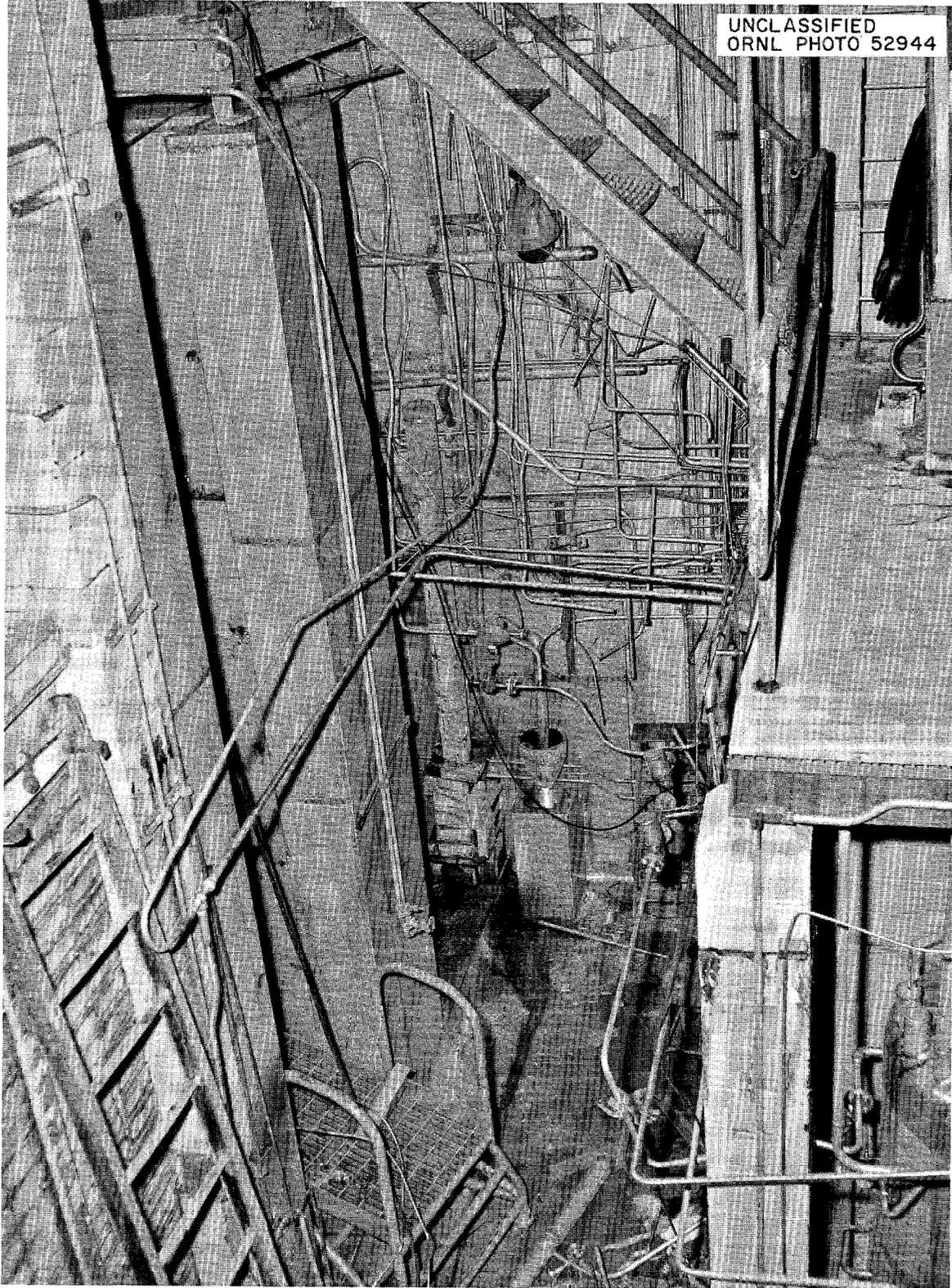


Fig. 5.2. View of cell 6 from upper level of cell 7 after block and debris removal.

2. The Health Physics surveyor, wearing clean cotton gloves over the rubber gloves on the air suit, disconnected the hooks from the drum, and the crane was returned to the penthouse for a second drum.
3. The operators filled the first drum with debris, and when it was full the Health Physicist removed a top from the bag, unwrapped it, and placed it on the full drum. He then removed the hooks from the second drum, which had been lowered in the meantime, placed them on the full drum, and, as the full drum was raised, he stripped the outer plastic covering.
4. The penthouse crew lowered the full drum into another plastic bag, installed the snap ring to hold the lid on, and installed a band around the drum for lifting and transferral to a truck for disposal.

These steps were repeated until the job was completed. The drums were unloaded by a crane at the burial ground and lowered into the trench provided.

The dry stacked blocks from the shielding walls were removed in similar drums in a telescoping elevator (Fig. 5.3). The elevator had overall dimensions of 69 by 30 in., a platform size of 3 by 5 ft, a collapsed height of 5 ft 8 in., a maximum lift of 35 ft, and a maximum load of 600 lb. To decrease contamination as much as possible, the elevator was covered with plastic sheeting, so installed that it collapsed as the elevator was lowered. A fresh air supply was continuously bled into the plastic shroud to prevent inleakage of the contaminated cell air due to the vacuum created when the elevator was raised.

The elevator was lowered into the cell, rolled to the required location, and leveled with built-in screw jacks. A dolly on casters that served as a loading platform, 27 by 45 in., gave sufficient working area for a man and a drum. The platform height of 27 in. provided a good working elevation for the operator, who removed the blocks from the elevator and placed them in a drum. The casters on the dolly were necessary to permit moving of the loaded drum to a position under the crane hatch.

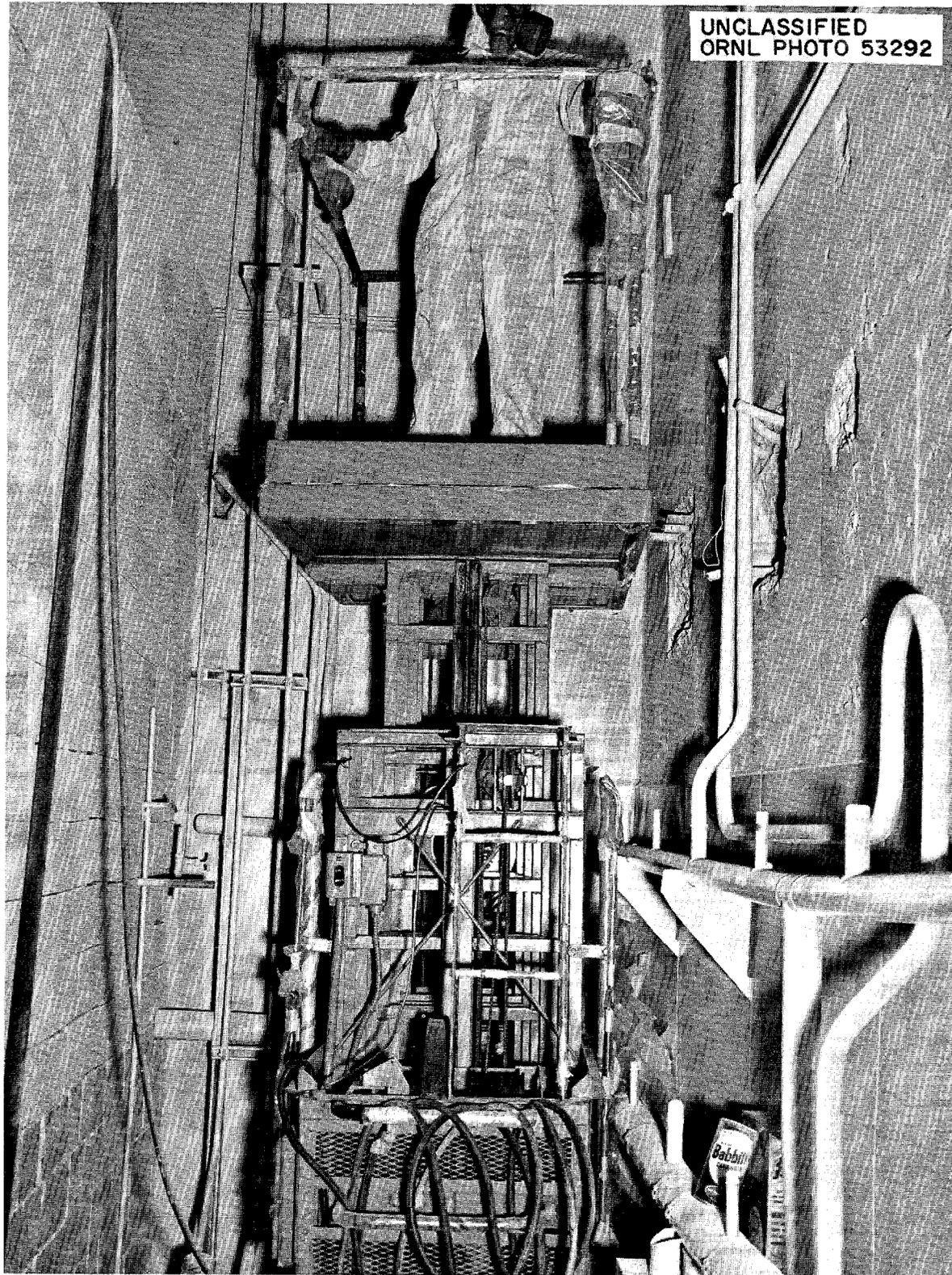


Fig. 5.3. Telescoping elevator used for removing shielding blocks.

The sequence of operations was (Fig. 5.4):

1. The elevator was extended to the top of the wall and 12 blocks were loaded by the first operator onto the floor of the elevator.
2. The elevator was lowered to the lowest position and the second operator removed the blocks from the elevator and placed them in a drum lowered there previously. Then, after changing gloves, he placed the top on the drum and stripped off the plastic as the drum was raised.
3. When it reached the penthouse the material was handled as before.

The operation was repeated until all blocks had been removed.

The elevator was used to remove the blocks from four cubicle walls in the cell. Upon completion of block removal, the elevator was stripped of plastic in the cell, raised to the penthouse, re-covered with plastic, and used in adjacent cells for cleaning, surveying, and painting.

All the debris and blocks were removed over a period of two months, beginning Nov. 3, 1960, and ending January 9, 1961. However, the majority of the blocks were removed in the week Dec. 16 to 23, 1959, and the elevator was used in the cell for only this week.

The effort expended in removing blocks and debris from the cell amounted to a total in-cell effort of 37.6 man-hr broken up into 19 cell entries by 13 different people. The total exposure received during the 37.6 man-hr in the cell was 1770 mrem. The highest single exposure was 260 mrem received in 1 hr during the initial entry.

The cell was flushed thoroughly at intervals, by procedures and solutions described in the next section, during block removal to decrease the amount of contamination spread by handling the blocks. Surveys during block removal showed some surfaces to be recontaminated by a factor as high as 10 due to high air contamination.

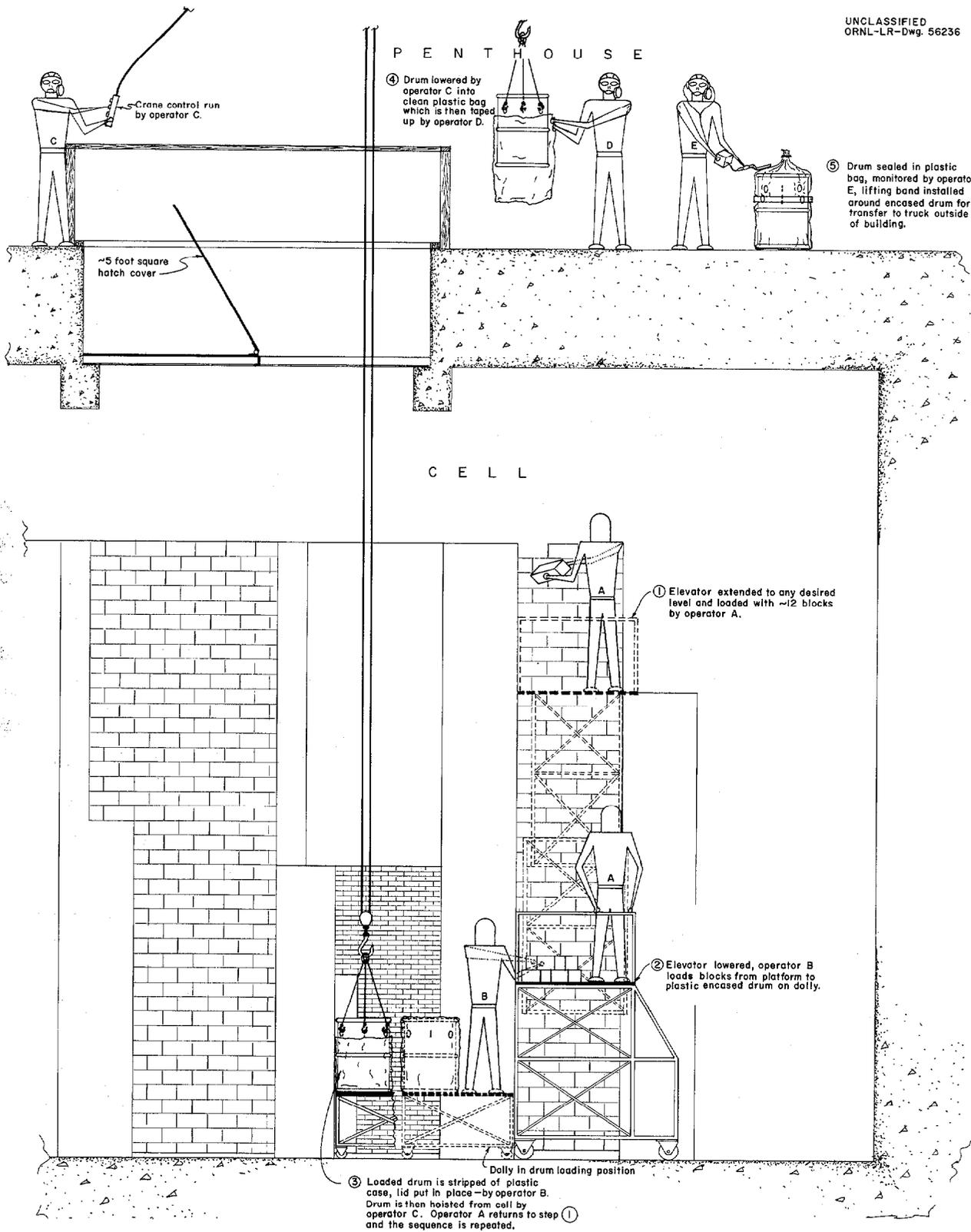


Fig. 5.4. Sequence of operations for removing contaminated concrete blocks from cells 6 and 7.

As soon as all blocks had been removed, the damaged components of the evaporator were burned loose, wrapped in plastic, and removed from the cell. The largest component of the evaporator, the stripper (P-5), 2 ft i.d. by 8 ft long and weighing ~1200 lb, was packaged in a plywood box and removed from the cell.

6.0 FINAL CELL FLUSHING AND PAINTING

Exhaustive spraying of the cell surfaces with a variety of reagents was started after the debris, shielding blocks, and equipment had been removed. A total of 430,600 liters of solution was used to decontaminate the 10,000 sq ft of the cell surface (Table 6.1). Of the 141 g of plutonium removed, 50% was found in the first 32,000 liters and 98.6% in the first 240,000 liters. A decontaminating agent containing fluoride was not used until the plutonium in the spent solution was constant at 3×10^{-5} g/liter, i.e. after 240,000 liters had been used. The first spent fluoride solution contained 3×10^{-4} g of plutonium per liter, a factor-of-10 increase in decontamination. Also, when the first solution of the Turco sequence was used, the alpha count in the spent solution increased to 1.0×10^{-3} g/liter, a factor of 10 higher than that in the preceding solution. After the second recirculation the alpha count was 5×10^{-4} g/liter. Cell smears after the complete Turco sequence were not sufficiently lower than those before the treatment to account for the high plutonium concentration in the spent decontaminant. However, it is possible the solution had a leaching effect on the stainless steel and concrete and that the surfaces were recontaminated by diffusion from underneath after the cleaning ended.

The increase in plutonium removal with the nitric acid-sodium fluoride solution over that during detergent washing was followed by a period of comparative equilibrium and then increased 2 g more (3×10^{-5} g/liter) when the Turco sequence and recirculation were used. If Turco 4501 had been used originally and recirculated, the waste volume might have been decreased considerably, but this was precluded by the possibility of sufficient plutonium being present to become critical in a recirculating solution.

Table 6.1. Sequence of Decontaminating Solutions with Resultant Transferable Contamination Levels for Six Representative Areas

Decontaminating Solution ^a	Subtotal Vol, liters	Date of Smearing	Surface Smeared ^b	Surface Reading, d/m/100 sq cm
		Aug. 12, 1960	2	5.0×10^6
			5	6.0×10^7
			6	7.4×10^7
8,000 liters of D		Nov. 9, 1960	1	6.0×10^4
2,000 liters of C			2	2.2×10^6
18,000 liters of P			3	5.4×10^6
4,000 liters of A			4	8.4×10^5
			5	1.4×10^6
			6	4.0×10^7
	32,000			
14,000 liters of B		Nov. 15, 1960	1	7.4×10^4
2,000 liters of C			2	8.4×10^4
2,000 liters of P			3	4.2×10^6
6,700 liters of D			4	1.0×10^5
			5	3.0×10^5
			6	4.4×10^7
	56,700			
43,000 liters of B		Nov. 23, 1960	1	7.0×10^4
1,000 liters of C			2	1.1×10^4
2,000 liters of P			3	9.6×10^5
1,000 liters of D			4	8.4×10^4
			5	3.4×10^5
			6	5.8×10^6
	103,700			

Decontaminating Solution ^a	Subtotal Vol, liters	Date of Smearing	Surface Smeared ^b	Surface Reading, d/m/100 sq cm
24,500 liters of E		Dec. 5, 1960	1	6.7×10^3
21,000 liters of B			2	1.6×10^3
			3	8.0×10^2
			4	1.6×10^3
			5	9.0×10^4
			6	1.4×10^6
	149,200			
12,000 liters of J		Dec. 8, 1960	1	2.0×10^3
			2	2.4×10^4
			3	2.0×10^3
			4	2.4×10^3
			5	2.4×10^5
			6	1.4×10^6
	161,200			
17,000 liters of L		Dec. 16, 1960	1	6.2×10^3
14,000 liters of E			2	1.4×10^3
13,000 liters of M			3	3.2×10^3
3,000 liters of N			4	2.4×10^3
24,000 liters of B			5	6.0×10^4
7,000 liters of P			6	4.4×10^5
	239,200			
3,000 liters of F		Jan. 3, 1961	1	5.6×10^3
			2	4.4×10^3
			3	2.8×10^3
			4	1.4×10^3
			5	7.2×10^4
			6	2.2×10^6
	242,200			

Decontaminating Solution ^a	Subtotal Vol, liters	Date of Smearing	Surface Smear ^b	Surface Reading, d/m/100 sq cm
25,000 liters of F		Jan. 11, 1961	1	1.3×10^4
16,000 liters of B			2	6.1×10^2
9,500 liters of E			3	6.4×10^3
			4	6.6×10^3
			5	9.8×10^4
			6	1.8×10^6
	292,700			
18,000 liters of B		Jan. 16, 1961	1	4.1×10^3
11,000 liters of F			2	4.5×10^3
8,000 liters of E			3	1.4×10^3
5 and 6 hand scrubbed			4	2.3×10^3
			5	1.7×10^4
			6	3.6×10^5
	329,700			
27,000 liters of F		Jan. 23, 1961	1	4.8×10^3
12,000 liters of K			2	1.5×10^3
9,000 liters of H			3	1.5×10^2
			4	3.7×10^3
			5	2.9×10^4
			6	3.2×10^5
	377,700			
8,000 liters of F		Feb. 13, 1961	1	7.1×10^3
8,000 liters of H			2	7.7×10^2
Recirculated 380 liters of G 11 hr at 19 l/min			3	2.1×10^3
			4	2.9×10^3
			5	1.0×10^4
Recirculated second 380 liters of G 9 hr at 19 l/min			6	1.8×10^5

Decontaminating Solution ^a	Subtotal Vol, liters	Date of Smearing	Surface, Smeared ^b	Surface Reading, d/m/100 sq cm
Recirculated 190 liters of H 4.5 hr at 19 l/min				
Recirculated 190 liters of k 2.5 hr at 19 l/min				
6,000 liters of P				
7,000 liters of F				
Recirculated 380 liters of H 4.5 hr at 19 l/min				
Recirculated 380 liters of K 3.5 hr at 19 l/min				
4,000 liters of P				
4,000 liters of F				
	416,600			
Scrubbed entire cell with steel wool and solution B		Feb. 21, 1961	1	5.9×10^3
7,000 liters of K			2	4.4×10^3
7,000 liters of P			3	2.1×10^2
			4	1.3×10^3
			5	2.8×10^3
			6	2.0×10^5
	430,600			

a

Solution	Constituent	Conc., g/liter	Vol., liters
A	Commercial detergent: Fab, Tide, etc.	1.5	4,000
B	Laundry detergent: Turco 4324	22	136,000

Solution	Constituent	Conc., g/liter	Vol., liters
C	Degreasing solution:		
	NaOH	2.2	
	Trisodium phosphate	4.5	
	Sodium carbonate	6.49	
	Detergent	1.0	5,000
D	Oxalic acid	2.2	15,700
E	Sulfamic acid	9.7	56,000
F	HNO ₃ NaF ³	1.5 M 0.02 M	85,000
G	Turco 4501	Undiluted	760
H	Turco 4502	360	17,570
J	Turco 4306B	27	12,000
K	Turco 4518	100	19,570
L	Sodium hydroxide	1	17,000
M	Sodium hydroxide	6	13,000
N	Oxalate-peroxide solution:		
	Sodium oxalate 4%		
	Hydrogen peroxide 3%		
	Oxalic acid 0.7%		3,000
P	H ₂ O		<u>46,000</u>
Total			430,600 liters 113,765 gal

Area	Type of Surface	Location
1	Painted steel	Cell 7-E, side of P-62 cubicle
2	Painted concrete	East side of cell 6 and 7 divider

Area	Type of Surface	Location
3	Lead	N-2, N-16 cubicles
4	Stainless steel	Wall between P-1 and P-15 cubicles
5	Stainless steel	Front of P-15 cubicle
6	Stainless steel	West wall inside P-15 cubicle

The reagents were prepared and heated in two 250-gal tanks in the penthouse and were directed to the wand accessible from the greenhouse. The wand was a piece of 1/2-in. pipe reduced to 1/4 in. at the end to increase the velocity; handles were welded to the 1/2-in. pipe. At first the solution was pumped by two canned rotor pumps at a rate of 3 gpm and pressure of 70 psig. On Nov. 22, 1960, the pump was replaced with a Sellers jet cleaner (Fig. 6.3), a unit with a capacity of 15 gpm at a delivered pressure of 200 psig. The decontaminating solution was then made up at 10 times the desired concentration and metered into the suction side of the jet. The Turco solutions, which were applied between Jan. 23 and Feb. 1, 1961, were recirculated from the cell sump with a turbine pump through a heat exchanger to increase the temperature and directed onto the surfaces by an operator at a rate of 4 gpm and a pressure at the wand of 20 psig. The solution temperature was maintained at 70°C. The first 3200 liters of solution used was a detergent solution containing 0.04 M sodium borate, which would poison 10 g of plutonium per liter and thus prevent a nuclear excursion if a large amount of plutonium should be removed. Analysis of the spent solution showed <0.01 mg of plutonium per milliliter, and the addition of boron was therefore discontinued. The detergent flushes were followed by various degreasing solutions, then by nitric-hydrofluoric acid, and finally by Turco solutions (Fig. 6.1), which are proprietary compounds designed for decontamination of various surfaces.

Spraying was controlled from outside the cell at first. After the cell had been flushed with 35,000 liters of various solutions, spraying from within the cell was started. All flushing from within the cell was done with the operator in an air suit (Fig. 6.2), a supervisor in the greenhouse, and another operator ready to enter the cell in an assault mask in the event of an emergency. Operation of the pumps was controlled by a signal from the operator in the cell to the supervisor in the greenhouse, who was connected to the penthouse area with a battery-powered intercom system and the control room with a two-way radio.

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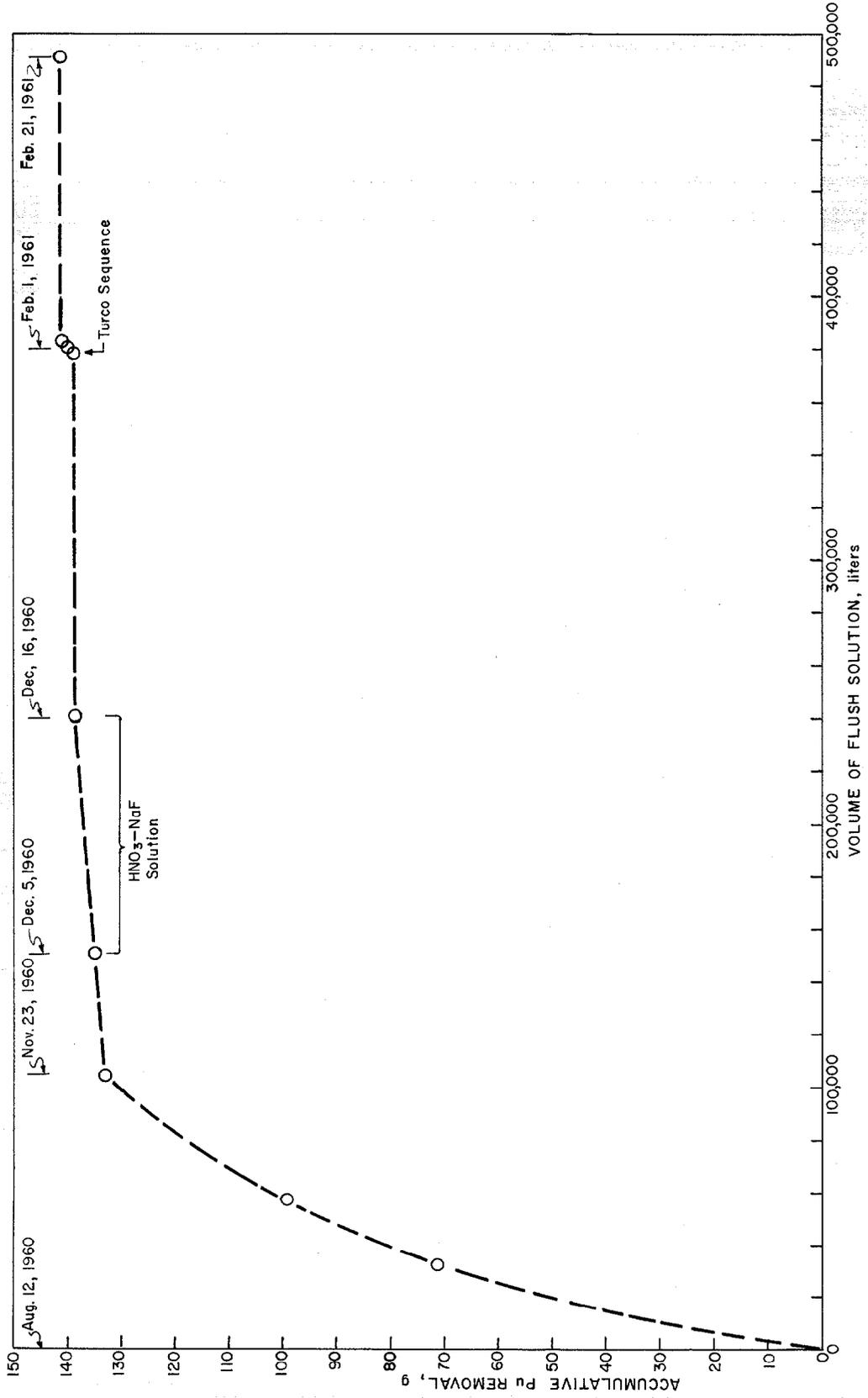


Fig. 6.1. Plutonium removal vs. volume of flush solution.

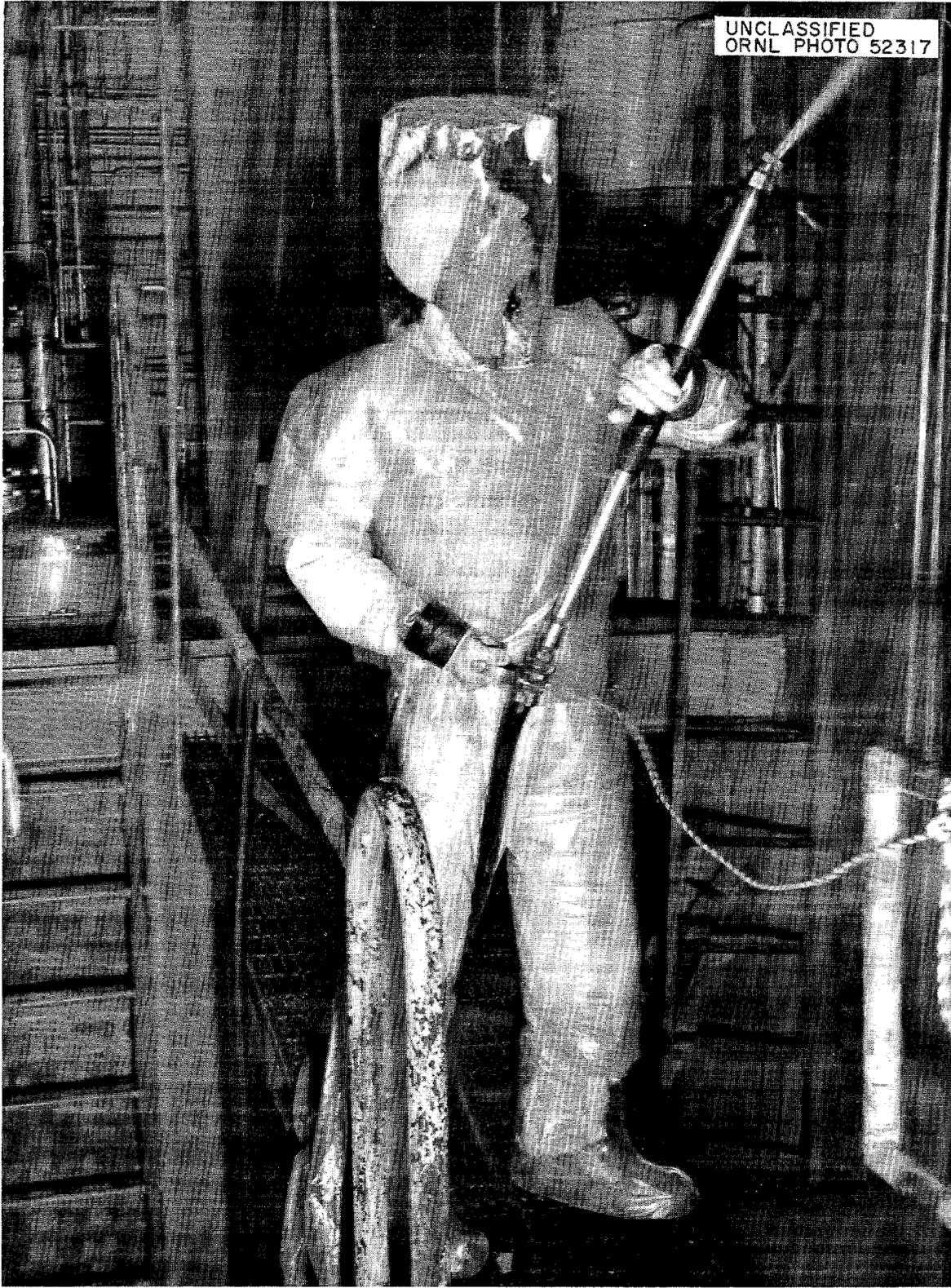


Fig. 6.2. Spraying of cells 6 and 7 with Sellers Jet.

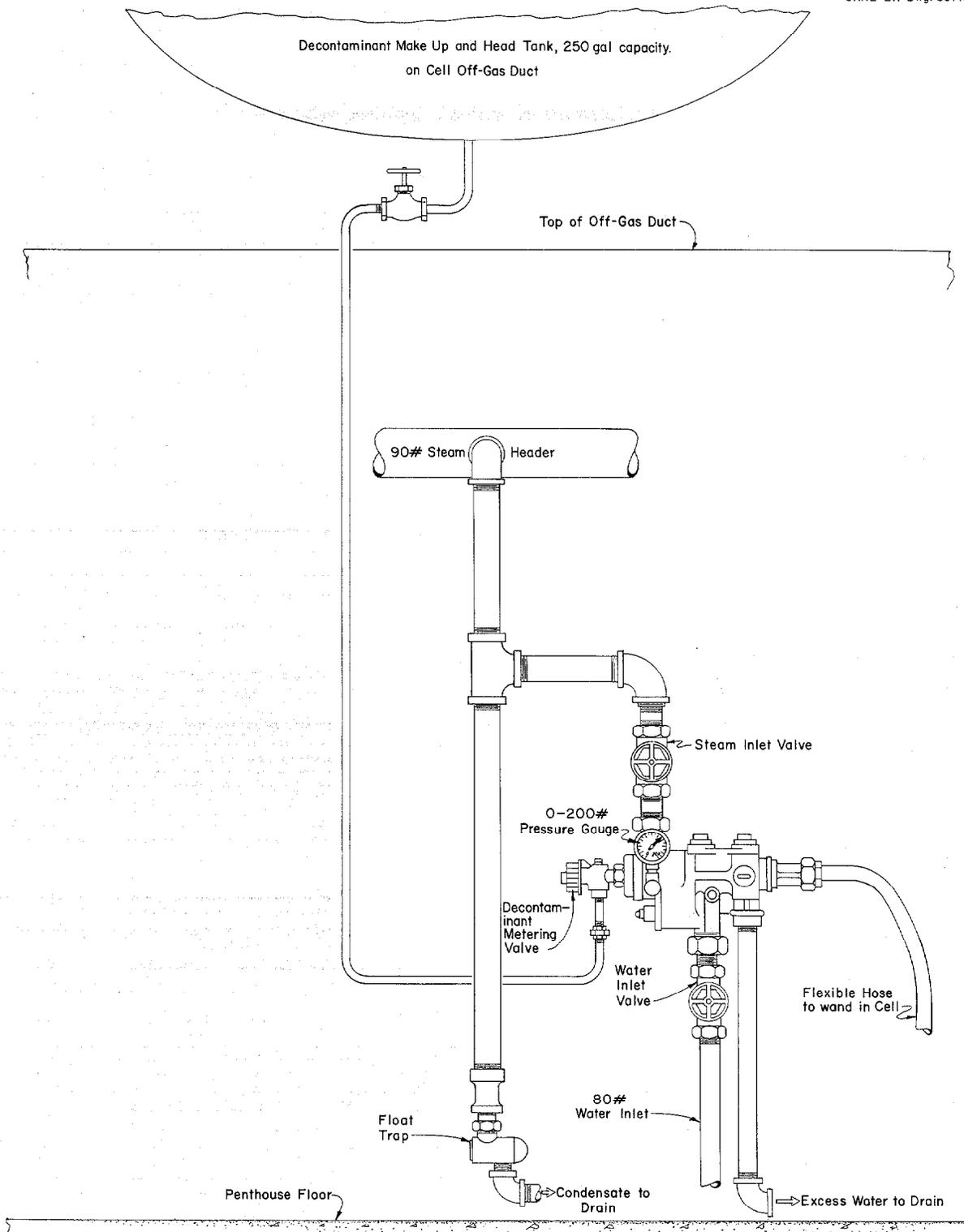


Fig. 6.3. Sellers "super booster" hydraulic jet cleaner.

Six areas in the cell were selected for routine checking of the contamination level in the cell. These areas were marked with paint and numbered to ensure survey of the same areas, and the same man performed the surveys to eliminate the difference in technique between people.

In addition to the six areas smeared routinely in the cell (Table 6.1), a number of other areas were smeared occasionally during decontamination. On Dec. 16, 1960 some of the smears indicated that an equilibrium value had been reached; additional cleaning failed to reduce the transferable activity significantly (Table 6.2).

The most difficult surfaces to decontaminate proved to be the bare concrete blocks and the stainless steel surfaces. Painted concrete walls, mild steel shielding block supports, structural members, grating, galvanized conduit, light fixtures, and lead shielding were less difficult. The bare blocks were removed from the cell and buried (Sect. 6.0) after a token effort to decontaminate them. The evaporator cuibcle stainless steel lining was contaminated to a smear reading of 10^8 d/m/100 sq cm, which was decreased to 10^4 d/m/100 sq cm by the solution sprayings. Experience in cell 3 with U^{233} contamination showed that the only feasible method of complete decontamination was the physical removal of a layer of stainless steel by grinding. However, one scrubbing of the stainless steel with steel wool and detergent increased the smear readings by a factor of 2 to 20. It was decided to permanently fix the contamination to the surface with a sealer such as paint and to require proper personnel protection during subsequent entries into the cell. The walls and piping attached to the walls were painted with one coat of Amercoat 86 followed with two coats of Amercoat 33. The stainless steel tanks and cell lining were painted with three coats of poly-vinyl-acetate paint ("PVA Spray" manufactured by Mono-Sol Corporation, Gary, Indiana), which can be easily removed by water washing if further chemical decontamination efforts are scheduled.

Table 6.2. Equilibrium Smear Results on Selected Surfaces
in Cells 6 and 7, Bldg. 3019

Date	Smear Results, d/m					
	East Wall P-15 Cubicle	Painted Wall W. of Greenhouse	Shield Support E. of P-62	W. Wall of P-15 Cubicle	N. Wall P-1 Cubicle	W. Wall of P-15 Entrance
November 28			1.8×10^4			
December 5		1.1×10^3	6.7×10^3			
8			2.0×10^3			
16	1.3×10^4		6.2×10^3	6.6×10^5	5.0×10^4	4.4×10^5
January 3			5.6×10^3			2.2×10^6
11	8.8×10^4	1.2×10^3	1.3×10^4	1.4×10^6	2.4×10^5	1.8×10^6
16	2.2×10^4	7.5×10^3	4.1×10^3	3.4×10^5	1.7×10^5	3.6×10^5
23	1.3×10^4	1.3×10^4	4.8×10^3	2.8×10^5	2.8×10^5	3.2×10^5
February 1	2.7×10^4	1.3×10^4		3.0×10^5	5.1×10^4	5.2×10^5
6	4.3×10^3				1.2×10^5	
13	5.7×10^3	1.6×10^3	7.1×10^3	2.4×10^5	2.1×10^4	1.8×10^5
21	1.6×10^4			1.0×10^5	1.1×10^4	
24						2.0×10^5

Assault masks will continue to be required in the cell to protect against ingestion or inhalation of contaminated particles which are not detected by the air sampler.

After thorough scrubbing by hand, 75% of 211 smears and probes of various surfaces were <5,000 and 90% <20,000 d/m/100 sq cm:

<u>Smear Reading,</u> <u>d/m/100 sq cm</u>	<u>No. of</u> <u>Smears</u>
100-1000	54
1000-5000	97
5000-20,000	35
20,000-100,000	12
>100,000	13

The 10% of the smears above 20,000 d/m/100 sq cm were largely from surfaces which probed off-scale (>700,000 d/m/100 sq cm) with the gas flow proportional alpha survey meter. Almost all these surfaces were stainless steel which, when contaminated with plutonium in certain corrosive solutions, was practically impossible to decontaminate by flooding with $\text{HNO}_3\text{-NaF}$ solution at 90-100°C.

Many surfaces other than stainless steel which continued to probe >700,000 d/m/100 sq cm were cleaned to smear levels almost as low as the average in the cell. Of 48 probes that were off-scale, the smears were distributed as follows:

<u>Smear Reading,</u> <u>d/m/100 sq cm</u>	<u>No. of</u> <u>Smears</u>
1000-5000	13
5000-20,000	13
20,000-100,000	11
>100,000	11

7.0 PERSONNEL PROTECTION

Entry into the cells was strictly controlled to prevent overexposure from beta-gamma radiation as well as exposure from the inhalation or ingestion of plutonium from the atmosphere.

The beta-gamma radiation dosage was controlled by frequently surveying the cell and working in areas of low radiation levels when possible. As cubicles were unshielded, the areas were surveyed, and new working times were calculated. The beta-gamma background varied from 50 to 5000 mr/hr, with small selected areas reading to 20,000 mr/hr when decontamination of the cell was begun. The average background decreased to 50 mr/hr after the first month of spraying and removal of debris.

Personnel entering the cell were required to wear the regular plant film badge which is processed quarterly, an additional film badge which was processed weekly, pocket meters which were read daily, and two dosimeters (0-200 and 0-500 mr). For the original entries the dosimeters were taped to the cuffs and read when the person left the cell, but later the operator determined his own exposure within the plastic suit while working in the cell by reading the dosimeters at intervals. The two dosimeters were mounted in a clamp which was mounted at the end of a short bar. The bar was tied to a piece of flexible cord which went around the operator's neck. The operator could maneuver the dosimeters inside the air suit into the head piece and, looking toward a light, read the dosimeters easily. The maximum single exposure received in the cell was 260 mrem and the accumulative exposure was controlled so that no individual received more than 1300 mrem in any 13-week period.

The long-lived alpha contamination in the cell atmosphere (see Fig. 7.1) dictated the use of an outside air supply when working in the cells. Initial entries were made in one-piece air suits with a zipper up the back; however, after the first few entries, two-piece suits were adopted exclusively due to the ease of removal in the event of an air failure. The radiation intensity

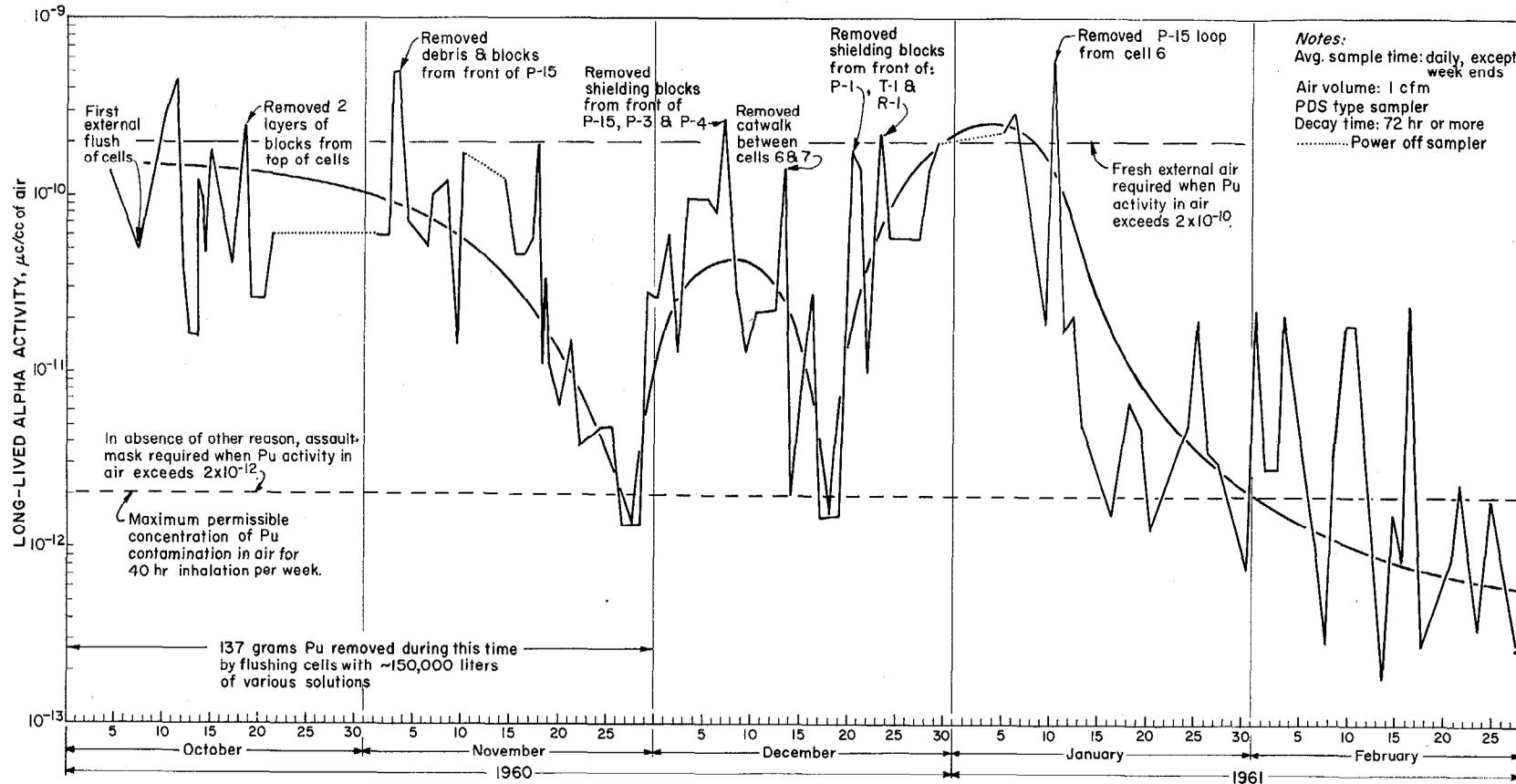


Fig. 7.1. Long-lived alpha activity during decontamination of cells 6 and 7.

in the "greenhouse" was 400 mr/hr at the front face when installed and personnel time in the cell was limited. By Nov. 10, 1960, after initial cell flushing and removal of the debris from the front of the evaporator cubicle, the radiation intensity at the front face of the greenhouse was 60 mr/hr, and working time in the cell was not limited by the radiation level but by physical endurance of personnel working in impermeable plastic suits.

Air was supplied to the suits through 100 ft of 5/16-in.-i.d. single-braid 125-psi-test rubber hose. The air flow to each suit was maintained at 50 cfh at 18 psig. The air was routed through a filter and relief valve, which was set to relieve at 20 psig. Of several schemes tried for routing the air inside the air suit, the most comfortable was the use of a section of surgical rubber hose clamped to a quick disconnect (Swagelok) at one end with the fitting wired to the coveralls near the hip and the other end routed up the operator's back, across his head through slits in a hood, and extending to just above the eyes (Fig. 7.2). The introduction of all the air at this point not only furnished fresh air for breathing but aided in keeping the face of the plastic hood clear. The heavy-wall surgical hose provided flexibility and did not crimp as easily as the Tygon hose provided by the manufacturer. The air exhausted through a port at the rear of the top piece of the suit.

The degree of protection worn in the cell was not dictated solely by the air contamination but rather by the job being performed. The air suit served to protect the operator from the solution being sprayed (Fig. 6.2).

The limit of contamination for plutonium for 40 hr/week continuous exposure for 50 years is 2×10^{-12} μc per cubic centimeter of air. At an activity $>2 \times 10^{-10}$ $\mu\text{c}/\text{cc}$ an air suit was always required. An arbitrary limit for use of the assault mask was set at 2×10^{-10} $\mu\text{c}/\text{cc}$ by the supervision in charge of the cell cleanup. It can be seen that a large safety factor was involved in these limits since the time spent in the cells was a very small portion of the operator's total weekly effort and the total cleanup operation

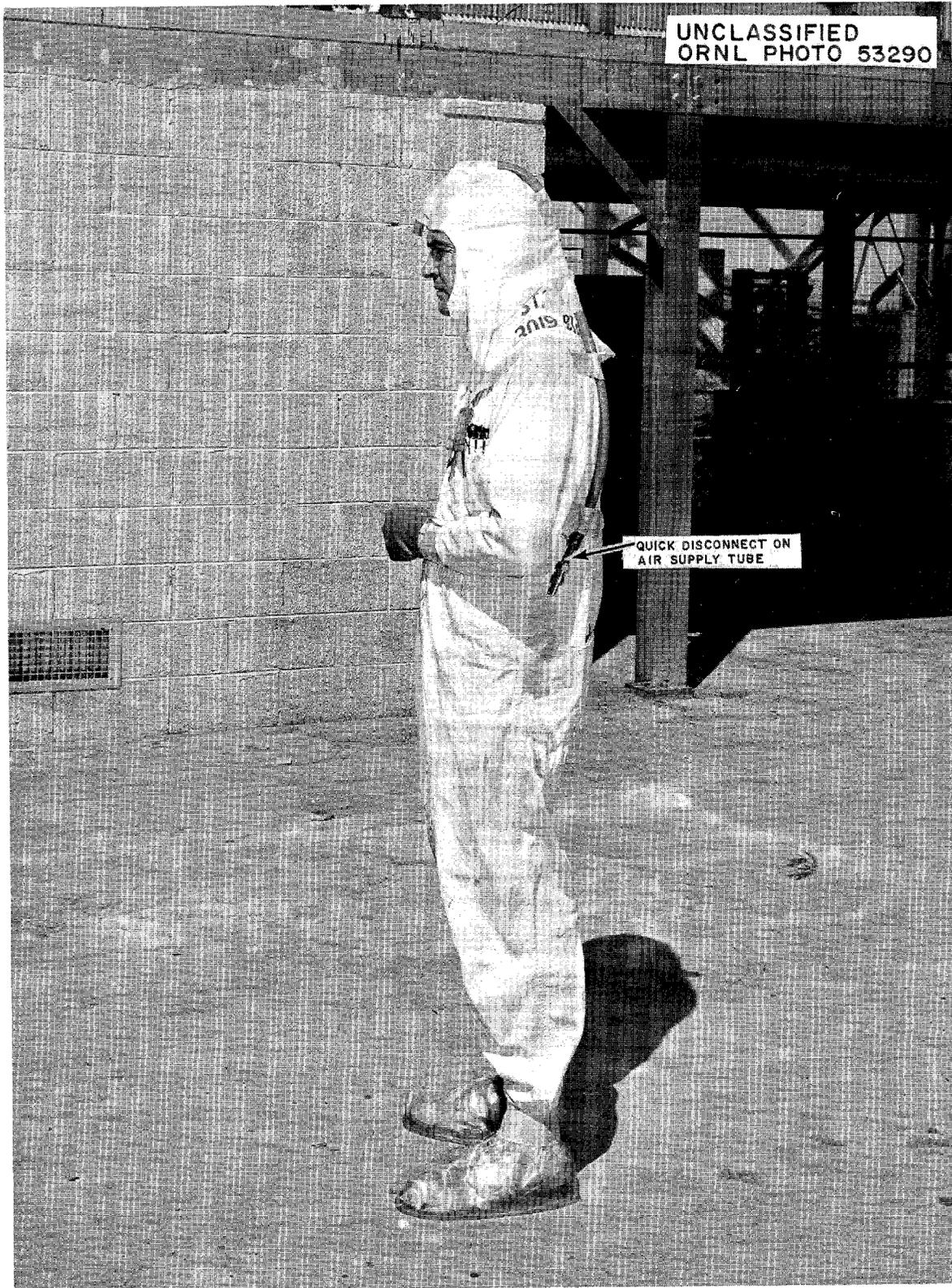


Fig. 7.2. Operator dress and air supply tube used inside plastic suit.

lasted only five months. However, the degree of uncertainty in sampling, the possibility of much higher concentrations in small areas, and possible misuse of the masks by transient personnel justified these precautions. In addition, results of air samples were not known until 72 hr after the sample was taken due to the necessity of decay of the samples in order to determine the long-life count. The plot shown in Fig. 7.1 illustrates the wide variation of contamination due to the particular operation in the cells.

Toward the end of the decontamination, personnel entered the cells for cleaning and painting in assault masks. Other clothing requirements were two pairs of coveralls, two pairs of shoe covers, two pairs of gloves, and a hood. The coveralls were taped at the wrists and ankles with masking tape. Upon completion of painting, assault masks were still required in the cell to protect against the inhalation or ingestion of particles which might have evaded the air sampler.

Welders working in the cell were outfitted with a fresh air hood with proper protective glass. The hood, containing a small volume of air, did not prove as comfortable as the air suit because a very slight interruption in air flow was felt immediately by the welder and there was a tendency to panic. Tests with the air suit proved that a man could remain in the air suit 5 min with no air flow before becoming uncomfortable.

Entry into the cells was controlled by use of a cell entry permit (attached), which reflected all the information known about the cell, the reason for entering, and the radiation background of the person involved. All entry forms required the approval of the Pilot Plant Section Chief or Assistant Section Chief. Entry into fields above 5 r/hr required approval of the Chemical Technology Division Director. Requiring of the entry permit ensured observation by a supervisor. The key to the cells was not issued by the operations supervisor until a completed, approved form was presented.

Personnel entered and left the cell via the shower room in the basement area. Upon leaving the cell, the operator in an air suit was washed down with a water hose on the steps between the shower and cell floor and

CELL ENTRY PERMIT
BUILDING 3019 - RPPP

Name _____ Date _____
Badge No. _____ Time _____
Radiation Exposure: Cell No. _____
Through last year _____ mr Air Count _____ $\mu\text{c}/\text{cc}$
This year to date _____ mr Max. Radiation Rdg. _____ mr/hr
Total _____ mr Radiation Background _____ mr/hr
% MPE _____ Survey by _____
Date of Survey _____
Predicted Working Time _____ Limit Exposure to _____ mr
Based on _____

Description of Work _____

PROTECTIVE EQUIPMENT REQUIRED

<u>Clothing</u>	<u>Safety Equipment</u>	<u>Radiation Monitors</u>
Safety Shoes _____	Fresh Air Suit _____	Pencil Meters _____
Coveralls _____	Fresh Air Mask _____	Dosimeter _____
Cap _____	Assault Mask _____	Security Badge _____
Hood _____	Raincoat _____	Film Badge _____
Gloves: Cotton _____	Rain hat _____	Film Ring _____
Rubber _____		Cutie Pie _____
Shoe Covers _____		Alpha Survey Meter _____

Dress Instructions _____

Permit Prepared by _____
Entry Approved by _____

Observer _____ Time In _____ Time Out _____
Dosimeter Reading _____ mr
Personnel Decontamination _____

then thoroughly scrubbed with brushes and rinsed under the shower. A second operator carefully removed his suit, installed a clean assault mask while the man held his breath, and placed the suit in a plastic bag for disposal. A checking station at the doors between the basement area and plenum chamber was set up to completely survey the operator. The operator then went through the shower room and was rechecked for alpha contamination before being permitted to continue his work.

The total number of entries into cells 6 and 7 during the cleanup operation was 252. Only three of the 252 people were contaminated, and the amount of contamination was insignificant. On no occasion did the building become contaminated due to a cell entry.

Approximately 175 plastic air suits were consumed and only two of these were faulty. Both developed an opening where the head piece is seam-welded together. One of these was in use in the cell when detected by the supervisor in the greenhouse and the other was found by examination before use. The first case resulted in slight contamination of the operator's face when decontaminating solution leaked in.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The decontamination of cells 6 and 7, Bldg. 3019, proceeded efficiently and safely. The actual time of 5 months for decontamination could have been decreased considerably at a sacrifice of simultaneous decontamination of other parts of the building. More than 95% of the plutonium was removed during the first two months.

The processing cells in Bldg. 3019 had been used over the past 8 years to process kilogram quantities of plutonium and U^{233} and, due to the absence of a complete alpha contamination survey prior to the explosion, the net

increase in contamination cannot be ascertained. It is conceivable that the cell contamination level after decontamination and prior to painting is less than a factor of 10 higher than it was originally. Prior to the incident, requirements for cell entry were based entirely on the long-lived air activity rather than the level of surface contamination.

The various decontaminating reagents, with the exception of the HNO_3 - NaF solution and the Turco 4501 solution, did not show a marked difference in their ability to remove contamination. The extremely corrosive HNO_3 - NaF solution, although effective in removing plutonium, is not recommended for spraying materials other than stainless steel unless such materials do not warrant salvage. The expense of the Turco 4501 solution demands a recirculating system including a heat exchanger, since the solution performs more efficiently at temperatures around 70°C . This system must be used only after the quantity of fissionable material present is below the critical amount required for a nuclear excursion, or a suitable continuous monitoring system must be incorporated.

A person can work in a plastic air suit for 2 to 3 hr in areas with extremely high air contamination with no internal exposure, contamination to the person, or exhaustion. However, persons with claustrophobia or respiratory ailments should not be used for this work. The principal objection to use of the air suit was entanglement of the air lines when more than one person worked in the cell. An air pack which the operator carries on his back is now being evaluated and may eliminate this problem. A person should not be permitted to work alone in an air suit unless he is under constant surveillance by another person with predetermined plans to follow in the event of an emergency.

The decontamination of stainless steel that has been contaminated with plutonium in an acid medium is very difficult. Although the transferable surface contamination could be decreased to reasonable levels, the contamination, as measured with a direct-reading alpha meter, remained as much as 10,000 times higher. Samples of stainless steel were removed from the cell for use in developing methods and solutions for more complete decontamination.

The use of resin-base paint to cover the residual activity appears safe and attractive. However, determination of the long-time health hazard associated with this scheme appears mandatory. Once cells become contaminated as a result of either an incident such as that described in this report or by equipment leakage or malfunction over a long period of time, it becomes a matter of administrative responsibility to protect individuals entering the area. These administrative decisions should be based on reasonable, established limits applied to air contamination as well as surface contamination and the area involved.

The designer of radioactive cells and equipment must not overlook the possibility of widespread contamination and subsequent decontaminations. Surfaces should be kept as smooth as is economically possible and protective coatings, such as water-soluble paint, should be applied where decontamination appears difficult. A system for handling decontaminating waste solutions with adequate nuclear safety features should be incorporated.

9.0 APPENDIX

9.1 Final Smears and Probes in Cells 6 and 7, Bldg. 3019

Sample No.	Alpha Activity, d/m/100 cm ²		Location
	Direct	Smear	
1	7,000	440	East wall, cell 7 upper level
2	10,500	380	East wall, cell 7 upper level
3	17,500	840	East wall, cell 7 upper level
4	10,500	363	East wall, cell 7 upper level
5	175,000	3,430	Stainless pipe and unistrut on same wall
6	70,000	14,438	Stainless pipe and unistrut on same wall
7	630,000	16,878	Stainless pipe and unistrut on same wall
8	21,000	5,280	Stainless pipe and unistrut on same wall
9	3,500	380	Ceiling above T-4; R-9; and P-69
10	7,000	960	Ceiling above T-4; R-9; and P-69
11	5,250	1,340	Ceiling above T-4; R-9; and P-69
12	3,500	960	Ceiling above T-4; R-9; and P-69
13	>700,000	12,640	Top of P-69
14	>700,000	245,000	Top of R-9
15	>700,000	2,680	Top of T-4
16	>700,000	500,000	Horizontal heat exchanger above R-9
17	>700,000	39,470	Off-gas line (4 in. near ceiling)
18	>700,000	5,100	Monorail, cell 7
19	14,000	1,855	Cell 7, near open port hole #10, N. wall
20	420,000	200,000	Stainless steel pipe
21	7,000	1,513	N. wall
22	>700,000	30,898	Stainless steel pipe
23	10,500	1,170	N. wall
24	>700,000	2,840	Stainless steel pipe
25	210,000	1,010	T-4, stainless steel part, east side
26	14,000	3,985	West wall
27	490,000	1,820	Stainless steel pipe
28	10,500	1,280	West wall
29	350,000	2,272	Stainless steel pipe
30	140,000	1,794	West side of R-9

Sample No.	Alpha Activity, d/m/100 cm ²		Location
	Direct	Smear	
31	350,000	2,160	West side P-69
32	42,000	1,195	N. side of T-1 column
33	140,000	2,631	N. side of P-25 column
34	>700,000	200,000	Top of T-20
35	490,000	1,070	Top of P-60
36	28,000	1,445	Column just W. of P-60
37	21,000	1,505	Column just N. of P-60
38	42,000	1,320	Column just NW of P-60
39	14,000	760	West wall
40	17,500	1,955	R-12
41	10,500	955	S. wall
42	280,000	24,405	Stainless steel pipe
43	3,500	614	Ceiling above sampling station
44	>700,000	47,616	Lines in sampling station
45	>700,000	150,000	Lines in sampling station
46	>700,000	27,680	Monorail at ceiling near P-65
47	21,000	1,895	N. wall of cell 7 cubicle
48	28,000	2,669	Ladder to sampling station
49	>700,000	3,090	Top of P-65
50	17,500	768	S. wall above P-65
51	10,500	253	Cell 7, high on W. wall in R-column cubicle
52	350,000	16,340	Stainless steel pipe and unistrut
53	10,500	535	W. wall of R-column cubicle
54	7,000	2,880	E. wall of R-column cubicle
55	10,500	605	N. wall, middle part of R-column cubicle
56	175,000	4,160	Stainless steel pipe
57	280,000	1,600	N. side of R-column
58	35,000	550	N. wall, lower part of R-column cubicle
59	42,000	1,600	E. wall of R-column cubicle
60	52,500	380	W. wall of R-column cubicle
61	490,000	2,835	Top of R-3 tank
62	28,000	570	Side R-3
63	17,500	505	N. wall of R-3 cubicle
64	56,000	825	S. wall of R-3 cubicle
65	49,000	1,045	W. wall of R-3 cubicle

Sample No.	Alpha Activity, d/m/100 cm ²		Location
	Direct	Smear	
66	28,000	3,515	Stainless steel pipe on W. wall
67	35,000	700	Stainless steel pipe on W. wall
68	63,000	3,235	Stainless steel pipe over R-3
69	700,000	1,550	Top of R-2
70	70,000	11,505	Top of R-2, stainless steel pipe
71	7,000	405	N. wall in R-2 cubicle
72	7,000	1,515	S. wall in R-2 cubicle
73	7,000	1,530	W. wall in R-2 cubicle
74	35,000	975	W. wall, stainless steel pipes
75	10,500	4,670	Monorail
76	210,000	1,265	Tank in T-column cubicle E. of R-2 cubicle
77	3,500	225	N. wall N. of tank
78	3,500	575	N. wall N. of tank
79	2,800	125	N. wall N. of tank
80	>700,000	3,850	Stainless steel along N. wall
81	70,000	5,090	Stainless steel along N. wall
82	70,000	814	E. wall in T-column cubicle
83	21,000	1,235	E. wall in T-column cubicle
84	35,000	800	E. wall in T-column cubicle
85	35,000	4,800	Stainless steel along E. wall
86	350,000	2,930	Stainless steel along E. wall
87	210,000	7,360	Stainless steel along E. wall
88	210,000	14,010	Monorail
89	140,000	1,790	T-column, middle
90	21,000	2,153	T-column, low
91	260,000	1,115	T-10 tank, top
92	30,000	1,255	SW column in T-10 cubicle, side
93	105,000	830	Side of T-10 tank
94	35,000	170	S. wall of T-10 cubicle
95	42,000	740	S. wall of T-10 cubicle
96	14,000	3,200	S. wall, stainless steel lines
97	12,500	410	W. wall in T-10 cubicle
98	24,000	435	NW column in T-10 cubicle
99	28,000	1,590	N. column in T-10 cubicle
100	10,500	1,150	N. wall in T-10 cubicle

Sample No.	Alpha Activity, d/m/100 cm ²		Location
	Direct	Smear	
101	70,000	2,750	N. side of P-65 (steel)
102	225,000	5,960	E. side of P-65 (steel)
103	7,000	640	S. wall of cell divider
104	595,000	640	Concrete cell divider
105	35,000	4,460	E. concrete cell divider
106	280,000	640	Entrance to B-column cubicle
107	225,000	1,280	E. side of doorway to B-column cubicle
108	700,000	6,720	E. wall of B-column cubicle
109	>700,000	16,000	W. wall of B-column cubicle
110	>700,000	11,520	N. wall of B-column cubicle
111	>700,000	150,000	N. side of B-column
112	>700,000	58,320	Stainless steel pipe of B-column cubicle
113	>700,000	5,120	W. wall of B-column cubicle
114	>700,000	6,290	N. wall of B-column cubicle
115	>700,000	5,045	E. wall of B-column cubicle
116	>700,000	1,920	Stainless steel pipe of B-column cubicle
117	>700,000	250,000	NW corner of B-column cubicle
118	>700,000	4,445	B-column top
119	7,000	18,895	E. wall at top of B-column cubicle
120	7,000	200,000	W. wall at top of B-column cubicle (stainless steel)
121	35,000	4,500	Stainless steel lines on W. wall at top of B-column
122	630,000	5,200	Conduit at top of B-column cubicle
123	3,500	600	N. wall above stainless steel in B-column cubicle
124	>700,000	1,665	Stainless steel lines on N. wall, B-column cubicle
125	10,500	515	N. wall of B-column
126	>700,000	6,045	Stainless steel at top of B-column
127	10,500	1,265	Ceiling over B-column
128	14,000	2,000	Ceiling over B-column
129	10,500	1,760	Ceiling over B-column, N-18
130	56,000	320	Stainless steel ceiling over B-column, N-18
131	63,000	2,560	Stainless steel over B-column, N-18
132	7,000	800	N. wall of B-column, N-18
133	420,000	4,800	Stainless steel, B-column, N-18
134	10,500	480	W. wall of B-column, N-18
135	17,500	1,280	E. wall of B-column, N-18

Sample No.	Alpha Activity, d/m/100 cm ²		Location
	Direct	Smear	
136	35,000	1,200	E. wall of B-column, N-18
137	280,000	900	Stainless steel wall of B-column, N-18
138	>700,000	20,740	Top of P-6
139	210,000	13,135	Monorail over P-6
140	7,000	2,710	Ceiling over P-6
141	7,000	560	Ceiling over P-6
142	>700,000	2,105	Stainless steel lines over P-6
143	5,250	4,060	E. walls at P-6
144	14,000	1,565	Stainless steel lines on E. wall at P-6
145	7,000	1,485	N. wall at P-6
146	70,000	2,320	Stainless steel lines on N. wall at P-6
147	280,000	5,005	N. side of P-6
148	7,000	1,850	E. wall at P-6
149	>700,000	2,800	Stainless steel lines high on E. wall
150	>700,000	1,690	Stainless steel lines on E. wall
151	21,000	8,280	Ceiling over cell 6 door
152	>700,000	13,280	Off-gas header over cell 6 door
153	>700,000	100,000	Stainless steel to sampling station, cell 6 door
154	>700,000	125,000	Stainless steel to sampling station, cell 6 door
155	140,000	19,440	Conduit at sampling station
156	525,000	125,000	Handrail at sampling station
157	63,000	3,380	Wall over cell 6 door
158	>700,000	2,500	Stainless steel lines over cell 6 door
159	35,000	16,990	Stainless steel lines over cell 6 door
160	105,000	15,840	Ladder to sampler
161	70,000	2,050	Wall W. of cell 6 door
162	56,000	Missing	Wall E. of cell 6 door
163	>700,000	250,000	Conduit near cell 6 door
164	3,500	830	Wall W. of cell 6 door
165	280,000	2,500	Stainless steel lines W. of cell 6 door
166	>700,000	27,545	Top of PB over P-3
167	>700,000	125,000	Front of cell 6 door
168	>700,000	5,730	Pb over P-4
169	17,500	1,040	Handrail near cell 6 door
170	4,200	960	S. wall at cell divider

Sample No.	Alpha Activity, d/m/100 cm ²		Location
	Direct	Smear	
171	>700,000	2,810	Stainless steel lines at cell divider
172	>700,000	32,840	W. wall of P-15, midway
173	>700,000	75,000	W. wall of P-15, low
174	>700,000	2,390	N. wall of P-15
175	>700,000	16,570	E. wall of P-15
176	>700,000	100,000	W. wall of P-15, high
177	>700,000	10,920	E. wall of P-15, high
178	>700,000	18,780	N. wall of P-15, high
179	>700,000	27,235	Stainless steel line on E. wall of P-15
180	>700,000	7,310	Top of P-3
181	140,000	2,755	E. wall at P-3
182	28,000	5,010	S. wall at P-3
183	175,000	2,560	S. side of P-3
184	17,500	2,255	W. wall at P-3
185	175,000	4,360	Stainless steel lines at P-3 W. wall
186	350,000	1,680	Top of P-4
187	7,000	970	S. wall at P-4
188	140,000	665	Stainless steel lines on S. wall at P-4
189	3,500	790	E. wall at P-4
190	70,000	2,760	Stainless steel off-gas header
191	490,000	4,290	Lines and air valve in front of P-3, P-4
192	50,500	2,020	Ladder to 2nd level
193	17,500	30,765	Heat exchanger in P-65 cubicle
194	150,000	1,625	W. wall at entrance to cell
195	35,000	885	E. wall at entrance to cell
196	140,000	4,225	Handrail at entrance to cell
197	28,000	1,620	S. wall halfway down steps
198	14,000	2,240	Ceiling of stairwell
199	14,000	3,060	Stainless steel conduit
200	10,500	1,130	Stainless steel conduit on N. wall
201	52,500	2,935	Cell 7 S. wall at bottom of steps
202	45,500	315	R-1 and T-1 cubicle divider
203	42,000	205	Lead shielding (Point 3)
204	140,000	520	Divider between P-1 and N-2
205	>700,000	2,800	Stainless steel wall outside P-15

Sample No.	Alpha Activity, d/m/100 cm ²		Location
	Direct	Smear	
206	>700,000	200,000*	W. entrance to P-15
207	10,500	405	P-4 tank on north side
208	140,000	2,240	Floor above N-2
209	14,000	115	S. wall west of cell 6 door (no paint)
210	105,000	4,920	P-6 south side
211	210,000	3,255	P-6 east side
212	5,250	265	Lead shielding on T-4

* Smear #6 read with GPA meter.

Table 9.2. Cells 6 and 7 Survey Results During Decontamination

		8/12/60	11/9/60		11/15/60		11/23/60		11/28/60		12/5/60			12/8/60		
		Smears, d/m/100 cm ²	Smears, d/m/100 cm ²	Radiation HSCP* mr/hr	Smears, d/m/100 cm ²	Radiation HSCP* mr/hr	Smears, d/m/100 cm ²	Radiation HSCP* mr/hr	Smears, d/m/100 cm ²	Gas Flow d/m/100 cm ²	Smears, d/m/100 cm ²	Radiation HSCP* mr/hr	Gas Flow d/m/100 cm ²	Smears, d/m/100 cm ²	Radiation HSCP* mr/hr	
Cell 6 Lower Level	East side VI and VII divider	5.0 × 10 ⁶	2.2 × 10 ⁶	250	8.4 × 10 ⁴	200	1.1 × 10 ⁴	200	8.4 × 10 ³	2.4 × 10 ⁵	1.6 × 10 ³	100	3.0 × 10 ⁵	2.4 × 10 ⁴		
	Lead shielding N-2 cubicle		5.4 × 10 ⁶	300	4.2 × 10 ⁶	200	9.6 × 10 ⁵	200	1.4 × 10 ⁴	8.0 × 10 ⁴	8.0 × 10 ²	70	4.0 × 10 ⁵	2.0 × 10 ³		
	S.S. wall between P-11 and P-15		8.4 × 10 ⁵	400	1.0 × 10 ⁵	210	8.4 × 10 ⁴	210	1.4 × 10 ⁴	6.4 × 10 ⁵	1.6 × 10 ³	200	>8.0 × 10 ⁵	2.4 × 10 ³		
	S.S. wall P-15 cubicle cat.	6.0 × 10 ⁷	1.4 × 10 ⁶	1000	3.0 × 10 ⁵	600	3.4 × 10 ⁵	600	1.6 × 10 ⁵	>8.0 × 10 ⁵	9.0 × 10 ⁴	500	>8.0 × 10 ⁵	2.4 × 10 ⁵		
	S.S. wall P-15 entrance west	7.4 × 10 ⁷	4.0 × 10 ⁷	2000	4.4 × 10 ⁷	1500	5.8 × 10 ⁶	1500	1.5 × 10 ⁶	>8.0 × 10 ⁵	1.4 × 10 ⁶	1500	>8.0 × 10 ⁵	1.4 × 10 ⁶		
	East wall P-15 cubicle															
	North wall P-15 cubicle															
	West wall P-15 cubicle															
	North wall P-1 cubicle													7.2 × 10 ⁵		150
	West wall P-1 cubicle															
	P-3 tank															
	P-4 tank															
	East wall on point	8.2 × 10 ⁶												2.0 × 10 ⁵		2000
Divider between P-1 and N-2	8.0 × 10 ⁶															
Cell 6 Upper Level	Ledge atop P-3 and P-4		1.2 × 10 ⁶		2.0 × 10 ⁶	50	6.4 × 10 ⁵	50			1.2 × 10 ⁶		>8.0 × 10 ⁵			
	South wall at greenhouse (no paint)															
	South wall at greenhouse (paint)		1.6 × 10 ⁵	100	1.0 × 10 ⁵	40	3.6 × 10 ⁴	40			1.1 × 10 ³		7.0 × 10 ³			
	East wall 1/2 way up P-6 steps									4.3 × 10 ³	500		>8.0 × 10 ⁵	2.2 × 10 ⁴		
	P-6 tank south side									4.3 × 10 ³	200		3.2 × 10 ⁵	1.4 × 10 ⁵		
	P-6 tank east side															
	P-6 tank north side															
	West wall above N-2										2.6 × 10 ³		8.0 × 10 ³			
	East wall above N-2										8.4 × 10 ⁴		4.0 × 10 ⁵			
	North wall above N-2										2.8 × 10 ³	30	8.0 × 10 ⁴			
Floor above N-2										2.8 × 10 ⁵	30	>8.0 × 10 ⁵				
East wall at P-6																
Cell 7 Lower Level	South wall stairwell, 1/3 down												1.0 × 10 ⁴			
	North wall stairwell, 2/3 down												1.2 × 10 ⁵			
	South wall stairwell, bottom												1.2 × 10 ⁵			
	South wall around entrance								5.4 × 10 ⁴	1.6 × 10 ⁵	1.1 × 10 ⁴		>8.0 × 10 ⁵			
	North wall P-62 cubicle	3.2 × 10 ⁵									4.6 × 10 ⁴		1.6 × 10 ⁵			
	T-10 tank			2000							7.2 × 10 ⁴		4.0 × 10 ⁵			
	R-3 tank										8.0 × 10 ³		8.0 × 10 ⁴			
T-1 cubicle, north wall																
P-70 tank																
R-1 column																
R-1 cubicle, north wall													1.2 × 10 ⁴			
South wall, point	5.2 × 10 ⁵									4.3 × 10 ³		1.0 × 10 ⁴				
South edge VI and VII divider										1.2 × 10 ⁵		8.0 × 10 ⁴				
South side R-1 and T-1 divider	1.6 × 10 ⁶											>8.0 × 10 ⁵				
P-62 shielding support, east		6.0 × 10 ⁴	20	7.4 × 10 ⁴	10	7.0 × 10 ⁴	10	1.8 × 10 ⁴	4.0 × 10 ⁵	6.7 × 10 ³	10	4.0 × 10 ⁵	2.0 × 10 ³			
Cell 7 Upper Level	Top of P-65												2.0 × 10 ⁴			
	Top of P-62												5.4 × 10 ³			
	South wall above P-65												8.3 × 10 ³			
	West wall P-60 cubicle												>8.0 × 10 ⁵			
	T-4 lead shielding			200									3.2 × 10 ⁴			
	T-4 stainless steel		3.6 × 10 ⁶		6.6 × 10 ⁶	90	4.8 × 10 ⁵	90			1.9 × 10 ³		2.0 × 10 ⁴			
	P-69 tank			200							9.3 × 10 ³		2.0 × 10 ⁴			
	T column			800							1.4 × 10 ⁴		2.0 × 10 ⁵		5.5 × 10 ³	
	T-25 filter		3.6 × 10 ⁵		2.8 × 10 ⁵	25	9.6 × 10 ⁴	25			3.2 × 10 ³		2.0 × 10 ⁵			
	Ceiling above R-1										3.4 × 10 ⁴	600	8.0 × 10 ⁴			
North cell wall										1.7 × 10 ⁵	80	2.0 × 10 ⁵	2.0 × 10 ⁵			
South wall between VI and VII										5.4 × 10 ³	200					
										1.4 × 10 ³	30	2.0 × 10 ⁴	7.0 × 10 ²			
										3.2 × 10 ³	20	8.0 × 10 ⁴	1.2 × 10 ⁵			

*Hard shell cutie pie.

Table 9.2 (continued)

		12/16/60	1/3/61	1/11/61	1/16/61	1/23/61	2/1/61	2/6/61	2/13/61	2/21/61					
		Smears, d/m/100 cm ²	Smears, d/m/100 cm ²	Smears, d/m/100 cm ²	Smears, d/m/100 cm ²	Smears, d/m/100 cm ²	Smears, d/m/100 cm ²								
			Radiation HSCP* mr/hr	Radiation HSCP* mr/hr			Gas Flow d/m/100 cm ²		Gas Flow d/m/100 cm ²						
Cell 6 Lower Level	East side VI and VII divider	1.4 × 10 ³	4.4 × 10 ³	6.1 × 10 ²	4.5 × 10 ³	1.5 × 10 ³			7.7 × 10 ²	4.0 × 10 ⁴	4.4 × 10 ³	3.5 × 10 ⁴			
	Lead shielding N-2 cubicle	3.2 × 10 ³	2.8 × 10 ³	6.5 × 10 ³	1.4 × 10 ³	1.5 × 10 ²			2.1 × 10 ³	8.0 × 10 ³	2.1 × 10 ²	4.2 × 10 ⁴			
	S.S. wall between P-11 and P-15	1.7 × 10 ³	1.4 × 10 ³	6.6 × 10 ³	2.3 × 10 ³	3.7 × 10 ³			2.9 × 10 ³	2.0 × 10 ⁵	1.3 × 10 ³	2.3 × 10 ⁵			
	S.S. wall P-15 cubicle cat.	6.0 × 10 ⁴	7.2 × 10 ⁴	9.8 × 10 ⁴	1.7 × 10 ⁴	2.9 × 10 ⁴			1.0 × 10 ⁴	>8.0 × 10 ⁵	2.8 × 10 ⁵	>7.0 × 10 ⁵			
	S.S. wall P-15 entrance west	4.4 × 10 ⁵	2.2 × 10 ⁶	1.8 × 10 ⁶	3.6 × 10 ⁵	3.2 × 10 ⁵	5.2 × 10 ⁵	>8.0 × 10 ⁵	1.8 × 10 ⁵	>8.0 × 10 ⁵	2.0 × 10 ⁵	>7.0 × 10 ⁵			
	East wall P-15 cubicle	1.3 × 10 ⁴		8.8 × 10 ⁴	2.2 × 10 ⁴	1.3 × 10 ⁴	2.7 × 10 ⁴	>8.0 × 10 ⁵	4.3 × 10 ³	5.7 × 10 ³	>8.0 × 10 ⁵	1.6 × 10 ⁴	>7.0 × 10 ⁵		
	North wall P-15 cubicle			1.1 × 10 ⁵	1.0 × 10 ⁵	4.5 × 10 ⁴	2.0 × 10 ⁴	>8.0 × 10 ⁵	1.7 × 10 ⁴	5.0 × 10 ³	>8.0 × 10 ⁵	2.4 × 10 ³	>7.0 × 10 ⁵		
	West wall P-15 cubicle	6.6 × 10 ⁵		1.4 × 10 ⁶	3.4 × 10 ⁵	2.8 × 10 ⁵	3.0 × 10 ⁵	>8.0 × 10 ⁵	4.2 × 10 ⁵	2.4 × 10 ⁵	>8.0 × 10 ⁵	3.3 × 10 ⁴	>7.0 × 10 ⁵		
	North wall P-1 cubicle	5.0 × 10 ⁴		2.4 × 10 ⁵	1.7 × 10 ⁵	2.8 × 10 ⁵	5.1 × 10 ⁴	>8.0 × 10 ⁵	1.2 × 10 ⁵	2.1 × 10 ⁴	>8.0 × 10 ⁵	1.2 × 10 ⁴	>7.0 × 10 ⁵		
	West wall P-1 cubicle		2.6 × 10 ⁵	40					3.2 × 10 ⁴	1.3 × 10 ⁴	>8.0 × 10 ⁵	1.3 × 10 ⁴	>7.0 × 10 ⁵		
	P-3 tank		1.8 × 10 ⁵	200	4.4 × 10 ³	400	2.0 × 10 ⁴	1.4 × 10 ⁴	3.8 × 10 ⁴	>8.0 × 10 ⁵	1.1 × 10 ⁴	5.1 × 10 ²	3.2 × 10 ⁴	2.6 × 10 ³	1.8 × 10 ³
	P-4 tank		3.4 × 10 ⁶	40	1.6 × 10 ⁴		4.9 × 10 ³	4.1 × 10 ⁴	2.8 × 10 ⁴	>8.0 × 10 ⁵	2.0 × 10 ³	6.1 × 10 ²	2.4 × 10 ⁴	4.1 × 10 ²	1.1 × 10 ⁴
	East wall on point			200								5.0 × 10 ²	8.0 × 10 ⁴	2.7 × 10 ²	1.4 × 10 ⁴
	Divider between P-1 and N-2											7.7 × 10 ²	8.0 × 10 ³	5.2 × 10 ²	1.4 × 10 ⁵
Cell 6 Upper Level	Ledge atop P-3 and P-4		2.5 × 10 ⁴						8.8 × 10 ³	1.2 × 10 ³	6.0 × 10 ⁴	2.8 × 10 ⁴	>7.0 × 10 ⁵		
	South wall at greenhouse (no paint)	1.6 × 10 ³	9.1 × 10 ³	1.2 × 10 ³	4.9 × 10 ³	3.5 × 10 ³	6.0 × 10 ³	2.0 × 10 ⁵	6.9 × 10 ³	3.1 × 10 ²	4.0 × 10 ⁴	1.2 × 10 ²	1.4 × 10 ⁴		
	South wall at greenhouse (paint)			1.2 × 10 ³	7.5 × 10 ³	1.3 × 10 ³	1.3 × 10 ⁴	8.0 × 10 ⁴		1.6 × 10 ³	1.6 × 10 ⁴	8.3 × 10 ²	3.5 × 10 ³		
	East wall 1/2 way up P-6 steps	4.5 × 10 ³	1.1 × 10 ⁴	7.8 × 10 ³	3.7 × 10 ³	1.1 × 10 ³	2.5 × 10 ⁴	4.0 × 10 ⁴	7.5 × 10 ³	8.5 × 10 ²	2.0 × 10 ⁴	1.9 × 10 ³	7.0 × 10 ³		
	P-6 tank south side	1.9 × 10 ³	1.8 × 10 ⁴	6.1 × 10 ³	2.6 × 10 ³	1.2 × 10 ³	1.7 × 10 ⁴	8.0 × 10 ⁵		4.8 × 10 ³	1.6 × 10 ⁵	4.9 × 10 ³	1.1 × 10 ⁵		
	P-6 tank east side	2.1 × 10 ³		2.8 × 10 ⁴	2.0 × 10 ⁴	1.9 × 10 ⁴	1.8 × 10 ⁴	>8.0 × 10 ⁵	7.8 × 10 ³	6.8 × 10 ³	4.0 × 10 ⁵	3.3 × 10 ³	2.1 × 10 ⁵		
	P-6 tank north side			3.1 × 10 ⁴	7.9 × 10 ³	1.8 × 10 ⁴	2.3 × 10 ⁴	>8.0 × 10 ⁵	1.0 × 10 ⁴	6.3 × 10 ²	4.0 × 10 ⁵	5.0 × 10 ³	2.8 × 10 ⁵		
	West wall above N-2									2.6 × 10 ³	2.0 × 10 ⁴	4.8 × 10 ²	1.1 × 10 ⁴		
	East wall above N-2							1.2 × 10 ⁵	>8.0 × 10 ⁵	3.7 × 10 ³	8.0 × 10 ⁴	1.2 × 10 ³	1.8 × 10 ⁴		
	North wall above N-2								5.5 × 10 ³	6.4 × 10 ²	1.6 × 10 ⁴	8.0 × 10 ²	7.0 × 10 ³		
	Floor above N-2				6.6 × 10 ³	1.7 × 10 ³	1.1 × 10 ³	1.0 × 10 ⁴	1.0 × 10 ⁵	3.0 × 10 ³	8.0 × 10 ⁴	2.2 × 10 ³	1.4 × 10 ⁵		
	East wall at P-6											4.0 × 10 ³	5.0 × 10 ³		
Cell 7 Lower Level	South wall stairwell, 1/3 down				5.4 × 10 ³					1.2 × 10 ³	1.2 × 10 ⁵	1.6 × 10 ³	2.8 × 10 ⁴		
	North wall stairwell, 2/3 down				8.7 × 10 ³					5.9 × 10 ³	9.6 × 10 ⁴	1.1 × 10 ³	1.0 × 10 ⁴		
	South wall stairwell, bottom				1.1 × 10 ⁴					6.7 × 10 ³	1.2 × 10 ⁵	2.9 × 10 ³	5.3 × 10 ⁴		
	South wall around entrance									1.0 × 10 ³	1.2 × 10 ⁴	1.0 × 10 ³	3.5 × 10 ⁵		
	North wall P-62 cubicle									2.0 × 10 ²	4.0 × 10 ³	2.7 × 10 ³	7.0 × 10 ⁴		
	T-10 tank					1.4 × 10 ³				1.3 × 10 ²	8.0 × 10 ⁴	8.3 × 10 ²	7.0 × 10 ⁵		
	R-3 tank		7.8 × 10 ⁴	1.1 × 10 ⁴	9.1 × 10 ³	2.5 × 10 ⁴				96	2.4 × 10 ⁴	5.7 × 10 ²	2.8 × 10 ⁴		
	T-1 cubicle, north wall			1.0 × 10 ⁴	1.0 × 10 ⁴	2.6 × 10 ³	3.1 × 10 ³			1.2 × 10 ³	3.2 × 10 ⁴	1.2 × 10 ³	2.1 × 10 ⁴		
	P-70 tank		1.0 × 10 ⁴	70						4.6 × 10 ²	6.4 × 10 ⁴	1.3 × 10 ³	2.1 × 10 ⁵		
	R-1 column		1.4 × 10 ⁴	80			4.3 × 10 ³			1.1 × 10 ³	8.0 × 10 ⁴	1.6 × 10 ³	2.8 × 10 ⁴		
	R-1 cubicle, north wall			1.9 × 10 ⁴	3.2 × 10 ³	2.3 × 10 ³				9.3 × 10 ²	4.8 × 10 ⁴	6.1 × 10 ²	1.1 × 10 ⁴		
	South wall, paint									1.1 × 10 ³	2.4 × 10 ⁴	6.4 × 10 ²	7.0 × 10 ³		
South edge VI and VII divider									1.8 × 10 ⁴	2.0 × 10 ⁵	6.4 × 10 ²	7.0 × 10 ³			
South side R-1 and T-1 divider									2.2 × 10 ³	2.0 × 10 ⁴	3.2 × 10 ²	4.6 × 10 ⁴			
P-62 shielding support, east	6.2 × 10 ³	5.6 × 10 ³	> 10,000	1.3 × 10 ⁴	4.1 × 10 ³	4.8 × 10 ³			7.1 × 10 ³	3.2 × 10 ⁵	5.9 × 10 ³	2.3 × 10 ⁵			
Cell 7 Upper Level	Top of P-65		1.6 × 10 ⁴							1.1 × 10 ²	6.4 × 10 ⁴	1.1 × 10 ³	4.9 × 10 ⁵		
	Top of P-62									1.7 × 10 ³	>8.0 × 10 ⁵	3.1 × 10 ³	>7.0 × 10 ⁵		
	South wall above P-65	3.6 × 10 ²	1.8 × 10 ⁴	1.2 × 10 ⁴	4.6 × 10 ³	3.5 × 10 ³				4.8 × 10 ²	1.2 × 10 ⁴	7.7 × 10 ²	1.7 × 10 ⁴		
	West wall P-60 cubicle	3.1 × 10 ²								1.2 × 10 ³	1.6 × 10 ⁴	7.6 × 10 ²	1.4 × 10 ³		
	T-4 lead shielding									3.1 × 10 ²	1.2 × 10 ⁴	2.6 × 10 ²	5.3 × 10 ³		
	T-4 stainless steel		7.4 × 10 ⁵	2.9 × 10 ⁴	4.1 × 10 ⁴	4.1 × 10 ⁴				1.3 × 10 ³	2.4 × 10 ⁵	1.0 × 10 ³	2.1 × 10 ⁵		
	P-69 tank									1.2 × 10 ³	2.4 × 10 ⁵	2.1 × 10 ³	3.5 × 10 ⁵		
	T column	6.6 × 10 ³	1.0 × 10 ⁴							1.6 × 10 ³	1.2 × 10 ⁴	1.2 × 10 ³	4.2 × 10 ⁴		
	T-25 filter		9.0 × 10 ³	2.0 × 10 ⁵	1.5 × 10 ⁵	2.9 × 10 ⁴				2.3 × 10 ³	8.0 × 10 ⁴	2.6 × 10 ³	1.4 × 10 ⁵		
	Ceiling above R-1														
North cell wall			3.4 × 10 ³	7.6 × 10 ²	1.0 × 10 ³				1.6 × 10 ³	1.2 × 10 ⁴	1.5 × 10 ³	7.0 × 10 ³			
South wall between VI and VII	9.2 × 10 ²								6.7 × 10 ²	6.0 × 10 ³	9.6 × 10 ²	4.2 × 10 ³			

*Hard shell cutie pie.

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