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WASTE SOLIDIFICATION PROGRAM

VOLUME II

DESIGN FEATURES OF THE WASTE SOLIDIFICATION ENGINEERING PROTOTYPES

FEBRUARY 1969

AEC RESEARCH & DEVELOPMENT REPORT

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Waste Disposal
and Processing

WASTE SOLIDIFICATION PROGRAM
VOLUME II
DESIGN FEATURES OF THE WASTE SOLIDIFICATION ENGINEERING PROTOTYPES

By

K. J. Schneider

and

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February 1969

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ABSTRACT

General design criteria and descriptions of the Waste Solidification Engineering Prototypes equipment are discussed. The WSEP is a developmental facility for solidifying highly radioactive liquid wastes from reprocessing of power reactor fuels by the pot, spray, and phosphate glass processes. Design criteria are based upon providing a developmental facility with a high degree of flexibility and integrity for demonstrations of various waste solidification processes and equipment with fully radioactive materials. Special features of the equipment for process and mechanical functions to be performed during the demonstrations are presented. Process functions include overall flowsheet requirements, process control features, process effluent treatment and control, and special features of process equipment. Mechanical functions include remote handling and transfer of material and equipment, and storage and testing of containers full of solidified waste. Equipment performance during nonradioactive shakedown tests, and the process safety review are summarized. Equipment performance has been good, and the first radioactive run was made in the WSEP in November 1966.

This report is one of a series of reports from the Waste Solidification Program being performed by Battelle-Northwest. Other current reports in this series are:

K. J. Schneider, editor, Waste Solidification Program, Volume 1, Process Technology for the Pot, Spray and Phosphate Glass Processes, In progress.

V. P. Kelly, Waste Solidification Program, Volume 3, Design Features of the Facilities and Equipment for the WSEP Product Evaluation Program, U.S. AEC Report BNWL-832, December 1968.

J. L. McElroy, C. R. Cooley, J. E. Mendel, W. V. DeMier, J. C. Suddath, and J. O. Blomeke, Waste Solidification Program, Volume 4, Pot Solidification Performance During the First Radioactive Tests in WSEP, U. S. AEC Report BNWL-814, December, 1968.

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1.0 INTRODUCTION

The Waste Solidification Engineering Prototypes (WSEP) is an engineering pilot plant to provide for full radioactivity-level demonstration and evaluation of technical, economic, and safety aspects of three of the more promising processes for solidification of highly radioactive liquid wastes. The three processes chosen for demonstration are: 1) The pot calcination process developed at Oak Ridge National Laboratory (ORNL); 2) the phosphate glass solidification process developed at Brookhaven National Laboratory (BNL); and 3) the spray solidification process developed at the Pacific Northwest Laboratory of Battelle Memorial Institute (Battelle-Northwest, BNW) here at Richland, Washington.

The major objective of the program is to provide the information that is necessary to select, design, fabricate, and operate a commercial waste solidification plant and a waste storage system. The WSEP program complements the fluid bed calcination demonstration by Idaho Nuclear Corporation (INC) at Idaho Falls, Idaho, and the previous hot laboratory scale program here by BNW in providing radioactive demonstration of developmental processes. The demonstration is a focal point for research and development on the program sponsored by the United States Atomic Energy Commission.

Development and design of the prototypes was the responsibility of the Engineering Development Section (ED) of BNW. Most of the design was done by the ED Section, with some detailed assistance by other organizations of BNW and by the Hanford Engineering Services Branch of the Vitro Corporation of America. Process design consultation services were furnished by the waste solidification development groups at ORNL and BNL.

Design was started late in 1962 and was completed early in 1965. Construction was started early in 1963 and was completed late in 1965. Fabrication and assembly were done mainly by the on-site CPFF (cost plus fixed fee) contractor, J. A. Jones Company, with major contributions by off-site fabricators. The WSEP equipment was installed in B-Cell of the new Chemical and Materials Engineering Laboratory (C-MEL or 324 Building) during the winter 1965-1966. Final shakedown and nonradioactive testing of the equipment were performed in Design Verification Tests (DVT's) during the spring and summer of 1966. The first radioactive run was completed in November 1966. Radioactive demonstrations are currently planned to be continued into 1970, and evaluative measurements on the solidified waste will be continued into 1973.

2.0 SUMMARY

An engineering-scale pilot plant has been designed, fabricated, installed, and extensively tested for the AEC by Battelle-Northwest. The pilot plant will provide for full-radioactivity-level demonstration of several promising processes for solidification of highly radioactive wastes from reprocessed nuclear fuels. Information necessary to select, design, fabricate, and operate a waste solidification production plant is anticipated from demonstrations in the prototypes. Processes to be demonstrated are pot solidification, spray solidification and phosphate glass solidification.

The developmental waste processing facility has the capacity to process high level wastes from reprocessing of 1 tonne*/ day of power reactor fuels (10 to 20 liters/hr of liquid waste). The facility is complete with extensive off-gas processing capabilities. The WSEP has been provided with the flexibility to demonstrate a wide variety of process flowsheets and waste solutions with a broad range of solidification processes and equipment. This flexibility has been incorporated into the facility by utilizing a favorable combination of fully-remote, semiremote, and contact operating techniques.

The WSEP is a highly instrumented plant whose design is based upon providing meaningful data for full engineering evaluation of equipment, flowsheet, operating, design, cost, and safeguard requirements for application to commercial fuel reprocessing plants. Means for evaluation of properties of various waste solids and selection of processes are included as a significant part of the program.

Because most of the solidification process steps were translated from laboratory-scale or incomplete pilot plant studies

Tonne is a metric ton, 1000 kilograms or 2205 pounds.

to full engineering-scale pilot plant equipment, extensive non-radioactive tests (designated Design Verification Tests or DVT's) were made on all equipment before start of radioactive service. The pilot plant equipment performed very well, and relatively few modifications were required before start of radioactive service which occurred in November 1966. This report summarizes the features and objectives of the design of the WSEP equipment, and the equipment performance during nonradioactive testing.

An extensive analysis of the safety of operating WSEP was performed. The conclusions were that the WSEP installation and the program test plans, in combination with the building which houses the WSEP, present almost no potential for escape of hazardous amounts of radionuclides. The maximum amount of radionuclides expected to be present in any one pot of solidified waste in WSEP is 4.6 million curies.

3.0 BASIC DESIGN CRITERIA AND OBJECTIVES

The major overall criteria for the design of the prototypes were:

- The prototypes must provide for evaluation of three waste solidification processes. These processes are: the (batch) pot solidification process developed by ORNL, the continuous phosphate glass solidification process developed by BNL, and the continuous spray solidification process developed by BNW. Flexibility for possible later evaluation of additional processes must be provided, although no other processes are currently planned.
- The prototypes should provide sufficient data to permit complete engineering analyses for application to commercial waste solidification facilities. Evaluations will include equipment, flowsheet, process systems, operating, design, cost, and safeguards requirements for specific waste solids and means for selection of the processes. Provisions for these evaluations are manifest in the prototypes by the complete processing facility, the high degree of instrumentation, and the broad flexibility incorporated.
- The prototypes must provide for process evaluation on a meaningful engineering scale. The design capacity was established at instantaneous rates and average rates of 10 to 40 and 10 to 20 liters/hr of liquid waste, respectively. This capacity is equivalent to waste from about one tonne of power reactor fuel per day.
- Demonstrations will be performed with radioactivity levels equivalent to those of power reactors with moderate-to-high fuel burnup. The basic design activity level and that to be demonstrated initially is that of waste from the Yankee Atomic Power Reactor at Rowe, Massachusetts; this waste is from enriched uranium fuel irradiated to 20,000 $MWd_{(t)}$/tonne* at a power level of 15 MW/tonne, aged 1 year

All megawatt values in this report are thermal megawatts.

and concentrated to a liquid volume of about 380 liters/tonne. Later demonstrations will be with wastes from thermal reactors operating up to 45,000 MWd/tonne at 30 MW/tonne power levels. Final demonstrations may be with wastes from fast reactors operating up to 100,000 MWd/tonne at 200 MW/tonne if needed.

- The prototypes should have relatively complete off-gas processing facilities. Although major off-gas processing facilities will likely be integrated with those of a chemical processing plant in an actual production case, the technical aspects of both approaches will be studied in the WSEP.

- The prototypes should have the flexibility to study a wide variety of feeds, flowsheets, equipment, and equipment arrangements, with a reasonable amount of turnaround time. This flexibility has been achieved primarily by what is believed to be a favorable combination of fully-remote, semiremote, and direct-contact maintenance and operating techniques.

- The prototypes should offer an optimized amount of process equipment serviceability. This has been done by a reasonable balance between "temporary" and "permanent" design concepts, ready replaceability of or dual equipment (but not necessarily similar) that is susceptible to failure, good quality control of materials and fabrication, and using simpler techniques where possible.

- The long-range cost of the equipment shall be reasonable. Three separate solidification processes will be demonstrated with the one system. Other solidifications or chemical processes could be evaluated with the same equipment with nominal cost additions. The total installed cost of the complete prototype equipment and all related auxiliaries was three million dollars.

- The prototypes must be operationally safe to meet radioactivity safety requirements. This factor has been applied by designing high-integrity equipment and using numerous safety devices and techniques.

4.0 PROCESS FEATURES

4.1 PROCESS FLOW DESCRIPTION

The main process features of the Waste Solidification Engineering Prototypes are shown in Figure 4.1. The liquid waste is loaded into a cask and brought into the plant from the Hanford separations plant operated by the Atlantic Richfield Hanford Company. The WSEP Plant is located in B-Cell of the Chemical & Materials Engineering Laboratory (C-MEL is discussed later in Section 5). The waste is chemically adjusted in a feed tank to reproduce a variety of reactor fuel processing waste solutions. In addition, purified and concentrated fission product solutions are similarly brought into the plant from the Hanford fission product separations facility in a cask, and added to the feed tank to reproduce feeds with varying fission product distribution and heat generation rate characteristics. (If necessary, digestion may be done in the feed tank to aid feed preparation or to decompose organic residues, if present. The wastes may also be fed to the evaporator for volume reduction and the elimination of gross quantities of nitric acid.) From the feed tank or the evaporator, the wastes are fed directly to one of the three solidification processes.

The vapors from the solidification processes are routed through a single off-gas system common to all processes. These vapors are first routed through a condenser and collected or are recycled to the evaporator. The condensates are reconcentrated in the evaporator (along with incoming waste in some cases). The vapors from the evaporator are decontaminated from entrained aerosols first in the evaporator tower and again during condensation and scrubbing in an acid fractionator. The vapors from the fractionator are again condensed and collected for disposal as a low-radioactivity-level water stream. The remaining gases are treated by "absolute" filtration, scrubbing, and additional back-up filtration before discharge to the atmosphere. The recovered acid is recycled to the production separations plant.

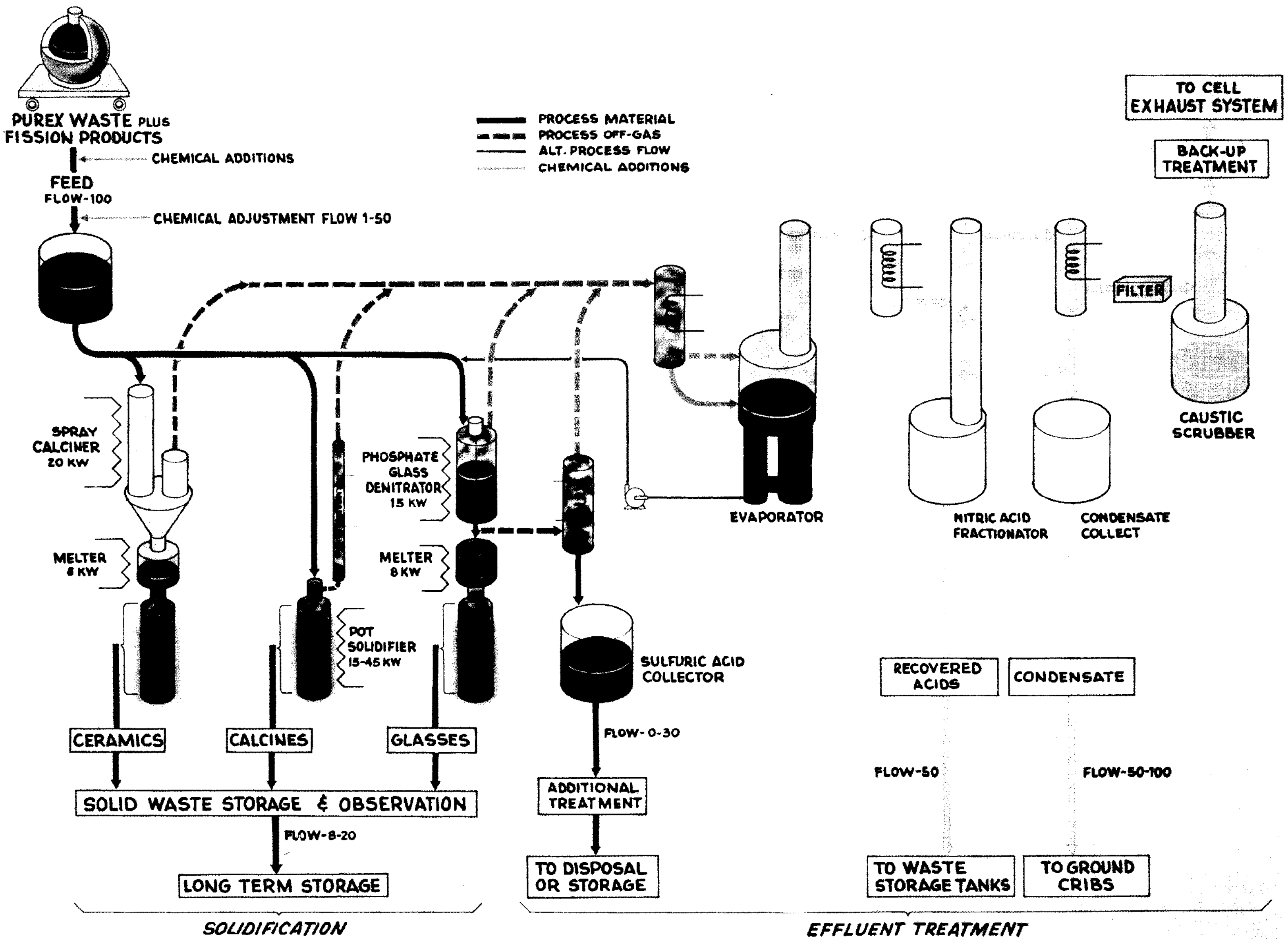

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FIGURE 4.1. WSEP Schematic Flow Diagram

The solidified waste is collected in "pots" 8 or 12 inches (and possibly 6 inches) in diameter and 8 feet long. Pots are sealed by welding before being stored in B-Cell (in air and/or water) for observations of temperature, pressure, leak rate, pot wall thickness, dimensions, and radiation levels. After initial measurements are taken on pots and their contents, some pots will be stored in B-Cell and be subjected to additional nondestructive testing measurements on a periodic schedule; other pots will be taken to the Solid Storage Engineering Test Facility (SSETF)[1] in A-Cell, where more detailed measurements (destructive and nondestructive) are taken, and storage under a larger variety of environmental conditions for periods up to 3 years is done. After interim storage periods up to about 5 years, pots will be taken to one or more long-term storage areas.

The main process functions for the three solidification devices are described briefly:

- The pot solidification process is a batch system, and the principal processing vessel is the permanent storage pot. In pot calcination, liquid waste is added to a heated pot held with a reasonably constant liquid level. After some time (usually 5 to 10 hours) the critical heat flux for boiling is exceeded and calcine scale begins to form on the pot wall. The calcine deposit grows inward and causes increased resistance to heat transfer, which in turn requires gradual reduction in feed rate until the pot is full of calcine except for a small core of thick sludge. At that time, feeding is stopped, and heating is continued until all the waste is converted into a calcine at about 900 °C. The pot is then cooled and sealed for storage.

  A potential alternative pot solidification technique for demonstration in the WSEP was the rising level glass process. (However, demonstration of this process in WSEP is not currently planned.) In rising level glass solidification, the feed and glass-making additives (such as phosphate, lithium, sodium, and aluminum salts) are fed to the pot. The feed is then evaporated, calcined, and converted to a glass in rising layers of aqueous phase above a hotter calcine phase, which is above a molten layer. The level is increased until the pot is full of molten glass. The pot is then cooled and sealed for storage.

- In spray solidification, liquid waste is fed into the top of a heated tower through a pneumatic atomizing nozzle. The spray is progressively dried and calcined to powder as it travels downward inside the reactor. The powder falls directly into the melter, while the process gas flows into the filter chamber, carrying along some of the finer waste powder as dust. The dust collects on porous metal filters and is periodically blown off the filters and into the melter by puffs of high pressure steam or air directed backward through the filters by small nozzles at the outlets of the filters. In the melter, the powder is dissolved in the molten waste at 700 to 1200 °C. The molten waste then flows through an overflow weir tube or freeze valve into the receiver-storage pot. The pot is then cooled and sealed for storage.
- In continuous phosphate glass solidification, liquid waste is mixed with glass-forming chemicals (normally phosphoric acid) and concentrated by a factor of about 5 to a thick slurry in an evaporator. The slurry is fed to a continuous melter where final evaporation and glass formation occur at temperatures of 900 to 1200 °C. The molten glass flows into the heated receiver-storage pot. The pot is then cooled and sealed for storage.

Two standard feed compositions were selected for design bases and for evaluation during the first experimental phase of the program. Three additional feed compositions were selected as alternatives for demonstration during the second experimental phase of the program. These are shown in Table 4.1. The five compositions bracket the range of feed compositions found in Purex or other flowsheets for aqueous fuel reprocessing. PW-1 represents a Purex waste solution high only in iron salt content and void of sulfate. PW-2 represents a Purex sulfate-containing waste solution high in sodium content and low in other salts. PW-3 represents a Purex sulfate-containing waste such as PW-2 which has been neutralized with caustic. PW-4 represents a relatively "clean" Purex waste stream without sulfate that has low concentrations of all salts except fission products. This waste is expected to be typical of future wastes. PW-5 represents a waste high in aluminum content, such as that resulting from the TBP-25 process. These basic feed compositions are modified chemically to fit each process. The overall flowsheets are summarized in Figure 4.2 for PW-1 and PW-2 feeds. The minimum and maximum feed volumes to fill an 8 inch diameter pot are about 300 to 800 liters, respectively. These volumes require 30 to 80 hours of actual feeding time.

4.2 GENERAL DESIGN FEATURES

The WSEP is a developmental facility. As such, many provisions for process flexibility, monitoring, and control are included that may not be required in a production facility. This was done in order to achieve one of the major objectives of obtaining ample information to determine what features are and are not necessary in a commercial plant.

Some of the more important of the general process design features of the Waste Solidification Engineering Prototypes are discussed below.

- The entire process system is maintained under a slight vacuum relative to the cell pressure to minimize release of radioactive contamination to the cell and to other nonprocess areas. The primary process vent system is maintained at a negative pressure of 3 to 30 inches of water. This

TABLE 4.1 *High Level Wastes for Possible Demonstration in WSEP*

Constituent	PW-1	PW-2	PW-3	PW-4	PW-5
	Concentration, Molarity @378 liters/tonne[a]				
General Chemical Composition of Inert Materials					
Na	low	high	high	low	low
Fe	high	med	med	low	low
Al	0	0	0	0	high
SO_4	0	high	high	0	0
Actual Chemical Composition of Inert Materials					
H	3.7	3.93	(-)0.10	6.29	4.25
Fe	0.93	0.445	0.445	0.05	0.05
Cr	0.012	0.024	0.024	0.012	0.012
Ni	0.005	0.010	0.010	0.008	0.008
Al	0.001	0.001	0.001	0.001	0.65
Na	0.138	0.93	5.58	0.10	0.10
U	0.010	0.010	0.010	0.010	0.010
Hg	<0.001	<0.001	<0.001	<0.001	<0.001
NO_3	7.5	5.37	5.37	6.66	6.5
SO_4	---	0.87	0.87	---	---
PO_4	0.003	0.006	0.006	0.003	0.003
SiO_3	0.010	0.010	0.010	0.010	0.010
F	<0.001	<0.001	<0.001	<0.001	<0.001
ΣM^{+}_{chem}[b]	3.03	2.48	8.06	0.365	2.31
kg oxide/tonne	31.7	28.1[c]	93.6[c]	4.6	17.2

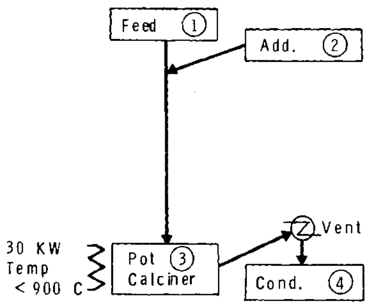
Chemical Composition of Major Materials from Nuclear Fission

	Fuel Exposure in Thermal Reactors	
	20,000 MWd/tonne @15 MW/tonne	45,000 MWd/tonne @30 MW/tonne
Mo	0.065	0.130
Tc	0.014	0.031
Sr	0.0155	0.036
Ba	0.0195	0.041
Cs	0.035	0.078
Rb	0.007	0.014
Y + RE[d]	0.12	0.274
Zr	0.065	0.143
Ru	0.032	0.082
Rh	0.0074	0.013
Pd	0.017	0.043
Ag	0.0008	0.0016
Cd	0.0008	0.0025
Te	0.0064	0.014
ΣM^{+}_{fp}[b]	0.91	2.10
kg oxide/tonne	22	49

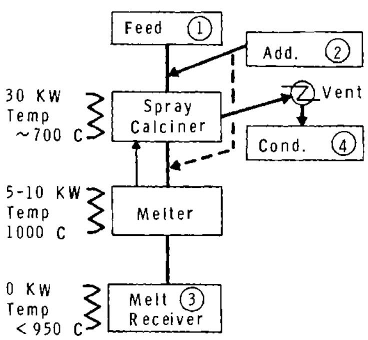
(a) *Tonne is a metric tonne, 1000 kg or 2205 pounds.*
(b) *M^+ is metal equivalents, or normality of metal ions (does not include acid)*
(c) *Does not include the sulfate. If sulfate is not volatilized, approximately 27 kg/tonne of additional oxides are formed.*
(d) *RE is rare earth elements.*

PROCESS	(1) FEED[Δ]	(2) ADDITIVE	(3) SOLID[*◇]	(4) CONDENSATE[‡]
Pot Solidification	PW-1[▽] Purex 1WW 380 ℓ/tonne Flow 100	Ca^{++} 1 M $SO_4^{=}$ 10 M Flow 0.9	$f_{P_2}O$* 33% M_2O* 54% SO_3 9% ρ 1.3 k 0.2 Heat◇ 90 w/ℓ Flow 9	HNO_3 >95% H_2SO_4 < 2% Ru 5% Flow 90
	PW-2[▽] Purex 1WW 380 ℓ/tonne Flow 100	Ca^{++} 4 M Flow 10	$f_{P_2}O$* 14% M_2O* 49% SO_3 37% ρ 1.4 k 0.2 Heat◇ 90 w/ℓ Flow 13	HNO_3 >95% H_2SO_4 < 2% Ru 20% Flow 95
Spray Solidification	PW-1[▽] Purex 1WW 380 ℓ/tonne Flow 100	Na^+, Li^+ 5 M $PO_4^{\equiv}$ 9 M Flow 20	$f_{P_2}O$* 14% M_2O* 47% P_2O_5 39% ρ 3.1 k 0.6 Heat◇ 210 w/ℓ Flow 8	HNO_3 100% Ru 70% Flow 110
	PW-2[▽] Purex 1WW 380 ℓ/tonne Flow 100	Ca^{++} 2 M $PO_4^{\equiv}$ 9.5 M Na^+, Li^+ 8 M Al^{+++} 0.8 M Flow 30	$f_{P_2}O$* 6% M_2O* 51% P_2O_5 27% SO_3 16% ρ 2.8 k 0.6 Heat◇ 210 w/ℓ Flow 17	HNO_3 100% H_2SO_4 < 5% Ru 70% Flow 110
Phosphate Glass Solidification	PW-1[▽] Purex 1WW 380 ℓ/tonne Flow 100	$PO_4^{\equiv}$ 13 M Na^+ 4.5 M Flow 45	$f_{P_2}O$* 7% M_2O* 32% P_2O_5 61% ρ 2.7 k 0.8 Heat◇ 280 w/ℓ Flow 20	(4a) HNO_3 90%, Ru <3%, Flow 80 (4b) HNO_3 10%, H_3PO_4 < 1%, Ru 10%, Flow 40
	PW-2[▽] Purex 1WW 380 ℓ/tonne Flow 100	$PO_4^{\equiv}$ 13 M Flow 26	$f_{P_2}O$* 12% M_2O* 27% P_2O_5 62% ρ 2.8 k 0.8 Heat◇ 280 w/ℓ Flow 12 Flow 12	(4a) HNO_3 >95%, Ru < 3%, H_2SO_4 <10%, Flow 100 (4b) HNO_3 <10%, H_2SO_4 >90%, H_3PO_4 < 1%, Ru 10%, Flow 20

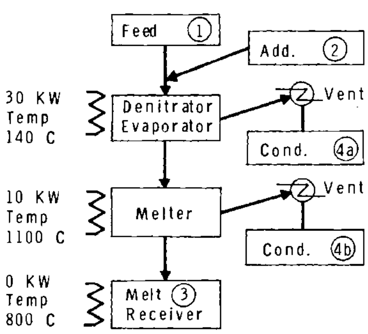
Pot Solidification process:



Spray Solidification process:



Phosphate Glass Solidification process:



▽Nominal Feed Compositions (in moles/) are:

	PW-1	PW-2
H	3.7	3.9
Na	0.14	0.93
Fe	0.93	0.45
Cr, Ni, Al	0.02	0.04
SO_4	0	0.87
NO_3	7.5	5.4

Fission Products 20,000 MWd/t (~0.9 N cations)

* Concentrations of solids are mole % as the oxides in their appropriate valence.

‡ Percent of that in feed + additives.

◇ Heat is for 8-inch diameter pots. Heat unit volume for 12-inch diameter pots is ~60% of these values.

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FIGURE 4.2. Solidification Flowsheet in WSEP for 2 Feeds

vacuum is automatically controlled by recycle of discharge gases from the ejector which generates the primary process vacuum at the end of the off-gas processing train. This system discharges into the secondary process vessel vent system which is maintained at a vacuum of 2 to 10 inches of water by a single stage turbine-type of centrifugal blower located outside the cell. This secondary system provides venting for the feed tanks, the fractionator condensate tank, and furnace hoods. The vent system for the three feedstock storage tanks is similar to the process vessel vent system, and the two systems may be valved together ahead of the final filtration step, if desired. The vent systems are shown in Figure 4.3. Piping connections between tanks at different operating vacuums are sealed to minimum vacuum differences by 36 inches of water by appropriate dip legs in the tanks. A small heel of liquid is, therefore, required in all tanks during processing. The routinely-disconnected pot-to-off-gas system is in a hood to further minimize contamination.

- All solidification equipment is equipped with emergency vent piping through water-filled seal pots in event of inadvertent undesirable reduction of vacuum. The designs of the seal pots provide variable pressure differential seals (up to 29 inches of water) to other tanks for added vapor capacitance and/or alternate vents.
- All solidification processes are serviced by the same off-gas processing train. This feature allows evaluation of different solidification equipment using common off-gas treatment.
- The prototypes are highly instrumented to provide sufficient data for full process evaluations. The facility was designed to be operated by electronic instrumentation in the control room. A small amount of operations will be

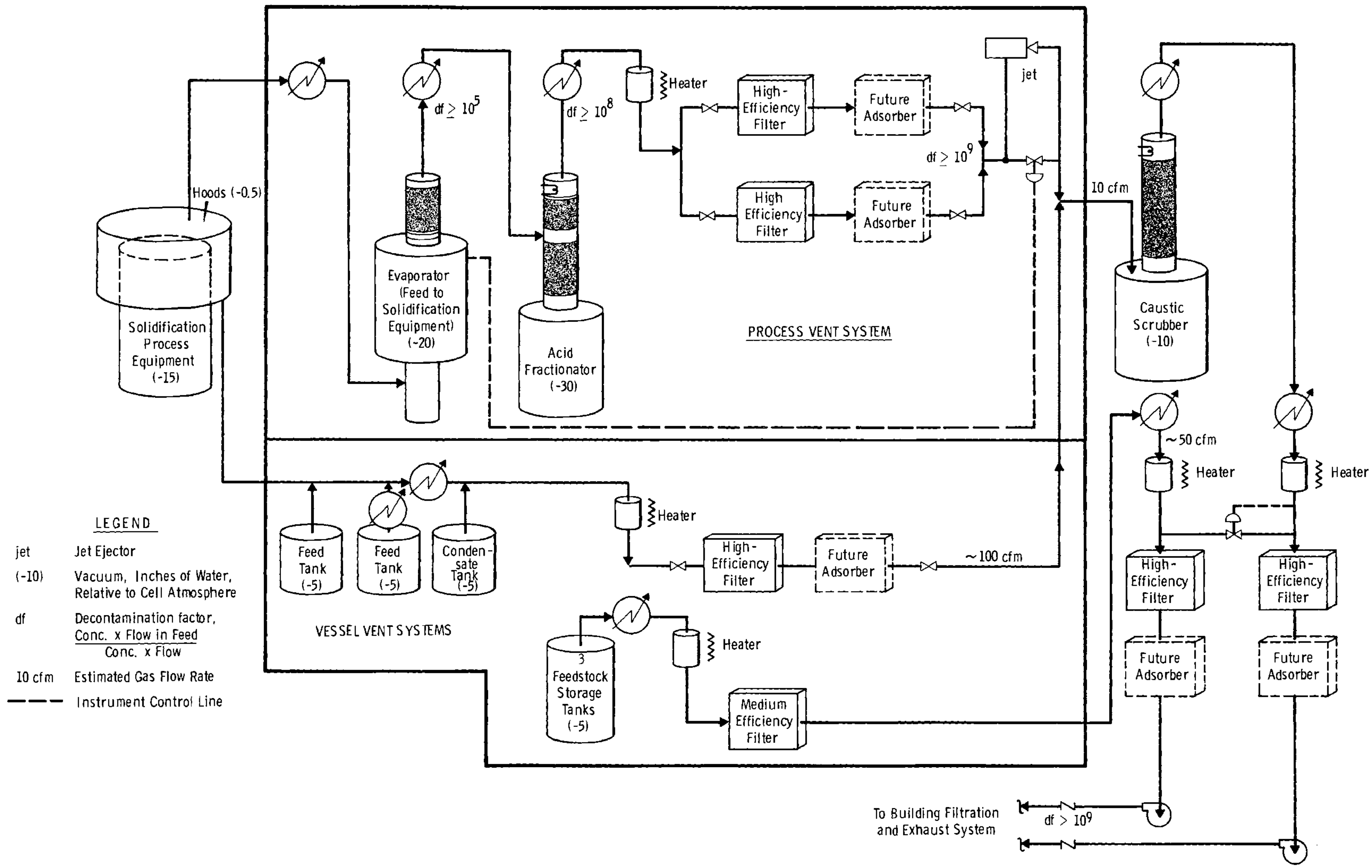

FIGURE 4.3. Process and Vessel Vent Systems, Waste Solidification Engineering Prototypes

performed manually by the use of master-slave manipulators, viewing windows, closed-circuit in-cell television, in-cell hoist and cranes, etc. Some of the manually-performed operations are: sampling, pot movement and positioning, some manual valving, and in-cell maintenance.

- Double containment is provided for solidification equipment exposed to potentially severe environments. Specifically, this feature is included for the solidification pots, the continuous melters, and the pot storage system.
- High quality fabrication is required. Fabrication requirements include all-welded construction (except at connector joints), use of corrosion-tested material in most places, X-ray of all critical welds, and close inspection of all fabrication (including off-site fabrication).
- In cases of borderline suitability of certain materials of construction, the better material is generally specified. Examples of the use of 1) Hastelloy-X for furnace susceptor material; 2) titanium for the waste evaporator and its condenser, the acid fractionator, the solidifier condenser, and the phosphate glass evaporator; 3) 310 stainless steel for the spray calciner; 4) platinum for the continuous melters and off-gas line for the phosphate glass melter, and 5) Nionel for the phosphate glass condenser. Standard process material of construction of 304-L stainless steel with 308 stainless steel weld rod.
- Off-gas cleanup treatment is included which will provide more decontamination of the off-gases than is required. Design and operation are aimed at emitting gaseous effluents with radioactivity levels below requirements in 10 CFR 20[2] and producing liquid effluents with reasonably low levels of radionuclide concentrations. Provisions for additional treatments are also included, such as adsorption

of radioruthenium and radiodine if desired in the future. Also, provisions for bypassing part of the cleanup stages are included. The gaseous emission limits for the C-MEL facility were used as WSEP design bases, and are given in Table 4.2.

TABLE 4.2. *Maximum Radioactivity Emission Limits, Chemical and Materials Engineering Laboratory*

Isotope	Maximum Emission, Ci/week
U (natural)	0.002
Pu (any isotope)	0.0005
Sr^{90}	0.005
I^{131}	0.02
Other mixed β-γ	1.0

- Solidification pot sizes and heat rate content of the solidified waste will be selected to limit the maximum internal pot temperature and pot wall temperatures to 900 and 427 °C, respectively. The maximum heat rate content for storage in water is thereby limited to approximately 20 kilowatts for the 8 or 12 inch pots. Some 6 inch diameter pots may also be used for solidified wastes with high specific heat generation rates--greater than about 300 W/liter of solid. The waste solutions will be made up from Hanford's Purex waste and concentrated solutions of Sr^{90} or Cs^{137} (to increase the long-term heat generation rates and total integrated radiation dose), and Ce^{144}/rare-earth fission products (to increase the short-to-medium time heat generation rates). The compositions of these solutions are shown in Table 4.3.
- A reasonable amount of interchangeability of equipment is provided. For example, the induction-heated pot furnace is interchangeable with the comparable resistance-heated furnace; the two continuous melters, melter furnaces, and many of their appurtenances are interchangeable; the

TABLE 4.3. *Compositions of Radioactive Liquid Source Solutions*

A. Hanford Purex 1WW

Component	Concentration
Radioactivity	2000 to 3000 Ci/ℓ
HNO_3	4 to 7M
$NaNO_3$	0.3 to 0.8M
$Al(NO_3)_3$	0.2 to 0.4M
$(Fe + Cr + Ni)(NO_3)$	≤0.1M
$SO_4^{=}$	0.01 to 0.05M
All Other Salts	≤0.1M

B. Concentrated Radiostrontium Solution

Component	Concentration
Sr^{90}	500 to 2000 Ci/ℓ [a]
Sr^{89}	600 to 3000 Ci/ℓ [b]
All Other Activity	<100 Ci/ℓ
$Sr(NO_3)_2$	0.07 to 0.3M [b]
$NaNO_3$	0.5 to 1.0M
$(Ca + Mg)(NO_3)_2$	0.05 to 0.1M
All Other Salts	∿0.01M

C. Concentrated Radiocesium Solution

Component	Concentration
Cs^{137}	1000 to 2000 Ci/ℓ
All Other Activity	∿100 Ci/ℓ
$CsNO_3$	0.2 to 0.4M
$NaNO_3$	1.0 to 2.0M
All Other Salts	∿0.01M

D. Concentrated Rare Earth Solution

Component	Concentration
Ce^{144}	2000 to 3000 Ci/ℓ [a]
All Other Activity	<300 Ci/ℓ [a]
$Ce(NO_3)_3$	0.01 to 0.03M
Other Rare Earth $(NO_3)_3$	0.03 to 0.06M
$NaNO_3$	0.2 to 0.4M
All Other Salts	≤0.05M
Solids	<0.1%

(a) *Does not include radioactivity content of the radioactive daughter.*
(b) *Approximately 50 weight percent of the strontium is radioactive.*

submerged pumps and agitators are interchangeable in the service tanks, and many service supply systems and piping jumpers are interchangeable.

- Where reasonably possible, process equipment was designed such that its salvage for use in possible future in-cell programs would be high. For example, the service tanks could be used for many types of processes; the waste evaporator could be used as a dissolver; the acid fractionator could be used as an evaporator, absorber, or scrubber; the scrubber could be used as an absorber or could service other programs simultaneously.
- Steam-operated jets are used for all batch transfers. Controls include semiautomatic air purging after each transfer.
- At least two means of transferring materials from one tank to another are provided in event of malfunction of one route. The two transfer routes are not usually identical.
- All components susceptible to failure, such as pumps, agitators, manual and control valves, flow and other instruments, are made readily replaceable by semiremote or fully-remote techniques.
- Equipment and instrumentation is designed to be fail-safe.
- Provisions for gas sampling are included for likely use later in the demonstration program. However, sampling of process gas streams is not planned for in the initial runs. Sampling of gases within the pots of solidified waste is also provided for.
- Relatively standard techniques are used for minimizing backup of radioactivity into the service areas, such as eliminating connections between pressurized process

equipment (pump discharge lines, etc.)[a] and the service areas, using seal pots in chemical addition lines, using check valves and other extra valves in steam, air, and water service piping, providing a separate chemical addition head tank area, air purging of supply pipes to transfer jets, etc.

- No services liquid effluents that exceed MPC[b] may be discharged to the ground at the laboratory area. To assure this, steam and water effluents from heat exchangers in severe service (e.g., evaporator and feed tank coils) are routed to the crib waste sewer (which is trucked to cribs in the chemical separations area at Hanford). Since early 1968, these services effluents are retained in batches in the C-MEL facility, then are analyzed for radioactivity before being routed to the nearby ponds. Similar effluents from heat exchangers in less severe service (e.g., condensers, tank jackets, condensate tank coils) are treated similarly.
- Provisions for evaluating several combinations of feed and condensate routings are included in the design. The three main feed-condensate equipment "lash-ups" are shown schematically in Figure 4.4. Basically, these options provide for (A) separate feed evaporation, (B) combined condensate evaporation and concentration of feed for the next run, and (C) combined and integrated feed and condensate evaporation.

A large amount of process, equipment, and piping information is given in Figures 4.5a and 4.5b. Discussions of information shown on these diagrams and on other major parts of the WSEP equipment is given in the following sections.

(a) *The only exception to this rule is the connection of the atomizing gas supply to the spray calciner feed nozzle and the feed supply to the nozzle. These streams meet under pressure inside the internal mixing atomizing nozzle. An extensive safety system is incorporated to keep atomizing gas pressure greater than the feed pump pressure.*

(b) *Maximum permissible concentration based on Reference 3.*

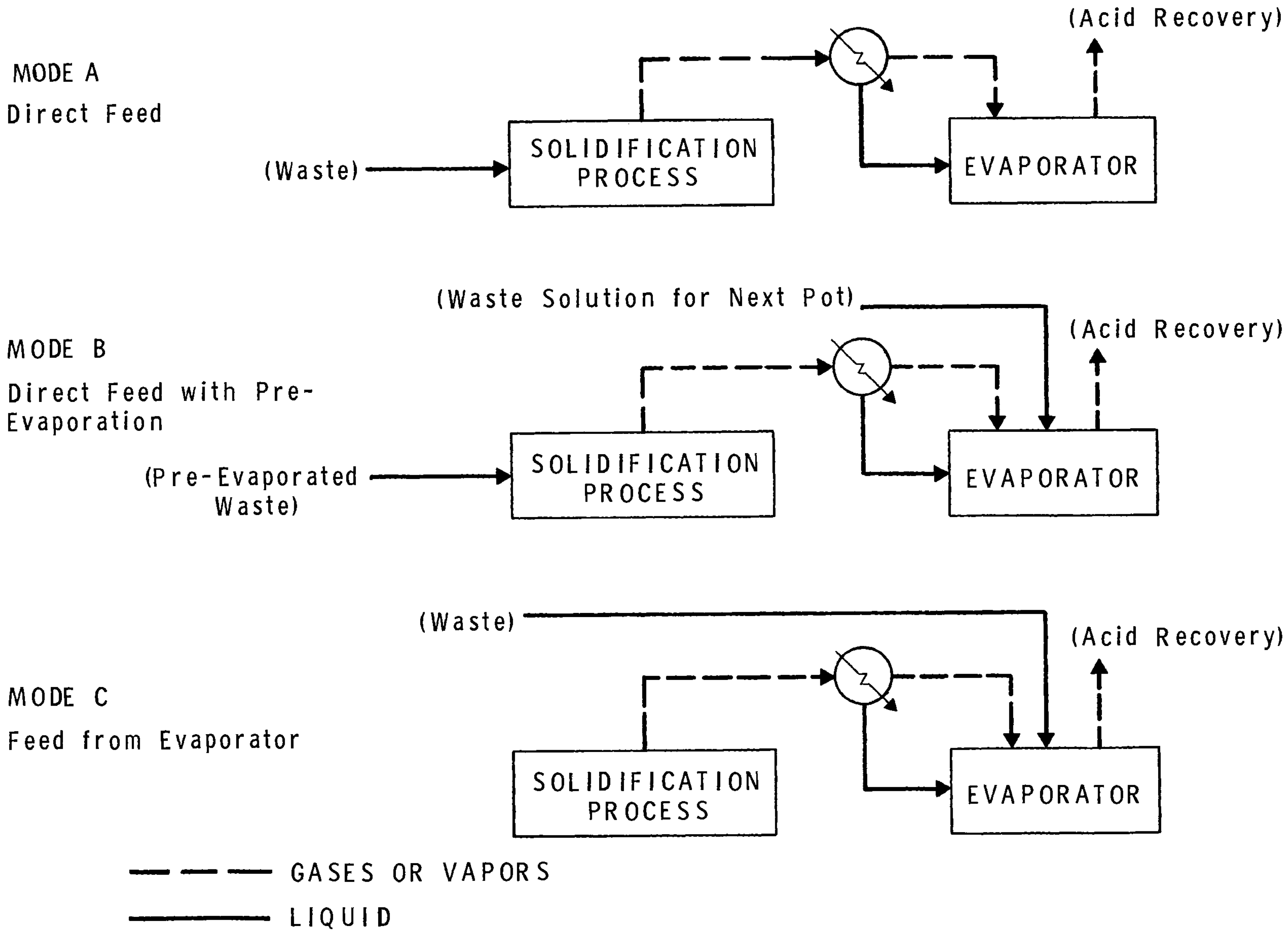

FIGURE 4.4. WSEP Process Options

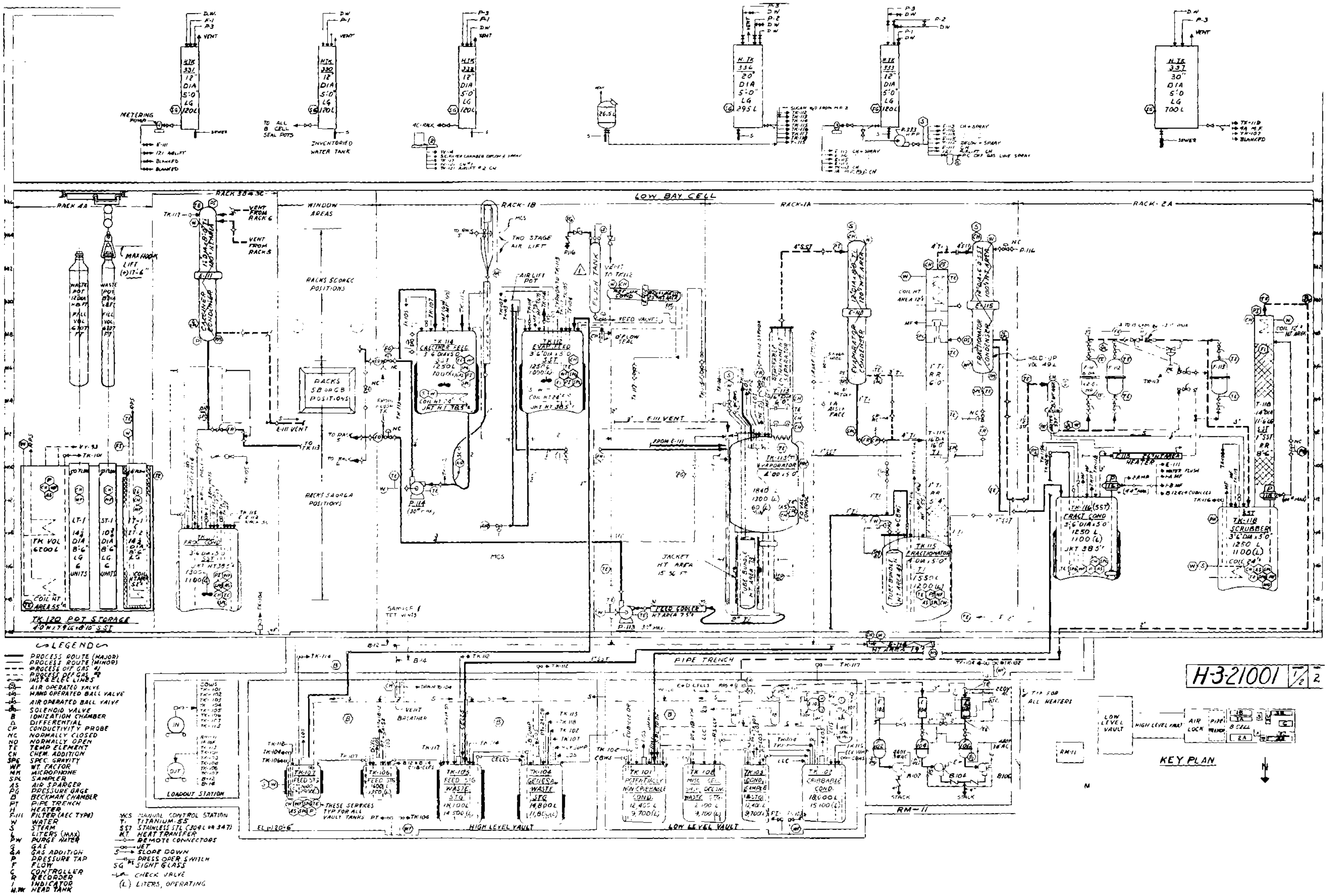

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FIGURE 4.5a. Engineering Flow Diagram of Auxiliary Process Equipment in WSEP (Sheet 1 of 2)

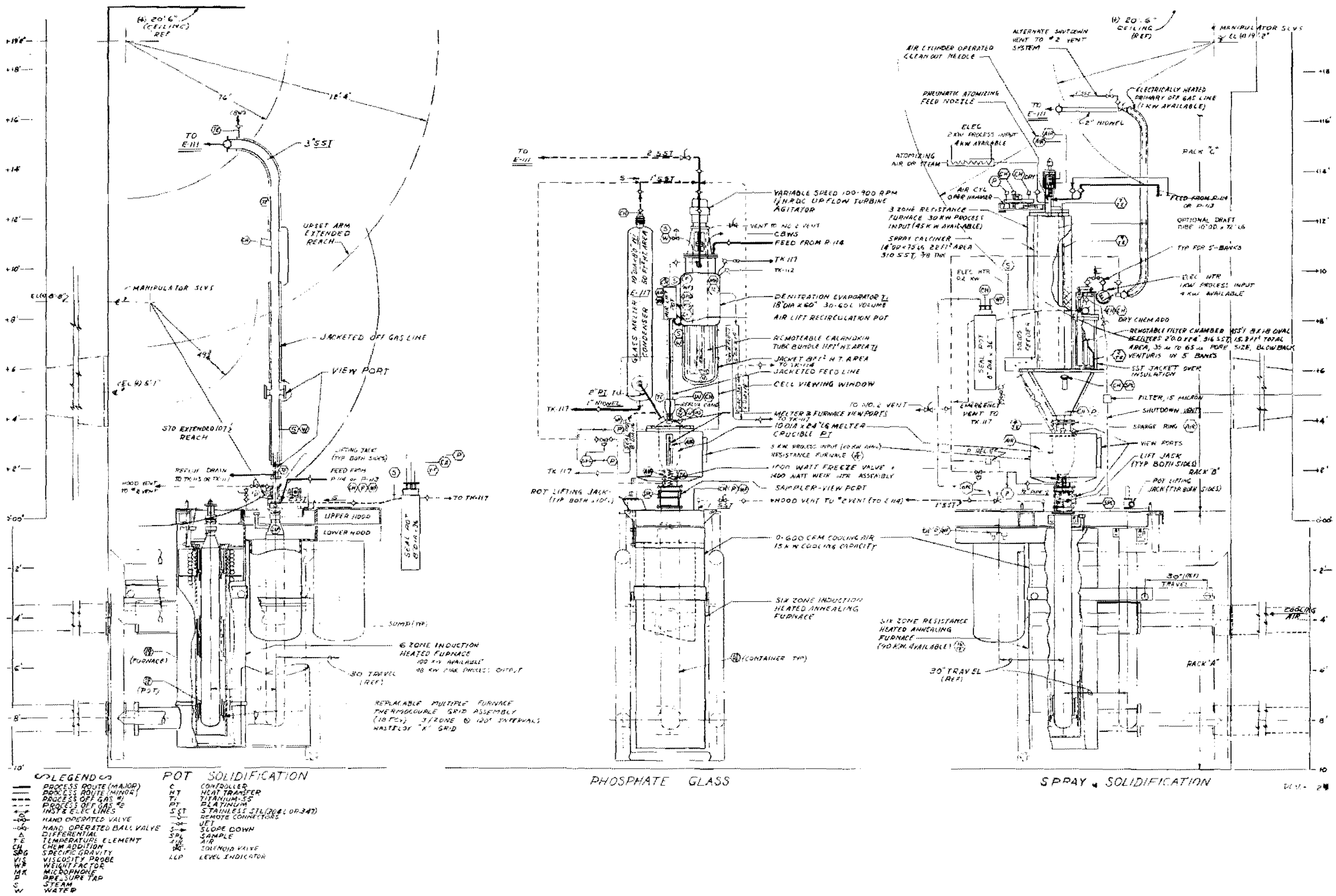


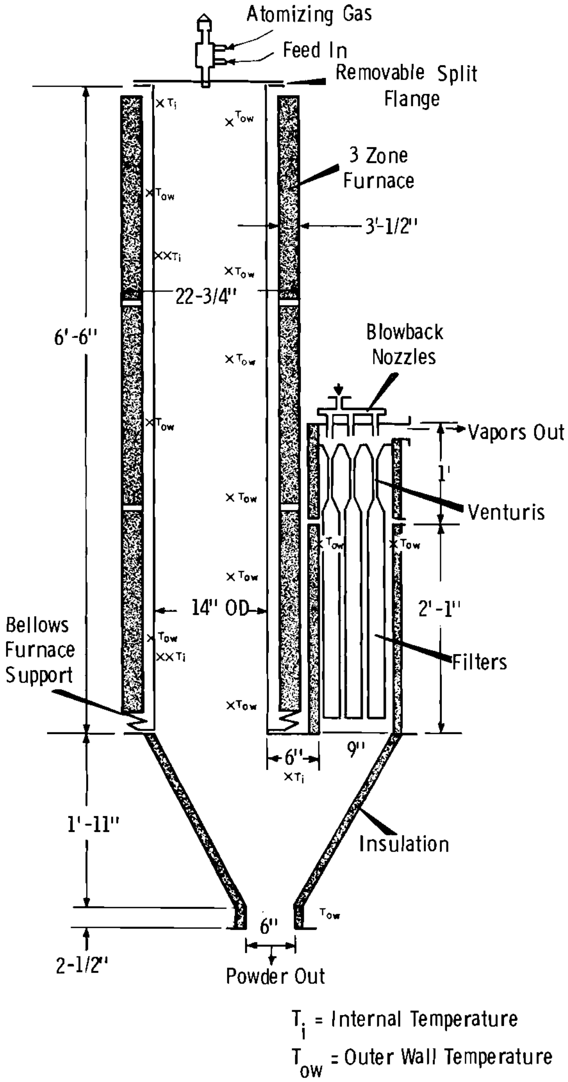
FIGURE 4.5b. Engineering Flow Diagram of Solidification Process Equipment in WSEP (Sheet 2 of 2)

4.3 SOLIDIFICATION EQUIPMENT

4.3.1 Spray Solidification

The major features of the spray calciner and its furnace assembly are shown in Figure 4.6. The calciner was constructed of 310 stainless steel because of its generally superior resistance to process corrosion and to high temperature air oxidation. Maximum operating calciner wall temperature is determined by the tendency for individual feeds to sinter and stick to the walls, and is generally in the range of 600 to 800 °C. Feed enters the calciner through an all-welded modification of a commercial-type of internal-mixing or external-mixing pneumatic atomizing nozzle that is remotable from the rest of the unit. The nozzle assembly includes a bellows-sealed, remotely-operated clean-out needle for the liquid passage, as well as the remote piping connections. Atomization is effected by air or steam at 40 to 100 psig pressure with provisions for preheating. Atomizing gas: liquid feed weight ratios of 0.8 to 1.2 are used. A remotable, free-piston, air-operated vibrating hammer is mounted on the top of the calciner reactor to help dislodge wall deposits.

The remotely replaceable filter cartridge contains 15 square feet of sintered stainless steel filter area in a compact, oval-shaped cylinder volume of 2 cubic feet. The 15 tubular filters are periodically cleaned in banks of three by short pulses of preheated steam directed backwards through the venturi-shaped filter exhausts. The calciner off-gases are routed through a line to the condenser which has electric heaters if necessary to assure that no condensate reflux returns to the dry calciner. The reactor and filter chambers are connected by an enlarged conical section to aid in settling of the spray-calcined powder. The top of the reactor chamber is removable to provide a means for remotely changing internal features, such as the insertion of a draft tube. (The use of



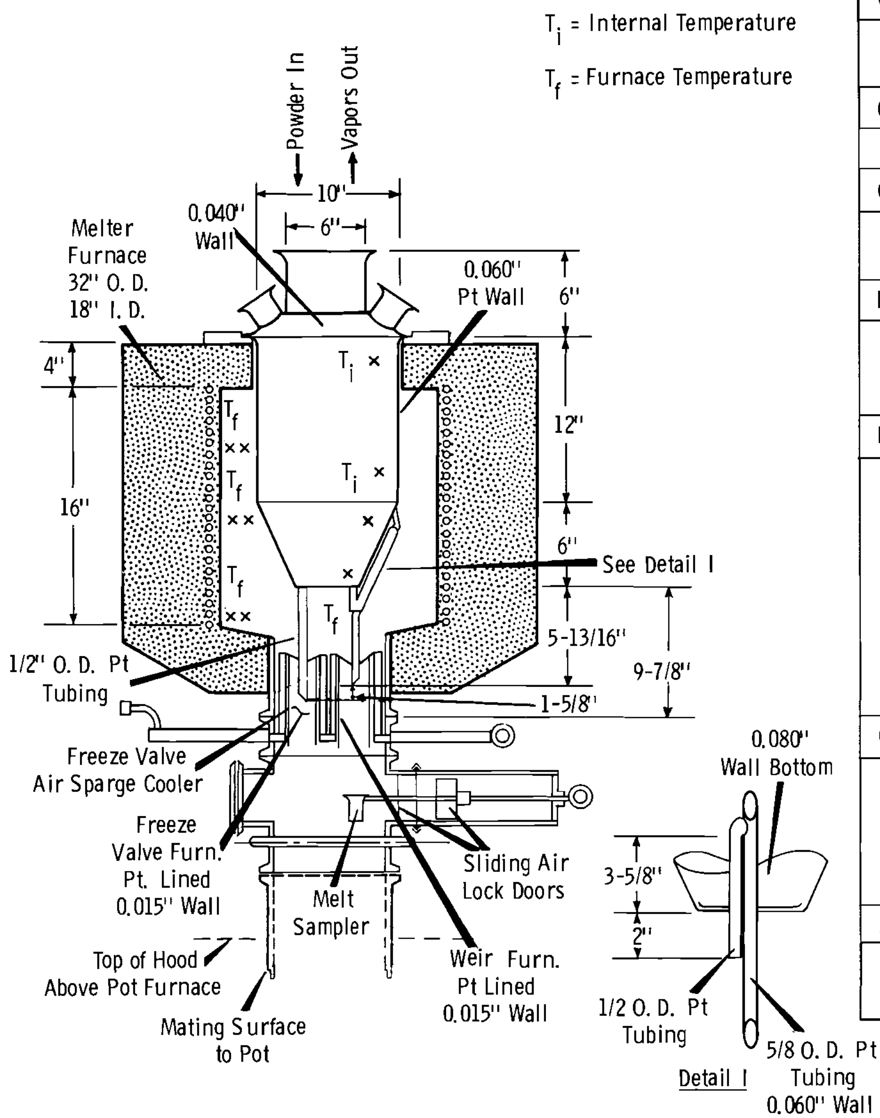
SHELL	
Heat Transfer Area	23 ft^2
Volume	
Drying Chamber	271 ℓ
Tapered Bottom	86 ℓ
Total Volume	433 ℓ
Filter Chamber	
Clean Side	24 ℓ
Dust Side	52 ℓ
Material	310 SST
Wall Thickness	0.375"
ATOM. NOZZLE	
Type - Pneumatic, Internal Mix all Welded	
Liquid Orifice	304L SST 0.100 in. I.D.
Final Orifice	303 SST 0.125 in I.D.
FURNACE	
Type - Electrical Resistance, 3 Zones, 3 Phase, 240V	
Power	45 kW
Heating Elements	Nichrome V 0.12 in. diam
Max. Temperature	1000 °C
Normal Temperature	600-800 °C
Insulation	Tipersul
FILTERS	
Total Number	15
Material	316L SST
Mean Pore Size	65 μm
Total Surface	15 sq. ft.
Normal Pressure Drop	6 in. water at 1800 ℓ/min
FILTER BLOWBACK SYSTEM	
Gas	Air or Steam
Flow	270 ℓ/min at 60 psig
Pressure	20-100 psig
Nozzles	0.11 in. I.D.
Venturis	
End Diam.	2 in.
Cone Angles	30 degrees

FIGURE 4.6. Spray Calciner and Furnace Assembly

a draft tube within the calciner "barrel", is an option available, primarily for increasing drying capacity.) In addition, the main reactor chamber is separable from the rest of the calciner.

Calciner and furnace temperatures are measured by Chromel-Alumel thermocouples inside 3/16 inch diameter sheaths made of 310 stainless steel. Temperatures are measured internally at distances of 2, 18, and 60 inches down from the top flange and next to the reactor wall, at one location in the lower conical section, on the walls externally at three locations of different elevation, at 120° around each zone of the reactor near the powder outlet, and on each side of the filter chamber. Furnace temperatures are controlled separately in each of the three heating zones by duration-adjustment type of rapid on-off, proportional controllers. Information on the spray calciner and melter furnaces is presented in Sections 5.3.3 and 5.3.4.

Powder falls from the spray calciner directly into the platinum melter shown in Figure 4.7. Platinum was selected for melter material because it was the only known metal that could withstand the temperature and chemical environments encountered. Nonmetals are generally not desirable for in-cell use because of their brittleness and because of the difficulties in forming good seals with other materials. The melter hangs by an integral lip from the upper flange of the melter furnace. The portion of the melter above this mounting flange is the only part which is not double-contained in event of vessel rupture. The platinum of the original melter was alloyed with 0.5% rhodium to improve the long-term high-temperature strength of the vessel by a factor of about 2. The final melter is made of 99.95% platinum (see Section 6.1.2). The normal melt level in the melter is at the top of the lower conical section. At this point, the melt hold-up is 4.5 liters and the heat transfer area above and below the melt level is 1.7 and 1.0 square



VOLUME	
Maximum	19.4 ℓ
Normal Operating	4.5 ℓ
CAPACITY	
Melter	40 ℓ/day melt
CONSTRUCTION	
Type	All Welded
Material	99.95% Pt
NOZZLES	
6" O. D.	1 } Top
2" O. D.	5 } Top
0.5" O. D.	2 (discharge)
FURNACES	
Melter	
Type	Elec. Resistance 3 Phase, 126V
Power	20 kW
Heating Elements	Kanthal A-1 0.18 in. diam.
Insulation K-28	K-28 and Fiberfrax
Freeze Valve	1 kW
Weir	1.3 kW
OPERATING	
Temperature Max.	1300 °C
Temperature Normal	1000-1200 °C
Pressure Max.	24 in. H_2O Vac
Net Furn. Power	4 kW
Gross Furn. Power	12 kW
MELTER HEAT TRANSFER AREA	
Above Melt Level	1.7 ft^2
Below Melt Level	1.0 ft^2

FIGURE 4.7. Continuous Melter and Furnace Assembly, Spray Solidifier

feet, respectively. The bottom of the melter is well recessed within the melter furnace to provide adequate heat at that point. Total process heat load into the melter is about 4 kilowatts.

An important design problem in using platinum melters is the poor thermal emissivity of platinum (about 0.2 at operating conditions). Melter surface treatment by sand blasting increases this value to about 0.3. Surface treatment by precise machining could theoretically increase the emissivity up to about 0.5. No treatment was used for the WSEP melters because of the extensive development requirements.

Internal melter temperatures at four varying heights are measured by an assembly of four 1/8 inch platinum-sheathed, platinum/platinum-10% rhodium thermocouples entering the melter from one of the five small melter nozzles at the top. Temperature is controlled by one of the 5 platinum/platinum-10% rhodium thermocouples entering the top of the single-zone furnace. Melt level may be continuously measured by the reflection of a microwave pulse transmission through a reflectometer probe entering the melter from another nozzle at the top. Direct viewing through a window at the top of the melter is the primary means for determining melter internal conditions.

The melter discharge piping includes a bottom-outlet, external weir within the main furnace, and a straight-tube freeze valve. The type of weir that is used provides constant-rate melt discharge with 1) a seal between the melt receiver space (normally at a negative pressure of less than 1 inch of water) and the inside of the melter (normally at a negative pressure of 5 to 10 inches of water; 2) variations in melt level control, through control of process vacuum, including complete draining of the melter by slight pressure; and 3) additional concentrated heat transfer to the effluent melt. Each melter outlet tube terminates inside a separate electrically-heated chamber to minimize uncontrolled freezing. The freeze valve discharge tube provides for intermittent batch dumping of the entire contents of the melter. Batch dumping is accomplished by increasing the temperature of the small freeze-valve furnace until the melt flows through the freeze valve tube. Once the melter is empty, the freeze valve tube can be resealed by reducing the process vacuum, shutting off the freeze valve furnace, and turning on the small air sparger-cooler in the freeze valve furnace. The small furnaces for the weir and freeze valve are each lined with a thin platinum sheath. These sheaths protect the two small furnaces from melt spatters, minimize flow of eddy currents of cold air from below the two melt discharge tubes, and help minimize heat losses out the bottom of the larger melt furnace.

The discharging melt drops about 18 inches through a melt sample chamber and other chamber connections to the melt receiver pot. The sample chamber and receiver pot are vented by pressure differential control through a control valve to the off-gas line downstream of the spray calciner filters. An adjustable, bellow-sealed mechanical pressure relief valve provides a safety relief around the control valve. The melt receiver pot is inside a six-zone electrical resistance heating-cooling furnace to provide zone temperature control as the pot is filled with melt. The temperatures for each heated zone in the pot are measured internally by thermocouples in wells and externally by thermocouples welded to the pot wall. The joint between the pot and the melt discharge chamber above is always kept in a hood to minimize contamination spread during pot change-out. More information on the pot, the furnaces, and the hood is given in Sections 4.3.4 and 5.

4.3.2 Pot Solidification

The major design features of the pot calcination equipment are shown in Figures 4.8a and 4.8b. The feed enters and the off-gases leave the pot through the fill "head" of the calciner.

CONSTRUCTION

Type	Welded or Flanged
Material	304-L SS
View Port	Quartz

OPERATION

Reflux Rate	2 to 5 liter/hr
Temperature	100 to 300 °C
Pressure	-20 in. H_2O

Vapor Velocity at 1 liter/hr Boil-up at 100 °C; 0.69 ft/sec in 2 in. Section, 0.31 ft/sec in 3 in. Section

DIMENSIONS

Vent Line Vertical Rise 10.6 ft
Jacketed Area 8.8 ft²

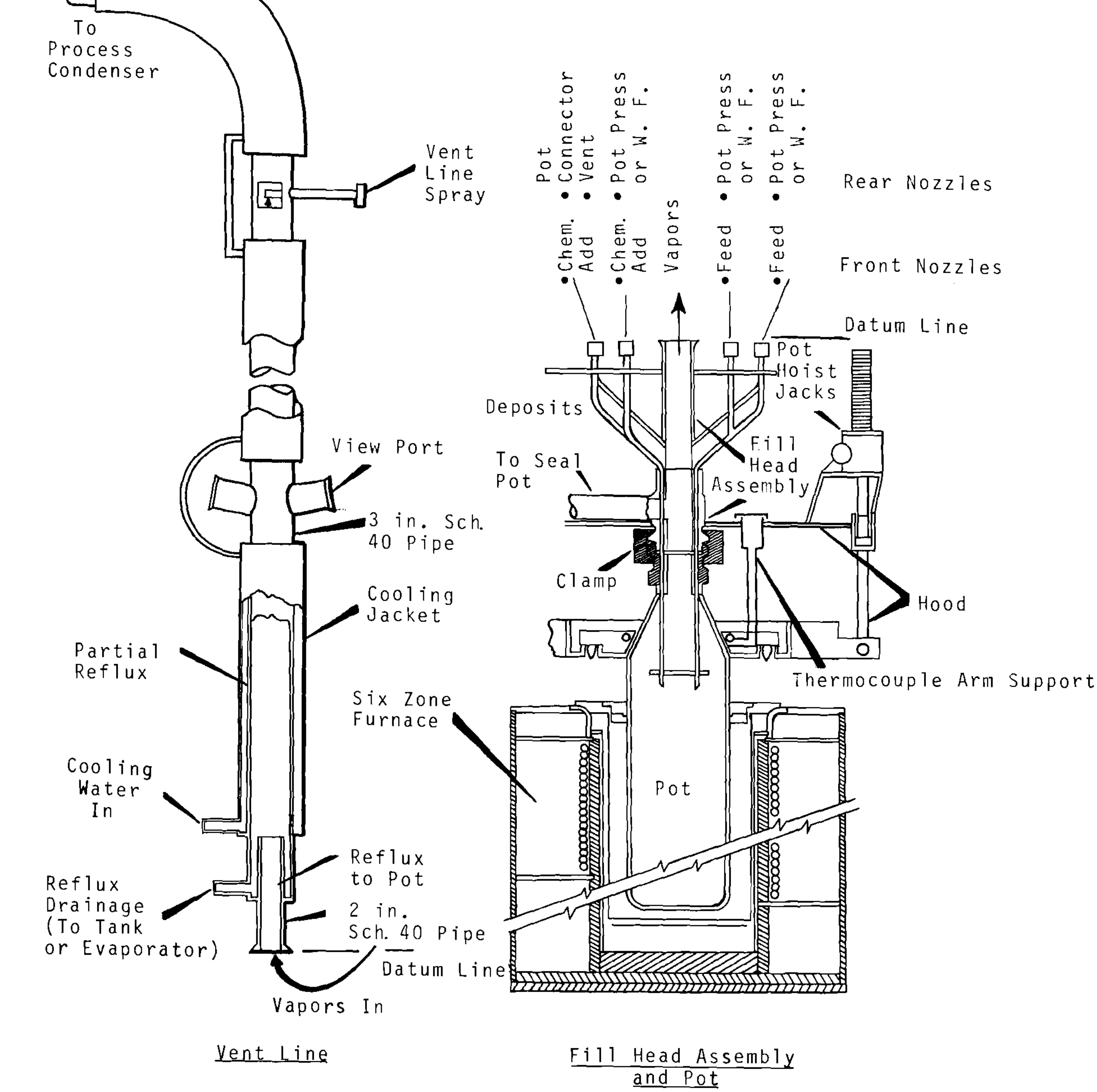


FIGURE 4.8a. Pot Solidification Equipment, Overall

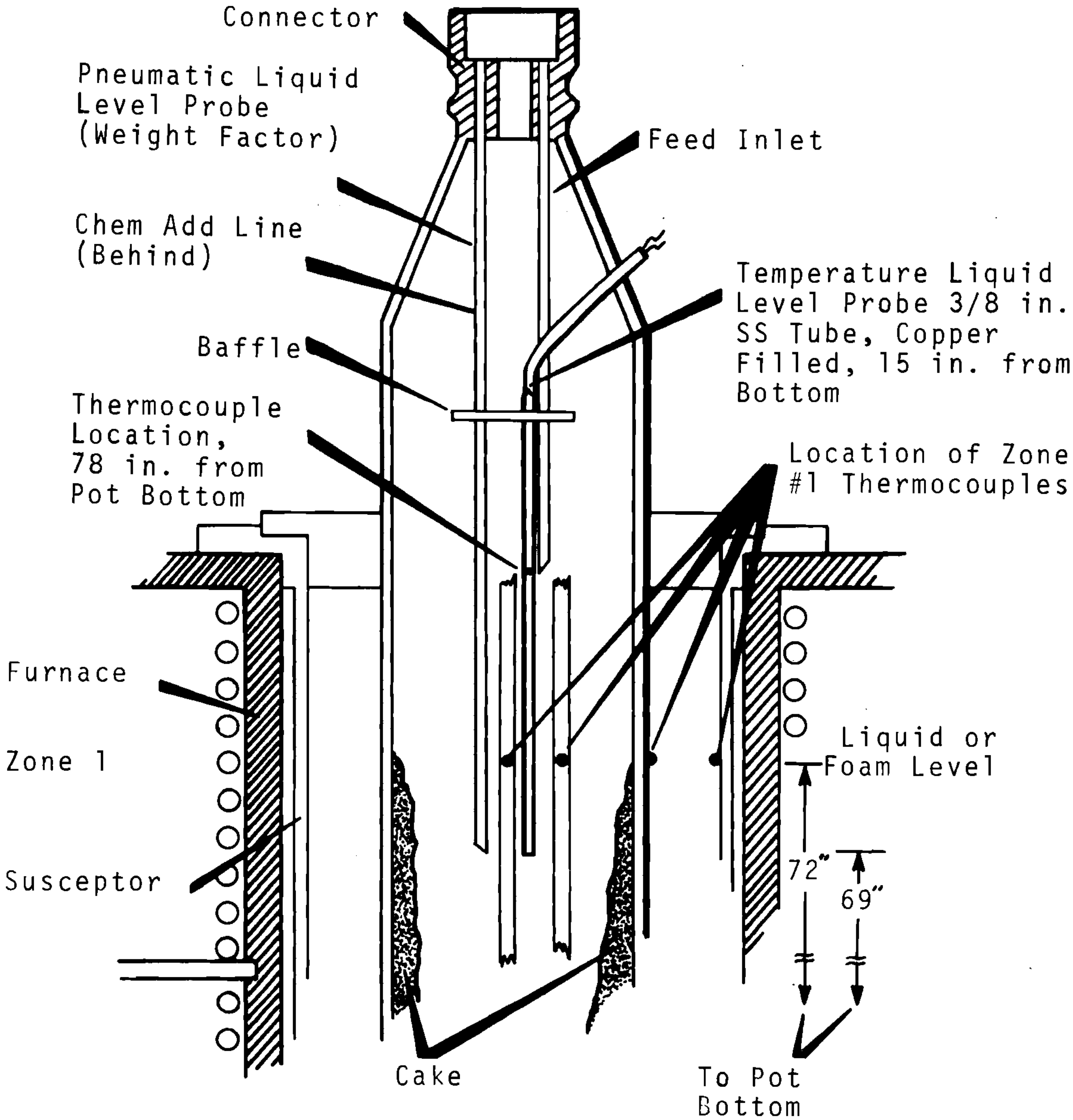


FIGURE 4.8b. Pot Solidification Equipment, Upper Part of Calciner

In addition, a liquid level dip tube (which can also be used as a chemical addition line) and a pot pressure dip tube enter the pot through the fill head. The fill head is remotely connected to the pot through a single clamp assembly discussed in Section 5.4. Liquid level in the upper section of the pot is measured by a conventional steam-air-purged dip tube and either of a pair of thermocouples tightly encased in a well at the top of the pot. Approximate liquid level with the "thermal probe" is indicated by the combined effect of the hot pot wall and the proximity of the cooler liquid surface. A small baffle is located near the top of the pot to provide some bulk deentrainment during operation.

Heating in each of the six induction-heated furnace zones is individually controlled by a combination of fixed furnace power level and furnace temperature. Pot temperatures for each heated zone in the pot are monitorized internally by thermocouples in wells at the pot centerline and near the pot walls, and externally by thermocouples welded to the pot wall. More information on the pot and the furnace is given in Sections 4.3.4 and 5.

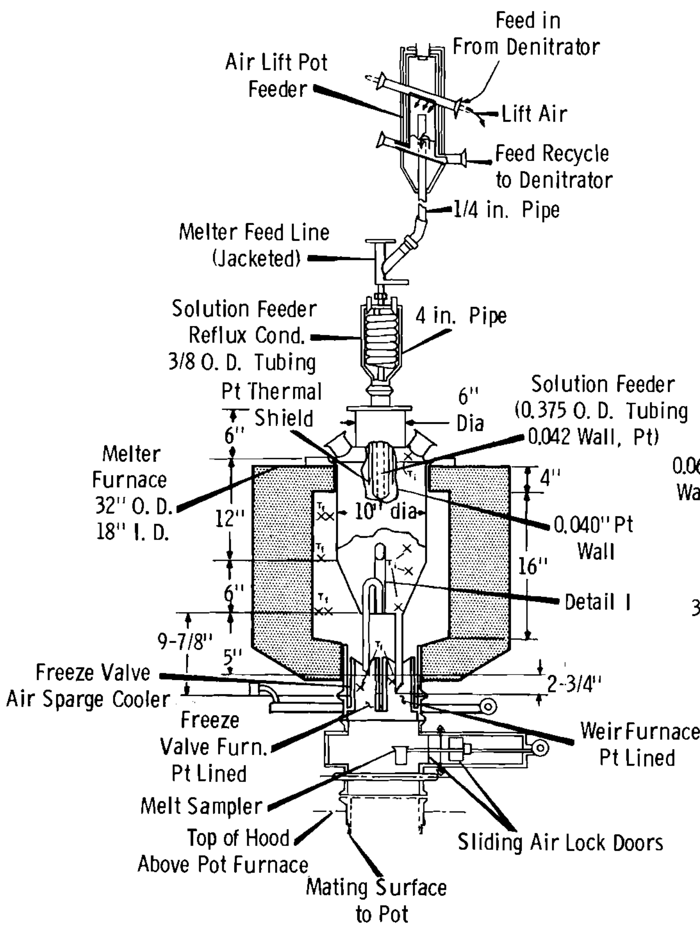
The off-gas line from the pot head includes a cooling jacket whereby reflux of some of the vapors is controlled to provide continuous flushing and cleaning of the pipe during operation. Without the flushing action of the reflux, the line would plug within a few days. The reflux is normally drained separately and routed to other vessels (the waste evaporator or the condensate collection tank) where it is combined with the rest of the calciner condensate. This feature minimizes the effects of the reflux on the heat load and processing rate in the pot calciner. The reflux may also be periodically drained back into the pot to wash the fillhead line and pot neck. The diameter of the off-gas pipe (3 inches) was made larger than required to accomodate process variations originally (but no longer) anticipated. A 2 inch diameter pipe should work at least as well as the existing pipe.

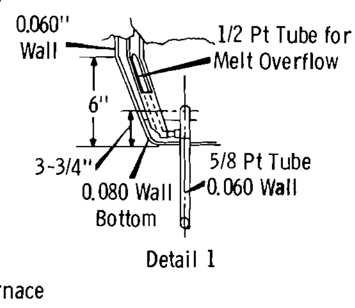
4.3.3 Phosphate Glass Solidification

The major features of the phosphate glass solidification equipment are shown in Figures 4.9 and 4.10. Feed premixed with phosphoric acid enters the denitrator evaporator through vapor-space or submerged dip tubes. The thick, syrupy, denitrated and concentrated solution is then airlifted into a pot feeder where it is fed at a controlled rate through the melter solution feeder into the platinum melter. The vapors from the platinum melter, mostly nitric acid and water (and sulfuric acid, if it is present in the original waste), are routed to the melter condenser from which the condensate is routed to a separate collection tank (Tank 117) for future processing. Provisions for recycle of this condensate back to the denitrator-evaporator are also included. The melter and its furnace, and the condenser are each remotely separable from the denitrator-evaporator and its structural supports.

The denitrator-evaporator is constructed of commercially-pure titanium because of its superior corrosion resistance in the denitrating solution. The heating surfaces of the denitrator consist of a remotable short-tube calandria and an external jacket (which is primarily provided as an option to reduce heat losses and to minimize freezing at the wall, if needed). The tube bundle was made with short, large 2-inch diameter tubes with 1/8 inch walls. This design provides good recirculation flow and good heat transfer with a reasonably low tendency to scale during operation with viscous slurries. Liquid in the evaporator will have viscosity and solids content up to 5 poise and 90 weight percent, respectively. Heat transfer is slightly augmented by about 10% [to an overall coefficient of 150 Btu/(hr)(ft)(°F)] by a variable speed turbine-type of agitator that is remotable with the tube bundle. The main purpose for the agitator is to provide solids suspension during temporary nonboiling operating periods. Steam flow to the

VOLUME	
Maximum	19.4ℓ
Normal Operating	4.5ℓ
CAPACITY	
Melter	4ℓ/hr Feed
Air Lift	10-100 ℓ/hr (Total) 4ℓ/hr (Feed)
CONSTRUCTION	
Type	All Welded
Material	99.95 % Pt
NOZZLES	
6 in. O. D.	1 } Top
2 in. O. D.	5 } Top
0.5 in. O. D.	2 (Discharge)
FURNACES	
Melter	
Type	Elec. Resistance, 3 Phase, 126V
Power	20 kW
Heating Elements	Kanthal A-1 0.18 in. diam
Insulation	K-28 and Fiberfrax
Freeze Valve	1 kW Max.
Weir	1.3 kW Max.
OPERATING	
Temp. Max.	1300 °C
Temp. Normal	1200 °C
Press. Max.	25in. Water Vac
Net Furn. Power	8 kW
Gross Furn. Power	16 kW
HEAT TRANSFER AREA	
Above Melt Level	1.7 ft^2
Below Melt Level	1.0 ft^2
Reflux Condenser	0.68 ft^2

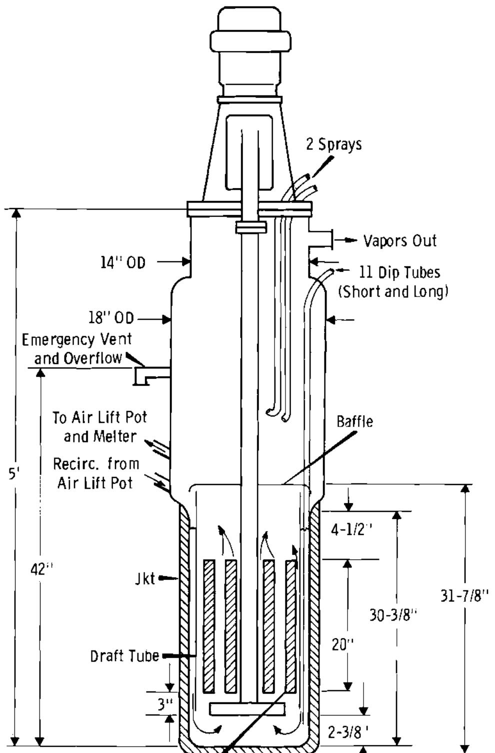




T_i = Internal Temperature

T_f = Furnace Temperature

FIGURE 4.9. Continuous Melter and Furnace Assembly, Phosphate Glass Solidifier



DENITRATION EVAPORATOR (TK-121)	
VOLUME	
Minimum	30ℓ
Operating	40-50ℓ
Maximum	70ℓ
CAPACITY	
Boilup	35 ℓ/hr
Holding Time	8 hr
AGITATOR	
Power	1-1/2 HP
Type	4 Blade Turbine
Speed	0-200 RPM 600-900 RPM
Shaft	2 in. Dia.
CONSTRUCTION	
Type	Welded
Material	Titanium
OPERATING	
Temperature	100-160 °C
Pressure	13-15 psia
HEAT TRANSFER AREA	
TK Tube Bundle	11 ft^2
TK Jacket	8 ft^2
AUXILIARIES	
Air Lift	Feed Out
Jets	Two 10 GPM

GLASS MELTER CONDENSER (E-117)	
CAPACITY	
Condensing Vapor at 900 °C to 100 °C at 5 ℓ/hr	
CONSTRUCTION (EXTERNAL)	
Type	Welded
Material	304-L
CONSTRUCTION (INTERNAL)	
Type	Welded
Material	Nionel®
OPERATING	
Temperature	100 °C
Pressure	13-15 psia
HEAT TRANSFER AREA	
Total	54 ft^2
AUXILIARIES	
Spray - Wide Angle Cone	

® Nionel-International Nickel Company

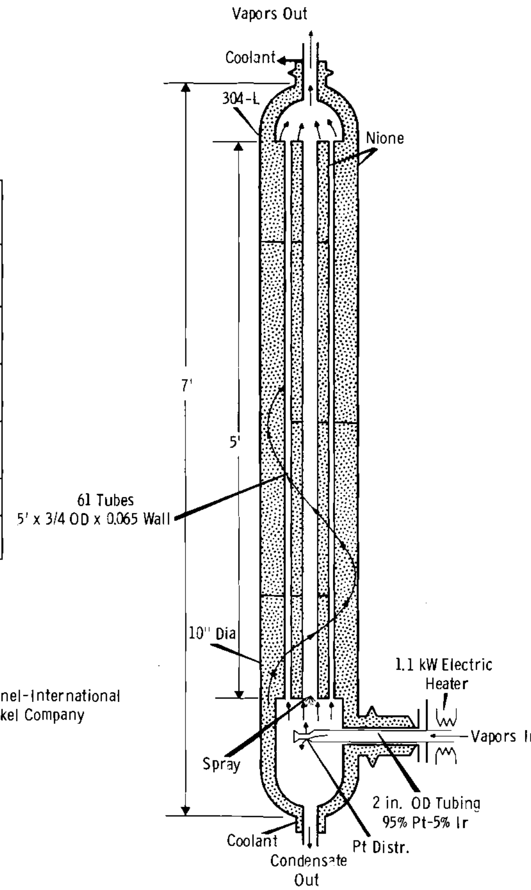


FIGURE 4.10. *Denitrator Evaporator and Melter Condenser for Phosphate Glass Solidifier*

denitrator may be controlled by solution temperature or specific gravity. The denitrator is equipped with an internal falling-rod type of viscometer for use as a relative indicator of viscosity during operations.

Denitrated feed is airlifted from near the bottom of the denitrator up to a small flow-splitting pot which drains and recirculates back to the denitrator and overflows into the melter feeder. Venting of the airlift pot may be accomplished through the melter feeding line into the melter (and thereby aid in keeping the melter feeding line clean), or by a separate vent jumper back to the denitrator. In the melter feeder, the feed flows through a jacketed and shielded platinum tube into the heated zone of the melter. Boiling water in the feeder jacket maintains the feed hot and fluid without boiling. The boiling water is refluxed by a small stainless steel condenser located above the melter.

The platinum melter vessel is identical to the one used in the spray solidifier except in this case the melt discharge weir is internal to the melter and requires 6 inches of melt level before melt will overflow. The main reason for the differences between the two melters is to provide field performance comparisons. Other instrumentation and auxiliaries to this melter and the melt discharge system are identical to those of the spray solidification melter. Even though each melter vessel is discussed with a particular process, they are interchangeable, and either one could be used for either process. Process power requirements are approximately 8 kilowatts.

The transition from the melter through the freeze valve and weir tubes into the melt sample chamber and on into the melt receiver pot and its furnace is the same as that for the spray solidifier. The pot calciner furnace is planned to be used as the furnace for the melt receiver pot of the phosphate glass process.

The vapors from the melter are routed through a 2 inch diameter platinum-5% iridium alloy tubing into the bottom of the melter condenser. This alloy was selected because of its superior strength and adequate corrosion resistance under the specific process conditions, which are somewhat less severe than in the melter but are too severe for nonprecious materials. This line is kept at 350 to 500 °C during operation with an electrical resistance heater. Heating the line prevents condensation, which in turn minimizes corrosion and the tendency for scale buildup in the line. All parts of this condenser that contact the process solution are made of Nionel. All Nionel surfaces not cooled by the condensing tubes are jacketed with stainless steel and are water cooled to provide additional corrosion protection for the condenser. The countercurrent flow of the condensed versus noncondensed fluids provides for improved absorption of vapors and improved mixing of the condensed components, thereby resulting in better control of corrosion rates. A steam spray is provided in the lower plenum to provide more rapid quench cooling of the incoming vapors.

4.3.4 Solidification Pots

Two basic sizes of solidification pots will be used in the WSEP: 1) 8.625 inches outside diameter by 0.312 inch thick walls (nominally 8 inch schedule 40 pipe) by 8 feet in overall length, and 2) 12.0 inches outside diameter by 0.312 inch thick walls by 8 feet in overall length. These sizes were selected primarily on the basis of heat generation rates anticipated. Other factors were size limitations in the WSEP processing cell, and a volumetric scale-up factor of 2.0 between the two sizes. The main features of the 8 inch diameter solidification pots are shown in Figure 4.11. Twelve inch diameter pots are identical except for the addition of a truncated conical reducer between the pot head and the pot shell. For solidified wastes with extremely high heat generation rates (greater than 300 W/liter

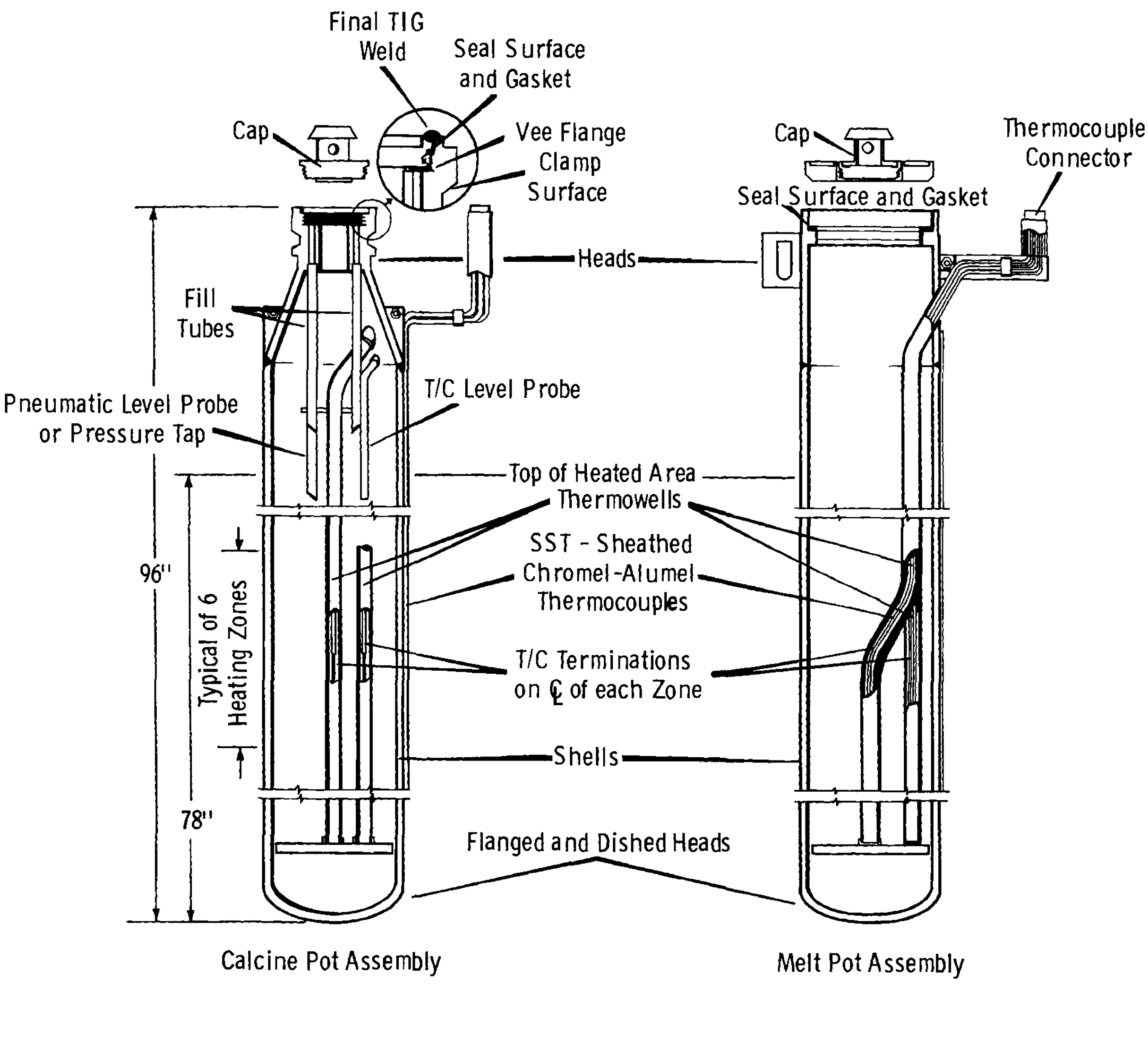


FIGURE 4.11. Pots for Solidified Waste in WSEP

of solid), 6 inch diameter pots may be used in the latter phases of the experimental program. The primary differences between the calcine and melt pots are in the pot head, the piping, and the instrumentation.

The calcine pots are made with relatively small heads (5 inches in outside diameter) to take advantage of easier clamping and sealing (since larger heads are not required), and to provide more easily for the four process pipe connections in one connector. These process connections are the 2 inch diameter off-gas vent and three pipes with 3/8 inch inside diameters: a feed line, a liquid level tap, and a pressure tap. The liquid level line may be used as a chemical addition line. The pot head incorporates a special vee flange for clamping to the mating process head, and an integral raised lip for sealing by fusion welding (discussed in Section 5).

The calcine pots have two internal thermocouple wells made of 3/4 inch schedule 80 pipe (310 stainless steel to provide improved high temperature strength and corrosion resistance), each of which contains one nonreplaceable thermocouple in each of the six furnace heating zones. The centerline thermocouples in the calcine pots provide operational information during processing and maximum calcine temperatures during storage after processing. The thermocouples near the pot wall provide information on wall scaling and advanced trends on centerline temperatures during processing, as well as effective thermal conductivity effects during storage. The thermocouples in the short well of the calcine pots provide indications of liquid level as discussed earlier.

The melt pots contain no internal fluid piping, and have a wide mouth (net free opening is 7 inches in diameter) to provide a larger target for molten waste dripping from the continuous melters. The melt pots contain one main thermocouple well and a secondary well. The main well contains one replaceable thermocouple in each of the six heating zones. This well provides centerline temperature readings for the bottom four heating zones. In the upper section of the pot, the thermocouple wells are near the wall to minimize dripping of melt onto the pipe where heat losses are sufficient to cause premature freezing of the melt and build-up of stalagmites. The secondary thermocouple well provides additional temperature readings near the pot wall to provide information on effective thermal conductivity.

One padded thermocouple is welded to the outside wall of all pots in each heating zone to provide auxiliary temperature information during and after processing. All thermocouples used in the WSEP pots are ungrounded Chromel-Alumel junctions with magnesia insulation, and are covered with 1/8 inch diameter 310 stainless steel sheathing. Ungrounded junctions are used to provide for checking the continuity of the wires within the thermocouples. Internal pot thermocouple inspection requirements include X-ray of the tips, thermal cycling, continuity checks and spot calibration checks. External (padded) pot thermocouple inspection requirements include continuity checks and spot calibration checks. All pot thermocouples terminate through short, high-temperature leads with braided stainless steel protection, into a single sealed 41-pin connector. The connector is mounted on light but rigid framework that is bolted to the pot. The bolts may be removed remotely and the thermocouple leads may then be bent to minimize protrusions from the pots.

It should be noted that the WSEP pots probably include many more temperature measurements and other features than would be needed in a commercial facility, primarily to obtain sufficient temperature data to determine how many measurements must be made in a commercial plant.

The solidification pots are made of one of two materials of construction: 304-L stainless steel and carbon steel Type AISI 1020. (Stainless steel type 310 was considered for use, but will likely be used to a very limited extent, if at all.) Stainless steel is used for pot calcination; either of the two may be used for spray and phosphate glass solidification. The selection between the two materials for a specific use depends primarily upon the internal and external corrosion rates during processing as determined by the flowsheet and filling conditions used.

The design criteria for the WSEP pots are summarized in Table 4.4. The design-base in-process temperatures are the normal maximum operating temperatures plus 50 °C for occasional intentional process requirements, plus an additional 30 °C for operational deviations. The design pressures are based upon expectantly conservative vessel strength under maximum expected conditions. Corrosion allowance is based on best available data and estimates. Criteria for time periods greater than 10 years were not used, primarily because of the myriad of potential long term disposal techniques.

Changes in the design of future WSEP pots will undoubtedly evolve from evaluation of existing designs. Such changes should result in pots with good integrity and lower costs, as more performance data are obtained.

4.4 PROCESS SERVICE EQUIPMENT

4.4.1 Service Tanks

The major features of the five stainless steel in-cell process service tanks are shown in Figure 4.12. The tanks were sized to contain feed or condensate batches of about 1000 liters each. The reverse-dish bottom provides the capability for near emptying of the tanks by the numerous dip tubes located around the periphery of the tank. All tanks have one

TABLE 4.4. *Design Criteria of Solidification Pots for WSEP*

	Type of Material	T_{max} + 30, °C	Internal Design, psig	Corrosion Allowance, inches
1. IN PROCESS (SHORT TERM)				
A. Minimum strength is 100 hr	304-L	980	20	-
creep rupture at maximum				-
operating temperature + 30 °C	C Stl	730	20	-
B. Internal corrosion allowance	-	-	-	0.125
C. External corrosion allowance	304-L	-	-	0.005
	310	-	-	0.0
	C Stl	-	-	0.03
2. INTERIM STORAGE (10 yr)				
A. Maximum strength is per ASME	304-L	457	150	-
Pressure Vessel Code, Section				-
VIII, at maximum operating	C Stl	380	150	-
temperature + 30 °C				
B. Cumulative internal corrosion allowance	-	-	-	0.125
C. Cumulative external corrosion	304-L	-	-	0.01
allowance	C Stl	-	-	0.05

Notes:

a. True wall thickness = 0.875 x nominal thickness (WSEP pots, 0.875 × 0.312 = 0.273 in.)
b. Joint efficiency = 100%
c. Heads are equivalent to, or stronger than ellipsoidal heads
d. Average nominal diameter will be used (WSEP port avg diam = 8.317 in., 11.687 in.)
e. Use one of the following equations that gives the lowest internal pressure rating (taken from Section VIII, ASME Unfired Pressure Vessel Code):

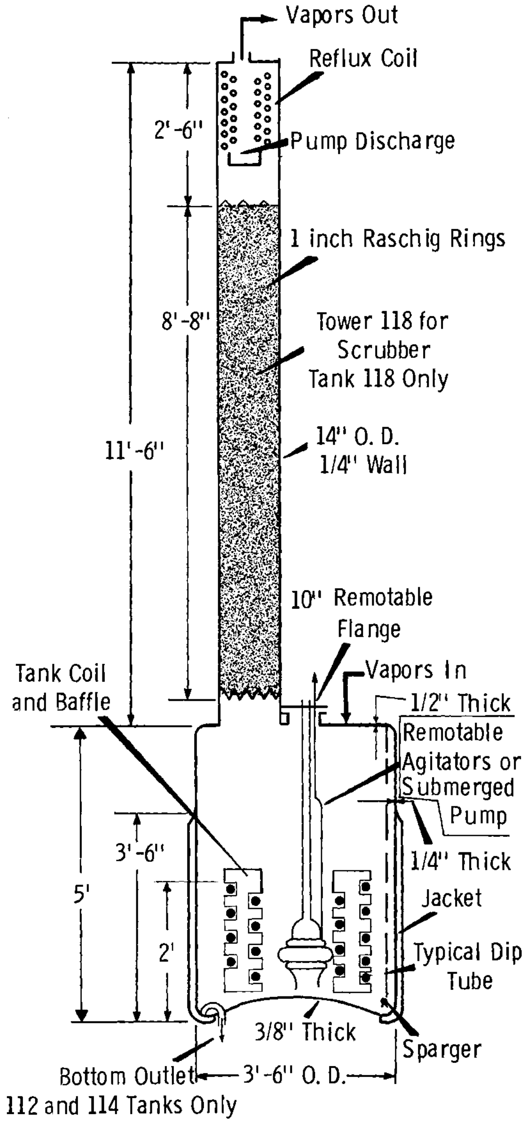
(1) Hoop stress $P = \frac{SET}{D/2 + 0.6T}$

(2) Longitudinal stress $P = \frac{2\ SET}{D/2 - 0.4T}$

(3) Ellispoidal head stress $P = \frac{2\ SET}{D - 0.2T}$

where:
T = net thickness, in.
P = internal pressure, psig
D = average diameter, in.
E = joint efficiency, %
S = allowable tensile stress, psi

f. Carbon steel material is AISI type 1020



Feed Tank 112	Feed Tank 114	Condensate Tank 116	Condensate Tank 117	Scrubber 118		
					VOLUME	
X	X	X	X	X	Maximum	1300 ℓ
X	X	X	X	X	Operating	1000 ℓ
					CONSTRUCTION	
X	X	X	X	X	Type	All Welded
X	X	X	X	X	Material	304-L SST
					OPERATING	
X	X	X	X	X	Temperature	20-120 °C
X	X	X	X	X	Pressure	13-15 psia
					COILS	
X	X			X	Tank 1 in. Sch. 40	24 ft^2
				X	Tower 1 in. O. D. T.	12 ft^2
					JACKET	
X	X	X	X		Tank	38.5 ft^2
					ROTATING EQUIPMENT	
		X		X	Pump (canned)	150 ℓ/min
X	X		X		Agitator - 1150 rpm, Propeller	
					JETS	
3	2	4	3	2	40 ℓpm	
					SCRUBBER	
				X	Liquid	1 Molar NaOH
				X	Liquid Rate	20-40 ℓ/min
				X	Gas Rate	3000-6000 ℓ/min

FIGURE 4.12. Process Service Tanks in WSEP

10 inch remotable flange at the center of the top head for insertion of an agitator or submerged pump. All tanks have a coil and/or a jacket to supply up to 75 kilowatts of heating or cooling by either heat transfer area. Internal baffles are integral with the coils, and also serve as the coil supports. Because of space limitations in the cell, thermal expansion provisions for the jackets were designed to "wrap around" the lower head of the tank. Design pressures for the coils and jackets are 100 and 15 psig, respectively.

All service tanks are provided with ring-shaped air spargers (using up to 560 liters/min air), air purged dip tubes for measuring liquid level, specific gravity, and pressure, temperature elements in sealed wells, in-cell liquid samplers, chemical addition pipes, piping for process transfers in and out of the tanks, and spare pipes to the manipulator-operated window areas of the cell. (These features are also applicable to the waste evaporator and the acid fractionator, discussed in later sections.)

In addition to these features, the caustic scrubber tank is surmounted by a packed scrubbing tower for back-up removal of acids, radioruthenium, radioiodine, and aerosols from process gases. The nominal gas capacity of the scrubber is 5500 liters/min. This is large enough to be used by other processes in the other cells if necessary. Recirculation pumping rate is controlled by a valve in a remotable pump piping jumper and is measured by the liquid level above a weir at the pump discharge point near the top of the tower. An auxiliary reflux coil is provided at the top of the tower.

4.4.2 Waste Evaporator (Tank 113)

The waste evaporator is a medium-length-tube thermosyphon type designed to operate with maximum:minimum operating volume ratio of 18:1, with the moderate overall heat transfer rate of 320 Btu/(hr)(ft^2)(°F), and with provisions for the relatively high deentrainment factor* of 1×10^4 to 1×10^6. The evaporator may be operated continuously or batch-wise with a maximum volume slightly larger than that of the feed tanks. The evaporator is constructed entirely of commercially-pure titanium for improved corrosion resistance. The evaporator is shown in Figure 4.13.

The remotable tube bundle has process solution outside the tubes to minimize choking by vapors near the outlet. At the maximum boil-up rate of 530 liters/hr, the boiling rate/cross section area is 1600 lb/(hr)(ft^2). Design pressure for the tube bundle is 125 psig. Maximum design boil-up capacity was established by the need for condensate recycle:feed ratios up to 7:1 while processing feed at maximum rates of 60 liters/hr. Recycle of condensates is used to control acidity of the evaporator overheads to less than about one molar for improved retention of ruthenium in the waste. Recycle rate is controlled by the acidity of the vapors. This acidity is measured by the electrical conductivity of the condensed evaporator overheads. The downcomer size was based on the minimum diameter to permit the shielded air-purged liquid level and specific gravity tubes to operate reasonably well. Control of the evaporator steam rate is primarily by specific gravity, but temperatures may also be used. A jacket is provided around the reboiler for auxiliary heating with low-pressure steam if needed. Design pressure for the jacket is 50 psig. When operated to continuously supply concentrate, the concentrate leaves the bottom of the downcomer and flows through a small shell and tube titanium concentrate cooler (shown only in Figure 4.5a) for about 20 °C subcooling to prevent cavitation of the feed pump.

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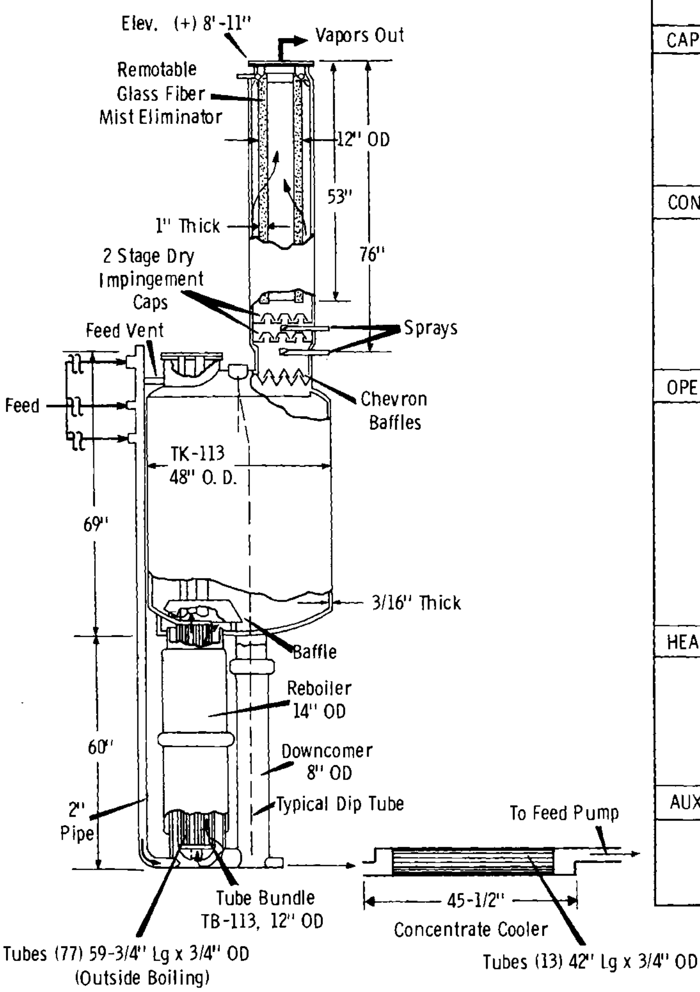
* *Deentrainment factor* $= \dfrac{\textit{weight of salts in evaporator bottoms}}{\textit{weight of salts in evaporator condensates}}$



VOLUME	
Min. /Max. Oper.	70 ℓ/1300 ℓ
Max. Volume	1840 ℓ
Normal Oper.	180 ℓ
Full Submergence	180 ℓ
CAPACITY	
Tube Bundle	530 ℓ/hr
Jacket	140 ℓ/hr
TK Heat Losses (Reflux)	7.1 ℓ/hr
Tower at 12 in. ΔP	600 ℓ/hr
Tower Heat Losses (Reflux)	1.6 ℓ/hr
CONSTRUCTION (ASME CODED)	
Type	All Welded
Material	A-55 Titanium
Tank and Tower Design Pressure	10 psia
Tank and Tower Design Temperature	115 °C
Tube Bundle Design Pressure	125 psig
Jacket Design Pressure	50 psig
OPERATING	
Temperature	115 °C
Pressure	13 psia
Bundle	55 psig
Jacket	15 psig
Deentrainment D. F.	10^4 - 10^6
Roughing Chevron	$\geq$ 25 µm
1st Stage Caps	$\geq$ 7 µm
2nd Stage Caps	$\geq$ 4 µm
Glass Fibers	~ 1 µm
HEAT TRANSFER AREAS	
Tube Bundle	73 ft^2
Jacket	15 ft^2
(Tank Shell	119 ft^2) } Heat Losses
(Tower Shell	27 ft^2) } Heat Losses
Concentrate Cooler	7.5 ft^2
AUXILIARIES	
Jets (1)	40 ℓ/min
Concentrate Cooler 20 °C ΔT	40 ℓ/min
Pump (Remotable)	0-200 ℓ/min

FIGURE 4.13. Waste Evaporator and Tower

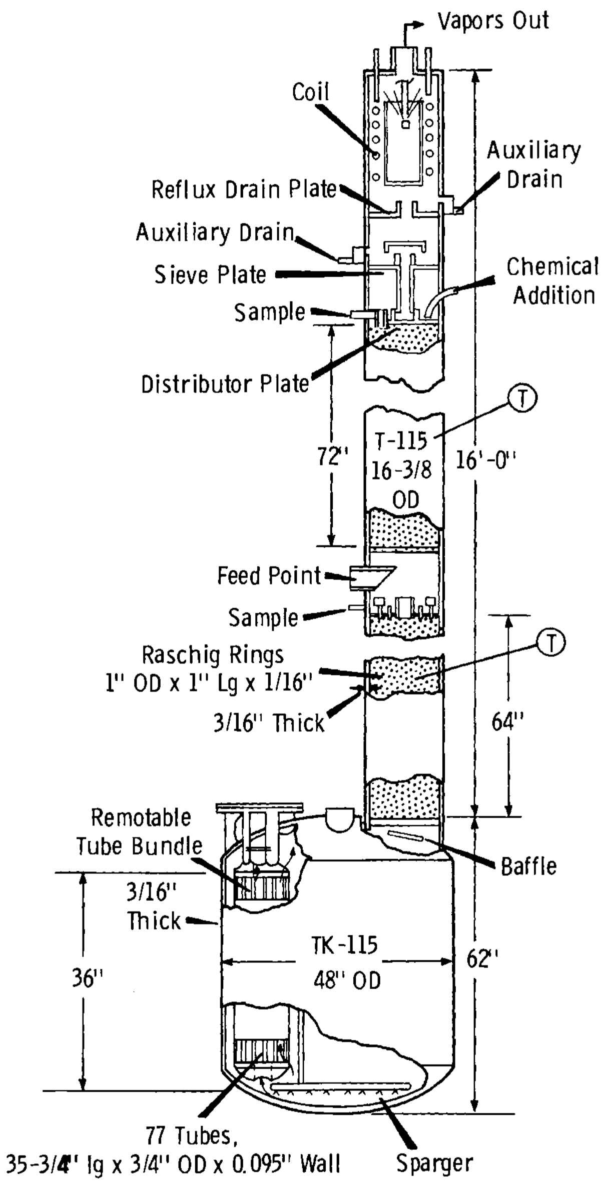
The evaporator tower consists of four stages of deentrainment: 1) a simple chevron baffle, 2) and 3) two stages of dry impingement caps, and 4) an upper section for remotable high-efficiency separators. At the maximum boil-up rate, the impingement velocities of stages 1, 2, and 3 are 36, 51, and 85 ft/sec, which is sufficient for nearly 100% removal of aerosols of 25, 7, and 4 micrometers in diameter, respectively. The remotable fourth stage deentrainer is a Brink fibrous glass mist eliminator. Total tower pressure drop at maximum capacity is 12 inches of water.

4.4.3 Acid Fractionator (Tank 115)

The all-titanium acid fractionator consists of a packed tower distillation column surmounting a relatively standard reboiler tank. The top and bottom spheriod heads are partially reinforced with an extra thickness of titanium plate for added strength, similar to those in the evaporator. Special features include a remotable tube bundle in the reboiler, a deentraining sieve plate with bypass provisions in the tower, and an integral reflux condenser. The acid fractionator is shown in Figure 4.14.

The remotable tube bundle is identical to that in the waste evaporator except it is shorter and includes a shroud to provide a controlled boiling pattern in the large 115 Tank. The tank is also identical to that of the evaporator, minus the separate reboiler and downcomer. The reboiler tank is operated on a semicontinuous basis, with either the liquid level or acid concentration (measured by specific gravity or temperature) held constant by controlling reboiler steam flow while the other increases during the run. Maximum design boil-up capacity of 310 liters/hr was based on maximum nitric acid distillation rates from the waste evaporator under conditions with partially condensed feed.

The rectifying section of the fractionator tower is packed with 1 inch diameter titanium Raschig rings. The exhausting



VOLUME	
Min./Max. Oper.	480/1150 ℓ
Max. Volume	1550 ℓ
Normal Oper	700 ℓ/60% Sub
Full Submergence	1000 ℓ
CAPACITY	
Tube Bundle	310 ℓ/hr
Tk. Heat Losses	5.3 ℓ/hr
Tower Heat Losses (Reflux)	4 → ℓ/hr
Tower at 14 in. ΔP	600 ℓ/hr
Tower Reflux Coil (Reflux)	220 ℓ/hr
Sieve Plate at 6 in. ΔP	600 ℓ/hr
Min. Sieve Plate Vapor	80 → ℓ/hr Boil-up
CONSTRUCTION (ASME CODED)	
Type	All Welded
Material	A-55 Titanium
Tank and Tower Design Pressure	10 psia
Tank and Tower Design Temperature	115 °C
Tube Bundle Design Pressure	125 psig
OPERATING	
Temperature	115 °C
Pressure	13 psia
Tube Bundle Pressure	55 psig
Aerosol D-F	100-1000
Jets (1)	40 ℓ/min
HEAT TRANSFER AREA	
Tube Bundle	43 ft^2
Tower Reflux Coil	12 ft^2
(Tank Shell	88 ft^2) Heat Losses
(Tower Shell	67 ft^2) Heat Losses
FRACTIONATION (NITRIC ACID)	
Feed	0.5-1.0M
Bottoms (L/V = 1.1)	10 M
Overheads (L/V = 0.2)	0.1 M

FIGURE 4.14. Acid Fractionator and Tower

section includes a similar packed section which is surmounted by a deentraining sieve plate and an integral reflux condenser. The impingement velocity of the vapors through the 3/16 inch diameter holes of the sieve plate at maximum capacity is 150 ft/sec. Minimum velocity to restrict weeping to reasonable amounts is 20 to 25 ft/sec. The sieve plate is provided with an alternate external drain and chemical addition piping to provide for special chemical treatment, such as removal of radioruthenium. To provide water reflux when the sieve plate is used for such special treatments, the reflux from the partial condenser at the top of the tower may be routed externally to bypass the sieve plate. Reflux rate is determined manually by the product of coolant flow and coolant temperature increase and is manually proportioned to the reboiler steam flow rate. Total tower pressure drop at maximum boil-up capacity is 8 inches of water.

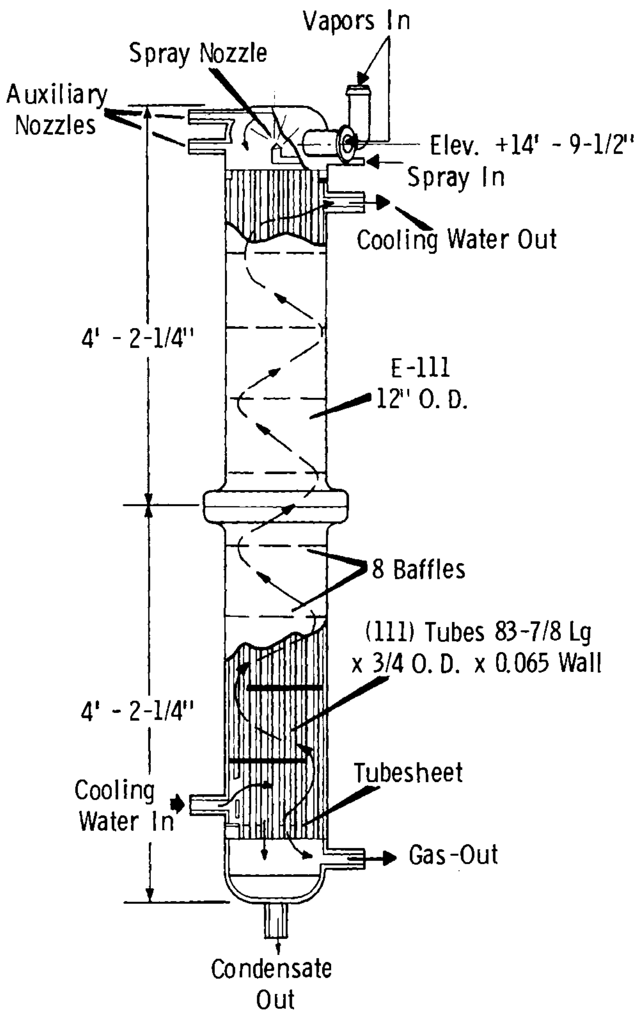
The fractionator is designed on the basis of liquid feed with 0.8M HNO_3 and an overhead fraction of 0.01M HNO_3. Since a literature search revealed no actual data on nitric acid-water fractionation efficiency while using ring packing, the efficiency was determined by Battelle-Northwest.[4] A summary of the data pertinent to the packed sections of this tower, is summarized in Table 4.5.

4.4.4 Condensers and Heat Exchangers

The main features of the solidification process off-gas condenser (E-111) are shown in Figure 4.15. This condenser is constructed of titanium for improved corrosion resistance.

TABLE 4.5. *Design Bases for Acid Fractionator Tower*

	HNO_3 in Product, M	L/V	Number of Transfer Units	Height of Transfer Unit, ft
Exhausting Section	0.01	0.3	9.4	0.65
Rectifying Section	10.0	1.1	2.4	2.3



CAPACITY	
Condensing Vapor at 200 °C to < 60 °C at 40 ℓ/hr	
CONSTRUCTION (ASME CODED)	
Type	All Welded
Material	A-55 Titanium
OPERATING	
Temperature	< 250 °C
Pressure	13 psia
HEAT TRANSFER AREA	
Total	120 ft^2
AUXILIARIES	
Spray	Wide Angle Cone

FIGURE 4.15. Primary Process Condenser

The condenser was sized to provide ample cooling of superheated vapors and up to 15 scfm of noncondensible gases, and subsequent condensation of liquid at instantaneous rates up to 80 liters/hr. Downdraft flow of the vapors inside the tubes was selected to provide good aerosol deentrainment, to provide self-cleaning of potentially muddy process condensates, and to provide good acid absorption. Two gas inlet pipes provide for simultaneous connection to two processes. A spray nozzle and other chemical addition provisions are included to aid solidification process performance, if necessary.

The waste evaporator condenser (E-113) is almost identical to the primary condenser, described above. It is also made of titanium for improved corrosion resistance. It is sized to provide capacity to condense (partially or completely) the vapors from the waste evaporator at the maximum boil-up rate of 530 liters/hr.

The fractionator condenser (E-115) is very similar to the preceding two. It differs primarily in that 1) it is made of stainless steel because of the less severe corrosion conditions, 2) it has a slightly lower condensing capacity of 450 liters/hr, 3) it is somewhat shorter and fatter to provide a small condensate hold-up tank of 58 liters capacity to assure continuous control of recycle, and to permit more head for controlling the flow rate of recycled condensate back to the waste evaporator.

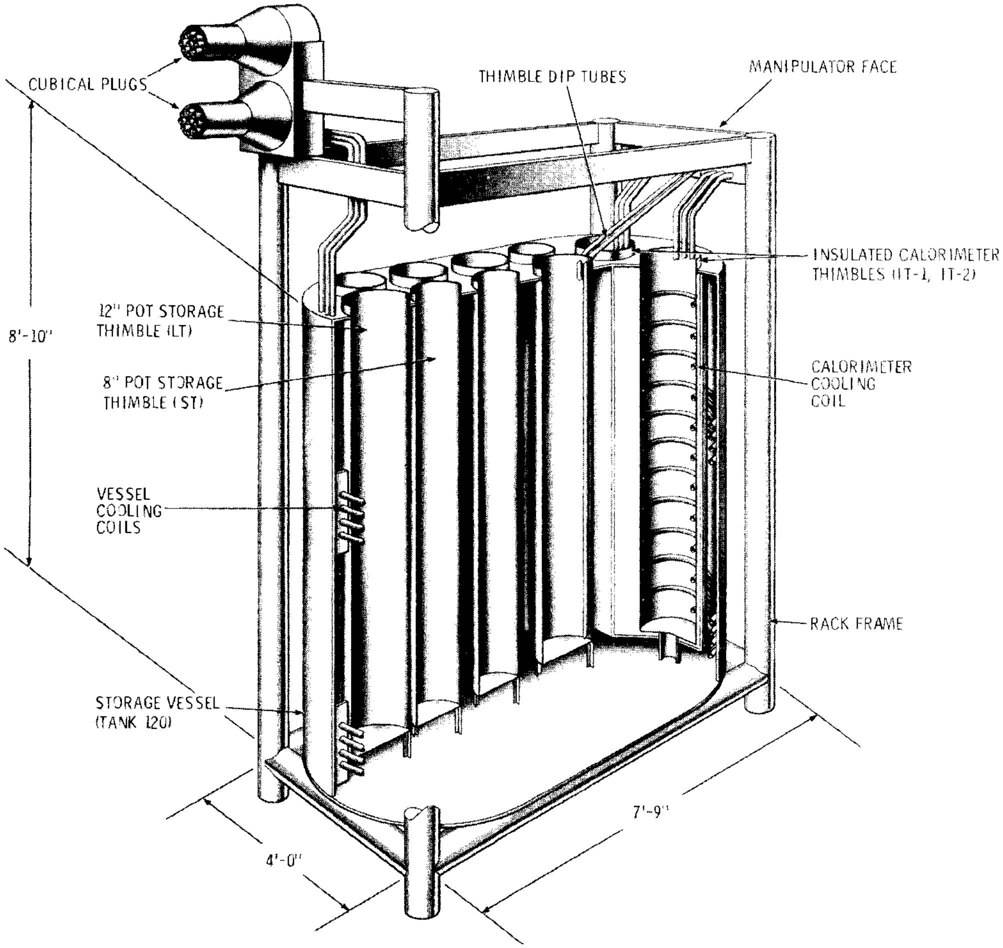
The two remaining process condensers are 1) the small feed tank reflux condenser (E-112), and 2) the process vessel vent condenser (E-114). These two units are made of stainless steel and are oriented horizontally because of cell head limitations. The design of the vessel vent condenser includes the bent-tube concept to accomodate thermal expansion and to minimize space requirements. Process vapors flow inside the tubes.

Two steam-heated exchangers are used to heat the process gases to protect the subsequent "absolute" filters. One (E-116) is in the primary process vent system and the other (E-118) is in the process vessel vent system. These are small, stainless steel heaters, also with process gases flowing inside the tubes. Steam is fed first to the E-116 heater, then is routed to the E-118 heater.

4.4.5 Pot Storage

A pot inspection and storage station is included to permit evaluation of the containers and the solidified wastes for suitability for long-term storage. Because the pot storage and inspection facilities are discussed in detail in Reference 1, discussion here is limited to overall features. The main features of the pot storage station are shown in Figure 4.16. The station consists of a large bathtub-shaped, water-filled tank (120 Tank) with 14 separate can-shaped compartments (called thimbles) for insertion and storage of solidification pots. Six storage positions are sized for pots with maximum nominal diameter of up to 8 inches and six positions are sized for pots with maximum nominal diameter of up to 12 inches. These 12 positions each include separate provisions for pot storage in air or in water, and provisions for water bath sampling and liquid level measurement. The other two storage positions (for pots up to 12 inches in diameter) are insulated (called insulated thimbles) to provide for measurements of heat generation rates and specific heat contents by calorimetric methods. A slight vacuum is maintained on 120 Tank to provide a continuous air sweep around the outside of the solidification pots during storage.

Connections to thermocouples on or in the stored pots provide periodic or continuous temperature and thermal conductivity monitoring. Pot pressure measurements, pot vending if required, and pot gas sampling will be done through piping



VOLUME

Tank 120	3200 liters
Insulated Thimbles (IT-1,2)	245 liters
Large Thimbles (LT)	250 liters
Small Thimbles (ST)	145 liters

HEAT TRANSFER AREA

TK-120 Coil 3/4 in. Sch. 40 Pipe	55 ft^2
Cooling Capacity	~100 kW
IT Coils 1/8 in. and 1/4 in. Sch. 40 Pipe	5.2 ft^2
Cooling Capacity, ea.	~23 kW

OPERATING CONDITIONS

TK-120	0 psig at 100 °C
TK-120 Coil	90 psig at 175 °C

CONSTRUCTION

Type	All Welded
Material	304L SST

WEIGHT

TK-120 Empty	2700 kg
TK-120 Water Filled	9100 kg
TK-120 with Maximum Thimble Loading	14,500 kg

FIGURE 4.16. Pot Storage Station in WSEP

on the pot heads. Similarly, pot gas leakage rates will be measured using a special pot head cover. Features of specific pot inspection devices are discussed in Section 5.

4.4.6 Instrumentation

All WSEP control, recording, and most indicating instruments are located in the control room. These instruments are the solid state electronic type powered by ac current with a dc output range of 0 to 50 milliamperes. Controls of the prototypes are set up using numerous simple control loops for separate automatic control of individual variables. A few single-cascade control loops are used. Many of the major control loops are shown in Figures 4.5a and 4.5b. Many instrument readings are set to alarm or shut down equipment in event of off-limits readings.

Pressure measurements are all made by air-purged dip tubes. These and other pneumatic signals are changed to direct current through solid-state differential-pressure cells by transmission to the control room. Flow rates, measured by magnetic flowmeters and variable inductance rotameters, are controlled by diaphragm operated control valves which receive signals from electronic-pneumatic converters. Low temperatures are generally measured by nonreplaceable resistance bulbs. Temperatures above 150 °C or those that are replaceable are measured by sheathed thermocouples of Chromel/Alumel or platinum/platinum-10% rhodium.

A General Electric Company model 412 digital computer is used for continuous data logging and on-line calculations of material balances, heat transfer, and equipment performance. A total of 115 computer outputs, utilizing 91 inputs and 24 calculated values are automatically logged on two typewriters, a third alarm typewriter, and simultaneously punched on tape.

4.4.7 Other Process Features

Considerable flexibility is provided in the feed flow systems to the solidification devices. The solidification equipment may be pumped from one feed tank (114 Tank) or from the waste evaporator (113 Tank) as shown in Figure 4.17. In either case, the feed solution is recirculated through similar piping (which includes a control valve) at the relatively high rate of about 40 liters/min to keep the solids in suspension. A side stream flows from the recirculated stream to the solidification devices through diaphragm-operated valves which are controlled by readings from radiation-resistant magnetic flowmeters. The two systems are interconnected so that the pump discharge from one pumping loop may be routed through the feed flow control system of the other loop. Several alternate feed take-off points are provided. To provide for water flushing the feed lines before and after each run, a 40 liter tank is connected to the feed lines between the control valve and the flowmeter. Water is supplied by pumping fractionator condensate (in 116 Tank) to the flush tank. To prevent contamination of the condensate system, the condensate pump (which delivers a slightly higher pressure than the feed pump) is kept on whenever a feed pump is on. By manipulation of a combination of manual and diaphragm-operated valves, water flushing of the entire feed line system from the feed tank to the solidifier may be effectively performed.

In addition to feed supply by pumping, a two-stage recirculating airlift from the 114 Feed Tank into an elevated pot is provided for gravity feed into the solidification equipment. A single-stage recirculating airlift from the 112 Feed Tank into an elevated pot is provided for controlled gravity feed into the waste evaporator. A controlled-rate siphon feed system from the 112 Feed Tank to the waste evaporator is also provided.

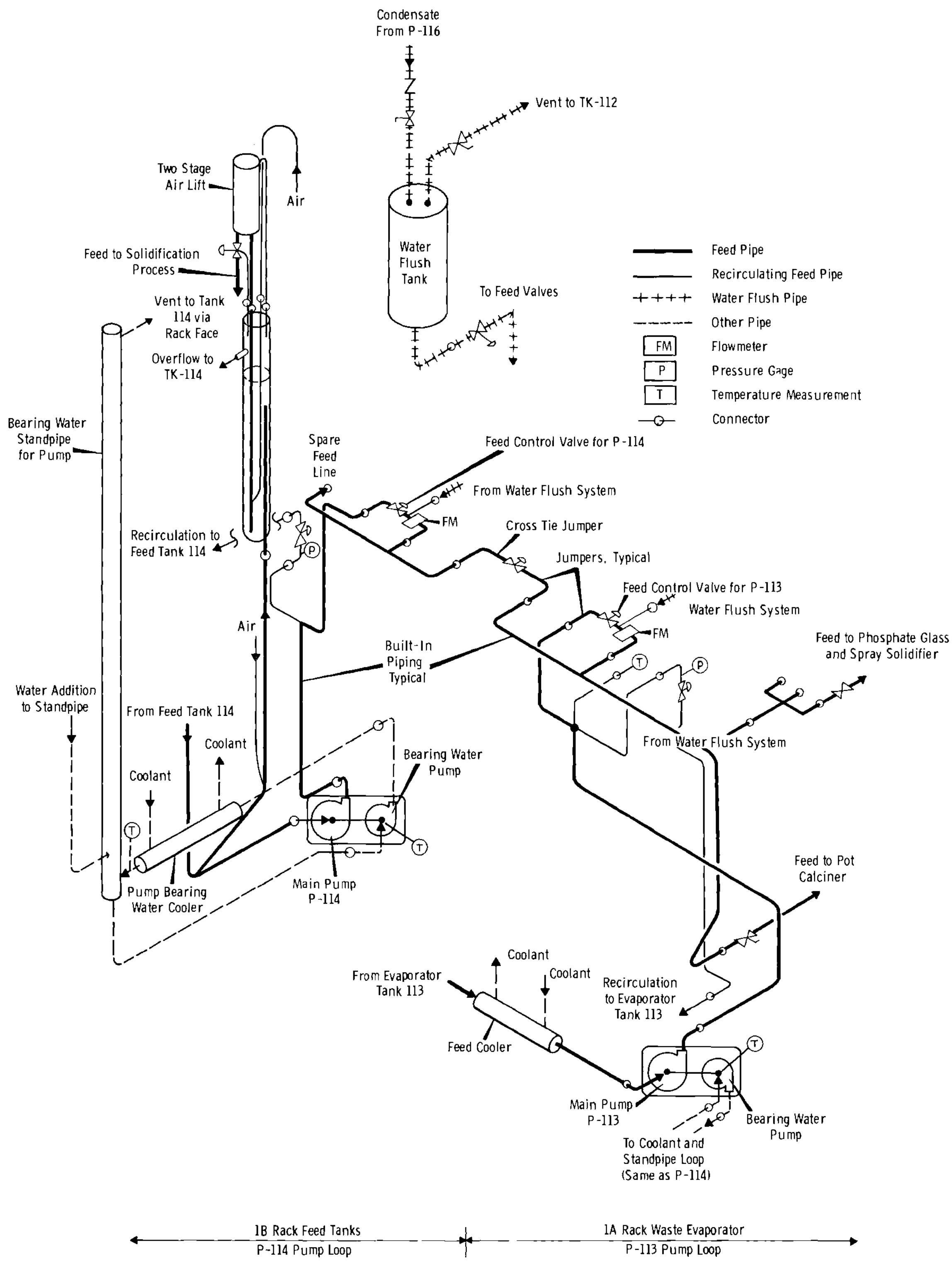


FIGURE 4.17. WSEP Feed Pump Loop

By means of completely remotable jumpers, the effluent from the E-113 waste evaporator condenser may be routed to bypass the 115 Tank acid fractionator. Under these conditions, the 113 Tank evaporator and the 115 Tank fractionator may be operated independently and simultaneously if desired.

A general service tank is provided in the cell, primarily for chemical decontamination of gross quantities of radioactivity from small to moderate-sized equipment (including pot furnace liners). The 119 Decontamination Tank is 42 inches in diameter and 11 feet high and holds 3000 liters. Its features include a removable coil with an internal clearance circle of 26 inches, a hinged lid, a sparger, and a spray nozzle, in addition to the typical dip tubes and transfer piping.

A small laboratory-scale chemical hood is provided within B-Cell for laboratory-scale "solidification processing" of 20 to 50 milliliters of feed materials before demonstration in the prototypes. With the equipment, the gross processing characteristics of each actual batch of feed (e.g., foaming tendency, sintering of "stick" temperature, melting temperature) are determined before the demonstration is begun. A stirring hot plate and electric muffle furnace are provided in the hood for these functions.

Several stainless steel process service tanks are being used by the WSEP which have not been discussed in detail. These are the service tanks in the C-MEL shielded tank vaults, and are shown in Figure 4.5a. Three tanks with capacities of 18,000, 3600, and 1600 liters will be used for lag storage of Purex waste and fission product concentrates. A 15,000 liter tank will be used for storage of left-over high level process solutions. One of four tanks with capacities of 12,000 to 18,000 liters each will be used for temporary storage of decontaminated condensates and recovered nitric acid.

Liquid chemical additions to the in-cell tanks are made from six stainless steel tanks (varying in capacity from 120 to 300 liters) in the head tank room above the cell. The contents of three tanks are fed to the in-cell tanks by gravity and the contents of the other three are fed through metering pumps. One tank may supply feed to a large centrifugal pump for high-pressure (100 psig) supply to the process sprays present in key locations inside most process vessels. One head tank is used for all nonroutine water additions to the process to aid in inventory control and material balances. Solids additions to in-cell process vessels are made from the service gallery outside the cell.

4.5 SULFATE CONDENSATE DISTILLATION EQUIPMENT

Solidification of wastes by the phosphate glass process results in vaporization of water and nitrates from the denitrator-evaporator and from the melter. As with the other processes, these condensates would normally be routed back to the high level liquid waste evaporation system of a fuel reprocessing plant where the nitric acid would be recovered for reuse in the fuel dissolution step. However, solidification of sulfate-containing wastes by the phosphate glass process results in volatilization of all the sulfate into the melter condensate stream. Since the sulfate cannot be reused, it must be decontaminated (primarily from its radioruthenium content) sufficiently to permit its safe disposal. Decontamination by a factor of about 200 (to a radionuclide concentration of 1 Ci/liter of solid) is required to permit incorporation of the sulfate into asphalt[5] for permanent storage. Distillation of the condensate under vacuum (at 20 to 150 millimeters of mercury absolute pressure) to volatilize the nitrate and the sulfate as separate fractions from the ruthenium-containing concentrate is planned to accomplish the necessary decontamination. Demonstration of distillation of actual sulfate-containing condensates from phosphate glass processing in WSEP is currently planned in engineering scale equipment called the Distillation Demonstration Unit (DDU). This equipment will be installed and operated in the adjacent C-Cell of the C-MEL facility.

The primary objective of the DDU program is to demonstrate in engineering scale equipment the necessary cleanup of actual radioactive sulfate-containing melter condensates by vacuum distillation to the degree necessary for final incorporation into asphalt. Demonstration of incorporation into asphalt is not currently planned.

The DDU is primarily a vacuum batch distillation in which water, nitric acid, and sulfuric acid are distilled successively from the evaporator, leaving behind phosphoric acid and fission products. The vapors generated are condensed and collected, water and nitric acid in one tank and sulfuric acid in another. Since the boiling point of the latter is very high even under vacuum, substantially all water and nitric acid may be removed and collected before the sulfuric acid is distilled to its receiving tank.

The main process features of the DDU equipment are shown in Figure 4.18. Melter condensate is brought adjacent to the unit in stainless steel drums and is drawn by vacuum to the main evaporator. The nitric acid and sulfuric acid condensate fractions are routed to the respective storage tanks by means of appropriate valving downstream of the C-1 Condenser. Chemical and activity measurements are carried out on the condensate stream at intervals through the distillation in order to evaluate separation efficiencies and decontamination values.

The major design features of the DDU are discussed below:

- The processing equipment consists of an evaporator with two deentrainment sections, a condenser, two storage tanks, a vacuum pump, and related auxiliaries.

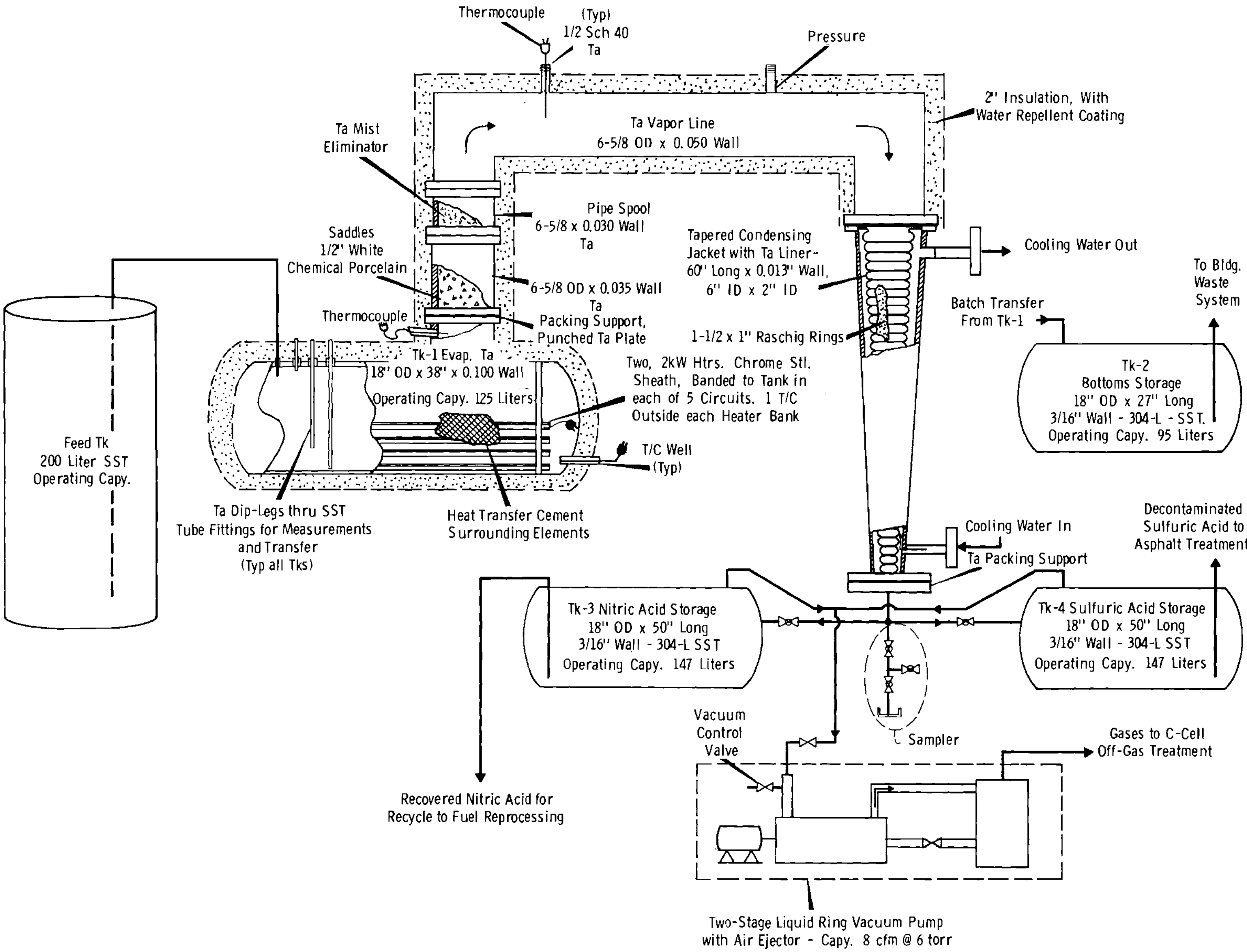


FIGURE 4.18. Distillation Demonstration Unit

- All equipment is mounted on a single rack located in the center of the cell midway between the two shielding windows such that the manually manipulated banks of valves on the two ends of the rack are in front of the windows.
- The equipment is designed to operate in the vacuum range of 20 to 100 millimeters of mercury. Vacuum is obtained by a liquid ring seal pump which is equipped with an air ejector which permits operation at a minimum of 15 millimeters of mercury and 50 liters/hr of noncondensible gases. The gases from the vacuum pump are discharged to the building process off-gas system for filtration before being emitted from the building stack.
- The evaporator is a cylindrical vessel mounted on its side to maximize disengaging space and to permit operation with volumes as low as 4 liters.
- Tantalum alloy was used for construction of the evaporator vessel, dip tube and vapor system to the inlet to the condenser. The condenser is a tapered, packed stainless steel vessel with tantalum lining that is cooled through a jacket. All other components are stainless steel.
- Heat input to the evaporator is supplied by five banks of electrical strip heaters embedded in heat transfer cement and strapped longitudinally and horizontally to the bottom half of the evaporator. A total of 20 kilowatts of heating capacity is thereby provided, which is sufficient to maintain about 7.5 liters/hr boilup during the distillation of the sulfuric acid, or an average boilup rate of 10 liters/hr for an 80-liter batch. Power to each bank of electric heaters is controlled manually with autotransformers and is measured by voltage and ampere meters. For operation with varying volumes, the heated area of the evaporator may be restricted to that of the bottom area only.

- Liquid entrainment from the evaporator is minimized by using a short tower packed with porcelain saddles which is surmounted by a knitted wire mesh mist eliminator section.
- The two product tanks are cylindrical stainless steel vessels which are mounted horizontally.
- Batch transfers are accomplished by vacuum provided by the vacuum pump. Valving is installed to permit transfer of feed into the system as well as transfer of products between tanks and to storage.
- Liquid level in the evaporator and the two product tanks is measured by gas-purged dip legs and differential pressure cells. The instrument purge gas is nitrogen to minimize oxidation of ruthenium to the volatile form. Temperatures are measured by Chromel-Alumel thermocouples which are tantalum sheathed where they are in direct contact with process fluids and are stainless steel sheathed where they are in wells. Vacuum is measured by gases and is controlled manually by adjusting the air inleakage rate to the ejector of the vacuum pump.

5.0 MECHANICAL FEATURES

5.1 SHIELDED CELL FACILITIES

5.1.1 The C-MEL Radiochemical Engineering Cells

Shielded cell facilities for WSEP are contained within the Radiochemical Engineering Cells Complex of the Chemical and Materials Engineering Laboratory.[6] The latter is a multipurpose facility which includes the Radiochemical Engineering Cells, a Shielded Materials Facility for radio-metallurgical studies, an Engineering Development Laboratory used for nonradioactive chemical processing studies, an Engineering Development Laboratory used for chemical processing studies with highly toxic materials, and a Sodium Studies Facility used for the Liquid Metals Fast Breeder Reactor program.

A floor plan of the C-MEL complex is shown in Figure 5.1. In the Radiochemical Engineering Cells, four operating cells (designated A-, B-, C-, and D-Cells) are grouped in the complex in a "Tee" arrangement. Access to each is gained through the centrally-located Air Lock Cell. D-Cell is above C-Cell and, therefore, does not show in Figure 5.1.

B-Cell houses the WSEP processing equipment and is described below. A-Cell is used for the controlled-environment storage test facility for waste pots from WSEP, and C-Cell is used for the hot laboratory testing portion of the WSEP product evaluation program. Detailed descriptions of the A- and C-Cell Facilities are given elsewhere.[1]

5.1.2 The Shielded Cell Facility for WSEP

B-Cell is 25 feet long, 22 feet wide, and 30.5 feet deep. The cell floor is 10 feet below grade. The cell walls are either high-density concrete that are 48 inches thick or are ordinary concrete that is 54 inches thick, depending on

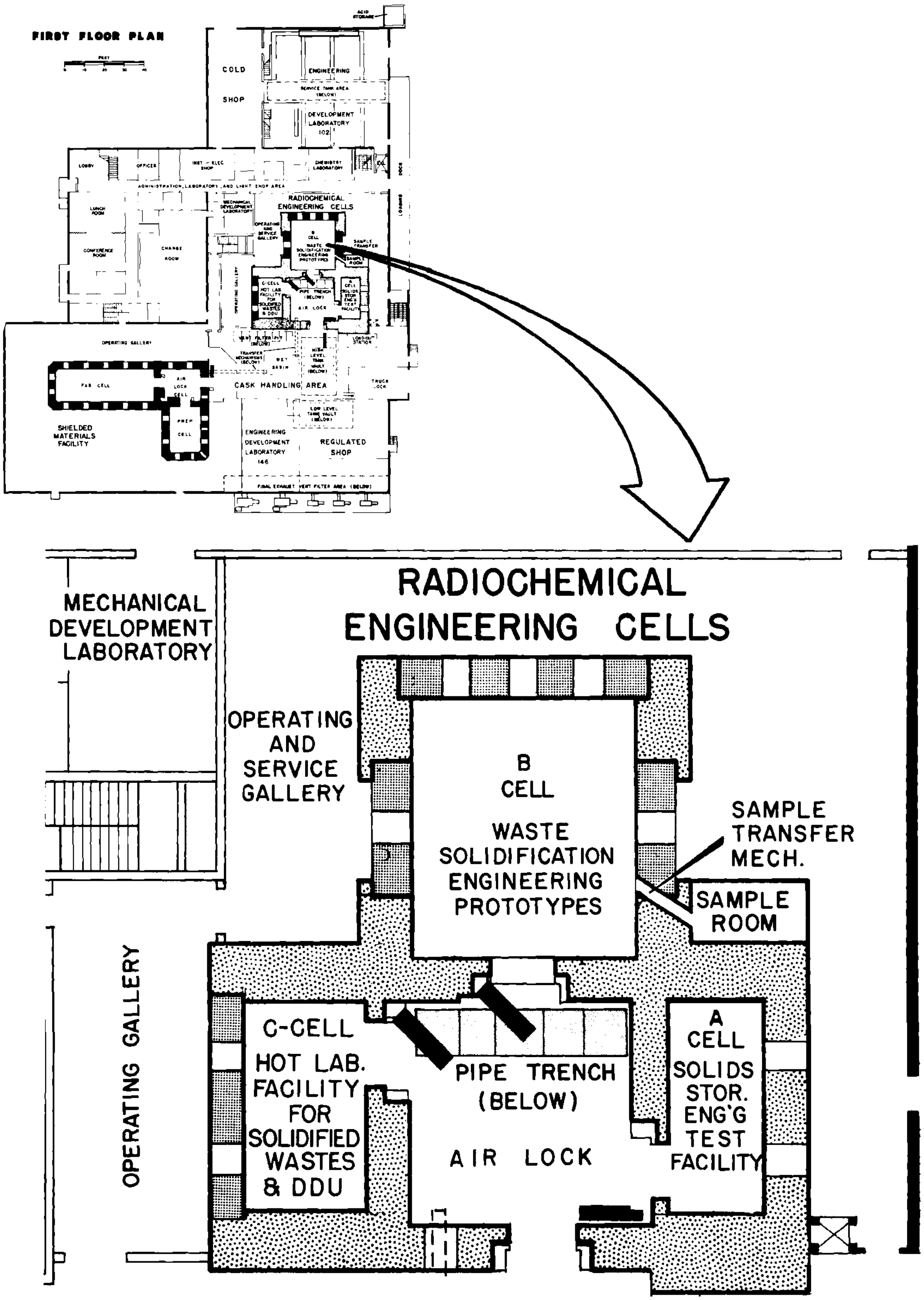


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FIGURE 5.1. *Floor Plan of the Chemical and Materials Engineering Laboratory*

location. Figures 5.1 and 5.2 illustrate various features of the cell. Major cell features include:

- A 78 inch wide, 18 inch thick (maximum) hinged steel entry door which opens into the Air Lock Cell for transfer of large materials. Since the Air Lock floor is at grade and the B-Cell floor is 10 feet below grade, the cell entry has a 10 foot high "step."
- The 3 foot wide, 4 inch thick hinged steel crane door which opens into the Air Lock Cell to permit the two B-Cell cranes to travel into the Air Lock Cell.
- The 12 inch wide by 15 inch high transfer mechanism opening which angles through the north cell wall into the cell for transfer of samples and other small materials between the cell and the service gallery.
- Three oil-filled, 4 foot thick lead-glass shielding windows located on the first floor level and centered along the three cell walls which are adjacent to service and operating galleries.
- Standard straight 10 inch diameter paired sleeves are located immediately above each window, and also above each window at the second floor levels above the crane rails. These sleeves are primarily used for insertion of master-slave manipulators, but may also be used for other services including television cameras.
- Numerous cell wall penetration sleeves that are 12 inches, 8 inches, or 4 inches in diameter and are stepped. These sleeves are used for piping and electrical services and rack plugs. The 8 inch and 4 inch sleeves are grouped around the shielding windows; the 12 inch sleeves are located away from the windows and at higher and lower elevations for inserting rack plugs or television.

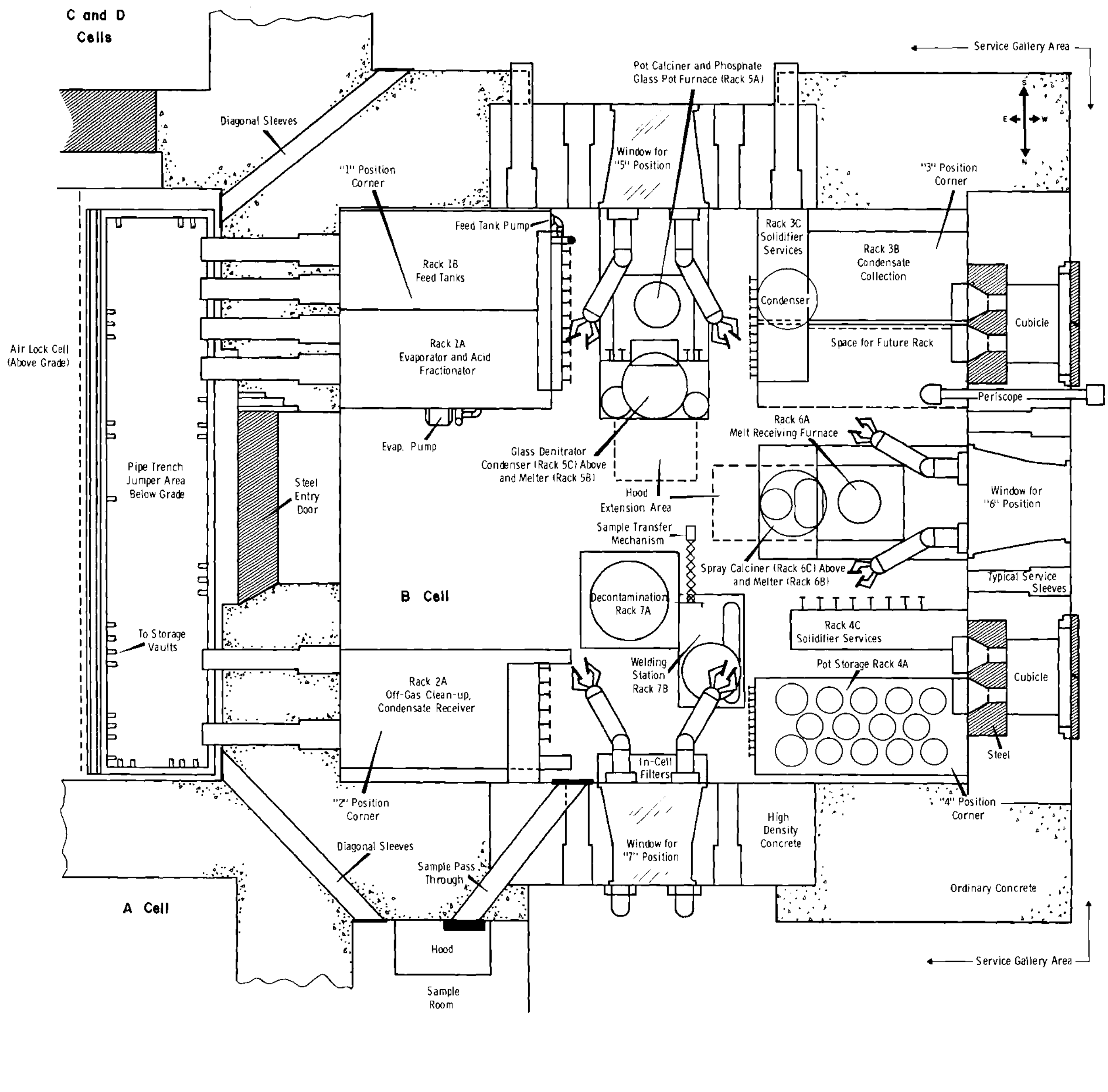

FIGURE 5.2. Plan View of B-Cell Equipment Arrangement

- An overhead crane system for moving large equipment within B-Cell or into the Air Lock Cell which consists of two cranes having capacity ratings of 6 tons and 3 tons, and operate on a common rail at an elevation of 17.5 feet above grade.
- A downdraft ventilation system with inlet ceiling ducts is equipped with automatically-controlled dampers, anti-backflow dampers, and medium-efficiency filters. The 2 feet by 8 feet rectangular outlet opening is located on the north cell wall below the shielding window.
- Two cubicles located in the west cell wall at the first floor on either side of the shielding window. Cubicles are cavities formed by casting 18 inch thick steel blocks in the concrete wall with the face of each 54 inch square block flush with the inside wall of the cell. The cavity or cubicle thus created in the cell wall is sealed on the gallery side by an aluminum or clear plastic ventilation control door and shielded by a 4 inch thick hinged steel door. In-the-wall piping routed from the service galleries and from other building areas into the cubicle provide for manual connections of radioactive and nonradioactive services inside the cubicle. Each cubicle casting has four 9 inch diameter openings into the cell. Thus, process equipment with mating plugs may be "plugged in" to the cubicle openings from inside the cell. These plugs may be connected and disconnected without entering the cell, as described in Section 5.2.
- A 4 foot wide pipe trench located below the Air Lock Cell floor and connected to B-Cell by 12 inch stepped sleeves. The pipe trench extends the full width of B-Cell and is covered by high density concrete shielding blocks that are 2 feet thick. The pipe trench provides for interconnection of radioactive process piping by semiremote manipulations from behind portable barriers.

5.2 EQUIPMENT ARRANGEMENTS

5.2.1 Equipment Racks

WSEP vessels with closely related functions and their associated piping are grouped together and mounted on and in structures called racks. Equipment racks simplify remote handling, benefit field installation by allowing prefabrication, facilitate replacement of groups of equipment, and permit efficient adaptation of complex piping systems to restricted cell geometry.

A typical rack shown in Figure 5.3 consists of the rack frame, large rack plugs which contain service piping and are integrally welded into the frame and arranged to fit sleeves in the cell walls, process vessels and equipment, piping systems, and connectors (mostly on the one face of the rack that is accessible to the cell manipulators). The rack shown is designated as WSEP Equipment Rack 2A and is used for final in-cell treatment of process off-gases. Other WSEP equipment racks with their respective functions and designations are listed in Table 5.1 in the next section. The rack designations (1A, 2A, etc.) denote the location of the rack in cell, as described below in Section 5.2.2.

Rack frames are fabricated mainly from tubular stainless steel such as the 6 inch schedule 10 pipe frame shown for the 2A Rack. These members were selected for maximum rigidity and minimum weight. The weight of an entire rack assembly was limited to 6 tons by the capacity of the in-cell crane. Most racks were designed to hang from the cell wall and to be supported by the frame plugs. Other racks were designed to rest on the cell floor. Racks taller than about 16 feet had to be designed to be tipped 90° during transfer into the cell because of the limited vertical clearance between the crane hook and the Air Lock Cell floor at the cell entrance.

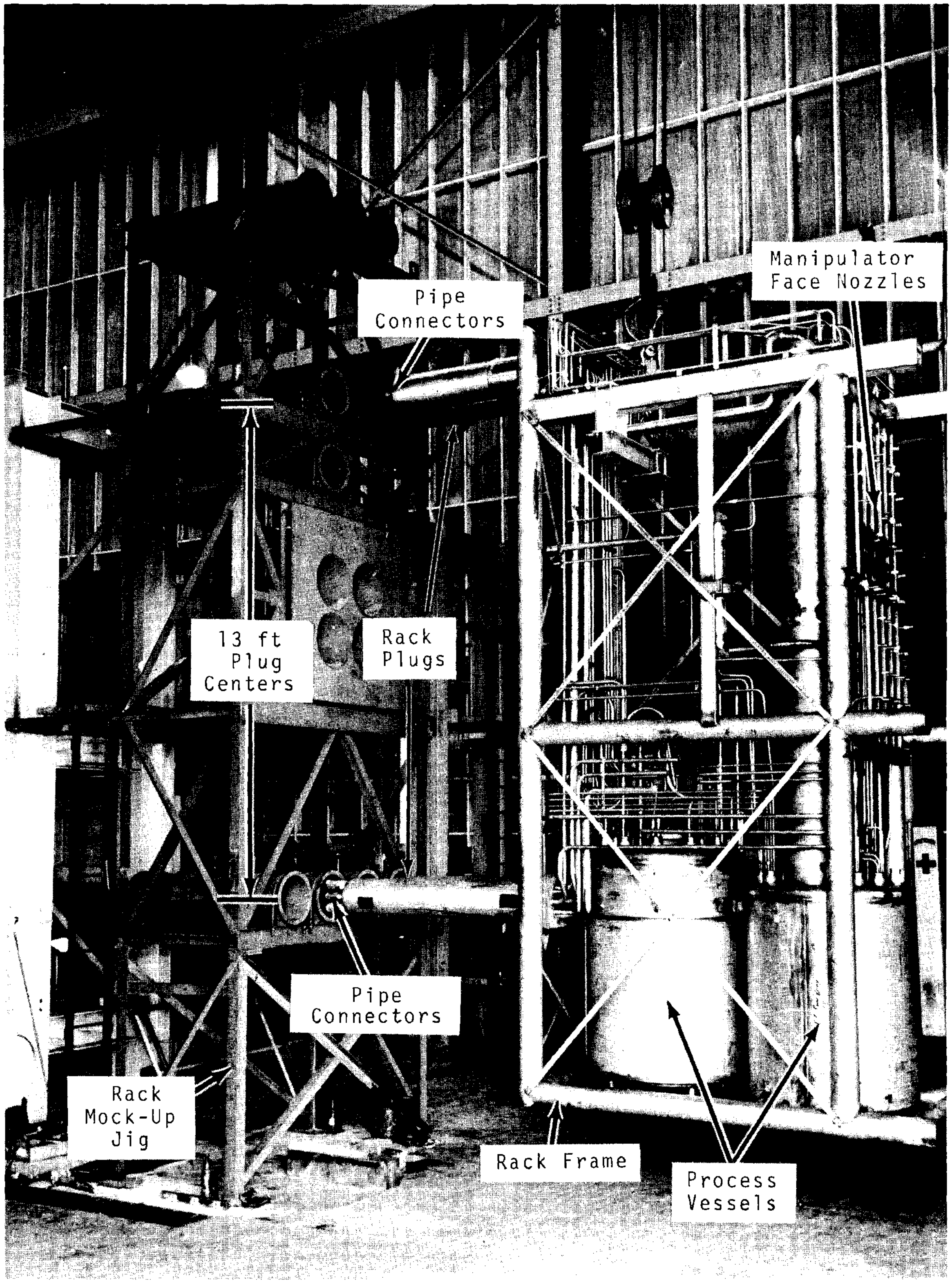

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FIGURE 5.3. WSEP Equipment Rack 2A and Mock-Up Jig

TABLE 5.1. *WSEP Equipment Racks and Functions*

Rack	Rack Function	Major Equipment in Racks
1A	Evaporation and Acid Recovery	Waste evaporator and condenser, acid fractionator and condenser, evaporator bottoms cooler
1B	Feed System	Two feed tanks and reflux condenser
2A	Final Off-Gas System	Caustic scrubber, two off-gas preheaters; fractionator condensate tank
3B	Calciner Condensate	Calciner condensate tank
3C	Fluid Services	Piping services to Racks 5A, 5B, 5C
4A	Pot Storage	Pot storage tank
4C	Fluid Services	Piping services to Racks 6A, 6B, 6C
5A	Pot Calciner	Calciner induction furnace and hood
5B	Pot Calciner Head[(a)]	Connection head for pot calciner
5-6B	Melter[(b)]	Spray calciner melter and furnace
5-6C	Spray Calciner[(b)]	Spray calciner furnace and filter chamber
6A	Melt Receiver	Melt receiver resistance furnace and hood
6B	Melter[(c)]	Phosphate glass melter and furnace
6C	Phosphate Glass[(c)]	Phosphate glass evaporator and condenser
7A	Decontamination	Decontamination tank
7B	Welding Station	Welder, tank and pot inspection

(a) *The pot calciner is designed primarily for the "5" position.*
(b) *The spray claciner is designed for either the "5" or "6" position, and will be installed in the "6" position at startup.*
(c) *The phosphate glass system is designed primarily for the "5" position.*

Crossbracing is provided for these racks to give the extra rigidity required for safe remote handling.

The shape of the rack plugs is either stepped-cylindrical, straight-cylindrical, or conical-cylindrical, depending on the shape or location of the mating sleeves in the cell walls. Figure 5.3 shows two 12 inch diameter stepped-cylindrical upper plugs on 2A Rack and two 10 inch pipe size straight cylindrical lower plugs. The upper plugs actually support the rack, which projects outward from the wall as a cantilever structure.

Rack plugs also serve as pipeways. For Racks 1A, 1B, and 2A, piping for up to 35 nonradioactive services extends through each of two upper plugs, and piping for up to ten radioactive process streams extends through each of two lower plugs. When these racks are in place hanging from the cell wall, the upper plug piping terminates in the Air Lock Cell and the lower plug piping terminates in the pipe trench accessible from the Air Lock Cell. Piping in the plugs of the other racks terminate in the service galleries or in the shielded cubicles where piping connections to the various racks can be made without entering the cell. Shielding is required in all plugs except those (on 1A, 1B, and 2A Racks) which terminate in the pipe trench of the Air Lock Cell. Where a shielded plug is required, piping in plugs is bent to provide a radiation barrier and the plug is filled with steel or lead shot.

Inside the rack and the cell, the stainless steel or titanium piping extends to the various process vessels or to the manipulator face of the rack. The manipulator face is located and arranged so that piping connections on the nozzles can be handled using master-slave manipulators. Connectors away from the manipulator face on process vessels, agitators, pumps, tube bundles, and off-gas lines must be actuated using the overhead crane and an impact wrench.

Figure 5.3 shows the 2A Rack being maneuvered into a mock-up rack jig. Dummy wall sleeves are fastened in the jig to simulate cell wall openings. Fitting racks into the jig assures that the rack can be installed in its assigned position in the cell.

5.2.2 In-Cell Process Equipment Arrangement

Arrangement of the B-Cell process equipment and its relationship with the various cell features and equipment is shown in Figures 5.2 and 5.4. The functions of the major racks are summarized in Table 5.1. In general, feed and process off-gas treatment racks are located in the corners of the cell, while the solidification equipment is located at two of the windows so that manipulations, if required, can be readily performed. Fluid services to these solidifier racks are provided by nearby service racks which are also reached by manipulators. The welding station and pot inspection equipment is located in front of the third window. The arrangement was designed so that the feed and process off-gas treatment racks would have access to the pipe trench. Cubicle piping services are provided to the condensate receiving rack and the pot storage rack. Either the pot calcination equipment or the phosphate glass solidification equipment may be installed in the "5" position in front of the south windows. The spray solidification equipment was designed to fit either the "5" or "6" position, but is planned to be demonstrated in the "6" position.

For pot calciner process demonstrations, the Rack 5 equipment consists of the induction-heated 5A pot furnace-cooler below, with the Rack 5B pot fill head bolted above. When the phosphate glass process is to be demonstrated, the 5B Rack pot fill head is removed and replaced by the 5B Rack melter and melter-furnace and the 5C Rack phosphate glass denitrator and melter condenser. Rack 6 consists of the

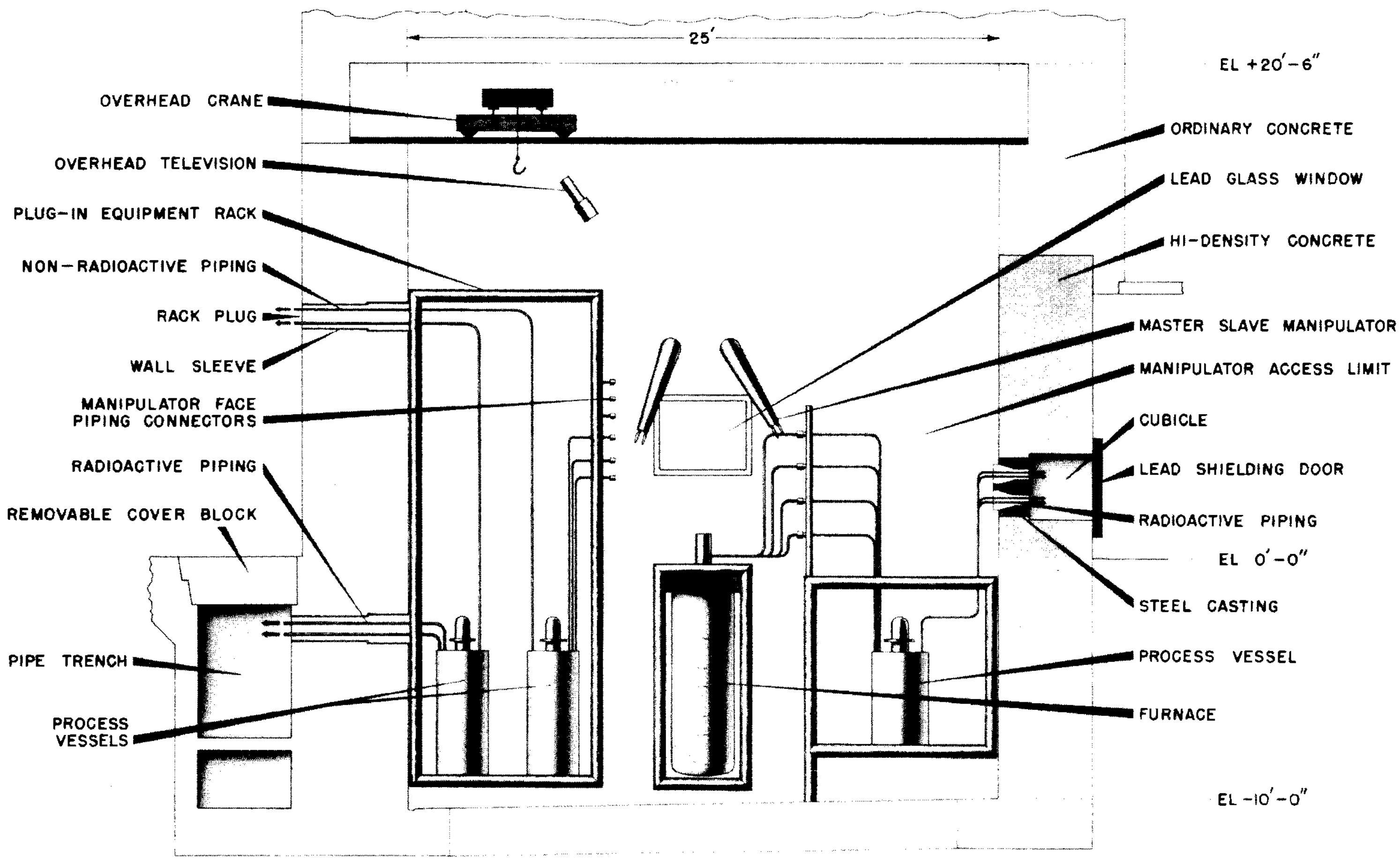

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FIGURE 5.4. Elevation View of B-Cell Equipment Arrangement

resistance-heated 6A pot furnace-cooler below, surmounted by the 6B melter and melter-furnace, which in turn is surmounted by the 6C spray calciner and its furnace. See Figure 4.5b for details of arrangement of the solidification equipment.

Feedstock for the waste solidification processes is transferred by jet from the tanks in the C-MEL high level vault through the pipe trench to the feed tanks on the 1B Rack where it is chemically adjusted for processing. The feed is pumped, airlifted, or siphoned to the solidifiers at rack positions 5 or 6 (via the evaporator on the 1A Rack in some cases). Vapors from the solidifiers flow to the E-111 condenser, from which the condensate is normally routed back to 1A Rack, through the evaporator and fractionator. The 3B Rack is primarily used for collection of sulfate condensate from the phosphate glass melter. The condensate is jetted to the waste storage vault for further treatment or for shipment to the Hanford fuel reprocessing areas along with the recovered nitric acid. Process off-gas then flows to the 2A Rack via the pipe trench before exhausting outside the cell to backup treatment.

Pots to be filled with solidified waste in B-Cell are transferred by crane through the large cell entry door and are loaded into one of the pot furnaces in the 5A or 6A Racks. After filling, the pots are transferred by crane to the welding station for weld closure, inspection, and nondestructive testing. The pots are then removed by crane to the 4A Storage Rack for measurement of heat rate content or for interim storage.

5.3 WASTE SOLIDIFICATION FURNACES

High temperature electric resistance-heated and induction-heated furnaces employed in the waste solidification processes in WSEP are:

- The six-zone heating-cooling furnaces for the waste pots at rack positions 5 and 6.
- The three-zone spray calciner furnace.

- The single-zone melt furnaces for the spray solidification and phosphate glass melters.

The physical features of these furnaces are described in the remainder of this section.

5.3.1 Waste Pot Induction Furnace-Cooler, 5A Rack

Major design criteria for the induction-heated waste pot furnace are:

- The size and rating must be adequate for heating pots which are 8 feet long and up to 12 inches in diameter to 1000 °C maximum for solidification processes.
- Air cooling capability up to 15 kilowatts must be provided to maintain pots at safe temperatures during and after processing.
- The furnaces must provide six-zone control of both heating and air cooling, and the potential for water quenching.
- The furnace system must incorporate secondary containment in the cell for spills, pot ruptures, or routine flushing operation.
- The furnaces must have the flexibility to operate as a furnace or as a water quench bath for special processes with minor modifications.
- The furnace system must integrate into the WSEP rack concept.

The induction-heated furnace shown in Figure 5.5 is comprised of four basic elements: the furnace itself, the hood and containment system, the rack frame, and the power supply. Descriptive information of the furnace established to meet the design criteria is given in Table 5.2. The furnace consists of a two-piece shell which is 32 inches in outside diameter. The shell is bolted to the underside of the lower half of the

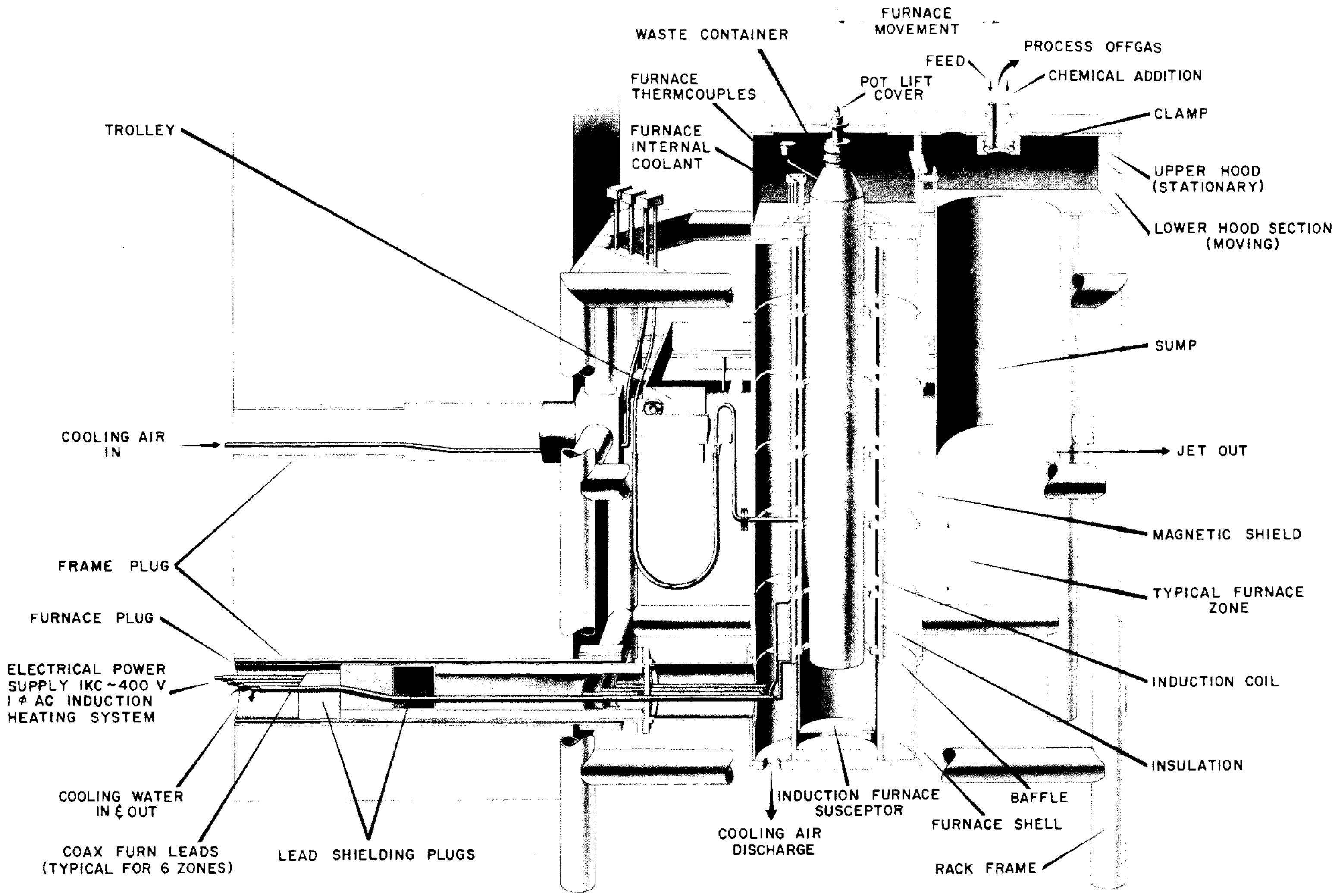

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FIGURE 5.5. *Waste Pot Induction Furnace-Cooler*

TABLE 5.2. *Waste Pot Furnace-Cooler Descriptions*

Item	Furnace Designation: Induction (5A)	Resistance (6A)
1. Number of Zones	6	6
2. Zone Height, in.	13	14
3. Heating Power/ Zone, kW	20	15
4. Design Temperature, °C	1000	1000
5. Zone Heating Element	20 turn, 18 in. ID, Insulated copper coil (1/2 in. OD x 0.088 in. Wall)	Kanthal A-1 resistance heating elements, ∿0.15 in. diameter
6. Power Supply	1 kc, 200 V, single phase ac from 175 kW motor generator set	95 V, 50 A, 3 phase ac power (from 480 V ac)
7. Insulation	1 in. thick built-up layer with Ceraform blocks cemented with Tipersul to asbestos paper backing	3 in. Tipersul plus ceramic heating element supports, mounted with Inconel bolts
8. Magnetic Shield	3 layered insulated, 1/16 in. carbon steel laminations	None
9. Susceptor	14 1/2 in. OD x 3/8 in. wall Hastelloy-X tube	15 in. OD x 1/4 in. wall Hastelloy-X tube
10. Air Cooling per Zone	2.5 kW with 100 scfm air supply	2.5 kW with 100 scfm air supply

hood and contains six assembled furnace sections called zones. Zones are separated by horizontal asbestos-cement baffles. Each zone consists of:

- An induction coil rolled from 1/2 inch diameter copper tubing.
- A 1 inch thick layer of insulation between the coil and the susceptor wall.
- An outer magnetic shield consisting of three layers of carbon steel sheet separated by asbestos sheet insulation.
- An air cooling supply system.

Each induction coil is insulated with braided fibrous glass sleeving and painted with insulating varnish. Each turn of the coil is tied to four equally-spaced, insulating, vertical coil supports (asbestos cement board) by braided glass cord.

Coil connections are brought out to the induction heating power supply in the service gallery through the furnace electrical supply plug which bolts to the furnace shell. Coil leads are arranged as coaxial copper tubing inside the supply plug to avoid electromagnetic coupling and subsequent heating of the plug. Three concentric tubes with outside diameters of 1 3/8, 1, and 1/2 inches, respectively, are arranged to form each coaxial lead. The leads are bent offset and lead blocks are fitted inside each plug for radiation barriers. Lead-filled shielding rings, not shown in Figure 5.5, are also provided in the service gallery for supplemental shielding.

Insulation in each zone is formed by first wrapping a layer of asbestos sheet insulation on the inside of the coil, then placing 4-inch wide slabs of Ceraform vertically around the inner periphery, and finally coating the inner surface with Tipersul to close up cracks between the slabs.

Air supply to each zone flows through 1 inch pipe in the upper frame plug and through connecting flexible hose to an annulus at the bottom of each furnace zone. Air then flows upward between the insulation and the susceptor. The air then discharges through slots in the insulation and then downward and out the bottom of the furnace to the cell. Air is supplied by two blowers located in the service gallery. Each blower is rated to deliver 275 scfm of dry air at 35 psig. Air flow is controlled by manually-energized solenoid valves.

Inside the furnace is the susceptor which provides the metal form required to complete the induction heating circuit and serves as an integral part of the hood containment system. The removable susceptor is flanged at the top for sealing to the lower half of the hood and is closed at the bottom to contain spills in the furnace.

Inside the susceptor is a removable furnace control and inner coolant cage. The cage consists of 24 equally-spaced vertical 1/4 inch diameter tubes made of Hastelloy-X. The tubes are assembled into an integral cage structure. Inside 18 of the tubes are Chromel-Alumel thermocouples. Three thermocouples are equally spaced circumferentially at the middle of each zone. One thermocouple per zone is selected for control of furnace temperatures. Two of the remaining tubes are used for the addition of direct air or water coolant or chemicals, three are available for a variety of services, and one is used as a dip tube for measurement of liquid level.

The furnace containment system was conceived to control the release of contamination to the cell in the event of pot rupture, leakage at the pot fill head connection, or for system flushdown. Four basic parts are represented:

- The stationary upper half of the hood which fastens to the rack frame.

- The lower half of the hood section which bolts to and moves with the furnace and slides along the upper half of the hood; a flushdown sump is integral with the hood.
- The furnace susceptor, previously described, which seals to the lower half of the hood.
- The pot lift cover, by which the pot is lowered into or raised from the furnace.

A pot to be filled is assembled with the lift cover in B-Cell, transferred to the furnace, and lowered into place. The lift cover thus closes the hood system. The pot is then lowered to engage the pot hoist, the furnace is pushed forward until the pot meets a stop directly beneath the fill head, and the pot is raised and connected to the fill head. The procedure is reversed to remove the pot. During the operation, the hood may be vented to one of the process vent systems to maintain air flow into the hood.

The frame of the furnace rack is a tubular structure designed to provide support and movement for the furnace. The frame is supported in the cell wall by the two 12 inch frame plugs. A four-wheel trolley directly supports the furnace shell and travels on tracks fastened to the rack frame. Thus, when the lower furnace plug is pushed or pulled from the gallery side of the plug, the furnace and trolley move from the "pot load-in" to the "pot fill" position, a distance of 30 inches.

The furnace power supply and control system, shown in Figure 5.6, has six induction heating stations electrically connected in parallel to a 960 cycle motor-driven generator. Each station consists of an on-off contactor, autotransformer for step-up/step-down voltage control, and capacitors for correcting power-factor. Coaxial or single cables connect the station output to individual furnace zone coil leads. Cooling

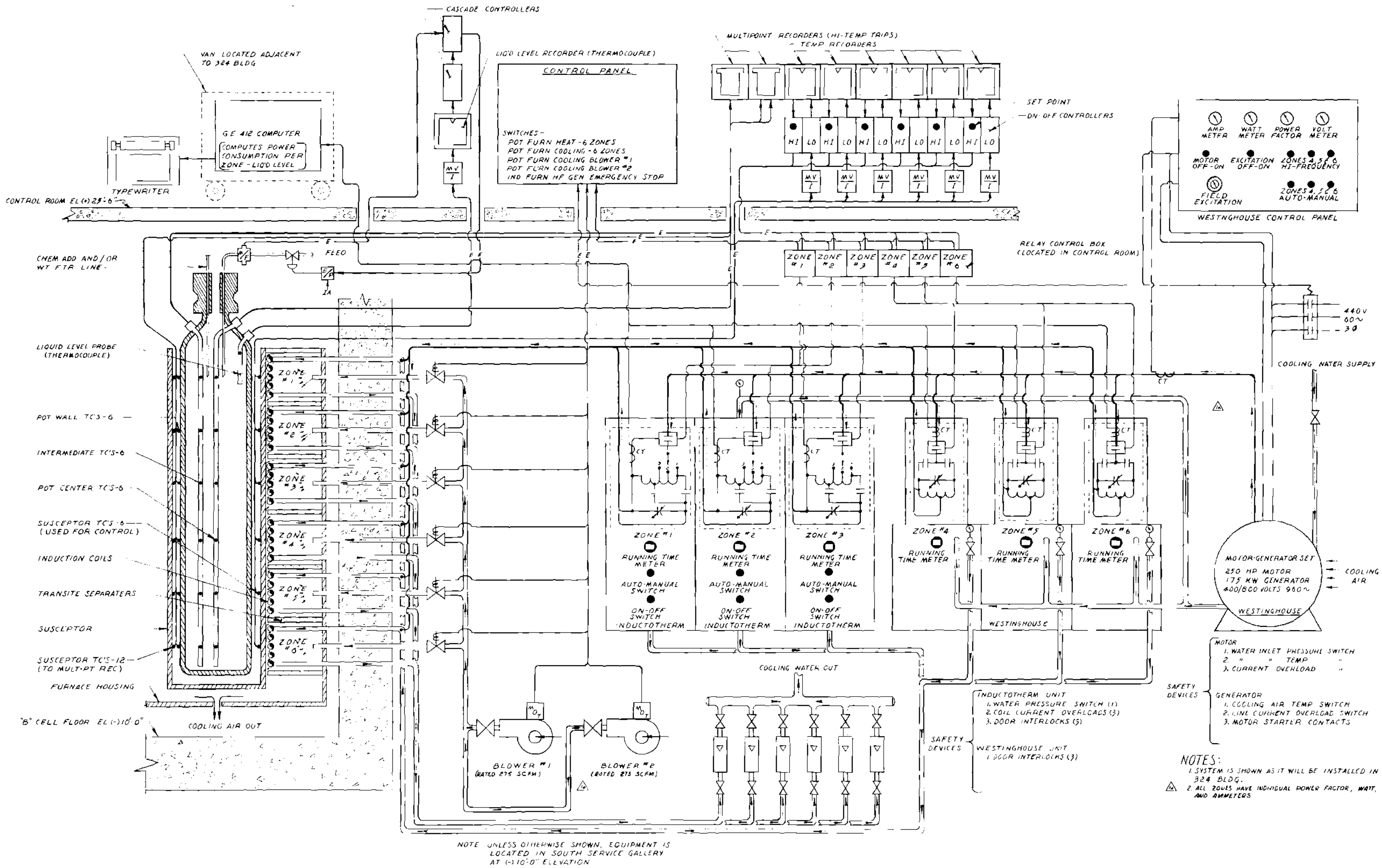

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FIGURE 5.6. Six Zone Induction Furnace-Cooler Control System

water flows through the motor-generator set, and through each station and cable set to the furnace coil, then returns to the gallery for flow metering and discharge to the sewer.

On-off operation of induction heating station contactors is controlled from millivolt signals transmitted from the furnace thermocouples to converters, thence to the on-off controllers which energize control relays.

5.3.2 Waste Pot Resistance Furnace-Cooler, 6A Rack

Rack 6A, the electric resistance-heated pot furnace-cooler, is functionally and physically interchangeable with the induction-heated pot furnace-cooler, Rack 5A. Consequently, the basic design criteria and details of the furnace containment system and rack frame are as described in the previous section. Descriptive information for the resistance furnace was also given in Table 5.2.

Internal furnace details, of course, are very different. Rather than having six zones assembled in a single shell, as does the induction furnace, the resistance furnace consists of six separable sections. Each section has a stacked height of 14 inches, an outer shell diameter of 32 inches, and is capable of operating independently as an air cooled furnace.

The Kanthal A-1 heating elements in each furnace section or zone are bent in a zigzag shape and are supported by conventional corrugated ceramic forms. The ceramic forms are fixed to the shell of the furnace with Inconel mounts. The heating elements are so arranged and connected that two completely separate circuits or continuous heating elements exist in each of the three phases in each section. Both leads from each heating element are brought out through the furnace electric supply plug to the service gallery, making a total of 72 wires extending through the cell wall for the entire furnace. Therefore, if any one element fails, the other two phases of that circuit may be disconnected to permit operation at half power with the remaining three phase circuit with reasonably uniform heat distribution, or the remaining two elements may be reconnected to operate on single phase. The normal connection arrangement is for three phase, grounded wye circuits. Electrical connectors at the terminal box of each furnace section and in the electrical supply plug facilitate remote replacement of individual sections, if necessary. Asbestos-insulated wire is used for all leads.

Indirect cooling air to each zone is supplied in the same manner as in the induction-heated furnace-cooler. However, in this case, the air discharges into each furnace zone through a perforated sparger-type of circular pipe header located at the bottom of each zone between the heating elements and the furnace liner. Cooling air impinges on the furnace liner wall and flows upwards and out into the cell through 10 ceramic-lined air discharge ports at the top of each zone. The supply air header pipe is supported by an insulated metal baffle which separates each zone.

Furnace leads are connected to power transformers located in the gallery. Rapid on-off temperature control is provided with main-line contactors which open or close in response to furnace thermocouple signals. The thermocouple signals are converted and transmitted to duration-adjusting controllers.

5.3.3 Spray Calciner Furnace, 6C Rack

The electrical resistance-heated spray calciner furnace has three heating zones assembled one above the other in a single stainless steel shell. Each zone is rated for 15 kilowatts with a 240 volt ac power supply to heating elements connected to three-phase grounded wye circuits. The furnace is designed to operate continuously at a maximum temperature of 1000 °C and is insulated for a maximum outer shell temperature of 100 °C. Heating elements are

Nichrome V wires with a diameter of 0.12 inches, and are wound circumferentially around the inside of the furnace. The heating elements in each zone are wound on 3/8 inch centers and mounted on open corrugated ceramic supports. Ceramic supports are held in place by the heating elements and an inner furnace shell of Nionel.

The cylindrical furnace shell has an outside diameter of 22 3/4 inches, a length of 74 inches, and an internal opening of 15 3/4 inches to allow for the 14 inch spray calciner reactor. The shell is fitted with lifting bails for remote handling. The two heating element leads from each phase of each zone terminate in a common junction box where connections are made to the lead wires from the service gallery. Electrical connectors are standard welding cable plug jacks. The furnace is insulated with 2 1/2 inches of Tipersul. A simplified functional sketch of the furnace was shown in Figure 4.6.

Furnace temperatures are controlled with Inconel-sheathed, magnesium oxide-insulated type S(platinum/platinum-10% rhodium) thermocouples located at the center of each furnace zone. These thermocouples are connected to millivolt converters outside the cell. Converter outputs connect to electronic recorders whose slidewire outputs are transmitted to duration-adjusting controllers. The controllers establish the proportion of rapid on and off time of the main furnace power contactors. A second thermocouple in each zone (diametrically opposite the control thermocouple) is read out on a multipoint recorder.

5.3.4 Melter Furnaces, 5B and 6B Racks

The melter furnaces, shown schematically in Figures 4.7 and 4.9, supply the heat required to maintain the platinum melter crucibles at melt-forming temperatures. The two identical pot-type furnaces are single-zone electric resistance-heated furnaces rated for a maximum power of 20 kilowatts and a maximum temperature of 1300 °C.

Special mechanical and electrical features of the furnaces include:

- Each platinum melter crucible is supported by and within the furnace, and hangs from a flange integral with its crucible shell. The furnace shell has a special five-bolt top flange to match the five nozzles on the melter, and which clamps the melter in position and seals the joint between the melter and the furnace.
- The furnace shell is a stainless steel cylinder which is 32 inches in diameter (including an air cooling jacket) and 24 inches high. An 8 inch diameter flange projects 2 inches out the bottom of the furnace to connect to the freeze valve and sample chamber assemblies below.
- The furnace shell is pierced by a narrow vertical viewing slot which is sealed by a quartz window. The window is used to visually monitor the temperature and condition of the platinum melter.
- Heating elements are Kanthal A-1 wire elements connected as a three-phase, 126 volt, grounded wye circuit in the furnace terminal box. The wires are bent in zigzag shape on 1/2 inch centers in nine elements alternating around the inner periphery of the furnace. Wires are mounted on open ceramic supports similar to those in the resistance heated pot furnace.
- Insulation consists of 2 5/16 inches of Fiberfrax and 2 1/2 inches of K-28 firebrick.
- Furnace temperature is controlled from the output of one of the five (platinum/platinum-10% rhodium) thermocouples which are in platinum sheathing that is 1/8 inch in diameter. The thermocouples are mounted vertically

from the top of the furnace. Thermocouple output is converted to control the continuous output of a saturable core reactor for temperature control.

- Individual standard welding cable plug jacks are used for power connections.

Each melter furnace is supported on four compression type adjustable pipe hangers mounted on a four-wheel trolley. This arrangement provides for support of the melter and the furnace, and allows for thermal expansion. During remote maintenance operations, the furnaces may be disconnected and rolled toward the window on furnace track extensions for removal or replacement of parts.

5.4 WASTE POT FILL HEADS

Pot fill heads provide the transition connection between the waste pots and the solidification process equipment above them. Two types of fill head are used in WSEP: The melt pot fill head, shown in Figure 5.7, and the calcine pot fill head, shown previously in Figure 4.8a.

The melt pot fill head consists of a simple open tube which interconnects the sample chamber of the melter above with the waste pot below. Clamping action required to seal the pot to the head is provided by the pot hoist mechanism which consists of two 5 ton capacity worm gear jacks interconnected to raise and lower in unison when operated by a single impact wrench. When the pot furnace is moved to the "pot fill" or operating position, hooks on the jack shafts engage clevises on the pot hoist linkage. Raising the jacks to lift the linkage engages the fill head and pot head. Further tightening compresses the gasket to make the seal. Pot hoist mechanisms for both types of fill heads are identical.

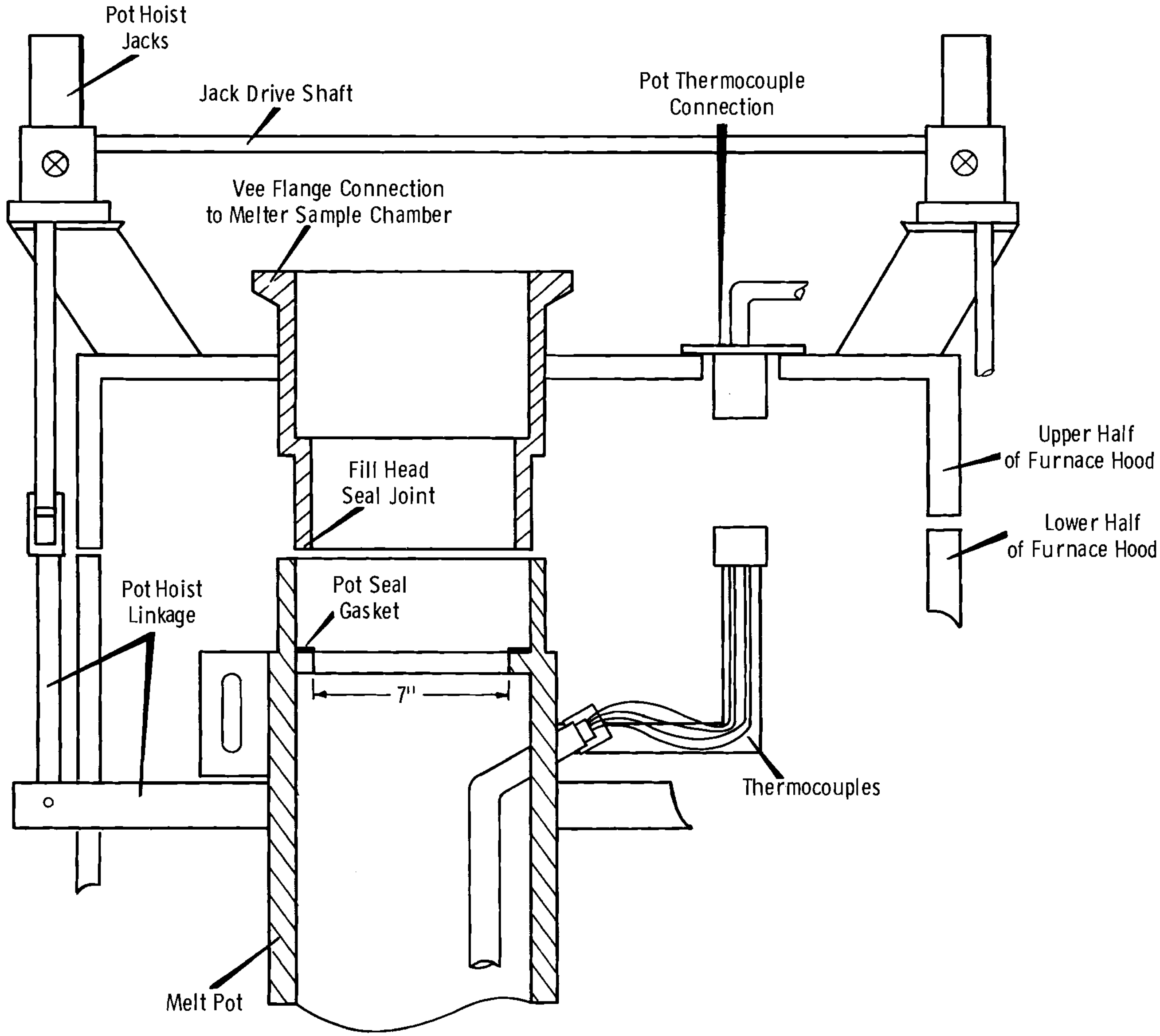


FIGURE 5.7. Melt Pot Fill Head

The calcine pot fill head is a manifold that is bolted to the pot furnace hood, and contains connections for off-gas, feed, chemical addition, pot pressure, and emergency vent piping. When the calcine pot is raised 6 inches to mate with the fill head, dowels in the head engage holes in the pot for alignment. The clamp drive is actuated by an impact wrench to close a special three-segment vee-flange clamp and seal the pot to the head.

5.5 PIPING CONNECTORS

Piping connectors were selected to meet the requirements of the specific chemical process and the remote handling requirements at minimum cost. General design and selection criteria are summarized in Table 5.3. One of the key factors is adaptability to the type of handling zone where the connector is to be used. Four handling zones can be identified in the B-Cell system:

- The fully remote handling zone is where all operations are performed using the remote overhead crane and an impact wrench suspended from the crane hook. Viewing is accomplished through shielding windows or with closed-circuit television. These areas are away from the viewing windows, and are usually inside, or on top of or on the aisle of racks inaccessible from the viewing windows.
- The semiremote handling zone is located around the viewing windows where at least one hand of a master-slave manipulator can reach objects for manipulation.
- The semicontact handling zone is located in the cubicles and the pipe trench where the operator must perform duties dressed in cumbersome radiation protection clothing. In these areas, the operator has direct contact with the connector through standard hand tools or has indirect contact through long-handled tools.

TABLE 5.3. *Piping Connector Requirements for WSEP*

Process	Mechanical	Economic
Leakage to be less than 10^{-3} cc/sec helium at pressures less than 100 psig	Must be adaptable to as many handling zones as possible	Connector must minimize time required to make/break under remote handling conditions
Corrosion rates to be no greater than with the associated piping	Connector must be durable, resistant to damage under severe make/break or special handling operations	Connector and gasket to be reasonably inexpensive
Connector must tolerate high gamma, beta radiation	Connector must tolerate misalignment	Connector and gasket to be readily replaceable
Most connectors must tolerate temperatures to 200 °C	Connector and tool size must be minimum to fit restricted cell space	Connector to permit reasonable jumper fabrication costs
Some connectors must tolerate temperatures to 700 °C	Maintenance must be minimized	Connector to permit ready decontamination
Connector must be suitable for sealing gases, liquids, and slurries	Connector must be suitable for connecting different materials at the same joint	Connector to require minimum maintenance
	Size from 1/4 inch pipe connector to 14 inch tank nozzle	
	Connectors must hold well with vibration	

- The contact handling zone is located in the Air Lock Cell and in operating and service gallery locations where normal maintenance is possible. Maintenance operations in these zones, as in the previous zones, are on the service side of piping through the plugs of process equipment.

Seven types of connectors were selected to provide the various connections in the WSEP equipment:

- The block connector
- Hanford remote connectors, called Purex connectors
- Hanford remote large flanges
- Commercial vee flanges modified for remote operations
- Standard bolted pipe flanges modified for remote service
- Compression-type tubing fittings
- Quick-disconnect fittings with and without integral shutoff.

The location, application, cost, and bases for selection for each type are given in Table 5.4. A brief description of the first five types is given below.

5.5.1 Block Connector

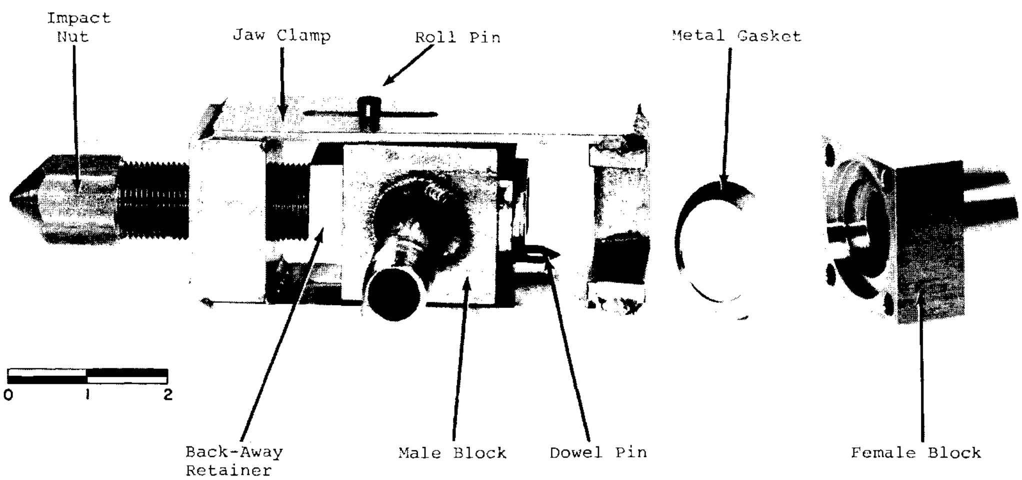
The WSEP block connector, shown in Figure 5.8, was developed by BNW specifically for the bulk of WSEP in-cell connectors. The block connector offers mechanical simplicity, durability, ease of operation with manipulators, small size for respective pipe sizes, and the option for using various types of face seals.

The block connector consists of male and female pipe nozzles on the ends of metal blocks, a U-shaped box-like hooking clamp with nonmoving side arms, a clamping bolt, and

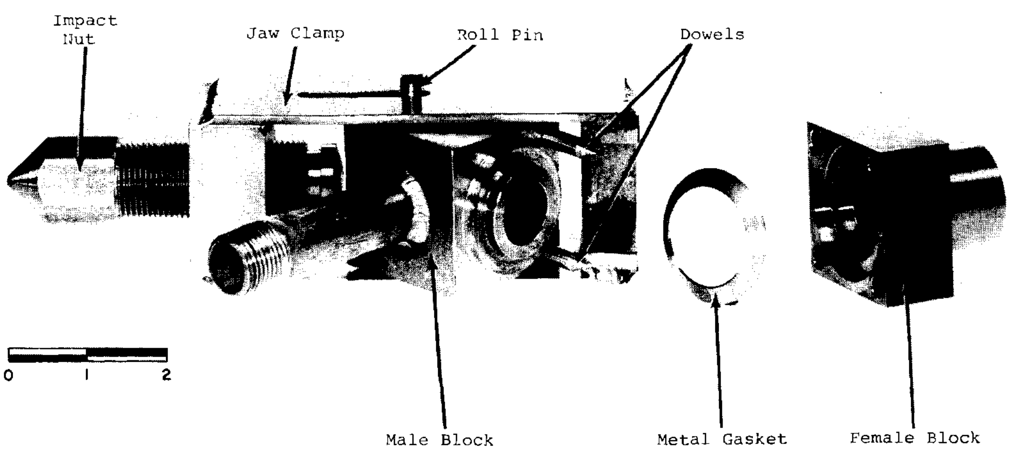
TABLE 5.4. *Pipe Connector Applications and Bases for Selection*

Connector	Zone[(a)]	Service or Application	Basis for Selection
1. Block Connector	2,3[(b)]	General process and utility service at the rack face and in the pipe trench	1. Mechanical simplicity and durability 2. Small size to minimize space 3. Adaptable to one-handed manipulator or simple tool manipulation 4. Available in all 304-L stainless, or in 304-L/titanium or other combination for transition joints 5. Good radiation, corrosion, and temperature resistance
2. Vee-flange Connectors	1,2,3	1. Large low-pressure offgas lines 2. Process lines where straight-through flow is a must 3. Small low pressure lines where transitions are required	1. Provides straight-through piping 2. Provides minimum axial and radial size and weight for larger offgas lines
3. Bolted pipe flanges	2	Offgas line or other process applications where connection to flanged equipment is required	Provides multibolt flanging to commercial equipment not available with other flange types
4. Purex Connector	1	Offgas or other process applications in the fully-remote handling zone	Only known reliable connector for this service at the time of selection
5. Remote flange	1	Pumps agitators and tube bundles in rack vessels	Fully remote flange required for Zone 1
6. Compression Type Tube Fittings	2,3,4	1. Cubicle process and service piping connectors 2. Limited space applications only in Zone 2 3. General purpose use in Zone 4	1. Minimum size 2. Lowest cost in acquisition and field installation
7. Quick-disconnect Fittings	2,3,4	Pot storage sampling	Convenience in fast make/break on multipoint sampling

(a) *Zone numbers refer to the tabulated descriptions in the text*
(b) *Block connectors are also used in Zone 1, primarily for transition joints in limited space applications, but require careful design to adapt to remote handling conditions*



Backaway Connector



Swing Connector

FIGURE 5.8. Block Connectors

a gasket. One or two dowels are normally used in the male nozzle for guide-in. The female nozzle is normally welded to the fixed equipment (e.g., at the end of a pipe which is welded to a major process vessel and which terminates at the rack face), while the male and the clamp are on the pipe jumper. The female connectors on the process racks are mounted to permit 1/16 to 1/8 inches of movement in any direction to allow for misfits in the piping jumpers.

Two versions of the block connector, shown in Figure 5.8, are used: the swing-type, and the backaway-type. In the swing-type of connector, the male block is attached to the clamp by roll pins which act as pivot points for rotating the clamp about the male block. The two parallel-faced nozzles on each end of the removable jumpers are first oriented directly in front of their respective mating nozzles with the clamps swung out of position. The mating nozzles are then pushed together using the alignment dowels. After the nozzles are together, the clamps are swung into position behind the female blocks, and the clamps are tightened by turning the bolts with a wrench. The swing connector is frequently used on rigid pipe jumpers. In the backaway-type of connector, the male block is attached to the clamp by roll pins plus a loose-fitting joint at the end of the bolt. For connections, the two mating nozzles are brought into approximate alignment by sliding the pipe jumper into position with the clamp behind the female block, then pushing the two nozzles together as guided by the dowels. The bolt is then tightened to seal the joint. For disconnection, the two blocks are pulled apart directly as the bolt is loosened. The backaway connector is frequently used on flexible pipe jumpers where the positive separating action is especially beneficial.

Connector dimensions and space requirements for the three sizes of block connectors used in WSEP are listed in Table 5.5. These space requirements may be compared with the 6 inch diameter clearance circle required for the 1 inch, 150 pound standard pipe flange.

TABLE 5.5. *Overall Dimensions of Block Connectors in WSEP (In Inches)*

Nominal Pipe Size	Overall Connector Cross Section with Clamp	Minimum Center Spacing*
3/8	1 5/8 x 2	1 3/4 x 3 1/2
3/4	2 x 2 1/2	2 1/4 x 5 1/2
1 1/2	3 x 3 1/2	3 1/2 x 7

* *Assuming that two blocks share swing or slide-in space for clamps.*

The face seal selected for the block connector is a patented configuration known as the Conoseal. The Conoseal features conical nozzle surfaces between which the metal conical gasket (a "Belleville" washer) is slightly flattened to produce a toggle action on the gasket. This flattening generates high unit seal pressures with minimum clamping forces. This type seal was chosen as basic to the block connector for four major reasons:

- Nozzles can be fabricated from austenitic stainless steels, titanium, or other materials available as bar stock that are machinable and weldable. Hence, they are readily adaptable to most WSEP piping systems and for use in transition joints (e.g., stainless steel or Nionel to titanium).
- The seal is reliable, and meets the leakage criteria in Table 5.3 under the adverse conditions of remote handling.
- The all-metal nozzle is resistant to corrosion, nuclear radiation, and high temperatures; hence, it has a wide range of use in WSEP processes.
- Sealing surfaces are protected by internal geometry against damage in remote handling, resulting in a relatively durable seal which suffers very little from the rough handling associated with remote operations.

The seal is also usable with soft gasketing materials, such as Teflon, Neoprene, or asbestos. Long-term effective sealing is accomplished with those materials which are damaged rapidly by radiation because of the total containment of the gasket within the joint. Such uses are planned in WSEP.

Some of the 1 1/2 inch connectors have three small pipes (one 1/2 inch and two 1/4 inch) arranged in a triangle. These are used for liquid samplers.

5.5.2 Purex Connector

The Purex connector, shown in Figure 5.9, is a rugged pipe connector which has given many years of reliable service in the nuclear chemical processing industry where fully remote handling is employed. The connector consists of:

- The spherical jointed male nozzle which is part of the fixed piping.
- The female block nozzle which is part of the movable piping.
- The guide skirt and gasket (Teflon or Teflon-asbestos) subassembly.
- The three-jaw gear-puller type clamp mechanism with a 2 inch drive nut.

The female block, guide skirt, and clamp are bolted together and operate as a unit. In operation, a pipe jumper which is hanging from its balance point on a crane hook is placed on the fixed male connector with the clamp hooks open. The loose jumper is held in position by its own weight, by the guide skirt, and by the stabilizing action of the open clamp hooks. An impact wrench is then picked up with the crane, placed on the clamp drive nut, and operated remotely to close the clamp and seal the connector nozzles. Positioning is normally by viewing through a periscope,

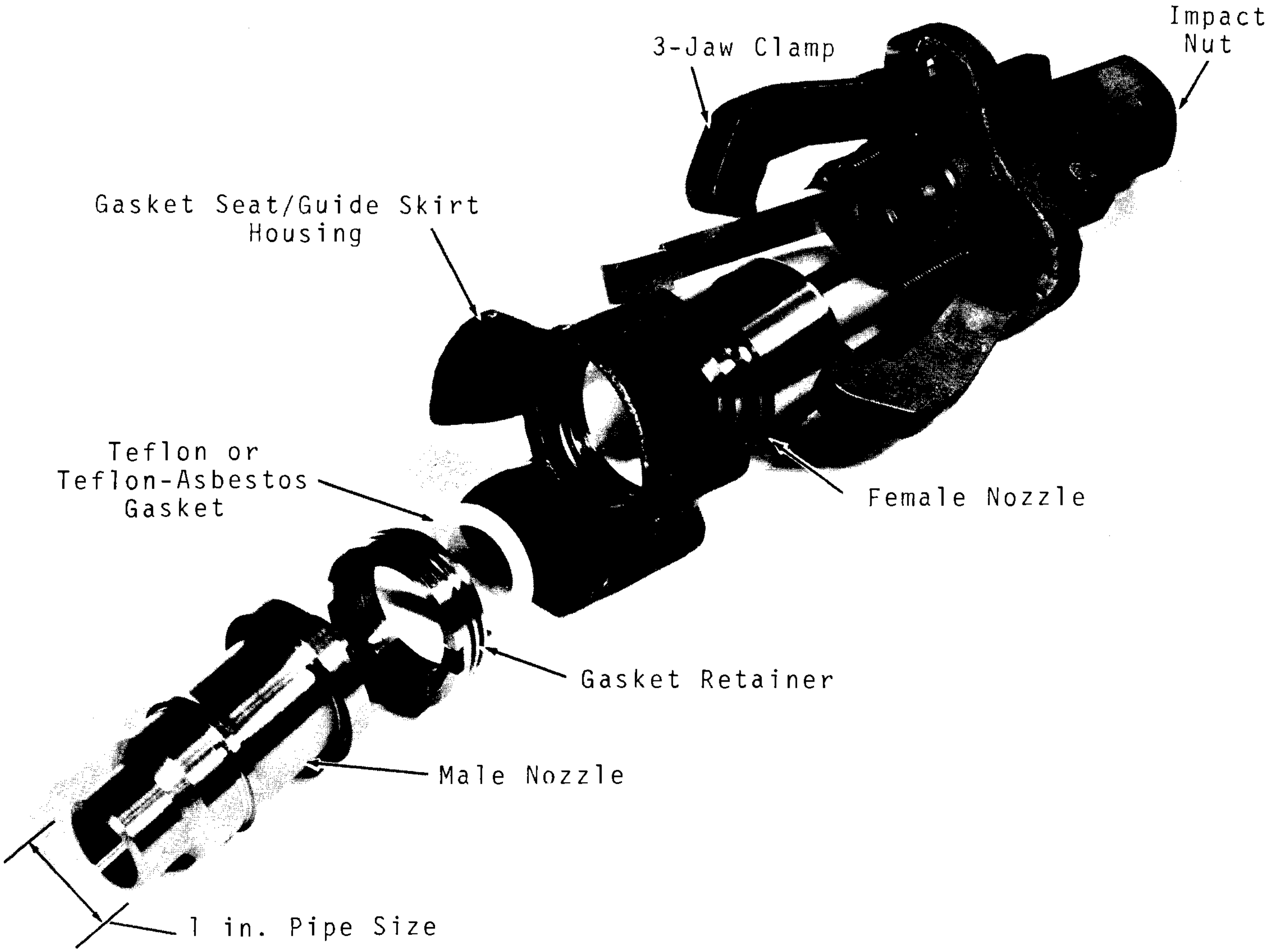


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FIGURE 5.9. *Purex Connector*

closed-circuit television, or shielding windows. Connectors are designed to be operated by impact wrenches rated for 500 ft-lb of torque. The connector provides a good seal long after the gasket deteriorates due to radiation, because the gasket is wholly confined until the connector is loosened. Application data for Purex connectors used in WSEP are given in Table 5.6.

5.5.3 Hanford Remote Flange

The Hanford remote flange was developed for remote operation in applications where the Purex three-jaw connector could not be used, primarily for joining pipes larger than 4 inches in diameter. These flanges are used in WSEP for mounting pumps, agitators, and tube bundles on nozzles that are 10 to 16 inches in diameter. Flatface sealing is employed with stainless steel/blue asbestos spiral-wound gaskets.

Remote flanges are machined from plate that is 3/4 to 1 1/4 inches thick. The flanges are guided into place by two diametrically-opposite dowels, and are fastened by four remote studs. The remote studs have Acme threads and tapered thread lead-in for ease of thread engagement with the nuts. Nuts are standardized at 2 inches across the flat portion of their hexagonal shape. The nuts have a tapered head for ease of engagement of the socket of the impact wrench and threadless lead-in at the bottom of the nuts. Retaining cups on the flanges hold the nuts in position during equipment transfer and removal. Remote dowels on the mating fixed flanges are tapered on the end and are of unequal length for improved ease of engagement.

5.5.4 Vee Flange Connectors

Vee flange connectors are used in pipe and tubing sizes from 1 inch to 8 inches for a wide variety of special applications, summarized in Table 5.7. The main reasons for using

TABLE 5.6. *Purex Connector Application Data for WSEP*

Pipe Size, in.	Type	Applications	Length,[a] in.	Weight,[a] lb	Clearance Circle Diam, in.
1	Standard	1. Acid fractionator and waste evaporator tube bundle steam supply and condensate outlet	14	20	6
		2. Agitator seal water connection			
		3. Inline feed pump and submerged condensate pump discharge			
		4. Acid fractionator scrub tower bypass nozzles			
2	Standard	1. Inline feed pump suction	13	30	8
2	3-way[b]	1. Inline feed pump cooling and lubricating water	13	30	8
3	Standard	1. Waste evaporator-acid fractionator tower offgas connections	18	90	12 3/8

(a) *Does not include the male nozzles*
(b) *3-way connectors contain three 1/2-inch pipes on the same nozzle.*

TABLE 5.7. *Vee Flange Connector Application Data for WSEP*

Connector	Nominal Size, in.	Type of Face Seal	Application	Special Features
Nucoseal	6 and 8	Flatface[a]	Melter furnace, spray calciner, and transition joints	1. Minimum axial space (1 1/4 inch) required 2. Chain and sprocket bolt drive for single bolt actuation 3. Machined clamp
Nucoseal	2	Flatface	Off-gas lines, and platinum melter nozzles to stainless steel transition joints	1. Formed clamp with minimum space requirement 2. 2-bolt drive
Grayloc	4	Grayloc[c]	T-113 to E-113 jumper and titanium to stainless steel transition joint from T-115 to E-115	1. 3-piece clamp with single bolt drive
Marman	1 to 3	Conoseal	Process lines where straight-through flow is required	1. Standard Marman pipe connector modified for remote handling[b]

(a) *Asbestos-gasketed and ungasketed flanges are used*
(b) *Remote handling modifications include: 1) Add manipulator tee-handle for gripping, 2) Weld bolt nuts to opposite clamp half, 3) Use extended bolts with keeper nuts on the ends to make a one-piece assembly*
(c) *A metal-to-metal mating of 2 truncated cones with different conical angles.*

vee flange connectors are to provide a straight through pipeway and to minimize space requirements. Conventional vee flange geometry consists of two mating flanges coupled with a split bolted clamp. The sides of the flanges and the clamp are tapered to provide a wedging action as the parts of the clamp are pulled together. The resultant sealing pressures are normally lower than for a standard bolted flange, so that low force seals must be used or the connector must be used for low pressure application.

Standard two-bolt vee flange pipe clamps were modified for in-cell use by welding tee-bar handles for manipulator use on the front half of the clamp, by welding the nuts to the back half of the clamp, and by welding "keeper" nuts on the remote flange bolts. The keeper nuts prevent disengagement and loss of the bolt in the cell.

The special two-piece, single-drive Nucoseal vee clamp is used in remote applications requiring sealing of relatively large diameter low-pressure vee flanges. Flange bolts are threaded right and left hand so that when rotated in unison, clamp halves separate equally. The two bolts are normally coupled together by drive chains so that the clamp may be opened or closed from a single input drive.

The three-piece Graloc vee flange clamp is used in the fully remote zone where use of the Purex connector is not feasible. Features of the remote three-piece vee clamp include:

- Single bolt drive to open or close the clamp
- Positive gasket retention
- Attachment of the clamp sections to the "jumper" by cam plates; the cams control the motion of the clamp segments to provide positive opening.

5.5.5 Modified Standard Pipe Flanges

Standard four-bolt pipe flanges are used in the cell only where the equipment is not readily adaptable to other types of connectors. Flanges are not commonly used in the cell because multibolt flanges are time-consuming to make and break (particularly when engaging stainless steel parts), and loose bolts and nuts are troublesome to handle. Where flanges are required, they are modified for in-cell use by tapping or welding nuts to the flanges to eliminate loose nuts, and by splitting the "permanent" flange and bolting it around the stub end of the pipe. If the threads on the flange gall, the flange may be removed and replaced.

5.6 PUMPS

The pumping needs for WSEP are to pump a continuous stream of feed solutions from the feed tanks on the 1B Rack or from the evaporator on the 1A Rack to either of the two solidifier positions, to continuously recirculate caustic from the tank to the tower of the scrubber, and to pump fractionator condensate from the 2A Rack to the solidifiers via the 1A and 1B Racks. Canned motor and conventional centrifugal pumps of three varieties are used. The three types of pumps used are referred to as the submerged pump, inline feed pump, and the modified inline feed pump.

5.6.1 Submerged Pump

The canned-motor submerged pumps, shown in Figure 5.10, are suspended vertically inside the 2A Rack vessels (116 and 118 Tanks) hanging downward from vessel flanges. As in typical canned-motor construction, both the rotor and stator are enclosed in a thin-walled stainless steel can, and process solution is used to cool the motor and lubricate the bearings. Pumps are rated for 40 liters/min at 90 feet of head. The rating of the three-phase ac drive motor is 3 horsepower at 480 volts.

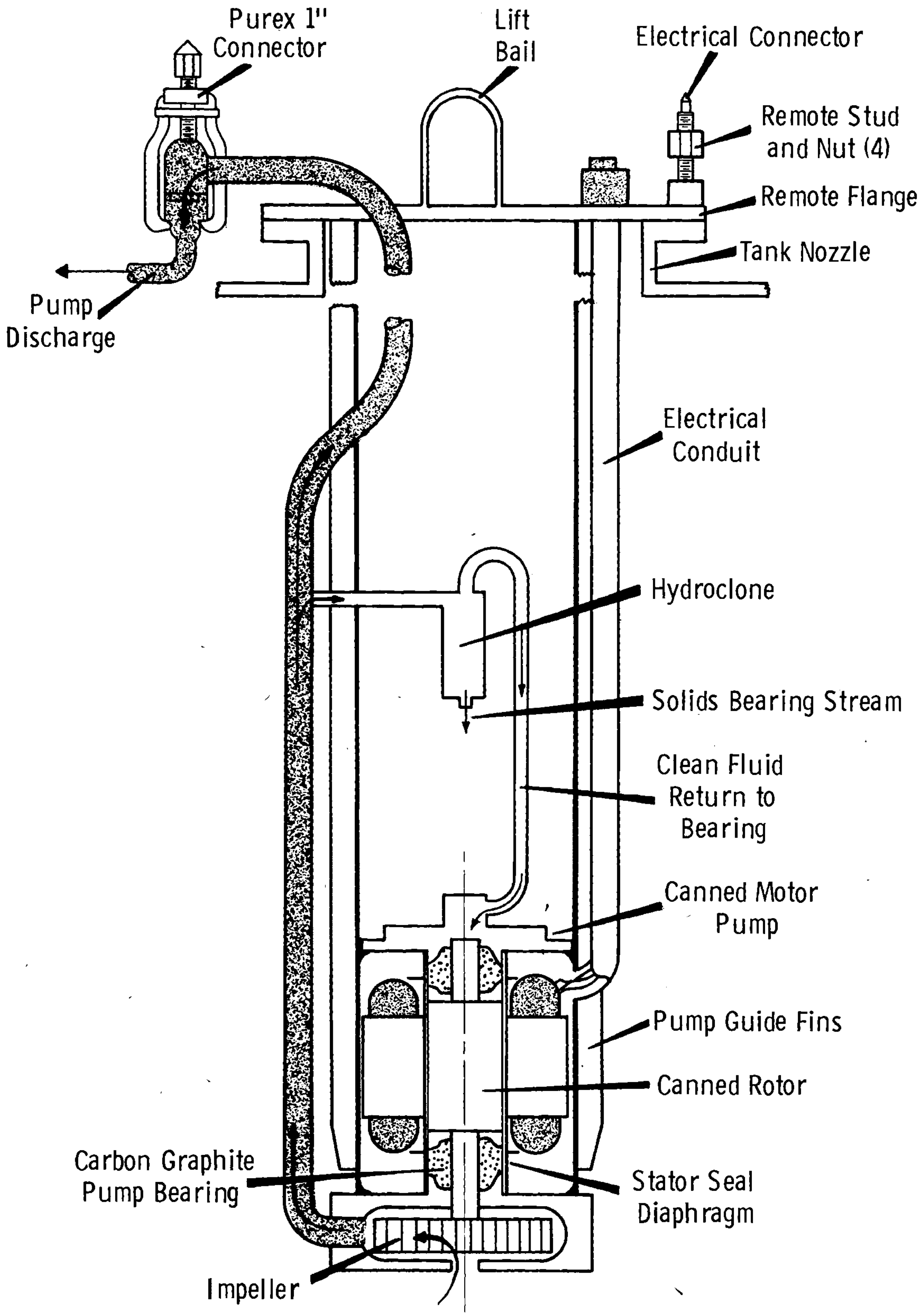

FIGURE 5.10. Submerged Pump Assembly

Fluid discharging from the centrifugal impeller flows upward and outward through a Purex connector. Part of the pumped stream is routed to a bypass which feeds a hydroclone where solids are removed and returned to the tank, and the cleaned stream is routed to the bearings and motor coolant channel. Thus, the bearings are protected from contact with large foreign particles in the tank.

5.6.2 Inline Pump

The inline pump, shown in Figure 5.11, uses a canned-motor pump with the same rating as the submerged pump, but arranged with a mechanical seal between the centrifugal impeller and the motor. With this arrangement, a separate clean water supply is used for motor coolant and lubricant, shown schematically in Figure 4.17, so that slurries at relatively high temperature and with a high percentage of solids can be pumped. Boron carbide, graphite, or other special materials are used for bearings and seals.

The inline pump is mounted horizontally, hanging from a channel frame, and is fitted with Purex connectors for pump suction and discharge, and motor coolant. The connectors are mounted horizontally with special nonadjustable hooks on the connector skirt. With these features, the assembly can be positioned on the nozzles by the crane, and will hang safely during the time required for the crane to return with the remote impact wrench.

5.6.3 Modified Inline Pump

The modified inline pump assembly, which was designed as a substitute or replacement for the inline pump, uses a conventional centrifugal pump. The pump assembly, shown in Figure 5.12, connects to the piping connectors of the feed tank on the 1B Rack with fully-remote Purex connectors, and elevates the pump into a more accessible location which is

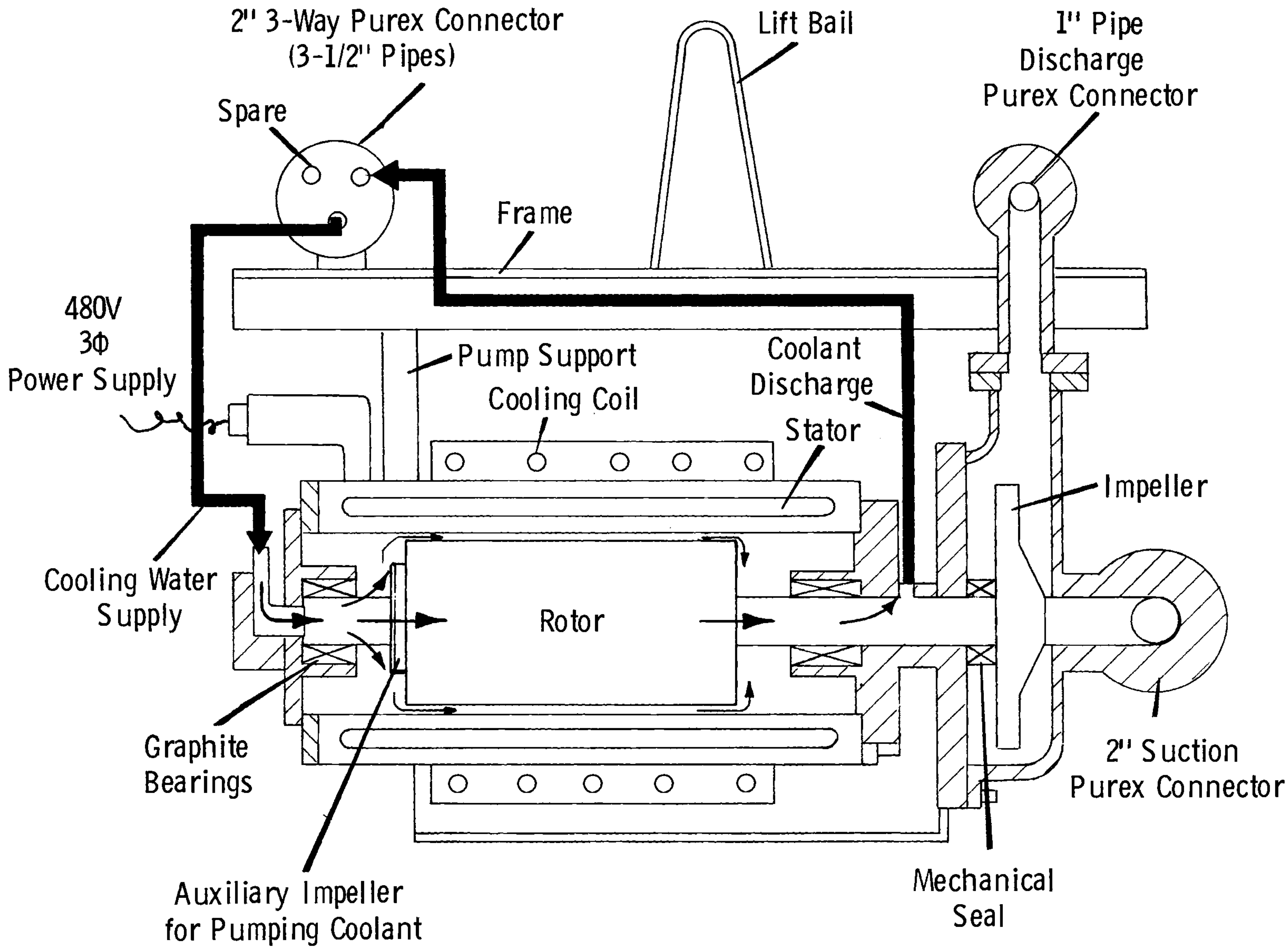

FIGURE 5.11. Inline Pump Assembly

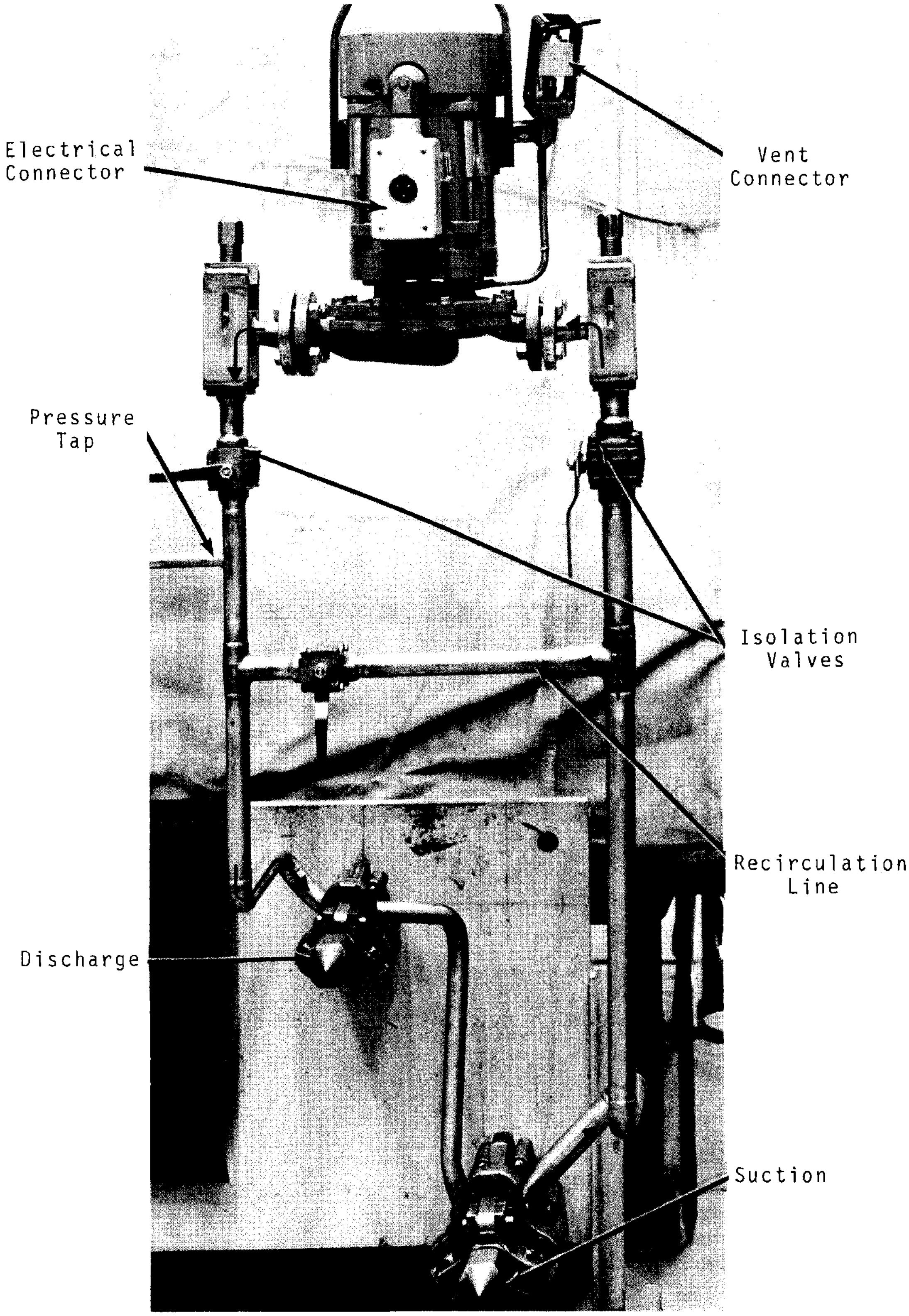

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FIGURE 5.12. Modified Inline Pump Assembly

suitable for quick remote change-out. The pump is remotable from the rest of the assembly through the two block connectors. Manual manipulator-operated valving is provided for pump recirculation to control discharge pressure, isolation of the pump during repairs, and venting to eliminate air locks during startup.

The pump contains double mechanical, water-lubricated seals with graphite rotating rings. The capacity of this pump is similar to the two discussed previously.

5.7 AGITATORS

Top entering agitators, as shown in Figure 5.13, are used in the feed and condensate tanks on the 1B and 3B Racks, and in the feed stock storage Tank 107 in the C-MEL waste vault, to keep solids suspended in the liquids. All are mounted vertically except the agitator in the 107 Tank, which is mounted 22 degrees from vertical to permit enough head room for installation and removal. Agitators are equipped with three-bladed propellers and double mechanical or labyrinth type seals. Design details for the five types used in WSEP are summarized in Table 5.8.

Dual-propeller agitators are preferred where cleanup of the upper portion of the tank internals (aided by agitator splashing from the propeller) is desired. Double mechanical seals are used on the agitators in feed Tanks 112 and 114 on the 1B Rack, and in Tank 117 on the 3B Rack where air inleakage to the tanks (tanks are maintained under slight vacuum) must be minimized. The labyrinth seal is used in the feedstock storage Tank 107 where air inleakage is less critical and where disposal of gland seal water is inconvenient.

The double mechanical seals require water for lubrication of the spring-loaded carbon-graphite seal rings rotating against stationary Stellite rings. The labyrinth seal consists of an unlubricated close-fitting carbon-graphite bushing which

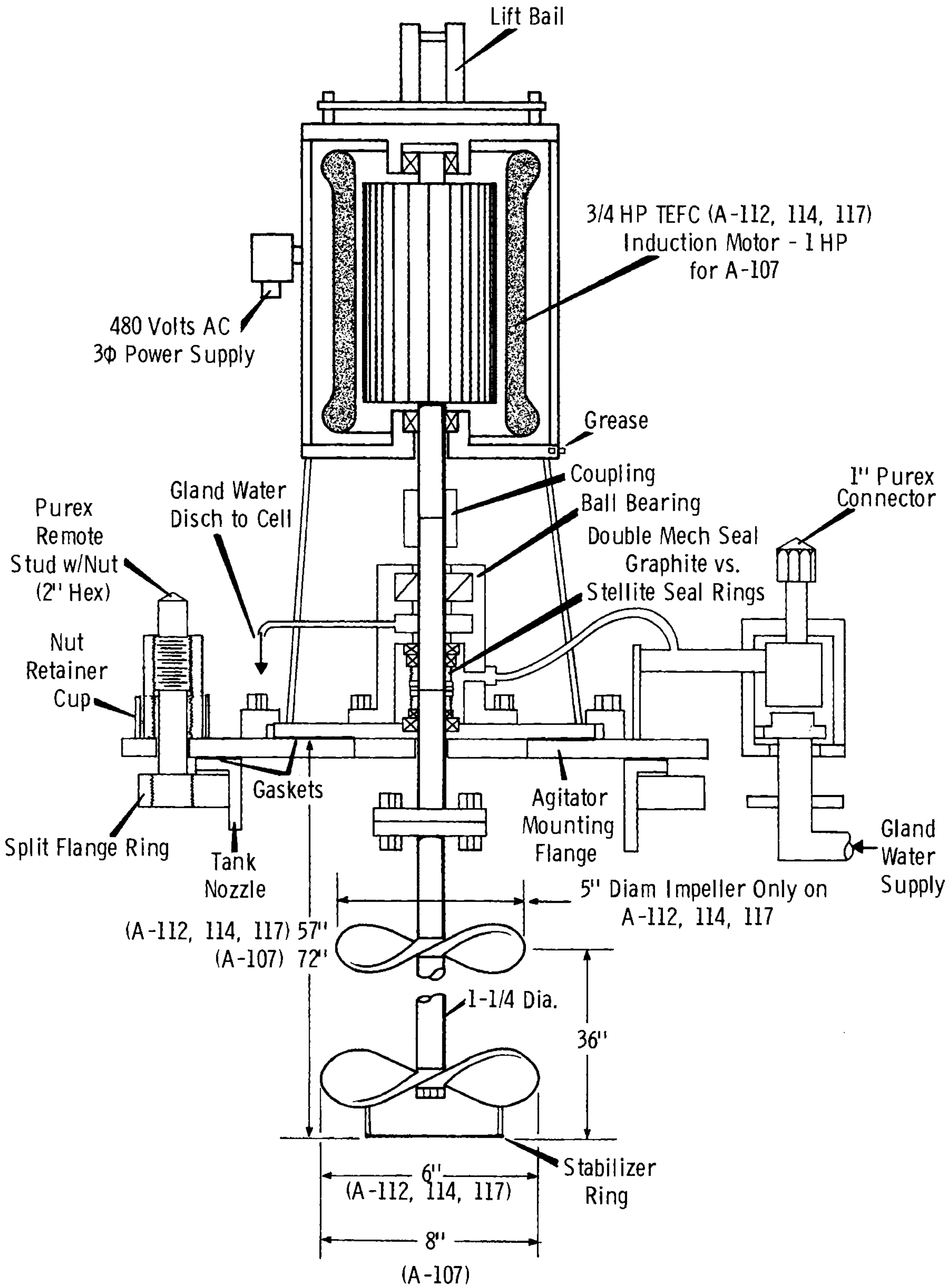


FIGURE 5.13. WSEP Agitator Assembly

TABLE 5.8. *WSEP Agitator Design Data*

Type	Motor Data	Propeller Arrangement	Stabilizing Ring	Shaft Seal Type[b]	Shaft Diam. Length,[a] in.	Initial Tank Use	Seal Guide Bearing
1	3/4 hp, 1150 rpm, 480 V, 3-phase ac, TEFC[c] with conventional shaft	Dual props-6 in. on bottom, 5 in. on top. Top 36 in. above bottom	Yes (bottom only)	Double Mechanical	1 1/4 x 57	112, 114, 117	Grease Lubed Ball Bearing
2	Same as Type 1	Single 7 in. diameter	Yes	Double Mechanical	1 1/4 x 57	Spare	Grease Lubed Ball Bearing
3	1 hp, 1150 rpm, 480 V, 3-phase ac, TEFC with conventional shaft	Single 8 in. diameter	Yes	Carbon-Graphite Labyrinth	1 1/4 x 72	107	Grease Lubed Ball Bearing
4	1 1/2 hp, 900 rpm, 480 V, 3-phase ac TEFC hollow shaft	Single 9 in. diameter	No	Double Mechanical	1 x 57	Spare	Water Lubed Bronze Sleeve
5	Same as Type 4	Single 9 in. diameter	No	Carbon-Graphite Labyrinth	1 x 72	Spare	Grease Lubed Ball Bearing

(a) *Below mounting flange*

(b) *Mechanical seals have carbon-graphite rotating seal rings and Stellite 6 (Union Carbide Corporation) stationary seal rings*

(c) *Totally enclosed fan cooled*

is grooved internally to reduce leakage. Seal guide bearings are located integral with or near the seal to reduce shaft whip and improve seal reliability. Some agitators have rings attached below the paddles to provide stability when low liquid levels are being agitated.

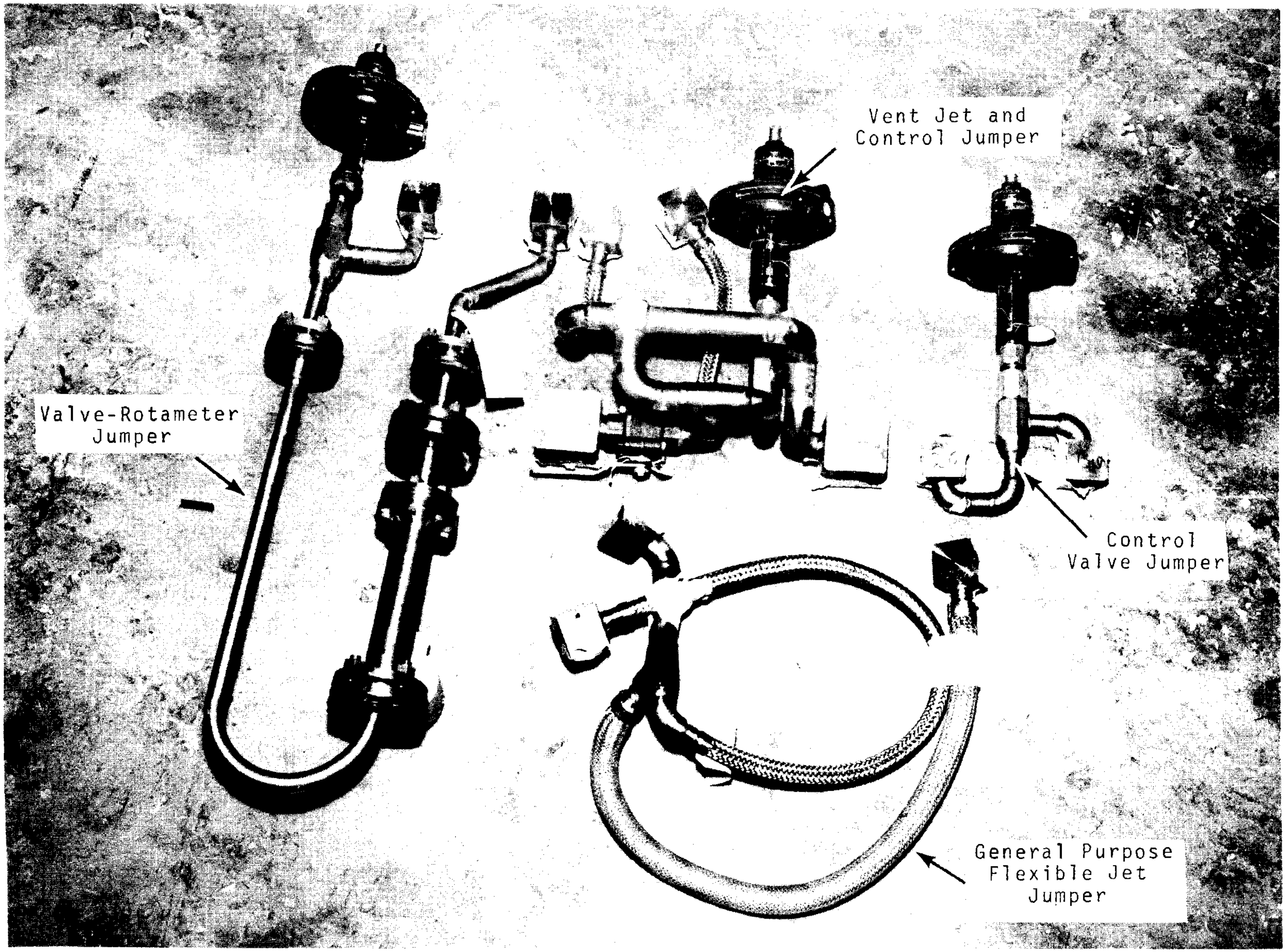
The agitators are mounted on remote flanges which are fastened to split removable flanges on the tanks. Agitators must be installed and removed by remote handling procedures described in Section 5.5.3.

5.8 PIPING JUMPERS

Fluid transfers between racks are made through removable pipe assemblies known as jumpers. Rotameters, control valves, jets, samplers and other fluid transfer and control devices which are subject to failure, are built into the jumpers to facilitate replacement for process or for maintenance purposes. Photographs of some typical jumpers are shown in Figure 5.14. Items shown in the figure are a utility jet jumper fitted with braid-covered stainless steel flexible hose for suction and motive gas supply lines, a jumper with a control valve and transmitting rotameter, and the process vacuum ejector with its vacuum control valve.

Variable flow control valves are air diaphragm-operated plug valves; shutoff valves are air cylinder or electric solenoid or manually operated valves with linear polyethylene or polytetrafluoroethylene seats. Most of these manual valves are ball valves, but the small valves are frequently blunt-needle valves. Radiation resistant magnetic flow meters are used for metering flows of streams containing large quantities of radiation, such as feed streams.

Jumpers are usually fitted with male block connector nozzles and clamps for connection to nozzles on the manipulator



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<u>FIGURE 5.14</u>. Typical Pipe Jumpers in WSEP

face of the process equipment racks. These rack face nozzles are arranged on a basic 7 inch square grid to insure the interchangeability of jumpers.

Jumper alignment from nozzle to nozzle is provided for in three ways:

- Rigid pipe jumpers are fabricated in special jigs to assure that the basic 7 inch grid spacing (or multiples or halves) is maintained in fabrication.
- Flexible metal hoses are used where possible, especially on jumpers with three or more connectors (e.g., for the air supply connection to diaphragm-operated valves).
- Permanent rack face nozzles are mounted with some freedom of motion in the nozzle support frame. Connecting pipes are brought through holes in the frame which are about 1/16 inch oversize in diameter. About 1/8 inch axial movement of the nozzle is provided by welding locking rings to the pipe on both sides of the frame. Thus, nozzles can be pushed, pulled, and twisted a limited amount to align with jumpers.

Dowels on the connectors provide the basic guide-in mechanism for alignment of male and female nozzles.

5.9 SAMPLING

Solids, liquids, and gases are sampled at various locations in the WSEP for process evaluations and control. The systems are represented schematically in Figure 5.15.

5.9.1 Solids Sampling

Solids sampling in WSEP is limited to "catch" samples of a stream of phosphate glass or spray solidifier melt as it flows out of the melter. Molten waste being discharged from glass melter crucibles into the waste containers below, drops through the melt sample chamber. Flared stainless steel

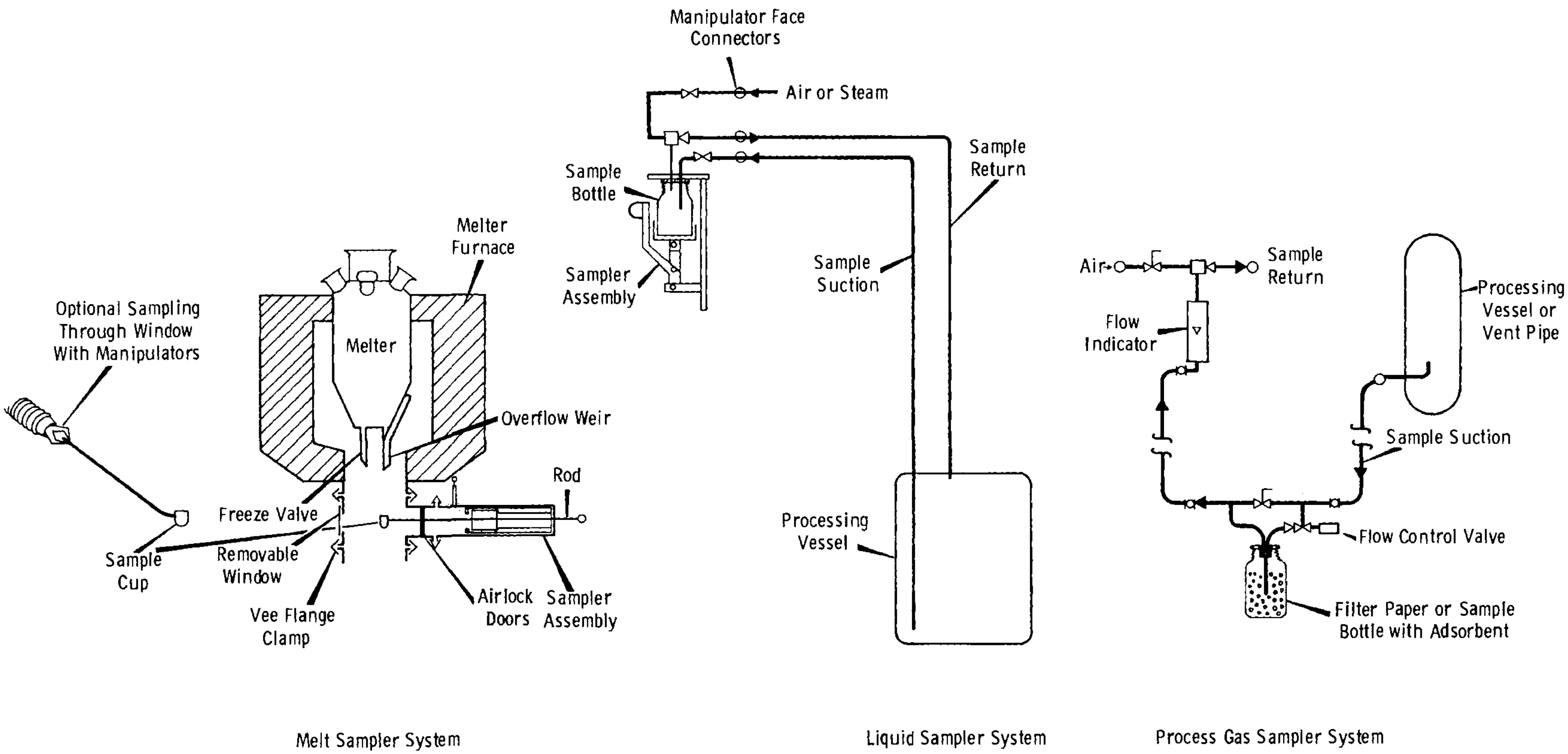


FIGURE 5.15. WSEP Sampling Systems

sample cups resting on two wire fingers at the end of a sliding rod are inserted under the stream of melt until filled, then the rod is retracted through a slide valve into a side chamber for recovery of the 8 milliliter sample plug of solidified melt. Samples may be taken from either of the two melter discharge ports in line with the sampler traverse.

An optional method of sampling the melt is to temporarily remove the front window on the sample chamber, then insert the sample cup through this open window on the end of a long handle (using manipulators).

Additional sampling of solidified waste will be done by core drilling through the filled pots in the product evaluation portion of the WSEP program. This technique and equipment is described elsewhere.[(1)]

5.9.2 Liquid Sampling

Liquid samplers are provided in all WSEP process tanks. In addition, samplers are provided in the condensate streams from the three main process condensers and at two points in the fractionator tower.

The liquid sampler system uses an ejector to pull the full flow of the sample through a sample bottle before returning the sample flow to the tank.

The liquid sampler is a miniaturized removable device which is connected to the rack face in the cell with a three-way block connector. The sampler contains all the equipment necessary to draw samples except connecting lines to the tank. The sampler consists of a toggle linkage mechanism for positioning the sample bottle, a sample transfer jet, manual valves for the jet motive gas and the jet suction pipe, interconnecting piping, and the sampler frame. The sampler assembly is shown in Figure 5.16. Fifteen milliliter glass sample bottles are placed in the positioner cup and the positioner is raised

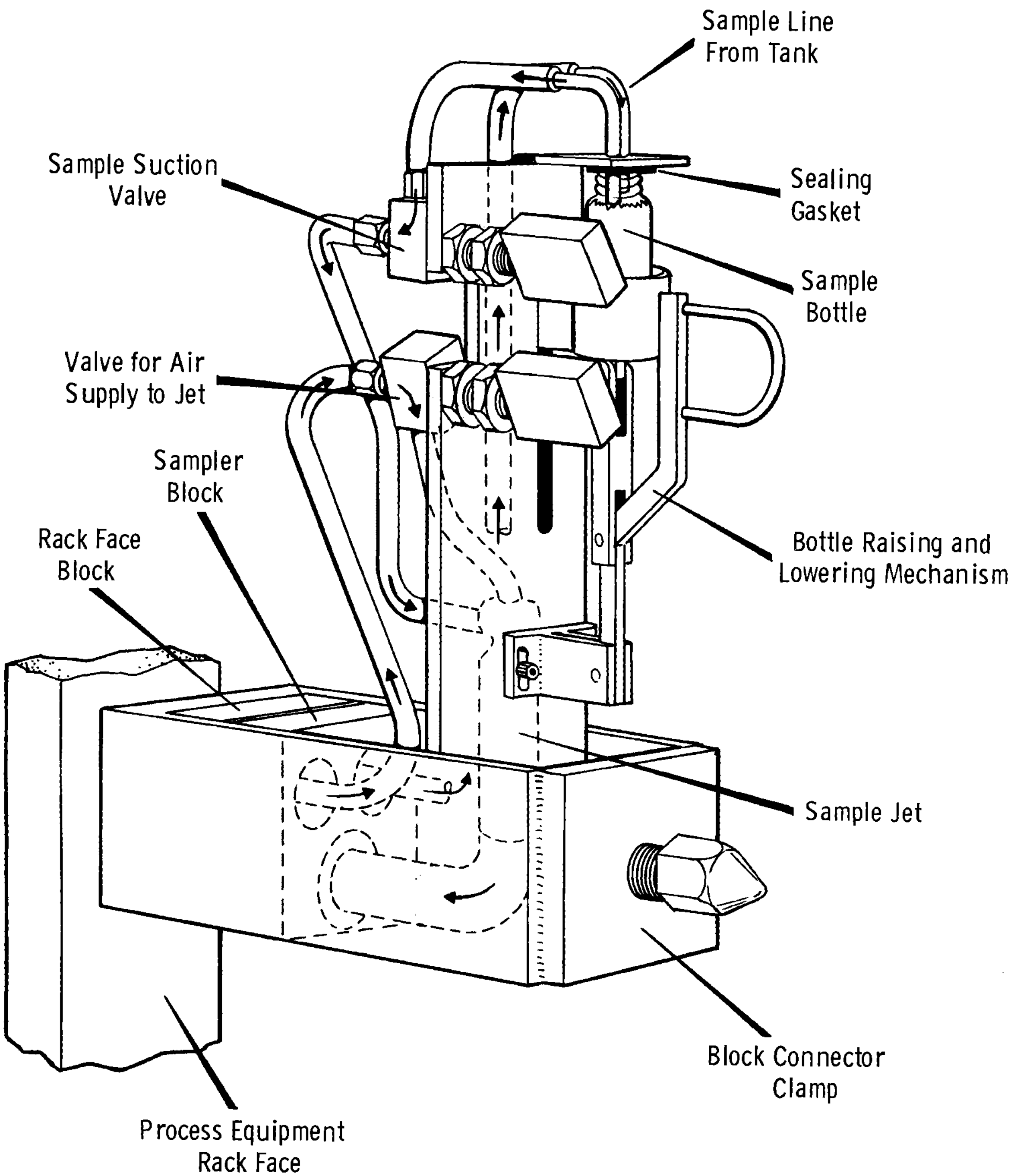


FIGURE 5.16. WSEP Liquid Sampler Assembly

to seal the bottle against a gasket surrounding the two sampler tubes. The air (or possibly steam) supply to the jet is turned on and the sample suction valve is opened. Liquid is sucked out of the tank and through the bottle, returning to the tank. After sufficient circulation to insure a representative sample (5 to 10 minutes), the two sampler valves are closed and the filled sample bottle is removed and capped with a screw top. The sample is put into appropriate shielding containers, removed from the cell, and trucked to the analytical laboratory. The sampler will circulate 0.4 liters/min of liquid using 15 liters/min of motive air at 90 psig for a 13 foot lift. If steam is used (not currently planned) the liquid flow rate is about 4 liters/min. The liquid holdup in the suction piping is about 1/2 to 1 liter.

5.9.3 Gas Sampling

Process gases and in-cell air may be sampled to monitor gases and airborne particulates in the gases for radioactivity content. Process gases may be sampled at three locations downstream from the solidifiers: 1) downstream from the primary process condenser (E-111), 2) downstream from the process evaporator condenser (E-113), and 3) downstream from the caustic scrubber. Downstream and outside of the cell, process and vessel vent gases from the waste storage tanks are mixed together where they are filtered. The process gases are then combined with the ventilation air from all the cells and other parts of the building, and are routinely sampled after the final stage of filtration and before being emitted from the stack.

Each of the three in-cell gas sampling points may be connected to a sampling jumper which contains a sample holder and a small suction jet that discharges the gases back into the process vent system downstream of the sample point. Gas sample streams of 10 to 100 cm^3/min are pulled through a container of adsorbent (such as formaldehyde-treated silica gel for trapping gaseous ruthenium) and/or a filter for trapping particulates. The samples are then removed from the cell for gamma emission analysis.

The sampling of the mixed process and vessel vent gases downstream of the cell involves sampling for radioiodine and particulates before or after the last stage of high efficiency filtration before the gases are mixed with the cell ventilation gases. Particulate sampling involves pulling 120 liters/min through a continuous strip filter from which the gross radiation reading is recorded. A parallel sample stream of 35 liters/min is pulled through a small bed charcoal (1/2 inch in diameter by 1 3/8 inches long) to adsorb iodine. Radiation readings of the charcoal filter are recorded, and the filter is replaced periodically.

Samples of the 3,000,000 liters/min of total building gases are taken from the duct just before the gases enter the stack. One 40 liters/min sample is pulled through a strip filter to trap particulates. Another 40 liters/min sample is prefiltered, then pulled through a small scrubber containing 0.1M NaOH for removal of gaseous iodine and ruthenium. Gross radioactivity is continuously recorded. The scrubber solution is analyzed weekly by a gamma scan and the filter paper is analyzed for total alpha and beta radioactivity.

5.10 TRANSFER MECHANISMS AND SPECIAL MECHANICAL DEVICES

5.10.1 Gallery-to-Cell Transfer Mechanism

Small casks for samples, tools, small jumpers and other objects which can be passed through a 12 inch square opening and which weigh less than 100 pounds are transferred between the cell and the service gallery through the sample transfer mechanism, shown in Figure 5.17. On the gallery side, the transfer mechanism terminates in a hood enclosure which, in

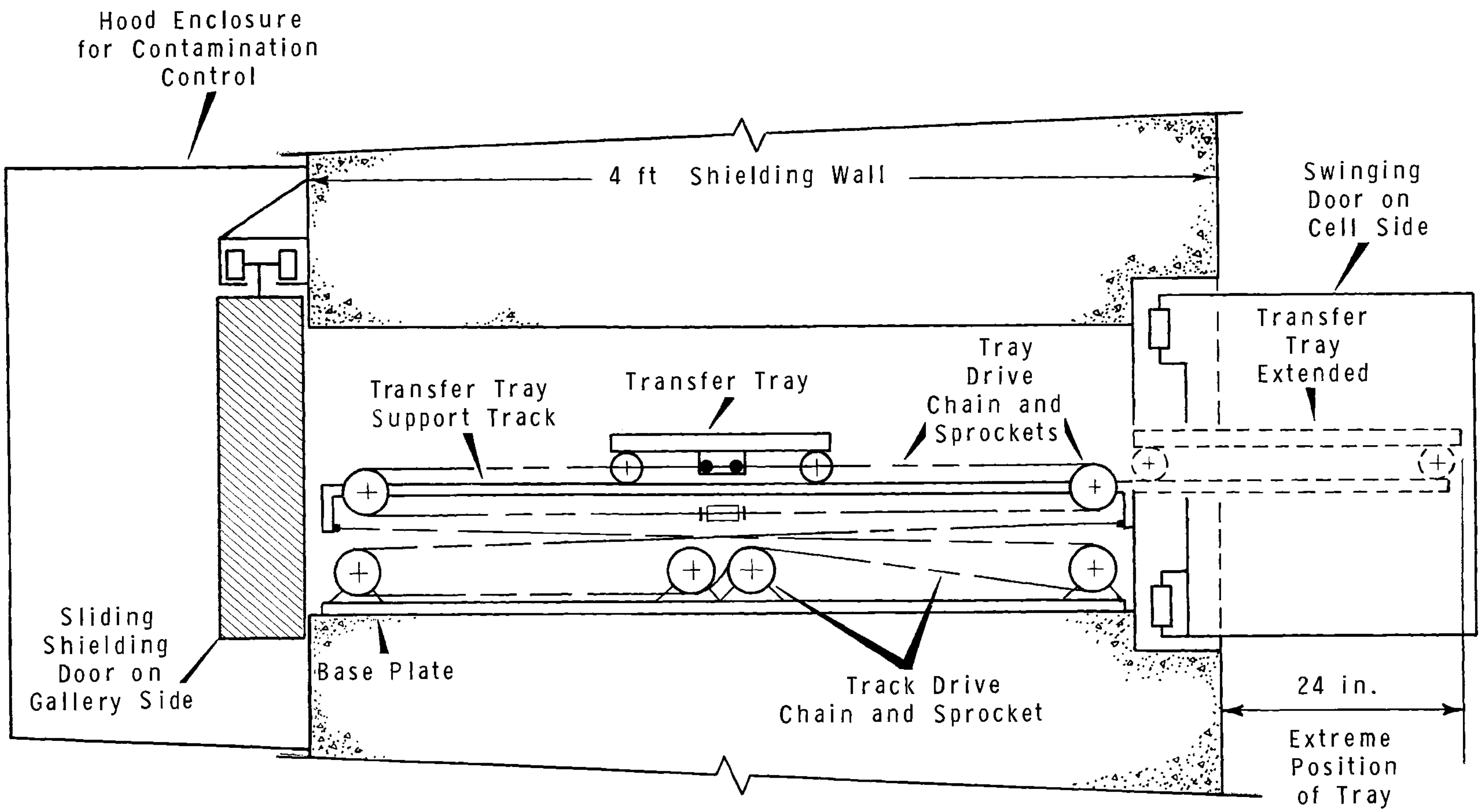


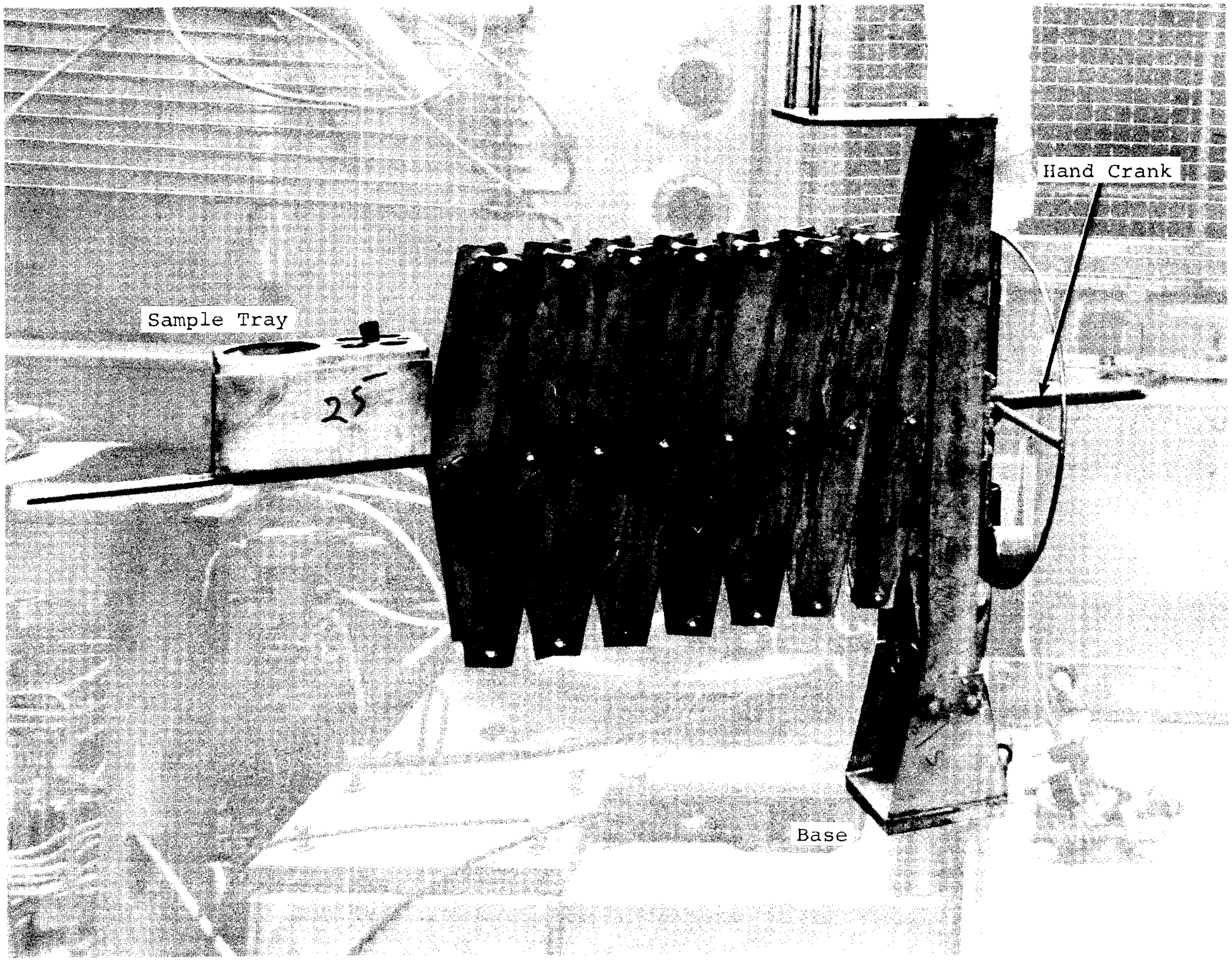
FIGURE 5.17. Gallery-to-Cell Transfer Mechanism

turn, is inside a small room, both of which are specially ventilated. In the mechanism, a chain-driven transfer tray support track is supported by and travels on dual three-piece nested aluminum drawer slides. The 12 inch square transfer tray rolls along the top of the support track and is driven the full length of the track by a differential chain drive as the track moves through its total travel. Transfer of an object placed on the extended tray in the cell is accomplished by movement of the tray to the opposite end of the track which in turn has moved approximately 4 feet to extend into the hood. Operation of the mechanism is manual through a crank.

The hood enclosure is a stainless steel box with clear plastic doors and panels which contain glove ports for glovebox-type manipulations. The lead-filled shielding doors provide a ventilation seal and protect personnel against radiation exposure from the cell. The in-cell hinged door is 4 inches thick and is opened and closed by the nearby master-slave manipulators. The sliding gallery door is 8 inches thick and is suspended from rollers on a track, and is operated by a manually-cranked screw. Only one door is open at one time.

5.10.2 In-Cell Sample Transfer

Since B-Cell is too large to permit transfer of materials directly from one manipulator station to another, an in-cell transfer mechanism is provided. With this mechanism, shown in Figure 5.18, samples and small objects may be transferred across B-Cell. This device is a manually-operated, screw-driven, multisection pantograph mechanism capable of extending 8 feet with a load of 25 pounds. The device is mounted near the north cell window, on the welding station 7B Rack. Samples or other small objects at window positions 5 or 6 (see Figure 5.3), are placed on the sample tray at the end of the arm. The pantograph mechanism is then retracted with a master-slave manipulator at the north window to move the samples or other objects within



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<u>*FIGURE 5.18*</u>. *In-Cell Sample Transfer Mechanism*

reach of manipulators at the north window. Each sample is then transferred to a small shielded cask on the tray of the gallery-to-cell transfer mechanism and transferred to the gallery where it is transported to the analytical laboratory or to other destinations.

5.10.3 Television Plug

Closed-circuit television is used for supplementary viewing and for primary viewing when working within the top 12 feet of the cell. Closed-circuit television cameras and auxiliary mechanisms are mounted in special plugs for use in 10 inch diameter master-slave manipulator sleeves in the cell walls, shown in Figure 5.19. The television plug houses a motor-driven, three-piece, nested-screw mechanism which is capable of extending the camera 5 feet into the cell, and mechanisms for focussing, panning and tilting the camera for viewing objects anywhere in the cell. The mechanism may also be inserted into larger sleeves which are fitted with adaptors. A shielding door on the in-cell side of the plug is rotated by a door operator mechanism to close or open the door after the camera is fully retracted into the plug.

Limit switches and safety control circuits are provided on the various electrically-powered mechanisms. The camera is operated from a control console in the service gallery, or it may be operated from more remote locations such as the control room.

5.10.4 In-Cell Cranes

Transfers of large objects such as waste pots and equipment racks to and from and within B-Cell are made with either one of two dc-powered electrical overhead travelling cranes with lift capacities of 6 and 3 tons. Both cranes travel between B-Cell and the Air Lock Cell on common tracks, and may be stored or serviced in the Air Lock Cell when not in use.

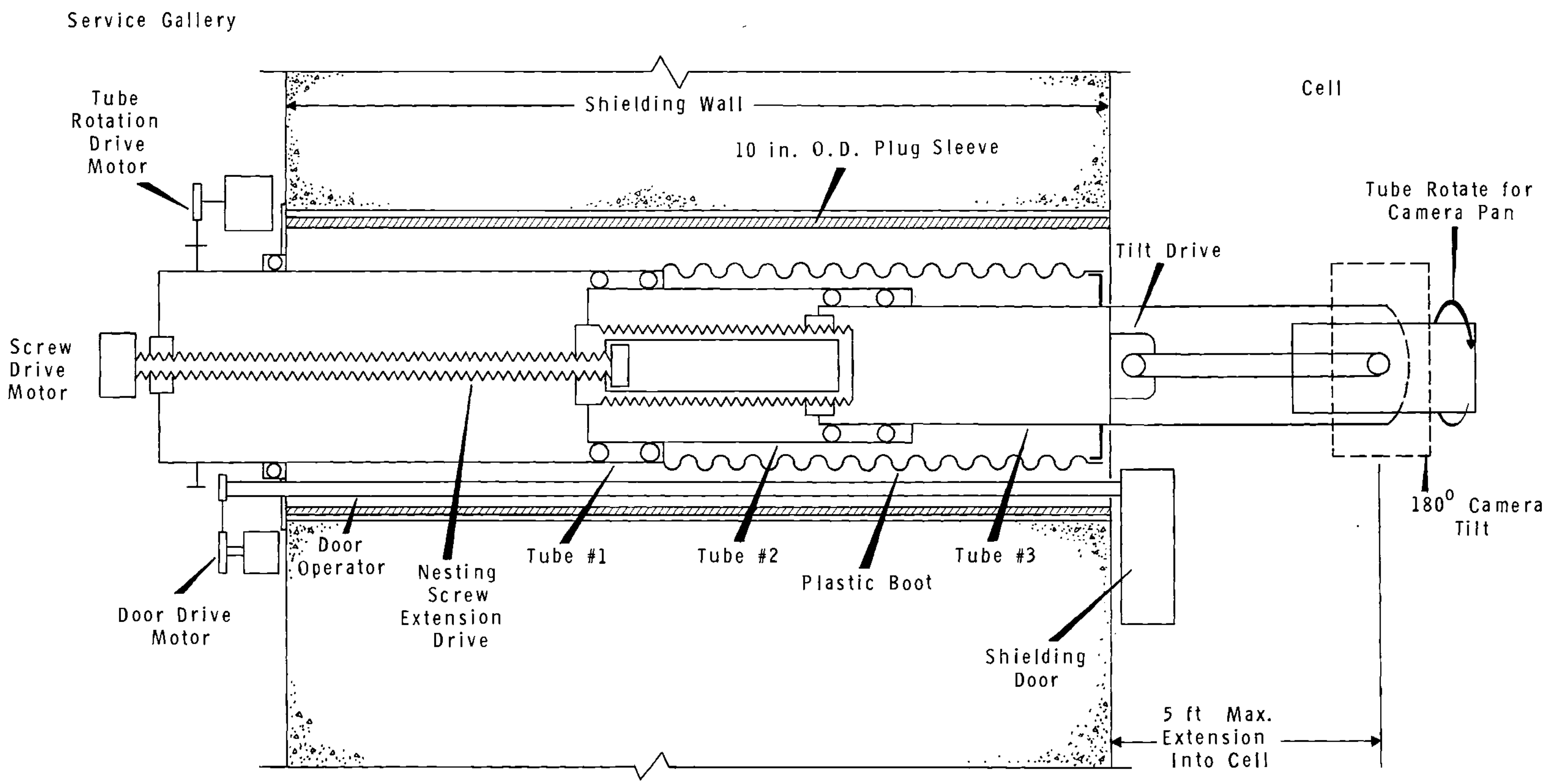

FIGURE 5.19. Television Plug

Power is supplied to each crane through multiconductor, plastic-sheathed cables from spring-driven takeup reels mounted outside the Air Lock Cell. Power to the cable is supplied from sets of motor-generators for the 6 ton crane, and from silicon controlled rectifier power sources for the 3 ton crane. Controls provide speed variation from 2 to 20 ft/sec for any motion (crane, trolley, and hook lift), and are interlocked so that only one crane motion can be used at a given time. Hooks on both cranes will lift from the cell floor to within 3 feet of the cell ceiling (a total of 27.5 feet), and will reach to within 15 inches of any cell wall.

The 6 ton crane has a cable-reeved trolley to fit the 6 ton bridge into the extra low head room (33 inches) available in the cell. With the cable-reeved trolley, the hoisting cable drum is stationary and is located at one end of the crane. The hoist cable passes over idler sheaves at the opposite end of the crane and through the trolley and hook block sheaves, returning to the hoist drum end of the crane where it is fastened. The trolley drive is also stationary and consists of a motor-driven cable drum, cable, and idler sheave system.

The more conventional 3 ton crane also has a swivelling sideboom mounted on the trolley for maneuvering light loads in the cell which require extra high lifts up to within 1 foot of the cell ceiling (compared to 4 feet from the ceiling for the main crane hooks). The sideboom is 6 feet long, has a 500 pound capacity, and can reach any cell wall.

5.10.5 In-Cell Filter Assembly

High-efficiency ventilation filters located outside and downstream of the cell are protected by "50%"* filters located at the ventilation exhaust port in B-Cell. The four filters in

* *The filters are rated for removal of at least 50% of all particles with diameters of 0.3 micrometers or greater.*

B-Cell, each of which is 2 feet square and 6 inches thick, are banded together vertically into a stack which is 2 feet wide and 8 feet high for remote installation in the cell. The filter assembly is held against the wall opening by a remotely-operated stainless steel filter frame to which is fastened a series of interconnected worm jacks. Hooks at the end of each jack shaft engage wall clips for the clamping reaction. After the filter assembly is lowered by crane into position between the filter frame and the wall opening, the drive is actuated to pull the filters in against the wall for sealing.

5.10.6 Wall Plugs

Electrical and instrument services and special piping services are routed from the service galleries into the cell through removable wall plugs inserted into stepped sleeves in the cell walls located mostly near the shielding windows. Two types of the 4 and 8 inch diameter plugs, shown in Figure 5.20, are used.

The first is a hollow cylinder fabricated from carbon or stainless steel pipe or tubing, and has a stepped section that mates with the step in the wall sleeve to provide a radiation barrier. The step in some plugs is removable from the rest of the plug to permit removal of the plug into the cell or to the service gallery, as desired. The ends of the plug are removable plates normally retained by snaprings. When a plug is prepared for installation, twisted wiring or bent offset piping is placed in the plug, and the endplate on the cell end is sealed to the pipes or wires and is locked or welded in place. The plug is then filled with steel or lead shot, and the other endplate is installed for closure. The serrated rubber, cup-shaped seal is then installed on the cell end, and the plug is inserted into the wall opening from the service gallery. If piping or wiring elements must be changed to modify services or to replace failed elements, the plug is removed and is replaced with a new one.

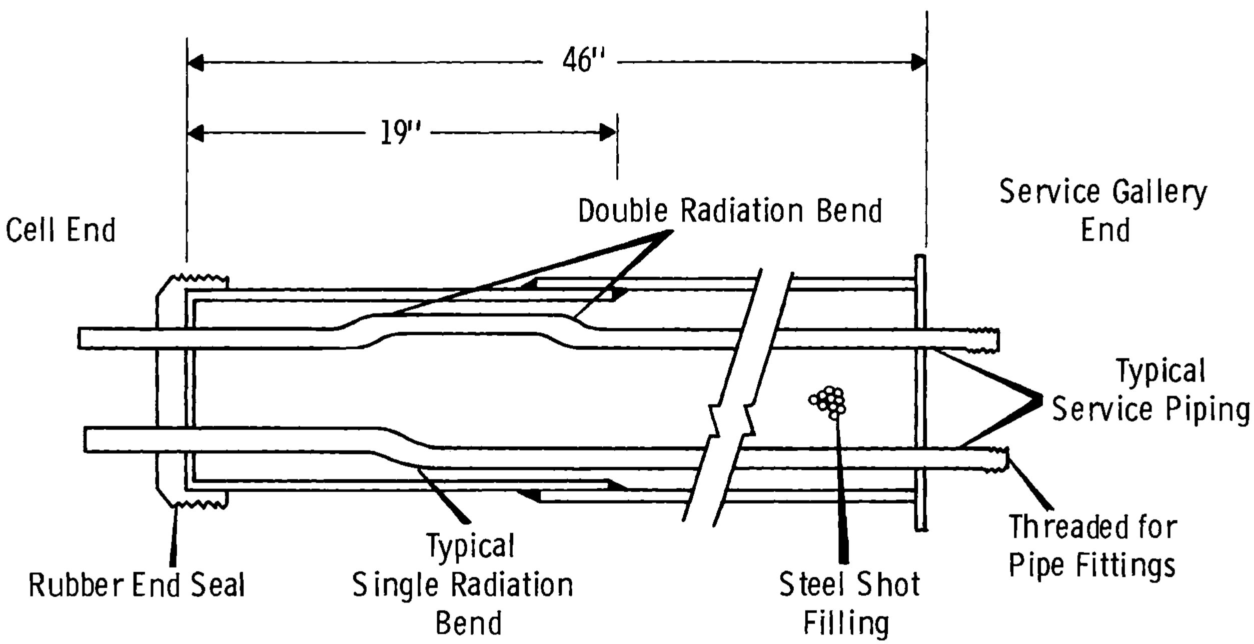

FIGURE 5.20a. Shot Filled Wall Plug (4, 8, and 12 in. diam)

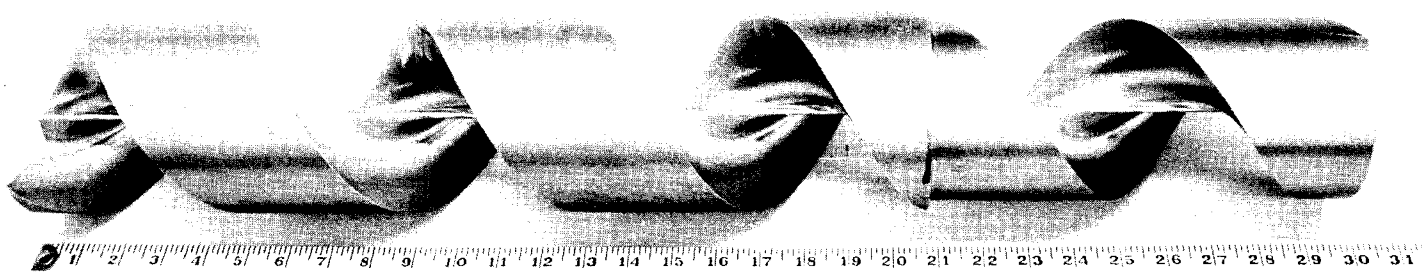

FIGURE 5.20b. Screw Plug

The helical plug is arranged so that flexible wiring or tubing can be inserted while the plug is in place in the cell wall. The screw plug consists of a solid metal bar which has been machined into a screw form. The space between the "threads" of the screw provide a helical pathway which permits passage of flexible objects, but blocks passage of radiation. The plug is sealed in the service gallery with flexible plastic filler. The helix plug provides good flexibility at low cost, with some reduction of capacity compared to the shot-filled step plug.

5.11 ELECTRICAL CONNECTORS AND WIRING SYSTEMS

Electrical leads enter the cell through wall plugs near the three viewing windows. "Dropcords" which contain wires that are insulated with rubber, plastic (usually linear polyethylene), or asbestos, pass through the plugs. Inside the cell, the wires may be connected to matching electrical connectors on the ends of "pigtails" of electrical equipment at the racks, or they may be connected through an intermediate electrical jumper with connectors at each end. Four types of electrical connectors are used in WSEP:

- Multipin bayonet-type KPTM miniaturized plugs with crimp-type pins and sockets and quarter-turn cam locks are used for most low power multiple-circuit applications such as pumps, agitators, rotameters, and some thermocouples. The plugs have a Neoprene insulating insert which provides good moisture protection with reasonable radiation resistance.
- Standard two-prong thermocouple plugs are used where ganging of thermocouple leads is not desired or required.
- Standard welding plugs are used on furnaces and high power connections in the manipulator zones.

- Multiple Cole connectors are used on the connections to the electric resistance heated waste pot furnace-cooler, where high-power connections must be made in a minimum space.

Wall-hung electrical fixtures used for in-cell lighting contain two or three outlets, and are removed and replaced remotely using only the cell crane. The assembly consists of a standard 7-pin Lockheed-Cole remote lighting fixture fitted with a wire lifting bail and horizontal guide wires. The fixture may be fitted with dual mercury-vapor lamp outlets or with combinations of up to three incandescent and vapor lamps. A fixture with sockets for two vapor lamps is shown in Figure 5.21.

When balanced properly, the connector end of the fixture hangs down and slightly tilted toward the cell wall when hanging from the crane hook. When moved toward the wall, the guide wire aligns the fixture square with a mating hook on the wall fixture. The crane hook is then lowered to allow the female half of the fixture to swing by its own weight into the fixed male half. The spherical male pins and spring-loaded segmented female sockets allow the hinging motion to make the electrical contacts without damaging them.

5.12 WASTE POT INSPECTION SYSTEM

Pots filled with solidified waste will be monitored and inspected for 1 to 3 years in B-Cell. Some of the pots will also be stored and monitored under controlled environment conditions in the Solids Storage Environmental Test Facility (SSETF) in the adjacent A-Cell for an additional 2 to 3 years. Detailed descriptions of these test monitoring, inspection, and environmental facilities and conditions are presented in Reference 1, but a brief description of the portions of the equipment located in B-Cell is presented here. In B-Cell, pots will be weighed for material balance information, sealed by welding caps containing fixtures for leak testing and pressure measurements, ultrasonically scanned to determine wall thickness,

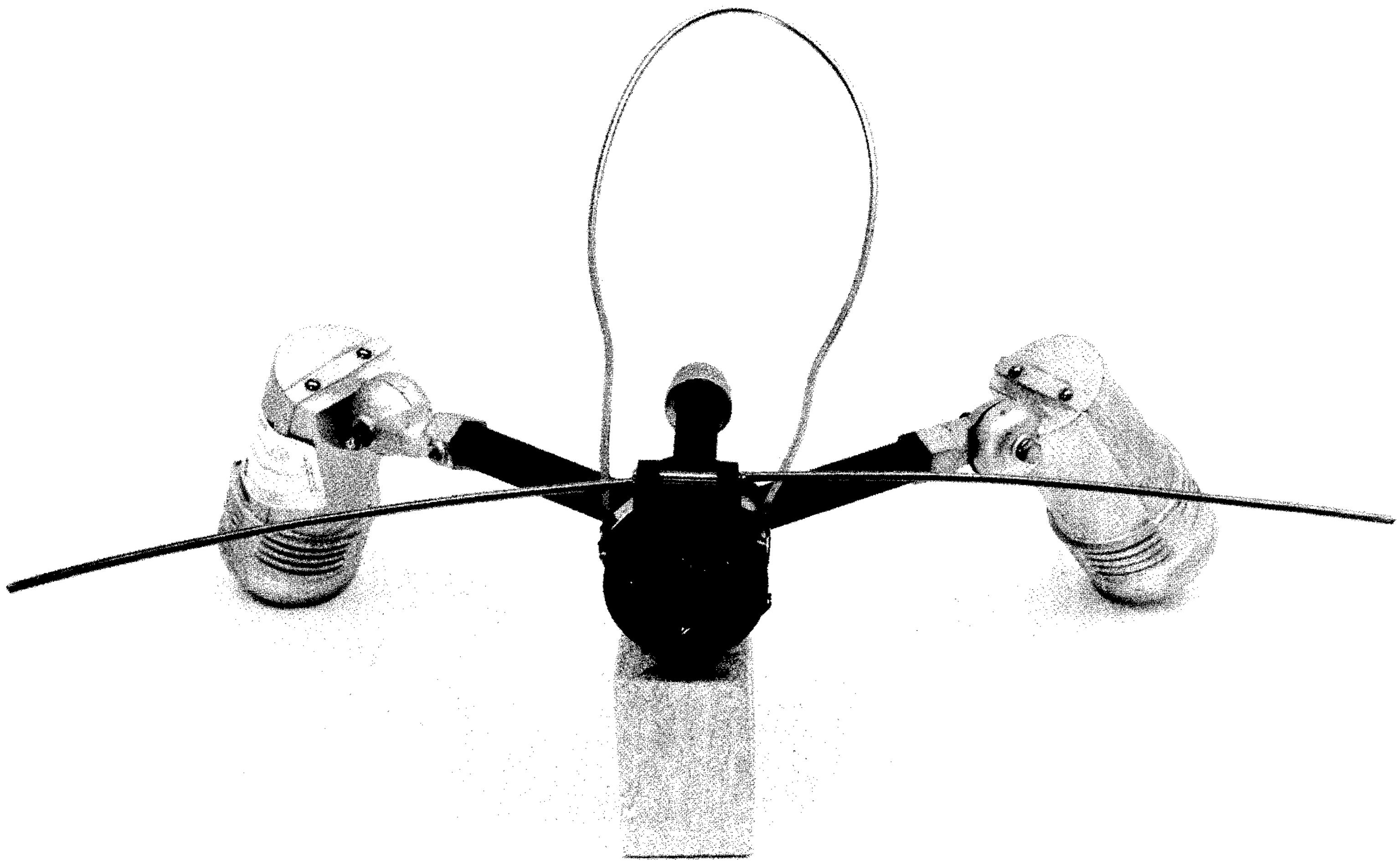

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FIGURE 5.21. In-Cell Lighting Fixture for WSEP

measured for diameter dimensional changes, measured calorimetrically for total heat rate content (discussed in Section 4.4.5), tested for leakage rate, measured for potential internal pressure buildup, measured for gross gamma radiation, and measured for temperature distribution within the pot. The overall pot inspection system is shown in Figure 5.22.

5.12.1 Pot Lid Welding Station

This station comprises a rack which contains a cylindrical tank which is surmounted by a turntable assembly. The turntable holds a waste pot vertically and rotates the pot slowly while the caps are welded to the open top end of the pots.

The tank is normally filled with water for cooling the pot during welding and ultrasonic scanning (discussed in the next section). The tank contains a removable cooling coil assembly which also includes liquid level, chemical addition, and sparging dip tubes.

The turntable is driven by a flexible shaft extending through the cell wall to the service gallery. The pots are held by four interconnected jack-driven chucks on the turntable. Objects up to 16 inches in diameter may be mounted at the welding station.

The lids are welded to the open end of the waste pots by fusion welding, using a tungsten inert gas system. Welding may be done manually by supporting the torch head with the manipulator, or automatically where a voltage control unit adjusts the position of the torch head with respect to the weld joint. The electrical power is supplied to the unit from a 300 volt silicon-rectified dc power source in an integral console containing controls for gas flow, amperage, voltage, and weld cycle sequence.

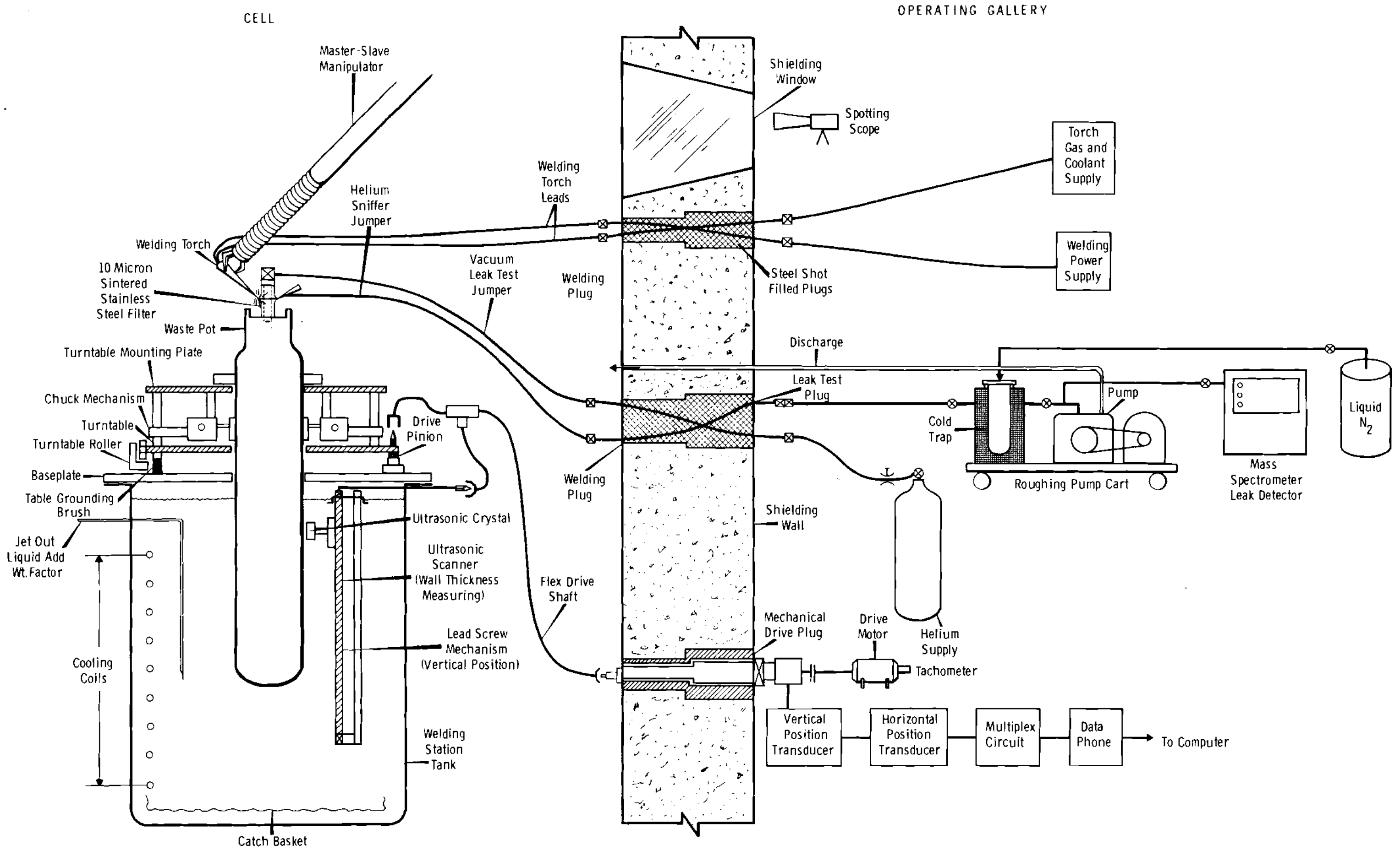

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FIGURE 5.22. Pot Inspection System in WSEP

5.12.2 Ultrasonic Wall Thickness Tester

Pots are positioned in the welding station for scanning and mapping the wall thickness of the pot with an ultrasonic transducer. The major in-cell elements of the tester are an ultrasonic transducer mounted on a vertical traversing and guiding mechanism, and the position indicator assembly on the welder turntable. The ultrasonic transducer has a ceramic piezoelectric crystal which transmits an ultrasound pulse signal through the water bath in the weld station tank to the pot wall. The signals are reflected from the inside and outside pot wall surfaces back through the crystal from which they are transmitted, and are converted and fed to a computer for printout as inch dimensions. Signals from position transducers (encoders) on the welding turntable are also fed into the computer and utilized in mapping the locations of the thickness measurements as the pot is rotated by the turntable. Scans taken over specific time periods will be used to detect potential progressive thinning of the pot wall at any location.

5.12.3 Pot Temperature Measurements

Pot internal and wall temperatures are monitored by connecting to the pot thermocouple connector for intermittent readout to a multipoint recorder.

5.12.4 Pot Pressure Monitoring

The pot lid contains fittings which permit connection of the internal pot volume to a pressure gage, or to a pressure gage plus a sampling/venting connection and a remote pressure readout. Remote pressure readout is through a bellows-sealed linear variable differential transducer. The signal from the transducer is converted and printed out on a multipoint recorder.

5.12.5 Pot Leak Testing

Pots are leak tested after the cap is welded on by "sniffing" for helium with a mass spectrometer testing system. The pots are evacuated to an absolute pressure of 0.2 microns or less by a vacuum pump located in the service gallery. Helium is then sprayed around the pot, and the leak rate is determined as a function of the amount of helium pulled into the pot. Leak rates as low as 10^{-10} standard cm^3/sec can be measured. For pots whose contents gas excessively at low vacuum, the flow of evacuated gas to the leak tester is throttled by valving to permit reaching the low vacuum required for testing. Accuracy for this type of testing is on the order of 10^{-5} standard cm^3/sec leakage.

5.12.6 Pot Gamma Radiation Measurements

Gross gamma radiation measurements of the pots containing wastes are periodically taken. Readings are taken over the entire length of the pot with a conventional ion chamber held at a fixed distance from the pot while the pot is moved vertically.

5.12.7 Pot Diameter and Weight Measurements

Pots are weighed before and after filling with solidified waste by hanging them from a dynamometer suspended from the cell crane. Diametral dimensions at several locations on the pots are determined before and after filling by the use of a manually-operated C-shaped micrometer modified for remote operation.

6.0 RESULTS OF DESIGN VERIFICATION TESTS OF CHEMICAL PROCESS EQUIPMENT

Design and construction of the WSEP equipment was scheduled to optimize time and manpower requirements by completing construction of equipment in functional groups which could be subjected to meaningful tests. During the period of time between October 1964 and May 1967, the WSEP equipment was subjected to extensive Design Verification Tests (DVT) without the presence of radioactivity. These tests were planned to verify the performance of the equipment and processes prior to actual radioactive demonstration. Extensive tests were necessary because of the relatively early state of technology of the processes with respect to fully radioactive demonstrations.

The overall schedule for DVT's of the WSEP equipment is summarized in Table 6.1. All equipment was generally found to perform rather well, and relatively few modifications were required before starting radioactive runs. Most of the results of these tests have been reported in detail.[7,8,9] Major results and conclusions from these tests related to equipment performance are summarized in the remaining portions of this section, including changes made before start of radioactive tests.

6.1 SOLIDIFICATION EQUIPMENT

6.1.1 Pot Calciner

The pot calcination equipment was the first in WSEP to be completed and tested nonradioactively. Eight Design Verification Test runs were made with the WSEP pot calciner during the period October 1964 to April 1965. In addition, two rising level glass test runs were made because radioactive demonstration of that process variation appeared likely at the time of the DVT tests. The overall performance of the equipment was

TABLE 6.1. *Chronology Summary for DVT's of WSEP Equipment*

Time Period	Solidification Equipment	Auxiliary Process Equipment	Mechanical Equipment
October 1964 to January 1965	Pot Calciner and Induction Pot Furnace	Feed Tanks, Samplers, Primary Condenser, Caustic Scrubber	Feed Flow Controls, Pumps, Agitators, Connectors, Furnaces
February 1965 to July 1965		Also Waste Evaporator, Acid Fractionator	
August 1965	Spray Calciner		
September 1965 to December 1965	Spray Calciner Melter, Induction Pot Furnace		
January 1966	Phosphate Glass Denitrator		
January 1966 to April 1966	Installation of WSEP equipment into B-Cell of C-MEL		
May 1966	Phosphate Glass Denitrator, Melter, Melter Condenser, Induction Pot Furnace		
June 1966 to July 1966	Spray Calciner Melter, Resistance Pot Furnace		
August 1966 to October 1966	Phosphate Glass Denitrator Melter, Melter Condenser		
November 1966	Radioactive Demonstrations started for Pot Calciner and Spray Solidifier		
November 1966 to May 1967	Phosphate Glass Denitrator Melter, Melter Condenser		

good, and the WSEP equipment was judged to be ready for remote operation in radioactive service.

Eight wastes were tested for performance in the prototype equipment as shown in Table 6.2. These wastes were designated Purex-1, Darex, Purex low and high iron, Purex low and high sulfate, TBP-25 and FTW-65. Simulated fission products were present in most of the wastes. The WSEP standard PW-1 and PW-2 wastes had not been established until the DVT tests for the WSEP pot calcination equipment were nearly completed, so no calcination tests were made with PW-1 or PW-2 feeds. One rising level glass run was made with PW-1 waste in the DVT's. All wastes performed satisfactorily except for the Purex low iron waste which was not processible because of excessive foaming. However, after chemical additions to modify its composition, satisfactory operation was achieved.

Two methods of operating the pot calcination equipment were tested. In the low heat flux method, the pot was kept full at all times, and a draft tube was used in the center of the pot to provide a definite downcomer for the circulating liquid. This technique allows maximum concentration of feed in the pot before scaling of the walls and calcination starts, provides for a more orderly boiling pattern, and minimizes the tendency for foaming. The net result is an improvement in deentrainment at comparable processing rates (about 5000 versus 1000), and a slightly harder and more dense (by 5 to 20%) calcine. In the high heat flux method, maximum thermal power is applied to the pot to maintain the pot walls at 800 to 900 °C to cause early scaling of the walls and calcination. Once scaling begins, the half-full pot is filled to the normal oeprating level for the completion of the process by feeding the pot at a high rate. Based on results of these tests, a combination of the two techniques was recommended for radioactive demonstrations. This technique involves applying a

TABLE 6.2. *Feed Compositions of DVT Tests in WSEP Pot Calciner*

Constituent	Purex[(a)] FTW-65	Purex[(a)] PW-1	Purex Low-Fe	Purex High-Fe	Purex Low-SO_4	Purex High-SO_4	TBP-25	Darex
	Type of Feed							
H^+	3.0M	3.7M	6.76M	4.65	6.57	5.0M	0.75	1.20M
Fe^{+3}	0.11	0.93	0.046	0.84	0.56	0.55	0.003	0.95
Cr^{+3}	0.02	0.012	0.012	0.0035	0.001	0.011	--	0.30
Ni^{+2}	0.01	0.005	0.005	0.0014	0.001	0.011	--	0.12
Al^{+3}	0.05	0.001	--	--	--	0.11	1.55	--
Na^+	0.33	0.138	0.462	0.138	0.35	0.66	0.100	--
F^-	--	--	--	--	--	--	--	0.002
Cl^-	--	--	--	--	--	--	--	0.003
BO_3^{-3}	--	--	--	--	--	--	--	0.05
NO_3^-	3.10	7.5	10.74	7.95	8.48	5.5	5.50	5.03
SO_4^{-2}	0.16	--	--	0.069	.35	1.1	--	--
PO_4^{-3}	--	0.003	0.013	--	--	--	0.01	--
SiO_3^{-2}	0.02	0.01	--	--	--	--	--	0.06
Sr^{+2} + Ba^{+2}[(b)]	0.02	0.035	0.066	0.039	0.015	--	0.0008	--
ZrO^{+2}	0.02	0.065	0.140	0.077	0.031	--	0.0016	--
MoO_4^{-2}	0.03	0.079	0.110	0.10	0.024	--	0.0013	--
Cs + (as Na^+ or K^+)	0.02	0.04	0.083	0.052	0.015	--	0.001	--
$(Y + RE)^{+3}$	0.05	0.12	0.250	0.136	0.055	--	0.0029	--
Ru^{+4} (as Mn^{+4})	0.03	--	0.051	0.028	0.001	0.004	0.0006	--
Additives								
Na^+	1.0	0.84	--	--	0.31	--	--	--
Ca^{+2}	--	--	--	0.007	--	0.33	--	--
Al^{+3}	0.28	--	0.55	--	--	--	--	--
Li^+	0.89	1.0	--	--	--	--	--	--
PO_4^{-3}	1.33	2.0	--	--	--	--	--	--
Solution Characteristics								
Specific gravity @ 25 °C	1.28	1.36	1.396	--	--	1.326	1.25	1.25
Volume percent solids	30	Gelatinous	5 (MoO_3)	Flocculant	3-5	5 ($CaSO_4$)	0	0
Volume liter/tonne	300	550	115	378	940	150	23,000[(c)]	2700
ΣM^+ [(d)]	4.0	5.85	4.0	4.0	2.8	3.4	4.8	4.0
Boiling Characteristics after Concentration	Mild Foam	--	Much Foam	Mild Foam	Moderate Foam	Stable	Puffy	Mild Foam

(a) *These compositions tested in RLG process only*
(b) *Ba and Sr were sometimes substituted with Ca*
(c) *Liter/tonne Al + U fuel*
(d) *ΣM^+ is the total normality of metallic cations*

moderately low heat flux, keeping the liquid level in the pot low during the initial phases of the processing cycle, and the elimination of the draft tube. (There is some indication that the thermocouple well in the center of the pot aids in forming a downcomer path for recirculation of boiling liquid.)

The WSEP concept of a vent line which is self-cleaned by 2 to 10 liters/hr of partial reflux has very effectively solved the previous plugging problems with this vent line. Additional gross spray down of the off-gas line with about 15 liters of water at the beginning of the next pot calcination cycle completes the washing. In addition, a small spray of about 2 liters of water into the pot via the off-gas line at the end of the calcination cycle has kept the mouth and throat of the pot clean.

Liquid level in the pot was measured by four methods during DVT tests. These were: 1) a thermocouple probe located just above the desired liquid level, 2) a wet air-purged pneumatic dip tube located at the desired liquid level, 3) a time-domain pulse reflectometer located at the desired liquid level, and 4) the internal thermocouples throughout the pot. All four methods worked, but none worked with complete reliability as designed. The thermocouple probe requires the pot wall temperature to be greater than about 700 °C to function, and this condition does not exist until about half the feed is into the pot for the preferred technique of low-heat flux operation. The dip tube worked reliably when purged with steam in all tests. However, in these tests the normal liquid level was below the dip tube, and tests were not made with the dip tube continuously submerged. The pulse reflectometer worked well in the only pot calcination run tested, but failed structurally during the rising level glass run. Temperature readings from the thermocouples in the pot provide crude, but perhaps satisfactory level indication when properly interpreted.

As developed in the DVT's, no one of these methods provided adequate detection of liquid level, but any two of them did. Minor design changes would likely result in satisfactory reliability from any one of the methods tested.

The thermocouple arrangements used during DVT tests provided reliable temperature information. The padded or shielded thermocouples on the outside of the pot walls consistently read 50 to 100 °C higher than the true temperature because of the effect of the hotter furnace. The electrical thermocouple connector failed due to overheating until the connector was cooled by air purging.

Corrosion of the 304-L stainless steel pots was not detectable (<0.005 inches) in all of the pot calcination tests and in the rising level glass test using FTW-65 waste at a pot wall temperature of 850 °C. (Some modest pitting of the centerline thermocouple well occurred in this rising level glass run.) For rising level glass solidification of PW-1 feeds, corrosion of the 310 stainless steel pot (which was shown in laboratory tests to have better corrosion resistance than 304-L stainless steel) was catastrophic at the rate of 0.2 in./day at the high temperature of 950 °C. No deformation of the pots occurred in any test. The increased emissivity of an oxidized pot (>0.8) compared to that for an unoxidized pot (about 0.5) was readily detected in pot and furnace operation. Preoxidation of a pot may benefit overall capacity by improving heat transfer during air cooling.

Maximum boil-up rate in the pots is limited by vapor-lifting due to the geometry of the pot at 85 liters/hr of water in a full 12 inch diameter pot. This rate corresponds to a superficial vapor velocity of 1.7 ft/sec and a corresponding maximum boil-up rate in an 8 inch diameter pot of 40 liters/hr. Maximum practical rates for good control if no foaming exists and those recommended for radioactive demonstration are

30 and 60 liters/hr for 8 and 12 inch pots, respectively. A high heat flux of 2.7 W/cm^2 to the pot wall for a short time period will maintain the temperature of the pot wall high enough to cause almost immediate scaling. A low heat flux of 1.3 W/cm^2 will delay significant scaling until the slurry concentration is approximately 30% greater (concentration factors of 3 to 7) than with the higher heat flux, and will result in the same overall time cycle.

The rising level glass technique was eliminated from radioactive demonstrations planning in WSEP because the corrosion information for the process was anomalous, and resolution of the corrosion problem was considered as not justifiable since two other melt-forming processes had been developed. During the DVT test in WSEP, a technique was developed for increasing the feed rate to a rising level glass process by about a factor of 2. This technique consisted of introducing the feed as a film of aqueous liquid which was partially evaporated as it flowed downward along the thermocouple well inside the pot. This technique also decreased spattering (and therefore decreased entrainment), helped maintain process stability by positive control of feed entry point into the melt, and restricted interface corrosion at the pot wall by eliminating contact with aqueous phase there.

In the two rising level glass tests, the overall feed rates were 10 and 18 liters/hr in the 8 inch diameter and 12 inch diameter pots, respectively. These compare with similar rates of 11 to 18 liters/hr for pot calcination tests, where overall throughput is essentially independent of pot sizes in this range.

A total of 5 minor pressure increases occurred within the pots in the two rising level glass tests. The surges lasted about 1 second and the highest pressure in the pots reached 3 inches of water. The decontamination factor to the condensate was good at 120. The off-gas line was kept clean in both tests, but plugging at the mouth of the pot occurred in one test from accumulation of dust. As a result of the tests, additional features were included in the off-gas line. These items were measurement of inlet and outlet vapor temperatures, flow rate and outlet temperature of the cooling water, and visual observation of reflux quality and approximate reflux rates.

The six-zone induction-heated furnace for heating and cooling the pots performed reliably and safely. Each zone was controlled within ±20 °C of the set point without gross influence from adjacent zones. Additional performance data are presented in Section 7.6.

6.1.2 Spray Solidifier

A total of 10 Design Verification Test runs were made with the WSEP spray solidification equipment during the time period of August 1965 to July 1966. The PW-1 and PW-2 feeds were tested with a variety of phosphate melt-making additives. One test was performed with a special Purex "Design Base" feed. Simulated fission products for 20,000 MWd/tonne fuel irradiated to 15 MW/tonne were included in most tests. The spray calciner only was tested in the first two runs, while the entire spray calciner-melter-melt receiver system was tested in the remaining runs. A summary listing of the equipment tested and the feed additives is shown in Table 6.3.[8]

Spray solidifier performance was satisfactory with all flowsheets tested except those in CSCM-3 and CSCM-5. In the CSCM-5 test, sulfate-containing PW-2 feed was processed under conditions in which all the sulfate was evolved from the melter. Sufficient sulfate condensed on the inlet of the melter and on the spray calciner filters to cause buildup of scale at these points. It was concluded that spray calciner internal

TABLE 6.3. *Summary of WSEP Spray Solidifier Design Verification Tests*

Equipment		Run Number									
		CSC-1	CSC-2	CSCM-3, 3a, 3b	CSCM-4	CSCM-5	CSCM-6	CSCM-7	CSCM-8	CSCM-9	Run C
Spray Calciner		WSEP	WSEP	WSEP	WSEP	WSEP	WSEP	WSEP	WSEP	WSEP	WSEP
Spray Calciner Furn.		Temp. Ind. Ht.[1]	Temp. Ind. Ht.[1]	Temp. Ind. Ht.[1]	Temp. Ind. Ht.[1]	WSEP	WSEP	WSEP	WSEP	WSEP	WSEP
Melter		--	--	WSEP[2]	WSEP	WSEP	WSEP	WSEP	WSEP	Dev.	WSEP[4]
Melt Receiver Furn.		WSEP (5A)	WSEP (5A)	WSEP (5A)	WSEP (5A)	WSEP (5A)	WSEP (5A)	WSEP (5A)	WSEP (6A)	WSEP (6A)	WSEP (6A)
Auxiliaries		E-111; 1A,1B, 3B and 2A Racks	E-111; 1A,1B, 3B and 2A Racks	E-111; 1B,2A Racks	E-111; 1B,2A Racks	E-111; 1B,2A Racks	E-111; 1A,1B, and 2A Racks	E-111; 1B,2A Racks	E-111; 1A,1B and 2A Racks	E-111; 1B Rack	E-111; 1A,1B and 2A Racks
Waste Designation		PW-1	PW-2	Design Base[7]	PW-1	PW-2	PW-1	PW-2[6]	PW-1	PW-2	PW-2
M of Additives[3]	Na^+	--	2.7	0.57	--	--	0.9	1.3[5]	0.5	1.3[5]	1.3[5]
	Li^+	--	2.4	--	--	--	--	1.2	0.5	1.2	1.2
	Ca^{+2}	--	--	--	--	--	--	0.6	--	0.6	0.6
	Al^{+3}	--	0.75	--	--	--	--	0.25	--	0.25	0.25
	Fe^{+3}	--	--	0.12	--	--	--	--	--	--	--
	PO_4^{-3}	--	3.6	1.3	2.0	1.6	1.8-2.0	2.9[5]	1.7	2.9[5]	2.9[5]
$\Sigma M^+/P$		--	2.3	2.25	1.9	2.0	2.6-2.2	2.7	2.75	2.7	2.7
Data Obtained On		Overall perfm.	Overall perfm.	Overall perfm.	Melter perfm.	Melter perfm.	Flow-sheets	Flow-sheet	Flow-sheet	Solids feeder	Ru volatility
		Steam atom.	Steam atom.	Melter perfm.	Flowsheet	Flow-sheet	Filling pots	Feed control	Filling pots	Feed flush syst.	Feed flush syst.
			Flowsheet	Steam-air atom.	Air atom.	Calciner furn.	Calciner capy.	Filling pots	Melt rcvr perfm.	C. stl pots	Solids feeder
				Flowsheet	Melt rcvr perfm.	Filling pots			Steam atom.-mod. nozzle	Steam atom.-mod. nozzle	In-place calciner cleaning
				Melt rcvr perfm.	Filling pots						

(1) *A temporary 3-zone induction-heated furnace was used until the 3-zone resistance-heated WSEP furnace became available.*
(2) *The melter was not used in runs 3a and 3b.*
(3) *The basis was 378 liters/tonne.*
(4) *The first WSEP melter failed during run 7 and was replaced for run C.*
(5) *Included is 1.3M $NaPO_3$ added as a solid directly to the melter.*
(6) *The sulfate concentration was 0.57M versus the flowsheet value of 0.87M..*
(7) *Composition of inert material is: Fe^{+3} 0.20M, Cr^{+3} 0.04M, Ni^{+2} 0.02M, Al^{+3} 0.10M, Na^+ 0.95M, NO_3^- 5.0M, SO_4 0.10M.*

temperatures must be maintained above the condensation point of sulfuric acid (approximately 350 °C) when operating under conditions which volatilize significant concentrations of sulfate (at least as little as 0.5M sulfate in the feed). The flowsheets used in the other three runs with PW-2 feeds were designed to retain most (greater than 95%) of the sulfate, and less than 0.05M sulfate was evolved from the feed. Spray solidification with these flowsheets was performed successfully. These flowsheets are to be used in radioactive demonstrations.

In the CSCM-3 test, solidifier performance was acceptable, but a heavy phase of rare earth phosphates which would not melt at 1250 °C settled and built up in the melter, and clogged the discharge tubes of the melter. Flowsheets which make homogeneous melts, such as those established for PW-1 and PW-2 waste, do not pose this problem.

The flowsheets for PW-1 wastes were successfully used in the WSEP spray solidification equipment with very few problems. The flowsheet selected for radioactive demonstration, that in CSCM-8, is processed exceptionally well. The flowsheet in run CSCM-4 which contains a large amount of phosphate ($M^+/P = 1.9$) and produced a glass, showed a slight tendency to form scale at the inlet to the melter, probably due to some volatilization of phosphate from the melter. However, this flowsheet was not tested further after air sparge cooling of the melter inlet was incorporated, which eliminated this tendency for the flowsheets to be used in radioactive demonstrations.

The capacity of the spray calciner when processing water, PW-1 and PW-2 feeds is 42, 28, and 21 liters/hr of liquid feed, respectively. The capacity of the melter when processing PW-1 and PW-2 feeds is about 36 and 17 liters/hr of liquid feed to the calciner, respectively, for the operating conditions recommended for radioactive demonstration. (The capacity of the spray calciner is arbitrarily established as that in which the minimum internal temperature is 200 °C.)

Adequate atomization in the feed nozzle is one of the most critical requirements for successful operation of a spray solidifier. Subtle inadequacies in atomization performance may not show up in a few short tests, so the extended run tests of the DVT's provided good information on atomization performance of the feed nozzles. From these tests it was determined that with commercial external mixing nozzles (wherein separate streams of atomizing gas and liquid mix immediately after being emitted from the nozzle), air atomization is borderline in any case, and steam atomization is inadequate. In either case, a center core of liquid spray is generated which is not sufficiently atomized to permit drying in the 6 foot long tower (although the nozzle may work in a longer tower). The result is a slow buildup of incompletely dried calcine directly below the feed nozzle on the conical lower section of the spray calciner.

Steam atomization was improved somewhat as the steam and feed were preheated to temperatures of 350 and 90 °C, respectively, and when the preheated steam passed through a mist eliminator, but atomization was never adequate. With either steam or air atomization, the barrel of the calciner is kept clean if the drying capacity of the calciner is not exceeded and if the calciner wall temperature does not exceed the sintering temperature ("stick point") of the powdered calcine. (In the event of a malfunction wherein caking occurs on the wall of the spray solidifier, in-place cleaning of the calciner may be accomplished by spraying 15 liters/min of water into the heated calciner. The water is collected in and transferred out from the melter to another tank for recirculation.) Malfunctions which result in a buildup of calcine in the cone directly under the nozzle can be detected by a temperature probe at that point. Therefore, a thermocuople was added to the outer wall of the cone for radioactive demonstrations.

Air atomization with commercial internal mixing pneumatic spray nozzles (wherein the atomizing gas and liquid mix just before being emitted from the nozzle) is satisfactory as long as the weight of atomizing air used is approximately equal to or greater than the weight of liquid atomized. The atomization requirement is that which will produce a maximum mass median particle diameter of about 50 micrometers. Steam with internal mixing nozzles was not extensively tested but pulsing in the feed nozzle and poor atomization resulted from the limited tests. Because air atomization with internal mixing nozzles produced adequate atomization, that combination was selected for use in most radioactive demonstration runs. The use of an internal mixing atomizing nozzle presents a potential hazard in radioactive processing because failure of atomizing gas pressure could result in feed solution being pumped to the personnel side of the processing cell. To prevent this condition from occurring, a safety system was installed for use with an internal mixing feed nozzle. The system consists of a pressure switch on the atomizing gas line which will shut off the feed pump if the atomizing gas pressure falls to less than 3 psig greater than feed pressure at the nozzle, and a radiation monitor and alarm at the point where the atomizing gas is routed into the processing cell.

Serious plugging of either type of atomizing nozzle can be limited to essentially zero by the combination of thorough flushes of feed from the feed piping before shutdown and start-up, and by the early operation of a cleanout needle which can rod through the final atomizing orifice. Severe plugs, which have required removal of the nozzle for mechanical and chemical unplugging, have occurred when these precautions were not taken, but have not occurred when the precautions were taken.

The sintered stainless steel filters and their periodic pulse blowback system worked well on most flowsheets. Typical steady-state pressure drop through the filters was 5 to 10 inches of water. Pressure drop during the short blowback pulses increased by about 5 inches of water. Blowback cleaning was satisfactory with steam at 250 to 350 °C or with air at room temperature or hotter. Filter deentrainment factors varied from 60 to 10,000, with typical values near 1000. Ruthenium volatilization in the one run tested was 70% of that in the feed. The only times that the filter system did not perform well were when other parts of the calciner were not functioning properly or when using a flowsheet undesirable to other parts of the solidifier system. Specifically, volatilization of excess sulfate followed by recondensation inside the calciner, and insufficient atomization to permit adequate drying of the calcine, both generated wet powder which could not be removed by the blowback system. A method for in-place cleaning of the filters was developed wherein dilute nitric acid is injected backwards into the filters at a rate of 100 to 150 liters/hr for about 6 hours while simultaneously blowing back the filters (collecting the flush water in the melter and continuously transferring the flush to another vessel). The built-in filter spray system did not adequately clean the filters.

During blowback of the filters, the powder was dislodged as a cake from 30 to 50% of the area of the filters each time, with the entire filter being cleaned every three to five blowbacks. Also, because the powder was removed as a thin cake, the baffles between the filters are unnecessary, but were left on the assembly for radioactive demonstrations. It was found that venting through the calciner filters for several days of downtime resulted in a less permeable layer of powder on the filters. Since weeks and months of downtime will be encountered during radioactive demonstrations (while tests are being performed with the other two solidifiers), a new vent with a replaceable filter was installed on the calciner for bypassing the process filters during periods of nonoperation.

The conical calciner section below the filter chamber has a slope which permits a maximum steady-state thickness of powder of one inch at that location. (The angle of repose of the powder is approximately 3° steeper than the slope of the calciner bottom.)

Overall performance of the melter was satisfactory. Essentially no foaming occurred in all flowsheets tested. The external weir design provided for maintained heating of the discharging melt while maintaining a good vacuum seal to the melt discharge chamber. An internal vertical rib at the weir tip effectively maintained vertical dropping of the melt. Some gassing of sulfate containing melts at the weir tip caused a minor amount of spattering. Operation of the pulse blowback for the spray calciner filters tends to aggravate spattering. Flow through the freeze valve tube was always smooth. Back-sparging of melt through the freeze valve or weir tubes after emptying the melter caused serious spattering of melt into the melter inlet port on some occasions, but this was effectively eliminated by balancing vacuums during these times.

The two small heaters for the weir and freeze valves maintained temperatures effectively, but were prone to frequent failures due to local overheating. Modified fabrication techniques and design in later assemblies provided improved performance. Melt level indication was best obtained by interpretation of the internal melt temperatures and by direct viewing into the melter viewport. Viewing through this viewport was fairly good, with the glass sometimes becoming covered with powder in 1 to 3 days. The pulse reflectometer device for detecting melt level worked well for a while but failed mechanically as designed. Further development should result in a satisfactory instrument.

The primary problem with the melter was failure by corrosion during run CSCM-8 after 440 hours of service. The corrosion was initiated by the inadvertent dropping of a small stainless steel assembly into the melter during run CSCM-3. The stainless steel locally reduced the phosphate to elemental phosphorous which alloyed with, corroded, and embrittled the platinum.(10) Except for the top section, the melter was replaced with a new unit constructed of pure platinum. Subsequent controls have been incorporated to minimize the potential for inadvertent addition of foreign materials into the melter.

The melt receiver pots were filled uniformly with less than 5% voids when filled by batch dumping of the melter (at rates of 20 to 40 liters/hr) or when filled by continuous drip overflow from the melter (at rates of 0.5 to 1.5 liters/hr) when the pot was heated to within 25 °C of the slump point of the melt. A mild steel pot held at 650 to 700 °C was filled with PW-2 melt and experienced an average corrosion rate from the air of 0.006 in./day (0.004 to 0.024 in./day range), corrosion of mild steel or stainless steel pots at 700 °C from the melts was negligible in all cases.

All furnaces and their control systems performed well. Heat losses from the spray calciner furnace were approximately 4.0, 2.0, and 4.5 kilowatts from the upper, middle, and lower zones respectively while operating at 700 °C; and from the melter furnace was 8 kilowatts at 1200 °C operating temperature. Results of tests on the resistance-heated pot furnace-cooler are presented in Section 7.7. The electrical heaters on the off-gas line from the calciner performed satisfactorily, but were found to be unnecessary.

The melt sample chamber below the melter furnace performed its function adequately after modifications to strengthen the shaft which held the sample container for the more demanding remote operations. In addition, the front window was made removable by the manipulation of a single lever to permit viewing down into the melt pot by insertion of a portable mirror. (The original built-in mirror would collect sublimate during a run and the built-in light system was not reliable.) Sampling of melt may also be accomplished through this front window. The chamber restricted air leakage into the outside of the melter to about 14 standard liters/min while maintaining a vacuum of 1 inch of water.

Because of rapid changes in vacuum which are caused by the filter blowback system in the spray solidifier, the water seal height of 25 inches in the seal pot emergency vent from the calciner would blow through periodically. When these bypassing calciner gases containing calcine dust would enter the cold pipe to the seal pot, condensation would occur and wet muddy calcine would be deposited in the pipe and in the seal pot. The problem was remedied in the later nonradioactive tests by increasing the seal leg to 29 inches, adding a small disengaging section to the seal pot, injecting 28 standard liters/min of preheated air (at about 200 °C) to the connecting pipe, and adding a baffle at the emergency outlet from the spray calciner. The bouncing water level in the seal pot adds significantly to pressure oscillations in the calciner-melter.

The free-piston air-operated vibrator on top of the calciner performed well without problems.

The vibrating trough solids feeder which is used to meter part of the melt-making flux ($NaPO_3$ chips) into the melter did not perform adequately. Problems were excessive air inleakage and plugging at the inlet to the melter. Plans for radioactive testing involve batch additions through a double-valve air lock entering the conical section of the calciner.

6.1.3 Phosphate Glass Solidifier

A total of seven DVT tests was made with the WSEP phosphate glass equipment between January 1966 and May 1967.[9] A summary of the tests is listed in Table 6.4.

Major operational difficulties were resolved, valuable experience was gained, and equipment was made ready for processing high level radioactive wastes. Flowsheets using the first two standard WSEP feed compositions, PW-1 and PW-2, were tested. The feeds included the chemical equivalents of the fission products present in waste from reactor fuel irradiated to 20,000 MWd/tonne at a power level of 15 MW/tonne.

Overall, the equipment performed satisfactorily, with relatively few modifications required for radioactive service. Very few difficulties were encountered during processing of the sulfate-containing PW-2 feed, while some potentially serious problems were encountered during processing of the less friendly, sulfate-free, PW-1 feed. The original equipment performed satisfactorily with PW-2 feeds at a maximum processing rate of chemically adjusted feed to the denitrator of 16 liters/hr (12 liters/hr at 378 liters/tonne concentration), and a maximum glass-making rate of 28 liters/day.

The processing of PW-1 feeds caused severe plugging of the recirculation line from the air lift pot to the denitrator-evaporator, and plugging of the liquid level dip tubes in the denitrator and in the air lift pot. The modified air lift pot assembly (shown in Figure 6.1, tested in later radioactive demonstrations, but not tested in the DVT's) permitted operation with PW-1 feeds by periodic rodding of the recirculation line to the denitrator, and by periodic on-line flushes of dilute nitric acid. Some tendency toward plugging of the feed tube to the melter was also kept under control by periodic flushes with dilute nitric acid.

TABLE 6.4. *Summary of WSEP Phosphate Glass Solidifier Design Verification Tests*

Equipment	Run Number CPG-1	CPG-2	CPG-3	CPG-4	CPG-5	CPG-6	CPG-7
Denitrator	WSEP	WSEP	WSEP	WSEP	WSEP	WSEP	WSEP
Melter & Condenser	--	WSEP	WSEP	WSEP	--	WSEP	WSEP
Melt Receiver Furnace	--	WSEP	WSEP	WSEP	--	WSEP	WSEP
Auxiliaries		E-111, 1A, 1B, 3B and 2A Racks					
Waste Designation	Special[(a)]	PW-2	PW-2→PW-1	PW-1	PW-1	PW-2	PW-1
$\underline{M}$ of add. Na^+	--	--	-- --	1.75	1.75	--	2.46
Al^{+3}	--	--	-- --	--	--	0.23[(b)]	--
PO_4^{-3}	1.3	3.2	3.2 3.9	8.24	6.05	3.16	6.17
$\Sigma M_T^+/P$	1.34	1.05	1.0 1.0	0.70	0.95	1.0	1.0
Na/(Fe + Al), M	1.38	2.09	2.09 0.15	2.08	2.08	2.09	2.8
Data Obtained on	Denitrator perf., op. procedure	Overall perfm., Flowsheet, Remote operability, Melt rcvr perfm.	Overall perfm., Flowsheet limits, Mild st'l rcvr	Flowsheet, Melter corrosion	Auto. controls, Modified melter feed syst.	Al in feed, Auto. controls, Steam spray in condenser, Condenser corrosion	Flowsheet, Melter sparging, Ru volatility

(a) *Composition was* $0.34\underline{M}$ Fe^{+3}, $0.5\underline{M}$ Na^+, $0.01\underline{M}$ Cr^{+3}, $0.005\underline{M}$ Ni^{+2}, $0.55\underline{M}$ SO_4^{-2}, $3.5\underline{M}$ NO_3^-, *plus partial fission product content.*
(b) *This aluminum replaced an equal molar quantity of iron.*

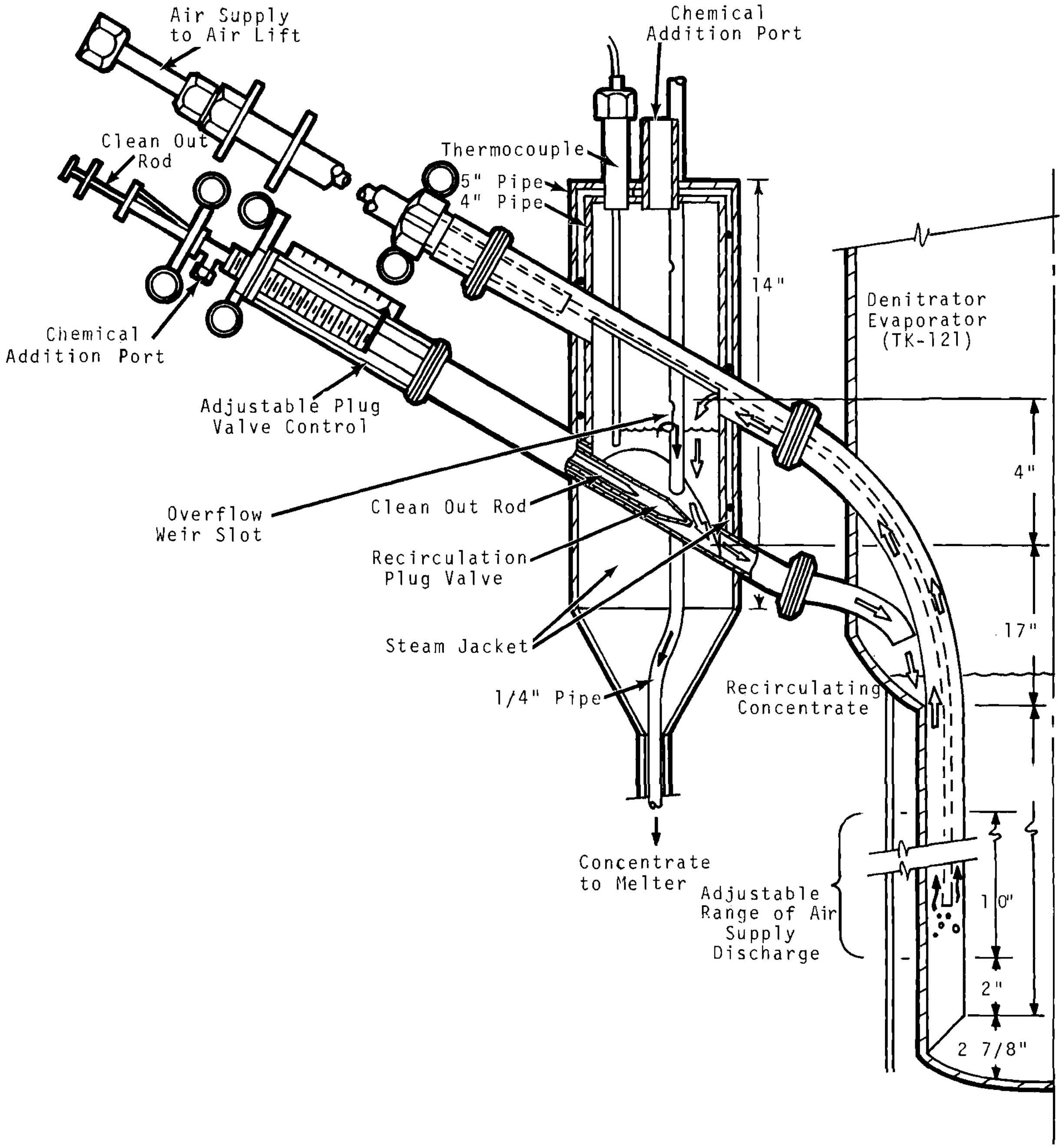

FIGURE 6.1. Airlift Pot Assembly #2 for Phosphate Glass Equipment in WSEP

The viscosimeter in the denitrator frequently became partially plugged, thereby indicating erroneous values. Consequently, the viscosimeter was deleted for radioactive demonstration tests.

The maximum processing capacity of the melter was limited by heat transfer to the melt at about 11 liters/hr of adjusted PW-1 feed to the diameter (about 7 liters/hr at 378 liters/tonne), or about 1.4 liters/hr of glass. In short-term tests with up to 6.0 standard liters/hr of air sparging, an apparent increase in the melting capacity with PW-1 melts was indicated. The lack of the mixing effect from volatile SO_3 which is absent in PW-1 feeds is believed to reduce the melter capacity.

The boil-up capacity of the denitrator-evaporator was greater than 40 liters/hr with its contents at 135 °C and using 100 psig steam for heating either PW-1 or PW-2 wastes. Spray of dilute nitric acid above the tube bundle at 2 to 4 hour intervals is necessary to prevent the buildup of scale in the vapor sections of the denitrator.

At maximum capacity conditions in the melter, the heat load for the melter furnace operating at 1250 °C was 7 kilowatts into the melt, 1 kilowatt into the shielded solution feeder, and 8 kilowatts of heat losses. At this condition, the temperature of the melt varied from 650 °C at the top to 1100 °C at the bottom of the melter.

With sulfate-containing PW-2 feed, a small amount of foam (about 1 inch high) exists on top of the melt in the melter at all times. During periods of low feed rates to the melter, this foam level can increase to several inches. During periods of high feed rates to the melter, the foam level can reach the melter off-gas line if the feed rates are high enough. With sulfate-free PW-1 feeds, about twice these quantities of foam exist, and the foam level is considerably more sensitive to feed rate to the melter. A reasonably good control of feed rate to the melter is desirable to minimize operating problems with foam.

Entrainment of aerosols in the vapor from the denitrator-evaporator is 0.05 to 0.2% of the total feed to the denitrator. Comparable values for the melter are 0.1 to 0.4% of the total feed to the melter. Ruthenium volatilization in the single run tested was 3% from the denitrator and 9% from the melter.

Severe corrosion of the platinum-5% iridium melter off-gas line was experienced until electric heaters were used to keep this line at a temperature above the condensation point (about 350 °C). The stainless steel condensate pipe from the Nionel melter condenser corroded at a rapid rate until it was replaced with a pipe made of Nionel.

The melter condenser has condensing capacity considerably greater than the duty capability of the melter. Retention of sulfate in the condensate stream from the melter condenser is enhanced and corrosion of the condensate drain line is reduced when steam spray is added to the lower section of the melter condenser. The continuous use of steam spray is recommended.

Mild steel and stainless steel receiver pots were used successfully. When maintained at a minimum of 450 °C, the pots can be filled during continuous dripwise discharge of melt from the melter. Below 450 °C, stalagmites form in the receiver pots. Batch dumping of melt through the melter freeze valve (at 50 to 150 liters/hr rates) permits filling of the pots held at room temperature. Mild steel pots can be held at 650 °C during pot filling without excessive corrosion. Corrosion of mild steel pots at 650 °C was 0.0067 in./day, compared to 0.0013 in./day when purged externally with nitrogen. Approximately 7 to 14% of the volume of the final product in the receiver are voids, presumably due primarily to entrapped gases.

Automatic control of the denitrator and melter appears possible providing the rate of concentrate flow to the melter is controlled. While the WSEP system can be satisfactorily controlled manually, control of feed rate to the melter is not adequate to permit automatic control of denitrator temperature, concentration, and level. The technique of using a pulse reflectometer probe for measurement of melt level in the melter worked satisfactorily, but the WSEP probe was inadequate as designed, primarily because of destruction of ceramic spacing insulators and some glass retention within the probe. Measurements of melt level in the melter were made visually through the viewing window in the top of the melter, although fogging up of the viewing windows required replacement every 1/2 to 1 day. Correct interpretation of melter internal temperatures also serves as a crude indicator of melt level.

The extensive thermal expansion of the system from room temperature to the maximum operating temperature of 1250 °C (in the melter furnace) was adequately controlled by proper spring loading of the melter furnace supports, and by the expansion provisions included. The same induction heated pot furnace used for pot calcination was used as the melt receiver furnace for the phosphate glass process. The furnace performed equally well in both services.

6.2 AUXILIARY EQUIPMENT

Design Verification Testing runs were made with most of the auxiliary processing equipment as part of the tests with the solidifiers, as designated in Table 6.1 and Section 6.1. Overall, the equipment performed very well, and required very few minor modifications before installation in B-Cell for radioactive service.

The overall safety of the equipment during operation was demonstrated by inadvertent failures of services in the temporary facility used for many of the tests. During the DVT runs, every service used (air, water, electricity, and steam) failed at least once. In all cases, operating personnel were able to shut down the process using the existing instrumentation and controls without damage to the equipment or significant loss of vacuum to the system. The desired safety aspects of the design were thereby confirmed.

6.2.1 Primary Process Condenser (E-111)

Although no tests were made specifically for capacity measurements, the E-111 Condenser readily condensed and cooled the off-gas from the initial part of a pot calcination DVT where the boil-up rate was 100 liters/hr.

During an early pot calciner test, steam addition to the condenser via the chemical addition spray nozzle was found to be effective in removing the dark oxides of nitrogen from the off-gas. Steam at 10 psig was used and added approximately 7 liters/hr to the condensate. Measurements following pot calciner run CPC-4 showed that up to 0.06 inches of localized corrosion had occurred just below the vapor inlet, and some etching occurred in the vapor inlet plenum. This excessive corrosion was due to excessive volatilization of sulfate because of errors in feed composition. Measurements near the end of the DVT's following spray calciner run CSCM-9 indicated negligible corrosion for the remaining DVT's (greater than 500 hours of service). No other corrosion was detected.

Between spray calciner runs CSCM-5 and CSCM-7, a 1/16 inch green scale was deposited on the vapor inlet nozzle. This deposit was the result of spray solidifier flowsheet tests where sulfates and phosphates were volatilized and condensed in that area. The deposit was readily cleared by water sprays and caused no damage.

6.2.2 Evaporator (TK-113)

Tests showed a boilup capacity for water of 515 liters/hr at a maximum steam flow of 570 liters/hr, a steam pressure of 43 psig, and a submergence level of 83 inches (representing a volume of 900 liters). The heat transfer coefficient was calculated to be 420 Btu/(hr)(ft^2)(°F). Water boilup capacity was 430 liters/hr with 28 psig steam and 80% of the tube bundle submerged (representing a volume of 140 liters). Although the exact design conditions were not tested, extrapolation shows that performance exceeds the design boilup capacity of 530 liters/hr and heat transfer coefficient of 320 Btu/(hr)(ft)(°F) with 55 psig steam and 100% submergence of the tube bundle. Nominal required boilup rates during DVT runs were 180 to 210 liters/hr.

Heat losses were measured at 90,000 Btu/hr or 44 liters/hr of reflux, assuming 100% efficient steam traps. Actual corrected losses are estimated at 50,000 Btu/hr or 24 liters/hr of reflux.

Because of the relatively high boilup capacity and small sensible heat sink in the evaporator under normal conditions (which contains approximately 100 to 200 liters of liquid), heat-up from room temperature should be done over at least a 45 minute period in order to maintain vacuum on the system. More rapid heat-up will cause excessive rates of air displacement through the vent system, and slight pressurization could result.

The liquid level dip tube performed satisfactorily, but the specific gravity dip tube was sometimes slightly affected by changes in boilup rates. The stilling chamber on the dip tube was not completely effective, but did give satisfactory results. The original "jet" type of 113 Tank feed pump recirculation return inlet to the tank was replaced with a conventional inlet located near the bottom of the tank. The original jet type (using feed solution as the motive fluid which pumped the gases from the E-111 condenser) was found to cause pressure oscillations in the inlets to the tank from the E-111 and E-115 condensers. The air sparger and steam jacket worked satisfactorily in all tests.

6.2.3 Acid Fractionator (TK-115)

Boilup capacity was found to be 380 liters/hr of water with a maximum steam pressure of 32 psig, a submergence level of 70% of the tube bundle (representing a volume of 780 liters), and a steam flow rate of 410 liters/hr. Another test showed a boilup capacity of 270 liters/hr for water with the steam coil pressure at 26 psig and a submergence level of 60% (representing a volume of 650 liters). Heat transfer coefficients varied from 500 Btu/(hr)(ft^2)(°F) at a boilup rate of 380 liters/hr to 250 Btu/(hr)(ft^2)(°F) at a boilup rate of 125 liters/hr. Extrapolation shows that the performance exceeds the design boilup capacity of 310 liters/hr with 100% submergence and 55 psig steam. Typical boilup rate during DVT runs was 200 liters/hr.

Heat losses were measured at 90,000 Btu/hr or 44 liters/hr of reflux, assuming completely efficient steam traps. Actual corrected losses were estimated at 50,000 Btu/hr or 44 liters/hr of reflux.

Each liter/min of additional reflux from the tower coil required approximately 9.1 liters/min of cooling water through the coil.

During one pot calciner test, minor titanium corrosion of the fractionator became evident by the presence of a milky precipitate in the acid bottoms. The corrosion was attributed to the modestly high fluoride concentration (0.017<u>M</u>) in the bottoms. Inhibition of further corrosion due to fluoride was successfully achieved by adding aluminum nitrate to the vessel at a ratio of 3 to 10 moles to 1 mole of fluoride.

Similarly to the evaporator, heat-up of the fractionator should be done over at least a 45 minute period in order to maintain vacuum on the system. However, heat-up of the fractionator is naturally slower than heat-up of the evaporator because of the larger heat sink and smaller tube bundle in the fractionator.

The maximum air sparging rate of 330 standard liters/min with 20 psig air supply gave good mixing of the tank contents. Dip tubes performed satisfactorily.

6.2.4 Service Tanks (TK-112, TK-114, TK-116, TK-117) and Caustic Scrubber (TK-118)

The reverse-dished bottom design provided for thorough emptying of the tanks. The nonremovable volume of liquid from each tank was 3 liters. The maximum boilup rates for Tanks 112, 114, and 118 using the coils with 60 psig steam was 300 liters/min. The air flow rate through the spargers of Tanks 112, 114, 116, and 118 was 60 standard liters/min with 20 psig air pressure and the 1/4 inch diameter orifice used in each air supply line. For the 117 Tank, the flow rate was reduced by a 3/16 inch diameter orifice to 35 standard liters/min with the 20 psig air supply. Good mixing of the tank contents was obtained with the spargers.

Heating and cooling times for the three tanks with routine process heat transfer requirements (Tanks 112, 114, and 118) were as follows:

- Heating with 60 psig steam (the maximum available) in the coil resulted in an average heat-up rate of 2.6 °C/min (approximately 190 kilowatts) when the tanks were nearly full with 1050 liters of water at an initial temperature of 30 °C, and with the sparger on.

- Heating with 15 psig steam in the jacket resulted in an average heat-up rate of 0.7 °C/min (approximately 50 kilowatts) when the tanks were nearly full with 1050 liters of water at an initial temperature of 30 °C, and with the sparger on.
- Cooling with water at 90 psig and 10 °C in the coil resulted in an average cool-down rate of 1.7 °C/min (approximately 125 kilowatts) when the tanks were nearly full with 1050 liters of water at an initial temperature of 90 °C, and with the sparger on.
- Cooling with water at 15 psig and 19 °C in the jacket resulted in an average cool-down rate of 0.7 °C/min (approximately 50 kilowatts) when the tank was nearly full with 1050 liters of water at an initial temperature of 90 °C, and with the sparger on.

These heating and cooling capacities are more than adequate for the needs during radioactive demonstrations.

As expected, the minimum usable volume of feed in Tank 114 before onset of cavitation in the P-114 feed pump (which also results in severe fluctuations in feed flow rate) was an acceptable 70 to 80 liters. Continuous agitation from the mechanical agitators (which are normally used) or the air spargers was necessary to keep solids in the feed solutions suspended. The minimum volume that was agitatable with the mechanical agitators in the tanks was 190 liters. Agitation below that level was done by air sparging.

The recirculation rate of caustic scrubbing solution in the 118 Tank was adequately measured and controlled by the liquid level over the weir at the pump discharge point in the tower. The flooding point of the caustic scrubber was 4500 standard liters/min of air at a water rate of 7.6 liters/min. Total pressure drop just under flooding conditions was 10 inches of water.

6.2.5 Instruments

Instrument performance was generally good, although the electronic transmitters sometimes tend to drift in calibration by as much as 2 to 3% in a few days. Drive clutches in the recorders tend to wear out in 2 or 3 days when the pens are "hard" off scale. Devices have been installed on some critical recorders to shut off the instrument when it travels to "hard" off scale in order to minimize clutch wear. This solution, however, is not ideal for providing continuous monitoring of process variables. Magnetic flowmeters generally performed satisfactorily, although the calibration tended to drift excessively (2 to 5%) at times. Dip tube measurements of tank pressures, liquid levels, and specific gravity worked satisfactorily. However, plugging sometimes occurred with some unfriendly feed solutions, and periodic steam cleaning was required to clear the tubes for these conditions.

Thermocouple performance was good except for some failures of Chromel-Alumel types at high temperatures (900 °C). Platinum/platinum-10% rhodium thermocuoples performed well at high temperatures, but are mechanically weak, and require careful attention during handling.

The variable reluctance rotameter systems worked without incident. Thermal conductivity probe measurements worked well after minor modifications of the piping provided the proper depth of submergence and venting to prevent air locks during sampling.

Data logging and summary output by the digital computer worked satisfactorily, but required excessive debugging efforts. Table 6.5 is a sample page of the computer output. The output is very useful in aiding on-line analyses of process test conditions by providing instantaneous measurements of key variables and material balances.

TABLE 6.5. *GE-412 Process Computer Readout*

THURSDAY SEPTEMBER 2, 1965

SHEET 3

CONSTANTS ENTERED INTO THE PANEL

SP.G. TK 114 - 1.55
SP.G. TK 117 - 1.02
SP.G. E 115 - 1.00

MAG FLOW TO SPRAY CALCINER - 2
K_2 FACTOR IN FILTER PERM CALC. - 3.0

TIME HR MIN	TK114 VOL. L.	MELTER PROBE IN.	TK113 VOL. L.	TK113 SP G	TK115 VOL. L.	TK115 SP G	TK116 VOL. L.	E115 VOL. L.	MAG FLOW TO S.C. L/H	ATOM RATE LB/H	E113 FLOW L/H	E115 FLOW L/H	S.C. PRES IN.	MELTER PRES IN.	E111 IPRES IN.	TK117 PRES IN.	SC 1 POWER RKWH	SC 2 POWER RKWH	SC 3 POWER RKWH
16-00	356.2	-20.4	149.1	1.111	591.5	0.980	296.8	36.0	9.3	31.3	152.2	154.6	-17.6	00.0	-20.0	-22.0	177.15	162.97	181.52
16-15	357.2	-6.7	150.2	1.099	580.5	0.945	294.7	34.9	9.3	31.3	143.8	154.5	-17.8	00.0	-19.9	-22.0	183.19	169.40	186.99
16-30	360.2	-14.8	152.1	1.103	599.2	0.978	299.7	34.0	10.5	31.3	149.4	144.9	-17.8	00.0	-20.5	-21.9	188.72	174.90	191.29
16-45	352.0	-7.2	153.0	1.101	602.9	0.966	294.2	33.3	9.8	31.2	152.2	144.7	-17.9	00.0	-20.3	-22.1	193.90	179.37	195.19
17-00	347.8	-16.1	147.9	1.113	620.0	0.947	292.2	37.2	9.6	31.3	155.0	61.0	-18.0	00.0	-19.9	-21.9	198.90	184.84	199.71
17-15	344.5	-6.4	144.0	1.115	638.5	0.937	294.3	37.4	9.7	31.4	147.7	146.2	-18.2	00.0	-20.5	-22.0	207.51	191.73	207.54
17-30	337.7	-13.6	142.4	1.121	644.5	0.927	298.1	36.7	10.2	31.1	150.4	145.0	-18.3	00.0	-20.7	-22.1	217.22	196.33	214.85
17-45	336.2	-6.7	142.8	1.121	651.3	0.861	293.7	35.1	9.5	31.3	152.0	146.0	-17.1	00.0	-20.1	-21.9	225.98	206.04	224.33
18-00	336.8	-16.6	143.5	1.115	649.8	0.914	297.0	34.6	9.8	31.4	150.1	143.8	-18.4	00.0	-20.3	-22.3	235.02	214.96	236.00
18-15	333.5	-12.7	144.3	1.111	710.3	0.847	294.9	32.8	9.6	31.2	127.6	146.2	-18.4	00.0	-20.7	-22.3	244.55	222.01	243.42
18-30	331.4	-9.8	143.9	1.119	723.4	0.818	294.7	28.9	9.5	31.2	148.4	145.3	-18.4	00.0	-20.5	-22.1	253.48	230.63	251.66
18-45	328.2	-8.3	145.2	1.117	708.6	0.810	295.2	29.8	8.9	31.3	151.5	144.9	-16.9	00.0	-19.9	-21.8	261.64	239.22	260.61
19-00	325.4	-17.2	142.7	1.119	723.6	0.810	295.6	33.0	10.2	31.5	152.8	144.9	-16.8	00.0	-20.9	-22.1	266.87	245.56	265.79
19-15	322.0	-4.7	142.7	1.121	721.0	0.810	298.5	34.9	10.1	31.3	144.8	148.7	-18.7	00.0	-20.2	-22.1	272.73	251.44	271.90
19-30	321.3	-16.4	140.5	1.125	726.4	0.810	295.0	34.8	9.8	31.4	148.0	144.4	-16.9	00.0	-19.9	-21.8	284.94	257.13	278.79
19-45	317.6	-11.3	139.5	1.126	719.9	0.810	297.5	32.3	10.3	31.4	152.2	146.3	-17.6	00.0	-20.0	-22.1	294.51	263.24	286.80
20-00	314.4	-6.0	136.7	1.128	726.5	0.810	296.6	28.9	1.1	1.3	151.1	148.3	-00.1	00.0	00.1	-01.8	297.94	266.27	290.42
20-15	310.5	1.1	133.9	1.128	726.0	0.806	295.8	27.6	1.9	1.3	154.6	145.9	-18.6	00.0	-18.9	-21.7	302.43	268.98	294.00
20-30	313.7	-2.2	130.0	1.138	710.5	0.810	297.6	27.9	1.3	31.3	116.6	144.5	-17.1	00.0	-19.0	-22.1	310.18	279.70	303.07
20-45	312.1	-3.7	138.8	1.125	710.5	0.806	293.9	27.5	9.8	31.2	99.6	145.3	-15.4	00.0	-19.6	-22.0	318.34	290.24	309.92
21-00	313.2	-7.9	151.2	1.101	710.3	0.810	299.6	27.0	10.0	31.3	103.5	145.5	-15.1	00.0	-19.8	-22.2	326.84	296.93	315.94
21-15	305.3	-14.7	169.4	1.085	717.5	0.804	296.6	27.9	9.6	31.3	122.8	128.6	-17.6	00.0	-20.0	-22.3	335.39	305.34	322.07
21-30	305.3	-10.3	174.3	1.082	727.0	0.806	297.2	28.3	9.6	31.3	144.0	132.1	-17.1	00.0	-18.9	-22.0	345.46	314.27	330.18
21-45	306.7	-13.6	171.7	1.083	671.8	1.019	297.8	30.8	9.6	31.4	138.7	130.5	-17.5	00.0	-18.9	-23.3	354.81	323.35	335.73
22-00	298.6	-10.0	169.2	1.080	675.6	1.017	294.7	32.7	9.1	31.4	139.1	132.5	-16.0	00.0	-19.0	-22.2	361.03	329.50	342.00
22-15	296.7	-10.3	165.4	1.085	680.7	1.017	298.7	32.0	9.6	31.3	145.2	131.7	-16.5	00.0	-18.6	-22.2	368.43	335.85	348.20
22-30	292.6	-4.3	160.7	1.085	687.9	1.011	298.8	32.5	9.2	31.3	142.7	131.1	-14.7	00.0	-18.9	-22.1	373.86	340.94	353.18
22-45	295.6	-15.5	155.1	1.083	693.3	1.013	299.0	34.1	9.2	31.3	135.0	132.0	-14.9	00.0	-18.9	-21.9	379.24	346.52	358.16
23-00 A-14 off	287.3	-7.3	153.9	1.091	701.4	1.015	297.6	34.4	9.9	31.2	139.5	131.9	-15.3	00.0	-19.9	-22.0	385.05	351.63	362.65
23-15	291.3	-4.2	224.1	1.101	697.8	1.001	296.6	8.6	1.5	1.3	-0.5	85.1	-05.8	00.0	-05.8	-07.5	386.46	353.51	364.73
23-30	288.6	-0.1	234.5	1.109	715.2	0.992	297.7	8.6	1.6	1.3	-1.1	16.8	-04.1	00.0	-03.9	-05.4	386.60	353.70	364.92
23-45	288.9	-2.7	231.5	1.113	710.5	0.992	297.2	8.6	1.6	1.3	-2.2	15.4	-04.8	00.0	-04.7	-06.1	386.62	353.87	365.05

IND 1 POWER RKWH	IND 2 POWER RKWH	IND 3 POWER RKWH	SC TEMP FURNACE C.	SC TEMP INNER W C.	SC D.T. C.	MELTER D.T. C.	FILTER TEMP C.	S.C. D.P. IN.	FILTER F. VEL. FT/M.	FILTER PERM. FT/M.IN.	REC. RATE KG/H	LIQUID RATE KG/H	REC AND RATE KG/H	E113 HNO3 M.	TK114 RATE L/H	TK116 RATE L/H
403.96	358.71	398.30	465.4	162.9	305.2	0.0	102.2	1.3	3.31	1.6	21.[illegible]	-936.[illegible]	-901.7	0.062	15.1	-0.5
421.54	373.49	410.33	466.9	159.1	306.5	0.0	82.6	1.8	-10.49	1.3	-5.4	-989.8	-973.2	0.064	-8.9	8.5
434.28	391.24	426.42	469.4	118.5	353.2	0.0	94.2	1.0	-50.33	-48.7	2.0	-953.4	-930.1	0.025	4.1	15.3
453.25	411.77	445.98	485.9	119.8	370.7	0.0	90.2	2.3	2.65	0.6	43.0	-813.2	-781.9	0.064	39.6	2.8
470.70	431.01	469.35	484.6	125.6	357.4	0.0	87.0	1.3	4.24	2.8	35.5	-88.4	-45.1	0.072	23.5	13.3
486.65	446.77	488.50	465.0	125.7	337.4	0.0	85.1	3.0	3.30	1.5	26.1	-958.6	-938.4	0.111	18.7	17.6
507.19	468.50	518.23	464.0	123.9	338.5	0.0	81.9	1.8	2.84	1.0	5.8	950.6	965.3	0.099	0.8	17.2
526.33	489.78	540.82	475.7	143.6	335.1	0.0	67.2	2.4	-10.66	1.6	-4.9	943.5	959.0	0.125	-4.9	7.6
540.61	508.10	559.54	472.8	135.1	335.2	0.0	78.3	2.0	-48.30	-21.9	4.1	924.0	979.5	0.089	5.1	23.5
561.96	523.74	580.30	453.9	144.8	308.0	0.0	66.0	1.9	2.25	0.8	10.7	915.5	972.2	0.107	8.8	-7.7
587.43	540.23	607.38	455.1	157.0	307.2	0.0	75.7	3.1	2.49	1.1	16.7	-951.6	-972.6	0.095	13.6	13.6
603.09	559.32	628.37	441.8	172.2	269.9	0.0	74.7	2.0	2.75	1.0	21.0	-956.7	-922.8	0.099	16.4	23.0
621.76	577.31	646.06	447.6	193.0	258.0	0.0	72.9	1.8	2.73	0.9	8.9	-715.5	-698.7	0.101	4.3	15.6
641.73	590.59	662.39	446.8	209.6	237.1	0.0	61.2	2.1	2.07	0.7	3.6	946.6	955.1	0.091	2.4	16.0
665.83	609.65	685.44	444.2	206.1	238.7	0.0	71.3	2.8	2.08	1.0	9.5	992.1	901.8	0.117	8.3	3.1
684.11	630.36	705.50	442.2	211.7	228.6	0.0	68.8	2.8	2.51	0.5	24.5	933.0	957.1	0.119	21.0	22.5
694.64	634.51	710.49	441.0	234.1	207.0	0.0	58.7	-0.2	1.08	11.0	8.0	972.4	991.2	0.125	2.3	-13.8
705.91	645.34	721.82	466.5	260.4	204.6	0.0	60.1	0.4	12.39	1.0	-1.5	-924.4	-920.7	0.250	-2.0	-8.1
717.39	657.81	742.57	477.1	319.4	159.4	0.0	75.2	-0.4	-60.12	-28.7	-19.8	-975.4	-988.3	0.296	-18.1	0.0
737.24	675.84	759.68	447.6	314.3	136.5	0.0	80.7	2.9	-48.90	-97.6	-4.3	913.8	905.2	0.156	0.4	12.0
754.82	691.76	778.03	447.7	296.0	149.4	0.0	71.6	1.8	2.18	0.6	18.8	-956.0	-937.8	0.025	17.5	-20.6
769.85	706.57	800.62	443.8	266.5	178.9	0.0	84.0	1.8	3.08	0.7	29.0	906.0	935.3	0.005	22.8	-17.2
790.46	722.12	818.33	433.8	254.7	182.0	0.0	85.1	1.9	3.32	1.4	30.7	986.2	916.6	0.000	23.2	2.3
810.64	739.33	836.33	431.2	243.9	194.8	0.0	84.7	2.1	-9.97	1.3	1.1	-963.4	-942.1	-0.001	-3.5	-1.2
825.71	756.77	857.56	435.9	242.1	192.1	0.0	71.7	1.9	-48.55	-22.5	10.9	-960.4	-952.2	0.011	11.1	12.9
845.11	772.04	875.79	429.0	209.3	215.8	0.0	82.9	3.0	-10.23	0.6	-0.0	961.2	969.2	0.005	-2.8	15.7
864.43	787.58	893.55	426.6	161.0	267.3	0.0	82.3	2.4	-48.32	-21.7	5.3	949.4	953.7	-0.001	5.7	0.7
879.03	801.59	913.08	418.0	143.1	273.7	0.0	69.3	3.1	-9.99	1.1	0.8	-981.1	-977.5	0.003	-0.6	5.3
898.41	820.30	932.36	430.6	134.3	293.0	0.0	80.4	2.3	-47.99	-14.4	6.6	972.8	979.0	0.035	6.4	-12.5
907.80	827.79	939.93	442.7	163.4	279.9	0.0	80.3	0.7	12.73	0.7	-17.9	-324.5	-330.2	0.107	-18.5	10.3
908.88	828.41	941.58	429.3	177.3	252.3	0.0	79.2	-0.1	49.07	-93.3	-4.4	-904.8	-907.4	3.179	0.5	11.0
909.94	829.52	943.24	411.4	189.8	222.0	0.0	78.3	-0.1	-12.43	-0.7	-1.0	-288.1	940.6	3.179	-1.1	970.7

The small control valves with 1/2 inch travel and standard control trims that are used for in-cell operations performed satisfactorily except in feed service. Later tests with a larger valve with a vee-groove type of trim and 3/4 inch of travel worked satisfactorily in feed service. These larger valves are to be used for feed flow control in radioactive demonstrations.

6.2.6 Other Auxiliary Process Equipment

The feed line flush system operated satisfactorily, but the flush tank system would not hold pressure when it was isolated by closing all connecting valves. Consequently, the P-116 flush supply pump must be operated at all times that the feed pump is operating to prevent contamination of the flush supply Tank 116 (the final process condensate receiver). The water flush system used before and after feeding a solidifier was effective in preventing feed line plugging.

The two-stage air lift system for pumping and metering feed from the 114 Tank was found to operate satisfactorily at feed flow rates of 8 to 18 liters/hr, even at low feed tank volumes. Maximum pumping rates up to 54 liters/hr could be achieved with air supply flows of 12 and 60 standard liters/min to the upper and lower air lifts, respectively. The single-stage air lift system for pumping from the 112 Tank to the 113 Tank also worked satisfactorily, but was oversized and required the addition of valve control of its discharge. The maximum pumping rate was 630 liters/hr with 50 inches of water in the 112 Tank (80% submergence of the air lift), and a supply air flow rate of 180 standard liters/min.

The primary process vent system (designated Number 1) could satisfactorily pump and control flow rates of noncondensible gases up to 260 standard liters/hr at a vacuum of 25 inches of water. This capacity was borderline to allow use of air atomization in the spray calciner with a calciner filter pressure drop of 10 inches of water and air inleakage less than 130 standard liters/min. These conditions represent the maximum venting requirements. The ejector for the primary process vent system was replaced after the DVT runs with one having a capacity 50% greater than the original. The new ejector can easily pump the amount of gases that can pass through the equipment train for process off-gas treatment at a total pressure drop of 30 inches of water.

High rates of air sparging and refluxing in the 112 Tank and the E-112 Condenser caused excessive entrainment in the vessel vent system. These entrained liquids were not sufficiently removed by the condensing and reheating capability of the vent system, and sometimes cause the F-113 vessel vent filter to become wet. Operation at reasonable rates overcomes this condition. Liquid samplers worked quite well. The sampling procedure adds up to 90 standard liters/min to the system, and reduces the vacuum by about 2 to 3 inches of water. Gas sampling was not tested in the DVT's, and solids sampling was discussed in Section 6.1.2.

6.3 DISTILLATION DEMONSTRATION UNIT

A total of 11 design verification runs was made with the Distillation Demonstration Unit between August and October of 1968. Various mixtures of nitric and sulfuric acids were employed to simulate melter condensate feed to the unit. All feed streams contained 0.19M phosphoric acid and 0.0067M ruthenium (added as a 10% solution of ruthenium nitrate). The performance of the DDU was satisfactory, and generally verified results gathered in earlier laboratory glassware runs.

The DDU will accept a batch charge of 80 liters of condensate, which is the equivalent of that from processing waste from 0.3 to 0.8 tonnes of power reactor fuel. The total cycle time for charging, distillation into two distillate fractions, shutdown and transfer is 12 hours. Average boil-off rates during the 10 hours of boiling during each cycle is 7.5 liters/hr.

The ruthenium removal from the sulfuric acid varies from a factor of 60 to 10,000, depending upon operating conditions. Ruthenium decontamination increases significantly with increasing vacuum and increases to a smaller degree with increasing boil-up rate, and with decreasing ratios of nitric acid:sulfuric acid. For absolute pressures of 25 torr, decontamination factors of 300 to 1000 are typical. Ruthenium retention in the system is essentially complete, as evidenced by the fact that no ruthenium can be detected in the vacuum pump exhaust line. However, some evidence indicates that the ruthenium decontamination factor may be reduced as more runs are made and some ruthenium plates out in the system.

The accuracy of the liquid level and specific gravity readings is affected by some changes in operating conditions, primarily due to the slight pressure drop in the pneumatic instrument lines. This condition is readily overcome by a quick calibration of the instruments at the start of each run.

7.0 RESULTS OF DESIGN VERIFICATION TESTS OF MECHANICAL EQUIPMENT

Design verification testing of mechanical equipment was performed simultaneously with that of the process equipment. The primary objective of these tests was to determine the suitability of the equipment for reliability of operation and for remote installation, maintenance, and removal. In nearly all cases, the equipment was determined to be satisfactory for use as designed. Occasional minor modifications and infrequent major modifications were completed before start of radioactive demonstrations.

7.1 EQUIPMENT RACKS

7.1.1 Rack Handling and Alignment Test

The feasibility of the plug-in rack concept was verified by a test installation of a major WSEP rack into a special jig under simulated remote handling conditions. The 2A Rack was used in the test. The jig, shown in Figure 5.2, consisted of a mock-up of cell wall sleeves designed and positioned to meet building tolerances. The centerline spacing and the parallelism of the plugs and sleeves were carefully checked, and both the jig and rack were carefully levelled before the test. Results of the test showed:

- No difficulties were encountered in inserting the rack plugs into the jig sleeves or in withdrawing the plugs.
- Tapered guides are desirable on the ends of the plugs to aid in guiding and to protect projecting plug nozzles.
- Wedging of plug ends is required after installation to center plugs in sleeves and to simplify jumper fitup.

7.1.2 Load Test on Rack Plug Box

Deflection of a dummy plug box under load was investigated to verify that the load-carrying capacity of the plug box/rack frame system is adequate to support the rack loads. The dummy assembly consisted of a plug box and plug joined to 6 inch pipe members in a form typical of that for WSEP equipment racks.

The plug assembly was securely fastened to the building structure and concentrated cantilever loads up to 10,000 pounds were applied to the end of the plug. The total applied moment about the plug box centerline was 440,000 in.-pounds. This moment produced the anticipated and acceptable maximum deflection at the end of the plug of 7/8 inches, with no permanent deformation. It was concluded that the plug box structure had sufficient strength to place the entire weight (6 tons) of the heaviest rack on the end of a single plug without buckling the structure. Such loading should not occur in normal handling since all large racks have two such plugs.

7.2 CELL EQUIPMENT

7.2.1 Wall Plug Seal Test

The 4 and 8 inch wall service plugs are sealed with serrated rubber caps which fit over the cell end of the plug. This seal prevents potentially contaminated fluids from flowing between the plug and sleeve from the cell to the gallery. The sealing capability of the cap was tested by holding a dummy cap seal joint under a static head of 18 inches of water for several hours. Since no leakage was observed during the test, the sealing capability of the cap was determined to be adequate to protect against leakage from the splashes which could occur in the cell.

7.2.2 Cell-to-Gallery Transfer Mechanism

The cell-to-gallery transfer mechanism was loaded with a 100 pound weight and cycled several times to verify operability and load carrying capacity. The commercial drawer slide mechanism used as the load-carrying member was found to be conservatively rated, and the nominal working capacity of 100 pounds could be exceeded by approximately 50% without damaging the mechanism. Other conclusions from the test were:

- A special cam was required and was added onto the slide mechanism for positive retraction of a free-floating inner member which is part of the three-piece slide assembly.
- Manipulator operation of the cell side swinging door was good.
- Manual operation of the screw-driven door opening mechanism used on the gallery side sliding door was time consuming, but acceptable.

7.2.3 Three-Ton Crane

In-cell crane performance was evaluated during special remotability tests. Conclusions and results from this evaluation were:

- The original silicon controlled rectifier (SCR) control system for the dc crane required considerable modifications to provide antisurge protection for the SCR units, to improve the controllability and operability of the main hook under rated load, and to improve the reliability of the dynamic braking system.
- The 500 pound capacity boom hook proved invaluable in the cell remote handling operations, but required utmost caution to avoid interference situations which could result in equipment damage. The boom system was modified to improve remote maintainability and reliability.
- Some bridge skewing occurred which sometimes caused jerky bridge travel and tendency for high rail wear, but the extent was judged to be acceptable. These effects are caused by the manufacturer's designs used to overcome the relatively high length:width ratio in the crane.

- The festooned cable system originally used for the trolley power supply was replaced with a commercial cabletrack system to eliminate the original cable pinching problems.

7.2.4 Television Plug and Systems

Operation of the television plug confirmed the mechanical operability of the plug mechanism and the utility of the plug for remote operations at the upper levels of the cell. In particular, the combination use of one manipulator and one television system for viewing at the second floor level for removing jumpers from the phosphate glass rack and the spray solidifier rack proved surprisingly effective. Depth perception difficulties with the "one-eyed" viewing caused less difficulty than anticipated.

One problem encountered was the disorientation of the picture produced by rotating the plug to pan the camera. The problem was corrected by modifying the coil of the picture tube of the television receiver to permit counter rotation at that point for restoring the picture to the true position.

7.3 REMOTE HANDLING TESTS

Extensive remote handling tests were conducted in the cell prior to "hot" startup to evaluate in-cell tools and viewing and handling equipment. These tests were also made to assure that remote transfer and handling of process equipment subassemblies, piping and electrical jumpers, lights, filters, and waste pots could indeed be accomplished. With relatively minor modifications to original designs, all functions were well performed. Highlights of these tests are discussed in the following subsections.

7.3.1 Pipe Trench Jumpers

Pipe trench jumpers are located at or below a plane located 3 feet below the floor level of the Air Lock Cell.

Removal and replacement of these jumpers were accomplished with some effort using an upset-arm manipulator (one with the slave arm longer than the master arm), a crane-suspended impact wrench, and a closed-circuit television. Some shielding in front of the manipulators will likely be required to remove these jumpers after they have become radioactive.

7.3.2 Rack Face Piping Jumpers

Most of these jumpers were found to be readily removable. The necessity for crowding of equipment in some cases and the necessary use of some marginally accessible areas created some time consuming handling requirements, but all manipulations were quite workable. Positive mechanical separation of the Conoseal nozzles was found to be desirable in most cases, since the metal gasket tends to spread and bind in the female half of the nozzle, thereby increasing the difficulty of separation. This is accomplished in the backaway type of block connector. Tapering the throat of the female block would significantly reduce the problems of separation, but this change was not made in WSEP. It was also concluded that rigid jumpers with more than two nozzles should be avoided where possible to speed up manipulations.

7.3.3 Intra-Rack Jumpers

These jumpers include the agitators, pumps, tube bundles, and off-gas lines in and on the main rack vessels, and away from window areas where manipulators are not available for remote handling. All of these jumpers use the "Purex" remote connector system. The system worked in all cases, although a considerable degree of operator skill and patience was sometimes required. One persistent minor problem was the tendency of the large remote nuts to re-engage during removal (and vibration) of an adjacent nut.

Guide tracks were found to be necessary and were provided for the remotable tube bundles for the acid fractionator and the evaporator on the 1A Rack to aid in aligning the flange holes of the tube bundles with respective dowel and bolt holes on the rack.

7.3.4 Inter-Rack Jumpers

The relatively long and awkward and sometimes limber off-gas, feed line, and condensate jumpers used for connections between racks surprisingly offered no serious remote handling problems.

7.3.5 Phosphate Glass Rack 5C

Rack 5C was remotely disconnected and removed from the cell, since remote installation of the rack would definitely be required after radioactive demonstrations with the pot calciner rack in the same position. Remote removal of the phosphate glass rack was readily accomplished without removing the melter and its furnace which were clamped in place for the transfer. The test identified the jumpers which were difficult or impossible to remove remotely, and minor modifications were made accordingly.

7.3.6 Waste Pot Furnace-Coolers, Racks 5A and 6A

Both pot furnaces were designed so that the thermocouple "birdcages" could be replaced remotely, since these assemblies were considered to be the most vulnerable to failure (and are required for operation of the induction-heated 5A Furnace). Replacement of the thermocouple cage involves removal and reassembly of pot fill heads, the upper halves of the furnace hoods, and miscellaneous hardware inside the hoods. These operations were accomplished successfully, although extension tools are required in some cases to span connectors beyond the normal manipulator reach. Complete remote replacement of both furnaces is also feasible.

7.3.7 Waste Pot Handling and Positioning System

Extensive pot handling tests were performed because handling of these relatively large items would be routine. Furthermore, expeditious handling is required, since these containers will house millions of curies of radionuclides, each of which will generate up to about 20 kilowatts of heat. Pot handling manipulations were carried out in remote handling tests which included the complete sequence of handling up through installation in the storage station in B-Cell. Tests included: 1) transfer of the pot into the cell and coupling with the pot hood cover, 2) lowering of the pot into the furnace, movement to the pot fill position, and connection to the pot fill head, 3) connection of the pot thermocouple connector, 4) withdrawal of the pot from the furnace and transfer to the welding station, and 5) capping of the pot mechanically and by welding (the pot cap has a mechanical and a weld joint) and transfer to pot storage in the 4A Rack.

The conclusions regarding modifications to the original equipment design were:

- Positively-locked bails for carrying the pots are preferred and will be used for safety reasons.
- Remote coupling of the two halves of the pot thermocouple connector required a guide system for positive alignment. A dowel-pin guiding device was added to the connector for alignment.
- Strict quality control is required in fabrication of the threaded cap used on the calcine pot and the press-in cap used on the melt pot to prevent assembly problems.

7.3.8 Electrical Connectors and Lights

Electrically-powered components in B-Cell except lights are connected in the cell by standard multipin connectors, by welding type plug-ins, or by standard thermocouple connectors which are accessible directly or by using drop cords for access by master-slave manipulators. No great difficulties were encountered in coupling these connectors; however, the use of a clamp or other holding device for the mating half is useful in coupling the multipin connectors.

Removal of the cell light fixtures was readily accomplished using only the crane.

7.3.9 Cell Filter

Special guide tracks and frame lead-ins were provided for the cell filter as a result of remote handling tests. Resultant manipulations were readily accomplished.

7.4 AGITATORS

Feed tank agitators with 1 inch diameter shafts and double-mechanical aluminum oxide/graphite seals were given operability tests. The 1 inch shafts with minimum lengths of 57 inches developed undesirable whip which caused cracking of the oxide seal rings. Following this unsuccessful performance, the agitators were reassigned for use out of cell, and were replaced with agitators featuring 1 1/4 inch diameter shafts and double-mechanical seals with Stellite/graphite rings. Performance of these agitators in subsequent tests was successful.

One agitator seal was replaced with a nonlubricated graphite throttle bushing. Subsequent testing of this agitator indicated smooth operation, and the agitator was installed in a radioactive feedstock storage tank in the waste vault of the building.

7.5 PUMPS

Process pumps were evaluated in the 321 Building and in B-Cell during Design Verification Tests of the process equipment. Inline canned pumps equipped with graphite bearings and seals failed rapidly in these tests when pumping simulated feed slurries. Pump failure every 100 to 400 hours persisted during tests with various forms of boron carbide bearings and seals in spite of the special water circulating system used to protect the bearings and seals of these pumps. The use of these expensive inline pumps for feed pumps was eventually abandoned in favor of the more conventional and less expensive (by a factor of 10) air-cooled motor-driven pump shown in Figure 5.12. The performance of this conventional pump, which employs a graphite/ceramic mechanical seal, has been at least comparable to that of the canned pump. Reliability of either pump is improved by extensive water flushing of the feed system between runs.

The canned pumps containing the integral hydroclone and used for pumping condensates and caustic scrubbing solution have operated for thousands of hours without difficulty.

7.6 WASTE POT INDUCTION FURNACE-COOLER

Mechanical, electrical, and heat transfer characteristics of the induction-heated furnace-cooler in the 5A Rack were determined in design verification tests.

Mechanical tests verified that the furnace could be remotely maintained, as discussed in Section 7.3.6. In addition, a stationary upper plug which extends through the cell wall for supply of cooling air, and a screw-jack mechanism for vertical movement and positioning of the pot were adopted for the furnace for improved remote operation.

Results of electrical tests of the 960 cycle induction heating system showed that:

- No significant tendency existed for adjacent coils to crosscouple and affect the electrical operating characteristics of the system. The variations in power factor which occurred as coils switched on or off were consistently less than 5%. Results conclusively confirmed the feasibility of multizone induction furnaces.

- The use of output load-matching transformers as used in WSEP is very desirable and is highly recommended for optimum matching of the coil to the load.
- The inductive effect of paired power transmission cables was negligible. No significant coupling with the rack wall sleeve was observed. This result suggests that the magnetic shield of the furnace might be eliminated or reduced in size, with a corresponding decrease in furnace diameter.

It should be noted that extrapolation of these results to higher-frequency systems must be approached with caution.

Overall net heating efficiency varied from 50% at 60 kilowatts down to 17% at 20 kilowatts of net heat rate at 600 to 700 °C furnace temperature. Steady-state natural heat losses from the furnace were measured in two tests with an empty pot in the furnace:[11] one with a furnace liner temperature at 900 °C, and one at 600 °C. Results showed a good balance between the net heating capability of the furnace and the needs for cooling the pots and minimizing heat losses to the cell. Heat losses for each of the six zones are summarized in Table 7.1. Heat losses to the coil coolant represent approximately 40% of the total losses. About 25% of the total losses were through each of the two end zones. Since the gross design power of each zone is 20 kilowatts, the heat loss from Zone 1 at 900 °C (7.3 kilowatts, the highest observed loss) represents only 36% of the total power available to that zone. The heat losses due to end effects substantiates the need for multiple furnace zones even without differences in power consumption needs in each zone due to process requirements.

TABLE 7.1. *Natural Heat Loss Data from Induction-Heated Pot Furnace*

Furnace Zone	Heat Losses, kW at Furnace Liner Temperatures	
	900 °C[a]	600 °C[b]
1 (top)	7.3	3.0
2	4.5	2.3
3	3.4	1.6
4	1.3	0.9
5	4.2	2.0
6 (bottom)	6.2	3.6
Total	26.9	13.4
Total Loss to Induction Coil Coolant for all Zones	11.7	5.4

(a) *Temperature of the furnace outer shell was 66 °C.*

(b) *Temperature of the furnace outer shell was 38 °C.*

Results from these tests were used in a computer study[12] of furnace cooling relationships. Pot wall temperatures were calculated and compared with actual measured values in later radioactive test runs as shown in Table 7.2 for the indirect air cooling. Relatively good agreement was obtained between calculated and observed values. Additional correlations from these studies, showing the calculated added effect of direct cooling air inside the furnace susceptor, is shown in Figure 7.1. These studies show that with the pot wall at 427 °C (one of the criteria for pots with maximum self-generation heat content), the cooling capacity of the furnace was 8.5 and 16 kilowatts with indirect cooling air and with indirect cooling air plus the direct cooling air, respectively, for 8 inch diameter pots. Cooling values for 12 inch diameter pots are 15 to 25% greater.

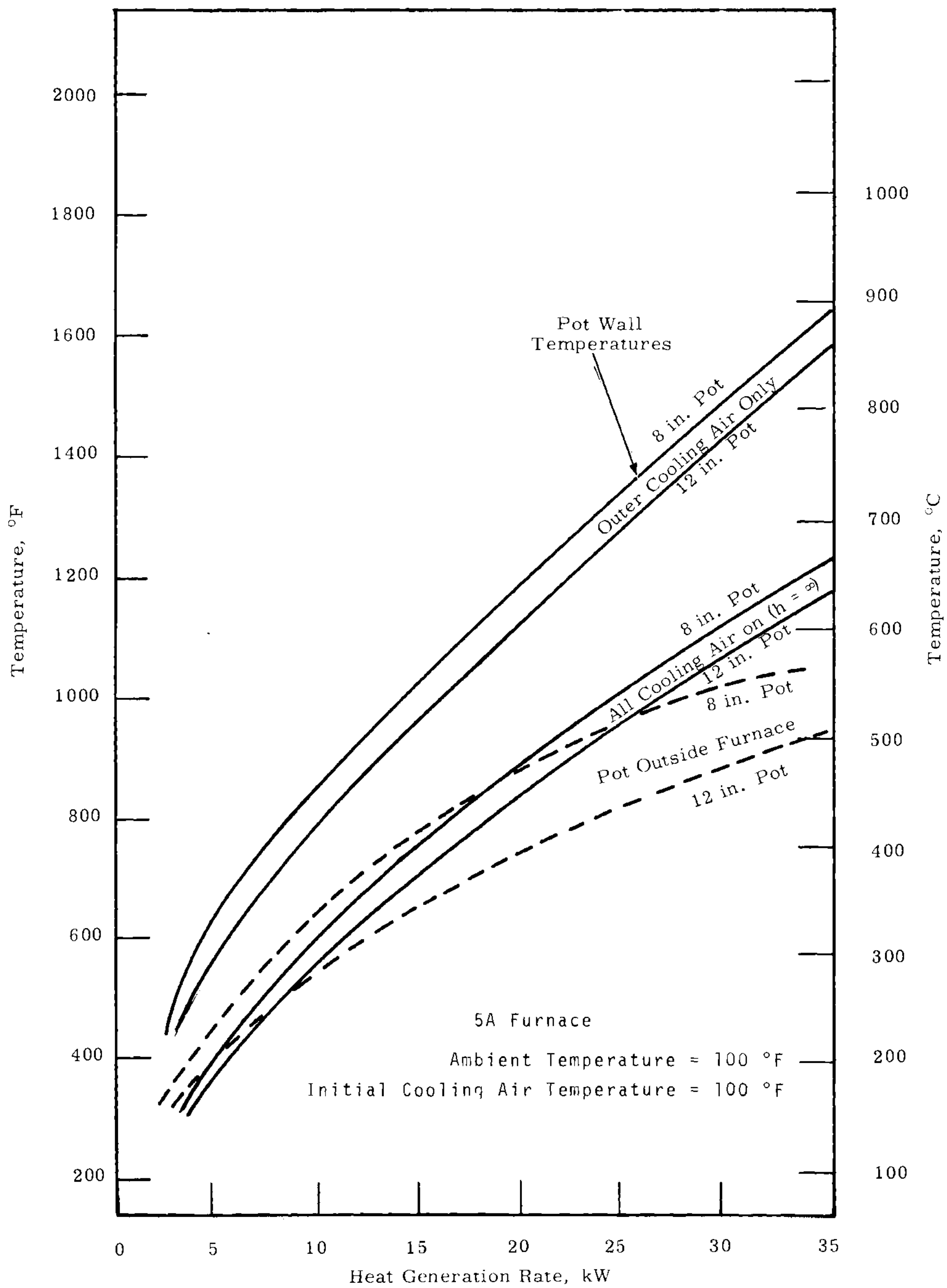

FIGURE 7.1. Cooling Characteristics of Induction-Heated Pot Furnace-Cooler

TABLE 7.2. *Measured and Calculated Pot Wall Temperatures in the Induction-Heated Pot Furnace*

WSEP Radioactive Run No.	Pot Heat Generation Rate, (kW)	Wall Temp., °C Measured	Wall Temp., °C Calculated	Cooling Condition In Furnace
Pot Calciner 6	5.1	240	200	Outer
Phosphate Glass 5	9.7	345	415	Cooling
Phosphate Glass 6	8.5	420	430	Air Only

Temperature profiles in the furnace were measured to characterize the uniformity of temperature in the susceptor wall and to identify possible "hot spot" problems. Unbonded thermocouples located at the quadrant points and centered at each zone were used to measure the wall temperatures in tests with three alternate furnace zones operated. Maximum temperature differentials of 100 °C axially and 25 °C radially were recorded with the wall at 900 °C. These results show very even temperature distribution for the difficult conditions imposed, and point out the lack of hot spots in the system. The use of low frequency and the heavy wall susceptor in the WSEP furnace contributed to the relatively uniform wall temperature with the relatively nonuniform heat losses.

7.7 WASTE POT RESISTANCE FURNACE-COOLER

Tests were made on the six-zone resistance heated pot furnace-cooler with a resistance-heated dummy pot (simulating a waste pot generating heat by radioactive decay) to measure heat losses from the system and to determine cooling capacity. Mechanical tests were not made since the mechanical details of remote handling features on this 5A Rack and on the 6A Rack are virtually identical.

At steady-state operation with the inner furnace wall at 800 °C, heat rate losses of 6 kilowatts were measured from each of the top and bottom zones. Heat rate losses from the four remaining zones totalled 19 kilowatts, or an average of 4.8 kilowatts for each zone. The maximum temperature observed at the furnace outer shell was 175 °C.

In other tests, system temperatures were measured at steady-state conditions for various simulated heat generation rates with rates of indirect cooling air (i.e., cooling air outside the susceptor) of 2300 standard liters/min to each zone. With a pot heat generation rate of 6.2 kilowatts, and no power to the furnace, the pot wall temperature was 250 °C. Heat balance calculations showed that 94% of the input heat was removed by the cooling air.

Further tests and analysis of the results[12] show that, for heat generation rates ($Q_{p \to s}$) from pots inside the furnace over the range of 2.9 to 12.3 kilowatts, the cooling capability is represented by:

$$Q_{p \to s} = 4.47 \times 10^{-5} (T_{pw}^4 - T_s^4), \text{ where:}$$

T_{pw} = pot wall temperature, °R

T_s = furnace susceptor temperature, °R

$Q_{p \to s}$ = heat rate between the pot and susceptor in kilowatts.

The results of these and later calculations are shown in Figure 7.2, which also shows the calculated cooling capability where air coolant inside the furnace susceptor is also used. Cooling capabilities are nearly identical to those in the induction-heated furnace, discussed in Section 7.6.

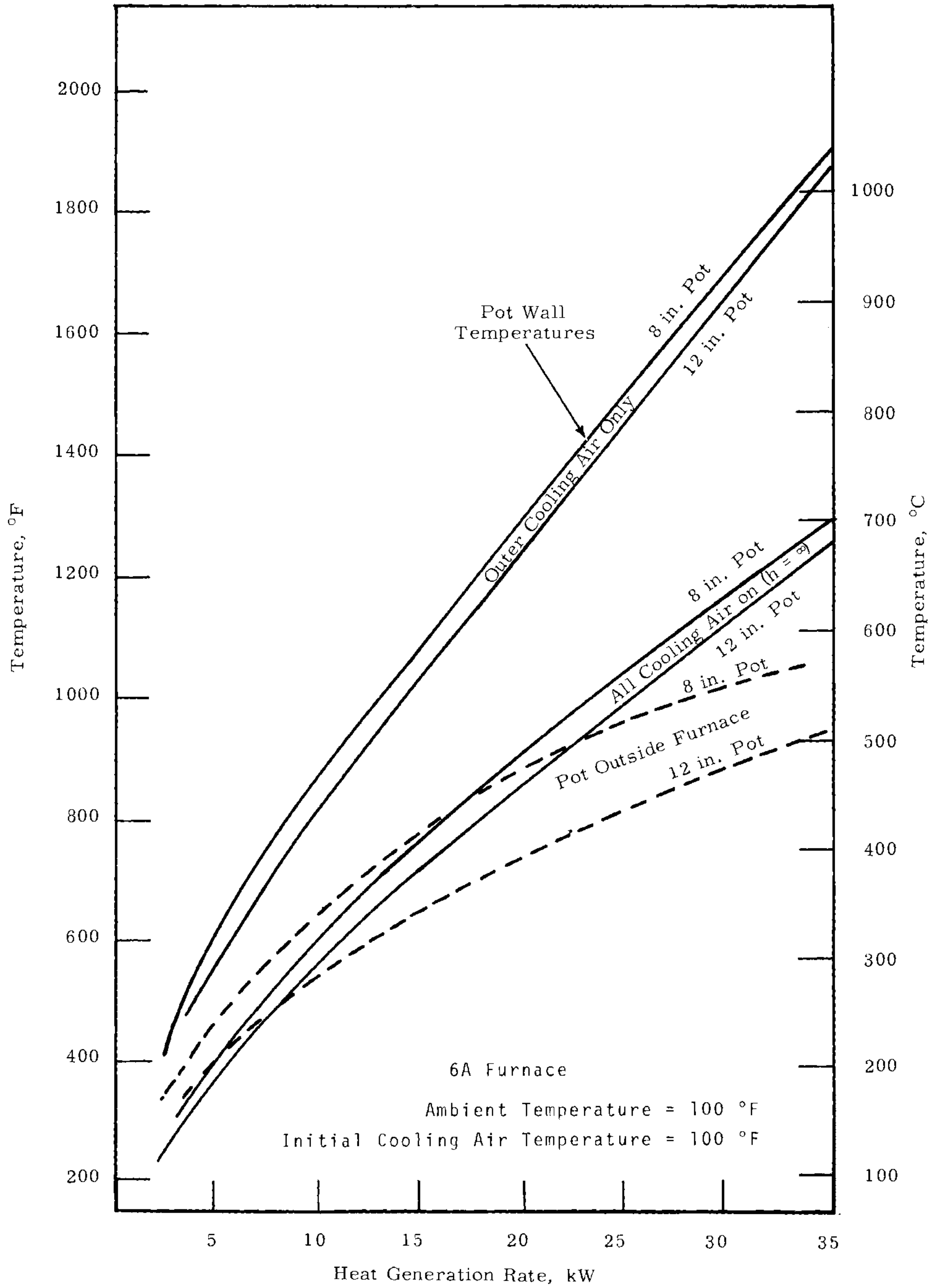

FIGURE 7.2. Cooling Characteristics of Resistance-Heated Pot Furnace-Cooler

8.0 ABSTRACT OF SAFEGUARDS REVIEW

The policy of Battelle-Northwest requires a careful safety analysis of all activities that have the potential for serious injury to persons or serious damage to any property affected by the activity. This safety analysis must be reviewed in detail and approved by a council of Battelle-Northwest staff members who are recognized experts in a broad range of technical-safety areas and hold responsible positions within the Battelle-Northwest organization. A safety analysis and a council review of the WSEP equipment, facility, and program plans were completed before the WSEP radioactive demonstrations began.

The overall conclusion from the results of the safety review was that the WSEP installation and program plans in combination with the C-MEL facility in which WSEP is located, presented almost no potential for escape of hazardous amounts of radionuclides. Furthermore, in the worst conceivable accident wherein the numerous safeguards incorporated into the facility were assumed to fail, the resultant escape of radionuclides would still not be major, and no clinically observable radioactivity-induced symptoms would result to off-site inhabitants.

The three hypothetical accidents which were determined to have the most potential for causing hazardous situations are listed in descending order of importance:

- Shielding window failure, resulting in a fire in the hot cell.
- "Red-Oil"* reaction.
- Melter failure.

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* *A "red-oil" reaction is one in which Purex-type of organic solvent is rapidly oxidized by the nitrate in solution, with the evolution of large quantities of gases and energy.*

Other conceivable incidents which were investigated and found to result in lesser releases of radionuclides than the aforementioned three are:

- Coolant failure to in-cell storage rack for pots full of solidified waste.
- Potential hydrogen explosion.
- Loss of pot furnace cooling.
- Failure of product container after encapsulation.
- Failure of services (air, water, steam electricity).
- Load-in and load-out hazards.
- Flooding of B-Cell.
- Excessive cell heat load.
- Cell pressurization from failed air supply line.
- Welding hazards.
- Radioiodine in waste solutions.
- Criticality incident.

Even though the safety analysis showed that the WSEP equipment and program was safe from major contamination of the environment, the safety analyses were helpful in establishing additional safeguards to meet the more stringent requirements of preventing minor incidents which might delay or increase the cost of the program.

The inventory of fission products with the maximum hazard potential in any one pot was estimated to include 4.6, 2.5, 0.3, and 0.3 megacuries of total radioactivity, cerium-rare earths, strontium-89 and strontium-90, respectively. The heat rate from a pot of solidified waste containing this inventory is 23 kilowatts. Storage of 14 of these pots in B-Cell was assumed.

Although the extensive safety review that was summarized above was specific to the WSEP program and systems, the relative safety in the WSEP confirms the fact that solidification of high level wastes and their interim storage can indeed be done safely.

9.0 ACKNOWLEDGMENTS

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C. R. Cooley, A. M. Platt, M. O. Rankin, G. Rey, D. H. Siemens, J. S. Wallner, and the authors.

Design Verification Testing required much additional effort by another team. Primary engineering members of this team were:

C. R. Cooley, G. V. Fitzpatrick, B. O. Kahle, J. L. McElroy, J. E. Mendel, J. D. Moore, F. L. Mourich, M. O. Rankin, G. Rey, D. H. Siemens, M. E. Spaeth, J. S. Wallner, and the authors.

Primary technician members of this team were:

E. O. Badgett, D. N. Berger, E. L. Doan, K. E. Eliason, F. E. Haun, H. H. Irby, M. G. Krisher, G. C. La Borde, H. N. Larson, G. E. Lysher, G. L. Mowery, and J. R. Nance.

The detailed safeguards review was performed by K. J. Schneider and M. E. Spaeth.

The sulfate condensate distillation equipment was designed by R. J. Thompson. This equipment was Design Verification Tested by engineer W. T. McKean and technician B. Norton, and the sections in this report on that subject were prepared by W. T. McKean.

The section on performance of process auxiliary equipment was written by A. S. Neuls.

Significant contributions were also made by others too numerous to mention.

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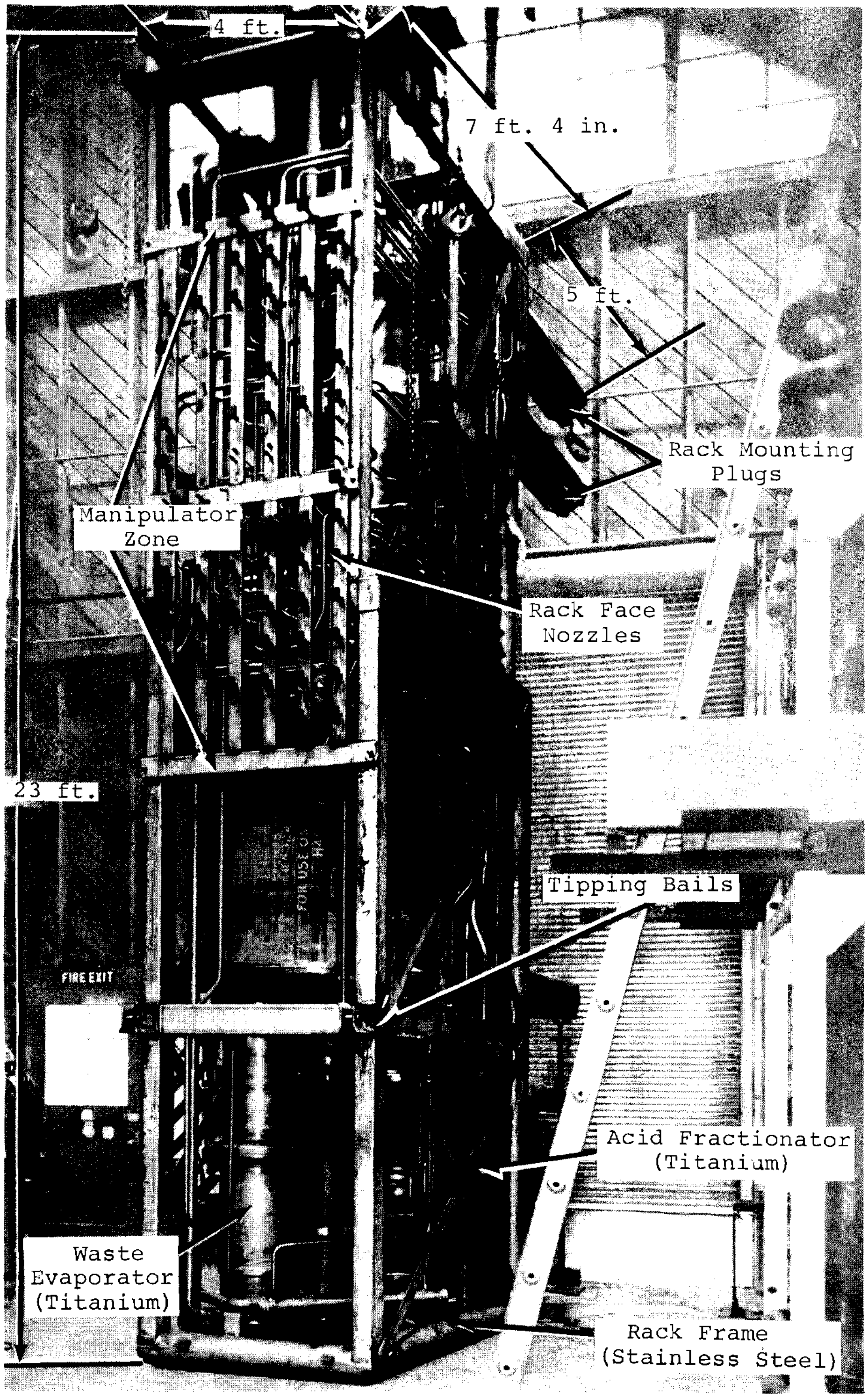
11.0 APPENDIX

SELECTED PHOTOGRAPHS OF WSEP EQUIPMENT

11.0 APPENDIX

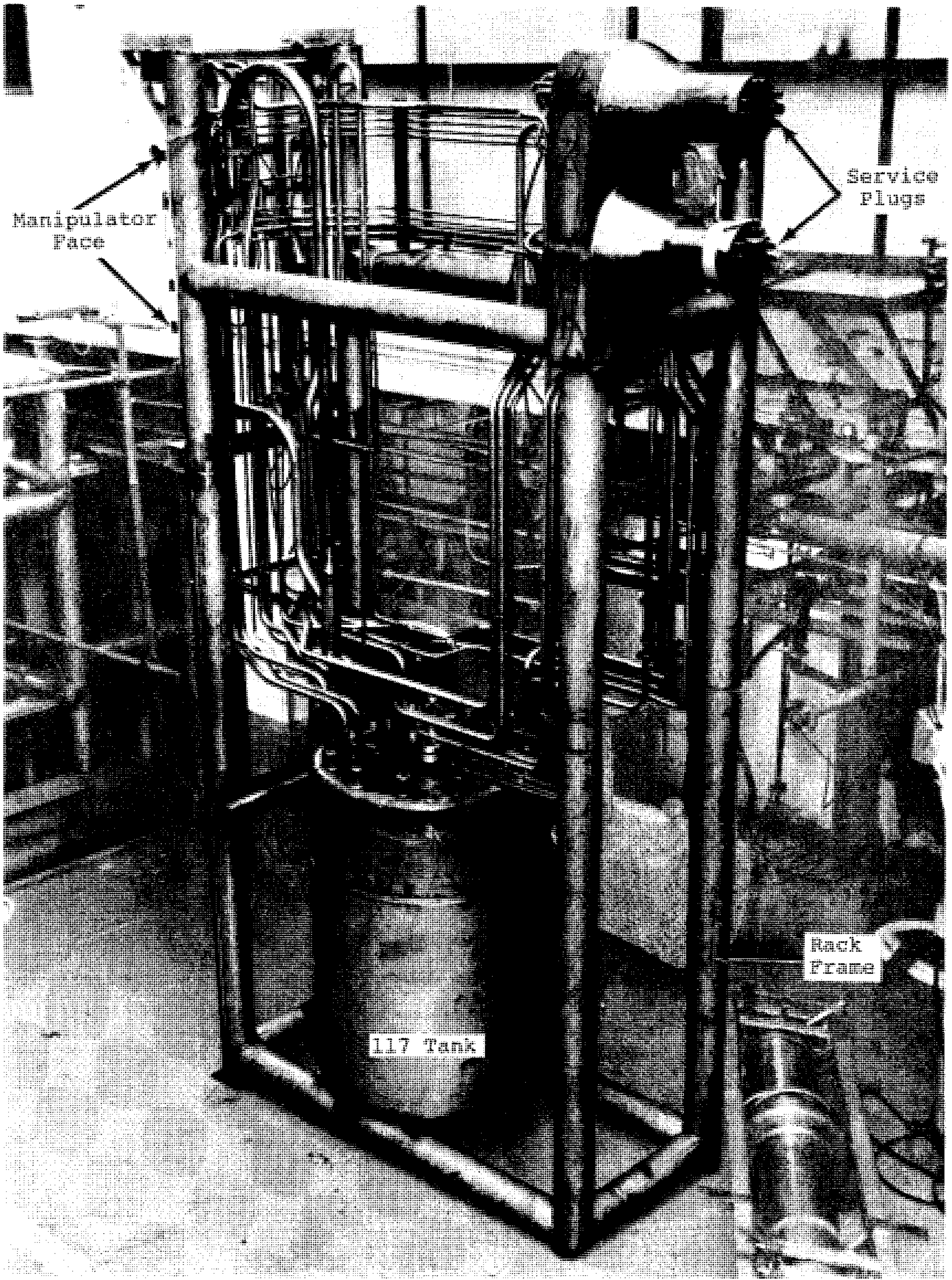
SELECTED PHOTOGRAPHS OF WSEP EQUIPMENT

The figures in the text of this report emphasize the functional aspects of the WSEP equipment. Photographs in this appendix were selected to show the actual appearance of most major WSEP equipment or facilities that were not shown in photographs in the text. The photographs shown in this appendix are:



Neg 38340-1-CN

FIGURE A.1. The 1A Rack (Evaporator and Fractionator) Before Installation

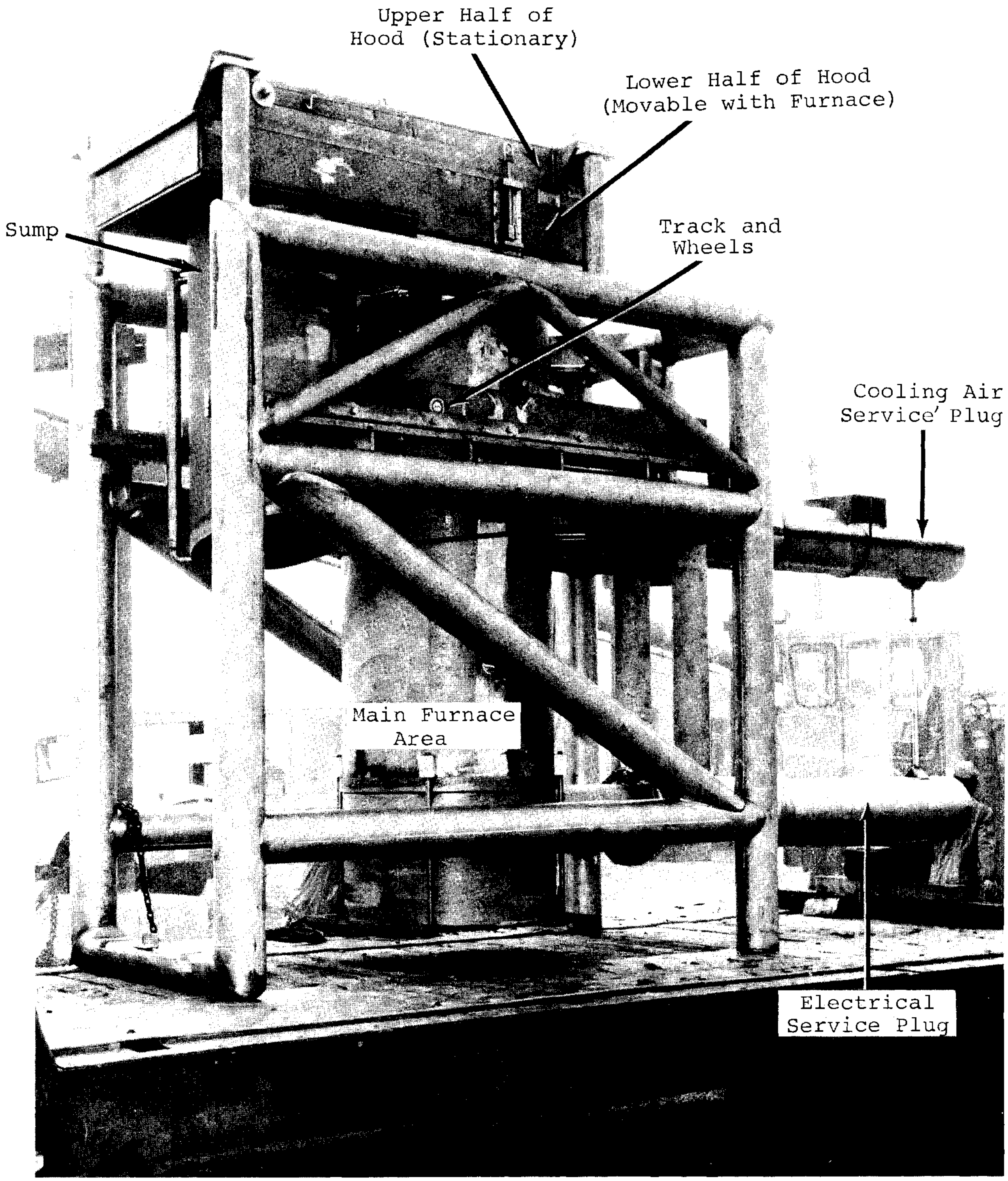


Neg 37299-2

FIGURE A.2. *The 3B Rack (Condensate Collection) Before Installation*

Neg 0641259

FIGURE A.3. The 4A Rack (Pot Storage) Before Installation



Neg 0641684-3

FIGURE A.4. The 5A Rack (Induction Heated Pot Furnace) Before Installation

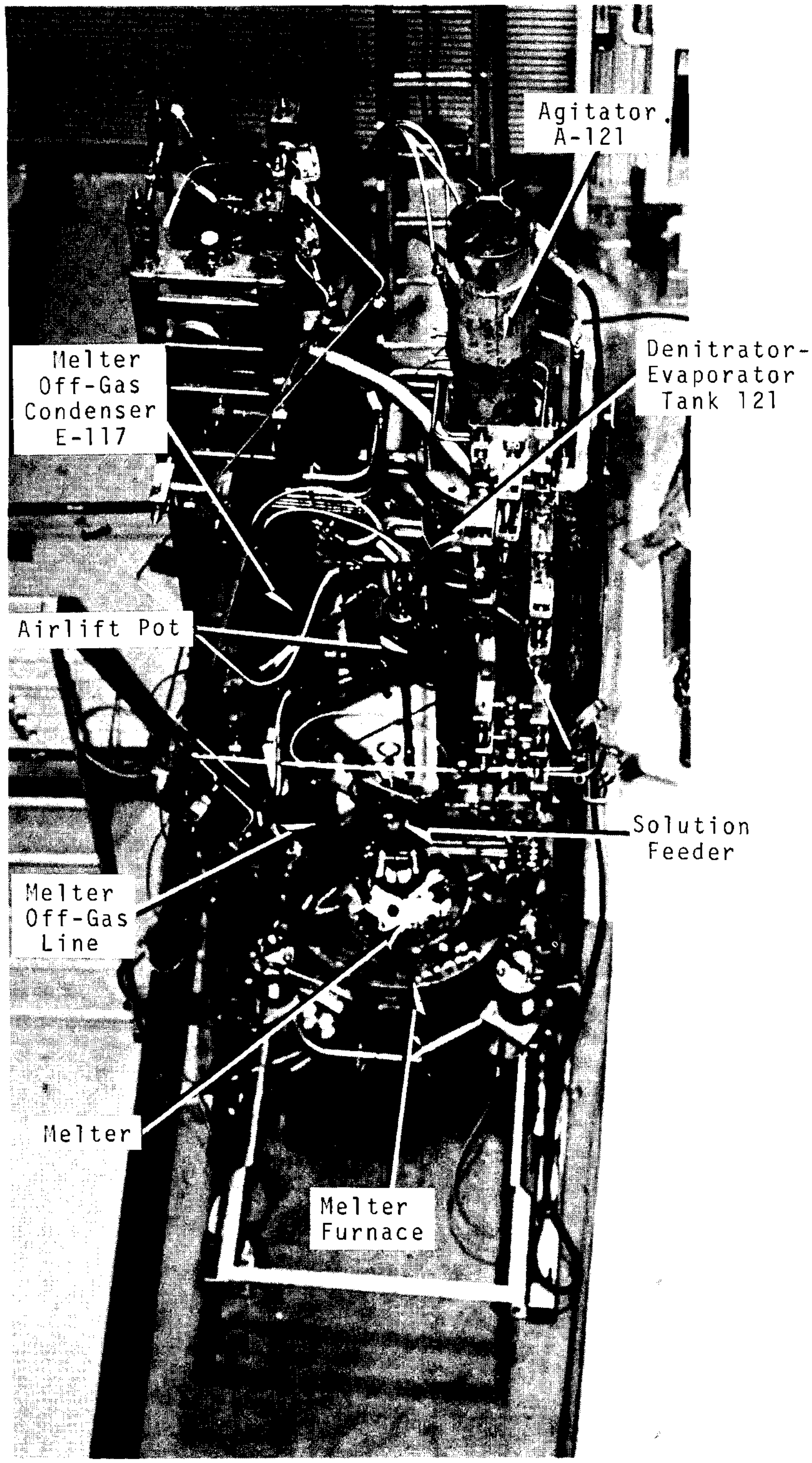


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FIGURE A.5. The 5B-C Rack (Phosphate Glass Solidifier) Before Installation

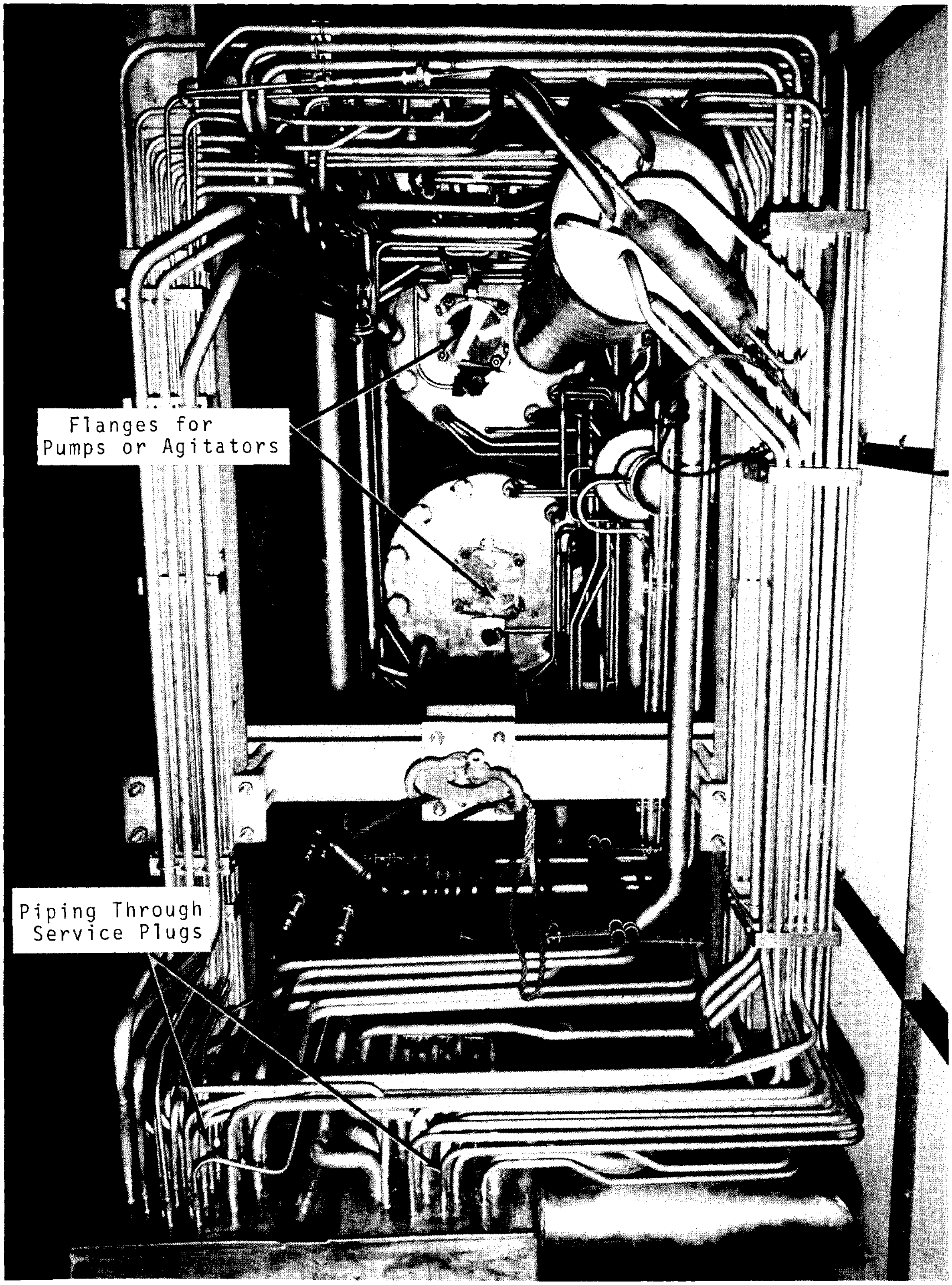

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FIGURE A.6. *Plan View of Typical Piping in 2A Rack (Off-Gas Scrubber and Final Condensate Receiver)*

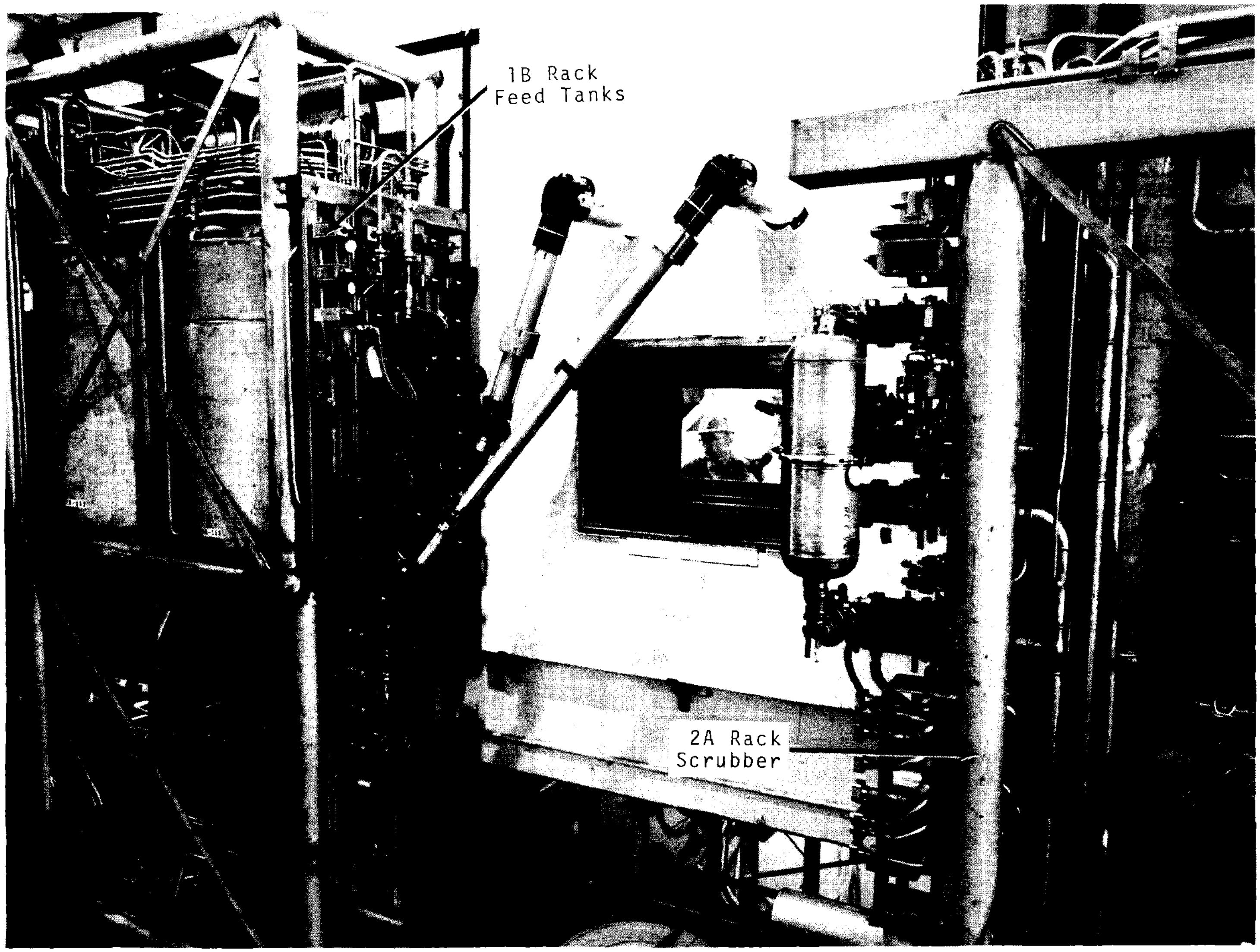

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FIGURE A.7. Equipment Mock-Up for DVT's

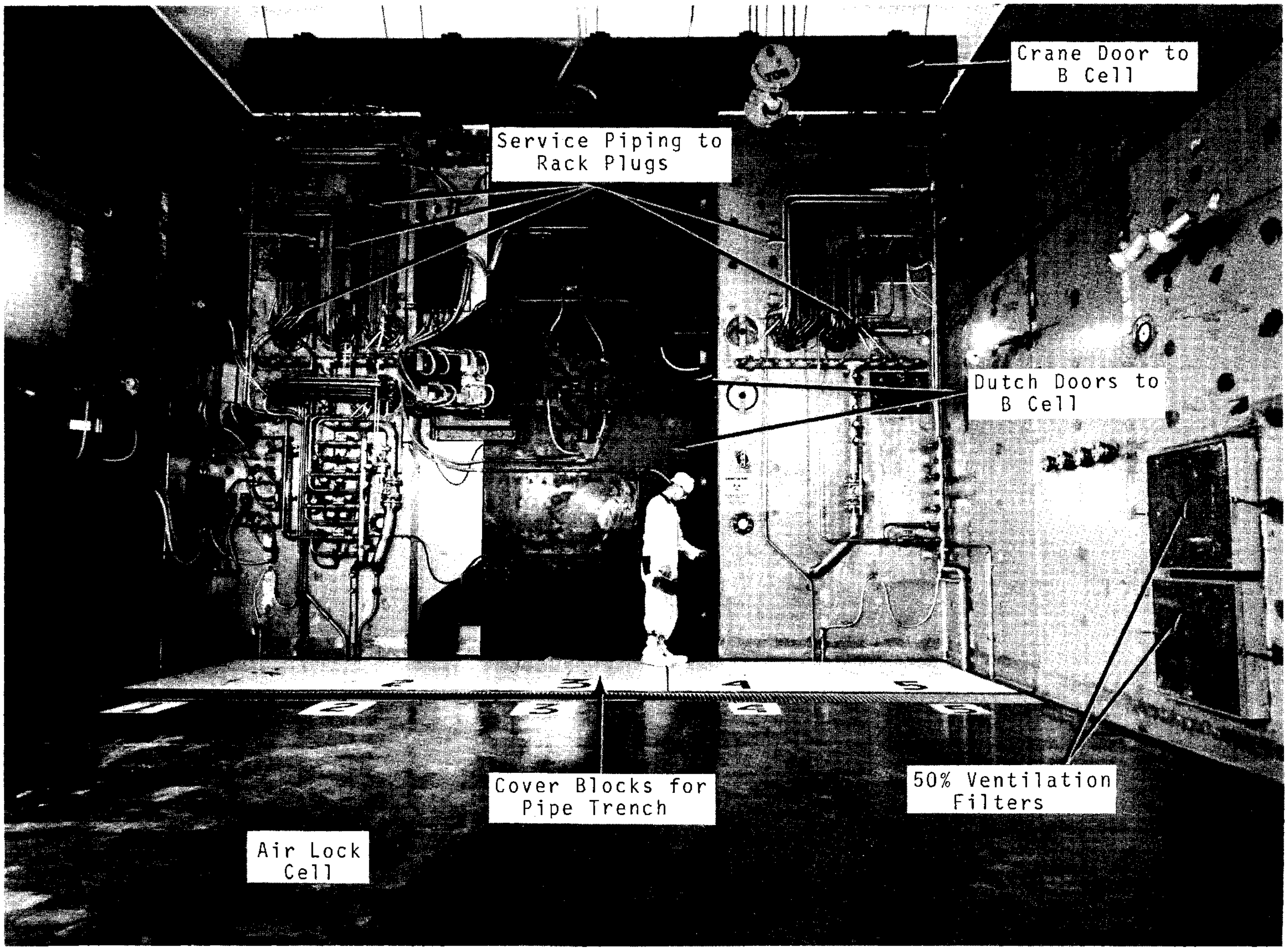

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FIGURE A.8. Air Lock Cell, Facing B-Cell Doors

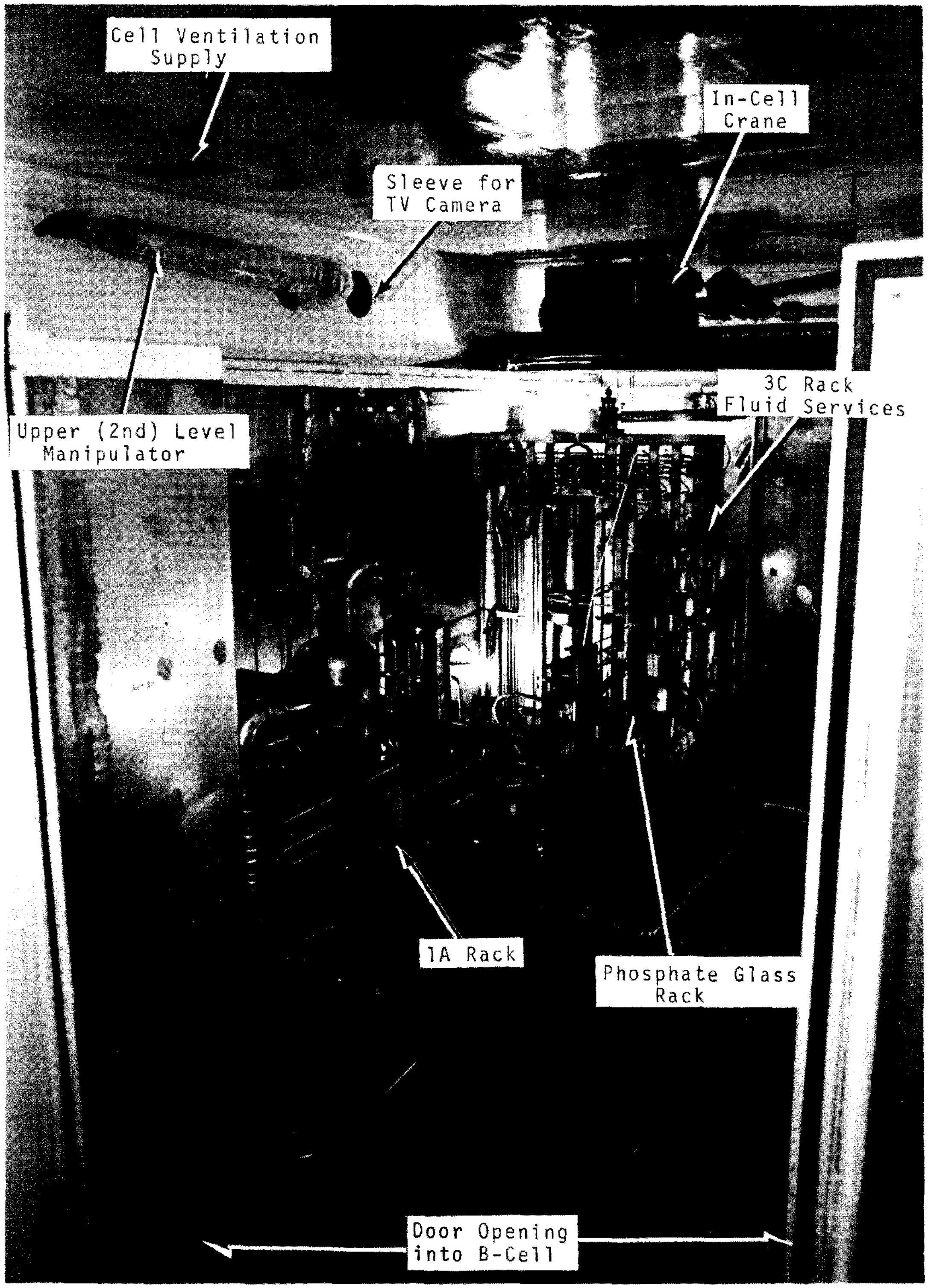

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FIGURE A.9. Looking Southwest Through Air Lock to B-Cell Doorway

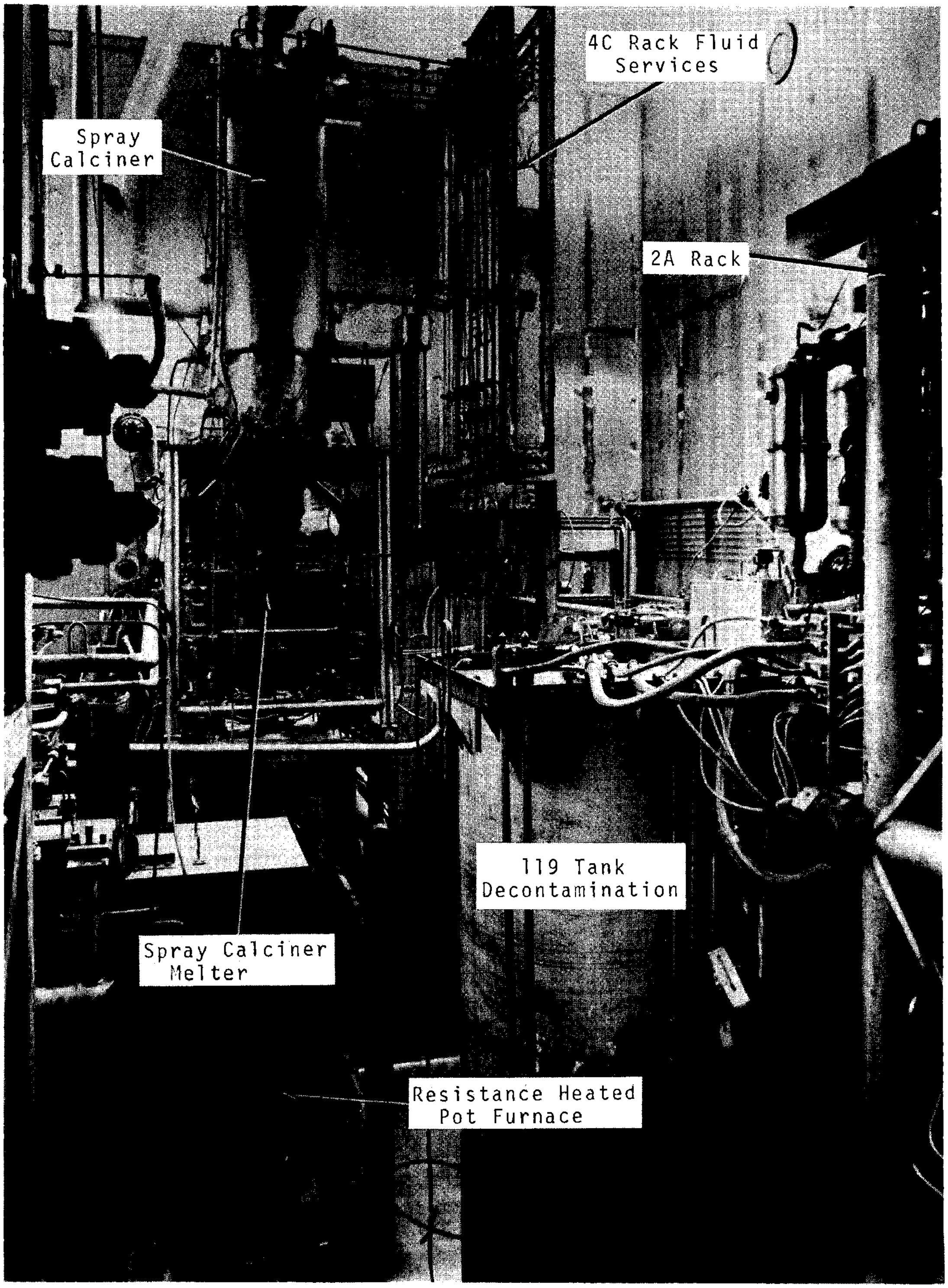

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FIGURE A.10. Looking West Through Air Lock to B-Cell Doorway

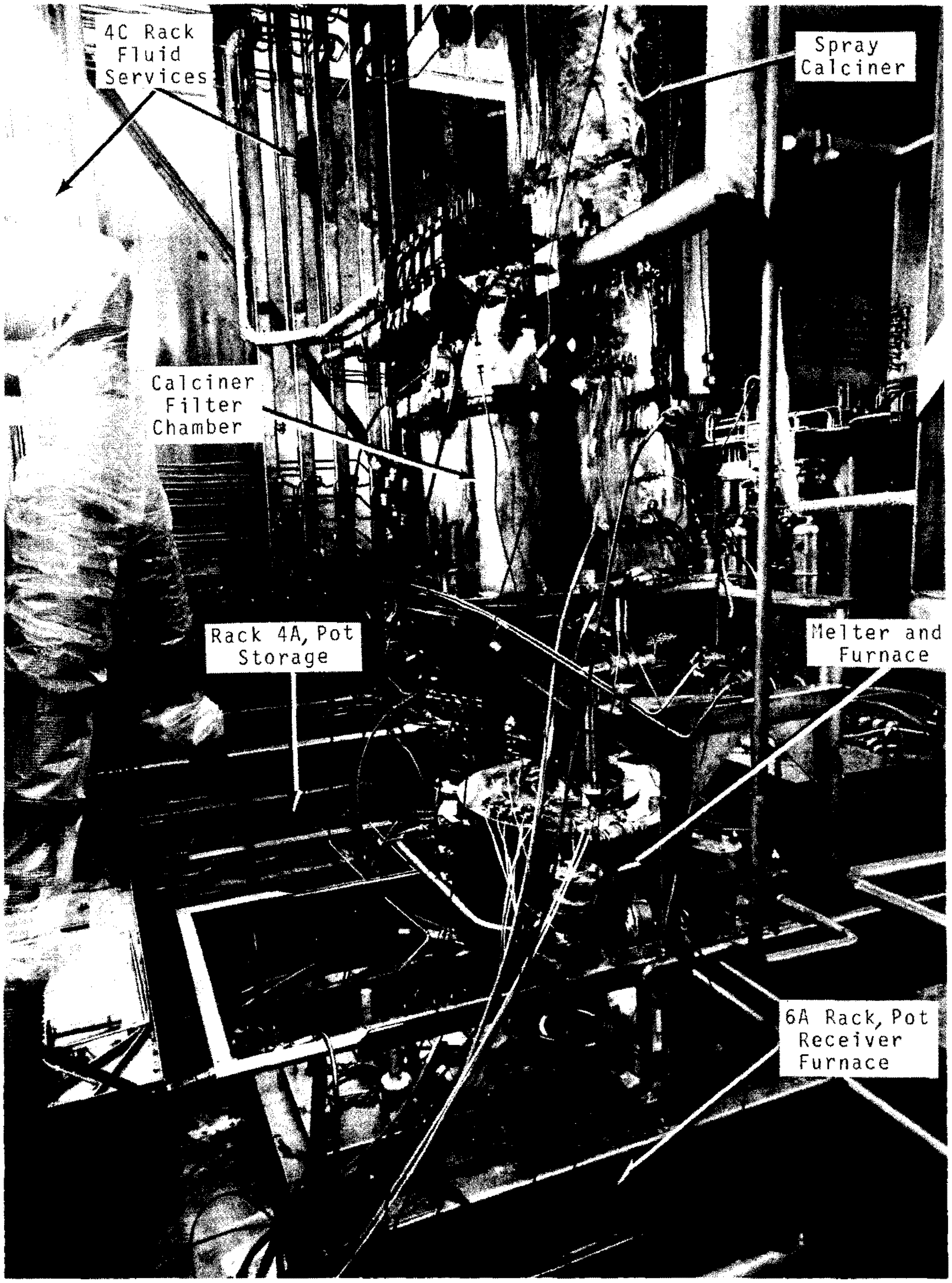

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FIGURE A.11. Looking North at the West End of B-Cell

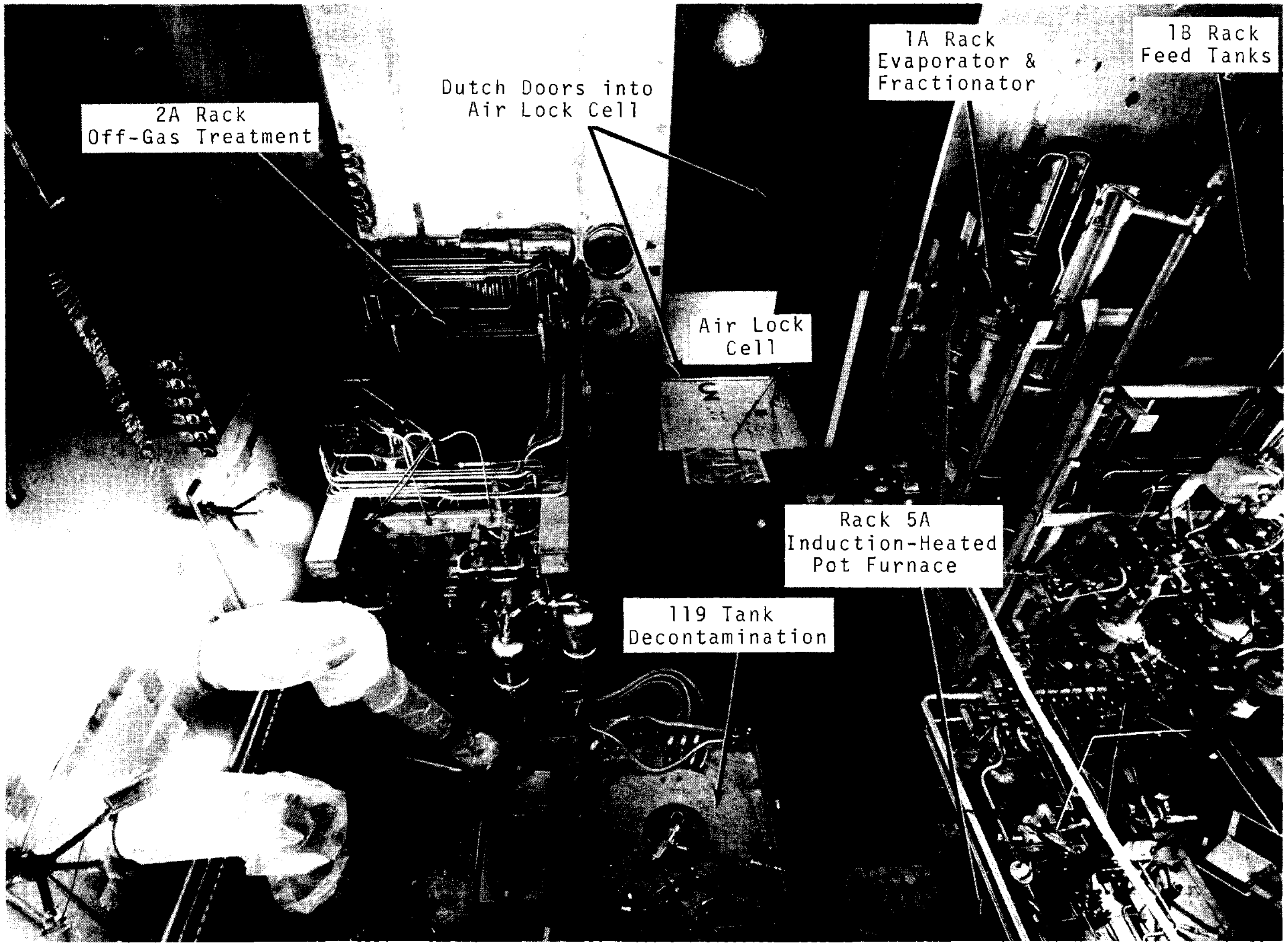

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FIGURE A.12. Looking East from the West End of B-Cell

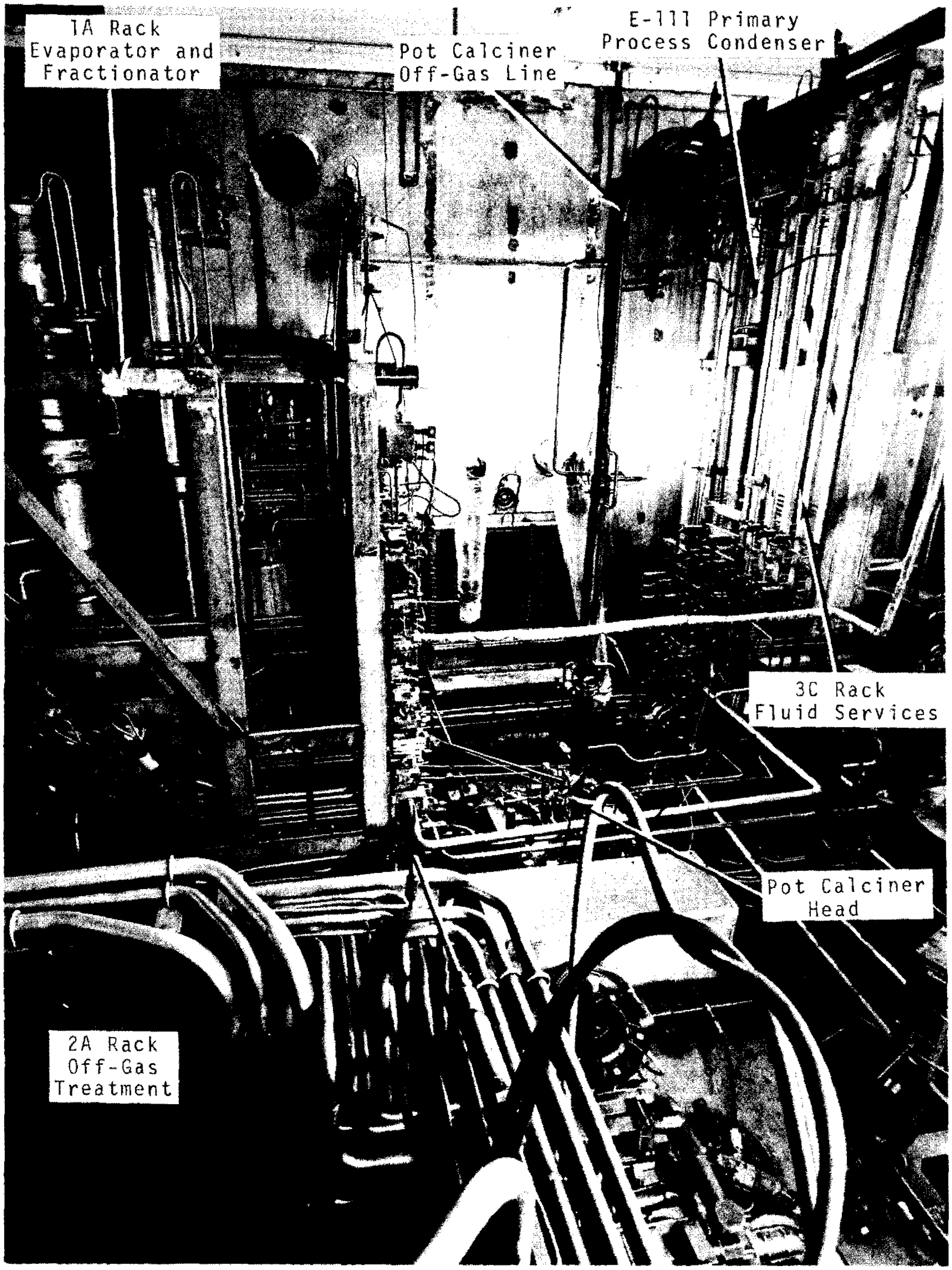

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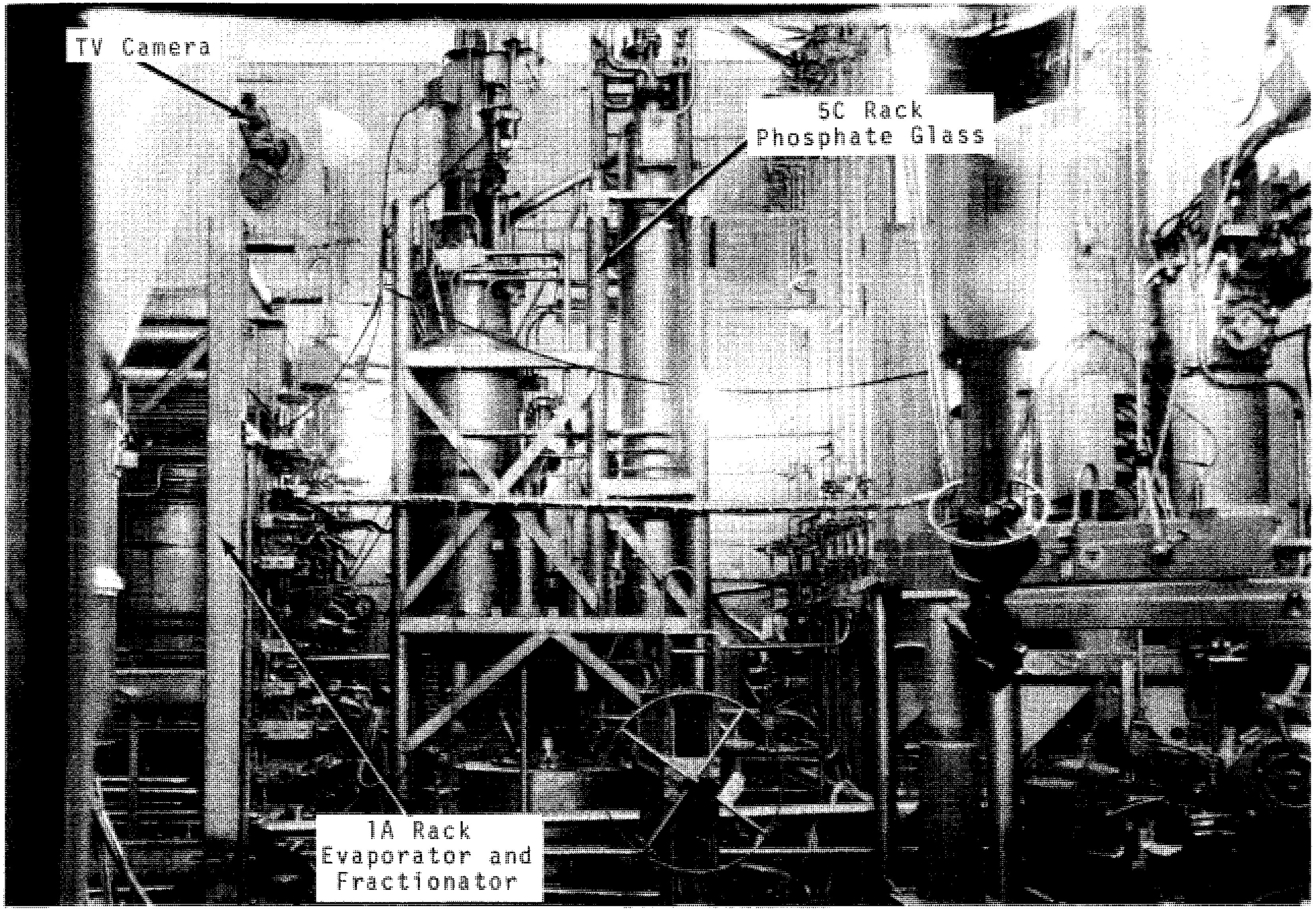
FIGURE A.13. *Looking South from Northeast End of B-Cell*



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<u>*FIGURE A.14*</u>. *Looking South from North Window of B-Cell*

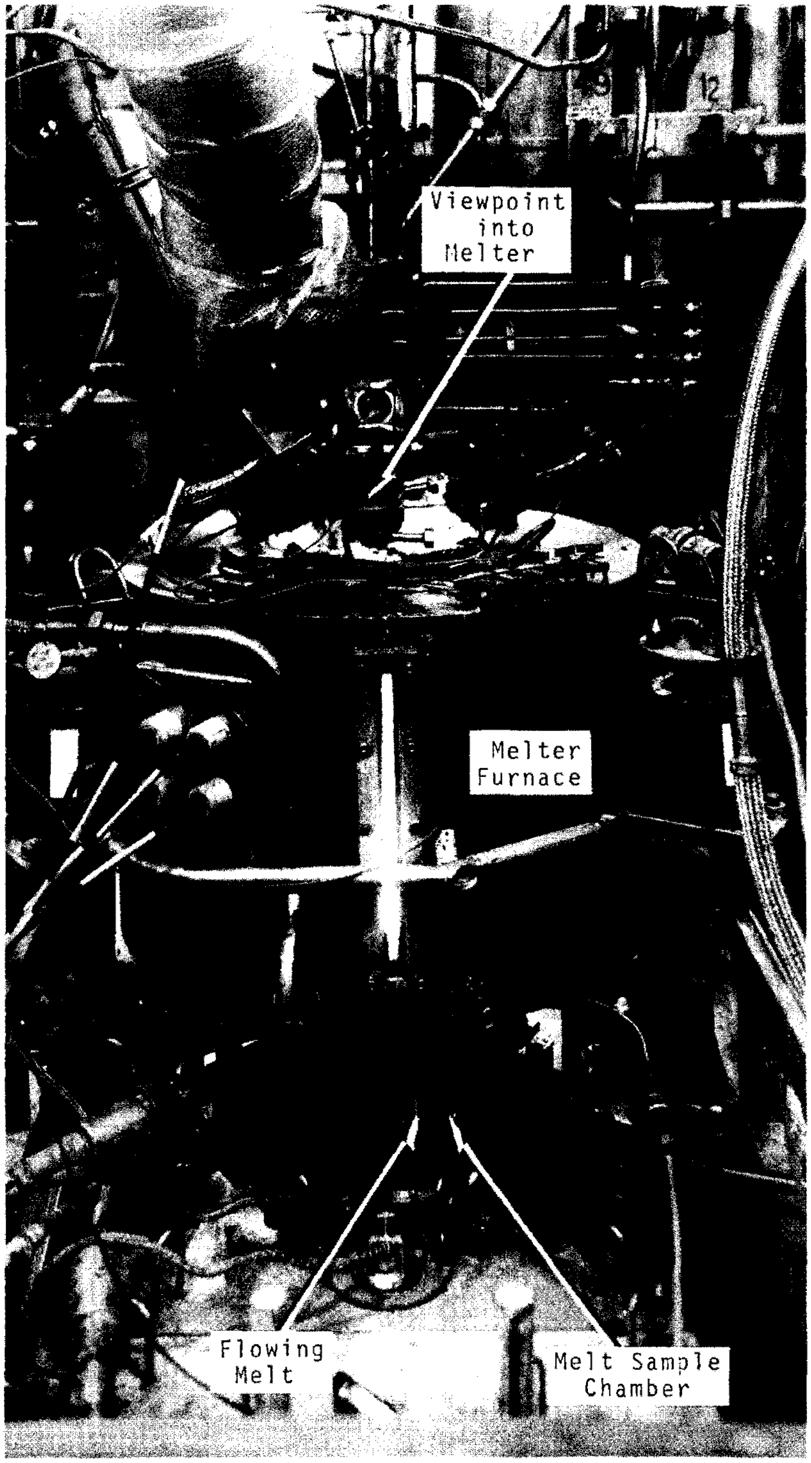

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FIGURE A.15. *Phosphate Glass Melter in Operation from South Window*

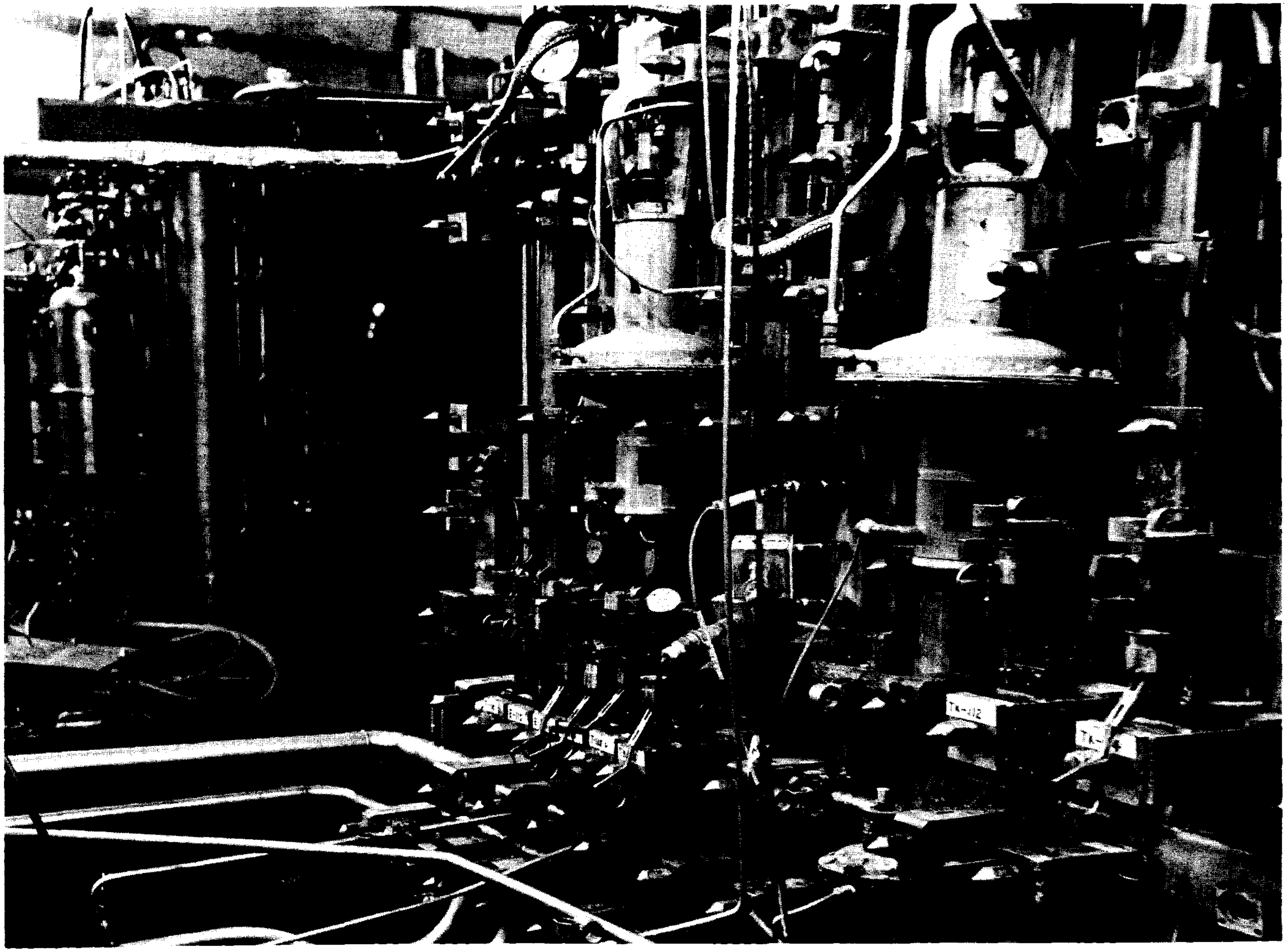

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FIGURE A.16. *Manipulator Face Jumpers from South Window*

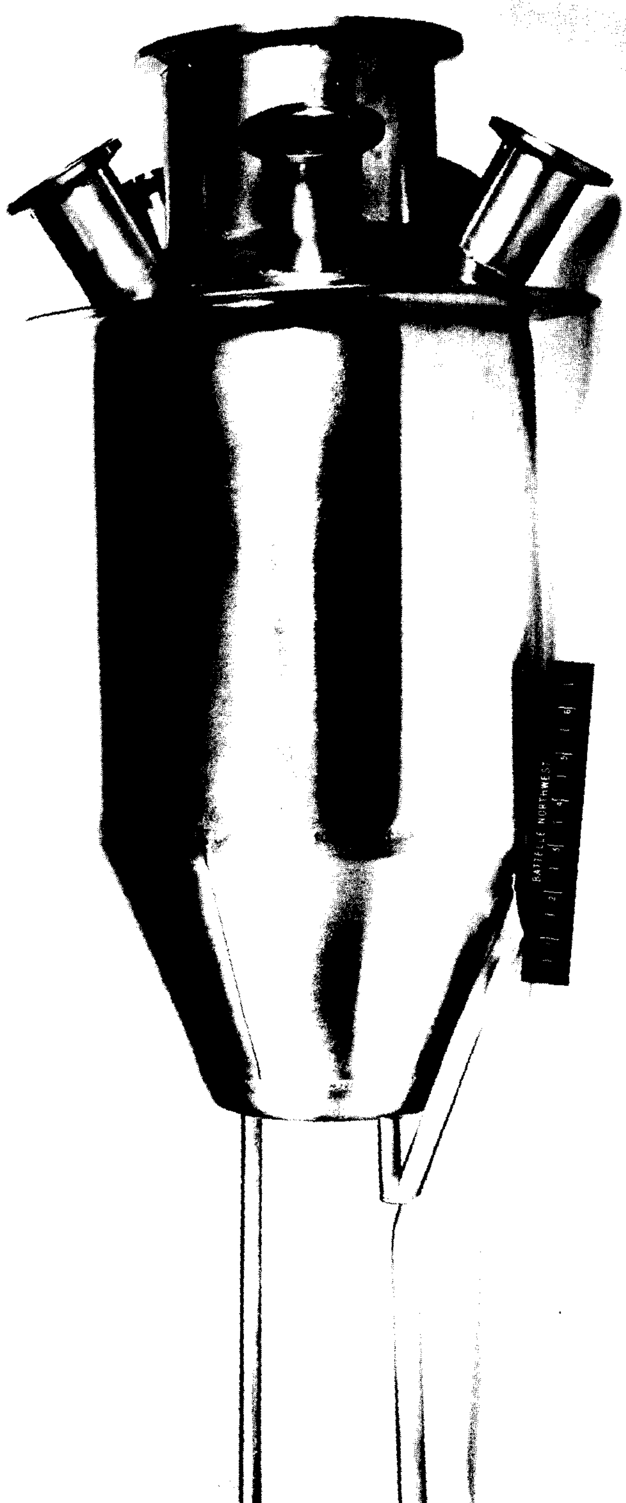

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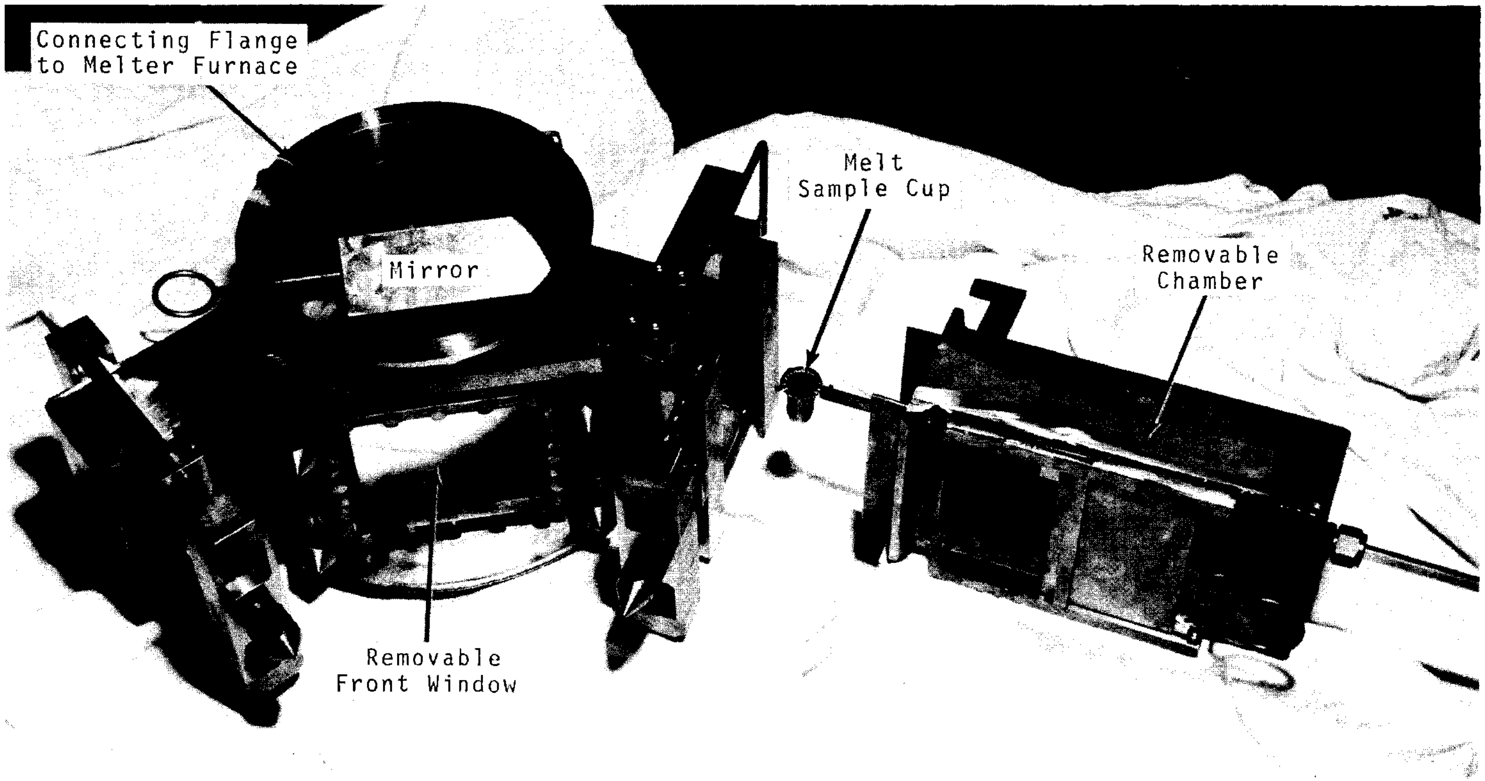
FIGURE A.17. Melter for Spray Solidifier



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<u>FIGURE A.18</u>. Melter Sample Chamber

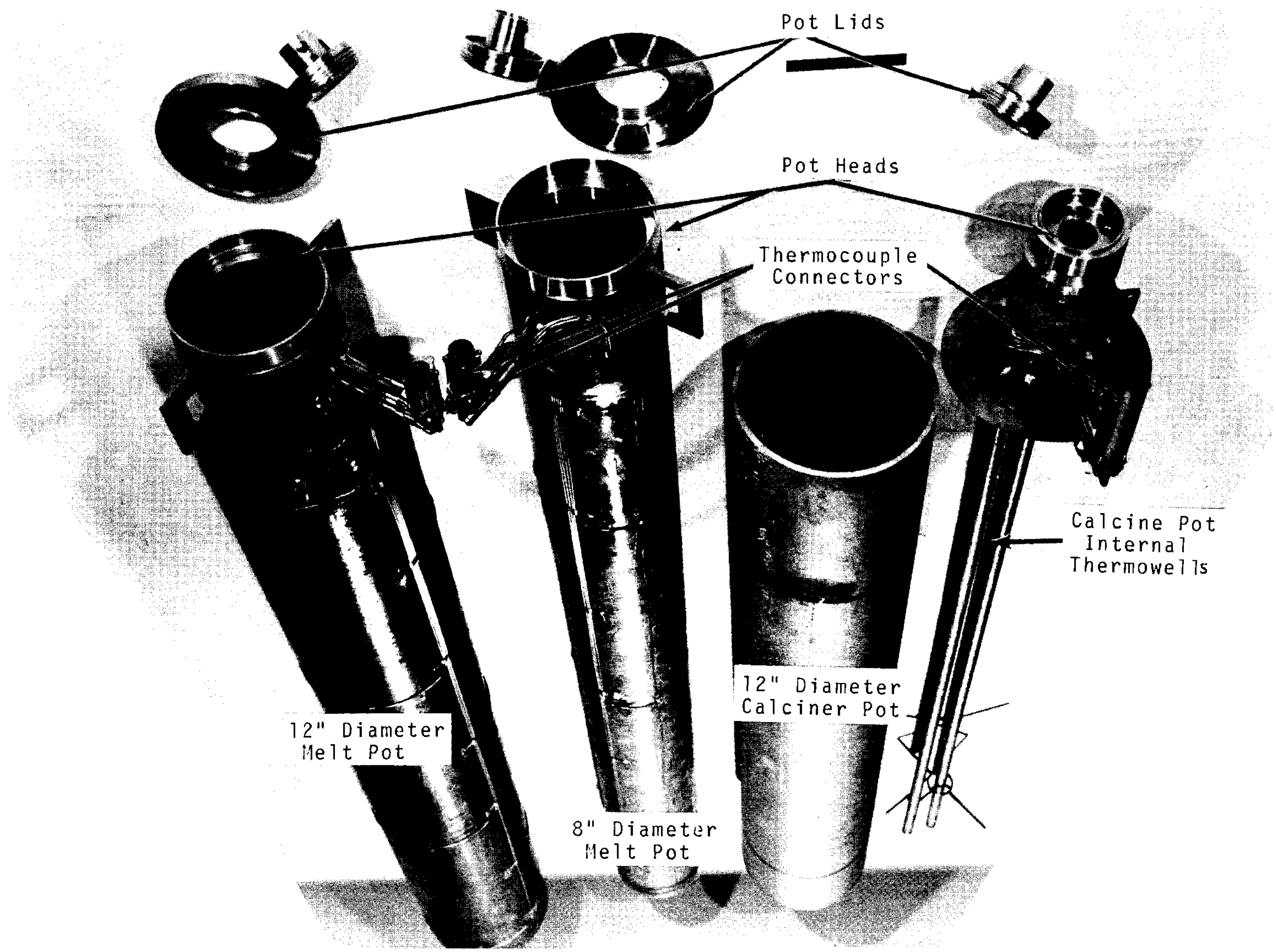

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FIGURE A.19. Pots for Solidified Waste

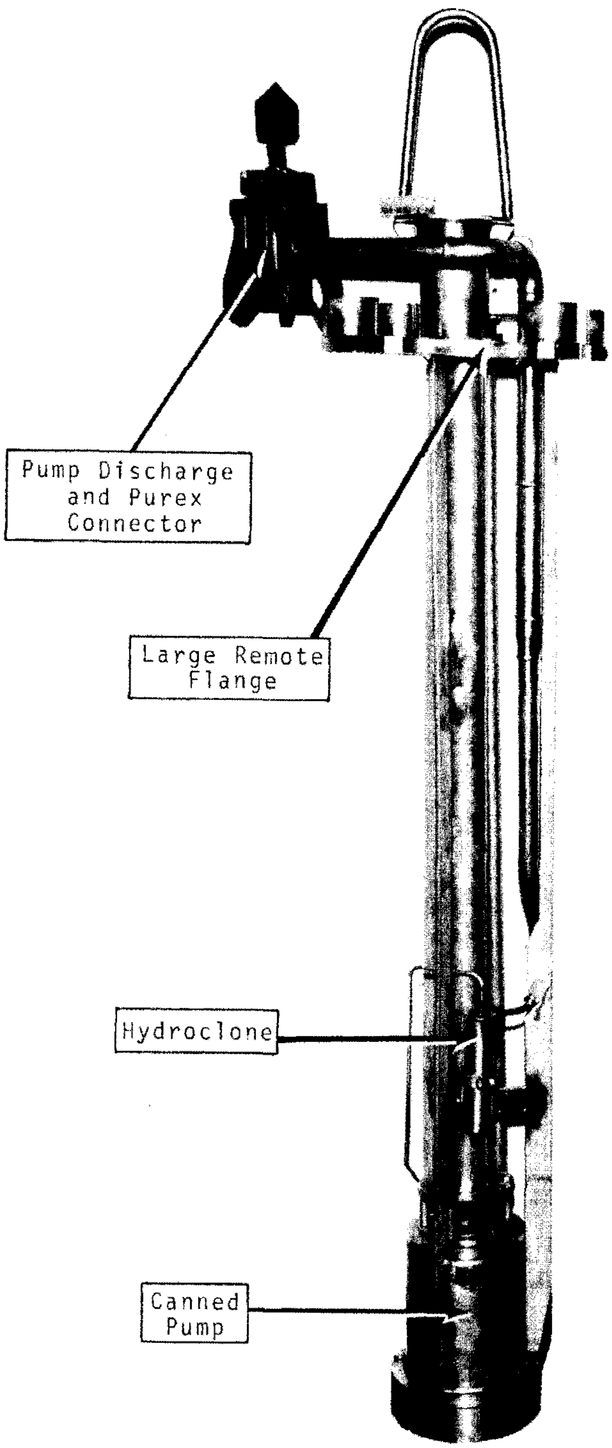

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FIGURE A.20. Submersible Pump Assembly

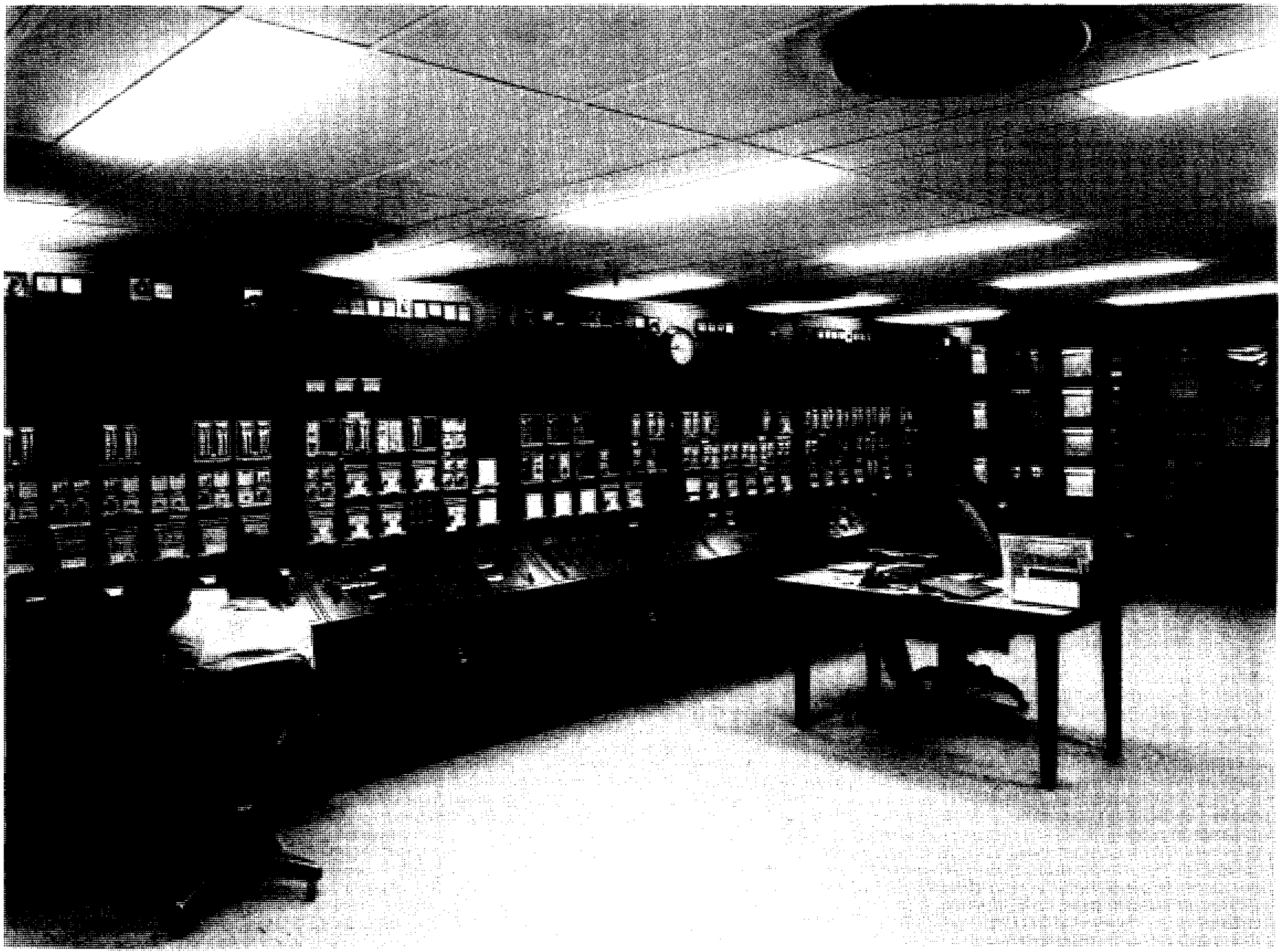

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FIGURE A.21. WSEP Control Room

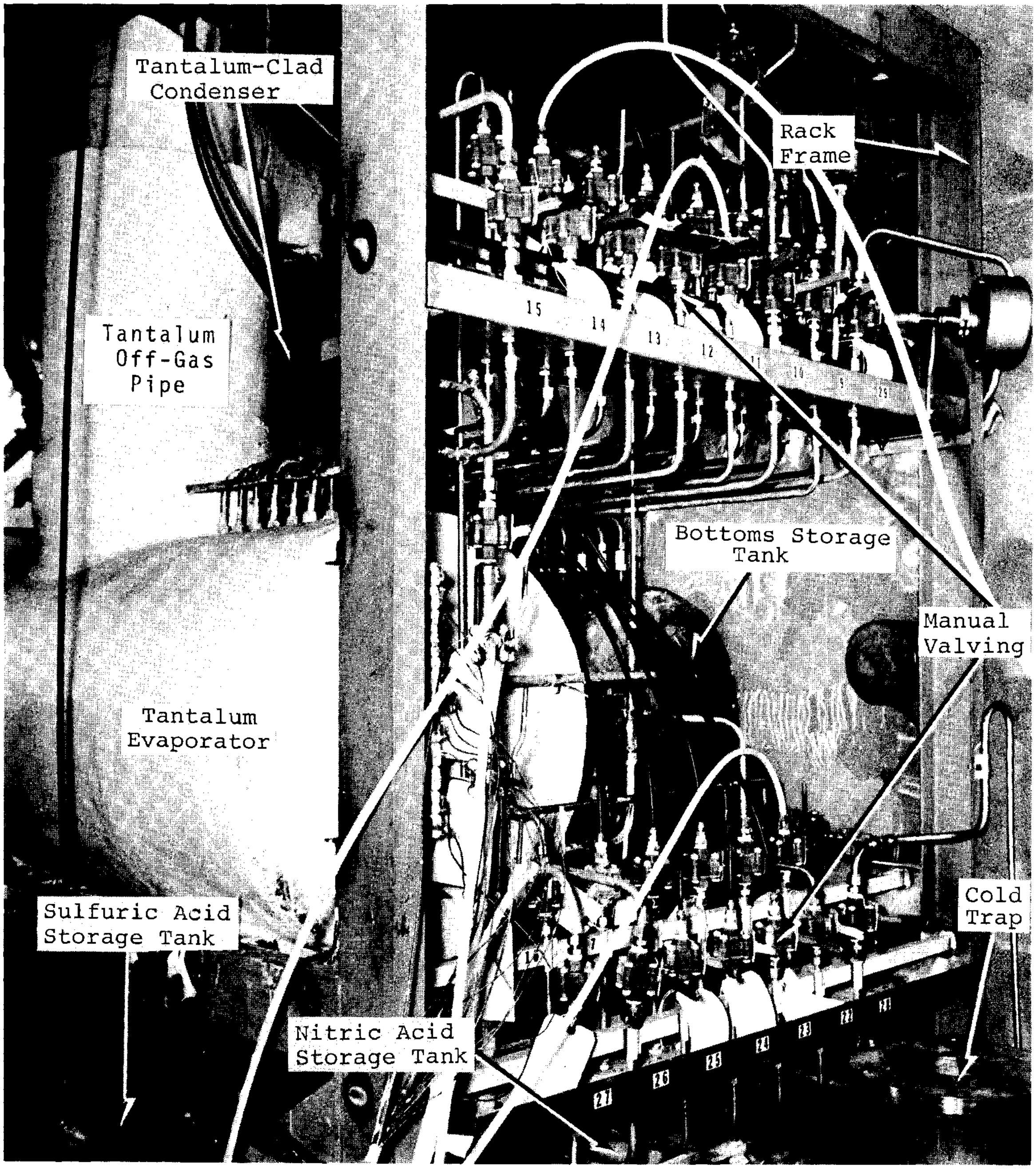

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FIGURE A.22. Distillation Demonstration Unit in WSEP

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