REPORT NO. 5

DETERMINATION OF THE QUANTITY AND LOCATIONS OF THE PLUTONIUM RETAINED IN THE CIMARRON FUEL PLANT SYSTEMS

This report is prepared and submitted as a Task 2 Requirement in accordance with Contract DE-AC06-83RL10382

U.S. Department of Energy
Richland Operations Office
P. O. Box 550
Richland, Washington 99352

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to the

U. S. Department of Energy
Richland Operations Office
P. O. Box 550
Richland, Washington

Prepared By

Sequoyah Fuels Corporation
P. O. Box 25861
Oklahoma City, Oklahoma 73125

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1.0 EXECUTIVE SUMMARY

In late 1975, Sequoyah Fuels Corporation (SFC)* announced its intention to suspend operations of its Cimarron Plutonium Fuel Fabrication Facility and to place the Facility in a standby status pending development of further activities. SFC, using non-destructive assay (NDA) measurment techniques, measured the residual plutonium held-up in the plant process equipment to establish a standby inventory hold-up baseline. The NRC's Office of Inspection and Enforcement assembled a team of various government experts that independently measured the plutonium hold-up, using NDA techniques.

In 1979, SFC elected to decontaminate the plutonium operation for purposes of decommissioning the site and terminating the NRC license. Care was taken throughout the

* SFC became the owner of the Cimarron Facility in 1983, when Kerr-McGee Nuclear Corporation was divided into SFC and Quivira Mining Corporation.

decontamination program to accurately measure the plutonium content and identify the origin of over 28,000 individual packages of contaminated equipment removed from the plant. The final measurement data for these smaller packages were compared with the results of the 1976 baseline measurement program.

This report compares the results of the 1976 baseline inventory data and the NRC team's data with the final measurement data obtained during the decontamination and decommissioning (D & D) effort.

The summary of the three independent measurement programs is shown in Table 1.

TABLE 1

SUMMARY

	GRAMS OF PLUTONIUM			
	Inventory Measurement	Lower Limit	Upper Limit	Limit-of-Error (1)
Baseline	10,818	7,843	13,793	±2,975
NRC Team	7,960	4,850	11,810	+3,850 -3,110
Final D&D	9,210	8,796	9,624	±414

(1) 95% Confidence Level

2.0 INTRODUCTION

Sequoyah Fuels Corporation's (SFC) Cimarron Plutonium Fuel Fabrication Facility was constructed in 1969 for the primary purpose of manufacturing plutonium-uranium mixed oxide fuel pins. The process consisted of coprecipitating plutonium and uranyl nitrate solutions into mixed oxide, pressing the mixed oxide into fuel pellets, and loading the finished pellets into fuel rods. The process also included complete scrap dissolution and recycle capabilities as well as necessary laboratory facilities to support production activities.

During the period 1970 through 1975, more than two million grams of plutonium were received in the form of plutonium nitrate and were converted into fuel pellets. The pellets were used in various governmental research and development programs, including the Zero Power Plutonium Reactor and Fast Flux Test Facility programs.

Since the plant equipment included more than 30,000 ft^2 of glovebox process area and almost one mile of process piping, methods were developed by SFC for conducting

in-place non-destructive assay (NDA) measurement programs to determine the inventory of plutonium hold-up in the process equipment. The methods developed by SFC during the 1973-1975 period for measuring inventory hold-up were used in early 1976 to establish a baseline inventory for purposes of placing the facility on standby status.

Shortly thereafter, NRC's Office of Inspection and Enforcement assembled a team of experts from various government laboratories to verify SFC's measurements. The NRC Audit team used independent instrumentation and developed specific techniques and procedures for their in-place NDA of the Plutonium Fuel Fabrication Facility.

The independent audit team was directed by W. A. Higenbotham of the Brookhaven National Laboratory. The members and their professional affiliations were:

Don M. Sikes - ERDA, Division of Safeguards and Security
Martin S. Zuker - Brookhaven National Laboratory
David M. Gordon - Brookhaven National Laboratory
Richard Machnowski - Brookhaven National Laboratory
James W. Tape - Los Alamos Scientific Laboratory
Michael L. Evans - Los Alamos Scientific Laboratory
Norbert Ensslin - Los Alamos Scientific Laboratory
Richard Siebelist - Los Alamos Scientific Laboratory

The results of the audit team's work were summarized by J. W. Tape in what has since become known as the "Tape Report".

Given the state of the art in early 1976, the experimental methods used, and the inherent difficulties of the task, the "Tape Report's" conclusion was that the results of the two independent measurements were in substantial agreement.

In 1979, SFC elected to decommission the plutonium fuel plant. Measurement data were collected throughout the subsequent decommissioning program for correlation and comparison with the data from the two measurement programs conducted in 1976.

This report discusses the methods used and the results obtained. It also provides detailed summaries of plant, room, and specific equipment measurements.

3.0 BACKGROUND

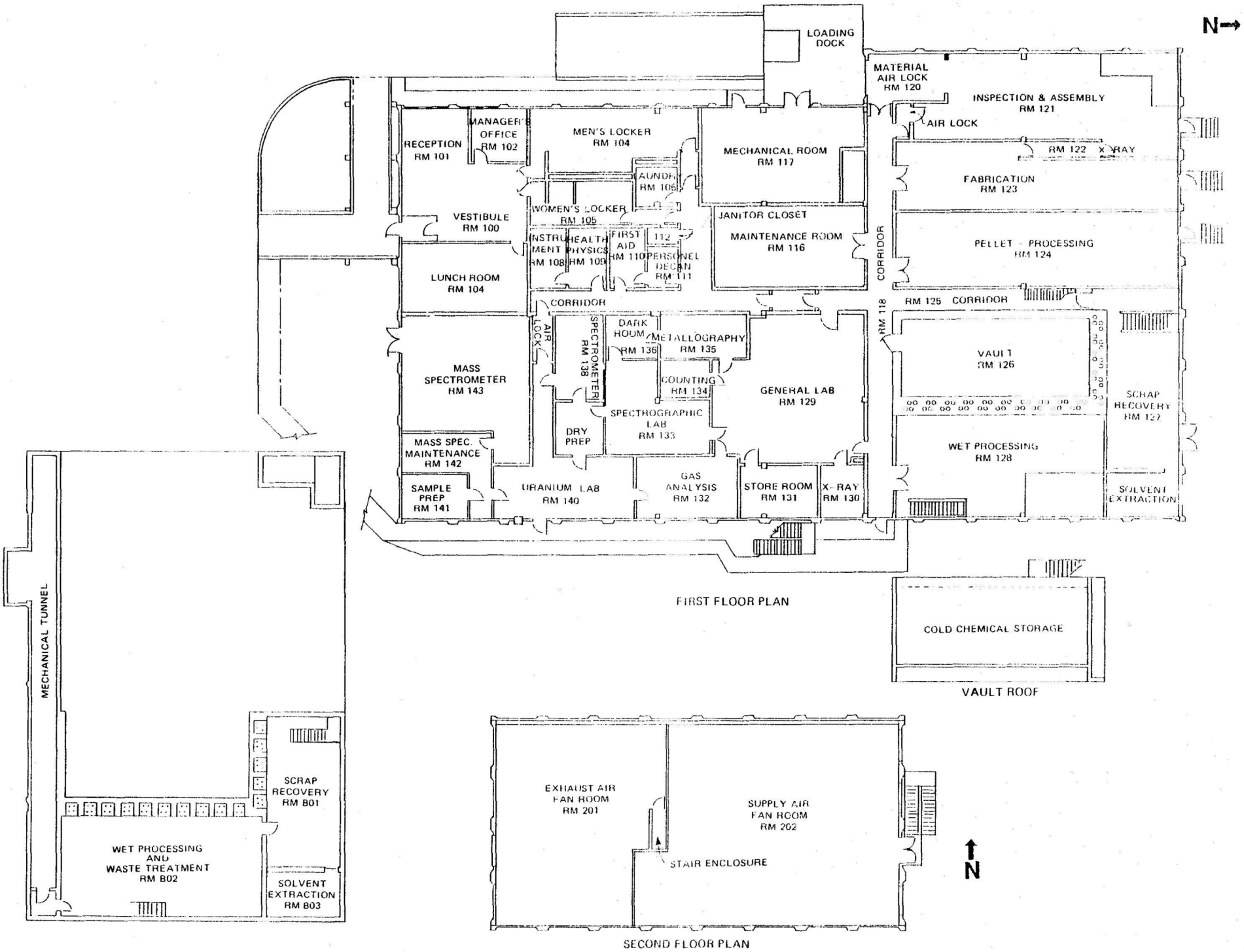
3.1 PLANT LAYOUT

The process area, shown in Figure 1, consisted of separate rooms for the major activities and was separate from the laboratory and administrative areas of the plant. Figures 2 through 8 depict each primary process area and the location of specific equipment in each of the areas. The primary process areas were:

Room 128 - Coprecipitation and Oxide Production
BO - 2 - Solution Storage and Blending
Room 124 - Pressing, Sintering, Grinding, Pellet inspection
Room 123 - Rod Loading and Welding
Room 121 - Final Inspection and Product Storage
Room 127 - Scrap Processing
BO - 1 - Scrap Dissolution
BO - 5 - Solvent Extraction

All process equipment was totally enclosed in forty-one gloveboxes of various sizes and dimensions. The solvent extraction glovebox, for example, was three stories tall and took up three walls of a room as shown in Figure 8.

FIGURE 1


N
LOADING DOCK
MATERIAL AIR LOCK RM 120
INSPECTION & ASSEMBLY RM 121
AIR LOCK
RM 122 X-RAY
FABRICATION RM 123
PELLET - PROCESSING RM 124
RM 125 CORRIDOR
RECEPTION RM 101
MANAGER'S OFFICE RM 102
MEN'S LOCKER RM 104
MECHANICAL ROOM RM 117
LAUNDRY RM 106
WOMEN'S LOCKER RM 105
VESTIBULE RM 100
INSTRUMENT RM 108
HEALTH PHYSICS RM 109
FIRST AID RM 110
112
PERSONNEL DECON RM 111
JANITOR CLOSET
MAINTENANCE ROOM RM 116
CORRIDOR
LUNCH ROOM RM 104
CORRIDOR
AIR LOCK
SPECTROMETER RM 138
DARK ROOM RM 136
METALLOGRAPHY RM 135
COUNTING RM 134
MASS SPECTROMETER RM 143
GENERAL LAB RM 129
SPECTROGRAPHIC LAB RM 133
DRY PREP
MASS SPEC. MAINTENANCE RM 142
SAMPLE PREP RM 141
URANIUM LAB RM 140
GAS ANALYSIS RM 132
STORE ROOM RM 131
X-RAY RM 130
RM 118
VAULT RM 126
SCRAP RECOVERY RM 127
WET PROCESSING RM 128
SOLVENT EXTRACTION
FIRST FLOOR PLAN
COLD CHEMICAL STORAGE
VAULT ROOF
MECHANICAL TUNNEL
SCRAP RECOVERY RM B01
WET PROCESSING AND WASTE TREATMENT RM B02
SOLVENT EXTRACTION RM B03
EXHAUST AIR FAN ROOM RM 201
SUPPLY AIR FAN ROOM RM 202
STAIR ENCLOSURE
N
SECOND FLOOR PLAN

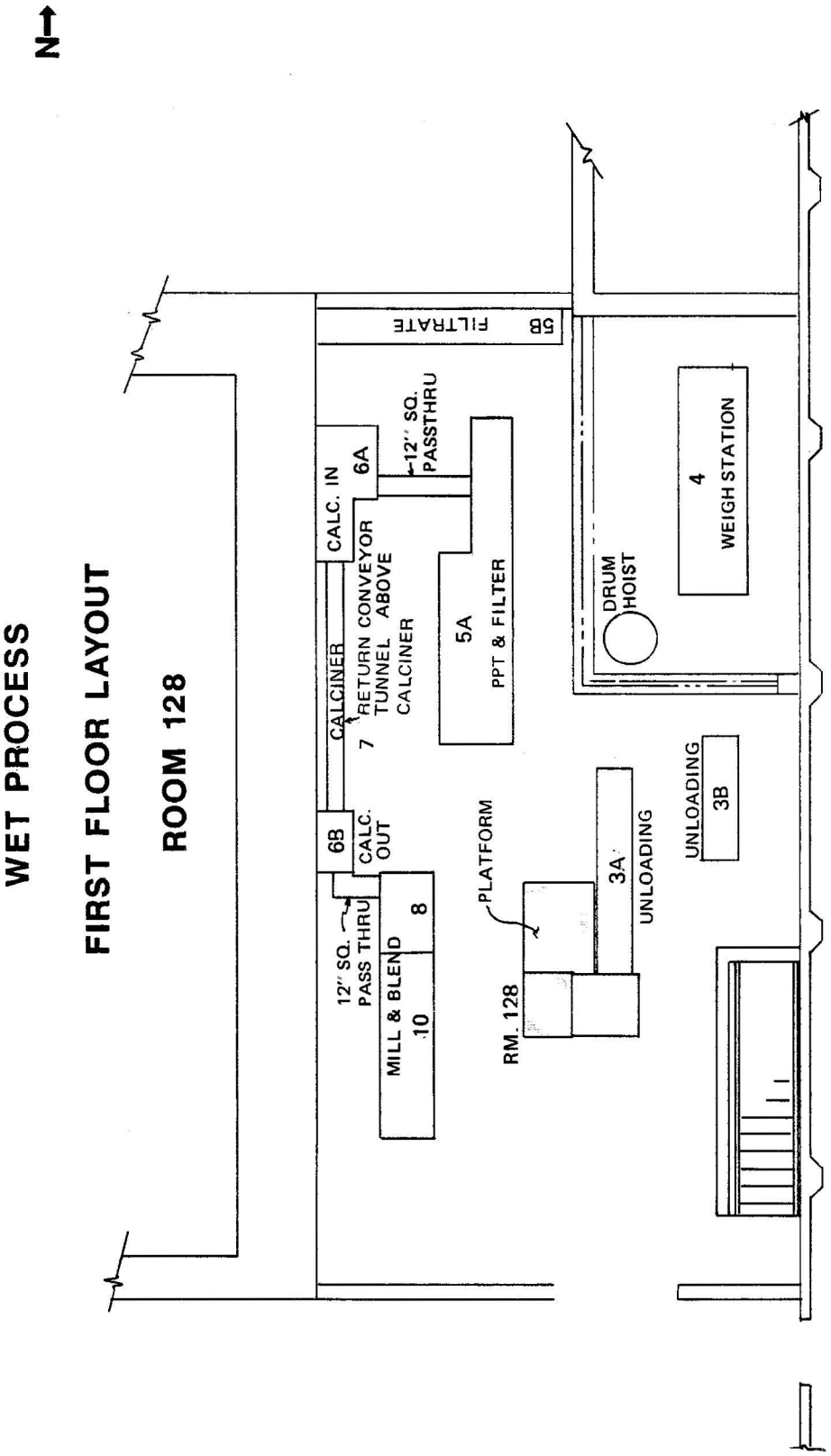

N
WET PROCESS
FIRST FLOOR LAYOUT
ROOM 128
5B FILTRATE
CALC. IN 6A
12" SQ. PASSTHRU
CALCINER
7 RETURN CONVEYOR TUNNEL ABOVE CALCINER
5A PPT & FILTER
DRUM HOIST
4 WEIGH STATION
6B CALC. OUT
12" SQ. PASS THRU
MILL & BLEND 8 10
PLATFORM
RM. 128
3A UNLOADING
UNLOADING 3B

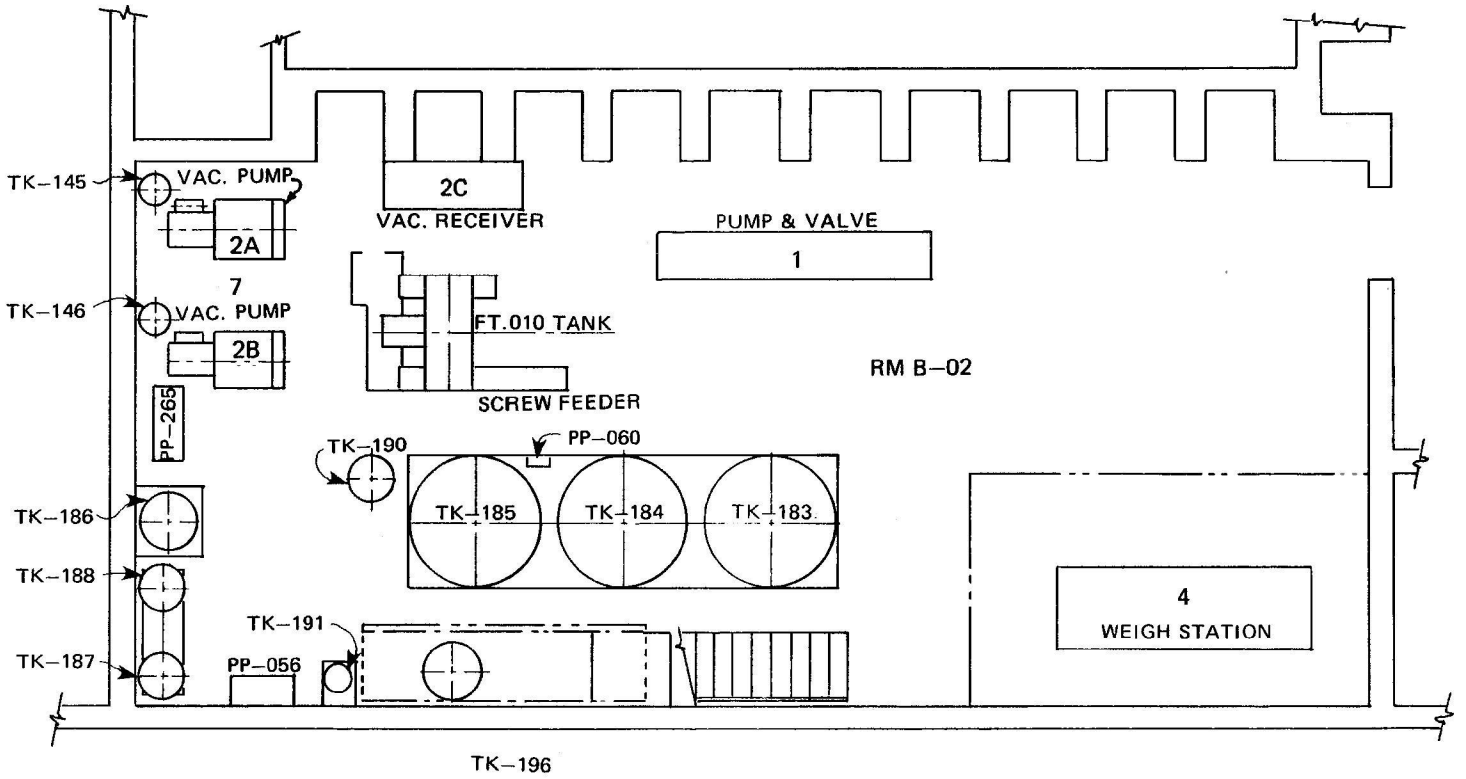
FIGURE 2

FIGURE 3

WET PROCESS

BASEMENT LAYOUT

ROOM BO-2



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DRY PROCESS LAYOUT

ROOM 124

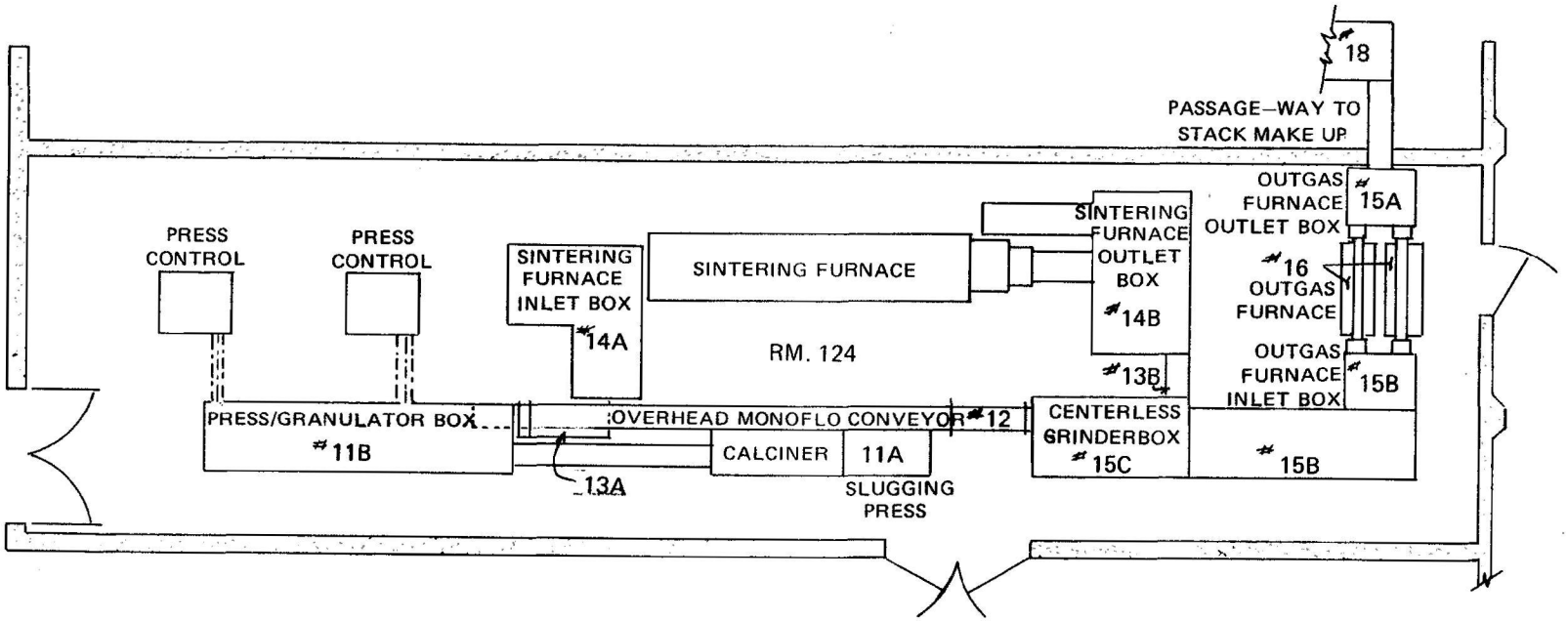

FIGURE 4

N→

FABRICATION LAYOUT

ROOM 123

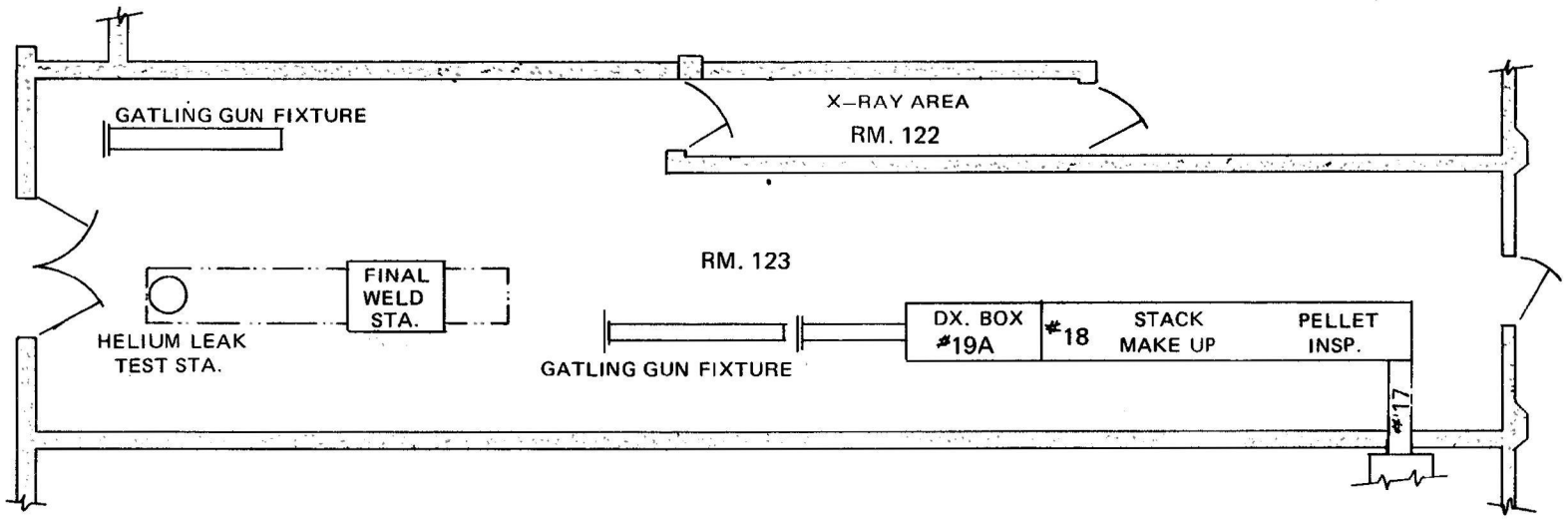

FIGURE 5

N→

CLEANING AND FINAL INSPECTION

ROOM 121

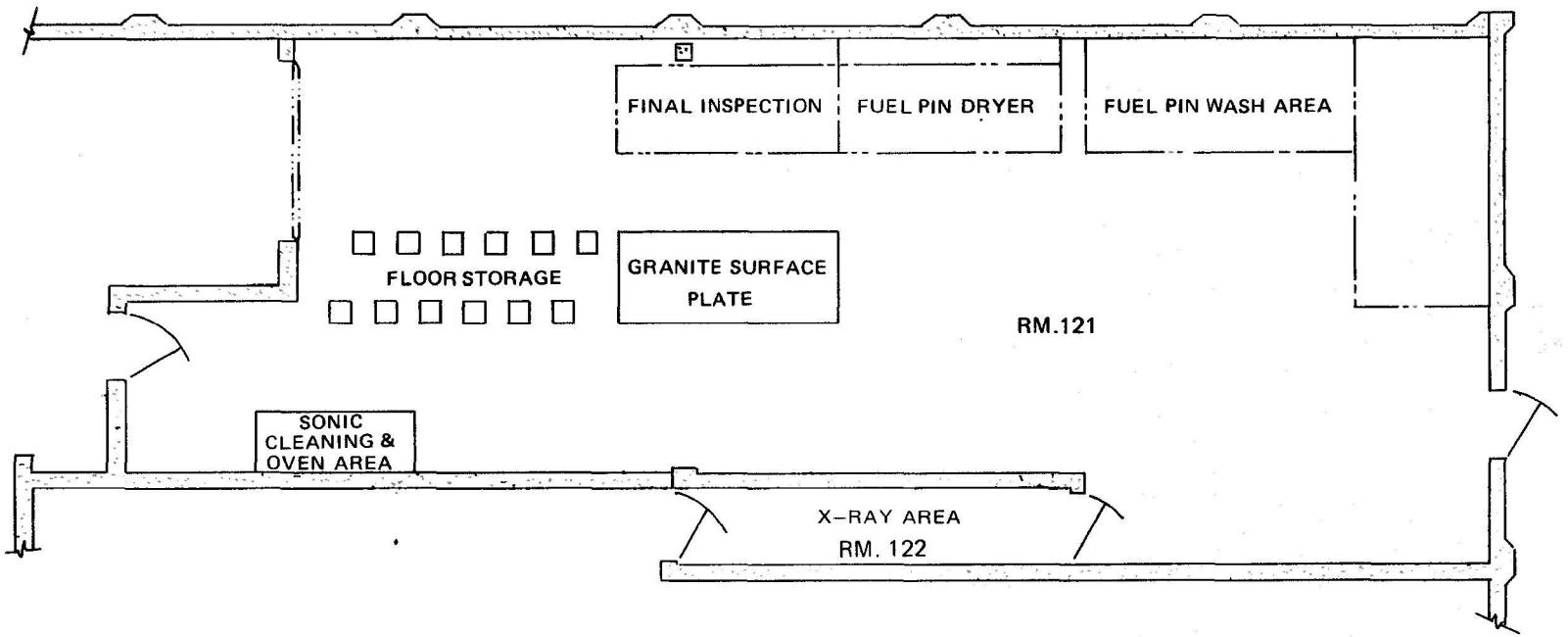

FIGURE 6

SCRAP FACILITY

FIRST FLOOR LAYOUT

ROOM 127

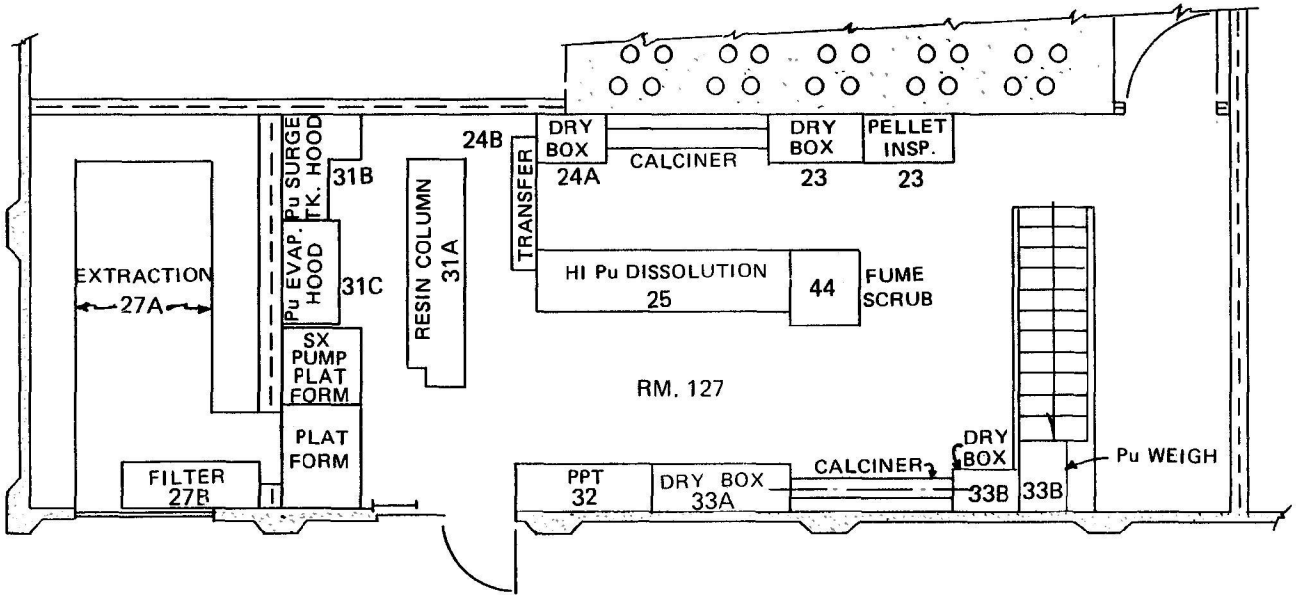

FIGURE 7

N

SCRAP FACILITY

BASEMENT LAYOUT

ROOM BO-1

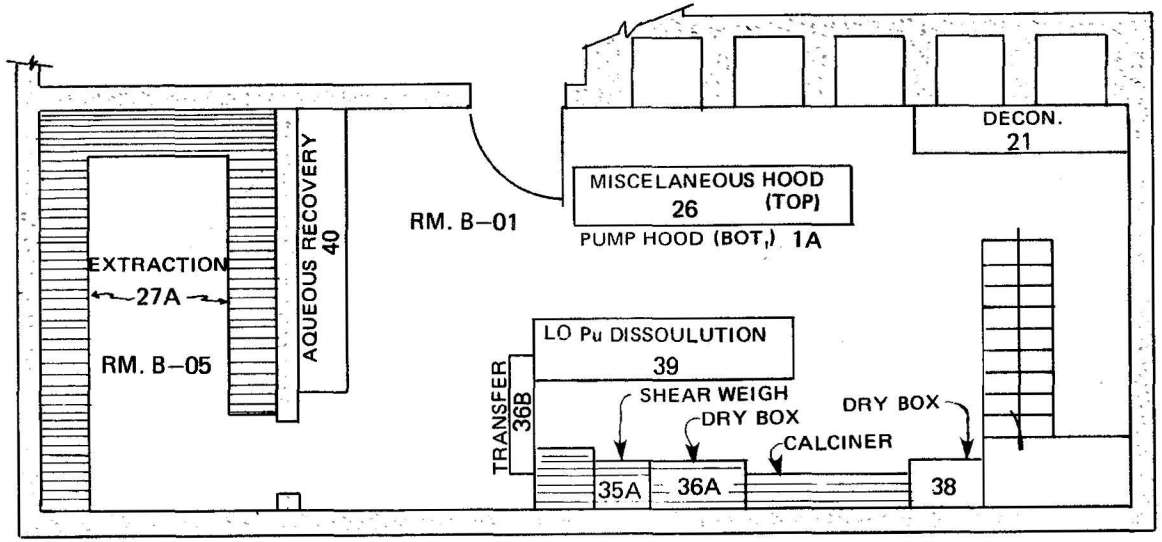

FIGURE 8

The gloveboxes represented approximately 30,000 ft^2 of surface area. In addition, approximately 4,500 linear feet of various piping connected the processes, ventilation ducts, solution holding tanks, and other process related items throughout the plant.

3.2 NDA PROGRAM

Sequoyah Fuels' NDA Program was developed over a two year period during production operations. This program generally involved a thorough clean-out of visual materials from gloveboxes, acid rinsing of pipes, and, in some areas, filter changes. Originally, acid washing of glovebox surfaces was accomplished prior to measurement; however, routine acid washing proved to be detrimental to the equipment. Removal of all containerized plutonium materials and a good thorough sweep down of the gloveboxes proved to be an acceptable method without degrading the confidence in the data.

The procedure was to establish a fixed set of representative measurement points to be measured each time an inventory was made and to extrapolate the measurements over areas not measured. For example, the full length of a forty foot long pipe was not measured. One accessible spot was measured and the data extrapolated over the forty feet.

Report #4 in this series, Non-Destructive Assay (NDA) Techniques and Procedures, identifies the equipment, techniques and procedures used to measure and calculate the quantities of plutonium heldup in the system for both semimonthly inventory purposes and SFC's early 1976 standby inventory measurement.

Figure 9 shows a typical arrangement of assay equipment during an NDA measurement of a glovebox.

3.3 STANDARDS DEVELOPMENT

Calibration standards traceable to the National Bureau of Standards with isotopic distribution similar to the plutonium materials in the plant were not available from any known source.

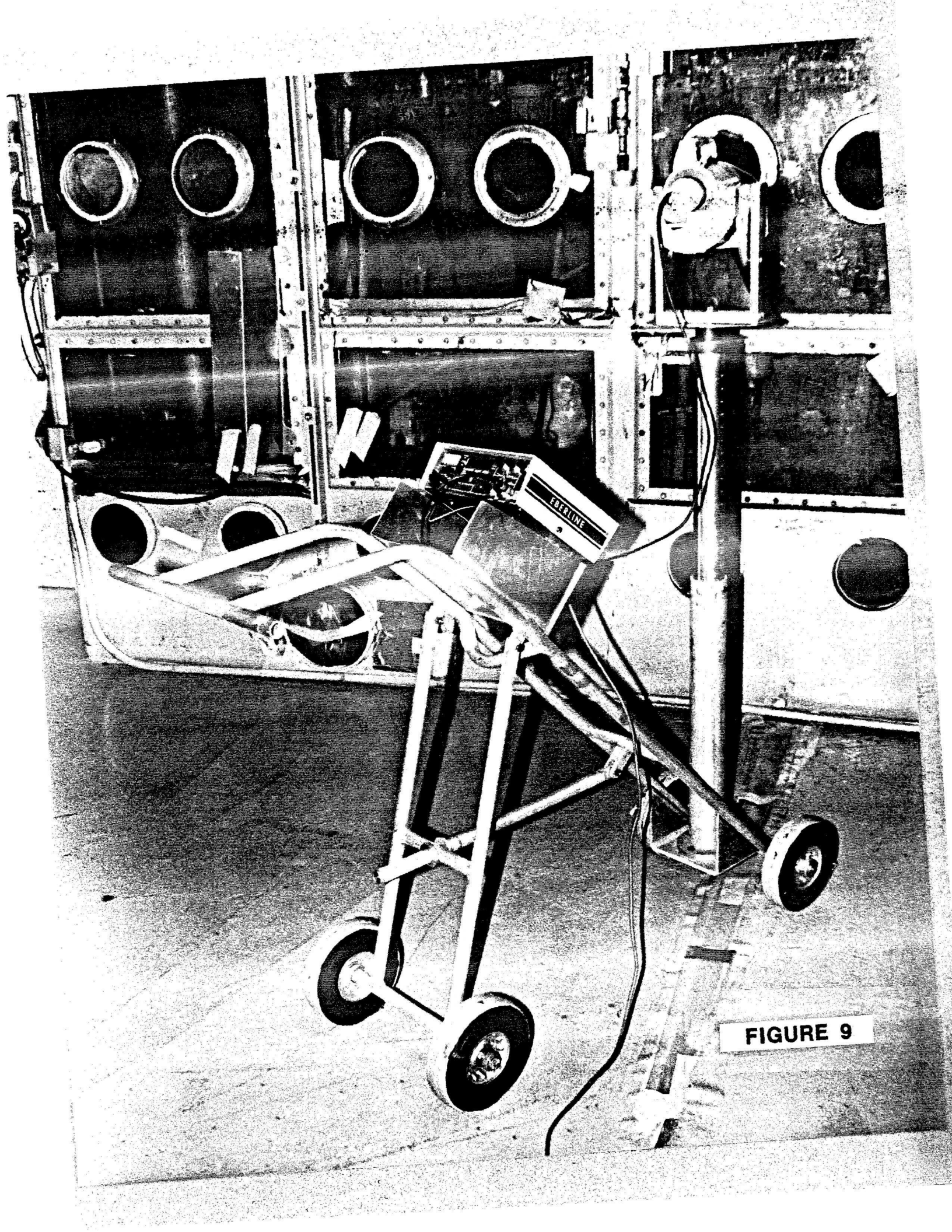

FIGURE 9

To calibrate and maintain confidence in the instrumentation used in the measurement program a set of calibration standards was developed by SFC from production materials. These standards were prepared as follows:

- o A specified quantity of mixed oxide (1.936 grams Pu) was mixed with a clear acrylic paint resin.
- o The resin mixture was spread on paper towels (10-1/2" x 12") in a thin layer as uniformly as possible.
- o The saturated towels were dried and encapsulated in 0.012" thick plastic packets.

A group of 13 packets was made; however, two were discarded because they contained small areas of highly concentrated activity (hot spots). The remaining 11 packets were then compared to Brookhaven National Laboratory and Los Alamos Scientific Laboratory standards and were determined appropriate for use.

During the NRC audit team's preparation for independently measuring the hold-up inventory, SFC's

standard packets were measured by the team. The results of both Sequoyah Fuel's measurements and the audit team's measurements are shown on Table 11. Except for K-M #7, the values determined by the audit team were within ± 10% of Sequoyah Fuel's values. As the audit team noted in their report, local non-uniformities in the distribution of Pu within the packet could lead to large errors in the calibration count rate if the sources were viewed at close range. However, viewing the sources at greater distances tended to average out the non-uniformities and to make the calibration count less sensitive to the exact positioning of sources relative to the detector.

Additionally, the audit team did not correct for self-attenuation of the sources. Any self-attenuation would reduce the observed count rate and measured mass which would have brought the observed results into even better agreement.

TABLE 2

STANDARDS EVALUATION

Packet Number	SFC Value (Grams Pu)	Audit Team Value (Grams Pu)
1	1.934	1.80 ± 0.15
3	1.937	1.82 ± 0.15
4*	1.944	1.88 ± 0.15
	1.944	1.88 ± 0.15
5*	1.932	1.89 ± 0.15
	1.932	1.88 ± 0.15
6	1.930	2.03 ± 0.16
7**	1.938	1.58 ± 0.13
8	1.932	1.85 ± 0.15
9	1.928	1.84 ± 0.15
10	1.940	1.74 ± 0.14
12	1.939	1.98 ± 0.16
13	1.941	1.75 ± 0.14

* Measured Twice

** Number 7 was not used for calibration purposes.

4.0 STAND-BY INVENTORY (1976)

4.1 PREPARATION

In preparation for placing the Facility on standby status, steps were taken to recover plutonium heldup in the process equipment. By March of 1976, all gloveboxes and pipes had been manually cleaned, all pipes had been flushed with acid, all glovebox filters had been replaced, all gloves had been removed from the gloveboxes, and all gloveports had been sealed with plastic covers. The remaining holdup plutonium was not accessible without removing the equipment as the plutonium was spread out in a very thin layer over the inner surfaces of the boxes, pipes and equipment or was retained in small amounts in pockets or crevices.

4.2 METHODOLOGY

The equipment, methods, and calculations employed for the in-place measurements are provided in detail in Report No. 4, Non-Destructive Assay (NDA) Techniques and Procedures, of this series.

The in-place non-destructive assay measurement program was difficult because of several design features of the plant. As shown in Figures 2 through 8, the process rooms were relatively small and allowed only enough room for technicians to operate the equipment. Additionally, most of the gloveboxes within each room were joined by a series of pass-through tunnels. These features prevented isolation of the item or area being measured; therefore, background radiation from adjacent equipment was present.

During the 1973-1975 development period, SFC demonstrated that the setup of the equipment could be consistently reproduced, the influence of background could be adequately shielded and the sensitivity of the instrumentation could be maintained. Thus, when the plant was placed on standby, SFC's NDA measurement program had been employed for some time, and confidence in the data was well established.

4.3 1976 Inventory Measurement

The 1976 inventory measurements conducted by SFC are shown in Tables 3 through 11.

TABLE 3

1976 IN-PLACE INVENTORY

ROOM - 128 COPRECIPITATION AND OXIDE PRODUCTION

		Grams Plutonium
Box 8 and 10	Mill and Blend	241
Box 8 Filter		5
Box 10 Filter		4
Box 6B	Calciner Out (Oxide)	21
Tunnel (10-6B)		5
Tunnel (6B-6A)		4
Calciner		37
Box 6A	Calciner In (ADU)	146
Box 6A Filter		3
Box 5B	Filtrate	78
Tunnel (5A-6A)		2
Box 5A	Precipitation & Filter	176
Box 3A	Nitrate Solution Unloading	32
Box 3B	Nitrate Solution Unloading	28
Box 3B Filter		-
Ducts		79
TOTAL ROOM 128		861
LIMIT-OF-ERROR		±237

TABLE 4

1976 IN-PLACE INVENTORY

ROOM BO-2 SOLUTION STORAGE AND BLENDING

		Grams Plutonium
Box 1	Storage Tank Pumps	58
Tanks 145-146	Vacuum receiver tanks	72
Box 2C	Vacuum Receiver	12
Box 2A-2B	Vacuum Pumps	6
Wall Storage Tanks (40)	Solution Storage	292
DP Cells	Tank level indicators	220
Box 4	Solution Weigh Station	643
Piping		393
TOTAL BO-2		1,696
LIMIT-OF-ERROR		± 358

TABLE 5

1976 IN-PLACE INVENTORY

ROOM 124 - PRESSING, SINTERING, GRINDING

		Grams Plutonium
Box 11B	Pressing and Granulating	382
Box 11B Filter		10
Calciner		65
Tunnel	Boat return	36
Box 11A	Slugging Press Box	557
Box 11A Filter		8
Box 12	Overhead tunnel	39
Box 14A	Sintering Furnace Inlet	109
Box 14B	Sintering Furnace Outlet	43
Box 15C	Centerless Grinder	283
Box 15C Filter		7
Box 15B	Outgas Furnace Inlet	50
Box 15B Filter		1
Box 15A	Outgas Furnace Outlet	5
Box 15A Filter		-
Box 16	Outgas Furnace	9
Box 13A	Press Trollys	2
Box 13B	Press Trollys	4
Filter		4
Duct		127
Portable Powder Carts (3)		51
Harper Furnace		203
TOTAL ROOM 124		1,995
LIMIT-OF-ERROR		±549

TABLE 6

1976 IN-PLACE INVENTORY

ROOM 123 - ROD LOADING AND WELDING

		Grams Plutonium
Box 17	Tunnel from 15A to Pellet storage	1
Box 18	Stack Make-Up	36
Box 18 Filter		-
Duct		1
TOTAL ROOM 123		38
LIMIT-OF-ERROR		±10

TABLE 7

1976 IN-PLACE INVENTORY

ROOM 116 - MAINTENANCE

		Grams Plutonium
Box 45	Maintenance Glovebox	18
Box 45 Filter		-
TOTAL ROOM 116		18
LIMIT-OF-ERROR		±5

TABLE 8

1976 IN-PLACE INVENTORY

ROOM 127 - SCRAP PROCESSING

		Grams Plutonium
Box 23	Pellet Inspection	106
Box 23 Filter		26
South Calciner		162
Tunnel South Calciner		30
Box 24A	Calciner exit box	23
Box 25	Dissolution	217
Box 25 Filter		14
Box 44	Fume Scrub	48
Box 44 Filter		1
Box 31A	Resin Column	301
Box 31B	Surge Tank	167
Box 31C	Evaporation Hood	39
Box 31B:31C		-
Box 32	Precipitation	31
Box 32 Filter		4
Box 33A	N. Calciner Entrance	30
Box 33A Filter		9
Box 33B	N. Calciner Exit	28
Box 33B Filter		14
Tunnel (24A-25)		29
North Calciner		51
R Tunnel Calciner		30
2 Portable I-X		13
Duct		49
Tank Farm		72
TOTAL ROOM 127		1,494
LIMIT-OF-ERROR		±411

TABLE 9

1976 IN-PLACE INVENTORY
ROOM BO-1 SCRAP TREATMENT

		Grams Plutonium
Box 40	Aqueous Recovery	158
Box 39	Dissolution	140
Box 26	Washables	90
Box 1A	Liquid transfer	116
Box 21	Decon Dissolver	83
Tunnel (36-39)		9
Box 36A	HEPA Filter Treatment	14
Box 36 Filter		7
Box 38	HEPA Filter Treatment	55
Tunnel (36-38)		2
Calciner		17
Duct		17
Wall Storage Tanks (20)		898
DP Cells		447
Piping		1,071
TOTAL ROOM BO-1		3,124
LIMIT-OF-ERROR		±565

TABLE 10

1976 IN-PLACE INVENTORY

ROOM BO-5 SOLVENT EXTRACTION

	Grams Plutonium
Box 27A	1,592
LIMIT-OF-ERROR	±438

TABLE 11

1976 IN-PLACE INVENTORY

SUMMARY - ALL INVENTORY

		Grams Plutonium
Room 128	Coprecipitation & Oxide Production	861
Room BO-2	Solution Storage & Blending	1,696
Room 124	Pressing, Sintering, Grinding	1,995
Room 123	Rod Loading & Welding	38
Room 116	Maintenance	18
Room BO-1	Scrap Treatment	3,124
Room 127	Scrap Processing	1,494
Room BO-5	Solvent Extraction	1,592
TOTAL		10,818
LIMIT-OF-ERROR		±2,975

5.0 FINAL MEASUREMENT

5.1 METHODOLOGY

SFC elected to decontaminate the plutonium facility by cutting the process equipment into small pieces (i.e., less than 15" by 15") which could be packaged into 55-gallon drums for shipment to an off-site disposal area. The small pieces were counted with a Ludlum 2500 unit with a 2" X 2" NaI detector which was set-up and calibrated to view each item.

In total, 28,357 packages were measured. Care was taken during the decontamination activities to segregate and document the origin of each piece for correlation of the early 1976 baseline measurement with the more accurate measurements of the 28,357 packages.

Several operational and administrative circumstances precluded correlations for all cases. First, some decontamination operations could not be conducted in a manner that allowed precisely assigning

recovered plutonium to the original location. For example, a special large glovebox was modified to contain a plasma arc cutting unit used to cut equipment, including entire gloveboxes. Small portions of contaminated material (from the cutting operations) being cut up in this special glovebox lost identity and could not be assigned to the source box. Similarly, plutonium contained in pipes which may have crossed through rooms and airborne particulates trapped in absolute filters during cut-up activities could not be precisely assigned to a specific location.

Second, the period between the 1976 baseline measurements and the completion of the decontamination activity measurements was some 10 years. Over this period, administrative and personnel changes occurred; consequently, some individuals who had personal knowledge about various procedures and activities and who developed the raw data were not available to aid in the interpretation or explanation of questions about specific operations.

In Tables 12 through 21, the data from the two sets of measurements are provided and reflect the above limitations.

Of particular note is the apparent transposition of the 1976 data for the wall storage tank measurements in Rooms BO-1 and BO-2. The final measurements indicate the earlier data were either recorded inaccurately or mislabeled during the 1976 inventory period.

	Grams Plutonium	
	1976 Inventory	Final Measurement
BO-1 Wall Tanks (20)	898	288
BO-2 Wall Tanks (40)	292	1,045

The audit team estimated the total plutonium for all 60 storage tanks and did not distinguish the 20 tanks in BO-1 from the 40 tanks in BO-2; therefore only SFC data are available for review. That the data were mislabeled is strongly supported by the fact that the BO-2 tanks were used to store concentrated production solution, whereas the BO-1 tanks were used to store waste solution.

TABLE 12

ROOM 128 COPRECIPITATION AND OXIDE PRODUCTION

		Grams Plutonium	
		1976 Inventory	Final Measurement
Box 8	Mill & Blend	241	153
Box 8 Filter		5	-
Box 10 Filter		4	-
Box 6B	Calciner Out	21	62
Tunnel (10-6B)		5	4
Tunnel (6A-6B)		4	25
Calciner		37	18
Box 6A	Calciner In	146	157
Box 6A Filter		3	-
Box 5B	Filtrate	78	25
Tunnel (5A-6A)		2	-
Box 5A	Precip. & Filter	176	161
Box 3A	Nitrate Unloading	32	29
Box 3B	Nitrate Unloading	28	23
Box 3B Filter		-	2
Ducts		79	40
Tank 63		-	-
Cement Box		-	-
Box 27C		-	1
Not Assigned		-	33
TOTAL ROOM 128		861	733
LIMIT-OF-ERROR		±237	±135
NUMBER OF PACKAGES MEASURED			3,201

For contamination control purposes, the cleaning and cut up operations on powder boxes 8-10 were performed with the exhaust air passing through the calciner tube into box 6A; therefore, the comparison of the 1976 value(s) with the final value can only be compared as a group (Box 8-10, 6B, 6A, and calciner and tunnels) rather than individually.

TABLE 13

ROOM BO-2 SOLUTION STORAGE AND BLENDING

		Grams Plutonium	
		1976 Inventory	Final Measurement
Box 1	Storage Tank Pumps	58	137
Tanks 145-146	Vacuum Receiver Tanks	72	294
Box 2C	Vacuum Receiver Box	12	23
Box 2A-2B	Vacuum Pumps	6	36
Wall Storage Tanks	Solution Storage (40)	292	1,045
DP Cells	Tank Level Indicators	220	177
Box 4	Solution Weigh Scales	643	409
Piping		393	-
	Flocculation Tanks	-	46
	Not Assigned	-	62
Tank 195		-	1
	Wash Pumps	-	18
Tank 196		-	-
	Cubicles & Floor	-	4
	Process Pipe	-	1
TOTAL ROOM BO-2		1,696	2,253
LIMIT-OF-ERROR		±466	±268
NUMBER OF PACKAGES MEASURED			7,855

The shielding involved with the raschig ring and liquid filled vacuum receiver tanks #145 and #146 resulted in a poor 1976 inventory measurement.

It appears that the 1976 value assigned to the BO-2 wall storage tanks was probably the BO-1 wall storage tank value.

TABLE 14

ROOM 124 PROCESSING, SINTERING, GRINDING

		Grams Plutonium	
		1976 Inventory	Final Measurement
Box 11B	Pressing & Granulator	382	332
Box 11B Filter		10	-
Calciner		65	35
Tunnel		36	-
Box 11A	Slugging	557	355
Filter Box 11A		8	-
Box 12	Tunnel	39	15
Box 14A	Sintering Furnace Inlet	109	147
Box 14B	Sintering Furnace Outlet	43	85
Box 15C	Centerless Grinder	283	224
Box 15C Filter		7	-
Box 15B	Outgas Furnace Inlet	50	14
Box 15B Filter		1	-
Box 15A	Outgas Furnace Outlet	5	11
Box 15A Filter		-	-
Box 16	Outgas Furnace	9	-
Box 13A	Calciner Exit	2	3
Box 13B	Calciner entrance	4	-
Int. Filter		4	17
Duct		127	82
Powder Carts		51	55
Harper Furance		203	150
Not Assigned		-	7
TOTAL ROOM 124		1,995	1,532
LIMIT-OF-ERROR		±549	±195
NUMBER OF PACKAGES MEASURED			3,161

The significant increase in the intermediate filter from the 4 grams to 17 grams is attributed to movement of materials during the cut-up operations.

TABLE 15

ROOM 123 ROD LOADING AND WELDING

		Grams Plutonium	
		1976 Inventory	Final Measurement
Box 17	Tunnel room	1	-
Box 18	Stack Make-Up	36	19
Box 18 Filter		-	-
Duct		1	2
TOTAL ROOM 123		38	21
LIMIT-OF-ERROR		±10	±8
NUMBER OF PACKAGES MEASURED			151

TABLE 16

ROOM 116 MAINTENANCE

		Grams Plutonium	
		1976 Inventory	Final Measurement
Box 45	Maintenance Glovebox	18	16
Box 45 Filter		-	-
TOTAL ROOM 116		18	16
LIMIT-OF-ERROR		±5	±28
NUMBER OF PACKAGES MEASURED			230

TABLE 17

ROOM 127 SCRAP PROCESSING

		Grams Plutonium	
		1976 Inventory	Final Measurement
Box 23	Calciner Entrance Glovebox	106	478
Box 23 Filter		26	-
South Calciner		162	69
Tunnel S. Calciner		30	26
Box 24A	Calciner exit	23	103
Box 25	Dissolution	217	287
Box 25 Filter		14	-
Box 44	Fume Scrub	48	4
Box 44 Filter		1	-
Box 31A	Resin Column	301	191
Box 31B	Surge Tank	167	40
Box 31C	Evaporation Hood	39	29
Box 31B -31C		-	55
Box 32	Precipitation	31	120
Box 32 Filter		4	-
Box 33A	N. Calciner Entrance	30	54
Box 33A Filter		9	-
Box 33B	N. Calciner Exit	28	71
Box 33B Filter		14	-
Tunnel (24A -25)		29	-
North Calciner		51	69
R. Tunnel Calciner		30	16
2 Portable IX		13	23
Duct		49	40
Tank Farm		72	18
Cut -Up Box		-	-
Not Assigned		-	38
TOTAL ROOM 127		1,494	1,731
LIMIT-OF-ERROR		±411	±203
NUMBER OF PACKAGES MEASURED			3,559

Material generated and unidentified from clean up of scrap area gloveboxes, calciner and tunnels was collected in glovebox #23. The tank farm was used as part of an ion exchange clean up system for glovebox decon solutions between the 1976 measurement and the final measurement.

TABLE 18

ROOM BO-1 SCRAP TREATMENT

		Grams Plutonium	
		1976 Inventory	Final Measurement
Box 40	Aqueous Recovery	158	180
Box 30	Dissolution	140	154
Box 26		90	187
Box 1A		116	103
Box 21	Decon	83	216
Tunnel (36-39)		9	-
Box 36A		14	33
Box 36 Filter		7	-
Box 38		55	39
Tunnel (36-38)		2	29
Calciner		17	-
Duct		17	1
Wall Storage Tanks (20)		898	288
DP Cells		447	335
Pipe		1,071	-
Cubicles & Floor		-	7
Not Assigned		-	21
TOTAL ROOM BO-1		3,124	1,593
LIMIT-OF-ERROR		±859	±169
NUMBER OF PACKAGES MEASURED			4,239

It appears that the 1976 value assigned to the BO-1 wall storage tanks was probably the BO-2 storage tank value.

TABLE 19

ROOM BO-5 SOLVENT EXTRACTION

	Grams Plutonium	
	1976 Inventory	Final Measurement
Box 27A	1,592	1,274
LIMIT-OF-ERROR	±438	±144
NUMBER OF PACKAGES MEASURED		4,044

TABLE 20

LABORATORY

	Grams Plutonium	
	1976 Inventory	Final Measurement
Laboratory	-	57
LIMIT-OF-ERROR		±28
NUMBER OF PACKAGES MEASURED		1,917

TABLE 21

SUMMARY - ALL INVENTORY

Room #		Grams Plutonium 1976 Inventory	Final Measurement	Difference
128	Coprecipitation & Oxide	861	733	128
BO-2	Solution Storage & Blending	1,696	2,253	(557)
124	Pressing & Sintering	1,995	1,532	463
123	Rod Loading	38	21	17
116	Maintenance	18	16	2
BO-1	Scrap Treatment	3,124	1,593	1,531
127	Scrap Processing	1,494	1,731	(237)
BO-5	Solvent Extraction	1,592	1,274	318
	Laboratory	-	57	(57)
		10,818	9,210	1,608
LIMIT-OF-ERROR		±2,975	±414	±72
NUMBER OF PACKAGES MEASURED			28,357	

6.0 AUDIT TEAM

6.1 GENERAL

SFC's Cimarron Facility was the first fuel cycle facility to apply non-destructive assay methods for measurement of hold-up of plutonium in a processing plant. The measurements performed by the audit team were also a first NDA audit of a private firm by a government agency.

Because its purpose was independent measurement, the audit team could make no assumptions concerning the location of the plutonium either within a room or a glovebox. When coupled with the need for precise measurements sufficient to allow a meaningful comparison of results, the audit team was required to perform many more measurements on some significant items than were performed by SFC for its inventory.

The techniques, instrumentation, results obtained and a discussion of start-up and operational problems

encountered by the audit team were provided to the NRC in a document entitled Measurement of Plutonium in Processing Equipment at Kerr-McGee Plutonium Fuel Fabrication Facility, May 28, 1976.

The audit team's strategy was to make careful measurements on the equipment expected to have the most significant plutonium hold-up and to supplement those measurements with semi-quantitative surveys of the entire process equipment to insure that no significant hold-up quantities had been missed. The strategy included the following considerations:

- The measurements of equipment would be very carefully made and with sufficient precision to permit meaningful comparisons with SFC's values for the same items.

- The measurements would be sufficiently extensive to encompass the great majority of the retained plutonium, thereby permitting a confident extrapolation of measured results into a total plant hold-up.

The bulk of the quantitative assay work was carried out using an Eberline Stabilized Assay Meter (SAM), a self-contained high-voltage supply, an amplifier, a single channel analyzer and a scaler, which were coupled to a NaI(Tl) - photomultiplier detector sensitive to the characteristic gamma radiations from plutonium. The surveys were performed using a hand-held NaI(Tl) detector-ratemeter instrument.

In those cases where the gamma-ray attenuation was so high as to make corrections unreliable, a semi-directional neutron detector was used to take advantage of the increased penetrability of the neutrons from plutonium.

A new concept in hold-up measurements was tried on an experimental basis for the first time. A non-directional neutron detector was used in an attempt to assay the total hold-up in a given room, without the detailed and laborious measurements and calculations required by the gamma measurements.

A new type of gamma ray detector, a cadmium telluride (CdTe) diode, was also used experimentally for the first time as a survey instrument for the special case of hold-up in pipes.

6.2 ITEMS MEASURED

Initially, the entire process area of the plant was surveyed using a lead shielded 2.5 cm by 2.5 cm NaI(Tl) gamma ray detector attached to a ratemeter. This preliminary scan permitted the identification of "hot spots" (i.e., places where higher concentrations of plutonium appeared to be located). In the remaining time, the audit team measured gloveboxes, pipes, and tanks identified in the preliminary survey as having measurable quantities of plutonium.

Time limitations prevented the quantitative measurement of every pipe, filter, and glovebox in the plant. It was therefore necessary to extrapolate from the measured quantities to obtain an estimated value for the entire facility. This extrapolation

was guided by the results of the early preliminary gamma ray scan and was confirmed by the overall neutron survey made with the large detector.

Table 22 shows the audit team's measured quantities of plutonium and the extrapolated values for different broad categories of equipment. Twenty gloveboxes were not directly measured. From the results of the preliminary gamma ray scan and quantitative results for gloveboxes with small amounts of material, the unmeasured gloveboxes were estimated to contain between zero and 50 grams of plutonium. The "estimate" value was obtained by assuming 30 grams per glovebox not measured and the "upper" and "lower limits" by assuming 50 grams per box and zero grams per box, respectively.

A similar exercise was followed to obtain values for plutonium in the pipes. After the pipes identified as having the largest residual plutonium were measured, an average pipe residue of 3.3×10^{-3} gm/cm was estimated for the remaining pipes, then multiplied by the approximately 10^{5} cm length of pipe that was still unmeasured.

The measured filters and ducts proved to have relatively little plutonium in them; thus the results of this extrapolation do not significantly affect the plant total.

An extrapolated value for the wall storage tanks embedded in 4' thick, heavily reinforced concrete walls was obtained by comparing these tanks with tanks in the plant that had held similar solutions. The 40 wall tanks in room BO-2 are similar to the weigh tanks in Box 4 which averaged 10 grams per tank. The 20 wall tanks in Room BO-1 do not have an obvious measurable counterpart; however, no measured tanks of that size exceeded 17 grams per tank. Allowing for a possible higher hold-up in these tanks, an average value of 30 grams per tank was assigned. The lower and upper limits were obtained by assuming values equal to one-half and twice the estimated values.

The gauges not assayed by the audit team were measured by SFC subsequent to the inventory and were accepted by the audit team, given the good agreement on other measurements.

TABLE 22

AUDIT TEAM RESULTS
TOTAL PLANT PLUTONIUM HOLD-UP

	GRAMS PLUTONIUM		
ITEM	ESTIMATE	LOWER LIMIT	UPPER LIMIT
Gloveboxes Measured	4,650	3,000	6,590
Gloveboxes Not Measured	600	-	1,000
TOTAL GLOVEBOXES	5,250	3,000	7,590
Pipes Measured	630	475	790
Pipes Not Measured	330	175	600
	960	650	1,390
Filters Measured	30	15	60
Filters Not Measured	50	15	100
	80	30	160
Wall Tanks (Not Measured)	1,000	500	2,000
Gauges (Not Measured)	670	670	670
TOTAL INVENTORY	7,960	4,850	11,810

7.0 COMPARISON OF MEASUREMENT DATA

7.1 GENERAL OBSERVATION

As noted previously, three sets of measurements were taken on the plutonium hold-up in the process equipment at the Cimarron Facility. SFC performed the first non-destructive assay measurement in early 1976, followed by the NRC's NDA. The third measurement occurred during the final packaging of plant equipment as it was loaded as small cut-up pieces into drums for shipment to an off-site disposal area.

The data from these sets of measurements are in Tables 23 through 31. In evaluating these data, several considerations are important to note:

First, SFC's 1976 procedure resulted from several years of testing, calibrations and experience and involved a significant number of repetitive measurements. Due to time constraints and other reasons, the audit team's 1976 measurements were less extensive and greater reliance was placed on extrapolation of measured data to unmeasured equipment.

Second, SFC's final inventory measurements were conducted on much smaller and relatively standardized packages, which yielded a much smaller limit-of-error.

Third, in order to reduce the potential of airborne contamination, decon solutions were used on the gloveboxes prior to cut up and the plutonium in the decon solutions lost identity when the decon solutions were cleaned by ion exchange.

In summary, the above observation is provided to emphasize that the significant data shown in the attached tables are room totals - as opposed to specific glovebox or equipment measurements.

TABLE 23

ROOM 128 COPRECIPITATION AND OXIDE PRODUCTION

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
Box 8-10	241	153	113
Box 8 Filter	5	-	-
Box 10 Filter	4	-	-
Box 6B	21	62	-
Tunnel (10-6B)	5	4	-
Tunnel (6A-6B)	4	25	-
Calciner	37	18	60
Box 6A	146	157	-
Box 6A Filter	3	-	-
Box 5B	78	25	-
Tunnel (5A-6A)	2	-	-
Box 5A	176	161	122
Box 3A	32	29	-
Box 3B	28	23	-
Box 3B Filter	-	2	-
Ducts	79	40	-
Tank 63	-	-	-
Cement Box	-	-	-
Box 27C	-	1	-
TOTAL MEASURED	861	700	295
NOT ASSIGNED		33	410
TOTAL ROOM 128	861	733	705
LIMIT-OF-ERROR	± 237	± 135	+ 360 - 250

Room 128 was difficult to measure by NDA techniques because of the large size of the gloveboxes within the room, the influence of the wall storage tanks in the wall adjacent to the room, and the density of equipment within each glovebox. Of note is that the audit team's extrapolated values for gloveboxes and pipes not measured were within only a few grams of Kerr-McGee's measured values.

TABLE 24

ROOM BO-2 SOLUTION STORAGE AND BLENDING

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
Box 1	58	137	72
Tanks 145-146	72	294	45
Box 2C	12	23	11
Box 2A-2B	6	36	-
Wall Storage Tanks	292	1,045	-
DP Cells	220	177	-
Box 4	643	409	
Piping	393	-	-
Flocculation Tanks	-	46	-
Tank 195	-	1	-
Wash Pumps	-	18	-
Tank 196	-	-	-
Cubicles and Floor	-	4	-
Process Pipe	-	1	-
TOTAL MEASURED	1,696	2,191	128
NOT ASSIGNED	-	62	-
TOTAL ROOM BO-2	1,696	2,253	128
LIMIT-OF-ERROR	± 466	± 268	+ 404 - 332

Several anomalies should be noted. First, flushing of tanks 145-146 was not as effective as had been anticipated. These tanks contained boron raschig rings which apparently masked the radiation. Second, Box 1 was primarily a series of pumps, valves, and a manifold which would be difficult to NDA under any circumstances. The primary difference between the two Kerr-McGee inventories was the apparent mislabeling of the wall storage tank hold-up data as noted earlier.

TABLE 25

ROOM 124 PROCESSING, SINTERING, GRINDING

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
Box 11B	382	332	333
Filter 11B	10	-	-
Calciner	65	35	249
Tunnel	36	-	-
Box 11A	557	355	236
Filter Box 11A	8	-	-
Box 12	39	15	-
Box 14A	109	147	-
Box 14B	43	85	-
Box 15C	283	224	123
Box 15C Filter	7	-	-
Box 15B	50	14	-
15B Filter	1	-	-
Box 15A	5	11	-
15A Filter	-	-	-
Box 16	9	-	-
Box 13A	2	3	-
Box 13B	4	-	-
Int. Filter	4	17	-
Duct	127	82	-
Powder Carts	51	55	1
Harper Furnace	203	150	451
TOTAL MEASURED	1,995	1,525	1,393
NOT ASSIGNED	-	7	2
TOTAL ROOM 124	1,995	1,532	1,395
LIMIT-OF-ERROR	± 549	± 195	+ 435 - 595

Several obvious differences exist in the individual item data shown for Room 124. The SFC data are fairly close between inventories. An explanation for the individual differences in the audit team's results is not readily apparent; however, the overall room total is in reasonable agreement.

TABLE 26

ROOM 123 ROD LOADING AND WELDING

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
TOTAL MEASURED	38	21	-
TOTAL ASSIGNED	-	-	10
TOTAL ROOM 123	38	21	10
LIMIT-OF-ERROR	±10	±10	+20 - 0

The audit team did not survey Room 123.

TABLE 27

ROOM 116 MAINTENANCE

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
TOTAL MEASURED	18	16	-
TOTAL ASSIGNED	-	-	-
TOTAL ROOM 116	18	16	-
LIMIT-OF-ERROR	±5	-	-

The audit team did not survey Room 116.

TABLE 28
ROOM 127 SCRAP PROCESSING

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
Box 23	106	478	-
Box 23 Filter	26	-	-
South Calciner	162	69	42
Tunnel	30	26	45
Box 24A	23	103	88
Box 25	217	287	207
Box 25 Filter	14	-	-
Box 44	48	4	-
Box 44 Filter	1	-	-
Box 31A	301	191	410
Box 31B	167	40	-
Box 31C	39	29	-
Box 31B & 31C	-	55	-
Box 32	31	120	72
Box 32 Filter	4	-	-
Box 33A	30	54	40
Box 33A Filter	9	-	-
Box 33B	28	71	110
Box 33B Filter	14	-	-
Tunnel (24A-25)	29	-	-
North Calciner	51	69	6
R. Tunnel Calciner	30	16	-
2 Portable IX	13	23	44
Duct	49	40	-
Tank Farm	72	18	-
Cut-Up Box	-	-	-
TOTAL MEASURED	1,494	1,693	1,064
NOT ASSIGNED	-	38	150
TOTAL ROOM 127	1,494	1,731	1,214
LIMIT-OF-ERROR	±411	±203	+455 -450

Given the number and size of gloveboxes in this room, the correlation of the data among the three independent inventories is remarkable. The major difference was in Box 23 where 478 grams of plutonium were measured in the final decommissioning inventory, and only 106 grams were measured in the 1976 NDA inventory. Material generated and unidentified from cleanup of scrap area gloveboxes, calciner and tunnels was collected in glovebox #23.

TABLE 29

ROOM BO-1 SCRAP TREATMENT

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
Box 40	158	180	18
Box 39	140	154	68
Box 26	90	187	-
Box 1A	116	103	141
Box 21	83	216	59
Tunnel (36-39)	9	-	-
Box 36A	14	33	10
Box 36 Filter	7	-	-
Box 38	55	39	17
Tunnel (36-38)	2	29	-
Calciner	17	-	26
Duct	17	1	-
Wall Storage Tanks	898	288	-
DP Cells	447	335	-
Pipe	1,071	-	-
Cubicles & Floor	-	7	-
TOTAL MEASURED	3,124	1,572	339
NOT ASSIGNED	-	21	-
TOTAL ROOM BO-1	3,124	1,593	339
LIMIT-OF-ERROR	±859	±169	+261 - 94

The apparent mislabeling of the wall tank recordings contributes significantly to the difference between the two Kerr-McGee inventory results. The apparent discrepancy in the audit team's results cannot be reasonably explained; however, for those items measured by the audit team, a close overall correlation with those items measured by Kerr-McGee in 1976 is shown.

TABLE 30

ROOM BO-5 SOLVENT EXTRACTION

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
Box 27A	1,592	1,274	850
LIMIT-OF-ERROR	±438	±144	+404 -332

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TABLE 31

SUMMARY - ALL INVENTORY

	1976 INVENTORY	FINAL MEASUREMENT	AUDIT TEAM
MEASURED			
Room - 128	861	700	295
Room - BO-2	1,696	2,191	128
Room - 124	1,995	1,525	1,393
Room - 123	38	21	-
Room - 116	18	16	-
Room - 127	1,494	1,693	1,064
Room - BO-1	3,124	1,572	339
Room - BO-5	1,592	1,274	850
Laboratory	-	57	-
Pipes Measured	-	-	630
Filters Measured	-	-	30
TOTAL MEASURED	10,818	9,049	4,729
ASSIGNED			
Room - 128	-	33	410
Room - BO-2	-	62	-
Room - 124	-	7	2
Room - 123	-	-	10
Room - 116	-	-	-
Room - 127	-	38	150
Room - BO-1	-	21	-
Room - BO-5	-	-	-
Gloveboxes Not Measured	-	-	600
Pipes Not Measured	-	-	330
Filters Not Measured	-	-	50
Wall Tanks Not Measured	-	-	1,000
Gauges Not Measured	-	-	670
TOTAL ASSIGNED	-	161	3,222
TOTAL	10,818	9,210	7,951

8.0 SUMMARY AND CONCLUSIONS

8.1 SUMMARY

Table 32 summarizes the key data from the three independent inventory measurements. Notably, the final inventory measurements fall within the upper and lower confidence levels of both 1976 in-place measurements.

The data suggest several methods and various pieces of equipment not specifically designed for that purpose can be useful tools to measure hold-up in process equipment. Additionally, the data suggest that a program involving repetitive measurements over a period of time would develop a higher level of confidence in the results.

Given the state of the art in 1976 and the difficulty of conducting an in-place measurement program within a plant not specifically designed to accommodate in-place measurements for inventory purposes, the techniques developed by Sequoyah Fuels and the audit team produced remarkably comparable results.

An acceptable limit of error can be achieved for determining plant hold-up for inventory purposes with in-place NDA measurements.

TABLE 32

	INITIAL KM NDA												
	3/10/76 INVENTORY REPORT			ERDA-DSS TEAM NDA			FINAL KM NDA						
ROOM NO.	GRAMS Pu	LOWER LIMIT	UPPER LIMIT	GRAMS Pu	LOWER LIMIT	UPPER LIMIT	GRAMS Pu	LOWER LIMIT	UPPER LIMIT	LIMIT OF ERROR	INVENTORY DIFFERENCE	*** L.E.I.D.	NUMBER OF PACKAGES
SX	1,592	1,154	2,030	850	630	1,145	1,274	1,130	1,418	± 144	- 318	± 36	4,044
123	38	28	48	10	0	20	21	13	29	± 8	- 17	± 6	151
124	1,995	1,446	2,544	1,405	810	1,840	1,532	1,337	1,727	± 195	- 463	± 59	3,161
Laboratory	-	-	-	-	-	-	57	29	85	± 28	+ 57	± 28	1,917
116	18	13	23	-	-	-	16	0	44	± 28	- 2	± 3	230
127	1,494	1,083	1,905	1,215	765	1,670	1,731	1,528	1,934	± 203	+ 237	± 28	3,559
128	861	624	1,098	705	455	1,065	733	598	868	± 135	- 128	± 23	3,201
BO-1 + Pipe	3,124	2,265	3,983	340	245	600	1,593	1,424	1,762	± 169	-1,531	±162	4,239
BO-2 + Pipe	1,696	1,230	2,162	125	95	250	2,253	1,985	2,521	± 268	+ 557	± 66	7,855
*Gloveboxes not measured	-	-	-	600	0	1,000	-	-	-	-	-	-	
*Pipes not measured	-	-	-	330	175	600	-	-	-	-	-	-	
**Pipes measured	-	-	-	630	475	790	-	-	-	-	-	-	
*Filters not measured	-	-	-	50	15	100	-	-	-	-	-	-	
**Filters measured	-	-	-	30	15	60	-	-	-	-	-	-	
*Wall tanks not measured	-	-	-	1,000	500	2,000	-	-	-	-	-	-	
*Gauges not measured	-	-	-	670	670	670	-	-	-	-	-	-	
PLANT HOLDUP	10,818	7,843	13,793	7,960	4,850	11,810	9,210	8,796	9,624	± 414	-1,608	± 72	28,357
VAULT	657			-	-	-							
TOTAL PLANT INVENTORY (3/10/76)	11,475				Shipped to 6/10/87		9,907				-1,568		

* Extrapolated Estimate by ERDA-DSS Team

**Measured by ERDA-DSS Team but not identified by room location

***Limit of Error of Inventory Difference

The final NDA total of 9,210 grams removed from the Pu-plant does not include an estimated 4 grams of Pu in low level waste that will be produced by the decontamination work remaining to be completed.

The discrepancy between the Plant Holdup Inventory Difference of -1608 grams and the difference of -1568 grams from comparing the 3/10/76 inventory to the shipment records is due to repackaging and NDA of the material that was in the vault on 3/10/76.