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PWR FLECHT SEASET UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD TASK: TASK PLAN REPORT

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PWR FLECHT-SEASET UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD TASK: TASK PLAN REPORT

March 1978

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ABSTRACT

This report presents a descriptive plan of tests for the Unblocked Bundle, Forced and Gravity Reflood Task of the Full-Length Emergency Core Heat Transfer for the Separate Effects and Systems Effects Tests (FLECHT-SEASET) program. These tests consist of forced and gravity reflooding experiments utilizing electrical heater rods to simulate current nuclear core fuel rod arrays (for example, 17 x 17 assemblies) of PWR and PWR fuel vendors. All tests will be performed with a cosine axial power profile. These tests will be used to determine effects of fuel rod size on reflooding behavior, to aid in development/verification of computational methods in predicting reflooding behavior of newer fuel rod array geometries, and to serve as a baseline for determining the effects of blockage in future flow blockage bundle tests.

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SECTION 1
SUMMARY

As part of the Westinghouse NRC/EPRI Full-Length Emergency Core Heat Transfer for the Separate Effects and Systems Effects Tests (FLECHT-SEASET) reflood heat transfer and hydraulic program[1], a series of forced flow and gravity feed bundle reflooding tests will be conducted on a heater rod bundle whose dimensions are typical of current PWR fuel rod arrays. The purpose of these tests is to provide a reflooding data base which can be used to help develop or verify reflood predictive methods, to serve as a comparison to the existing FLECHT[2,3,4,5] reflood data on previous fuel rod array sizes, and to provide a baseline to evaluate the effects of flow blockage in a 161-rod FLECHT bundle during reflood.

This document describes the data requirements, instrumentation plan, facility description, test matrix and current ideas on data reduction and analysis for Task 3.2.1, Unblocked Bundle, Forced and Gravity Reflood Task, in the FLECHT-SEASET program[1].

In this test program, the existing FLECHT[6] facility will be modified to accept a new heater rod bundle whose dimensions are typical of the newer PWR fuel rod array sizes currently in use by PWR and PWR fuel vendors. Sufficient instrumentation will be installed in the test facility such that mass and energy balances can be computed from the data. In addition, the instrumentation plan has also been developed such that local thermal-hydraulic parameters can be calculated from the experimental data. This information can then be used to develop or

1. Conway, C. E., Hochreiter, L. E., Krepinevich, M., Massie Jr., H. W., Rosal, E. R. and Howard, R. C., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI/Westinghouse Report Number 1, December 1977.
2. Cadek, F., Dominicis, D. P. and Leyse, R. H., "PWR FLECHT (Full Length Emergency Cooling Heat Transfer) Final Report," WCAP-7665, April 1971.
3. Cadek, F. F., Dominicis, D. P., Yeh, H. C. and Leyse, R. H., "PWR FLECHT Final Report Supplement," WCAP-7931, October 1972.
4. Lilly, G. P., Yeh, H. C., Hochreiter, L. E., Yamaguchi, N., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.
5. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.
6. Rosal, E. R., Conway, C. E. and Krepinevich, M. C., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.

verify mechanistic thermal hydraulic reflood models which are based on localized fluid flow conditions. The thermal-hydraulic phenomena occurring during these tests will be identified and analyzed. The resulting heat transfer data from this task will be correlated in a FLECHT-type correlation[1,2] to provide overlap with previously obtained 15 x 15 FLECHT data.

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1. Lilly, G. P., Yeh, H. C., Hochreiter, L. E., Yamaguchi, N., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.
2. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.

SECTION 2
BACKGROUND AND TASK OBJECTIVES

2-1. BACKGROUND

The present nonproprietary data base for reflood heat transfer in a simulated Pressurized Water Reactor (PWR) is limited to heater rod bundles that are typified by the Westinghouse 15 x 15 design[1,2,3,4] and were designated as FLECHT tests. These tests utilized Westinghouse 15 x 15 (or 14 x 14) dimensions and were representative of all the PWR vendors' dimensions as shown in table 2-1 (under old fuel assembly dimensions). Currently PWR reactor and PWR fuel vendors are utilizing new fuel assembly dimensions (smaller fuel rod diameter and pitch) in their nuclear power plants also as shown in table 2-1.

Models which predict the dependence of reflood heat transfer and mass carryout rate fractions (CRF)[5] as a function of fuel bundle geometry (particularly rod diameter and pitch) have not been fully established in either phenomenological or correlational form. Carryout rate fraction models have been developed utilizing an energy balance method by Sun and Duffey[6] and similarly by Yeh and Hochreiter[7]. However, these models could benefit from experimental verification relative to fuel rod geometries other than the 15 x 15 type rod geometry.

The tests planned under this task – Unblocked Bundle, Forced and Gravity Reflood Task – will utilize a new core rod geometry (CRG) that is typified by the Westinghouse 17 x 17 fuel rod design as presented in table 2-1. This CRG is representative of all current vendors' PWR fuel assembly geometries.

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1. Cadek, F. F., Dominicis, D. P. and Leyse, R. H., "PWR FLECHT (Full Length Emergency Cooling Heat Transfer) Final Report," WCAP-7665, April 1971.
2. Cadek, F. F., Dominicis, D. P., Yeh, H. C. and Leyse, R. H., "PWR FLECHT Final Report Supplement," WCAP-7931, October 1972.
3. Lilly, G. P., Yeh, H. C., Hochreiter, L. E., Yamaguchi, N., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.
4. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.
5. Definitions of key terms are provided in appendix H.
6. Sun, K. H. and Duffey, R. B., "A Generalized Model for Predicting Mass Effluence During Reflooding," *Trans. Amer. Nucl. Soc. 27,* 604-605 (1977).
7. Yeh, H. C. and Hochreiter, L. E., "Mass Effluence During FLECHT Forced Reflood Experiments," *Trans. Amer. Nucl. Soc. 24,* 301-302 (1976).

TABLE 2-1

COMPARISON OF PWR VENDORS' FUEL ROD GEOMETRIES (OLD AND NEW)

Vendor	Dimension	
	Rod Diameter mm (in.)	Rod Pitch mm (in.)
NEW FUEL ASSEMBLIES (CRG[a])		
Westinghouse	9.5 (0.374)	12.6 (0.496)
Babcock & Wilcox	9.63 (0.379)	12.8 (0.502)
Combustion Engineering	9.7 (0.382)	12.9 (0.506)
OLD FUEL ASSEMBLIES		
Westinghouse	10.7 (0.422)	14.3 (0.563)
Babcock & Wilcox	10.9 (0.430)	14.4 (0.568)
Combustion Engineering	11.2 (0.440)	14.7 (0.580)

a. The CRG is defined in this program as a nominal rod-to-rod pitch of 12.6 millimetres (0.496 inch) and outside nominal diameter of 9.0 millimetres (0.374 inch) representative of various nuclear fuel vendors' new fuel assembly geometries commonly referred to as the 17 x 17 or 16 x 16 assemblies.

The tests performed in this task are classified as separate effects tests. In this case the bundle is isolated from the system and the thermal-hydraulic conditions are prescribed at the bundle entrance and exit. Within the bundle, the dimensions are full scale, as compared to a PWR, with the exception of overall radial dimension. The low mass housing used in these test series is designed to minimize the wall effects such that the rods one row or more away from the housing in the FLECHT bundle are representative of any region in a PWR core. Examination of the housing performance for the skewed axial profile FLECHT tests indicates that it does simulate this radial boundary condition and that only the rods immediately adjacent to the housing are effected by the housing presence. To preserve proper thermal scaling of the FLECHT facility with respect to a PWR, the power to flow area ratio is nearly the same as that of a PWR fuel assembly. In this fashion, the steam vapor superheat, entrainment, and fluid flow behavior should be similar to that expected in a PWR for the same boundary conditions. It should be noted that the one parameter not scaled or exactly represented is the difference between the boron nitride filled electric rod heat release and the heat release characteristics of a nuclear rod having a gap between the pellet and cladding. This effect will not be simulated in these tests.

In addition to examination of fuel assembly geometry effects on reflood heat transfer and carryout rate fraction behavior, the tests in this task will be utilized as a baseline in assessing the effects of flow blockage. Presently, the Appendix K[1] rule requires a conservative steam cooling heat transfer calculation when the core flooding rate is below 25.4 mm/s (1 in./sec). This is a result of having only a limited amount of flow blockage data. The test results of the limited data base (22 forced flooding tests) indicated heat transfer improvement at flooding rates of 25.4 mm/s (1 in./sec) or larger. Since the existing data base is sparse and only one test exists at flooding rates of less than 25.4 mm/s (1 in./sec), the observed improved reflood heat transfer was disallowed in the Appendix K rule for flooding rates above 25.4 mm/s (1 in./sec) and a steam cooling calculation was imposed when the flooding rate during reflood is below 25.4 mm/s (1 in./sec). This steam cooling calculation results in an increase in calculated peak cladding temperature for flow blockage cases. Currently, flow blockage tests are planned as part of the FLECHT-SEASET Program[2] utilizing the new CRG and will be described in a future Task Plan.

The data in this task (Unblocked Bundle Task) will be utilized as a baseline or reference point for 0 percent flow blockage in a CRG bundle. To this extent, the data from this task will be used as an aid in addressing Appendix K flow blockage/steam cooling requirements.

The data generated from this task will also aid in the development or verification of phenomenological reflood models which attempt to mechanistically describe the reflood process. The additional instrumentation within the bundle and the separate effects nature of these experiments make the resulting data useful for this purpose. The data will also be analyzed with the express purpose of providing the basis for reflood code comparison and verification.

2-2. TASK OBJECTIVES

The objectives of the unblocked bundle task (with a bundle having a cosine axial profile) are to develop a data base which provides the following:

- Aid in the development or verification of computational methods used by others to predict the reflood thermal-hydraulic behavior of CRG rod assays.
- Establish a baseline for comparison with the Flow Blockage Task (Task 3.2.3)[2] data to determine the effect of blockage.

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1. "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Cooled Nuclear Power Reactors," 10CFR50.46 and Appendix K of 10CFR50, Federal Registor, Volume 39, Number 3; January 4, 1974.
2. Conway, C. E., Hochreiter, L. E., Krepinevich, M., Massie Jr., H. W., Rosal, E. R. and Howard, R. C., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI/Westinghouse Report Number 1, December 1977.

- Evaluate the effects of bundle geometry on reflood heat transfer when compared to previous FLECHT 15 x 15 unblocked tests.

The first objective of this task will be to provide data for reflood model development and verification for CRG rod arrays. Reflood modeling requires the ability to calculate the local fluid conditions from data such that mechanistic calculational schemes or models can be compared to the actual fluid conditions found in the experiment. The emphasis in this task will be to model the bundle in a one-dimensional nature such that these calculations can be performed on the test data. The data which is needed to help develop reflood models is listed in table 2-2. It should be emphasized that these are desired quantities from the model developer's point of view and it may not be possible to obtain all this information to the desired accuracy. The methods which will be used to obtain this data, type of sensor used, and location is discussed in section 5.

The second objective is to utilize the data obtained in this task as a baseline for comparison to future flow blockage tests (described in a future Task Plan report). The bundle thermocouple layout (axial and radial location) for this task should ideally be identical to that of Task 3.2.3 (161-Rod Flow Blockage Bundle Tests). Based on the current schedule, the thermocouple locations for this task were defined prior to the design of the flow blockage tests. Hence, the thermocouple locations for this task (161-Rod Unblocked Bundle) and Task 3.2.3 (161-Rod Blocked Bundle) may not be identical. However, it is believed that enough thermocouple variation will exist in this bundle such that effective data comparison can be made.

The third objective will be handled by comparing the data from this task to previous 15 x 15 FLECHT unblocked tests. The thermocouple layout is defined in such a way to make this possible. The selected tests for the overlap comparison are discussed in section 6.

TABLE 2-2

REFLOOD MODELING REQUIREMENTS FOR THE UNBLOCKED BUNDLE TASK 3.2.1

Type of Information	Location
Initial conditions	Bundle and Loop
Total mass flow	Bundle inlet and exit
Liquid flow, vapor flow	Specified locations above the quench front, bundle exit
Liquid and vapor temperature	Specified locations above the quench front, bundle exit, below quench front
Void fraction	Specified locations over the bundle length
Quench front velocity	In bundle
System pressure	In bundle
Injection water temperature	Bundle inlet
Heater rod wall temperature	Specified locations in bundle
Heater rod wall heat flux	Specified locations in bundle
Thimble temperature	Specified locations in bundle
Test section housing temperature	Specified locations on housing
Droplet size, velocity and distribution	At the quench front and locations above the quench front
Flow regimes	At the quench front and locations above the quench front
Liquid accumulation rates	Bundle, upper plenum, carryover tank, and steam separator collection tank

SECTION 3
DATA REQUIREMENTS

Data requirements are determined by the task objectives which are presented in paragraph 2-2 of this report and by contract commitments as presented in the work scope for the Unblocked Bundle, Forced and Gravity Reflood Task (refer to appendix F). In order to meet the task objectives, test facility instrumentation must be designed to provide sufficient data for calculating the following:

- Mass and energy balances around each loop component
- Global and local thermal — hydraulic conditions to develop models based on experimental data which can be used to interpret reflooding phenomena, and to identify flow and heat transfer regimes during reflood
- Heat transfer and mass entrainment data for formulating empirical correlations

Table 3-1 summarizes the basic data to be obtained using the instrumentation that will allow the above calculations to be made and hence accomplish task objectives and task work scope. A more detailed description of bundle and system instrumentation is presented in paragraphs 5-17 through 5-26 of this report.

TABLE 3-1
BASIC DATA TO BE OBTAINED FOR THE UNBLOCKED BUNDLE TASK 3.2.1

Desired Data	Measured By	Location
Clad temperatures	Heater rod thermocouples	Inside surface of heater cladding at various axial and radial bundle locations
Fluid temperatures	Fluid thermocouples and aspirating steam probes	Test section plenums, in bundle at various elevations
Housing temperatures	Wall thermocouples	Outside housing surface at various elevations
Inlet flow rate	Turbine meter	Injection line
Inlet enthalpy	Fluid thermocouple and pressure transducer	Injection line and accumulator
System pressure	Pressure transducer	Test section upper plenum
System pressure drops	Differential pressure transducer	Across various loop components
Bundle exit steam mass flow rate	Orifice plate flowmeter	Exhaust line
Bundle exit liquid mass flow rate	Differential pressure transducer	Carryover tank and steam separator tank
Mass storage (void fraction distributions)	Differential pressure transducer	At each foot increment along the rod bundle heated length
System component temperatures	Wall thermocouples	Accumulator, carryover tank, and steam separator, piping
Rod bundle power	Watt meter transducer	Input power lines
Flow regime	Photographs and movies	Bundle and Upper Plenum

SECTION 4
TEST PARAMETER RANGES AND REFERENCE CONDITIONS

Test parameter ranges have been chosen to evaluate differences in bundle rod geometry effects, to replace the Appendix K steam cooling requirements at flooding rates below 25.4 mm/s (1 in./sec) with a more realistic design requirement, and to enable comparison with future flow blockage reflood experiments. In addition, the test parameter ranges will cover the different thermal-hydraulic conditions expected in a postulated LOCA reflood condition such that reflood models can be developed or verified.

Parameter studies will be performed around the reference initial conditions listed in table 4-1 for a worst case analysis of a hypothetical loss-of-coolant accident typical of a standard Westinghouse 17 x 17 four loop[1] or other PWR vendor plants.

TABLE 4-1
REFERENCE TEST CONDITIONS FOR THE UNBLOCKED BUNDLE TASK 3.2.1

Parameter	Initial Condition
Initial clad temperature	871°C (1600°F)
Peak power	2.30 kW/m (.7 kw/ft)
Upper plenum pressure	0.28 MPa (40 psia)
Injection rate with lower plenum initially full	25.4 mm/s (1.0 in./sec)
Coolant ΔT subcooling	78°C (140°F)
Radial power distribution	Uniform
Axial power shape	Cosine
Initial downcomer head	0.0 M (0.0 feet)

1. Johnson, W. J., Massie, Jr., H. W., Thompson, C. M., "Westinghouse ECCS-Four Loop Plant (17 x 17) Sensitivity Studies," WCAP-8566, July 1975.

These specific conditions were derived from the following reference assumptions:

- The core hot assembly is simulated in terms of peak power (kW/m) and initial temperature at the time of core recovery.
- Decay Power is ANS + 20 percent.
- The initial rod clad temperature is primarily dependent on the full power linear heating rate at the time of core recovery. For the period from 30 seconds to core recovery, typical results yield an initial clad temperature in the hot assembly of 871°C (1600°F).
- Coolant temperatures will be selected to maintain a constant subcooling to facilitate the determination of parametric effects.
- Coolant will be injected directly into the test section lower plenum for the forced flooding rate tests, and into the bottom of the downcomer for the gravity reflood scoping tests. Injection into the bottom of the downcomer is used for better test facility pressure control.
- Upper plenum pressure at the end of blowdown is approximately 0.14 MPa (20 psia) for an ice condenser plant, and about 0.285 MPa (40 psia) for a dry containment plant.
- The majority of tests will be performed with a uniform radial power profile, but some tests will be performed with radial power distribution which assumes a 1.05 peak-to-average based on simulating a quarter section of a 17 x 17 PWR fuel assembly. Some 1.10 peak-to-average tests will be run to provide continuity with previous 15 x 15 FLECHT data.
- The axial power shape built in the heater rod will be the modified cosine with a power peak-to-average ratio of 1.66, shown in figure 4-1.

The use of the 1.66 axial power profile will allow easier comparisons with the earlier 15 x 15 FLECHT[1] tests such that only the rod array dimensions are different between the two comparison tests. The effect of different axial power shapes has been studied in the FLECHT program and data is available to the code developer on different power shapes. In addition, while the 1.66 axial power profile is more peaked than current LOCA analysis which indicates an axial peaking factor at 1.5; these differences are relatively small, typically 15 percent variations over a given axial increment.

The range of initial test conditions are listed in table 4-2. Best Estimate or Best Judgment conditions are also included in the range of conditions and are reflected in the low power, low initial temperature, and high flooding rate tests. Input from other PWR nuclear reactor and fuel vendors was considered in the range of initial test conditions (refer to appendix A).

---

1. Rosal, E. R., Hochreiter, L. E., McGuire, M. F., Krepinevich, M.C., "FLECHT Low Flooding Rate Cosine Test Series Data Report" WCAP-8651, December 1975.

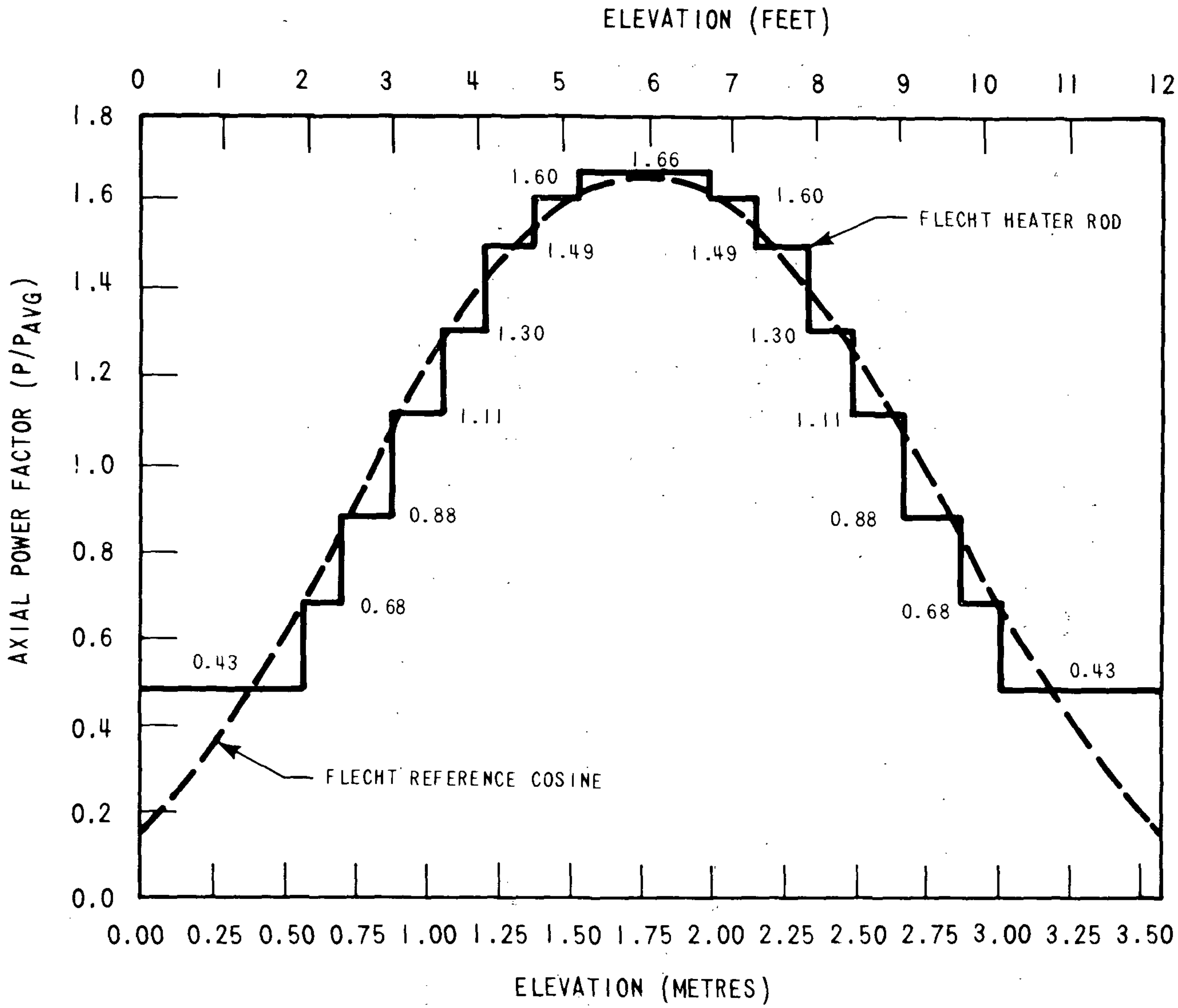


Figure 4-1. Cosine Axial Power Profile

13,108-11

Appendix D of the FLECHT-SEASET Program Plan[1] has been reproduced in this report as appendix A and contains input in leter-form from these vendors. The specific tests to be conducted in this series are presented in paragraph 6-24 through 6-40 of this report.

TABLE 4-2
RANGE OF INITIAL TEST CONDITIONS FOR THE UNBLOCKED BUNDLE TASK 3.2.1

Parameter	Parameter Range
Initial clad temperature	149-871°C (330-1600°F)
Peak power	1.30-3.10 kW/m (0.4-0.95 kw/ft)
Upper plenum pressure	0.1-0.4 MPa (20-60 psia)
Flooding Rates:	
Constant	8-150 mm/s (0.4-6 in./sec)
Variable in steps	150→15 mm/s[a] (6.0→.6 in./sec)[a]
Injection Rates (Gravity Reflood Tests)	
Variable in steps	6.49→9.77 kg/s[a] (14.3→1.7 lbs/sec)[a]
Coolant subcooling	3-78°C (5-140°F)

a. For specific variable flooding rate, refer to section 6 of this report.

1. Conway, C. E., Hochreiter, L. E., Krepinevich, M., Massie Jr., H. W., Rosal, E. R. and Howard, R. C., "PWR FLECHT *Separate Effects and System Effects Test* (SEASET) *Program Plan*," NRC/EPRI/Westinghouse Report Number 1, December 1977.

SECTION 5

TEST FACILITY DESCRIPTION

5-1. FACILITY LAYOUT

The existing FLECHT facility in which the Low Flooding Rate Skewed Test Series[1] was conducted will be used as the basic configuration for this task (Task 3.2.1 – Unblocked Bundle). A loop schematic is shown in figure 5-1.

A detailed facility description is presented in WCAP-9108[1] and updated SEASET test facility drawings are presented in section 5 and appendix G of this report. During operation, coolant flow from the 1.514 m^3 (400 gallon) capacity water supply accumulator will enter the test section housing through a series of hand valves, automatically through a hydraulic control valve, or through a series of solenoid valves. Coolant flow will be measured by a turbine meter and rotameter located in the injection line. Test section pressure will initially be established by a steam boiler connected to the upper plenum of the test section. During the experimental run, the boiler is valved out of the system and pressure is maintained by a pneumatically-operated control valve located in the exhaust line. Liquid effluent leaving the test section is separated in the upper plenum and collected in a close-coupled carryover tank. An entrainment separator located in the exhaust line is used to separate any remaining entrained liquid in the vapor. Dry steam flow leaving the separator is measured by an orifice meter before it is exhausted to the atmosphere. Additional system features include the following:

- axial test section differential pressure (DP) cells installed every foot for more accurate mass accumulation and void fraction measurements
- a steam probe located in the test section outlet pipe
- a Vee-Ball control valve to improve system pressure control.

The facility will be modified during the test series to conduct gravity reflood tests (refer to figure 5-2). The modifications consist of connecting a downcomer to the lower plenum, moving the injection line from the lower plenum to the bottom of the downcomer[2], installing a

1. Rosal, E. R., Conway, C. E. and Krepinevich, M. C., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.
2. In previous gravity reflood experiments,[3] injection into the top of the simulated downcomer resulted in severe flow oscillation in the test section. This phenomenum was believed to be due to condensation effects which were reduced by injection into the bottom of the downcomer.
3. Waring, J. P. and Hochreiter L. E., "PWR FLECHT-SET Phase-B1 Evaluation Report," WCAP-8583, August 1975.

resistance orifice plate between the test section outlet pipe and the inlet flange to the entrainment separator to simulate hot leg resistances, venting the top of the downcomer to the entrainment separator, and installing additional instrumentation and differential pressure cells. Reflood flow into the test section and any reverse flow out of the test section is measured by a turboprobe located in the downcomer crossover leg.

5-2. FACILITY COMPONENT DESCRIPTION

Paragraphs 5-3 through 5-10 describe facility components such as test section, test bundle, carryover vessel, entrainment separator, coolant injection system, downcomer and boiler.

5-3. Test Section

The low mass housing together with the lower and upper plenums constitutes the test section as shown in figure 5-3. The low mass housing shown in figure 5-4 is a cylindrical vessel 193.7 mm (7.625 in.) I.D. by 5.08 mm (0.200 in.) wall thickness constructed of 304 stainless steel rated for 0.52 MPa (60 psig) at 816°C (1500°F). The wall thickness is the minimum thickness allowed by Section I of the ASME Boiler and Pressure Vessel Code and was chosen so that the housing will absorb and hence, release a minimum amount of heat as compared with the rod bundle (refer to paragraph 5-25). The inside diameter of the housing was made as close to the rod bundle outer dimensions as possible to minimize excess flow area. The excess flow area is further minimized by solid triangular fillers as shown in figure 5-5. The housing has two commercially manufactured sight glasses located 180 degrees apart at the 0.9, 1.8 and 2.7 metre (3-, 6- and 9-foot) elevations which will be used for viewing and photographic studies. The sight glass configuration allows both front and back lighting for photographic studies. The two piece quartz sight glass will be gasketed together to help minimize heat loss through the window. The sight glasses will also have clamp-on heaters to raise the quartz temperature above saturation at the initiation of reflood to approximately 260°C (500°F). This feature will help eliminate the problem of forming a liquid film on the windows during a test run. The housing will also have differential pressure cell pressure taps located at every foot to measure liquid level in the housing. To help eliminate buckling and thermal distortion, the section will be supported from the upper plenum to permit the housing to freely expand downwards.

View ports will be added to the upper plenum for viewing and photographic studies. Provisions will also be made in the upper plenum to insert fluid thermocouples and endoscopes.

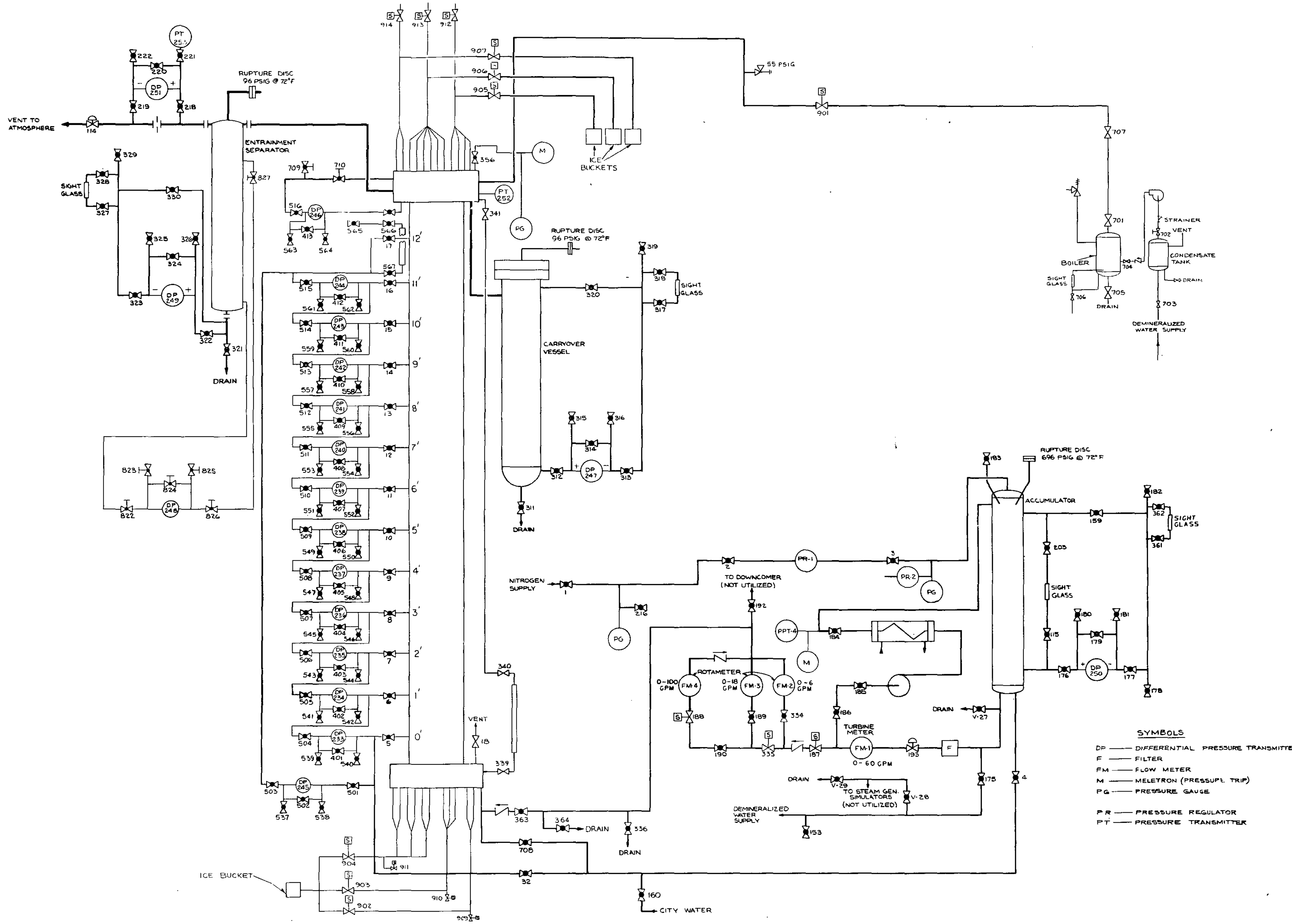


Figure 5-1. Flow Diagram for the Forced Reflood Configuration (FLECHT-SEASET Unblocked Bundle)

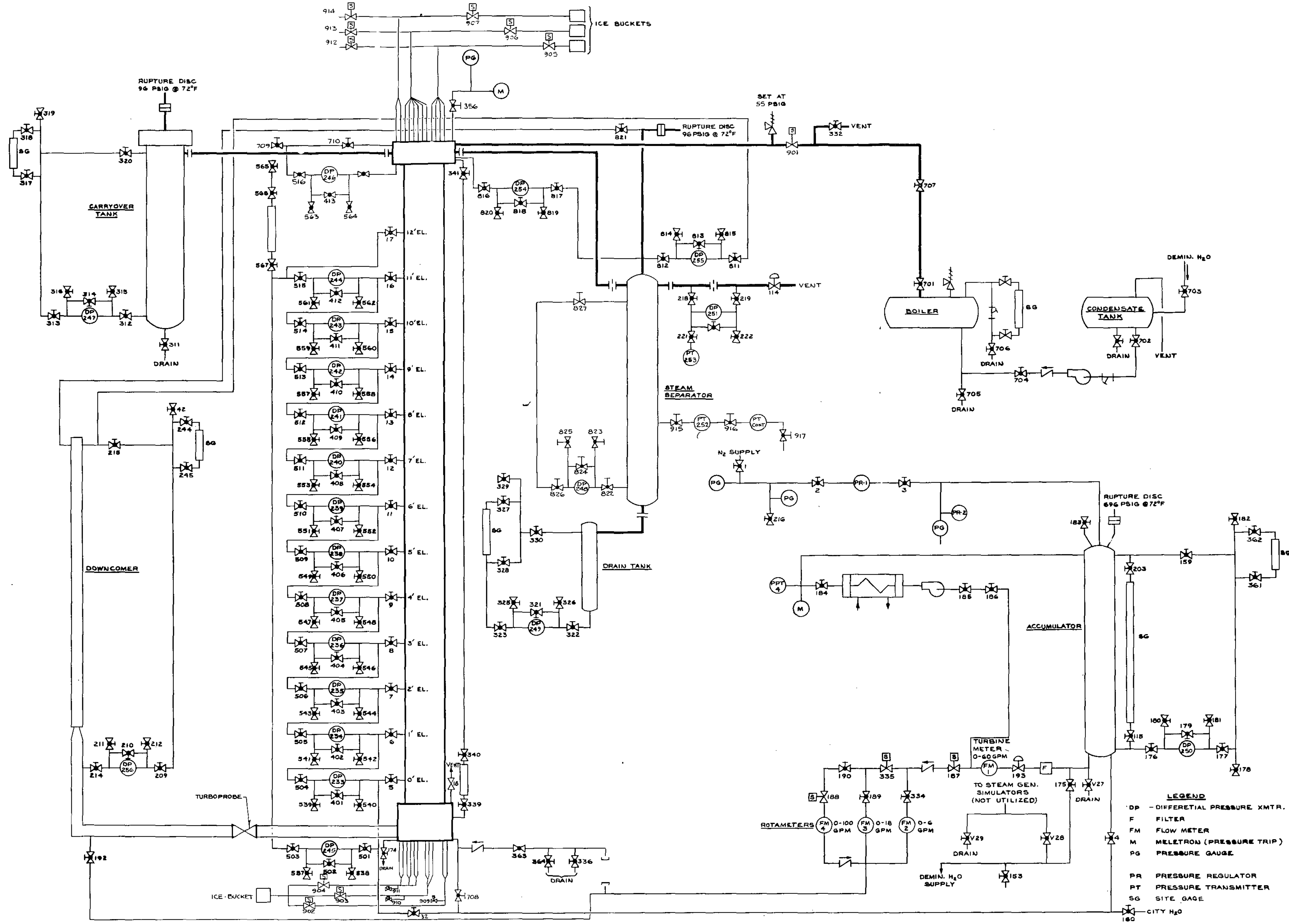
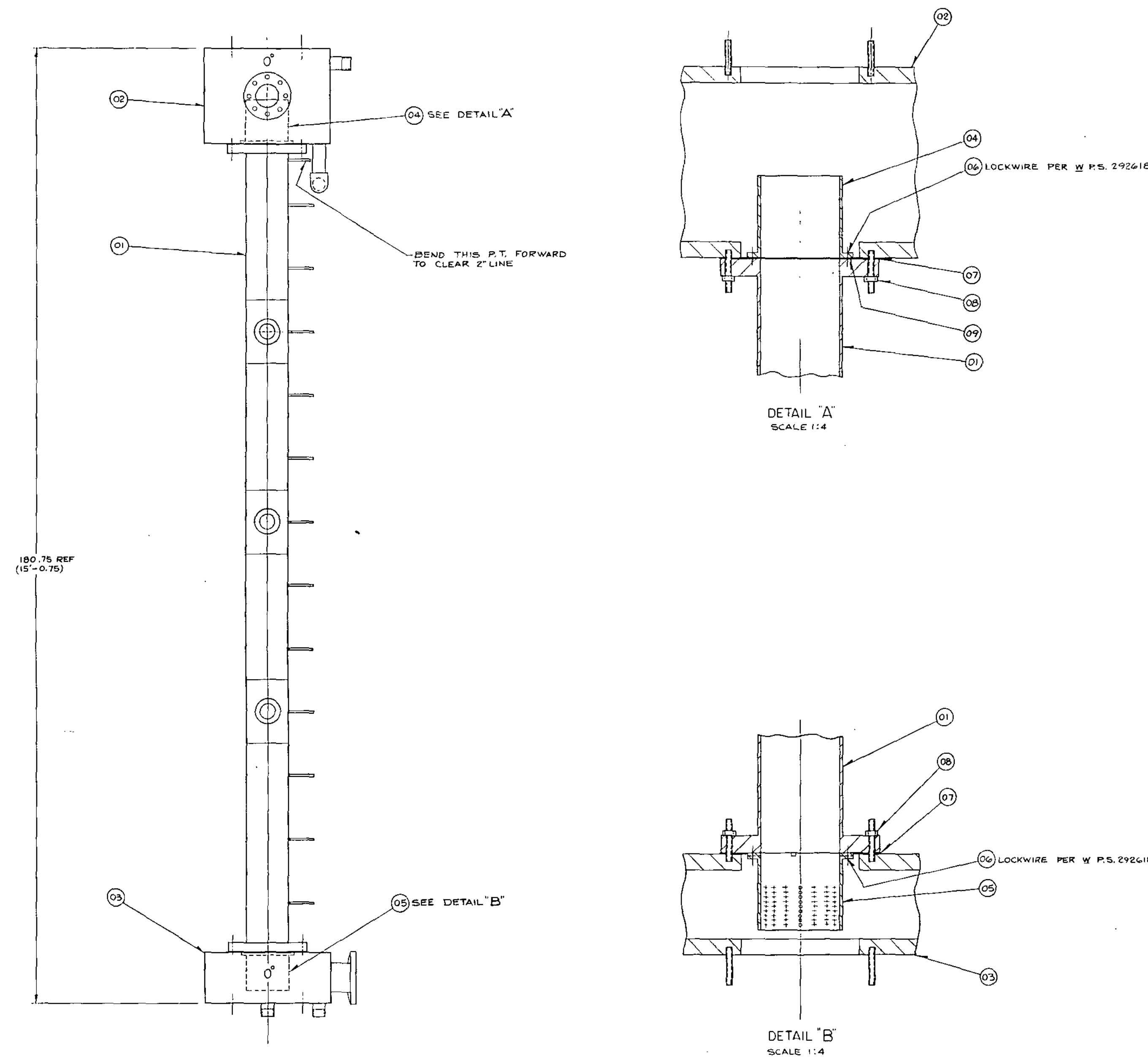


Figure 5-2. Flow Diagram for the Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)



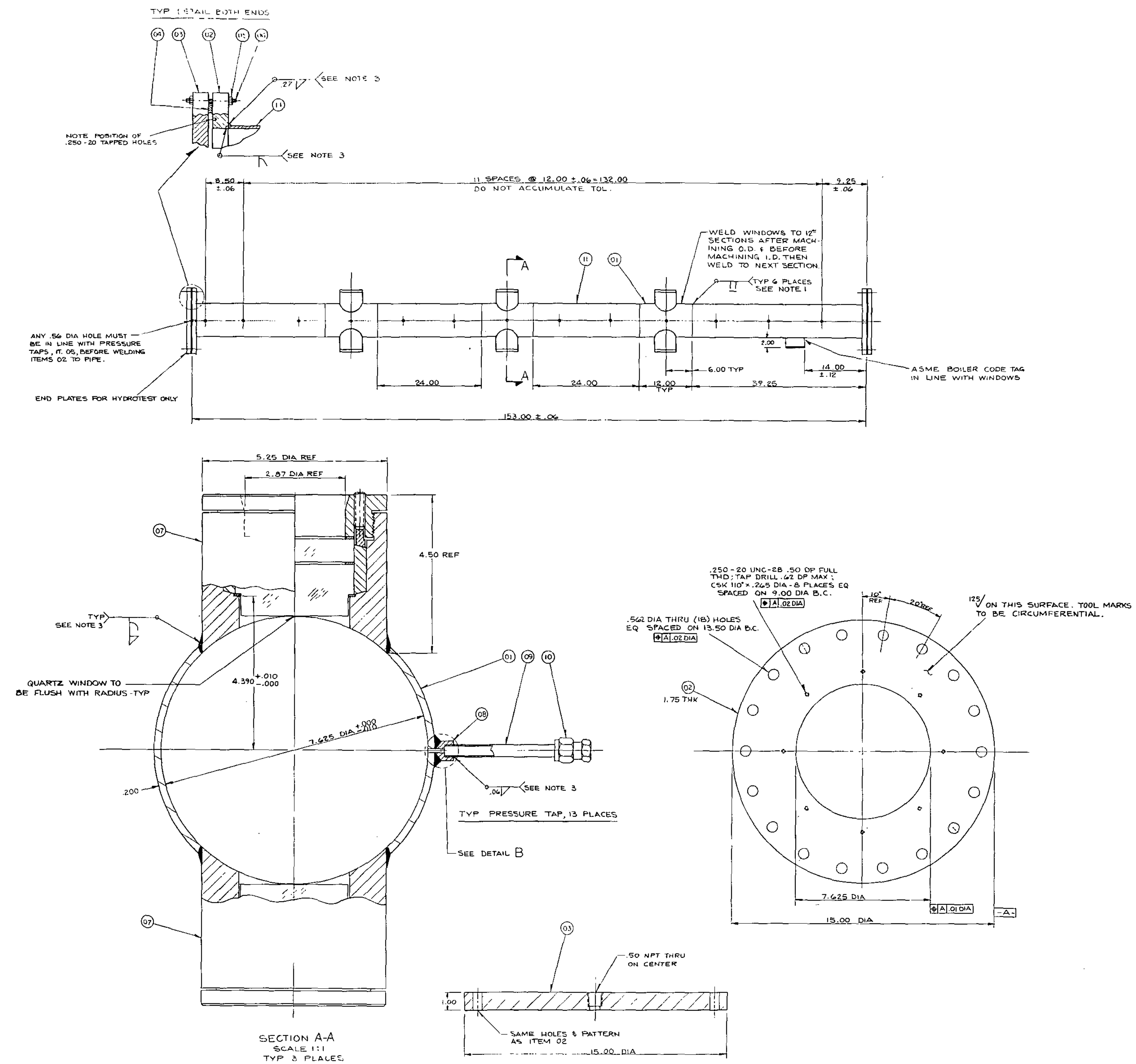
BILL OF MATERIAL								
ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ. PER GROUP 01	02	03	04
01		HOUSING	1446E97G01		1			
02		UPPER PLENUM	1447E25G01		1			
03		LOWER PLENUM	1447E29G01		1			
04		UPPER EXTENSION	8764D55G01		1			
05		LOWER EXTENSION	8764D55G02		1			
06		.25-20 UNC-2A × 1" SOC HD CAP SCR		SST	16			
07		GASKET	8764D55H06		2			
08		.50-13 UNC-2B HEX NUT		SST	36			
09		GASKET	8764D55H05		1			

UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY

STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND ANGULARITY VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE. VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. CONCENTRICITY MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES 250 √ MAX. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER) - ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ANSI B1.1 - PIPE THREADS PER ANSI B2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°

SEE PROCESS SPECIFICATION NO. CAP595128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

Figure 5-3. Low Mass Housing Assembly (FLECHT-SEASET Unblocked Bundle)



BILL OF MATERIAL								
ITEM	NOTE	PART NAME	PART NO.	MATERIAL	REQ. PER GROUP 01	02	03	04
01		PIPE		SA 182 TYPE 304	3			
02		FLANGE		SA 240 TYPE 304	2			
03		BLIND FLANGE			2			
04	A	GASKET	CG-1R		2			
05		.500-13 UNC HEX NUT		C. STL	72			
06		.500-13 UNC × 6" LG ALL THD		C. STL	36			
07	B	WINDOW ASSY - 3" 60 LB	MODEL B		6			
08		COUPLING		SA 479 GR 304	13			
09		TUBING .375 O.D. × .049 W. × 4.00 LG		SA 213 TYPE 304	13			
10	C	SWAGELOK CAP	SS-600-C		13			
11		PIPE		SA 312 TYPE 304	4			

A - FLEXITALLIC GASKET CO, CAMDEN, N.J.
B - PRESSURE PRODUCTS CO, CHARLESTON, W.VA.
C - PGH VALVE & FITTING CO, PGH, PA.

NOTES:

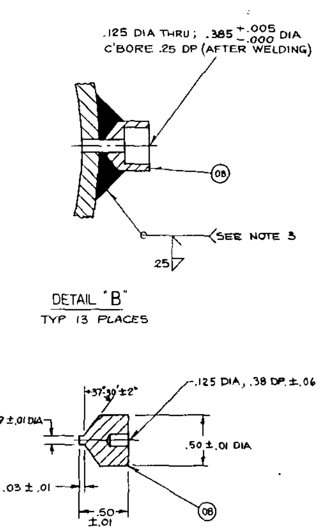
1 - WELD PER W PWR PROC. SPEC. 292613-1.

2 - TO BE MADE PER ASME BOILER CODE SECTION I FOR 60 PSIG AT 1500°F. PEAK TEMP. @ MID ELEVATION, 1000°F @ FLANGES, ITEM 02.

3 - WELD PER W PWR PROC. SPEC. 292613. LIQUID PENETRANT EXAM PER W P.S. 595139, QUALITY LEVEL A.

4 - ITEMS 01 & 11 TO BE STRESS RELIEVED BEFORE FINAL MACHINING.

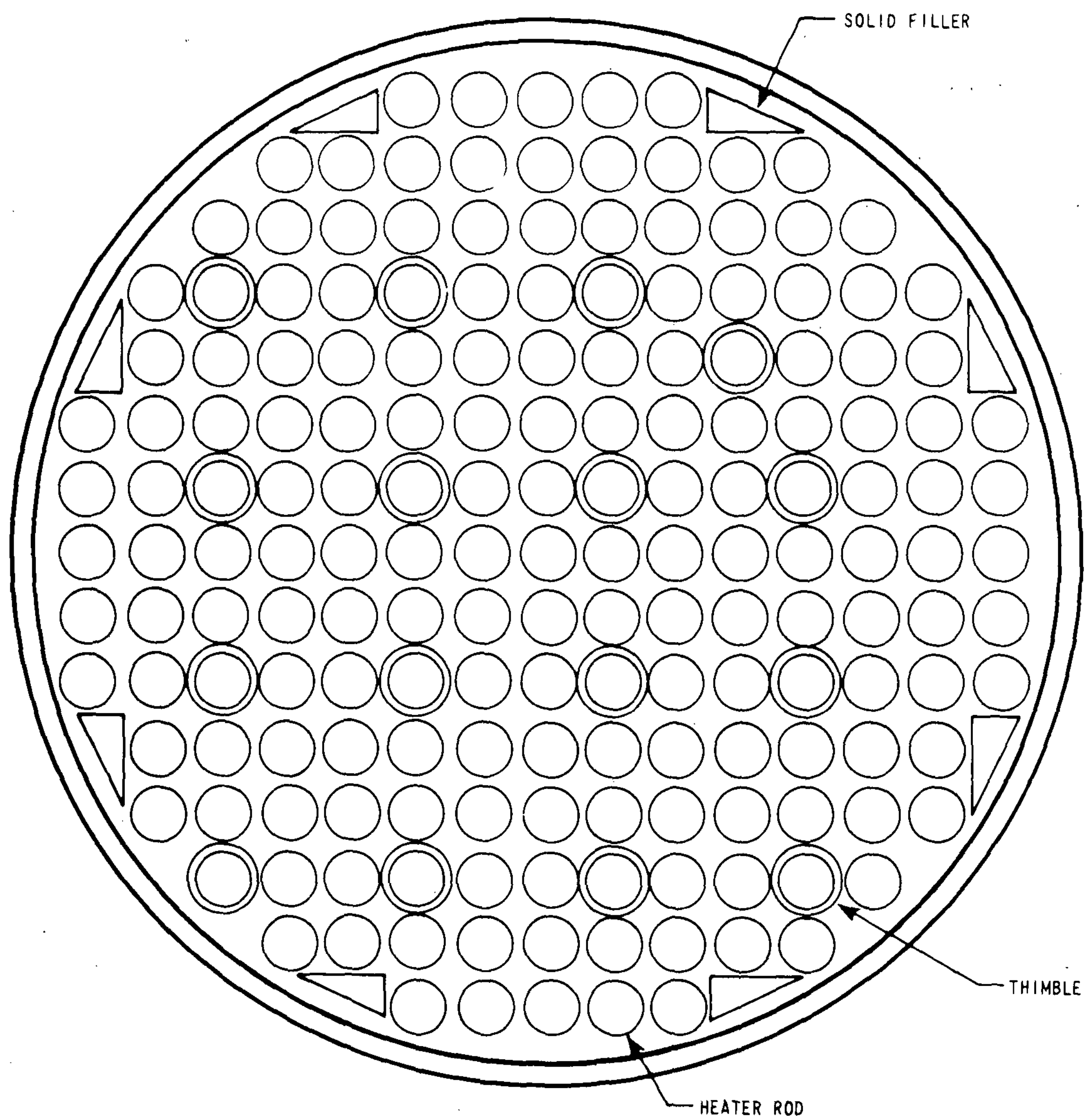
5 - HOUSING BODY TO BE STRAIGHT WITHIN .25 OVER ENTIRE LENGTH.



UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
THREE PLACE DIMS. = ±.005 TWO PLACE DIMS. = ±.02

SEE PROCESS SPECIFICATION NO. CAP595128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

Figure 5-4. Low Mass Housing Details (FLECHT-SEASET Unblocked Bundle)



BUNDLE STATISTICS

Housing Inside Diameter	194.0 mm	7.625 in.
Housing Wall Thickness	5.08 mm	0.200 in.
Rod Diameter	9.50 mm	0.374 in.
Thimble Diameter	12.3 mm	0.484 in.
Rod Pitch	12.6 mm	0.496 in.
Cross-Sectional Flow Area	15476. mm^2	23.989 $in.^2$
Filler Dimensions	19.43 mm x 8.64 mm	0.765 in. x 0.340 in.
161 Heater Rods	-	-
16 Thimbles	-	-
8 Fillers	-	-

Figure 5-5. Bundle Cross Section

5-4. Test Bundle

A cross section of the test bundle is shown in figure 5-5. The bundle is comprised of 161 heater rods (91 noninstrumented and 70 instrumented[1]), 4 instrumented thimbles, 12 steam probe thimbles and 8 solid triangular fillers. Details of the heater rods are shown in figure 5-6. The triangular fillers will be welded to the grids to maintain the proper grid location. The fillers will also help to reduce the amount of excess flow area in the housing. The excess flow area is 4.7 percent with the fillers and 9.3 percent without the fillers.

5-5. Carryover Vessel

The function of the carryover vessel is to collect liquid which flows out of the bundle and is deentrained in the upper plenum. The vessel shell, a 152.4 mm (6 in.) standard weight carbon steel pipe, is connected to the upper plenum via a stainless steel flexible hose. Eleven standard weight nozzle connections penetrate the vessel as follows:

Number of Connections	Size of Connection
1	50.8 mm (2 in.)
1	25.4 mm (1 in.)
9	12.7 mm (0.5 in.)

5-6. Entrainment Separator

Located in the exhaust line, the steam separator is designed to remove any remaining water droplets leaving the upper plenum such that a meaningful single-phase flow measurement can be obtained by an orifice meter downstream from the separator. The vessel shell is 0.30 m (12 in.) standard weight carbon steel pipe and the vessel volume is 0.212 m^3 (7.8 ft^3). The separator operates by utilizing centrifugal action to force the heavier moisture against the wall where it drains to the bottom. The water is collected in a separator drain tank connected to the bottom of the separator. The drain tank shell is a 101.6 mm (4 in.), standard weight carbon steel pipe and the volume is 0.011 m^3 (0.4 ft^3).

5-7. Exhaust Line Piping and Components

Test section effluent discharges to the atmosphere via the exhaust line piping (refer to figure 5-7). The existing 127 mm (5 in.) nozzle penetration on the upper plenum provides the attachment point for the exhaust line piping. Sandwiched between the two mating flanges is a 12.7 mm (1/2 in.) plate which serves as a structural attachment for an internal 76.2 mm (3 in.) baffle pipe assembly (upper plenum baffle – refer to figure 5-8). This baffle serves to

1. This represents the current breakdown.

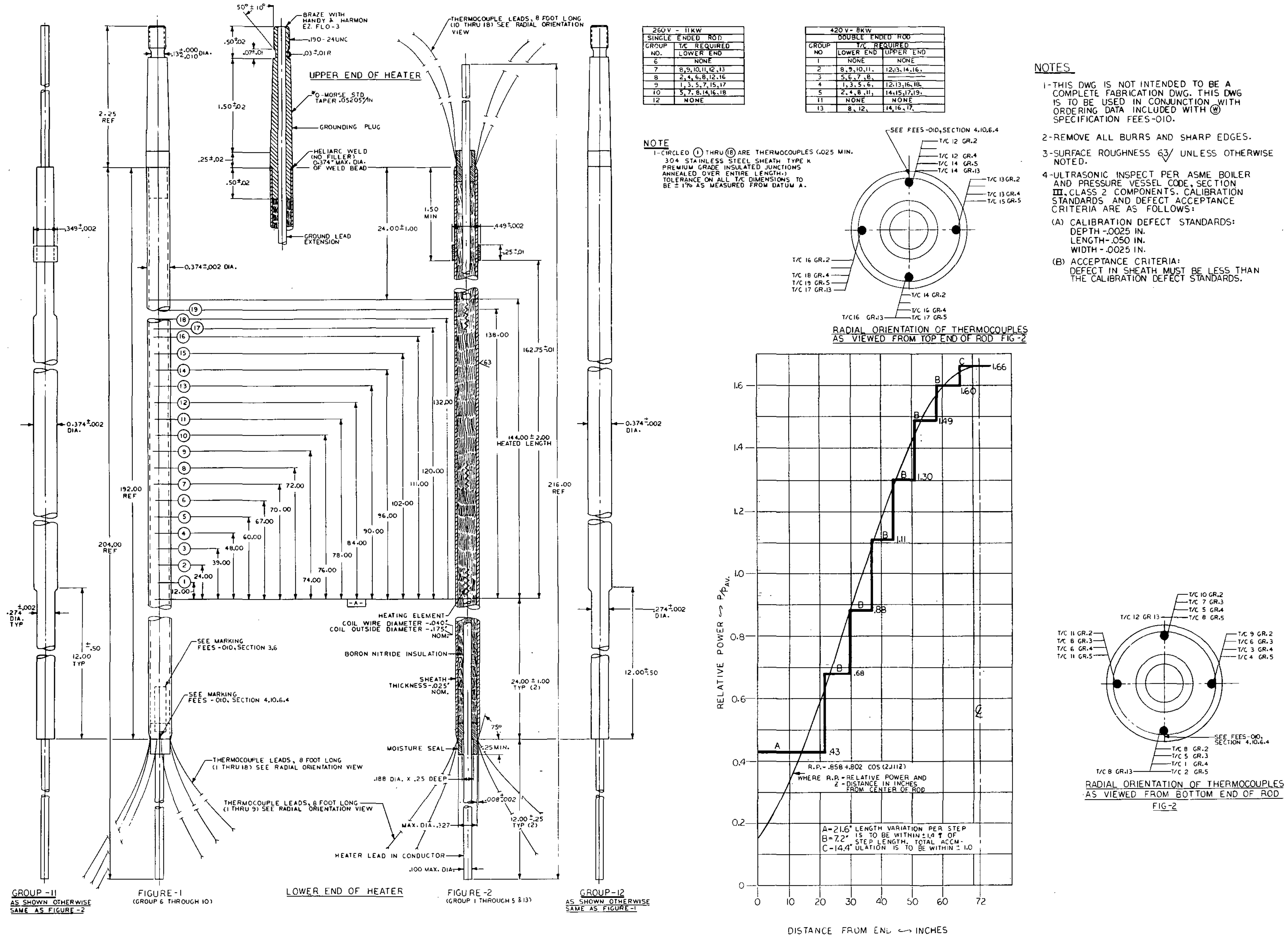
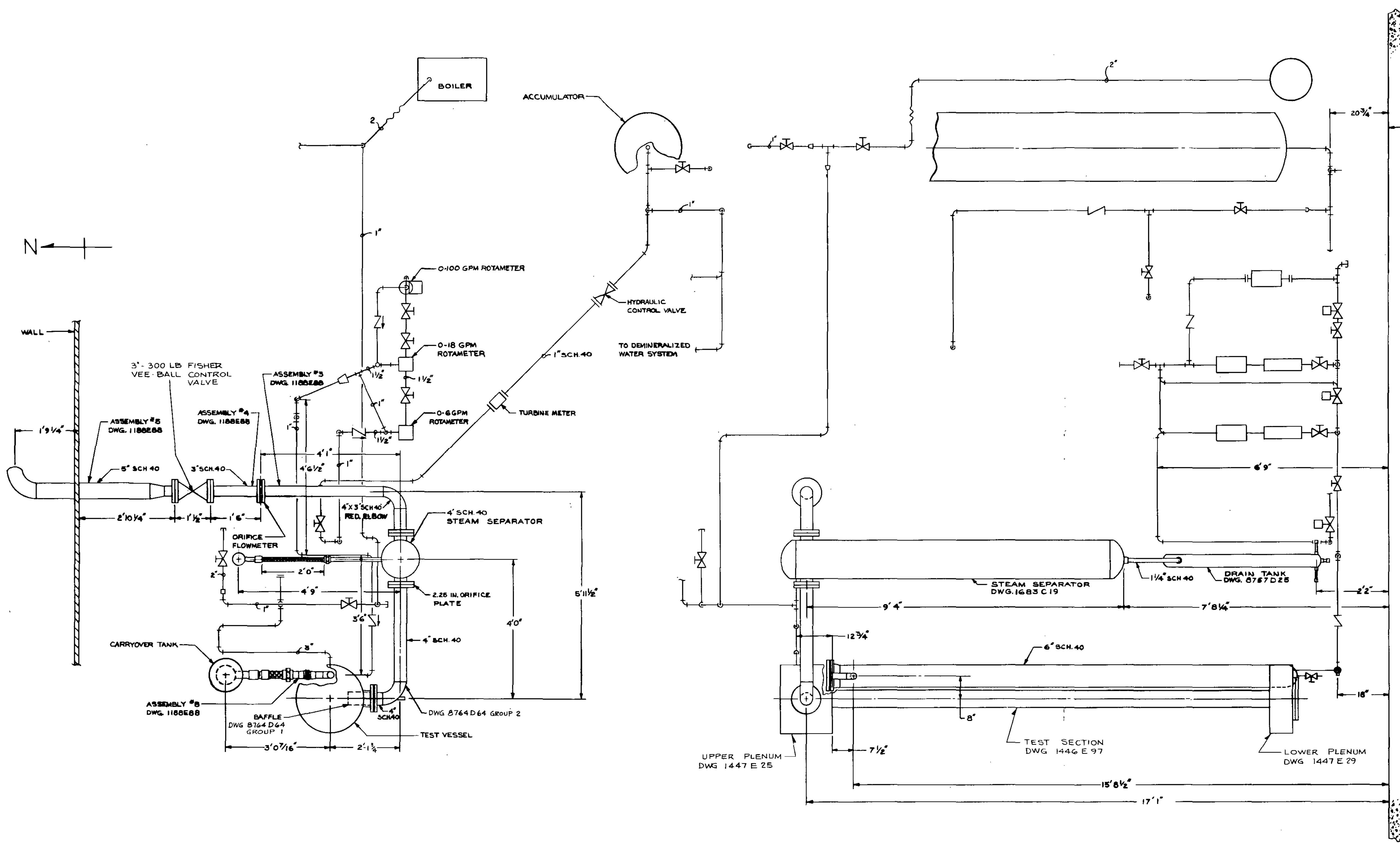


Figure 5-6. Heater Rod Details (FLECHT-SEASET Unblocked Bundle



PLAN VIEW

ELEVATION VIEW

Figure 5-7. Piping Diagram for the Forced Reflood Configuration (FLECHT-SEASET Unblocked Bundle)

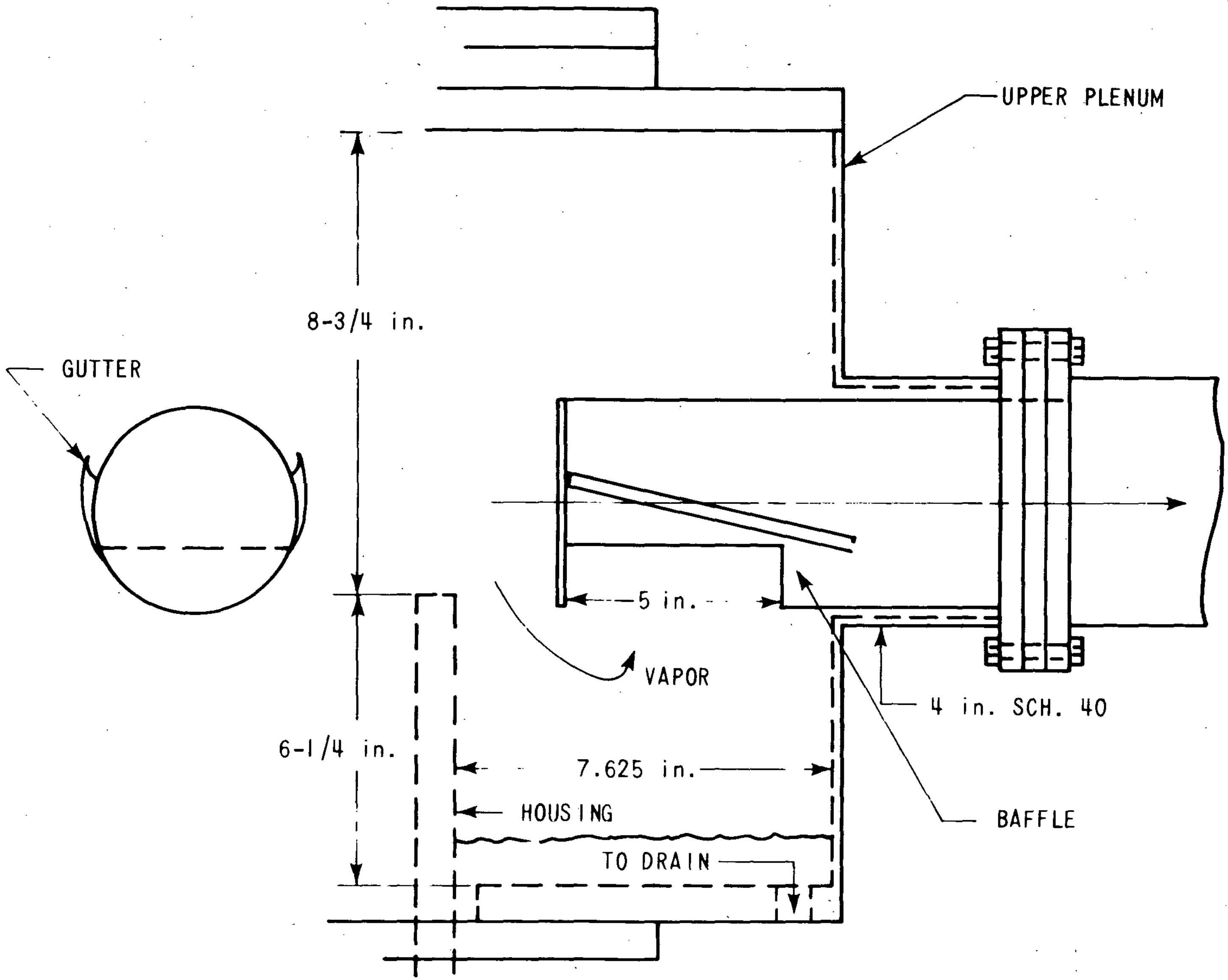


Figure 5-8. FLECHT Test Upper Plenum Baffle

improve the liquid carryout separation and minimize liquid entrainment into the exhaust vapor. After passing through the upper plenum baffle pipe, the exhaust vapor passes through a 101.6 mm (4 in.) 90 degree elbow and into a straight run of 101.6 mm (4 in.) pipe. A steam probe is located in the 101.6 mm (4 in.) elbow to measure the temperature of the exhaust steam. The 101.6 mm (4 in.) pipe takes the effluent into the entrainment separator. Dry steam leaving the separator passes through a 101.6 mm (4 in.) by 76.2 mm (3 in.) 90 degree reducing elbow and along a straight run of 76.2 mm (3 in.) pipe to a orifice flange assembly utilized to measure flow rate. Clamp-on strip heaters on the 76.2 mm (3 in.) pipe are used to heat the pipe to 260°C (500°F) to assure single-phase steam flow through the orifice. Steam then exhausts to the atmosphere through the 300 pound system pressure control valve. The control valve is an air-operated, Vee-Ball control valve which was used successfully on the skewed test series[1] to minimize the pressure oscillations during a test run.

A resistance orifice plate will be installed before the inlet flange of the entrainment separator for the gravity reflood tests (figure 5-9). The orifice plate will simulate the hot leg resistances. Figure 5-9 also shows the details of construction of the exhaust line components.

5-8. Coolant Injection System

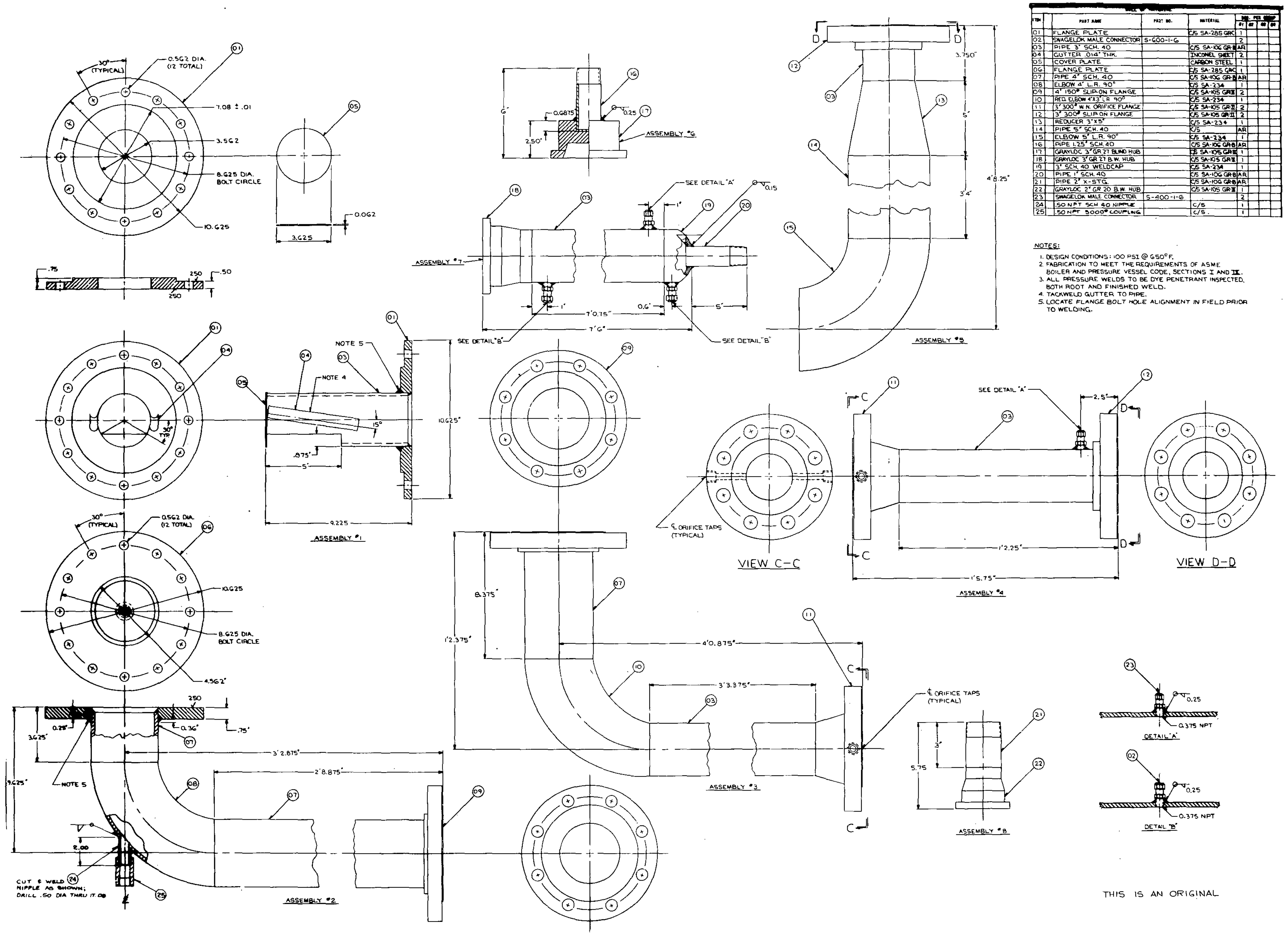
This system provides reflood water to quench the rod bundle during testing. In brief, coolant injection water is supplied by the 1.514 m^3 (400 gal) accumulator via a series of valves and meters. Nitrogen over pressure on the accumulator provides the necessary driving head to attain the required injection rates.

Constant or stepped-injection flow is accomplished by the proper sequencing of solenoid valves which are located in a piping manifold arrangement. This is shown on figure 5-8. Programmed flow to the test section is controlled by means of a hydraulic valve which operates from a demand signal from the computer with feedback from the turbine meter.

The flow meters will include a 0 to 37.8 x 10^{-5} m^3/s (0 to 6 gpm), 0 to 113.5 x 10^{-5} m^3/s (0 to 18 gpm) and 0 to 6.309 x 10^{-3} m^3/s (0 to 100 gpm) rotameter and a 3.78 x 10^{-5} to 378. x 10^{-5} m^3/s (0.6 to 60 gpm) and 9.46 x 10^{-5} to 946.35 x 10^{-5} m^3/s (1.5 to 150 gpm) turbine meter. The rotameters are used in conjunction with the turbine meters to provide a redundant system of flow rate measurement.

A 1135.62 x 10^{-5} m^3/s (180 gpm) bidirectional turboprobe will be installed in the downcomer crossover leg during gravity reflood tests to measure flow into the test section and any reverse flow from the test section to the downcomer.

1. Rosal, E. R., Conway, C. E. and Krepinevich, M. C., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.



ITEM		PART NAME	PART NO.	MATERIAL	NO. PER GROUP			
01		FLANGE PLATE		C/S SA-285 GRC	1			
02		SWAGELOK MALE CONNECTOR	S-600-1-6		2			
03		PIPE 3" SCH. 40		C/S SA-106 GR-B	AR			
04		GUTTER .014" THK.		INCONEL SHEET	2			
05		COVER PLATE		CARBON STEEL	1			
06		FLANGE PLATE		C/S SA-285 GRC	1			
07		PIPE 4" SCH. 40		C/S SA-106 GR-B	AR			
08		ELBOW 4" L.R. 90°		C/S SA-234	1			
09		4" 150# SLIP-ON FLANGE		C/S SA-105 GR II	2			
10		RED. ELBOW 4"X3" LR 90°		C/S SA-234	1			
11		3" 300# W.N. ORIFICE FLANGE		C/S SA-105 GR II	2			
12		3" 300# SLIP ON FLANGE		C/S SA-105 GR II	2			
13		REDUCER 3"X5"		C/S SA-234	1			
14		PIPE 5" SCH. 40		C/S	AR			
15		ELBOW 5" L.R. 90°		C/S SA-234	1			
16		PIPE 1.25" SCH. 40		C/S SA-106 GR-B	AR			
17		GRAYLOC 3" GR 27 BLIND HUB		C/S SA-105 GR II	1			
18		GRAYLOC 3" GR 27 B.W. HUB		C/S SA-105 GR II	1			
19		3" SCH. 40 WELDCAP		C/S SA-234	1			
20		PIPE 1" SCH. 40		C/S SA-106 GR-B	AR			
21		PIPE 2" X-STG.		C/S SA-106 GR-B	AR			
22		GRAYLOC 2" GR 20 B.W. HUB		C/S SA-105 GR II	1			
23		SWAGELOK MALE CONNECTOR	S-400-1-6		2			
24		.50 NPT SCH 40 NIPPLE		C/S	1			
25		.50 NPT 3000# COUPLING		C/S	1			

NOTES:

1. DESIGN CONDITIONS: 100 PSI @ 650°F.
2. FABRICATION TO MEET THE REQUIREMENTS OF ASME BOILER AND PRESSURE VESSEL CODE, SECTIONS I AND IX.
3. ALL PRESSURE WELDS TO BE DYE PENETRANT INSPECTED, BOTH ROOT AND FINISHED WELD.
4. TACKWELD GUTTER TO PIPE.
5. LOCATE FLANGE BOLT HOLE ALIGNMENT IN FIELD PRIOR TO WELDING.

Figure 5-9. Exhaust Line Details (FLECHT-SEASET Unblocked Bundle)

5-9. Downcomer

The downcomer will be connected to the test section lower plenum for the gravity reflood tests. The downcomer is fabricated from a 127 mm (5 in.) carbon steel tubing having a wall thickness of 3.05 mm (0.12 in.), a 127 mm (5 in.) 90 degree long radius elbow, a specially designed spool piece, and a flexible rubber pipe. The rubber pipe connects the downcomer to the lower plenum and allows for downward thermal expansion of the test section. The horizontal run of the downcomer is 2.3 m (7.5 ft) long and the vertical run is approximately 6.1 m (20 ft). A 38.1 mm (1.5 in.) nozzle located in the elbow of the downcomer will be used to inject the coolant water from the accumulator. The bidirectional turboprobe will be located in the spool piece. A schematic diagram of the downcomer is shown in figure 5-10.

5-10. Boiler

The boiler is a Reimers Electric Steam Boiler with a steam capacity of 15.74×10^{-3} kg/s (125 lbm/hr) at 100°C (212°F). The boiler is used to pressurize the facility to post-blowdown reactor core conditions following a loss of coolant accident. This is accomplished by valving the boiler into the upper plenum of the test section.

5-11. GENERAL INSTRUMENTATION DESCRIPTION

The instrumentation recorded on this task will consist of temperature, power, flow, level, and static pressure. The temperature data will be measured by type K (Chromel-Alumel) thermocouples using 66°C (150°F) reference junctions. The thermocouple locations are divided into two groups; test section bundle and loop. Bundle thermocouples consist of heater rod, thimble wall, steam probes, and fluid thermocouples. The heater rod thermocouples will be monitored by the Computer Data Acquisition System (CDAS) for flood temperature, over-temperature, and bundle quench temperature. The loop thermocouples measure fluid, vessel wall, and piping wall temperature.

Power input to the bundle heater rods will be measured by Hall effect watt transducers. These watt transducers produce a direct current electrical output proportional to the power input. The voltage and current input to the watt transducer is scaled down by transformers so the range of the watt transducer matches the bundle power. The scaling factor of the transformers will be accounted for when the raw data (millivolts) is converted to engineering units. Injection flow will be measured by a turbine meter and one of three rotameters. Gravity feed flow will be measured by the same instrumentation plus an additional turboprobe.

Because of its high accuracy and range, a standard turbine meter will be the primary flow measurement device. It will be connected to a preamplifier and flow rate monitor for conversion of turbine blade pulses into flow rate in engineering units. The rotameters will be a backup measurement for flow and will be used to set flow for stepped injection. (Refer to loop flow diagram for more details.) The rotameter float displacement, which is flow-rate dependent, is converted to an analog signal and recorded by the data acquisition system. The bidirectional turboprobe will be used only during gravity reflood tests to measure flow into or out of the bundle through the downcomer crossover pipe. The turboprobe flow rate monitor analog signal is proportional to the speed and direction of flow in the downcomer crossover. Calibration of the turboprobe by the manufacturer provides data conversion to volumetric flows for the turboprobe analog signal.

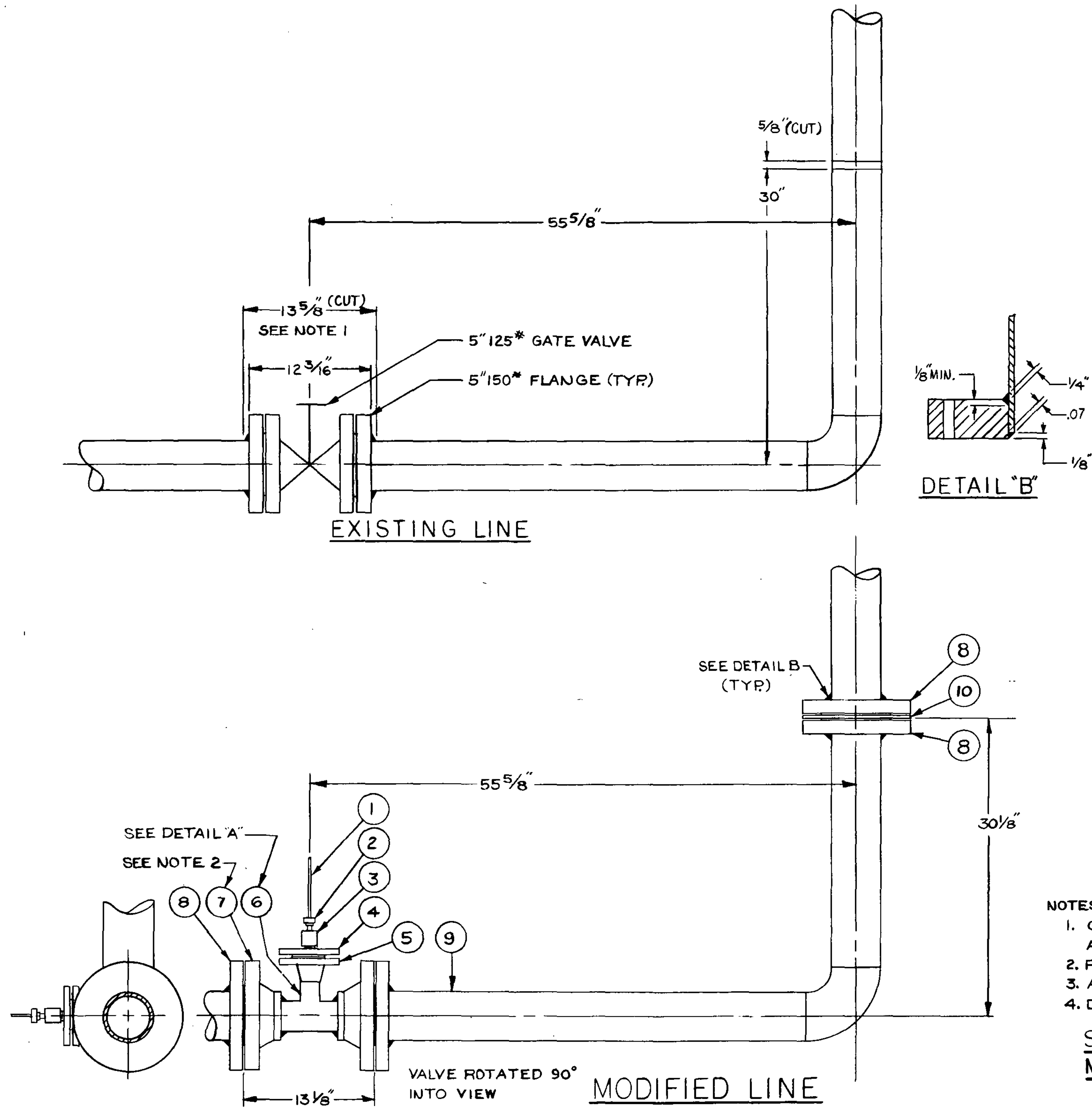
The system-pressure measurements will be both static and differential. The pressure transducers will be balanced bridge strain gage devices. The differential pressure readings will measure level in the vessels and the bundle and pressure drops across selected horizontal pipes. Standard thermocouple calibration table entries and the corresponding coefficients will be used to compute the temperature value. All other channel calibration files will be a straight line interpolation of calibration data. The slope, intercept, and zero for the least-squares fit of a straight line to the equipment calibration data is computed for each channel and entered into its calibration file. The software uses this straight line formula to convert millivolts to engineering units. Figure 5-11 presents a schematic diagram of the computer hardware interface.

5-12. Data Acquisition System

Primarily there will be three types of recording systems that will monitor the instrumentation on the FLECHT facility. The data acquisition consists of a PDP-11/20 computer, Fluke data logger and strip chart pen recorders. Figures 5-12 and 5-13 are the facility instrumentation schematic diagrams which can be used in conjunction with table 5-1 to locate and identify all the facility instrumentation monitored by the various data acquisition systems.

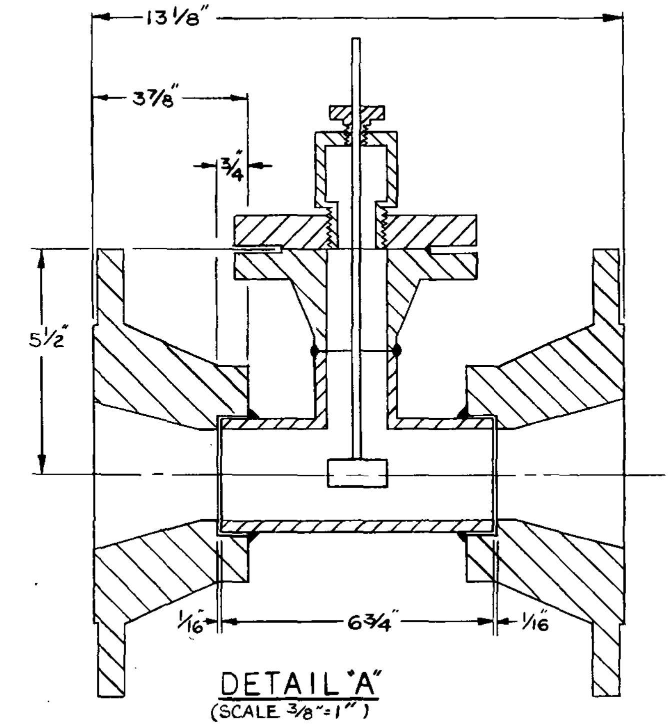
5-13. Computer Data Acquisition System (CDAS) – The CDAS is the primary data collecting system used on the FLECHT facility and consists of a PDP-11/20 computer and associated equipment. The system can record 256 channels of analog input data representing bundle and system temperatures, bundle power, flows, and absolute and differential pressures. The computer is capable of storing 1400 data scans for each of the 256 analog input channels.

Typically, each data channel was recorded once every second until flood, then once every 0.5 second for 200 seconds and then back to once every second thereafter to a maximum of 1400 data points.



NOTE	ITEM	TITLE	DRAWING & GR. OR IT.	MATERIAL SPECIFICATION	EQUIVALENT SPECIFICATION FOR (W) USE ONLY
	1	TURBOPROBE			
A	2	SWAGELOK MALE CONN.		TYPE 316 S.S.	
B	3	SPECIAL THREADED CPLG.		TYPE 316 S.S.	
C	4	2" 150# BLIND FLANGE		SA 105 GR. 1	
	5	2" 150# W/N FLANGE		SA 105 GR. 1	
D	6	3"x3"x2" STD. WT. TEE		SA 234 W.P.B.	
	7	5" 300# W/N FLANGE		SA 105 GR. 1	
E	8	5" 300# BLIND FLANGE		SA 105 GR. 1	
	9	5" O.D. x .12" WALL TUBING C.S.		SA 53 GR B	
	10	SPACER PLATE		316 S.S.	

A- 1210-1-12-BT
B- FURNISHED WITH TURBOPROBE
C- TAPPED TO FIT ITEM 3
D- SPECIAL BORE
E- BORED TO FIT 5" O.D. TUBING



NOTES:

1. CUT AFTER TURBOPROBE SPOOL PIECE HAS BEEN FABRICATED AND DIMENSIONALLY CHECKED.
2. FIELD FIT TURBOPROBE SPOOL PIECE AFTER FABRICATION.
3. ALL WELDING PER (W) PROCESS SPEC. 82148, REV. 2.
4. DYE PENETRANT EXAMINATION OF ALL WELD REQUIRED.

SEE DWG. 501B615 FOR TURBOPROBE MODIFICATION

Figure 5-10. Downcomer for Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)

TABLE 5-1
BUNDLE INSTRUMENTATION (UNBLOCKED BUNDLE TASK 3.2.1)

Instrumentation		Number of Channels Used		
		CDAS	FLUKE	Strip Chart Recorders (Texas Instrument)
Report				
Text Section				
5-18	Rod Bundle			
5-19	Heater Rod Thermocouples	178	–	4
5-20	Thimbles Thermocouples	6	8	–
5-21	Steam Probes	22	–	6
	Differential Pressure Cells	13	13	1
5-22	Power			
	Primary	3	–	3
	Independent	3	–	–
5-23	Upper Plenum			
	Pressure	1	–	1
	Differential Pressure Cell	1	1	–
	Fluid Thermocouples	3	–	–
	Wall Thermocouples	–	1	–
5-24	Lower Plenum			
	Fluid Thermocouples	1	2	–
	Wall Thermocouples	–	–	–
5-25	Housing			
	Wall Thermocouples	–	12	–
	Windows Thermocouples	–	6	–

TABLE 5-1 (cont)
BUNDLE INSTRUMENTATION (UNBLOCKED BUNDLE TASK 3.2.1)

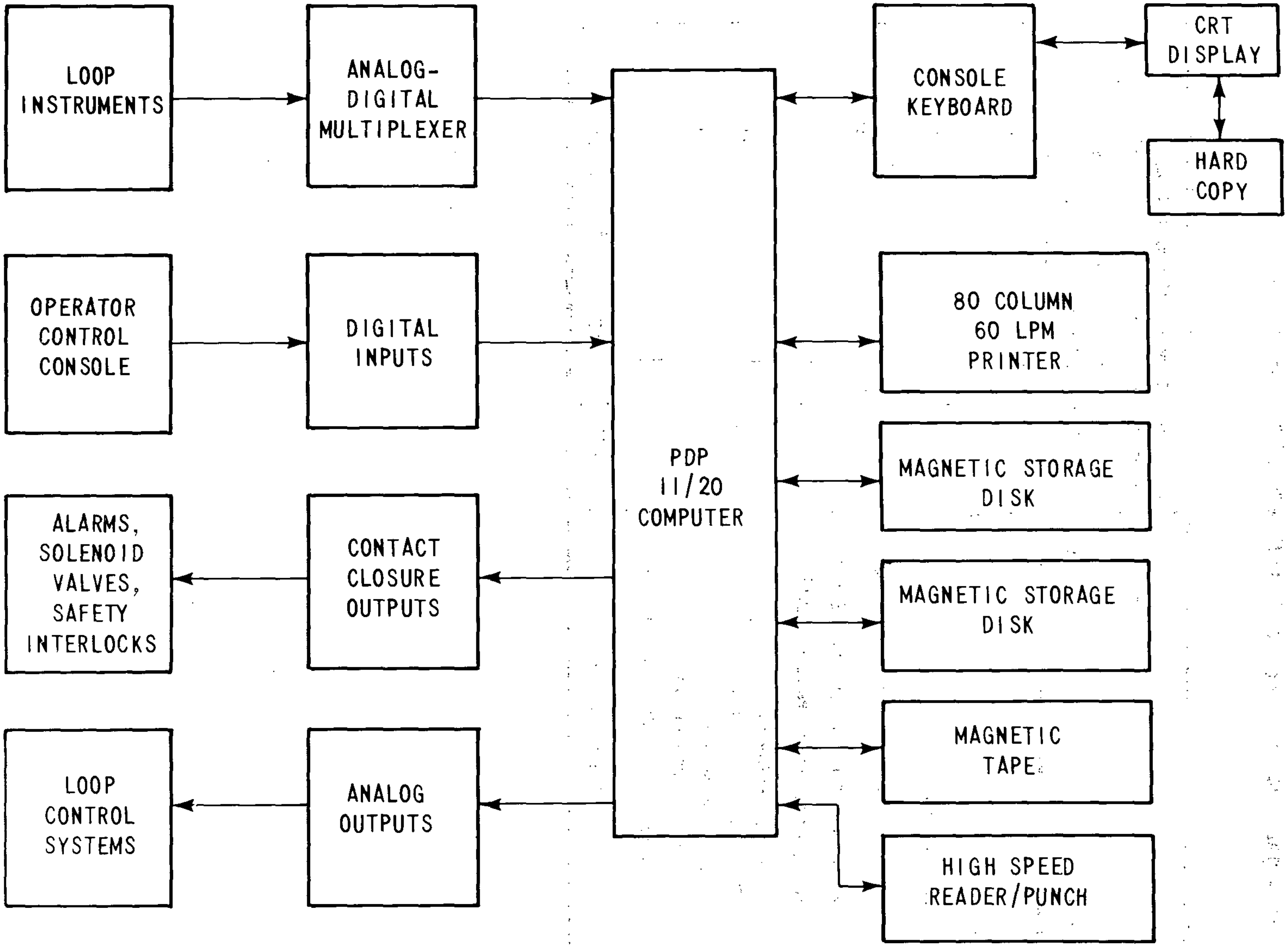
Instrumentation	Number of Channels Used		
	CDAS	FLUKE	Strip Chart Recorders (Texas Instrument)
Report			
Text Section			
5-26 Loop			
Water Supply System			
Fluid Thermocouples	1	2	—
Wall Thermocouples	—	—	—
Flow Meters:			
Rotameter	3	—	3
Turbine Meter	1	1	1
Accumulator Differential Pressure Cell	1	—	1
Exhaust System			
Steam Probe	1	—	—
Fluid Thermocouples	3	2	—
Wall Thermocouples	5	8	—
Pressure	1	—	—
Differential Pressure Cells			
Tanks Levels	3	—	2
Orifice Plate ΔP	1	—	1
Gravity Reflood Test (Additional)			
Differential Pressure Cells:			
Downcomer Level	1	—	1
UP[a] /Steam Separator	1	—	—

a. UP — Upper Plenum

TABLE 5-1 (cont)

BUNDLE INSTRUMENTATION (UNBLOCKED BUNDLE TASK 3.2.1)

Instrumentation	Number of Channels Used		
	CDAS	FLUKE	Strip Chart Recorders (Texas Instrument)
Report			
Text Section			
5-26 Loop (cont)			
Differential Pressure Cells (cont)			
Downcomer/Steam Separator	1	–	–
Bidirectional Turboprobe	1	–	1
Downcomer Fluid Thermocouple	1	–	–
Downcomer Wall Thermocouple	–	–	–
Crossover Pipe Wall	–	1	–
Total Channels	256	57	25



12325-25

Figure 5-11. FLECHT-SEASET Computer-Hardware Interface (Unblocked Bundle, Task 3.2.1)

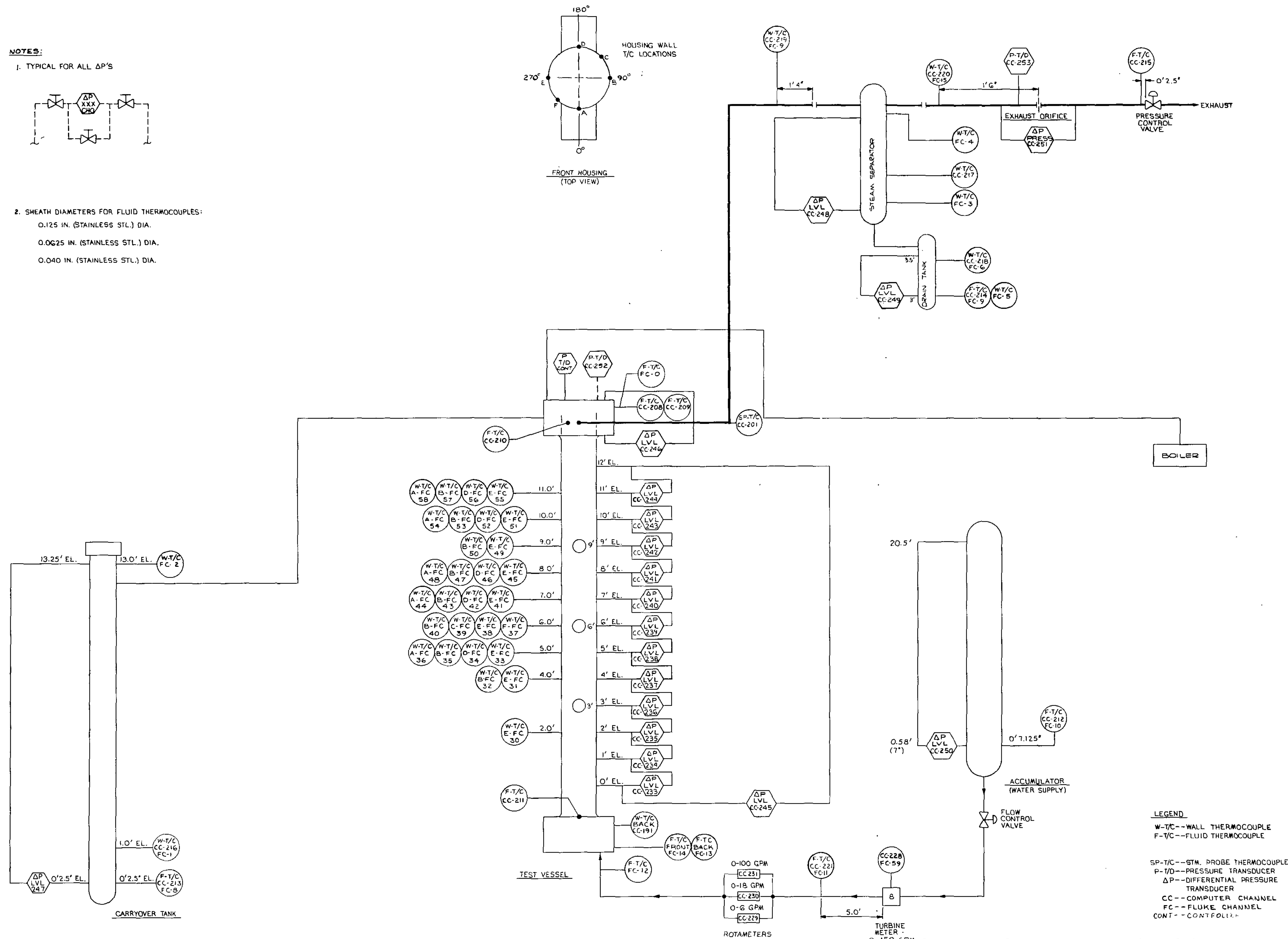


Figure 5-12. Instrumentation Schematic Diagram for the Forced Reflood Configuration (FLECHT-SEASET Unblocked Bundle)

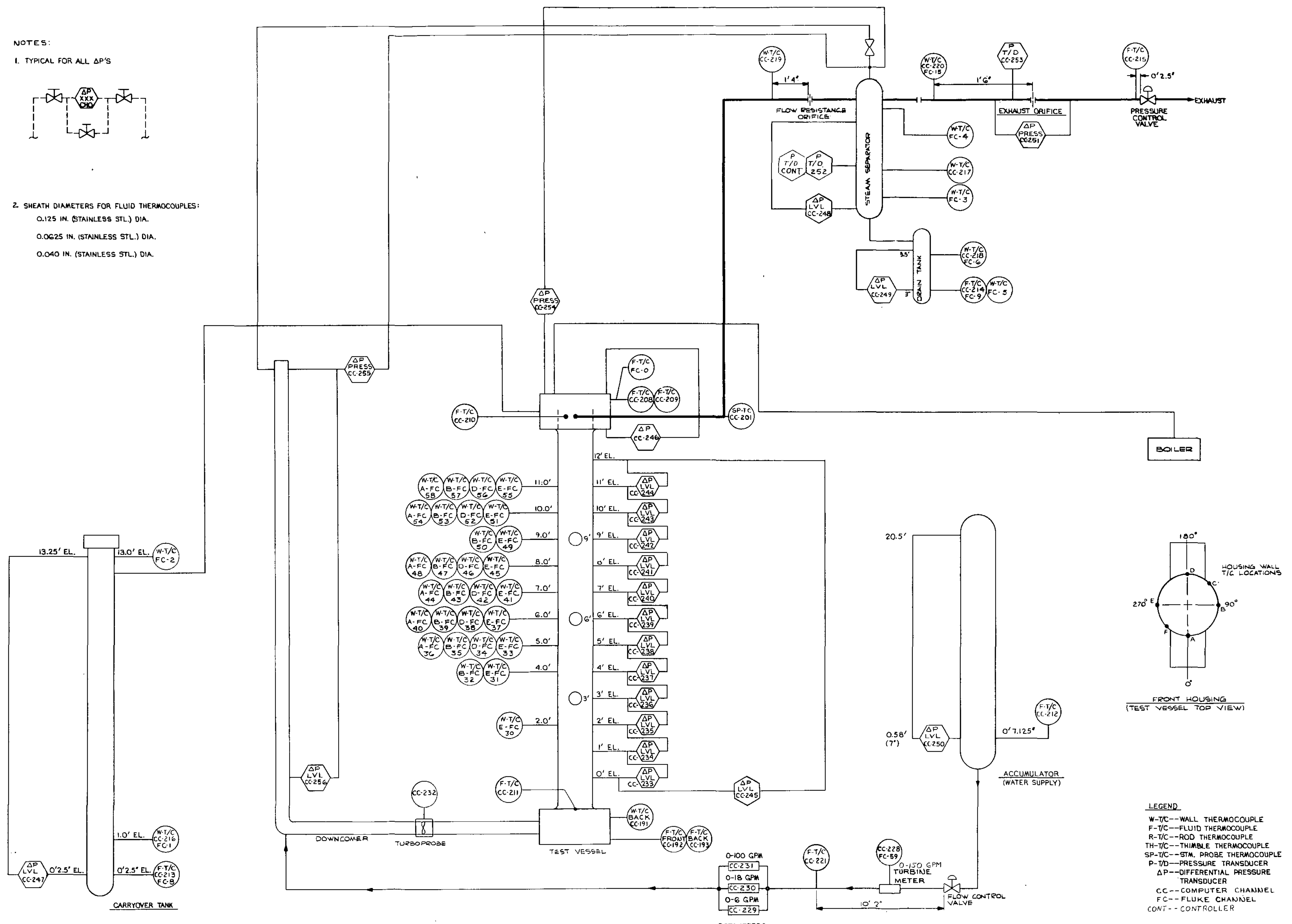


Figure 5-13. Instrumentation Schematic Diagram for the Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)

The computer software has the following features:

- A calibration file to convert raw data into engineering units.
- A preliminary data reduction program which transfers the raw data stored on a disc to a magnetic tape in a format which is compatible for entry into a Control Data Corporation 7600 Computer.
- A program called "F-LOOK" (refer to appendix E) which reduces raw data into engineering units. A program called "FVALID" (refer to appendix E) which prints out key data used in validating FLECHT-SEASET runs. A "PLOT" program (refer to appendix E) which plots up to four data channels on a single graph. All three programs are utilized to evaluate test runs.

In addition to its role as a data acquisition system, the computer also plays a key role in the performance of an experimental run. Important control functions include initiation and control of reflood flow and power decay as well as termination of bundle power in the event of an over-temperature condition. Table 5-1 lists the instrumentation recorded on the CDAS.

5-14. Fluke Data Logger — The Fluke data logger has 60 channels of analog input for monitoring loop heatup and aiding in equipment troubleshooting. The Fluke records key facility vessel and fluid temperatures and displays temperature directly in engineering units. This makes the job of monitoring loop heatup more efficient. The Fluke also records millivolt data from the test section differential pressure cells thus allowing the operator to keep a check on the operation and repeatability of differential pressure cells. The Fluke is also used to troubleshoot problems with loop equipment in a quick and convenient manner. Table 5-1 lists channels monitored on the Fluke.

5-15. Multiple Pen Strip Chart Recorders (Texas Instrument)

Six Texas Instrument strip chart recorders are used to record bundle power, selected bundle thermocouples; steam probe thermocouples; reflood line rotameter and turbine meter flows; turboprobe flows; accumulator, separator drain tank, housing and carryover tank levels; and exhaust orifice differential pressure. These recorders give the loop operators and test directors immediate information on test progress and warning in the event of system anomalies. The strip charts give an analog recording of critical data channels as a backup to the computer. Strip charts are also needed during the heatup phase of the facility when the computer is not available. Table 5-1 lists the channels associated with the strip chart recorders.

5-16. FACILITY OPERATION

The facility operation will be similar to the detailed procedures presented in WCAP-9108.[1] The following general procedure will be used to conduct a typical test.

(1) Fill accumulator with water and heat to desired coolant temperature [53°C (127°F) nominal].

(2) Turn on boiler and bring the pressure up to 0.517 MPa (75 psig) nominal gage pressure.

(3) Heat the carryover vessel, entrainment separator, separator drain tank, test section plenum and test section outlet piping (located before the entrainment separator) while they are empty to slightly above the saturation temperature corresponding to the test run pressure. The exhaust line between the separator and exhaust orifice is heated to 260°C (500°F) nominal; test section lower plenum is heated to the temperature of the coolant in the accumulator.

(4) Pressurize the test section, carryover vessel, and exhaust line components to the specified test run pressure by valving in the boiler and setting the exhaust line control valve to the specified pressure.

(5) Scan all instrumentation channels by the computer to check for defective instrumentation. The differential pressure and static pressure cell "zero" readings are taken and entered into the computer calibration file. These "zero" readings are compared with the component calibration zero reading. The straight line conversion to engineering units are changed to the new zero when the raw data is converted to engineering units. This zero shift process accounts for errors due to transducer zero shifts and compensates for level reference legs enabling the engineering units to start with an empty reading.

(6) Apply power to the test bundle and allow rods to heat up. When the temperature in any two designated bundle thermocouples reaches the desired test flood temperature, 871°C (1600°F), the computer automatically initiates flood and controls power decay. The exhaust control valve regulates the system pressure at the preset value by releasing steam to the atmosphere.

(7) Ascertain that all designated rods have quenched (indicated by the computer printout of bundle quench).

(8) Cut power from heaters, terminate coolant injection, and depressurize the entire system.

(9) Drain and weigh water from all components.

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1. Rosal, E. R., Conway, C. E. and Krepinevich, M. C., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.

During the test series, the facility will be modified to conduct gravity reflood tests. The same procedure will be used to conduct these tests with the following exception; after flood is initiated, the flooding rate will be adjusted if necessary to assure that the level in the downcomer does not exceed the 4.88 m (16 ft) elevation. This is necessary to avoid condensation which effects the pressure transient of the facility.[1]

5-17. INSTRUMENTATION PLAN

The proper choice of instrumentation is essential if meaningful results are to be obtained from an experimental or testing program. In recognition of this, considerable effort was expended to optimize allocation of instrumentation channels based on projected data requirements and historical usage. As discussed previously in section 5-12, the unblocked bundle facility has three types of data acquisition equipment available. These are as follows:

- Computer Data Acquisition System (CDAS)
- FLUKE Data Logger
- Strip Chart Recorders

Only channels connected to the CDAS will be described. (A detailed instrumentation channel listing appears in appendix C.) Other channels connected to the FLUKE and strip chart recorders are utilized for loop performance. Data recorded via the FLUKE and strip charts are not used directly for data analysis and evaluation. The overall instrumentation description for the unblocked bundle test facility is given in table 5-1.

The CDAS has a total of 256 channels available for data storage. Usage of each channel for the Low Flooding Rate Skewed Test[2] series was critically reviewed and a number of channels were identified which were not important to data reduction and analysis work. This effort released significant computer space which will be used to increase test section instrumentation. For example, the unblocked bundle is 53 percent larger than the skewed bundle. A reallocation of many housing, window, upper plenum and lower plenum wall thermocouples was warranted to increase the number of heater rod thermocouples 14 percent above skewed levels. More than seven times as many steam probes have been placed in the unblocked bundle as were found in the skewed series. Much of this reallocated information will be hooked up to the FLUKE data recorder. All instrumentation needed for the mass and energy balances will be placed on the computer.

1. Waring, J. P. and Hochreiter L. E., "PWR FLECHT-SET Phase-B1 Evaluation Report," WCAP-8583, August 1975.

5-18. Rod Bundle

The following paragraphs (5-19 through 5-22) discuss heater rod thermocouples, thimble instrumentation, steam probe instrumentation and power measurements found in the rod bundle.

5-19. Heater Rod Thermocouples – The number of heater rod thermocouples have been increased from 156 in the skewed test series to 180 in the 17 x 17 unblocked test. This increase is needed to account for the following:

- Effective instrumentation of the larger bundle – the 17 x 17 bundle contains 161 heater rods while the skewed bundle contained 105 heater rods.
- One-to-one correspondence with blocked bundle instrumentation such that the effects of blockage can be determined. Performing flow blockage tests forces a change in philosophy in bundle instrumentation over previous testing programs. Heavy instrumentation of one half of the bundle is no longer acceptable since symmetry is invalid if blockage is located on one side of the bundle centerline.

A number of competing requirements were identified which influence the axial and radial distribution of thermocouples. They are as follows:

- An equal number of heater rod thermocouples are needed at each instrumented elevation above 0.61 m (2 ft) to obtain the same relative accuracy in energy balance and thermal-hydraulic properties.
- A greater number of heater rod thermocouples is needed near the peak power elevations to determine the following:

  (1) Maximum clad temperature

  (2) Empirical FLECHT type, 1.83 m (6 ft) quench time correlation[1,2]

  (3) Empirical FLECHT type heat transfer correlation.[1,2]

- Heater rod thermocouples are needed in the vicinity of steam probes to determine wall temperatures and heat fluxes for mechanistic model development.

1. Lilly, G. P., Yeh, H. C., Hochreiter, L. E., Yamaguchi, N., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.
2. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.

- Heater rod thermocouples are needed in and above the anticipated blockage zone such that future comparisons between blocked and unblocked heat transfer may be made. The blocked heat transfer data will be generated in Task 3.2.3.[1]

- Other special purpose heater rod thermocouples are needed to:

  (1) Account for variations in five different radial power profiles

  (2) Obtain detailed heat transfer data at locations between those elevations having primary instrumentation in the vicinity of the anticipated blockage zone. This data will be compared with similar data obtained from the Blockage Task 3.2.3.[1]

A study was performed to develop a rationale, based upon statistical considerations as well as the above requirements, for the assignment of thermocouples and steam probes under uniform radial power conditions. The first four requirements above were considered to be of primary importance and were allocated 160 thermocouples for axial assignment. The last item was not considered in this analysis, but was expected to be satisfied with the balance of available heater rod instrumentation.

In order to quantify the statistical considerations, it was assumed that the heater rod characteristics of the proposed FLECHT-SEASET experiments follow similar probability distributions as in the skewed axial power experiments. In particular the heat transfer coefficients at each thermocouple location at an instrumented elevation were obtained from the results of run number 13303 of the skewed axial power low flooding rate tests.[2] If the resultant heat transfer coefficients at a given time are a random sample from a representative probability distribution for the case of uniform radial power, then the mean and standard deviation of the sample are "best" estimates of the corresponding parameters of the probability distribution.

The average, $\bar{h}$, and standard deviation, σ, of the heat transfer coefficient of run 13303 as a function of time were examined at 3.05 m (10 ft) peak power, 1.22 m (4 ft), and 0.30 m (1 ft) levels.

Prior to quench, a measure of the relative error $\epsilon = \sigma/\bar{h} = 0.14$ was determined in the study as was an upper value of $\epsilon = 0.18$. Using statistical theory, these values for relative errors, and additional preliminary ground rules for nominal instrumentation elevations and for steam probe placement, a hypothetical assignment of thermocouples and expected accuracy of

1. Conway, C. E., Hochreiter, L. E., Krepinevich, M., Massie Jr., H. W., Rosal, E. R. and Howard, R. C., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI/Westinghouse Report Number 1, December 1977.
2. Rosel, E. R. Hochreiter, L. E., McGuire, M. F., Krepinevich, M. C., "FLECHT Low Flooding Rate Cosine Test Series Data Report," WCAP-8651, December 1975.

reduced data was developed. In the final instrumentation plan, competing requirements prohibit verbatim use of the assignments developed in this study, but the study recommendations were used as a guide to reduce error due simply to instrumentation distribution.

Seventy instrumented rods will be manufactured having five different thermocouple groupings as shown in figure 5-14. Group 1 not shown in figure 5-14 are noninstrumented heater rods; Group 2 and Group 3 are designed to obtain detailed heat transfer data in the region of expected flow blockage. When placed in neighboring locations, Groups 2 and 3 rods cover most of the zone of interest for correlation development, namely 1.22 m (4 ft) to 2.44 m (8 ft). Rods in Groups 4 and 5 give fairly uniform axial coverage when placed in neighboring positions. These two distributions also fill voids in upper and lower elevation instrumentation created by the distribution of Group 2 and Group 3. Group 13, like Group 2, heater rods are designed to measure heat transfer above the peak power elevation but without as much elevation detail.

Most of the seventy selected instrumented heater rods placed in the bundle will contain eight thermocouples. Less than one-half of the approximately 450 possible thermocouples will actually be connected to the computer. This margin in channel connection allows for thermocouple failure encountered during rod manufacture, installation in the bundle, and testing.

In general, thermocouple instrumentation is found at either 0.15 m (0.5 ft) or 0.30 m (1.0 ft) increments. However, due to grid interference at 0.91 m (3 ft) and 2.47 m (9 ft), the steam probe, thimble, thermocouple instrumentation locations have been raised 76 mm (3 in.) above these locations.

The number of connected thermocouples at each instrumented elevation excluding thermocouples in heater rods adjacent to the housing has been extracted from the detailed instrumentation plan presented in appendix C and listed in table 5-2. Those thermocouples next to the housing are normally not used in determining bundle-average properties to assure that influence of the cold housing is minimized.

The accuracy of the measured mean is predicted for various conditions. The values of ϵ = 0.14 and 0.18 for the relative error and the Student t-distribution (similar to the normal distribution, but for small samples) were used to compute the 95 percent confidence interval for the mean; that is, the computed band width required to be able to say with 95 percent confidence that the true population mean will be captured by the sample mean at an instrumented elevation. These results are also shown in table 5-2.

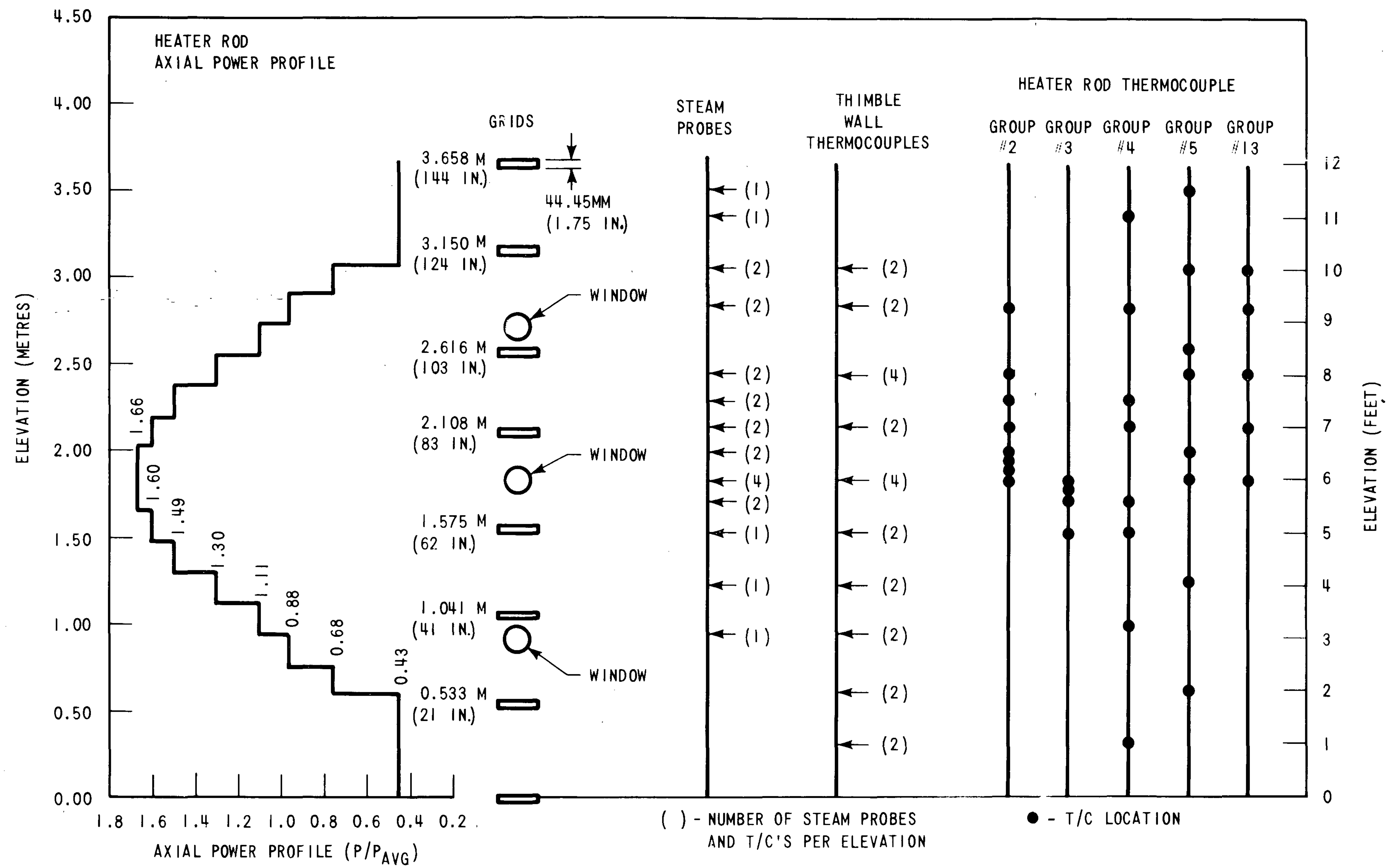


Figure 5-14. Axial Rod Bundle Instrumentation Availability (Unblocked Bundle Task 3.2.1)

TABLE 5-2
RELATIVE ACCURACY OF REDUCED DATA FROM THERMOCOUPLE (UNBLOCKED BUNDLE TASK 3.2.1)

Elevation (m)	Elevation (ft-in.)	Number of[a] Thermocouples (n)	Student[b] t-Distr. Factor $t_{n-1}/\sqrt{n}$	Half-Width Expected to Capture the Population Mean With 95% Confidence For Relative Error = $\epsilon = \sigma/h$: ϵ = 0.14	ϵ = 0.18
0.30	1-0	3	2.484	35	95
0.61	2-0	3	2.484	35	95
0.99	3-3	3	2.484	35	95
1.22	4-0	7	0.925	13	17
1.52	5-0	8	0.836	12	15
1.70	5-7	8	0.836	12	15
1.77	5-10	11	0.672	9.4	12
1.83	6-0	19	0.482	6.7	9
1.88	6-2	10	0.715	10	13
1.93	6-4	10	0.715	10	13
1.98	6-6	14	0.577	8	10

a. Number of thermocouples excludes those in heater rods next to the housing

b. Student t-distribution at 95 percent confidence level with n-1 degrees of freedom for sample size n, t_{n-1},

$$\text{Probability} = P\left\{ \frac{\bar{h}-\mu}{\bar{h}} < \frac{\epsilon}{\sqrt{n}}\, t_{n-1} \right\} = 95 \text{ percent}$$

TABLE 5-2 (cont)

RELATIVE ACCURACY OF REDUCED DATA FROM THERMOCOUPLE (UNBLOCKED BUNDLE TASK 3.2.1)

Elevation		Number of[a] Thermocouples (n)	Student[b] t-Distr. Factor $t_{n-1}/\sqrt{n}$	Half-Width Expected to Capture the Population Mean With 95% Confidence For Relative Error = $\epsilon = \sigma/h$	
(m)	(ft-in.)			$\epsilon = 0.14$	$\epsilon = 0.18$
2.13	7-0	12	0.635	8.9	11
2.29	7-6	12	0.635	8.9	11
2.44	8-0	11	0.672	9.4	12
2.59	8-6	10	0.715	10	13
2.82	9-3	10	0.715	10	13
3.05	10-0	10	0.715	10	13
3.35	11-0	7	0.925	13	17
3.51	11-6	4	1.591	22	29

a. Number of thermocouples excludes those in heater rods next to the housing.

b. Student t-distribution at 95 percent confidence level with n-1 degrees of freedom for sample size n, t_{n-1}.

$$\text{Probability} = P\left\{\frac{\bar{h}-\mu}{\bar{h}} < \frac{\epsilon}{\sqrt{n}}\, t_{n-1}\right\} = 95 \text{ percent}$$

As an example, the instrumentation distribution specified by table 5-2 indicates that 19 thermocouples will be connected at 1.83 m (6 ft). At this elevation with uniform radial power, one can say with 95 percent confidence that the true population mean will be captured within a half width of 7 percent (band width of 14%) of the measured (sample) mean for a relative error ϵ = 0.14.

It is also noted for uniform radial power and uniform flow experiments that in the important interval between 1.52 m (5 ft) and 3.35 m (11 ft), a 95 percent confidence interval for the true mean is expected to have a half width within about 13 percent of the mean for ϵ = 0.14.

5-20. Thimble Instrumentation — Four thimbles have been instrumented with wall thermocouples as shown in figures 5-14 and 5-15. This information will be used as follows:

- To evaluate radiation heat transfer between surfaces in the upper half of the bundle.

- To evaluate subcooling in the bottom of the bundle. Thimbles are thin wall tubes which store little energy. Shortly after quenching, the thimble thermocouples should record reflood water temperature.

5-21. Steam Probe Instrumentation — Vapor temperatures are key measurements in data analysis and evaluation efforts. The number of bundle steam probes have been increased from 3 in previous test series to 23 (22 connected to the computer; 1 spare). These probes will provide essential data for determining the following:

- Mass and energy balances for the system

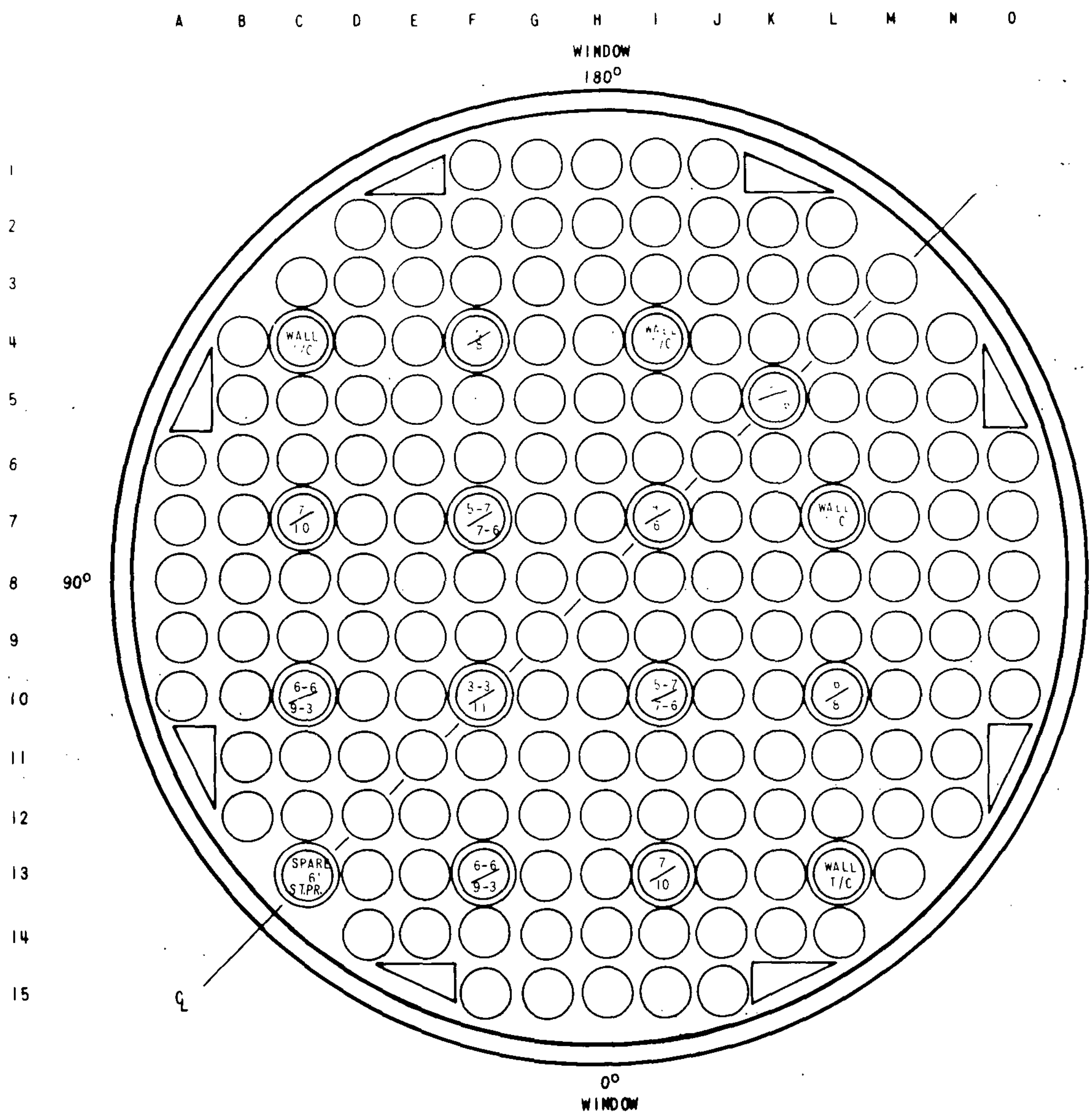
- Highly nonequilibrium vapor properties for mechanistic correlation and model development

- Radial vapor temperature variation at the same elevation

- Vapor superheat for comparison with blockage experiments

For these reasons, the steam probe system has been redesigned such that each thimble contains two thermocouples separated by a membrane as shown in figures 5-15 and 5-16. This feature permits substantial increase in axial and radial vapor sampling capability for a fixed number of thimbles. However, increasing the number of probes could increase the mass removed from the bundle. Examination of skewed data[1] showed that roughly 1 percent of the total injected mass was removed from the test section per steam probe. Extrapolation of skewed results to the proposed steam probe distribution indicated that an unacceptable 22 percent of the injected flow would be removed from the test section. Consequently, a manifolding

1. Lilly, G. P., Yeh, H. C. Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.



ELEVATION (METRES)	0.30	0.61	0.99	1.22	1.52	1.70	1.83	1.98	2.13	2.29	2.44	2.82	3.05	3.35	3.51
ELEVATION (FEET - INCHES)	1	2	3-3	4	5	5-7	6	6-6	7	7-6	8	9-3	10	11	11-6
INSTRUMENTATION AVAILABILITY															
NUMBER OF STEAM PROBES	-	-	1	1	1	2	4	2	2	2	2	2	2	1	1
NUMBER OF THIMBLE WALL THERMOCOUPLES	2	2	2	2	2	-	4	-	2	-	4	2	2	-	-

Figure 5-15. Steam Probe and Thimble Wall Thermocouple Location (Unblocked Bundle Task 3.2.1)

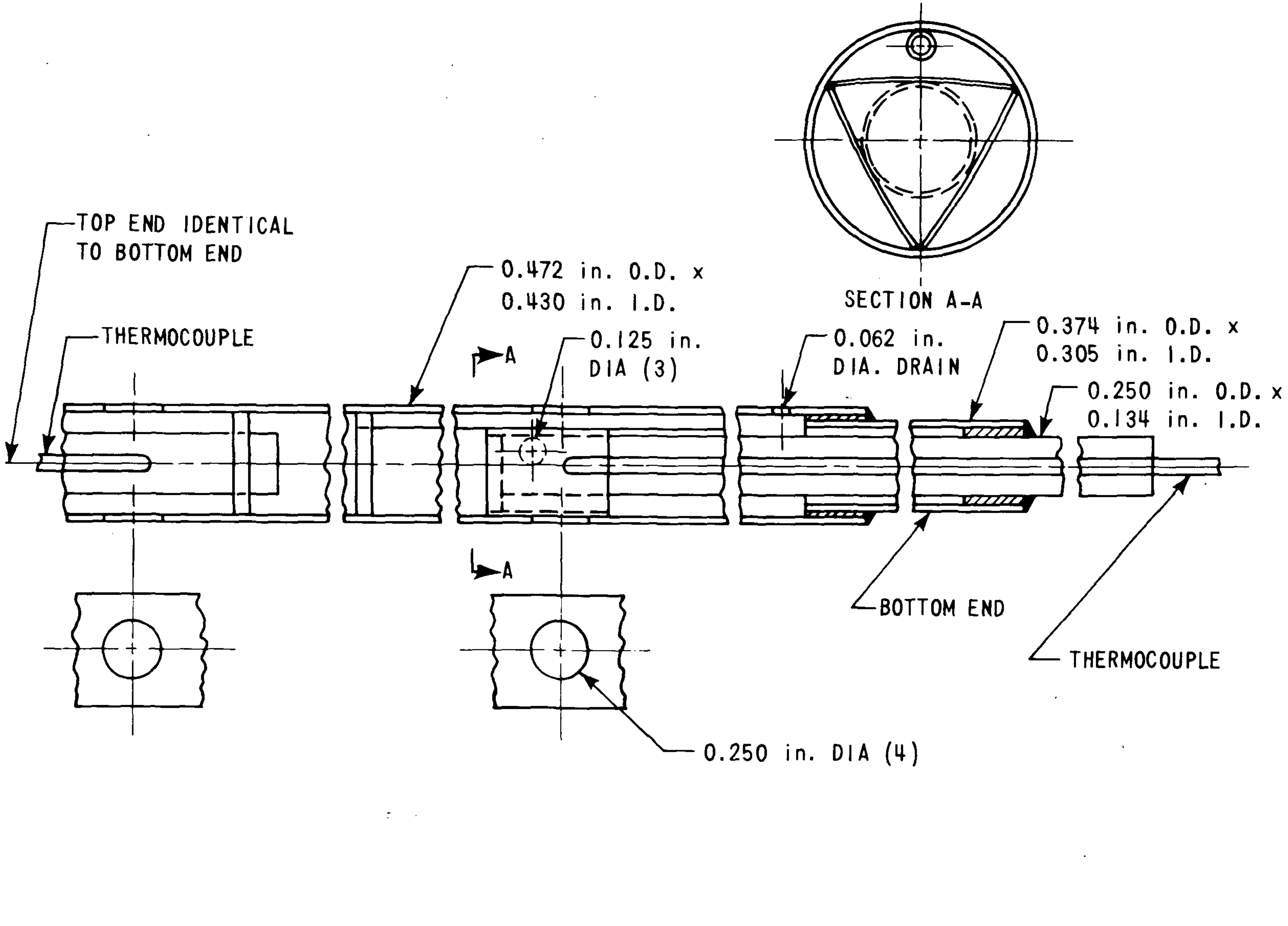


Figure 5-16. Steam Probe Schematic

scheme has been designed whereby the 22 steam probes will be divided into six groups (see appendix C). Each group will have one steam probe at the upper elevation in that given group (refer to figure 5-15) connected to a strip chart recorder. Once the steam probe wets, the whole group will be valved out of the system and no more flow will pass through the quenched steam probe piping. This manifolding scheme, combined with a smaller sampling tube diameter will reduce the total flow out of the bundle to a steam probe ice bath and permit greater vapor temperature measurement capability without sacrificing detailed time-dependent mass balance computations.

Figure 5-15 illustrates the radial and axial distribution of steam probes for the bundle. Eleven of sixteen thimbles have been instrumented with two steam probes per thimble. The steam probes at 0.99 m (3 ft, 3 in.) 1.22 m (4 ft), and 1.52 m (5 ft) are placed in the center of the bundle without redundancy. They will be particularly important in measuring the development of vapor superheat even though the fraction of total test time during which they operate may be small.

Steam probe redundancy begins at 1.70 m (5 ft, 7 in.) elevation and continues through 3.05 m (10 ft). Each of these elevations, with the exception of 1.83 m (6 ft), is instrumented with two steam probes located symmetrically about but staggered along the bundle centerline. It is hoped that little difference will be found in vapor temperature measurement across the bundle centerline and that redundant steam probes may be disconnected thus enabling additional rod thermocouple data to be obtained.

The 1.83 m (6 ft) elevation has been instrumented with a total of four steam probes; one located on the centerline and two others located symmetrically about the first will be connected to the computer. The spare steam probe location near the wall bundle will also be a 1.83 m (6 ft) steam probe. These steam probes will allow evaluation of steam temperature uniformity across the bundle. Only one steam probe has been allocated to each of 3.35 m (11 ft) and 3.50 m (11 ft, 6 in.) elevations. These elevations will quench relatively rapidly from the top and, like the lower elevations, will be of little use later in the test. One final steam probe has been placed in the elbow of the exhaust line leading from the upper plenum. This instrumentation is designed to measure vapor nonequilibrium at the test section exit. The design is shown in figure 5-17.

Thirteen differential pressure cells recording friction, acceleration, and elevation head pressure drops are connected from the bottom to the top of the bundle (refer to figures 5-4, 5-12, and 5-13). Twelve cells spaced over 0.30 m (1 ft) increments are designed to give detailed differential pressure measurements within the heated length of the bundle. An additional cell measures the overall pressure drop from the bottom to the top of the heated length.

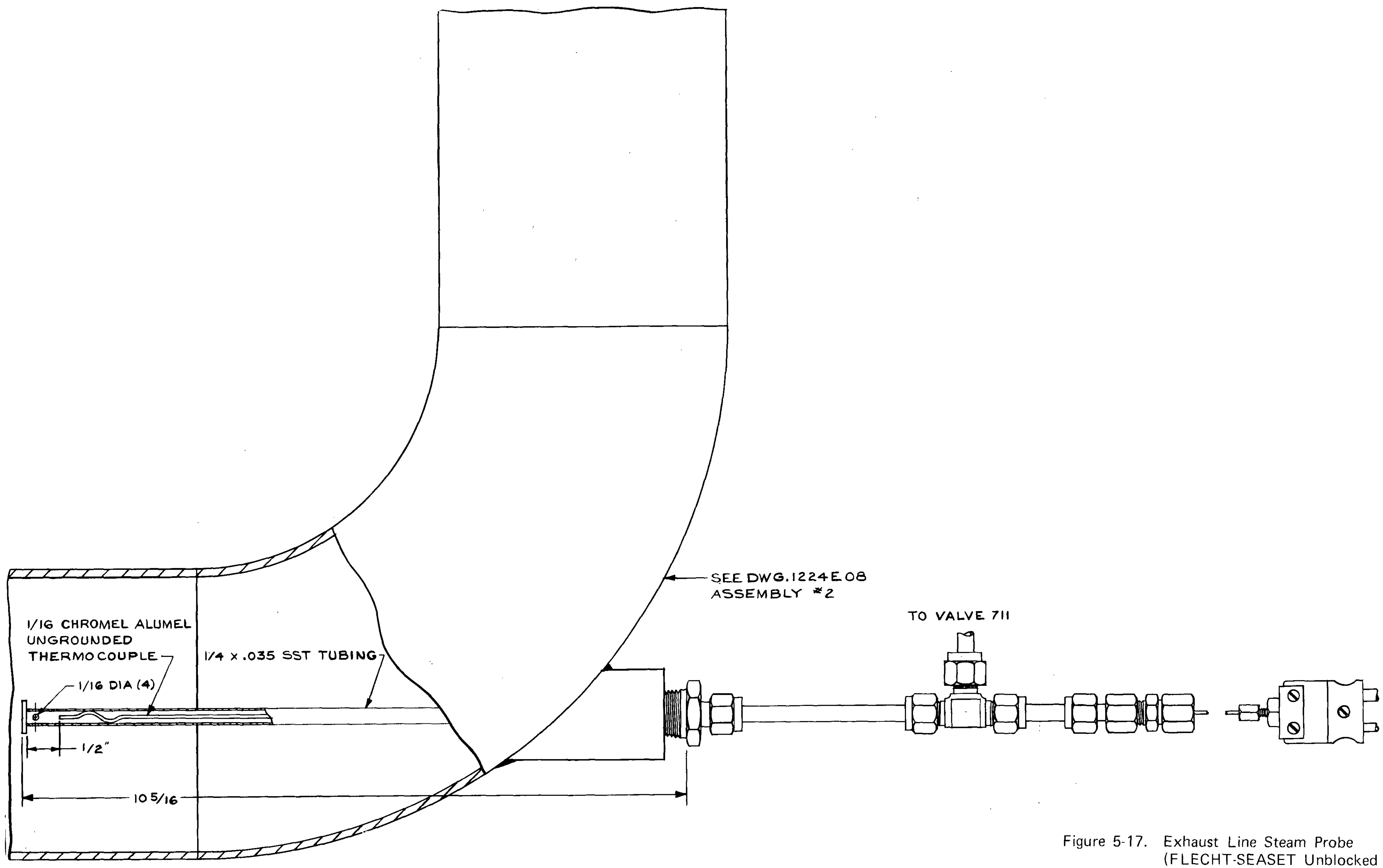


Figure 5-17. Exhaust Line Steam Probe (FLECHT-SEASET Unblocked Bundle)

5-22. Power Measurements – Six instrumentation channels are devoted to measurement of power into the bundle. Three are used as a primary measurement from which power is controlled by the computer software. Three independent power measurements will be used for data reduction purposes.

5-23. Upper Plenum

The upper plenum (refer to figure 5-18) is an important component of the FLECHT loop. System pressure is controlled from a transducer located in the upper plenum for constant flooding rate tests. Another transducer is connected to the computer for system pressure data acquisition. A differential pressure cell connected between the top and bottom of the upper plenum is used to measure liquid accumulation within this component. Liquid will collect at the bottom of the upper plenum before draining into the carryover tank. In addition, windows are being incorporated which will allow visual examination of the separation phenomenon (figure 5-18).

Three upper plenum thermocouples are designed to measure the fluid temperature above the top of heated length, at upper plenum exit, and in the upper plenum extension. These thermocouples should indicate the location and presence of liquid in the upper plenum and housing extension.

5-24. Lower Plenum

The only instrumentation found in the lower plenum (figure 5-18) is a fluid thermocouple which will be used to measure inlet subcooling as water floods the bundle.

5-25. Housing

Housing wall temperatures were recorded by the computer in skewed testing programs. These data were used by FLEMB (appendix E) to compute housing heat release as part of the overall mass and energy balance analysis. While the low mass housing heat release accounts for roughly 25 percent at the beginning of reflood (heat flow from bundle to housing), the percentage decreases rapidly with time to less than 1 percent. If integrated over time, the effect of housing heat release is negligible compared with bundle heat release. Therefore, the low mass housing wall thermocouples were moved from the computer (FLECHT skewed Low Flooding Rate (LFR) testing program) to the FLUKE (FLECHT-SEASET 17 x 17 unblocked) to free additional channels for heater rod thermocouples and steam probes. Therefore, housing heat release will not be computed in FLEMB for 17 x 17 tests.

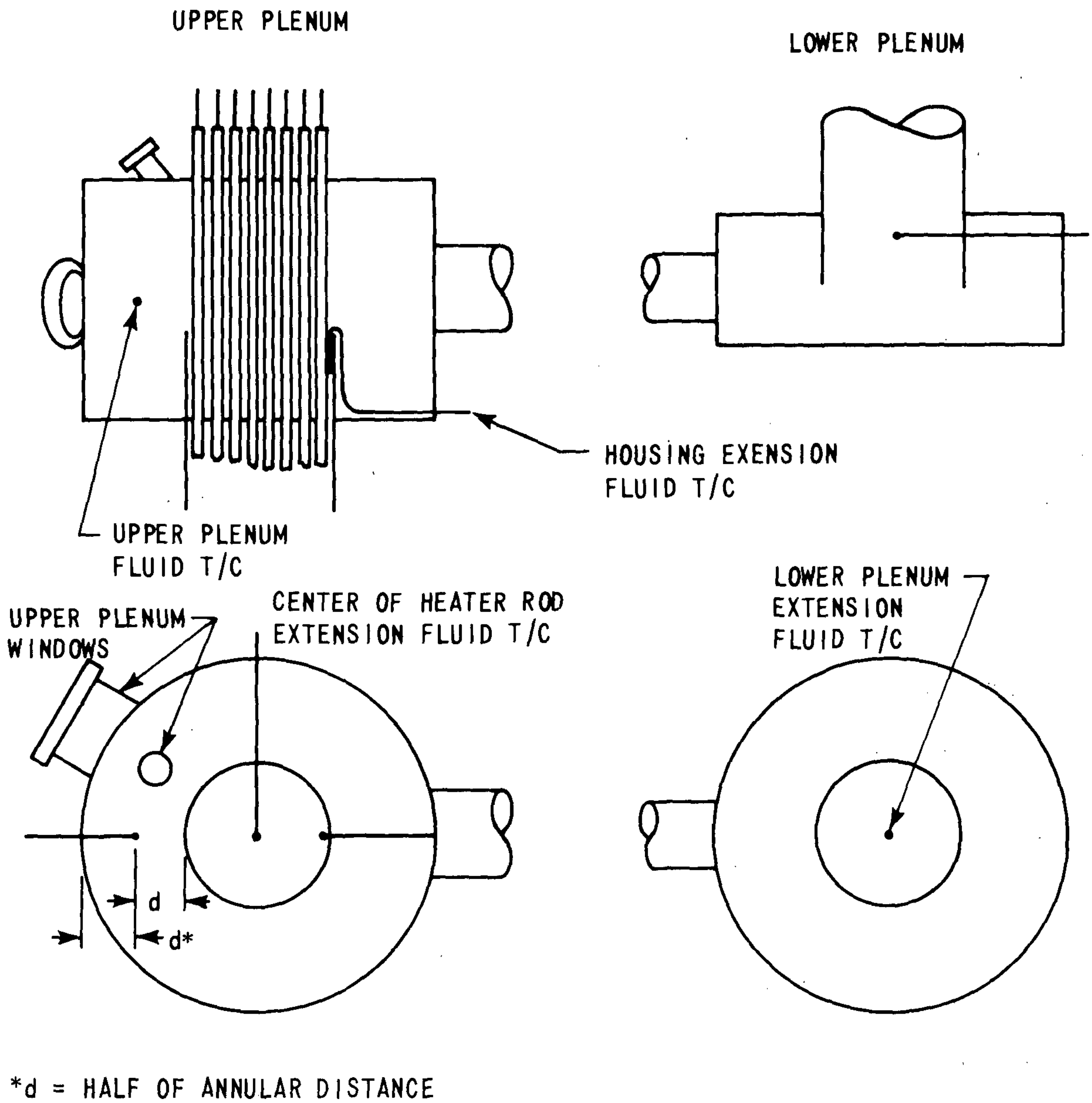


Figure 5-18. Upper and Lower Plenum Thermocouple Location (Unblocked Bundle Task 3.2.1)

The FLECHT housing has been equipped with three pairs of windows located at 0.91 m (3 ft), 1.83 m (6 ft) and 2.74 m (9 ft) (figures 5-4 and 5-14). These windows are used to make visual observations and motion pictures of two-phase flow regimes and quench-front progression. Good visibility through the quartz windows is a prerequisite for quality movies. In previous FLECHT tests, a liquid film formed on the inside of the glass which obstructed the viewing area. Therefore, heaters will be placed on the outside of the window housing and the window temperature will be monitored by connection to the FLUKE. The heaters will raise the inner surface of the quartz to approximately 260°C (500°F) prior to initiation of test. At this point, the heaters will be turned off. The windows are expected to maintain their temperature due to heat input from rods. In previous testing programs, the window thermocouples were connected to the computer. Again, connection of this instrumentation (which was not used in data analysis) to the FLUKE frees computer channels for heater rod and steam probe instrumentation.

5-26. Loop Instrumentation

Twenty-three computer channels have been allocated to collection of temperature and flow data throughout the loop exclusive of instrumentation found between the upper and lower plenums, bundle, and housing. (figures 5-12 and 5-13). The five loop fluid thermocouples are placed in the carryover tank, steam separator drain tank, exhaust orifice, and the accumulator injection line. Each is designed to measure either collected or injected liquid temperature. Five wall thermocouples to be monitored on the computer have been placed in the carryover drain tank, steam separator, steam separator drain tank, pipe between exhaust orifice and steam separator, and test section outlet. This instrumentation is needed to control the heatup period. At the initiation of the test, component wall temperatures are specified at T_{SAT} + 11.1°C (T_{SAT} + 20°F). Furthermore, this instrumentation is also used to estimate the heat release from the working fluid to the loop components during the test.

The four storage tanks – accumulator, carryover tank, steam separator, and steam separator drain tank – are all instrumented with differential pressure cells designed to measure either liquid injection in the case of the accumulator or separated liquid deposited in the collection tanks. A total of four computer channels, one per tank, are used to record the separated liquid.

Dry steam flow rate is measured downstream of the separator using an orifice meter. Flow rates can be calculated from a differential pressure cell connected to the orifice meter in conjunction with fluid temperature and static pressure measurements.

Gravity reflooding tests require several changes in loop instrumentation (figure 5-13). First, the large steam separator tank is used to simulate the containment. Since the pressure control is referred to containment, the sensor must be moved from the upper plenum to the separator. Gravity reflooding tests also require the use of a downcomer attached to the lower plenum. Therefore, one computer channel must be allocated to a downcomer differential pressure cell to properly account for mass within the system and another to measure the downcomer fluid temperatures. A bidirectional turboprobe in the crossover pipe will measure both forward and reverse flow to the lower plenum. The upper plenum and top of downcomer pressures are obtained from differential pressure cells connected from these components to the containment tank. A static pressure cell connected to the exhaust orifice in conjunction with a fluid thermocouple and differential pressure cell are used to calculate the steam density and hence, mass flow rate of steam passing through the orifice. This measurement is needed for mass balance calculations.

Injected flow into the lower plenum is measured by several different types of flow meters as described in paragraph 5-8. A turbine meter is used for primary injected fluid flow measurement. Three rotameters having different flow ranges provide redundancy for the turbine meter measurements. Together, these instruments require 4 computer channels. An additional bidirectional turboprobe located in the crossover leg will be used to measure both forward and reverse flow into and out of the test section during gravity reflooding experiments.

5-27. DATA VALIDATION CRITERIA AND PROCEDURES

The data validation process is initiated when all instrumentation is checked for proper operation prior to the actual running of a test. A reading from each channel is recorded and compared to the expected value for that channel. In this manner, an abnormal reading will indicate a problem in that channel and corrective actions will be taken before the actual test is run. This channel verification procedure will increase the probability that all instrumentation will work properly once a test is underway.

If some instrumentation fails just prior to or during a test but the remaining instrumentation is sufficient to calculate overall mass balances, void fraction in the test section, some heat transfer coefficients, fluid temperatures and carryout fraction; then the run may still be considered valid. If the instrumentation is not sufficient for these calculations, the run is considered invalid and will be repeated. When more than 50 percent of the rod bundle and/or fluid thermocouples fail, serious consideration will be given to discontinuing testing and repairing or replacing the affected channels. In any event, an attempt will be made to repair any failure before another test is performed.

The following requirements are the criteria used to determine if sufficient instrumentation exists for conducting a valid test. Refer to paragraph 5-17 for details on the complete instrumentation layout for the test facility.

- For each of the five radial power distributions planned for the unblocked test series, the number of heater rod thermocouples required to be functioning properly for a valid test at each elevation is specified in table 5-3.

- For flooding rates above 38.1 mm/s (1.5 in./sec), the upper plenum differential pressure cell is required to be functioning properly for a valid test. Of the twelve bundle differential pressure cells no more than one can fail for the test to be valid.

- Five thimble wall thermocouples have been selected at the 1.83, 2.13, 2.44, 2.74, and 3.05 m (6, 7, 8, 9 and 10 ft) elevations as being required functional for a valid test.

- Of the test section steam probes, five have been selected at the 1.83, 2.13, 2.44, 2.74, and 3.05 m (6, 7, 8, 9 and 10 ft) elevations along with the exit steam probe as being required functional for a valid test.

- The upper plenum pressure transducer is required to be functioning properly for all tests except for the Gravity Reflood Tests. The steam separator pressure transducer is required to be functional for Gravity Reflood Tests.

- For a valid test, one lower plenum and one upper plenum fluid thermocouple are also required.

- It is required, for the test section bundle power supply, that the three independent power meters be functioning properly for a valid test. Also, these power measurements must be within the accuracy range specified for a test.

- Four loop fluid thermocouples required for a valid test are as follows:

  (1) Carryover tank 0.305 m (1 ft) elevation

  (2) Steam separator drain tank 76 mm (3 in.) elevation

  (3) Exhaust orifice

  (4) Accumulator fluid thermocouple 0.184 m (7.25 in.) elevation

- Four additional loop wall thermocouples required for a valid test are as follows:

  (1) Upper plenum

  (2) Carryover tank – 0.305 m (1 ft) elevation

  (3) Steam separator drain tank – 76 mm (3 in.) elevation

  (4) Test section hot leg

- The injection line turbine meter must be functioning properly for a valid test.

- Three liquid level measurements required for a valid test are as follows:

  (1) Carryover tank

  (2) Steam separator

  (3) Accumulator

- At the exhaust orifice, both the orifice differential pressure measurement and the static pressure measurement upstream of the orifice are required.

- For the gravity reflood tests the additional instrumentation required to be functioning are as follows:

  (1) Downcomer level differential pressure cell

  (2) Bidirectional turboprobe

  (3) High flow range injection line turbine meter

  (4) Steam separator pressure transducer

  (5) Upper plenum-to-steam separator differential pressure cell

  (6) Downcomer-to-steam separator differential pressure cell.

A Run Specification and Validation Sheet will be completed (refer to appendix D). This table specifies the initial test conditions and the validation requirements for each FLECHT-SEASET, 17 x 17 Unblocked Bundle test. It also provides space for comments on run conditions, causes for terminating and invalidating a run, instrumentation failures, preliminary selected thermocouple data, and drained water weights from collection tanks and the test section.

Once the instrumentation checks out satisfactorily and the test is run, the data for each channel are scrutinized to see if the system behaved as expected. Abnormal behavior of a

TABLE 5-3
OPERABLE HEATER ROD THERMOCOUPLES REQUIRED FOR DATA VALIDATION (UNBLOCKED BUNDLE TASK 3.2.1)

Radial Power Distribution	Radial Power Zone	Number of Operable Thermocouples Required at Each Elevation	Elevations m (ft-in.)
Uniform Tests (figure 6-2)	A – Hot Zone	2	0.305, 0.991, 1.22, 1.52, 1.70, 1.83, 1.98, 2.13, 2.44, 2.82, 3.05, 3.35, 3.51 (1, 3-3, 4,5, 5-7, 6, 6-6, 7, 8, 9-3, 10, 11, 11-6)
	B and C – Cold Zone	2	1.22, 1.52, 1.70, 1.83, 1.98 2.13, 2.44, 2.82, 3.05 (4, 5, 5-7, 6, 6-6, 7, 8, 9-3, 10)
Simulated FLECHT Radial Power Distribution for a 15 x 15 Hot Assembly (figure 6-4)	1.1	1	0.305, 0.991, 1.52, 1.70, 1.83, 1.98, 2.13, 2.44, 2.82, 3.05, 3.35, 3.51 (1, 3-3, 5, 5-7, 6, 6-6, 7, 8, 9-3, 10, 11, 11-6)
	1.0	2	1.22, 1.83, 2.44, 3.05, 3.35 (4, 6, 8, 10, 11)
	0.95	1	1.22, 1.83, 2.44, 3.05 (4, 6, 8, 10)

TABLE 5-3 (cont)

OPERABLE HEATER ROD THERMOCOUPLES REQUIRED FOR DATA VALIDATION (UNBLOCKED BUNDLE TASK 3.2.1)

Radial Power Distribution	Radial Power Zone	Number of Operable Thermocouples Required at Each Elevation	Elevations m (ft-in.)
Simulated Radial Power Distribution for a 17 x 17 Hot Assembly (figure 6-3)	1.05	1	0.305, 0.991, 1.52, 1.70, 1.83 1.98, 2.13, 2.44, 2.82, 3.05, 3.35, 3.51 (1, 3-3, 5, 5-7, 6, 6-6, 7, 8, 9-3, 10, 11, 11-6)
	1.0	2	1.22, 1.83, 2.44, 3.05, 3.35 (4, 6, 8, 10, 11)
	0.95	1	1.22, 1.83, 2.44, 3.05 (4, 6, 8, 10)
Hot/Cold Channels (figure 6-2)	A – Hot Zone	2	0.305, 0.991, 1.22, 1.52, 1.70, 1.83, 1.98, 2.13, 2.43, 2.82, 3.05, 3.35, 3.51 (1, 3-3, 4, 5, 5-7, 6, 6-6, 7, 8, 9-3, 10, 11, 11-6)
	B and C – Cold Zone	2	1.22, 1.52, 1.70, 1.83, 1.98, 2.13, 2.43, 2.82, 3.05 (4, 5, 5-7, 6, 6-6, 7, 8, 9-3, 10)
Half Bundle Hot, Half Bundle Cold (figure 6-5)	B and C – Hot Zone	1	0.305, 0.610, 0.991, 3.51 (1, 2, 3-3, 11-6)
		3	1.22, 1.52, 1.70, 1.83, 1.98, 2.13, 2.44, 2.82, 3.05, 3.35 (4, 5, 5-7, 6, 6-6, 7, 8, 9-3, 10, 11)
	A – Cold Zone	1	0.305, 0.610, 0.991, 3.51 (1, 2, 3-3, 11-6)
		2	1.22, 1.52, 1.70, 1.83, 1.98, 2.13, 2.44, 2.82, 3.05, 3.35 (4, 5, 5-7, 6, 6-6, 7, 8, 9-3, 10, 11

data channel is investigated to determine if it is due to equipment malfunction or a physical phenomena. These procedures along with periodic equipment calibrations are designed to assure that the data recorded are accurate and reliable.

Another aspect of data validation is considered once the instrumentation reliability is determined. The actual test conditions are compared to the parameters specified by the test matrix to see if the run satisfies the test matrix. The facility conditions before initiation of reflood will be compared to the expected values for such parameters as bundle power, system pressure, average vessel wall temperature, and hottest thermocouple at the start of reflood. The injection flow is checked against what is specified and the system pressure is reviewed to see if the system pressure control worked properly.

After the instrumentation is functionally checked and the test parameters and performance compared with the test matrix, the final validation is performed during data analysis. In the process of analysis, a system mass and energy balance will be computed. These calculations determine if the data are within specified accuracy and whether the instrumentation is adequate for analyzing what has happened in the system.

SECTION 6
TEST MATRIX

6-1. INTRODUCTION

Paragraphs 6-2 through 6-23 of this section describe the bench tests, single-phase, forced reflood and gravity reflood shakedown tests required to insure that the FLECHT-SEASET unblocked loop would operate properly and perform tests specified in the test matrix. The test matrix, which is explained in paragraphs 6-24 through 6-41, is designed to meet the task objectives and fulfill the data requirements discussed in sections 2 and 3.

6-2. SHAKEDOWN TEST MATRIX

Prior to conducting the reflood tests outlined in paragraphs 6-24 through 6-41, a series of shakedown tests will be run on the test facility. These shakedown tests will be conducted not only on separate facility components (bench tests) prior to final assembly but also on the completely assembled test facility.

The purpose of the shakedown tests is to insure that the instrumentation, control, and data acquisition systems are working properly so that useful and valid data can be obtained during the reflood experiments. Some of the shakedown tests are also intended to verify and adjust control procedures. A brief summary of each shakedown test follows. A more detailed discussion is presented in appendix B.

6-3. Bench Tests

The following list of tests outline the portion of the shakedown test matrix that will be conducted on various facility components prior to final assembly of the test facility.

6-4. **Housing Window Heatup Check** – This test is intended to verify and adjust heatup control procedures for the housing windows. Heating of the windows will minimize steam condensation on the windows because of early quenching of the quartz lens.

6-5. **Thermocouple Wiring Connection Checks** – The purpose of this test is to check the continuity of each thermocouple wiring connection from the patch board to the computer. If any deviation is observed, the circuit will be checked, repaired and retested.

6-6. Forced Reflood Configuration Test Facility Shakedown Testing

The following list of tests outlines another portion of the shakedown test matrix. This section will be involved with those shakedown tests conducted on the completely assembled test facility in the forced reflood configuration.

6-7. Heater Rod Power Connection Check — This test is intended to check the continuity of each heater rod power connection at the fuse panel. If any abnormal reading is observed, the circuit will be checked, repaired, and retested.

6-8. Instrumented Heater Rod Radial Location and Corresponding Thermocouple Checks — This test will be performed only on rods whose thermocouples are connected to the computer and is intended to check the following items:

- For each instrumented heater rod, all corresponding thermocouples are checked for appropriate computer channel hookup and proper recording of data.
- In completing the above check, radial power connections between the fuse panel and the appropriate heater rod are confirmed.
- The output polarity of each thermocouple at the computer will also be checked.

6-9. Heater Rod, Thimble and Steam Probe Thermocouple Axial Location Checks — This test will be performed using only instrumented heater rods and is intended to check the following items:

- For each bundle thermocouple elevation all corresponding heater rod, thimble and steam probe thermocouples are checked for appropriate computer channel axial hookup and proper recording of data.
- In completing the above check each heater rod, thimble and steam probe thermocouple elevation is confirmed.

6-10. Test Section Differential Pressure Cell Axial Locations, Steam Separator Collection Tank and Carryover Tank Volume and Level Transmitter Checks — This test is intended to check the following items:

- Test section differential pressure cells are checked for appropriate computer channel axial hookup.
- Test section control volumes will be established in one foot increments.
- The lower plenum volume will be checked.

- The steam separator collection tank and the carryover tank volumes will be determined.

- The steam separator collection tank and the carryover tank level transmitters along with the test section differential pressure cells will be checked for proper operation.

6-11. Pressure Control Valve Operation, Exhaust Orifice Plate Flow Check and Differential Pressure Cell Zero Shifts — The following checks will be conducted during this test:

- The test section, tanks, and orifice differential pressure cells zero readings and zero shifts will be checked.

- The response of the pressure control valve to sudden changes in flow will also be checked.

6-12. Rotameters and Turbine Flowmeter Calibration, and Flow Control Valve Operation Checks — This test is intended to check the following items:

- A spot check of rotameters and turbine meter calibration for agreement with the "full flow range" calibrations performed prior to the shakedown tests will be conducted.

- The flowmeters will be checked for appropriate computer channel hookup.

- Flow control valve response to a continuously variable flooding signal will also be checked.

6-13. Carryover Tank, Steam Separator Tank, and Connecting Piping Heatup Checks — This test is intended to evaluate the pretest heatup of the test facility's tanks and connecting piping. The heatup of this portion of the test facility is achieved initially by powering strip heaters attached to the external surfaces and then by circulating slightly superheated steam through the facility. Loop thermocouple temperatures will be reviewed to determine termperature uniformity of the tanks and piping walls both before and after the steam is injected. The time needed for heating the facility components to the required temperatures will also be determined from this test.

6-14. Motion Picture Check — Four motion picture cameras will be available for use in the test program. One camera can accommodate a 365.8 m (1200 ft) reel of film and the other three new high-speed cameras can accommodate 30.5 m (100 ft) reels. This test is intended to examine the operation of one of the new high speed cameras and will be run in conjunction with the following low power and low temperature shakedown test. From this test it will be determined how much time is needed to reload these cameras for further filming and the quality of the movies will be reviewed for any changes needed in filming techniques.

6-15. Low Power and Low Temperature Test, Forced Reflood Configuration – This shakedown test is intended as a trial run for the complete test facility in the forced reflood configuration. The test will be conducted according to normal procedures (paragraph 5-16), with care taken to meet all requirements for a valid run (paragraph 5-27). Test conditions are the same for Test Matrix No. 21, a nominal 0.28 MPa (40 psia) run having low power and low initial clad temperature.

6-16. *Test Facility Special Single-Phase Testing*

The shakedown tests outlined in the following paragraphs will employ only single-phase steam flow through the facility in the forced reflood configuration.

6-17. Steam Cooling Shakedown Test – This unpowered shakedown test will be used to examine and adjust control procedures in preparation for the steam cooling tests described in paragraph 6-37. The following items are specific goals of this steam cooling shakedown test:

- Pressure control valve response to the initial steam injection into the lower plenum at about 0.31 MPa (45 psia) pressure will be observed.
- The value of the lower plenum pressure will be determined in order to achieve a 0.28 MPa (40 psia) upper plenum setpoint pressure when steady flow conditions are established.
- The magnitude of pressure oscillations will be studied to determine how well automatic controls can maintain a 0.28 MPa (40 psia) static pressure in the upper plenum with the high steam flow velocity.
- After the test is completed any control adjustments needed to improve the results will be determined.

6-18. Steam Probe Operation Checks – Two steam probe operation tests, one at 0.28 MPa (40 psia) and the other at 0.14 MPa (20 psia) upper plenum pressure, will be outlined in this paragraph. These shakedown tests will be run in conjunction with the steam cooling shakedown test (paragraph 6-17) in order to utilize the modified facility layout. The 23 steam probes located in the test vessel are grouped by elevation into six manifold systems. Each manifold outlet empties into a separate ice-packed collection tank at atmospheric pressure. These tests will be unpowered and are intended to determine the following items:

- The amount of steam flow through each of the six manifolds.
- A reasonable response to changing flow conditions from all steam probe thermocouples.
- Operating procedure check for steam probe valving, manifolding, and condensate measurement.

- Operating pressures throughout the test vessel for steady-state flow conditions will be measured in order to determine the steam probe to atmosphere pressure differential.
- Differences in system response between the 0.28 MPa (40 psia) and 0.14 MPa (20 psia) shakedown tests.

6-19. Additional Shakedown Tests for Gravity Reflood Testing

Gravity reflood modifications and testing will be scheduled after completion of the forced reflood testing. The following list of shakedown tests will be conducted on the completely assembled facility after it has been modified for the gravity reflood configuration (paragraph 5-1).

6-20. High Range Turbine Flowmeter Flow Checks — With the facility modified for the gravity reflood testing, this shakedown test is intended to check the following items:

- The flowmeters will be checked for appropriate computer channel hookup.
- A spot check of the new high range 9.5 x 10^{-5} m^3/s to 9.5 x 10^{-3} m^3/s (1.5 to 150 gpm) turbine meter calibration will be made for agreement with the "full flow range" calibrations that will be conducted prior to the shakedown tests.

6-21. Bidirectional Turboprobe Flow Checks — With the facility in the gravity reflood configuration, this shakedown test is intended to be a functional check of the bidirectional turboprobe calibration for agreement with its "full flow range" calibrations. This test will be conducted in two phases; the first with the turboprobe oriented in its forward direction and the second with the turboprobe turned 3.14 rad (180°) to check the reverse flow measurements of the instrument. This test will also review the turboprobe instrumentation for appropriate computer channel hookup.

6-22. Quick Drain Tests — This series of shakedown tests will be used to examine and adjust control procedures in preparation for the Series No. 11 tests described in paragraph 6-36. Two sets of tests will be conducted in this series; the first with an unpowered "cold" bundle and the second with a powered "hot" bundle. In these shakedown tests the bundle will be initially flooded to the 0.914 m (3 ft) elevation in order to simulate a partially quenched rod bundle at the beginning of reflood. The intended results of these tests will be as follows:

- The length of time required to drain the partially flooded bundle to the bottom of the heated length will be measured.

- After the water has been drained to the bottom of the heated length, the effect of partially quenched rods on the axial temperature profile in the bundle will be evaluated for the powered shakedown tests.

- The specified 0.914 m (3 ft) prefill elevation will be evaluated as to suitability.

- After the tests are completed, it may be necessary to make control adjustments to improve the results.

6-23. **Low Power and Low Temperature Test, Gravity Reflood Configuration** — This shakedown test is intended as a trial run for the complete test facility in the gravity reflood configuration. The test will be conducted according to normal procedures (paragraph 5-16) and will strive to meet all requirements for a valid run (paragraph 5-27). Test conditions are the same as for Test Matrix No. 36, a nominal 0.28 MPa (40 psia) run having low power and low initial clad temperature.

6-24. TEST MATRIX

A test matrix was designed to satisfy the objectives in this task (section 2) and is presented in tables 6-1 and 6-2.[1] In the selection of the initial conditions for these tests, as indicated previously in section 4, input from other PWR nuclear reactor and fuel vendors were considered.

The test parameters are centered on two containment pressures representing the range applicable to PWR plants as shown in figure 6-1. Within these containment pressures, initial clad temperature, peak power, flooding rate (or injection rates for gravity reflood tests), inlet subcooling, and radial power distribution are varied to determine reflood behavior (maximum clad temperature, turnaround time, quench time, mass effluent, and the like) and heat transfer capability on a comparable basis with previous FLECHT rod geometries. This test matrix has similar parameter effects as those in the previous FLECHT cosine power tests.

6-25. Test Series

The test matrix is divided into the following series presented in paragraphs 6-26 through 6-40.

6-26. **Constant Flooding Rate** — Data from these tests will be used to examine the effects of decreasing flooding rates on heat transfer and entrainment. These tests will be used as a base for comparisons with other test series and to study effects of various flooding rates at reference conditions such as pressure, rod initial clad temperature, rod peak power, and inlet

1. Table 6-1 presents the test matrix information in SI units. Table 6-2 presents the same test matrix information but in English units.

TABLE 6-1

FLECHT-SEASET – TASK 3.2.1 – 17 x 17 UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD MATRIX[a]

Test Matrix No.	U.P. Pressure (MPa)	Rod Initial T_{clad} (°C)	Rod Peak Power (kW/m)	Flooding Rate (mm/s)	Inlet Subcooling (°C)	Radial Power Distribution	Movies/ Pictures	Parameter	Comments
1	0.276	871	2.3	152	78	Uniform	X	Series No. 1 Constant Flooding Rate	Radial Power Distribution (figure 6-2)[b]
2	0.276	871	2.3	76.2	78	Uniform			
3	0.276	871	2.3	38.1	78	Uniform			Overlap Test – Low Flooding Rate Cosine Run No. 03113
4	0.276	871	2.3	25.4	78	Uniform	X		
5	0.276	871	2.3	20.3	78	Uniform			Overlap Test – Low Flooding Rate Cosine Run No. 02414
6	0.276	871	1.31	15.2	78	Uniform			
7	0.276	871	1.31	10.1	78	Uniform	X		
8	0.138	871	2.3	76.2	78	Uniform		Series No. 2 Pressure	
9	0.138	871	2.3	25.4	78	Uniform			
10	0.138	871	1.31	20.3	78	Uniform			
11	0.138	871	1.31	15.2	78	Uniform	X		
12	0.138	871	1.31	10.1	78	Uniform	X		
13	0.414	871	2.3	25.4	78	Uniform			
14	0.276	871	2.30	25.4	3	Uniform	X	Series No. 3 ΔT Subcooling	
15	0.138	871	2.30	25.4	3	Uniform			
16	0.276	538	2.30	38.1	78	Uniform		Series No. 4 Low Initial T_{clad}	
17	0.276	260	2.30	38.1	78	Uniform			
18	0.138	260	2.30	38.1	78	Uniform			
19	0.276	871	1.31	38.1	78	Uniform		Series No. 5 Rod Peak Power	
20	0.138	871	1.31	25.4	78	Uniform			
21	0.276	260	1.31	38.1	78	Uniform			
22	0.276	871	3.12	38.1	78	Uniform	X		
23	0.276	649	2.62	38.1	56	Uniform			

a. SI units

b. Refer to figure 6-2 for all tests with uniform radial power distribution.

TABLE 6-1 (cont)

FLECHT-SEASET – TASK 3.2.1 – 17 x 17 UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD MATRIX[a]

Test Matrix No.	U.P. Pressure (MPa)	Rod Initial T_{clad} (°C)	Rod Peak Power (kW/m)	Flooding Rate (mm/s)	Inlet Subcooling (°C)	Radial Power Distribution	Movies/ Pictures	Parameter	Comments
24	0.276	871	2.30	25.4	78	FLECHT (15 x 15)	X	Series No. 6 Radial Power Distribution	Overlap Test Low Flooding Rate Cosine Run No. 05132 – Radial Power Distribution (figure 6-4)
25	0.276	871	2.30	25.4	78	FLECHT (17 x 17)	X		Radial Power Distribution (figure 6-3)
26	0.276	871	2.30	25.4	78	Uniform		Series No. 7 Repeat Test	
27	0.276	871	2.30	25.4	78	Uniform			
28	0.276	871		0-482.6-31.75 (5 sec) 31.75-12.70 (onward)	78	Uniform	X	Series No. 8 Variable Flooding Rate	Continuously Variable Flow – Dry Containment Plant (figure 6-6)
29	0.138	871	1.64	0-101.6-38.10 (5 sec) 38.10-12.70 (onward)	3	Uniform	X		Continuously Variable Flow – UHI Plant (figure 6-7)
30	0.276	871	2.30	38.10-10.16 (400 sec) 10.16 (onward)	78	Uniform			Continuously Variable Flow – Dry Containment Plant (figure 6-8)
31	0.276	871	2.30	152.40 (5 sec) 20.32 (onward)	78	Uniform			Variable Stepped Flow – Dry Containment Plant (figure 6-9)
32	0.138	871	2.30	152.40 (5 sec) 20.32 (onward)	78	Uniform			Variable Stepped Flow – Dry Containment Plant (figure 6-9)
33	0.138	871	2.30	152.40 (5 sec) 25.40 (200 sec) 15.24 (onward)	78	Uniform	X		Variable Stepped Flow – Dry Containment Plant (figure 6-10)
				Downcomer Injection Rate (kg/s)					
34	0.276	871	2.30	6.49 (14 sec) .77 (onward)	78	Uniform	X	Series No. 9 Simulated Gravity Reflood	
35	0.138	871	2.30	6.49 (14 sec) .77 (onward)	78	Uniform	X		
36	0.276	457	1.64	6.49 (14 sec) .77 (onward)	78	Uniform			
37	0.276	871/260	2.30/1.31	6.49 (14 sec) .77 (onward)	78	Hot and Cold Channels			Radial Power Distribution (figure 6-2)
38	0.138	871/260	2.30/1.31	6.49 (14 sec) .77 (onward)	78	Hot and Cold Channels			Radial Power Distribution (figure 6-2)

a. SI units

TABLE 6-1 (cont)

FLECHT-SEASET – TASK 3.2.1 – 17 x 17 UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD MATRIX[a]

Test Matrix No.	U.P. Pressure (MPa)	Rod Initial T_{clad} (°C)	Rod Peak Power (kW/m)	Flooding Rate (mm/s)	Inlet Subcooling (°C)	Radial Power Distribution	Movies/ Pictures	Parameter	Comments
39	0.276	871/260	2.30/1.31	38.10	78	Hot and Cold Channels		Series No. 10 Hot and Cold Channels	Radial Power Distribution (figure 6-2)
40	0.138	871/260	2.30/1.31	38.10	78	Hot and Cold Channels			Radial Power Distribution (figure 6-2)
41	0.276	871/260	2.30/1.31	38.10	78	Half Bundle			Radial Power Distribution (figure 6-5)
				Downcomer Injection Rate (kg/s)					
42	0.138	871	2.30	2.81 (25 sec) 0.79 (onward)	78	Uniform		Series No. 11 Axial Temperature Distribution Simulated Gravity Reflood	
43	0.138	(0 to 0.9m)– 149 (1.83m) – 871	2.30	2.81 (25 sec) 0.79 (onward) 2.81 (25 sec) 0.79 (onward)	78 78	Uniform Uniform			
				Injection Rate (kg/s)					
44	0.276	871	2.30	20.32 (steam) at 131°C	0	Uniform		Series No. 12 Steam Cooling	
45	0.138	871	2.30	20.32 (steam) at 109°C	0	Uniform			
46	0.269	846	2.46	152.40 (5 sec) 20.32 (onward)	75	FLECHT (15 x 15)		Series No. 13 Overlap Test	Overlap with Low Flooding Rate Cosine Run No. 04516 – Radial Power Distribution (figure 6-4)
47	0.138	844	2.46	25.40	77	FLECHT (15 x 15)			Overlap with Low Flooding Rate Cosine Run No. 04641 – Radial Power Distribution (figure 6-4)
48	0.276	732	1.87	25.40	67	Uniform		Series No. 14 – Comparison with Westinghouse Prop. Reflood Data	
49	0.138	732	1.51	25.40	67	Uniform			
50	0.276	871	2.30	25.40	78	Uniform		Series No. 15 Power Decay	Power Decay Based on 40 sec after initiation of LOCA

a. SI units

TABLE 6-2

FLECHT-SEASET – TASK 3.2.1 – 17 x 17 UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD TEST MATRIX[a]

Test Matrix No.	U.P. Pressure (psia)	Rod Initial T_{clad} (°F)	Rod Peak Power (kw/ft)	Flooding Rate (in./sec)	Inlet Subcooling (°F)	Radial Power Distribution	Movies/ Pictures	Parameter	Comments
1	40	1600	0.7	6.0	140	Uniform	X	Series No. 1 Constant Flooding Rate	Radial Power Distribution (figure 6-2)[b]
2	40	1600	0.7	3.0	140	Uniform			
3	40	1600	0.7	1.5	140	Uniform			Overlap Test – Low Flooding Rate Cosine Run No. 03113
4	40	1600	0.7	1.0	140	Uniform	X		
5	40	1600	0.7	0.8	140	Uniform			Overlap Test – Low Flooding Rate Cosine Run No. 02414
6	40	1600	0.4	0.6	140	Uniform			
7	40	1600	0.4	0.4	140	Uniform	X		
8	20	1600	0.7	3.0	140	Uniform		Series No. 2 Pressure	
9	20	1600	0.7	1.0	140	Uniform			
10	20	1600	0.4	0.8	140	Uniform			
11	20	1600	0.4	0.6	140	Uniform	X		
12	20	1600	0.4	0.4	140	Uniform	X		
13	60	1600	0.7	1.0	140	Uniform			
14	40	1600	0.7	1.0	5	Uniform	X	Series No. 3 Coolant Subcooling	
15	20	1600	0.7	1.0	5	Uniform			
16	40	1000	0.7	1.5	140	Uniform		Series No. 4 Low Initial T_{clad}	
17	40	500	0.7	1.5	140	Uniform			
18	20	500	0.7	1.5	140	Uniform			
19	40	1600	0.4	1.5	140	Uniform		Series No. 5 Rod Peak Power	
20	20	1600	0.4	1.0	140	Uniform			
21	40	500	0.4	1.5	140	Uniform			
22	40	1600	0.95	1.5	140	Uniform	X		
23	40	1200	0.8	1.5	100	Uniform			

a. English units

b. Refer to figure 6-2 for all tests with uniform radial power distribution.

TABLE 6-2 (cont)

FLECHT-SEASET – TASK 3.2.1 – 17 x 17 UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD TEST MATRIX[a]

Test Matrix No.	U.P. Pressure (psia)	Rod Initial T_{clad} (°F)	Rod Peak Power (kw/ft)	Flooding Rate (in./sec)	Inlet Subcooling (°F)	Radial Power Distribution	Movies/ Pictures	Parameter	Comments
24	40	1600	0.7	1.0	140	FLECHT (15 x 15)	X	Series No. 6 Radial Power Distribution	Overlap Test – Low Flooding Rate Cosine Run No. 05132 – Radial Power Distribution (figure 6-4)
25	40	1600	0.7	1.0	140	FLECHT (17 x 17)	X		Radial Power Distribution (figure 6-3)
26	40	1600	0.7	1.0	140	Uniform		Series No. 7 Repeat Test	
27	40	1600	0.7	1.0	140	Uniform			
28	40	1600	0.7	0-19-1.25 (5 sec) 1.25-0.5 (onward)	140	Uniform	X	Series No. 8 Variable Flooding Rate	Continuously Variable Flow – Dry Containment Plant (figure 6-6)
29	20	1600	0.5	0-4-1.5 (5 sec) 1.5-0.5 (onward)	5	Uniform	X		Continuously Variable Flow – UHI Plant (figure 6-7)
30	40	1600	0.7	1.5-0.4 (400 sec) 0.4 (onward)	140	Uniform			Continuously Variable Flow – Dry Containment Plant (figure 6-8)
31	40	1600	0.7	6 (5 sec) 0.8 (onward)	140	Uniform			Variable Stepped Flow – Dry Containment Plant (figure 6-9)
32	20	1600	0.7	6 (5 sec) 0.8 (onward)	140	Uniform			Variable Stepped Flow – Dry Containment Plant (figure 6-9)
33	20	1600	0.7	6 (5 sec) 1.0 (200 sec) 0.6 (onward)	140	Uniform	X		Variable Stepped Flow – Dry Containment Plant (figure 6-10)
				Downcomer Injection Rate (lbm/sec)					
34	40	1600	0.7	14.3 (14 sec) 1.7 (onward)	140	Uniform	X	Series No. 9 Simulated Gravity Reflood	
35	20	1600	0.7	14.3 (14 sec) 1.7 (onward)	140	Uniform	X		
36	40	855	0.5	14.3 (14 sec) 1.7 (onward)	140	Uniform			
37	40	1600/ 500	0.7/0.4	14.3 (14 sec) 1.7 (onward)	140	Hot and Cold Channels			Radial Power Distribution (figure 6-2)
38	20	1600/ 500	0.7/0.4	14.3 (14 sec) 1.7 (onward)	140	Hot and Cold Channels			Radial Power Distribution (figure 6-2)

a. English units

TABLE 6-2 (cont)

FLECHT-SEASET –TASK 3.2.1 – 17 x 17 UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD TEST MATRIX[a]

Test Matrix No.	U.P. Pressure (psia)	Rod Initial T_{clad} (°F)	Rod Peak Power (kw/ft)	Flooding Rate (in./sec)	Inlet Subcooling (°F)	Radial Power Distribution	Movies/ Pictures	Parameter	Comments
39	40	1600/ 500	0.7/0.4	1.5	140	Hot and Cold Channels		Series No. 10 Hot and Cold Channels	Radial Power Distribution (figure 6-2)
40	20	1600/ 500	0.7/0.4	1.5	140	Hot and Cold Channels			Radial Power Distribution (figure 6-2)
41	40	1600/ 500	0.7/0.4	1.5	140	Half Bundle			Radial Power Distribution (figure 6-5)
				Downcomer Injection Rate (lbm/sec)					
42	20	1600	0.7	6.2 (25 sec) 1.74 (onward)	140	Uniform		Series No. 11 Axial Temperature Distribution Simulated Gravity Reflood	
43	20	(0 to 3 ft) –300°F (6 ft) – 1600°F	0.7	6.2 (25 sec) 1.74 (onward)	140	Uniform			
				Injection Rate (lbm/sec)					
44	40	1600	0.7	0.81 (steam) at 267°F	0	Uniform		Series No. 12 Steam Cooling	
45	20	1600	0.7	0.82 (steam) at 228°F	0	Uniform			
46	39	1554	0.75	6 (5 sec) 0.8 (onward)	135	FLECHT (15 x 15)		Series No. 13 Overlap Test	Overlap with Low Flooding Cosine Run No. 04516 – Radial Power Distribution (figure 6-4)
47	20	1552	0.75	1.0	139	FLECHT (15 x 15)			Overlap with Low Flooding Rate Cosine Run No. 04641 – Radial Power Distribution (figure 6-4)
48	40	1350	0.57	1.0	120	Uniform		Series No. 14 – Comparison with Westinghouse Prop. Reflood Data	
49	20	1350	0.46	1.0	120	Uniform			
50	40	1600	0.7	1.0	140	Uniform		Series No. 15 Power Decay	Power Decay Based on 40 sec. after initiation of LOCA

a. English units

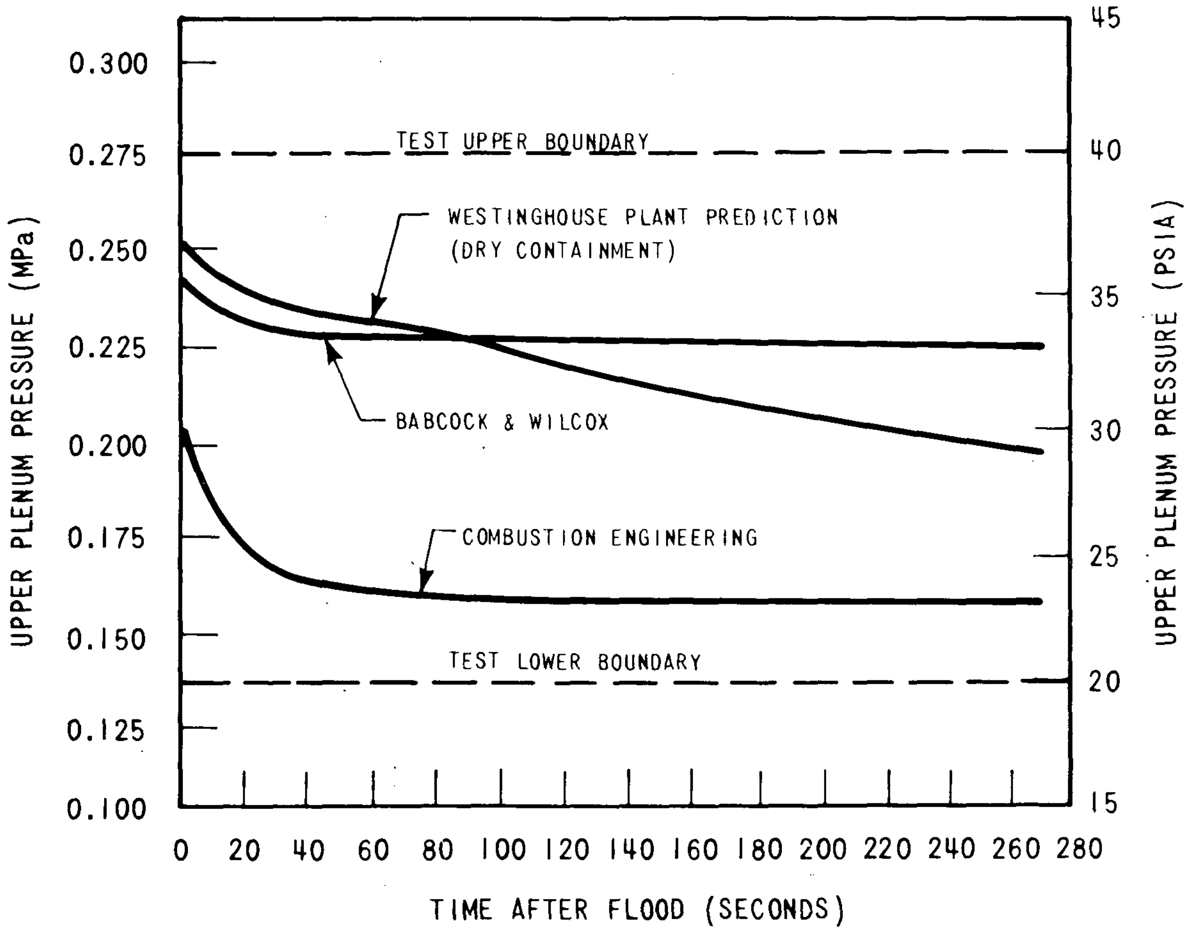


Figure 6-1. Test-Simulated Boundaries of Predicted Upper Plenum Pressures During Reflood

13.108-5

subcooling. However, for Test Number 6 and 7 the peak power was reduced to 1.31 kW/m (0.4 kw/ft) because predictions using Westinghouse proprietary analytical correlation showed that peak clad temperatures above 2250°F could be reached for the test bundle if the rod peak power were 2.30 kW/m (0.7 kw/ft). These elevated temperatures reduce the life of the rod bundle. More details on the temperature rise predictions are given in paragraph 6-41.

6-27. **Pressure Effects** – To study the parametric effect of pressure on heat transfer and entrainment at 0.138 MPa (20 psia) and 0.414 MPa (60 psia) at reference conditions by comparing Test Numbers 9 and 13 of this series with Test Number 4 of Series I. These data will also be used to determine the effect of decreasing flooding rates on heat transfer and entrainment at low pressures (Test Numbers 8 through 12).

6-28. **Coolant Subcooling Effects** – Data from these tests will be used to examine the effects of coolant subcooling at 0.138 MPa (20 psia) and 0.276 MPa (40 psia) by comparing results of Test Numbers 14 with 4, and 15 with 9. It would also be desirable to perform the test with the coolant at saturation temperature (no subcooling). However, this would cause cavitation across the injection line and flow meters thereby impeding proper flooding rate measurements and, consequently, mass balance calculations.

6-29. **Low Initial Clad Temperatures Effects** – These tests will provide a data base to study entrainment from cold channels with low initial stored energy at the beginning of reflood.

6-30. **Rod Peak Power Tests** – Data from these tests will be used to examine the effect of rod peak power on heat transfer and entrainment at high and low initial rod clad temperatures (Test Numbers 19-22). In addition, Test Number 23 accommodates the nominal evaluation model reflood conditions specified by B&W (appendix A).

6-31. **Radial Power Distribution** – These tests examine the effects of nonuniform radial power distribution on heat transfer and entrainment with a typical 17 x 17 hot assembly radial power profile (Test Number 25), and a simulated 15 x 15 assembly radial power profile (Test Number 24). Rationale for simulating the FLECHT radial power profiles is given below. Results from Test Number 24 will be compared directly with Run Number 05132 from the Low Flooding Rate Cosine Test Series[1] to determine the effects of different rod geometries, and provide basic data for developing a unified correlation or analytical model for these geometries.

1. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.

The need for five different radial power profiles has been identified in the 17 x 17 unblocked bundle. Connections to the three silicon controlled rectifiers (SCR) have been designed such that four wiring changes are necessary. Each radial power profile is described briefly below.

- **Uniform Radial Power Profile, Figure 6-2**

  This power profile will serve as the base case for the majority of tests. The same power will be fed to each of the heater rods thereby eliminating hot and cold rod effects. This profile should yield the least variation in heat transfer data at one elevation and should be the easiest to analyze. Effects of perturbations of radial rod power in the other power profiles can then be compared with uniform radial power results to study hot rod behavior.

- **Hot and Cold Channel Power Profile, Figure 6-2**

  The same wiring scheme will be used for this power profile as for the uniform power profile. Each SCR will deliver different amounts of power to zones A, B, C thus creating the hot and cold channels. Most FLECHT initial test conditions simulate one small segment of a reactor core at the start of reflood following a hypothetical LOCA. A significant radial variation of both peak power and initial cladding temperature could be expected across a PWR core under these circumstances. The small FLECHT bundle cannot fully simulate these radial variations. It is of interest, however, to examine the effect of large power and initial cladding temperature gradients in the FLECHT rod bundle and determine their effect on hot rod temperature rise, turnaround time and quench time as compared with uniform bundle test results.

- **Radial Power Distribution Typical of a 17 x 17 Hot Assembly, Figure 6-3**

  This configuration, as shown in figure 6-3, is typical of a current 17 x 17 hot fuel assembly. The actual profile has been idealized into groupings such that three SCRs can be used to power the bundle. The different power zones are 0.95, 1.00 and 1.05. Experimental data from this profile is needed to study hot rod behavior within a hot assembly of current design.

- **Simulated 15 x 15 FLECHT Radial Power Profile, Figure 6-4**

  While this power profile is not typical of a 17 x 17 PWR fuel assembly, a link with data from previous FLECHT testing programs is needed. These older tests were heated by an idealized 15 x 15 fuel assembly power distribution having radial power factors of 0.95, 1.0, and 1.1. The general shape of the 15 x 15 FLECHT distribution has been maintained as has the percentage of rods in each power zone in the new 17 x 17 bundle. As shown in figure 6-4, besides providing overlap with the old FLECHT tests, this radial power profile will generate data from which hot rod effects can be isolated within the assembly.

- **Radial Power Profile Having Half of the Bundle at Low Power, Half at High Power, Figure 6-5**

  This profile shown in figure 6-5 is designed such that half of the bundle will be run by one SCR and will therefore be at low power, and the other half will be driven by two SCRs and will be able to generate nearly twice as much energy. This configuration will be used to study the effects of a major power gradient on two-phase flow and heat transfer. Such a situation might occur in a blocked assembly adjacent to an unblocked or low power assembly.

6-32. **Repeat Tests** – Statistical analysis will be performed on the results of these tests to determine repeatability and validity of the heat transfer coefficient and entrainment data within the test matrix. Test Numbers 26 and 27 are planned to be run in the middle and close to the end of the test program. These tests are expected to show that usage of the bundle and its instrumentation does not influence recorded data from one run to the next.[1,2]

6-33. **Variable Flooding Rate** – The flooding rate predicted by plant analysis[3,4] is constantly changing as shown in figure 6-6 for a dry containment plant and figure 6-7 for an ice condenser plant. Therefore, continuously variable flooding rates have been specified to cover the range of calculated flooding rates to examine the rod heat transfer and resulting entrainment. Test Numbers 28 and 30 will address the continuously flooding rates for a dry containment plant as shown in figure 6-6. Test Number 29 will study the same effects for a low pressure dry and ice condenser plant, as shown in figure 6-7. Test Numbers 31, 32, and 33 have variable stepped flow, as shown in figures 6-8, 6-9, and 6-10, to facilitate data analysis and to be compared to previous FLECHT tests in the low flooding rate cosine series having similar initial conditions.

6-34. **Gravity Reflood** – The effects of gravity reflooding on heat transfer and entrainment at two different pressures will be studied in this series. Test Numbers 34 and 35 will be compared to Test Numbers 39 and 40 of Test Series Number 10 to evaluate the difference in heat transfer, mass storage in the bundle and entrainment between gravity and forced flooding. Test Number 36 was designed to represent bundle average stored and generated energies and it will be used as a base for comparisons to simulated hot and cold flow channels specified in Test Number 37. In addition, comparisons among Test Numbers 34 and 35, and Test

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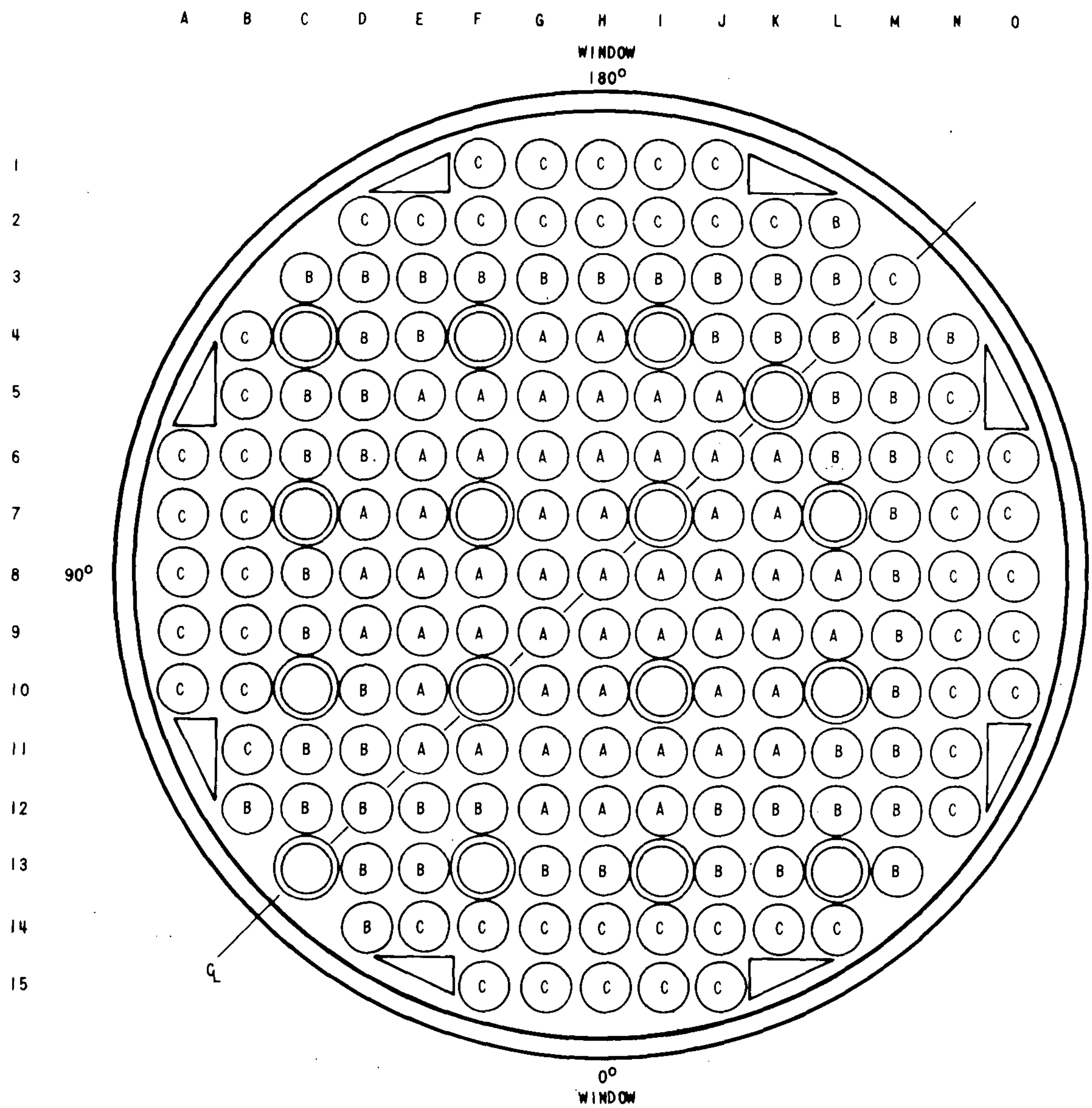
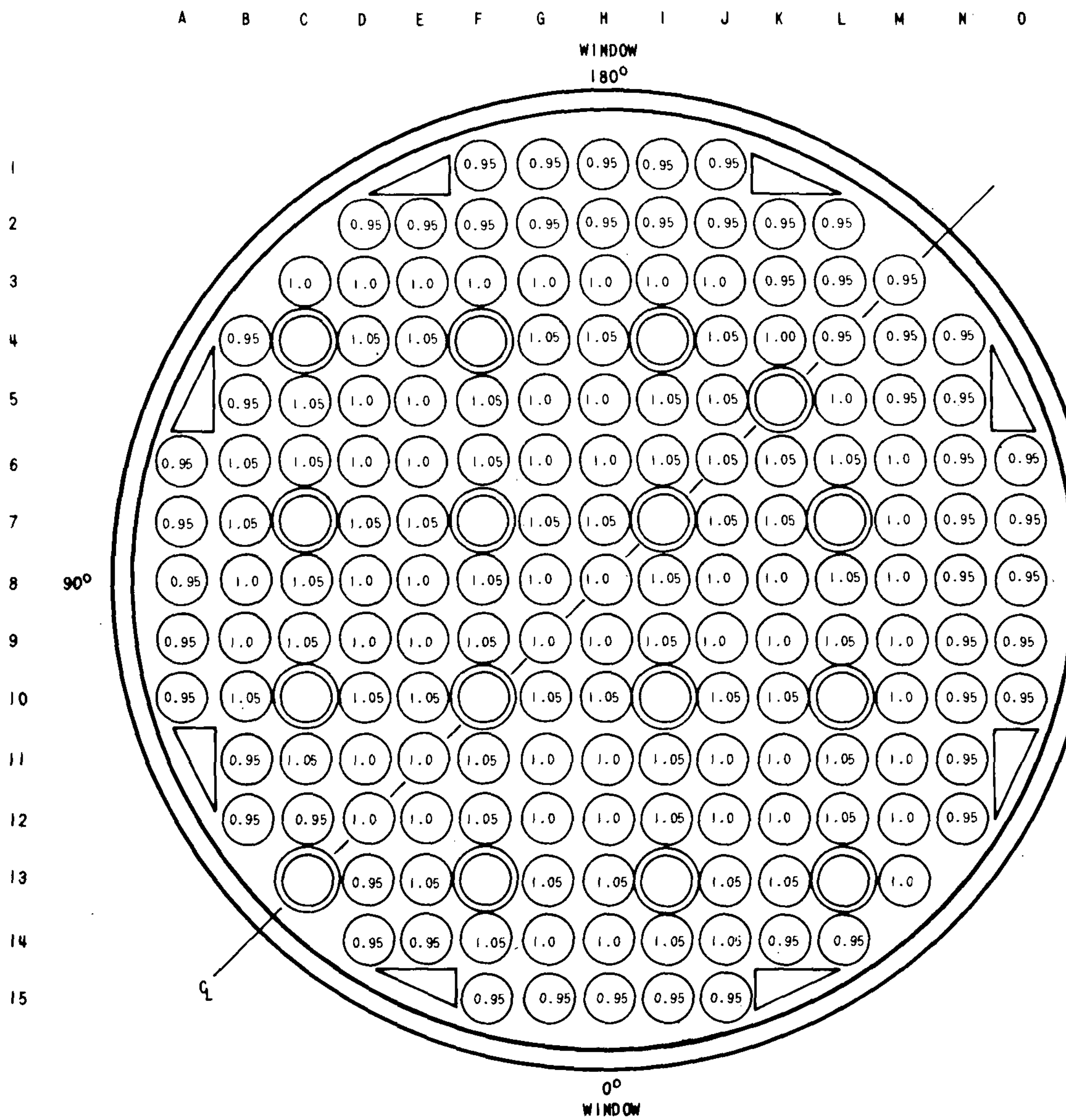
1. Lilly, G. P., Yeh, H. C., Hochreiter, L. E., Yamaguchi, N., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.
2. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.
3. Cadek, F. F., Dominicis, D. P. and Leyse, R. H., "PWR FLECHT (Full Length Emergency Cooling Heat Transfer) Final Report," WCAP-7665, April 1971.
4. Cadek, F. F., Dominicis, D. P., Yeh, H. C. and Leyse, R. H., "PWR FLECHT Final Report Supplement," WCAP-7931, October 1972.



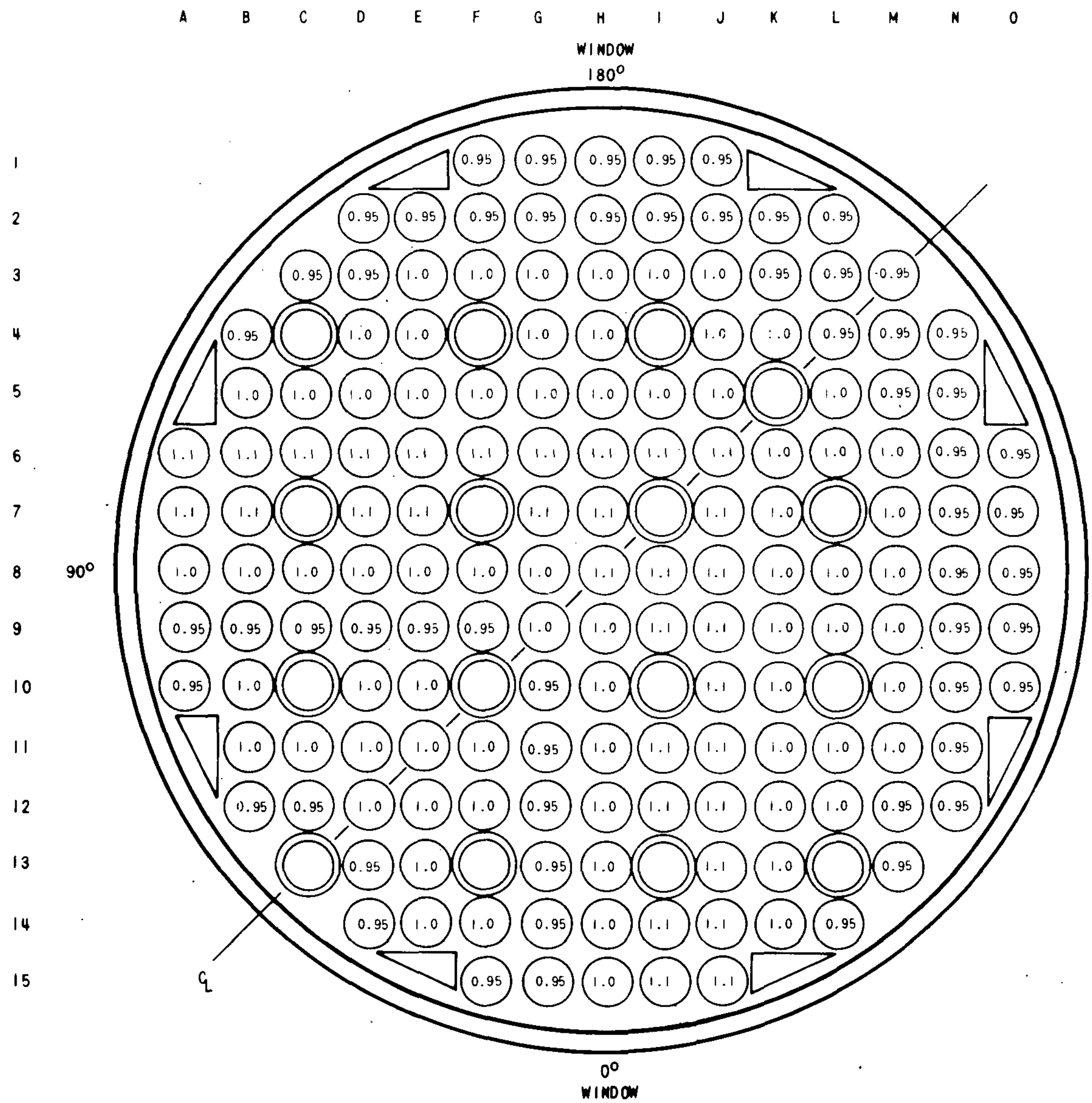
POWER ZONE	NUMBER OF RODS
A	54
B	54
C	53

Figure 6-2. Radial Power Distribution for Uniform Tests (Power Zone SCR A, B, and C at Same Peak Power) Hot – Cold Channel Tests Power Zone SCR A, B, and C at Different Peak Powers



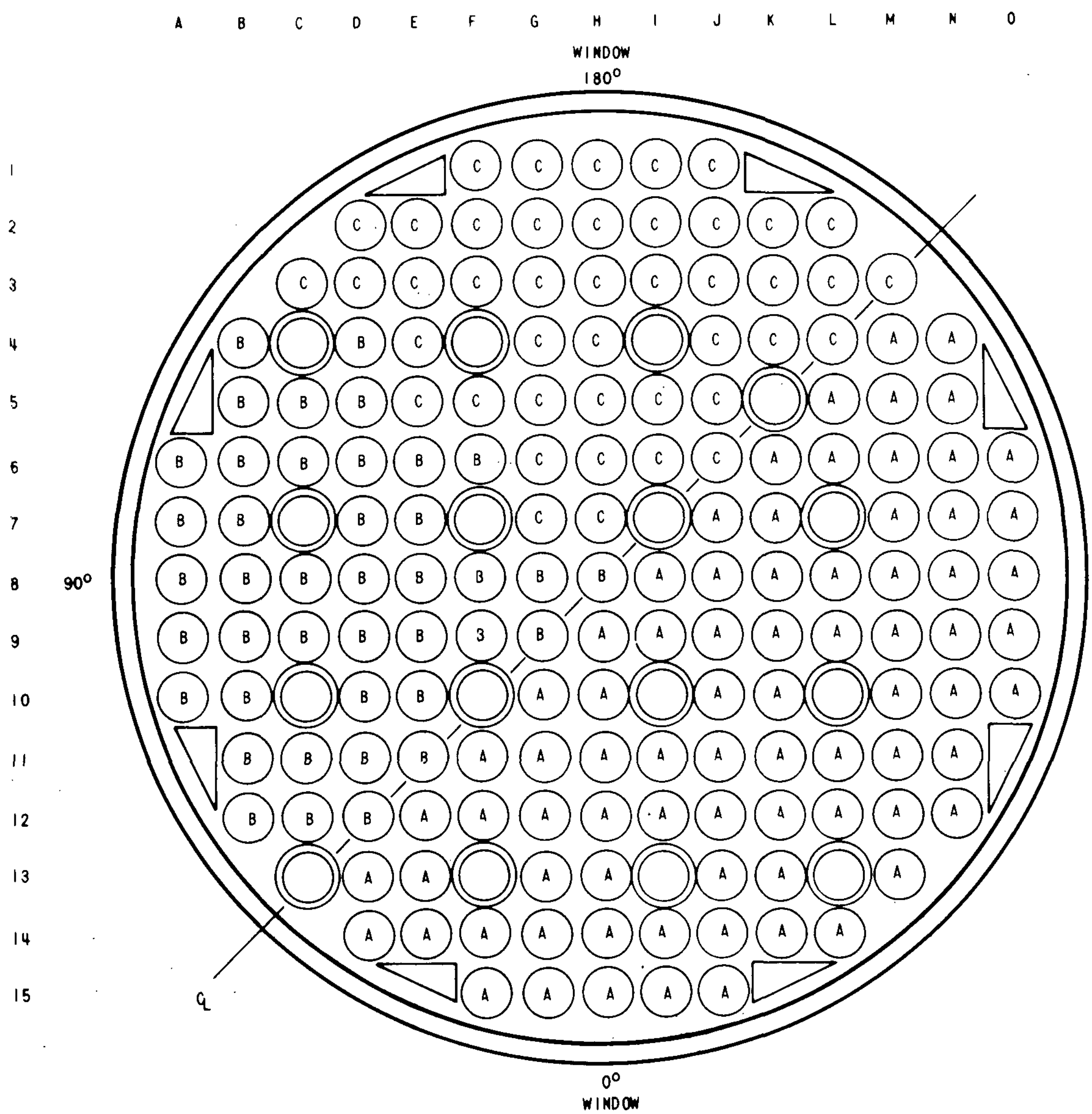
NUMBER OF RODS	POWER ZONE
53	1.05
54	1.0
54	0.95

Figure 6-3. Simulated Radial Power Distribution for 17 x 17 Hot Assembly



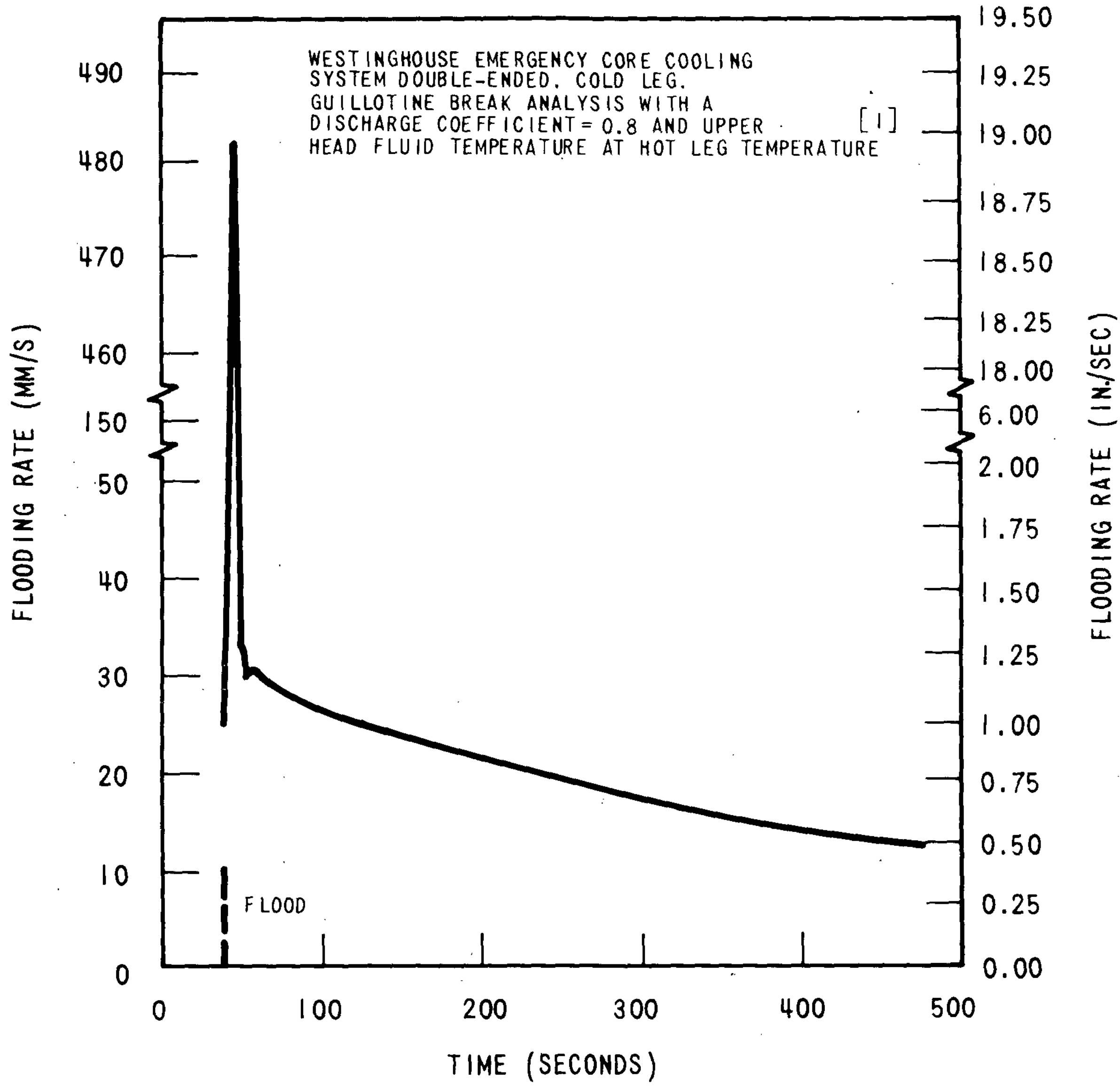
NUMBER OF RODS	RADIAL POWER ZONE
32	1.1
71	1.0
58	0.95

Figure 6-4. Simulated FLECHT Radial Power Distribution for 15 x 15 Hot Assembly



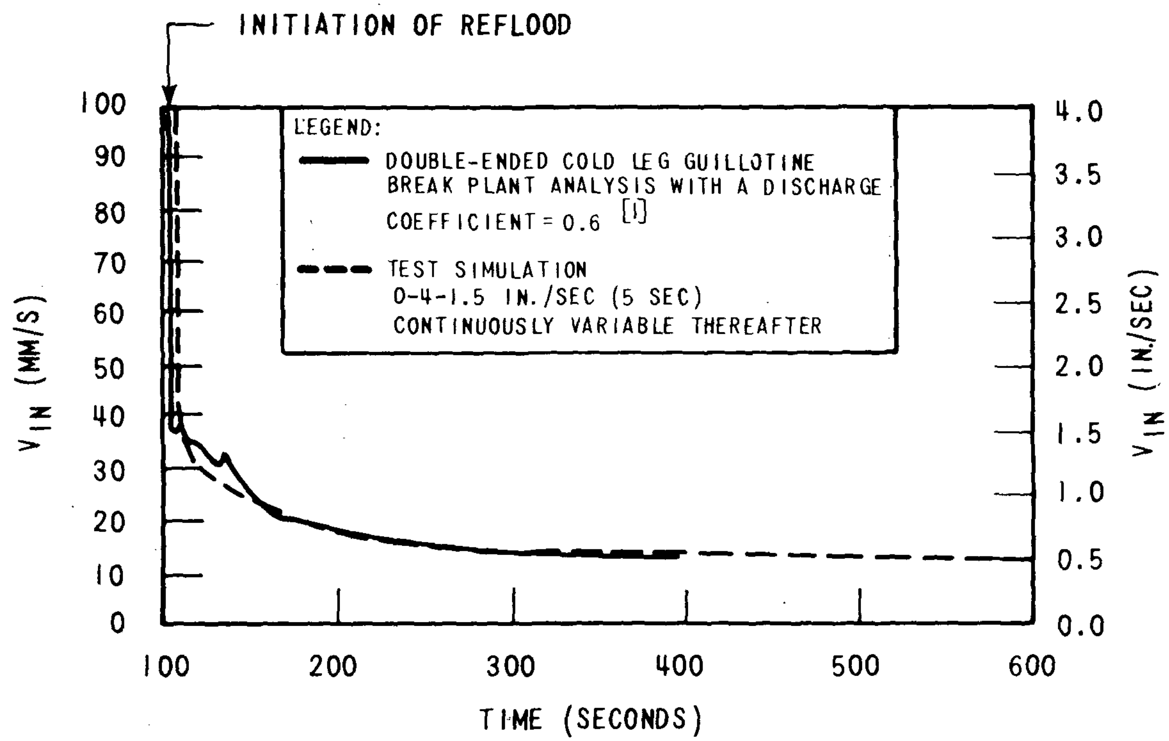
SCR	NUMBER OF RODS
A	77
B	41
C	43

Figure 6-5. Radial Power Distribution for Half of Bundle at Low Power, Half at High Power



1. Beck, H. S. and Kemper, R. M., "Westinghouse ECCS - Four Loop Plant (17 x 17) Sensitivity Studies With Upper Head Fluid Temperatures a T_{HOT}," WCAP-8865-A, May 1977.

Figure 6-6. Predicted Flooding Rate During Core Reflood of a Westinghouse PWR Dry Containment Plant



1. Sequoyah Nuclear Power Plant, FSAR Amendment 50, January 31, 1978

Figure 6-7. Predicted Flooding Rate During Core Reflood of a Westinghouse Ice Condenser Plant

13.108-1

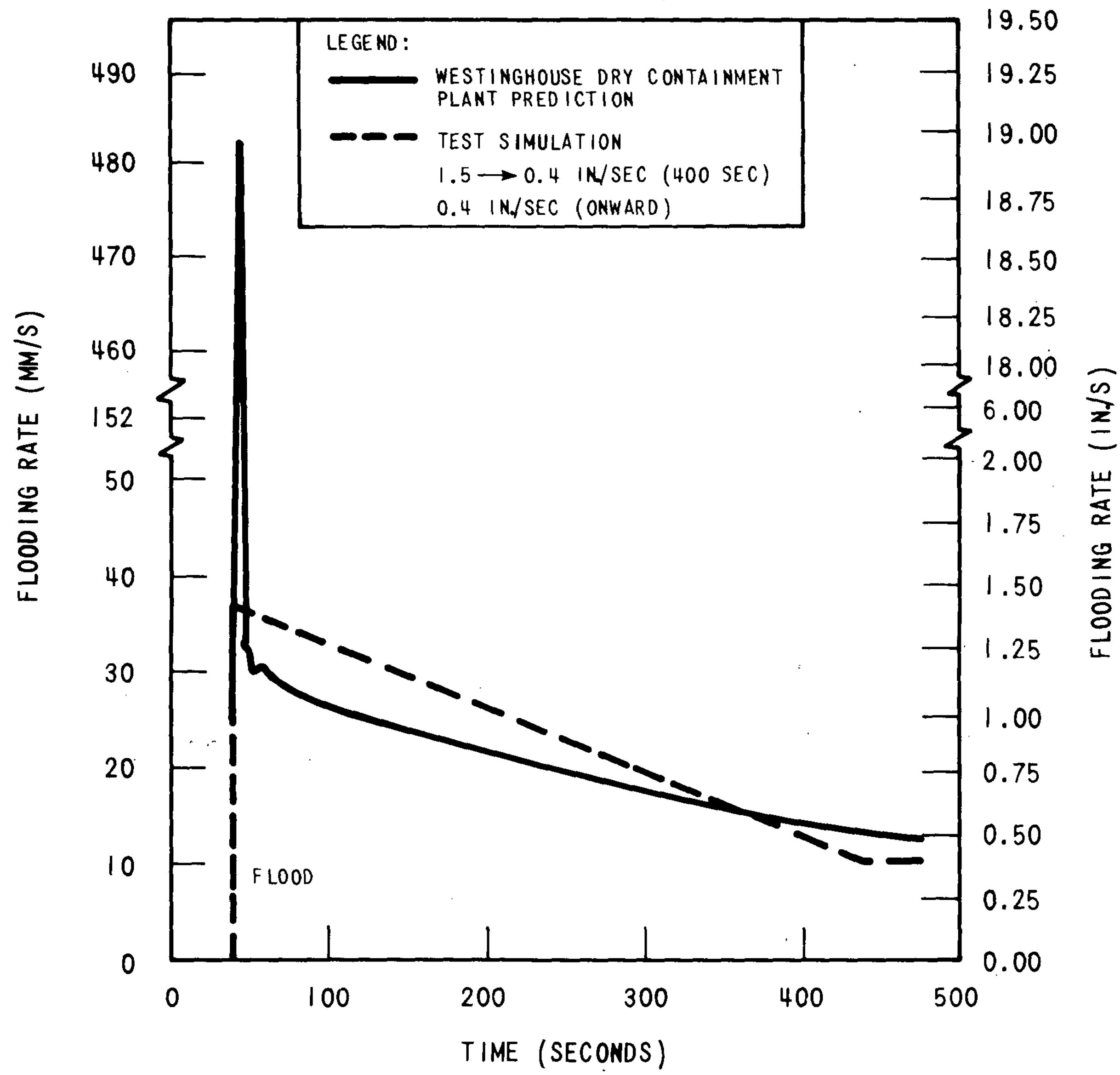


Figure 6-8. Variable Flow Simulation of Predicted Core Reflood of a Westinghouse PWR Dry Containment Plant

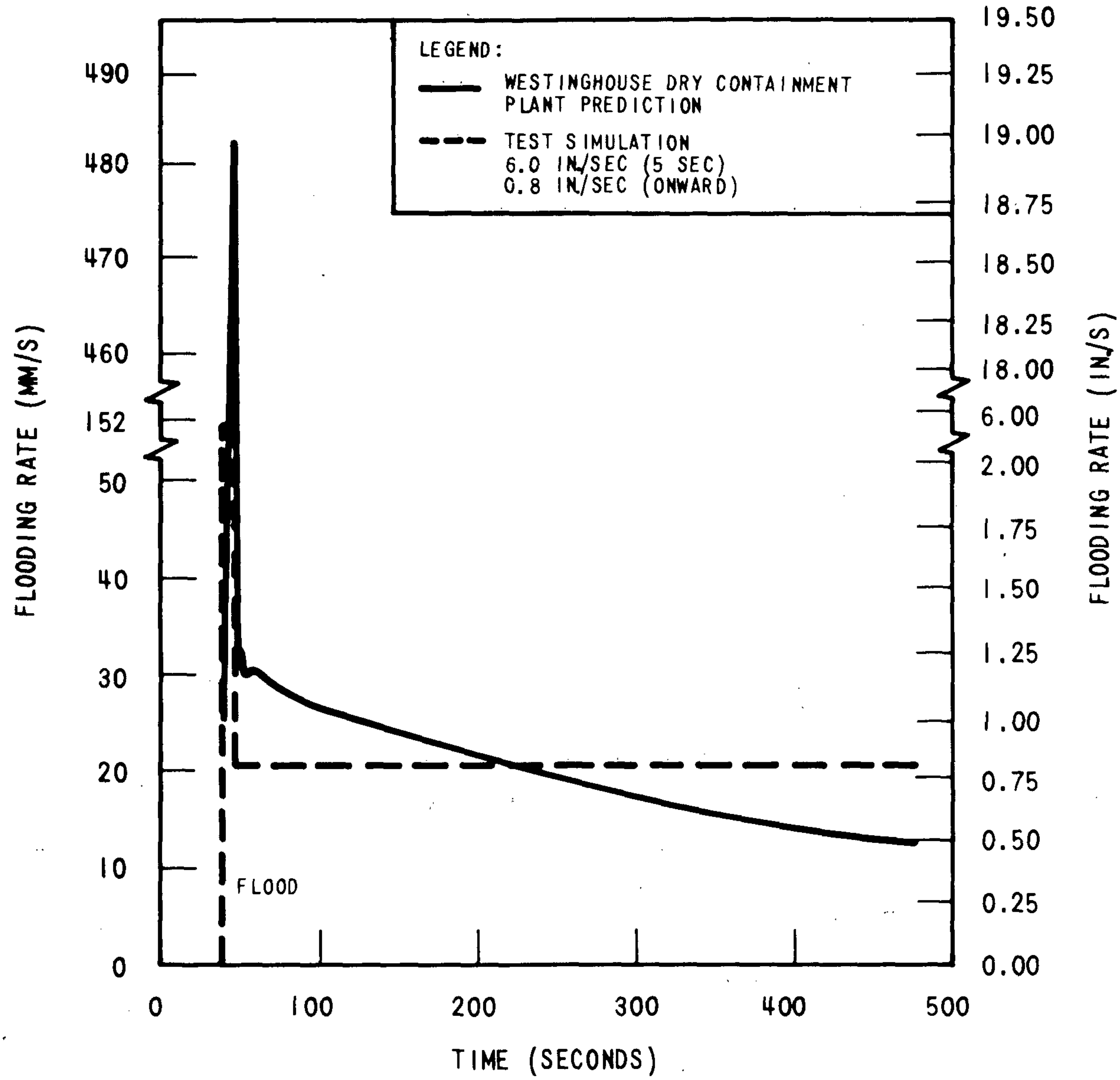


Figure 6-9. Variable Stepped Flow Simulation of Predicted Core Reflood of a Westinghouse PWR Dry Containment Plant (Two Steps)

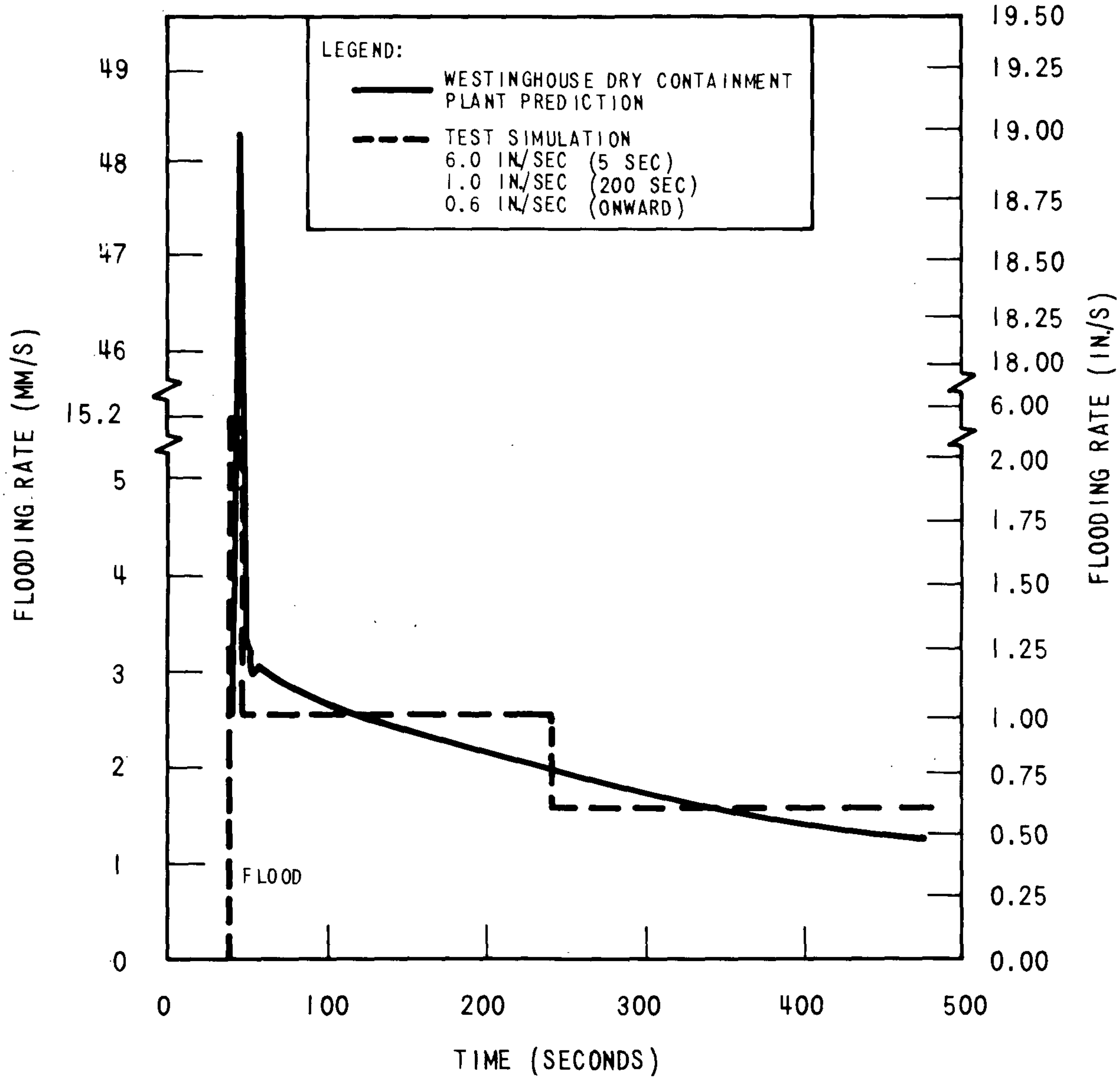


Figure 6-10. Variable Stepped Flow Simulation of Predicted Core Reflood of a Westinghouse PWR Dry Containment Plant (Three Steps)

Numbers 37 and 38 will yield information on the behavior of hot channels adjacent to cold channels and their combined effect on entrainment. In addition, results from Test Number 37 and 38 will be compared with test results obtained in the system effects tests (Task 3.2.7) having the same initial test conditions.

6-35. Hot and Cold Channels – These tests will examine hot rod heat transfer with average core entrainment as well as cold channel effects on entrainment. Test Number 41 will provide a data base for comparisons with blockage test where half of the bundle has blockage and the other half has bypass simulating hot assemblies with blockage adjacent to cold assemblies without blockage.

6-36. Axial Temperature Distribution and Gravity Reflood – These tests will be used to evaluate the effects of partially quenched rods at the beginning of reflood. Nuclear power plants equiped with Upper Head Injection (UHI) have a different calculated blowdown transient during a hypothetical Loss-of-Coolant Accident (LOCA). The Emergency Core Cooling (ECC) water injected during blowdown promotes cooling in the core and results in partially quenched rods at the beginning of reflood. Rod quenching is calculated to occur for the low power zones in the core and the bottom and top portion of the hottest rod. When reflood is initiated with partially quenched rods, steam binding effects are significantly reduced since the majority of the core-stored energy was removed by the UHI water.

Reflood in a UHI plant is postulated to start at 100 seconds after a hypothetical LOCA is initiated. Consequently, power decay rates, injection rates, and inlet subcooling will be adjusted accordingly in the following two tests. Test Number 42 will have a cosine initial temperature profile and will be compared with Test Number 43 in which the bottom three feet of the bundle will be quenched and the midplane initial temperature will be approximately 1600°F.

6-37. Steam Cooling – Data from these tests will be used to provide the basis for addressing the Appendix K steam cooling penalty and to make comparisons with blockage tests having the same initial test conditions.

6-38. Overlap Tests – Five overlap tests linking the previous 15 x 15 FLECHT tests with the current 17 x 17 array have been incorporated into the proposed test matrix. The method used to rescale 15 x 15 test conditions preserves both generated power and stored energy on a per unit flow area basis.

Generated energy is presented by the following equation:

$$\left[\begin{array}{l}\text{Constant for} \\ \text{each bundle} \\ \text{array}\end{array} = \frac{P_{peak,\ hot\ rod}}{f_{hot\ rod}}\left(\frac{P_{avg}}{P_{peak}}\right)\sum_{j=1}^{3}\frac{n_j f_j}{A_j}\right] \tag{6-1}$$

where

$\left(\frac{P_{avg}}{P_{peak}}\right)$ = inverse of the peak to average power ratio

n_j = number of rods in each radial power profile zone

f_j = radial power factor of each radial profile zone

A_j = bundle cross sectional flow area of each power factor zone

$f_{hot\ rod}$ = radial power factor of the hot or high power zone of the bundle

Stored energy is preserved by the following equation:

$$\begin{array}{l}\text{Constant for} \\ \text{each bundle} \\ \text{array}\end{array} = \left(\frac{P_{avg}}{P_{peak}}\right)\left(\frac{1}{f_{hot\ rod}}\right)\left[\sum_{j=1}^{k}\frac{n_j f_j}{A_j}\int_{T_{sat}}^{T_{init}}\sum_{i=1}^{3}\rho_i Cp_i A_i\, dT\right] \tag{6-2}$$

where

$\left(\frac{P_{avg}}{P_{peak}}\right)$, $f_{hot\ rod}$, n_j, f_j, A_j have the same meaning as equation (6-1)

T_{sat} = saturation temperature

T_{init} = hot rod initial temperature

$\rho_i Cp_i A_i$ = stored energy per unit length per degree of each of the three materials, (stainless steel, boron nitride, Kanthal) comprising a heater rod.

Using the equations above to rescale two uniform radial power tests from the Low Flooding Rate (LFR) cosine series[1] Run Number 03113 and 02414, results in test conditions which are similar to constant flooding rate Test Numbers 3 and 5, respectively. The differences between test conditions are considered minor and Test Numbers 3 and 5 can be used for overlap tests directly. Therefore, two overlap tests have been gained without increasing the number of tests in the proposed matrix.

1. Rosal, E. R., Hochreiter, L. E., McGuire, M. F., Krepinevich, M. C., "FLECHT Low Flooding Rate Cosine Test Series Data Report," WCAP-8651, December 1975.

Differences in flooding rate at low pressure 1.37 MPa (20 psia) will be shown by comparison of the Low Flooding Rate Cosine Series[1] Run Number 04641 with its 17 x 17 rescaled overlap run, Test Number 47.

A 17 x 17 overlap Test Number 24 comparison with Low Flooding Rate Cosine Series[1] (LFR) Run Number 05132 is needed for several reasons. First, Run Number 05132, like Run Number 02833 mentioned earlier, is one of the reference runs for which substantial data reduction and analysis has been completed. Second, overlap of Run Number 05132 and 04641 results will illustrate the effects of pressure between the two bundle arrays. Lastly, Run Number 05132 was used as an overlap run with a high temperature-low power Low Flooding Rate skewed series[2] power profile Test Number 14548.

Test Number 46 has been included to study the effect of variable flooding rate on bundle array. Overlap of 04516 has been selected for this study.

6-39. Comparison With Westinghouse 17 x 17 Data – Test Numbers 48 and 49 will be used to compare FLECHT-SEASET 17 x 17 data with Westinghouse proprietary 17 x 17 data. These tests will also provide initial temperature and power decay curve sensitivity studies.

6-40. Power Decay – Bottom of Core Recovery (BOCR) or reflood does not occur at the same time for all PWR. Reflood time ranges from 30 to 40 seconds for dry containment plants and 100 seconds for Westinghouse-UHI plants. As indicated in section 4 reference conditions, power decay for this task is based on reflood starting at 30 seconds after LOCA initiation. Therefore, Test Number 50 was designed to study the effects of power decay rates based on reflood starting at 40 seconds after LOCA initiation.

6-41. Temperature Rise Predictions

FLECHT-SEASET 9.50 mm (0.374 in.) heater rods are a new design featuring a tightly wound Kanthal coil capable of generating 8 kW and 0.635 mm (0.025 in.) thermocouples welded to the inside of the cladding. To prevent failure of the heating element and over heating of the thermocouples, a method was developed as an initial guide to insure that the test conditions given in tables 6-1 and 6-2 were not too extreme.

Westinghouse has performed proprietary 17 x 17 reflooding tests and has developed a proprietary reflood heat transfer correlation which predicted those tests. There were several differences between the Westinghouse bundle and the 17 x 17 unblocked tests proposed in

1. Rosal, E. R., Hochreiter, L. E., McGuire, M. F., Krepinevich, M. C., "FLECHT Low Flooding Rate Cosine Test Series Data Report," WCAP-8651, December 1975.
2. Rosal, E. R., Conway, C. E., and Krepinevich, M. C., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.

Task 3.2.1. Among those differences were the use of Westinghouse proprietary mixing vane grids, housing design, and rod bundle length. Estimates have been made of the 17 x 17 unblocked heat transfer using a modified version of the Westinghouse proprietary reflood correlation.

In this case, the mixing vane grid benefit was deleted, and the heat transfer coefficient correlation was degraded by 10 percent to conservatively estimate the heat transfer in the FLECHT-SEASET unblocked 17 x 17 bundle. The heat transfer calculation was coupled to a lumped capacitance heater rod model to estimate temperature rise of the 17 x 17 heater rod. The results of these calculations are shown in figures 6-11 and 6-12 where temperature rise has been plotted as a function of flooding rate for different peak powers. Temperature rise is defined as the difference between the rod temperature after flood and the initial rod temperature at the beginning of flood. To insure that the heater rod temperatures do not exceed 1232°C (2250°F), the temperature rise must be kept below 343°C (650°F) since the nominal reflood temperature is assumed to be 871°C (1600°F). Therefore, to maintain heater rod integrity, the test power must be decreased at low constant flooding rates as indicated by the curves.

It should be emphasized that these calculations are being used only to help plan and order the testing sequence. As test data is accumulated, the data can be used to extrapolate to other conditions or to modify this calculational approach. At that time, some of the test conditions, primarily rod power, could change.

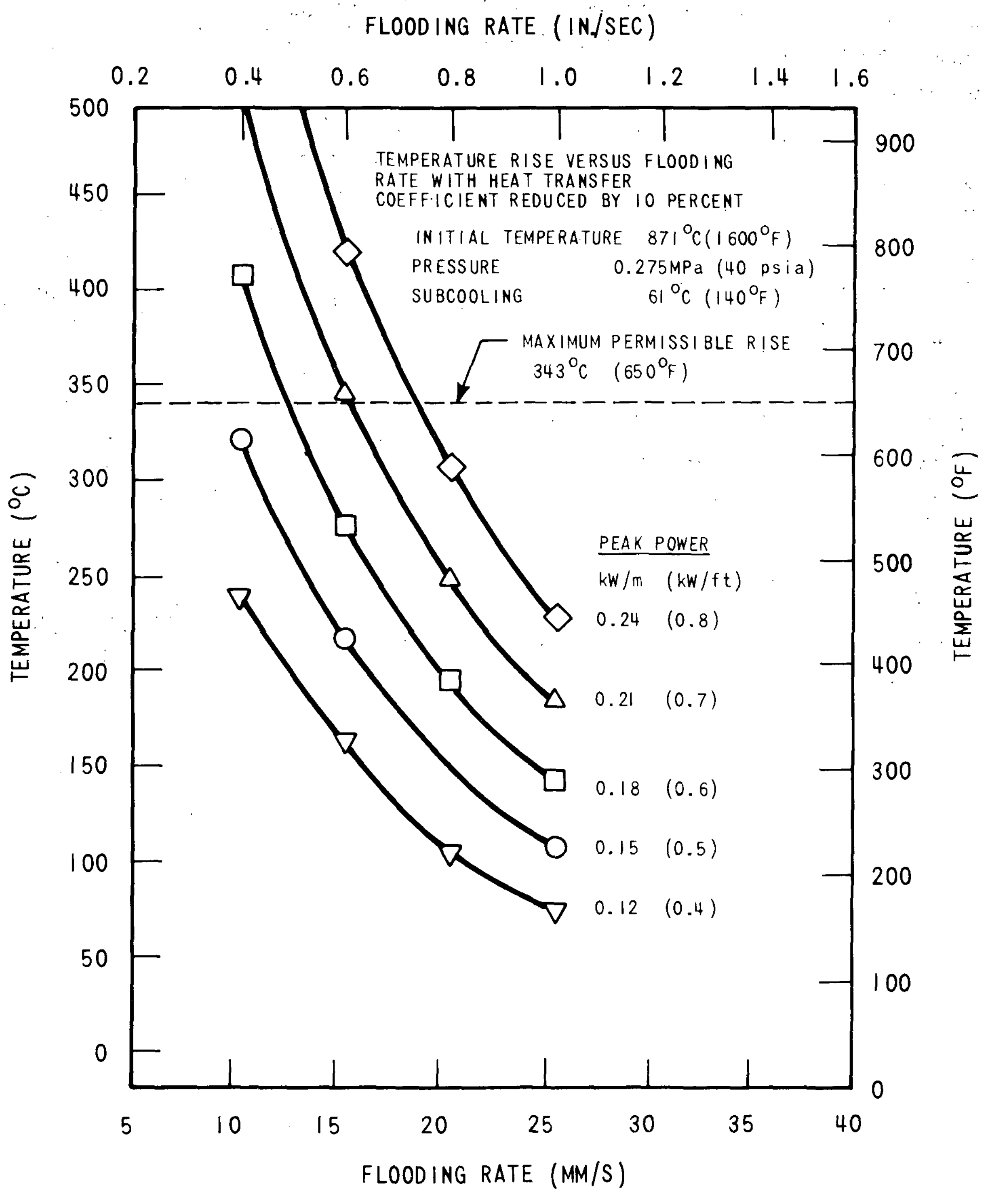


Figure 6-11. Predicted Hot Rod Surface Temperature Rise as a Function of Flooding Rate and Rod Peak Power During Reflood at 0.275 MPa (40 psia) (Unblocked Bundle Task 3.2.1)

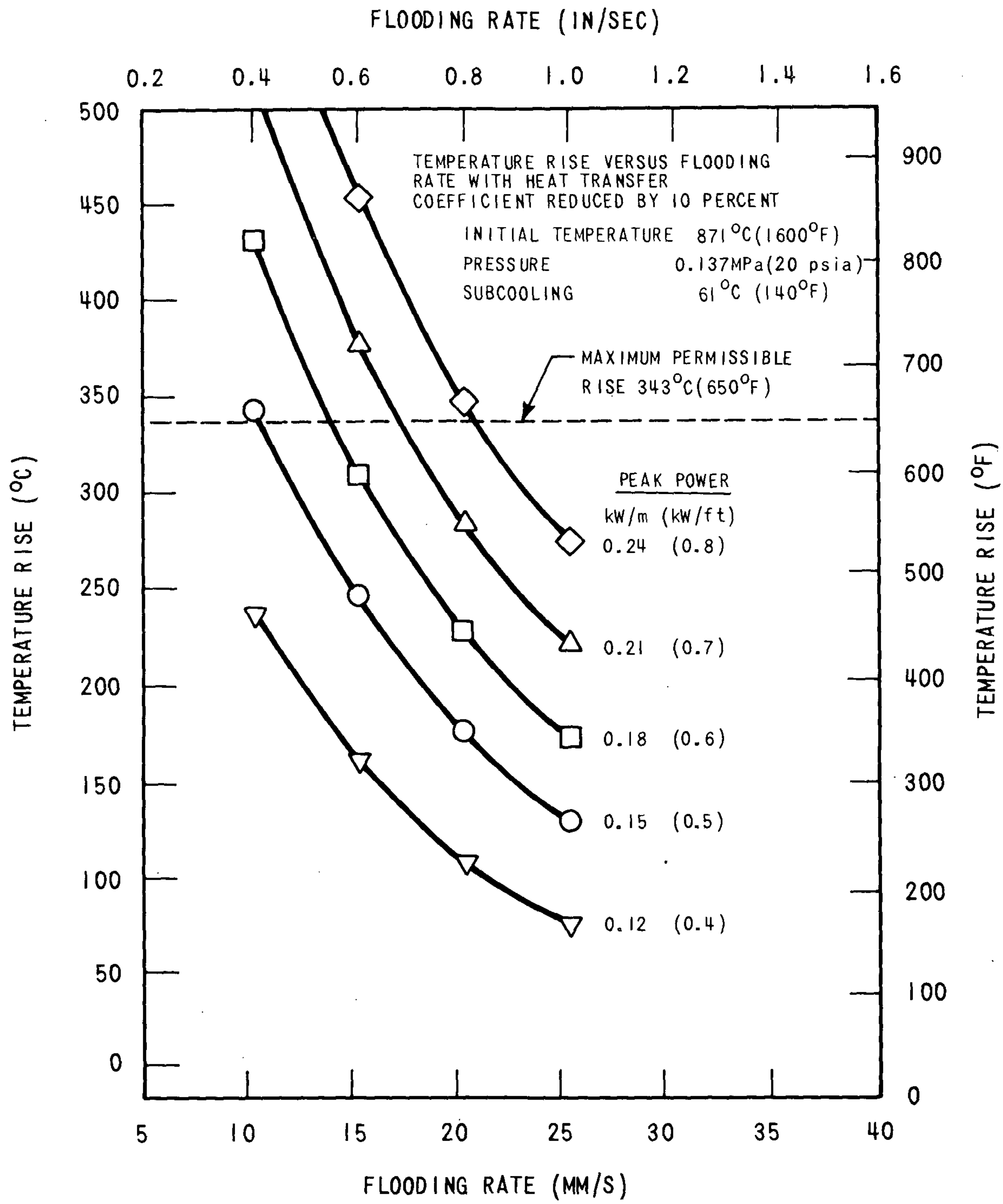


Figure 6-12. Predicted Hot Rod Surface Temperature Rise as a Function of Flooding Rate and Rod Peak Power During Reflood at 0.137 MPa (20 psia) (Unblocked Bundle Task 3.2.1)

SECTION 7
DATA REDUCTION, ANALYSIS, AND EVALUATION PLANS

7-1. DATA REDUCTION

The data which is to be analyzed in detail is recorded on the PDP-11/20 computer at the Forest Hills (Forest Hills, Pa) test site, then is transferred to magnetic tape. The magnetic tape is then processed at the Westinghouse Nuclear Center (Monroeville, Pa) through a series of data reduction and analysis programs to obtain the desired information. The flow logic of the computer codes is shown in figures 7-1 and 7-2. The different data reduction stages needed to first validate the test and then to evaluate the data are also shown. In this fashion, only test data which are judged to be valid data are fully reduced. The catalog tape for all tests, whether valid or invalid, is saved. Table 7-1 briefly describes the main function and the output for each data reduction and analysis code. New codes for either data reduction or analysis which will be used in this task will be discussed in either the data or evaluation reports. Details of each of the codes given in table 7-1 are discussed in appendix E.

All data reduction and analysis codes are written in English engineering units. This system will be maintained and results of these calculations will be converted to metric units for presentation in reports.

7-2. DATA ANALYSIS AND EVALUATION

The data for this task will be evaluated and analyzed similar to the low flooding rate skew profile data.[1] As part of the data evaluation process, the single parameter trends in temperature rise, turnaround time, and quench time will be compared to see if consistent trends are found in this new data with smaller pin diameters and the older FLECHT data. The data trends will be investigated for each test parameter such as pressure, flooding rate, power, subcooling, and initial temperature. In addition, heat transfer, clad temperature, and total mass carryout will be compared for each test parameter.

1. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.

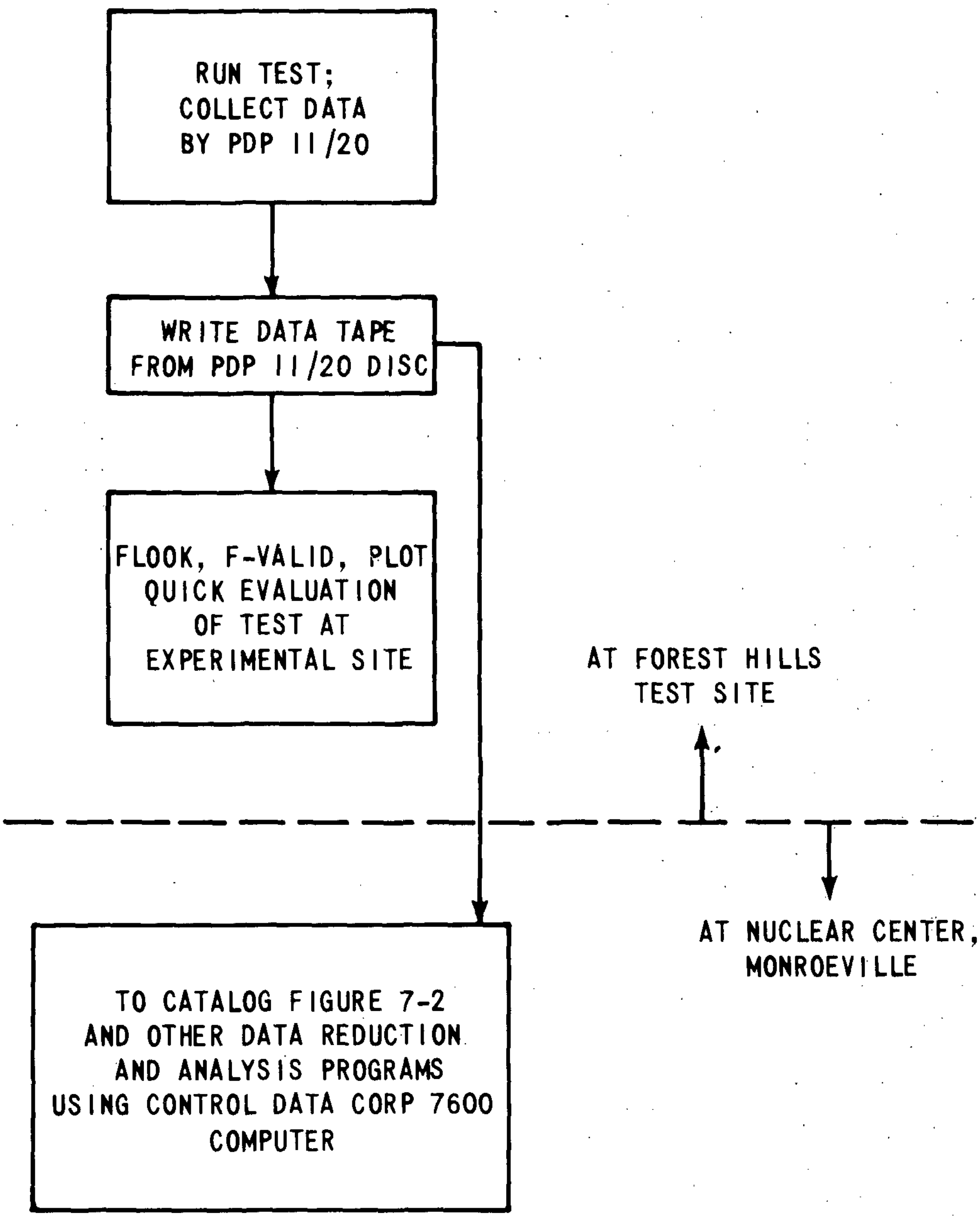


Figure 7-1. Flow Logic of Computer Codes

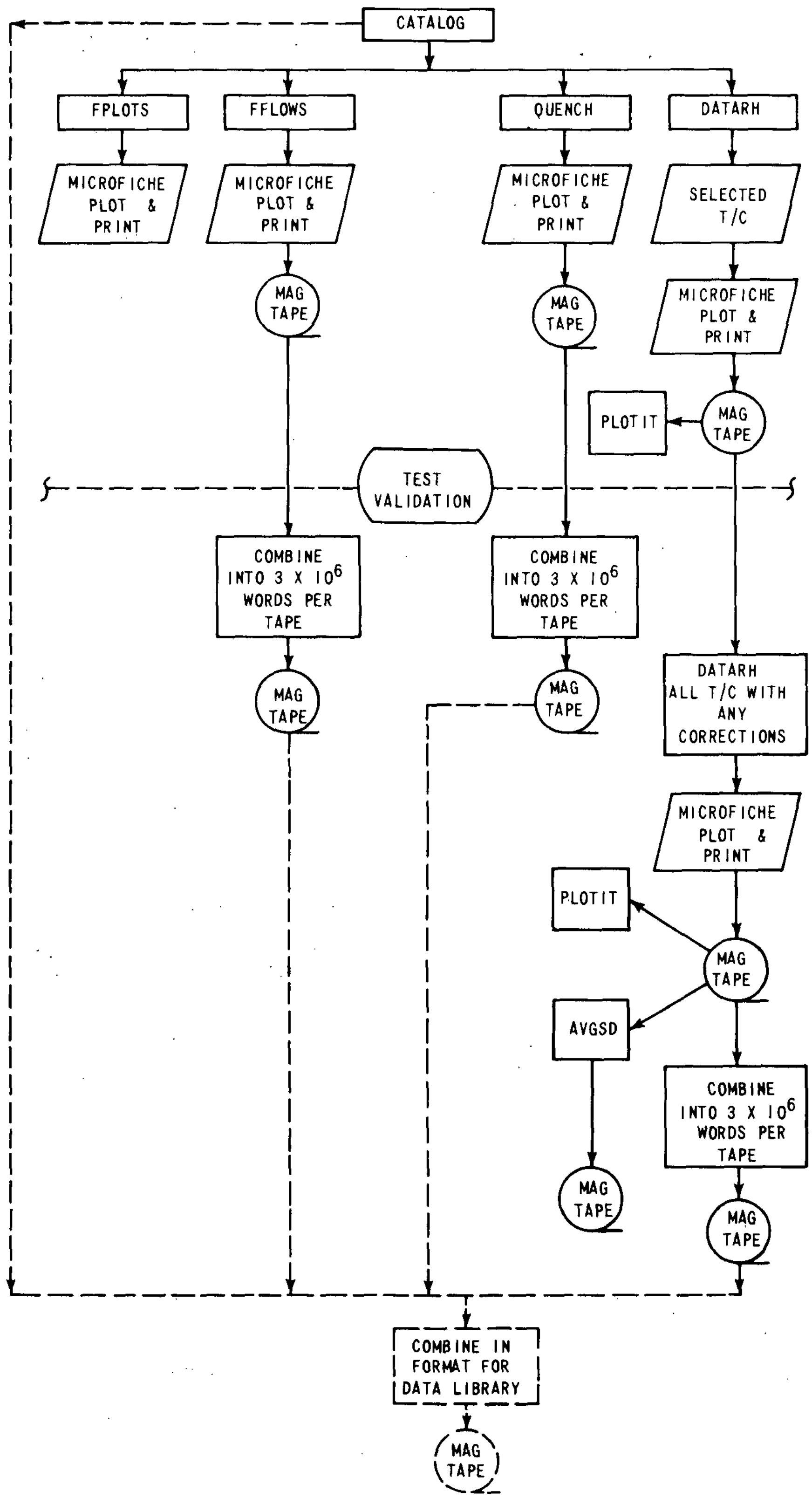


Figure 7-2. FLECHT-SEASET Data Reduction Flow Chart

TABLE 7-1

DESCRIPTION OF DATA REDUCTION AND ANALYSIS OF COMPUTER CODES (FLECHT-SEASET 17 x 17 UNBLOCKED BUNDLE, TASK 3.2.1)

Data Reduction Code	Main Function	Output	Units	
			SI	English Engineering
CATALOG	Lists each data channel as a function of run time	Tables of data and time in engineering units:		
		Time	s	sec
		Temperature	°C	°F
		Pressure	MPa	psia
		Differential pressure	MPa	psig
		Flow	m^3/s	gpm
		Power	kilowatts	kilowatts
FPLOTS	Plots each data channel as a function of time	Same as CATALOG	Same as CATALOG	Same as CATALOG
FFLOWS	Calculates overall mass balances, mass accumulation and bundle exit rates	Two-phase pressure drop	MPa	psig
		Void fraction	—	—
		Two-phase density	kg/m^3	lbm/ft^3
		Two-phase mass	kg	lbm
		Two-phase frictional pressure drop	MPa	psig
		Mass stored in bundle based on:		
		a) Overall differential pressure cell 0-3.66 m (0-12 ft)	kg	lbm
		b) Sum of incremental differential pressure cells $\sum_{i=1}^{12} \Delta P_i$	kg	lbm
		Mass difference	kg	lbm
		Upper plenum to 3.66 m (12 ft) pressure drop	MPa	psig
		Two-phase pressure drop steam velocity	m/s	ft/sec

TABLE 7-1 (cont)

DESCRIPTION OF DATA REDUCTION AND ANALYSIS OF COMPUTER CODES (FLECHT-SEASET 17 x 17 UNBLOCKED BUNDLE, TASK 3.2.1)

Data Reduction Code	Main Function	Output	Units	
			SI	English Engineering
FFLOWS (cont)		Time	s	sec
		Accumulator mass losss	kg	lbm
		Mass injected		
		(Total)	kg	lbm
		(Rate)	kg/s	lbm/sec
		Mass stored		
		(Total)	kg	lbm
		(Rate)	kg/s	lbm/sec
		Mass out		
		(Total)	kg	lbm
		(Rate)	kg/s	lbm/sec
		Mass difference		
		(Total)	kg	lbm
		(Rate)	kg/s	lbm/sec
		Carryout fraction:		
		a) Based on mass stored		
		(Total)	—	—
		(Rate)	—	—
		b) Based on mass out		
		(Total)	—	—
		(Rate)	—	—
		Test section mass		
		(Total)	kg	lbm
		(Rate)	kg/s	lbm/sec
		Carryover tank mass		
		(Total)	kg	lbm
		(Rate)	kg/s	lbm/sec

TABLE 7-1 (cont)

DESCRIPTION OF DATA REDUCTION AND ANALYSIS OF COMPUTER CODES (FLECHT-SEASET 17 x 17 UNBLOCKED BUNDLE, TASK 3.2.1)

Data Reduction Code	Main Function	Output	Units	
			SI	English Engineering
FFLOWS (cont)		Steam separator mass (Total) (Rate) Exhaust orifice mass (Total) (Rate) Overall mass balance Lower bound quality Upper bound quality Mass leaving each differential pressure increment	 kg kg/s kg kg/s kg — — kg	 lbm lbm/sec lbm lbm/sec lbm — — lbm
QUENCH	Determines time — temperature history for each rod thermocouple	Initial temperature Turnaround temperature Turnaround time Temperature rise Quench time Quench temperature	°C °C s °C s °C	°F °F sec °F sec °F
DATARH	Calculates local surface temperature, heat flux, and heat transfer coefficients for each rod thermocouple	Measured temperature Calculated surface temperature Heat flux Heat transfer coefficient	°C °C W/m^2 W/m^2 — °K	°F °F $Btu/hr\text{-}ft^2$ $Btu/hr\text{-}ft^2$ — °F
PLOTIT	Plots DATARH variables vs time	Plots of DATARH output	Same as DATARH	Same as DATARH
AVGSD	Statistical analysis of DATARH output	Mean, one standard deviation, maximum and minimum for rod temperature heat transfer coefficient and heat flux in specified bundle zones	Same as DATARH	Same as DATARH

TABLE 7-1 (cont)

DESCRIPTION OF DATA REDUCTION AND ANALYSIS OF COMPUTER CODES (FLECHT-SEASET 17 x 17 UNBLOCKED BUNDLE, TASK 3.2.1)

Data Reduction Code	Main Function	Output	Units	
			SI	English Engineering
Mass and energy	Calculates local conditions and	Mass flow	kg/s	lbm/sec
balance	other quantities relevant to	Quality	—	—
	heat transfer	Enthalpy	J/kg	Btu/lbm
		Vapor Reynolds number	—	—
		Nusselt number	—	—
		Radiative heat flux to vapor	J/kg	Btu/lbm
		Void fraction	—	—
		Wall temperature	°C	°F
		Vapor temperature	°C	°F
		Hot rod heat flux	W/m^2	Btu/ft^2-hr
		Total integrated heat flow	J	Btu
ALLTURN	Calculates heat transfer	Heat transfer coefficient	W/m^2 – °F	Btu/hr – ft^2-°F
(Z-Zq)	coefficient based on distance	as a function of elevation	m	ft
	above the quench front	for a given time	s	sec
HEAT II	Calculates components of heat	Droplet diameter	m	ft
	transfer to entrained liquid	Droplet number density	$drops/m^3$	$drops/ft^3$
	and steam	Droplet velocity	m/s	ft/sec
		Vapor velocity	m/s	ft/sec
		Slip ratio	—	—
		Void fraction	—	—
		Droplet Reynolds number	—	—
		Droplet Weber number	—	—
		Rod heat flux	W/m^2	Btu/ft^2-hr
		Surface-to-surface radiation	W/m^2	Btu/ft^2-hr
		Radiation to vapor	W/m^2	Btu/ft^2-hr
		Radiation to drops	W/m^2	Btu/ft^2-hr
		Convection wall to vapor	W/m^2	Btu/ft^2-hr
		Radiation vapor to drops	W/m^2	Btu/ft^2-hr
		Heat transfer coefficient	W/m^2 – °K	Btu/hr – ft^2-°F
		Nusselt number wall to vapor	—	—

TABLE 7-1 (cont)

DESCRIPTION OF DATA REDUCTION AND ANALYSIS OF COMPUTER CODES (FLECHT-SEASET 17 x 17 UNBLOCKED BUNDLE, TASK 3.2.1)

Data Reduction Code	Main Function	Output	Units	
			SI	English Engineering
HEAT II (cont)		Quality	–	–
		Steam temperature	°C	°F
		Wall temperature	°C	°F
		Normalized surface-to-surface radiation heat flux	–	–
		Normalized wall-to-droplet radiation heat flux	–	–
		Normalized wall-to-vapor radiation heat flux	–	–
		Normalized convective wall-to-vapor heat flux	–	–
		Vapor Reynolds number	–	–
		Optical thickness	–	–

The special tests, such as hot and cold channel tests, different radial power distributions, and the gravity reflood tests will be examined separately to determine the effect of each test variation on the heat transfer, clad temperature, and total mass entrainment. In this fashion, qualitative statements can be made on the effect of each test parameter.

There are several tests which will be used to relate the previous 15 x 15 FLECHT data[1] to the current 17 x 17 cosine data. These tests will be analyzed and compared with the 15 x 15 comparison tests to determine the effect of smaller rod diameter on temperature rise, turnaround time, quench time, heat transfer, and total mass entrainment. In addition, a FLECHT type empirical heat transfer correlation similar to that given in WCAP-9183[2] will be developed which should represent both the 15 x 15 data and the 17 x 17 data. This same correlation should also be able to predict the skewed power shape data analyzed in WCAP-9183.[2] The goal will be to make this correlation a best fit to all FLECHT data.

The entrainment and bundle void fraction data which is also obtained from the experiments will be compared to the semi-empirical entrainment model developed in WCAP-8838.[3] The model proposed by Sun and Duffey[4] will also be compared with the mass effluent data and the entrainment model given in WCAP-8838. In addition to examining these entrainment models, entrainment criteria such as superficial velocity, or critical void fraction will be investigated and compared with criteria in the literature.

In addition to evaluating the data from this test series, the data will be analyzed to investigate heat transfer mechanisms which are occurring during reflood. The analysis methods developed in WCAP-9183[2] will be used to perform a mass and energy balance on the test bundle.

The bundle thermal-hydraulics parameters which will be calculated from the bundle mass and energy balance are given in table 7-2. Using these quantities, the measured wall heat flux will be divided into the individual heat transfer mechanisms using the HEAT-II computer code described in paragraph 7-1. The HEAT-II program will give the radiation-to-vapor wall heat flux component, radiation to drops, radiation to other surfaces, and the resulting convective wall heat flux component. This approach will be used to enable quantification of the different

1. Rosal, E. R. Hochreiter, L. E., McGuire, M. F., Krepinevich, M. C., "FLECHT Low Flooding Rate Cosine Test Series Data Report," WCAP-8651, December 1975.
2. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.
3. Lilly, G. P., Yeh, H. C., Hochreiter, L. E., Yamaguchi, N., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.
4. Sun, K. H. and Duffey, R. B., "A Generalized Model for Predicting Mass Effluence During Reflooding," *Trans. Amer. Nucl. Soc. 27,* 604-605 (1977).

TABLE 7-2

INFORMATION DERIVED FROM BASIC DATA (UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD TASK 3.2.1)

Derived Thermo-hydraulic Quantity	Method Used – Code	Location
Rod surface heat flux	Inverse conduction code – DATARH	At each rod thermocouple elevation
Heat transfer coefficient	Heat flux and rod surface and saturation temperatures – DATARH	At each rod thermocouple elevation
Bundle rod heat release rate	Bundle energy balance – AVGSD	Rod bundle heated length
Fluid mass storage rate	Test section mass balance – FFLOWS	Rod bundle
Effluent rate	Test section mass balance – FFLOWS	Exhaust orifice, carryover and steam separator tank
Quench front velocity	Rod thermocouple quench data – QUENCH	Rod bundle heated length
Bundle axial void fraction	Momentum balance using differential pressure readings corrected for frictional losses – FFLOWS	Rod bundle heated length
Carryout fraction	Mass balance around test section – FFLOWS	Injection rates, mass storage and exhaust liquid and steam measurements
Liquid entrainment rate	Mass balance around test section – FFLOWS	Carryover and steam separator collection tanks
Nonequilibrium quality	Mass and energy balance	Rod bundle at each steam probe location
Equilibrium quality	Mass and energy balance	Rod bundle at each steam probe location
Exit quality	From test section exit liquid and steam flow measurements – FFLOWS	Test section exhaust
Heat flow to droplet	From axial quality changes, mass flows and two-phase flow temperatures – HEAT II	Rod bundle at each steam probe location
Convective heat flux to steam	From axial quality changes, mass flows and two-phase flow temperatures – HEAT II	Rod bundle at each steam probe location
Radiative heat flux to drops	From axial quality changes, mass flows and two-phase flow temperatures – HEAT II	Rod bundle at each steam probe location
Radiative heat flux to steam	From axial quality changes, mass flows and two-phase flow temperatures – HEAT II	Rod bundle at each steam probe location
Flow and heat transfer regimes	Photographic and appropriate data	Rod bundle and upper plenum

reflooding heat transfer mechanisms which will allow others to verify or develop mechanistic reflood heat transfer models. The analyzed data will also be compared with existing heat transfer correlations or models and, if possible, improved models will be proposed. The resulting information will also be presented in tabular form to enable correlation of the data in various ways.

In addition to analyzing the data in this fashion, heat transfer regimes, flow regimes, and droplet information will be obtained from the movies. Previously, it has been difficult to accurately obtain flow regime and droplet information. Camera speeds were not fast enough to accurately calculate either drop velocity or drop size. In addition, a water film formed over the inside of the bundle window which interfered with observation of physical phenomena occurring in the outside rows of the bundle. Improved photographic techniques, together with high speed cameras will be used to obtain this information. Transitions among heat transfer regimes will also be identified from the movies and other data.

SECTION 8
TASK SCHEDULE

The sechedule for this task (Task 3.2.1) has been revised relative to that presented in the FLECHT-SEASET Program Plan[1] by four months. This was essentially due to increased time required for heater rod procurement and unplanned procurement of a new bundle housing. Table 8-1 lists the major milestones for this Task which supersede those presented previously in the Program Plan. Based on the contract report review and publish cycle (consisting of 30 days for PMG review, 30 days for resolution of comments, and 45 days for Westinghouse to publish reports), and the schedule in table 8-1, the final data report will be published in mid-December 1979 and the final data analysis and evaluation report will be published in mid-March 1980.

Figure 8-1 presents a more detailed flow diagram overview of the schedule for major test loop components. It is anticipated that the critical item will be heater rod procurement.

TABLE 8-1
MAJOR MILESTONES (UNBLOCKED BUNDLE, FORCED AND GRAVITY REFLOOD TASK 3.2.1)

Milestone No.	Milestone	Months After Contract Start Date (7/1/77)	Calendar Date
B1	Initiate test planning and facility modification	3	10/1/77
B2	Issue draft task plan for review	7	2/1/78
B3	Initiate shakedown testing	14	9/1/78
B4	Complete testing	23	6/1/79
B5	Complete draft data report	26	9/1/79
B6	Complete draft data analysis and evaluation report	29	12/1/79

1. Cadek, F. F., Dominicis, D. P. and Leyse, R. H., "PWR FLECHT (Full Length Emergency Cooling Heat Transfer) Final Report," WCAP-7665, April 1971.

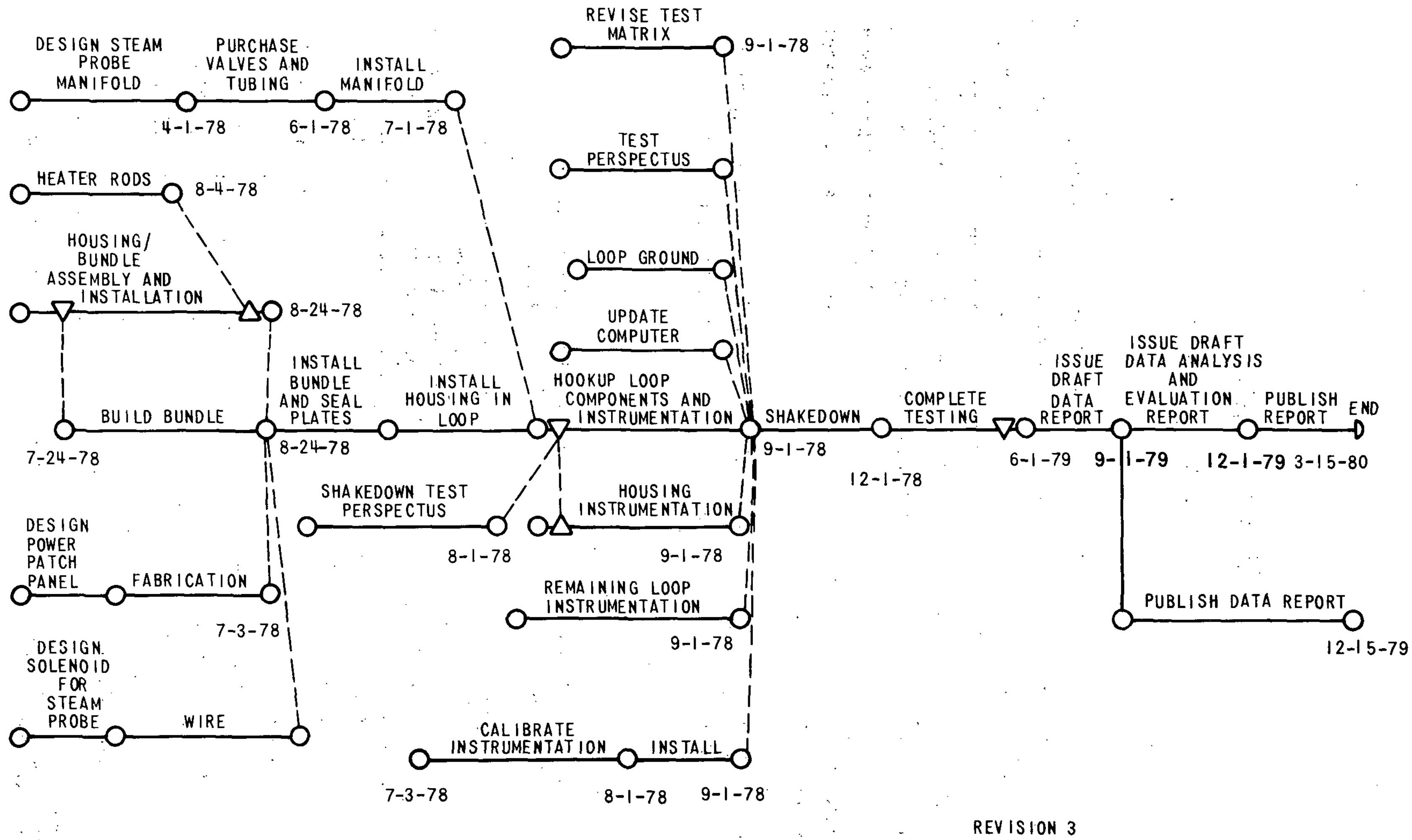


Figure 8-1. Flow Diagram Overview of Projected Schedule (Unblocked Bundle, Task 3.2.1)

13,108-44

APPENDIX A

REVIEW OF TEST PARAMETER RANGES

Correspondence with Combustion Engineering, Babcock and Wilcox, Exxon, and EG&G regarding test parameter ranges is reproduced on the following pages.

Combustion Engineering, Ir
1000 Prospect Hill Road
Windsor, Connecticut 06095

Tel. 203/688-1911
Telex: 9-9297

COMBUSTION ENGINEERING

November 30, 1977

Mr. H. W. Massie
FLECHT-SEASET Project Engineer
Westinghouse Electric Corporation
Box 355
Pittsburgh, Pennsylvania 15230

Dear Mr. Massie:

In response to your letter of October 12, 1977 I have enclosed comments on the proposed FLECHT-SEASET program. Note that the best estimate conditions listed in the attached tables are values based on calculations using best estimate input parameters and LOCA Evaluation Model codes.

I have also enclosed information contained in CESSAR on the System 80 steam generator. I hope this information will assist you in planning the FLECHT-SEASET tests.

Sincerely,

James H. Holderness

James H. Holderness
ECCS Analysis

JHH:jdg
Encl.

TABLE 6

17 X 17 BLOCKED TESTS

	Nominal EM Conditions	Preferred Range of Condition
1. PARAMETER		
Flooding Rate	3.2→0.7 in/sec variable in steps over 65 seconds	Same as unblocked
Pressure	24-32 psia	"
Peak Power at BOC	0.7 kw/ft	"
ECC Water Subcooling	100°F	"
Rod Initial Temperature at BOC	1200°F	"
% Blockage ($\frac{\Delta \text{Blocked}}{\Delta \text{Unblocked}}$)		20-90%
% Bypass *	90%	0-90%
2. SPECIAL TESTS	Same as unblocked	
3. COMMENTS ON INSTRUMENTATION	Steam prove measurement in blocked subchannel and comparable unblocked subchannel location	
4. ANY ADDITIONAL COMMENTS	3-zone blockage capability, e.g. 90% blockage (four subchannels) 50% blockage (50% of bundle) 0% blockage (remainder of bundle)	

* Definition: Percent Bypass - Percent of Subchannels which are unblocked; e.g., 0% = uniform coplanar blockage.

TABLE 7

17 X 17 UNBLOCKED TESTS

	Nominal EM Condition	Nominal BE Condition	Preferred Range of Conditions
1. **Parameter**			
- Flooding Rate	3.2→0.7 in/sec variable in steps over 65 sec	6→1.1 in/sec continuously variable over 65 sec	0.5-6 in/sec, constant & variable in steps [illegible] continuously over [illegible] sec
- Pressure	24-32 psia	30-50 psia	20-60 psia
- Peak Power at BOC	0.7 kw/ft	0.6 kw/ft	0.3-1.0 kw/ft
- ECC Water Subcooling	≤ 100°F	100-0°F variable over 200 sec	0-150°F constant & variable
- Rod Initial Temp. at BOC	1200°F	1000°F	300-1600°F

2. Special Tests
   - i) reflood rate variable in steps and continuously over ∿65 second period
   - ii) time-varying enthalpy from maximum subcooling to saturation over ∿200 second period

3. Comments on Instrumentation: redundancy in steam probe measurement at each elevation

4. Any Additional Comments

TABLE 8

STEAM GENERATOR SEPARATE EFFECTS TESTS

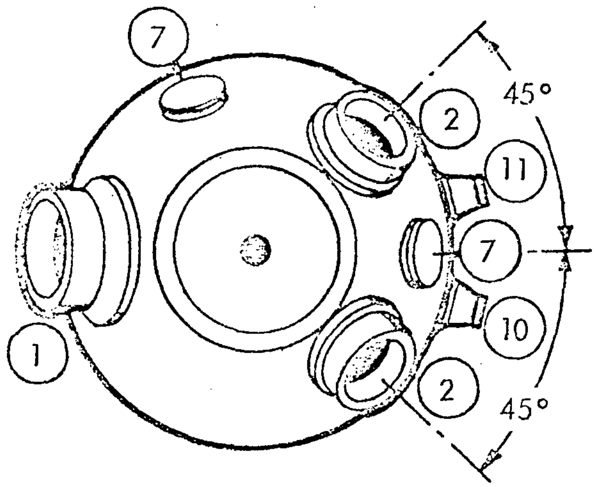
	Nominal EM Conditions	Nominal BE Conditions	Preferred Range of Conditions
1. PARAMETER			
- Inlet Primary Steam Flow	4-5 #/ft^2-sec	2-3 #/ft^2-sec	1-5 #/ft^2-sec
- Inlet Primary Quality	1.0	0.3	0.1-1.0
- Primary System Pressure	24-32 psia	30-50 psia	20-60 psia
- S.G. Secondary Pressure	1060 psia	920-1000	20-1200
- S.G. Secondary Level	tubes covered	tubes covered	tubes covered & partially covered
- S.G. Secondary Water Temperature	550	535-545	230-570

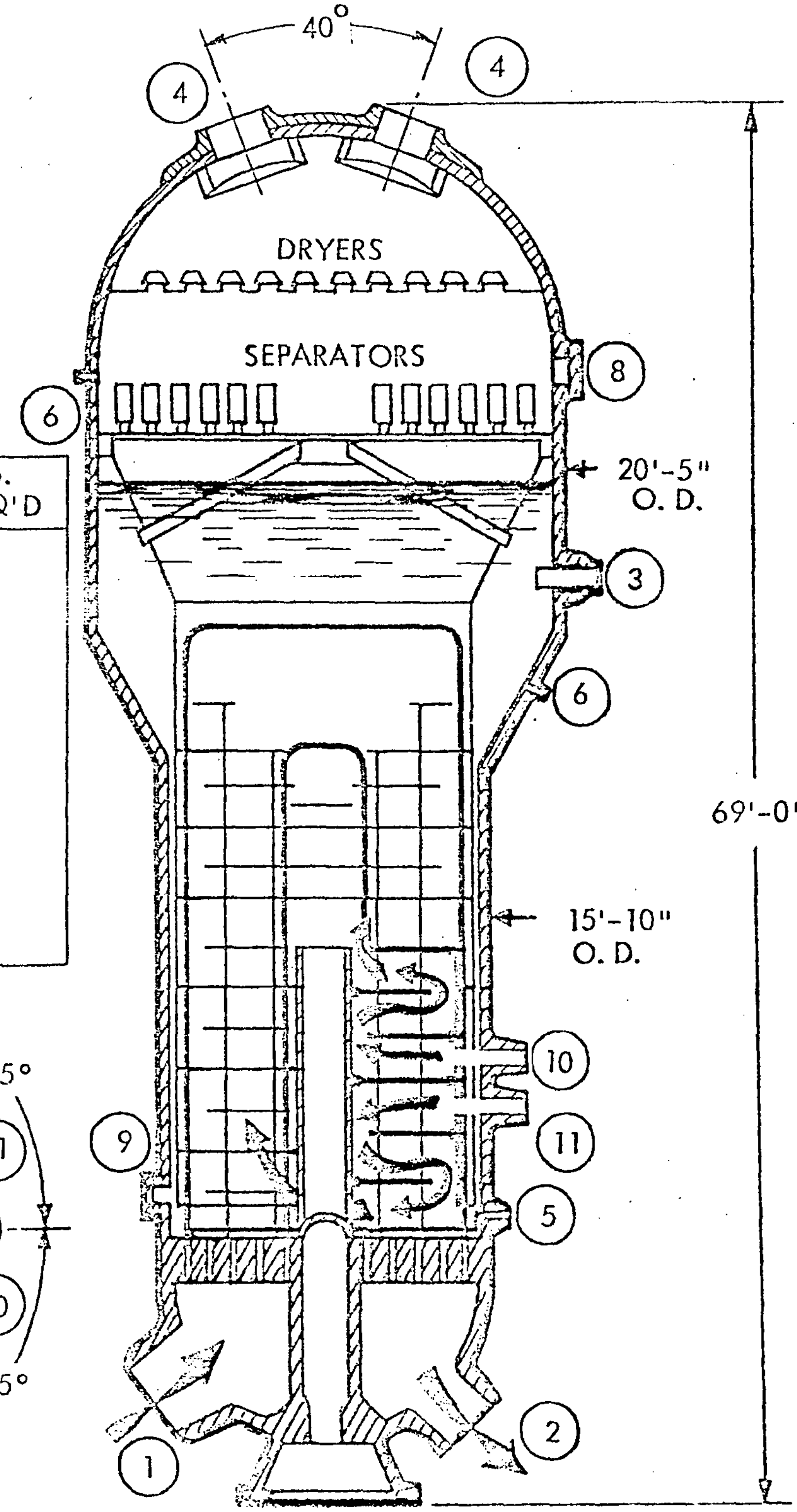
2. SPECIAL TESTS

3. COMMENTS ON INSTRUMENTATION

4. ANY ADDITIONAL COMMENTS

NO.	SERVICE	No. REQ'D
1	PRIMARY INLET	1
2	PRIMARY OUTLET	2
3	DOWNCOMER FEEDWATER	1
4	STEAM OUTLET	2
5	BOTTOM BLOWDOWN	1
6	LIQUID LEVEL	8
7	PRIMARY MANWAY	2
8	SECONDARY MANWAY	2
9	HANDHOLE	2
10	UPPER ECONOMIZER FEEDWATER	1
11	LOWER ECONOMIZER FEEDWATER	1





DRY WEIGHT	1,428,900 LBS	
FLOODED WEIGHT	2,220,000 LBS	
NORMAL OPERATING WT.	1,725,000 LBS	(FULL LOAD)
SHIPPING WEIGHT	1,570,000 LBS	

Amendment No. 28
May 5, 1975

C-E SYSTEM 80

STEAM GENERATOR

Figure 5.5-2

TABLE 5.5-2

STEAM GENERATOR PARAMETERS (1)

Number of Units	2	
Heat Transfer Rate, each, Btu/hr	6.512×10^9	
Primary Side		
Coolant Inlet Temperature, F	621.2	
Coolant Outlet Temperature, F	564.5	
Coolant Flow Rate, each, lb/hr	82×10^6	
Coolant Volume at 68°F each, ft^3	2158	
Tube Size, OD, in.	3/4	
Tube Thickness, in., nominal	.042	
Secondary Side		
Steam Pressure, psia	1070	
Steam Flow Rate (at .25% moisture) each, lb/hr	8.59×10^6	
Feedwater Temperature at full power °F	450	
Moisture Carryover, weight percent maximum	0.25	
Primary Inlet Nozzle, No/ID, in.	1/42	
Primary Outlet Nozzle, No/ID, in.	2/30	
Steam Nozzle, No/ID, in.	2/28	
Feedwater Nozzles, No/Size/Sch.	2/14/80	8
Auxiliary Feedwater Nozzle, No/Size/Sch.	1/6/80	
Overall Heat Transfer Coefficient (estimated), Btu/hr-ft^2-°F	1728	8

(1) Performance parameters are based on full power operation. See Table 5.3-2 also.

Amendment No. 8
October 7, 1974

Babcock & Wilcox

Power Generation Group
P.O. Box 1260, Lynchburg, Va. 24505
Telephone: (804) 384-5111

November 11, 1977

H. W. Massie, Jr.
Westinghouse Electric Corporation
Box 355
Pittsburgh, PA. 15230

Dear Mr. Massie:

I regret our delay in responding to your letter of October 12 requesting proposed test conditions for the unblocked, blocked, and steam generator separate effects FLECHT tests.

We have reviewed the nominal or reference conditions and ranges of conditions given in Tables 1-5 of the attachments to your request. We are in general agreement with the proposed conditions and have no further comments in that regard.

As also requested, we have reviewed Tables 6-8 of the attachments and have provided nominal EM values and suggested ranges of conditions for the listed parameters.

I hope that this information can be of value to you in designing the test program. If you require clarification or have need of further information, please feel free to contact me directly.

Sincerely,

J Cudlin

J. J. Cudlin, Manager
LOCA Methods Unit
Technical Staff

JJC/bm
Attachments

TABLE 6

17 X 17 BLOCKED TESTS

	Nominal EM Conditions	Preferred Range of Condition
1. PARAMETER		
Flooding Rate in/s	1.5	.8 to 6
Pressure psia	40	25 to 50
Peak Power at BOC Kw/ft	0.8	0.5 to 1.0
ECC Water Subcooling F	100	50 to 150 try one at 0
Rod Initial Temperature at BOC F	1200	600 - 1600
% Blockage $\left(\frac{\Delta \text{ Blocked}}{\Delta \text{ Unblocked}}\right)$	60%	10% - 70%
% Bypass	Not Available	

2. SPECIAL TESTS

3. COMMENTS ON INSTRUMENTATION

4. ANY ADDITIONAL COMMENTS

TABLE 7

17 X 17 UNBLOCKED TESTS

	Nominal EM Condition	Nominal BE Condition	Preferred Range of Conditions
1. Parameter			
- Flooding Rate in/s	1.5	1.5	0.8 to 6.0
- Pressure psia	40	40	25 to 50
- Peak Power at BOC Kw/ft	0.8	0.8	0.5 to 1.0
- ECC Water Subcooling F	100	100	50 to 150
- Rod Initial Temp. at BOC F	1200	1200	600 to 1600

2. Special Tests

3. Comments on Instrumentation

4. Any Additional Comments

TABLE 8

STEAM GENERATOR SEPARATE EFFECTS TESTS

	Nominal EM Conditions	Nominal BE Conditions	Preferred Range of Conditions
1. PARAMETER			
- Inlet Primary Steam Flow lbm/sec	150	150	50 - 200
- Inlet Primary Quality %	50	50	30 - 100
- Primary System Pressure psia	40	40	25 - 50
- S.G. Secondary Pressure ft	470	470	250 - 1000
- S.G. Secondary Level ft	20	20	16 - 26
- S.G. Secondary Water Temperature ^oF	460	460	400 - 540

2. SPECIAL TESTS

3. COMMENTS ON INSTRUMENTATION

4. ANY ADDITIONAL COMMENTS

EXXON NUCLEAR COMPANY, Inc.

2101 Horn Rapids Road
P. O. Box 130, Richland, Washington 99352
Phone—(509) 943-8100 Telex: 32-6353

WVK-77-6 November 15, 1977

Mr. E. H. Davidson
Division of Reactor Safety Research
Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Davidson:

Exxon Nuclear has the following comments regarding the proposed FLECHT-SEASET tests (Westinghouse letter SPM-77-665 of October 12, 1977):

1. The reference test conditions for blocked and unblocked tests presented in Tables 1 and 3 are acceptable.

2. The range of test conditions for the blocked and unblocked tests are acceptable except for two parameters, the peak power and the coolant subcooling. The maximum peak power appears to be too high. We suggest a maximum of 0.8 Kw/ft. Also the coolant subcooling should range between 50 and 180°F.

3. The range of conditions for the steam generator separate effect tests are acceptable except for the secondary side pressure and temperature which should have lower limits of perhaps 200 psia and 382°F.

4. A useful separate effects test would be to model the upper plenum region of the fuel rod and to measure the response of wall temperature and fill gas temperature with time. The upper fuel rod plenum condition is a very sensitive parameter in determining rupture conditions of the fuel rod during a LOCA.

5. Measurements of droplet density and size near the upper tie plate (11 to 12 ft elevation) would be helpful in predictions of fallback into the core as well as heat transfer to the upper fuel rod plenum.

6. For the flow blockage tests, ENC would like to see the experiments made with 20-70% of the flow channel blocked.

Sincerely,

William V. Kayser

Dr. William V. Kayser
Nuclear Safety Engineering

WVK:mh
cc: Mr. H. W. Massie, Jr.

EG&G Idaho, Inc.

P. O. Box 1625
Idaho Falls, Idaho 83401

October 14, 1977

Mr. R. E. Tiller, Director
Reactor Operations and Programs Division
Idaho Operations Office - DOE
Idaho Falls, Idaho 83401

"BEST ESTIMATE" DESIGN DATA FOR FLECHT-SEASET TEST FACILITIES - Stig-293-77

Ref: G. W. Johnsen, et. al., A Comparison of "Best-Estimate" and "Evaluation Model" LOCA Calculations: The BE/EM Study, EG&G Idaho Inc., PG-R-76-009, December 1976

Dear Mr. Tiller:

At the August 30, 31, 1977 FLECHT-SEASET Program Management Group meeting, EG&G Idaho, Inc. was asked to provide "Best Estimate" type data to aid in the design of the several test facilities of that program. Specifically, the following information was requested for a four-loop PWR:

1. Total core power at the beginning of reflood.

2. Core inlet, equivalent forced-feed, flooding rate (inches per second) as a function of time throughout the reflood period.

3. Upper plenum pressure as a function of time during reflood.

4. Representative fuel rod axial temperature profile at reflood initiation.

5. The subcooled temperature of the liquid at the core inlet as a function of time during reflood.

The following information is our response to the subject request. It is our understanding that Westinghouse (Test Contractor) is asking for max-min type data with which to size the test facilities rather than specific tests to be performed. Depending upon the specific parameter under discussion, "Best Estimate" type predictions would dictate the limit of one end of the test range (Maximum or minimum) and licensing criteria the other extreme (minimum or maximum). Westinghouse will establish the licensing limits based on data from the several PWR vendors (i.e. W, CE, B&W, etc).

As your are aware, there are currently no universally accepted criteria as to what constitutes a "Best Estimate" analysis of a PWR. Further, because current codes are in a developmental stage, it is sometimes necessary to perform analyses in ways that cannot be proven to be prototypical at this time. Thus we must state that while the following information is based on our evaluation of calculations from current BE codes and constitutes our best judgement as to the desired data, those data are not without some uncertainty. It is our recommendation that Westinghouse provide healthy contingencies over and above the "Best Estimate" data reported herein. Where possible, we have indicated what constitutes, in our judgement, reasonable contingencies.

I. Total Core Power at the Beginning of Reflood

The blowdown, "Best Estimate" analysis of the reference shows that reflood starts at approximately 39 seconds after rupture. The assumptions used in that analysis are identified in the reference. Briefly these were:

1. Rated power (3238 MW) at rupture (Zion I).

2. ANS standard decay heat profile.

3. The fuel condition was defined in terms of "most probable state", which translates to a middle-of-cycle, equilibrium condition (Initial peak power = 10.91 KW/ft).

4. SCRAM occurs.

5. Nominal containment pressure.

Based on the above, the total core power at reflood initiation would be:

$$3238 \text{ MW} \cdot PF_{ANS} = (3238 \times 0.04) = 129.5 \text{ MW}$$

In our judgement, future improvement of the analytical process and tools could affect the calculated time of reflood by up to ± 5 seconds. Based on these criteria, the test facility should be capable of simulating a total core power(BE) at reflood initiation of:

$$(3238 \text{ MW})(0.039) \leq \text{Total Core Power} \leq (3238 \text{ MW})(0.041)$$
$$126.3 \text{ MW} \leq \text{Total Core Power} \leq 132.7 \text{ MW}$$

II. Core Inlet, Equivalent Forced-Feed Flooding Rate

Several "Best Estimate" studies of a prototypical plant have been reviewed in order to develop the desired data. The majority of these studies came from the reflood follow-on effort of the reference. This effort has not been formally documented to date. All of the studies reviewed used gravity reflood models thus the core inlet flow was oscillatory in nature. Concerning the period and amplitude of these oscillations we recognize that there is a measure of uncertainty about the protypicality of the calculated values. However, it is our judgement that equivalent forced-feed flooding rates reduced from the calculated data base can be used as guides in the subject test facility design.

As a result of our review, we conclude that a stepped flooding rate of 6 inches per second for the first 5 seconds and 4 inches per second thereafter, most nearly represents the composite calculated results, However, because of the stated uncertainty in the analytical tools, we feel that the test facilities should have the capability for both stepped and constant flooding rates up to 8 inches per seconds. We do not wish to discourage Westinghouse from designing for flooding rates higher than 8 inches per second, but feel such a decision rests on the degree of increased cost associated with this additional capability.

III. Upper Plenum Pressure

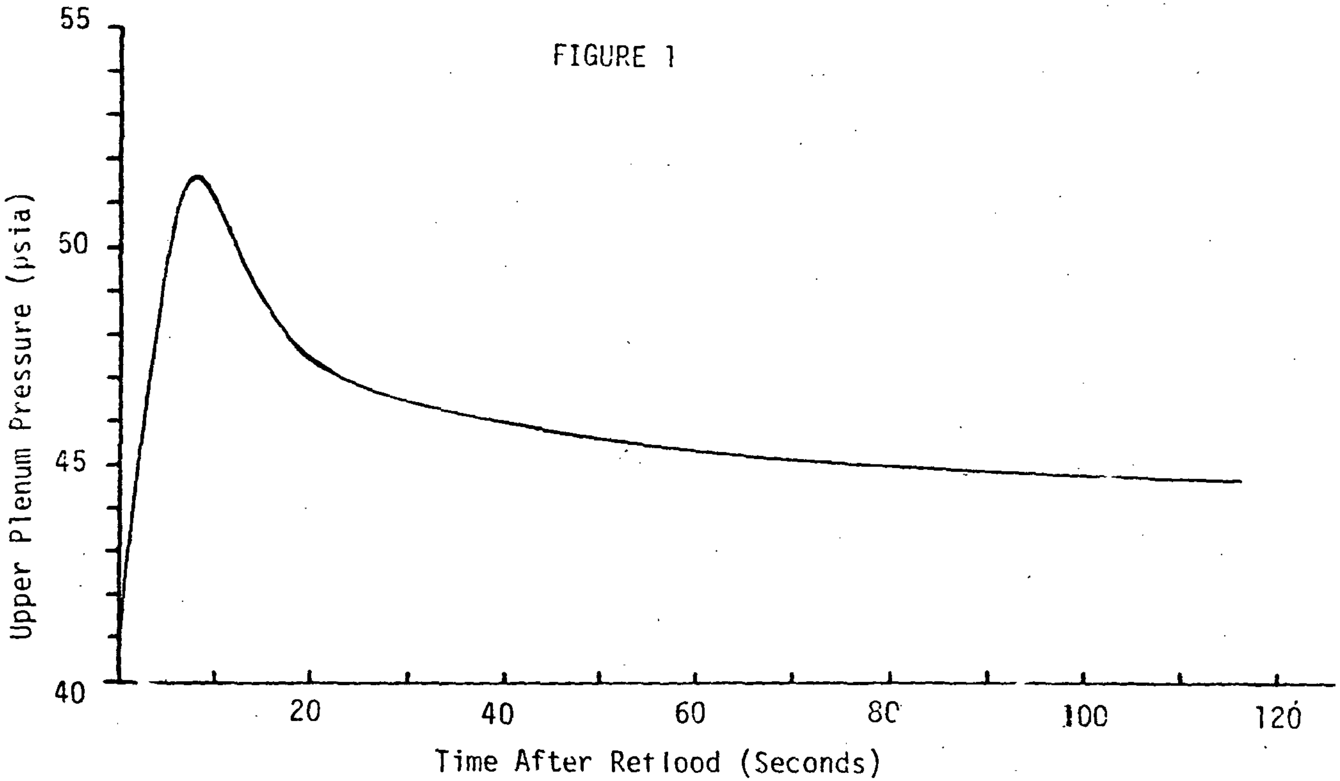
The following information was developed from the same calculated data base as was the flooding rate discussed in Section II and is, therefore, subject to the same uncertainty identified in that section. In the subject studies the upper plenum pressure was also oscillatory; however, because the local (short duration) oscillations are a result of gravity-feed phenomena, not simulated in the FLECHT-SEASET separate effects tests, a smoothed profile is a more appropriate design base for those test facilities. The profile developed from the source studies is shown in Figure 1. Please be aware that we are not saying that Figure 1 is "The Reflood Profile", but rather we conclude that:

1. The test facilities should have the capability of programming a desired upper plenum pressure profile.

2. The current "best estimate" pressure level at reflood initiation is 40 psia for a Zion type four loop plant.

3. The test facility should have the capability to vary the upper plenum pressure over a 15 psi (minimum) range during reflood.

FIGURE 1


55
50
45
40
Upper Plenum Pressure (psia)
20
40
60
80
100
120
Time After Reflood (Seconds)

IV. Fuel Rod Axial Temperature Profile at Reflood Initiation

The average core temperature profile developed from the "Best Estimate" blowdown/refill study of the reference is shown in Table I.

TABLE I

Elevation (ft)	Fuel Rod Surface Temperature (°F)	Elevation (ft)	Fuel Rod Surface Temperature (°F)
0	550	7	971
1	685	7.8	980(Peak)
2	840	8	978
3	893	9	961
4	917	10	910
5	937	11	780
6	956	12	530

The data in the table indicate that at reflood initiation, the temperature is slightly skewed toward the top. This condition appears to be result of hydraulic phenomena rather than the rod power profile (approximately symmetrical about the 6 foot elevation) and may or may not be prototypical. Again we do not wish to imply that Table I defines "The Profile". Rather we conclude that the test facility design should provide for:

1. Peak heater rod temperatures as low as 900°F.

2. Heater rod temperatures at the top and bottom of the rod as low as 500 °F.

It is our understanding that the shape of the axial temperature profile in the test facility heater rods is a direct function of the heater element wrap design. Thus to vary the temperature profile, significantly, a different heater rod design is required for each desired profile. In terms of heater equipment cost, it may be prohibitively expensive to provide the capability for more than one initial temperature profile. If this is indeed the case, we recommend that the cosine profile used in the FLECHT-SET test program be continued in this program. However, we would also suggest that serious consideration be given to using the skewed profile of FLECHT-SET in addition to the cosine profile.

V. Core Inlet, Liquid Subcooling Profile During Reflood

It is our understanding that Westinghouse is asking for information regarding the bulk liquid temperature response in the lower plenum during reflood. Of all the data requested, this information has proven to be the most difficult to predict. The subject response depends on such items as the point of ECC injection (upper plenum, cold leg, etc.), the ECC subcooling at point of injection, system pressure response, assumed steam/water mixing at point of injection, etc. If one assumes minimum steam/water mixing at the point of injection, and minimum short-term heat transfer in the injection path (downcomer, etc.), then our calculations indicate that the lower plenum bulk liquid subcooling can increase from zero at reflood start to that at the point of ECC injection within 50 to 70 seconds after reflood initiation. If on the other hand one assumes that considerable steam is generated and available at the point of injection, that this steam is well mixed with the injected ECC upstream of the lower plenum, and that considerable residual heat is extracted from the injection path (wall heat), then it is possible to foresee zero subcooling in the lower plenum throughout most of the reflood. Until such time as our analytical tools and the experimental data on which they are based are improved, we can only recommend that the capability for considerable subcooling be provided in the test facility design. We feel that 140 °F of subcooling is historically significant and is, therefore, appropriate in the absence of other criteria. We further recommend that the test facility be capable of providing a smoothed subcooled profile ranging from zero at reflood initiation to full subcooling some 50 to 70 seconds after reflood initiation. It is our judgement that such a capability should allow for the proper subcooling profile at such time in the future as that profile can be determined with an acceptable degree of certainty.

Very truly yours,

R. R. Stiger, Manager
Reactor Behavior Division

GEW:sw

cc: E. H. Davidson, NRC-RES (Proj. Manager) - 3
R. W. Kiehn EG&G Idaho, Inc.

APPENDIX B
SHAKEDOWN TEST MATRIX DETAILS

B-1. INTRODUCTION

This appendix serves as a detailed corollary to paragraphs 6-3 through 6-23 of this report. These specific paragraphs briefly summarized bench tests, single-phase, forced reflood and gravity reflood shakedown tests. Some repetition of text material from section 6 will be necessary to identify specific tests.

B-2. SHAKEDOWN TEST MATRIX

Prior to conducting the reflood tests outlined in paragraphs 6-24 through 6-41, a series of shakedown tests will be run on the test facility. These shakedown tests will be conducted not only on separate facility components (bench tests) prior to final assembly but also on the completely assembled test facility.

The purpose of the shakedown tests is to insure that the instrumentation, control, and data acquisition systems are working properly so that useful and valid data can be obtained during the reflood experiments. Some of the shakedown tests are also intended to verify and adjust control procedures.

Paragraphs B-3 through B-23 present a detailed description of each shakedown test.

B-3. Bench Tests

The following list of tests outline the portion of the shakedown test matrix that will be conducted on various facility components prior to final assembly of the test facility.

B-4. Housing Window Heatup Check — This test is intended to verify and adjust heatup control procedures for the housing windows. Heating of the windows will minimize steam condensation on the windows because of early quenching of the quartz lens.

Before installing the heater rod bundle in the housing, one window will be instrumented with three thermocouples. For this shakedown test, one thermocouple will be placed at the center of the quartz lens inside surface nearest the heater rods. This thermocouple will monitor the window surface temperature response once the heaters are turned on. The other two thermocouples will be located at the clamp-on-type window heater as shown in the schematic (figure B-1). One of these thermocouples is attached to the window housing beneath the heater and will be used for data acquisition on the FLUKE and for on/off heater control. The third thermocouple is attached to the heater outside surface and will be connected to an upper temperature limiter to prevent heater burnout.

This shakedown test will be conducted by powering the heater according to predetermined guidelines such as power level, setpoints, and so forth. Power will be supplied to the heater based on feedback from the control monitoring thermocouple until an inside surface window temperature of 260°C (500°F) is reached. The required time for window heatup will be recorded and incorporated into the facility heatup procedure.

B-5. Thermocouple Wiring Connection Checks — The purpose of this test is to check the continuity of each thermocouple wiring connection from the patch board to the computer. A known direct current millivolt signal will be applied to each circuit at the thermocouple patch board and compared to the respective computer output reading. If a deviation of more than plus or minus 0.1 millivolts is observed, the circuit will be checked, repaired and retested.

B-6. Forced Reflood Configuration Test Facility Shakedown Testing

The following list of tests outlines another portion of the shakedown test matrix. This section will be involved with those shakedown tests conducted on the completely assembled test facility in the forced reflood configuration.

B-7. Heater Rod Power Connection Check — This test is intended to check the continuity of each heater rod power connection at the fuse panel. Using a Wheatstone bridge or an accurate digital ohmmeter, measurements will be recorded for each circuit resistance with an accuracy of plus or minus 0.001 ohms. If an abnormal reading is taken, the circuit will be checked, repaired and retested.

B-8. Instrumented Heater Rod Radial Location and Corresponding Thermocouple Checks — This test will be performed only on rods whose thermocouples are connected to the computer and is intended to check the following items:

- For each instrumented heater rod, all corresponding thermocouples are checked for appropriate computer channel hookup and proper recording of data.
- In completing the above check, radial power connections between the fuse panel and the appropriate heater rod are confirmed.
- The output polarity of each thermocouple at the computer will also be checked.

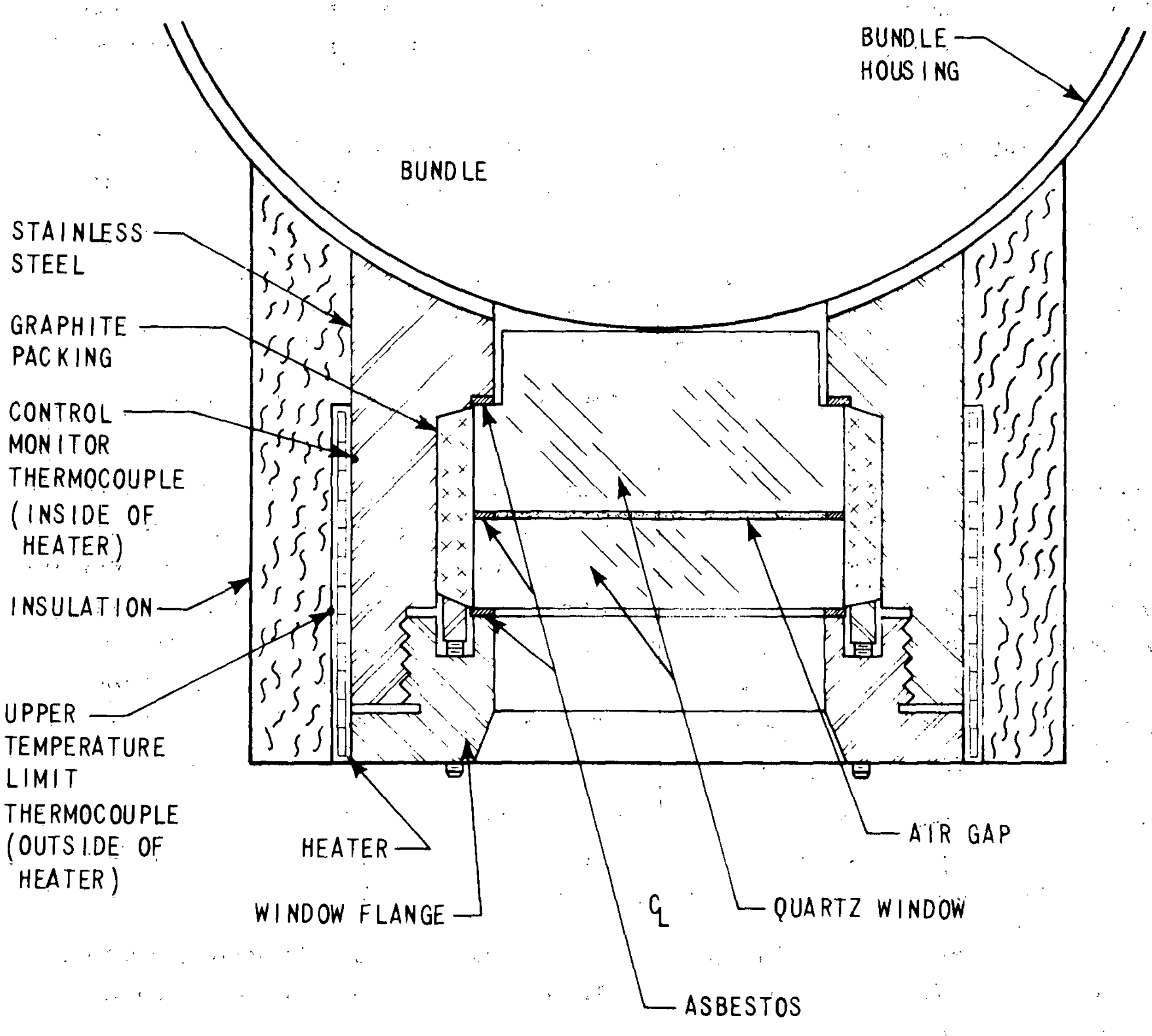


Figure B-1. Window Flange Heater Schematic.

In order to conduct this test, all instrumented heater rods will be connected one at a time to a small, manually-controlled power supply. The rod bundle will be filled with cold water at atmospheric pressure, the exhaust valve will be fully opened, and the computer will be in operation for data acquisition. The over-temperature limit alarm will be set at 149°C (300°F).

In turn, minimal power will be applied to each heater rod and all corresponding thermocouple outputs will be recorded through the computer. After the power is disconnected, all computer channels will be scanned to check that the appropriate thermocouple computer channels have responded and that data was recorded properly.

B-9. Heater Rod, Thimble and Steam Probe Thermocouple Axial Location Checks — This test will be performed using only instrumented heater rods and is intended to check the following items:

- For each bundle thermocouple elevation all corresponding heater rod, thimble and steam probe thermocouples are checked for appropriate computer channel axial hookup and proper recording of data.
- In completing the above check each heater rod, thimble and steam probe thermocouple elevation is confirmed.

In order to conduct this test, all instrumented heater rods will be connected to the power supply. Output from all heater rod, thimble and steam probe thermocouples as well as all test vessel differential pressure cells will be recorded by the computer. The computer will also control bundle power automatically. An over-temperature limit will be set at 260°C (500°F) and this limit will be checked before the atmospheric pressure test is conducted. The lower plenum will be filled to the bottom of the heated length with water at room temperature or colder and the exhaust valve will be fully opened. A level sight gauge will be installed across the test section to aid manual control of the flooding rate.

With the facility prepared as specified above, power is applied to the rod bundle until it is automatically tripped on an over-temperature condition. As the bundle is progressively flooded, all bundle thermocouple responses will be recorded to verify axial position.

B-10. Test Section Differential Pressure Cell Axial Locations, Steam Separator Collection Tank and Carryover Tank Volume and Level Transmitter Checks — This test is intended to check the following items:

- Test section differential pressure cells are checked for appropriate computer channel axial hookup.
- Test section control volumes will be established in one foot increments.
- The lower plenum volume will be checked.

- The steam separator collection tank and the carryover tank volumes will be determined.

- The steam separator collection tank and the carryover tank level transmitters along with the test section differential pressure cells will be checked for proper operation.

For operation of this test all housing differential pressure cells, along with the steam separator collection tank and the carryover tank level transducers will be connected to the computer. A sight gauge will be connected across the test section and a weigh tank will be installed to measure the drained water. With the exhaust valve closed and the upper plenum vent opened, all differential pressure cells should be vented and the required transmission lines filled with water. At this point the test section, steam separator collection tank, and the carryover tank will be filled with cold water until water runs out of the highest test section differential pressure cell tap at 3.66 m (12 ft) and tank vents.

With the water solid facility prepared as outlined above, water will be drained and weighed from the test section in 0.305 m (1 ft) increments, and the differential pressure cell outputs will be recorded until the bottom of the heated length is reached. This process will then be continued until the lower plenum is emptied. Then water will be drained and weighed from the steam separator collection tank and the carryover tank in 0.61 m (2 ft) increments to determine tank volumes and level transmitter operation.

B-11. Pressure Control Valve Operation, Exhaust Orifice Plate Flow Check and Differential Pressure Cell Zero Shifts — The following checks will be conducted during this test:

- The test section, tanks, and orifice differential pressure cells zero readings and zero shifts will be checked.

- The response of the pressure control valve to sudden changes in flow will also be checked.

For operation of this test all test section, tanks, and orifice differential pressure cells will be connected to the computer. A nitrogen supply will be connected to the bottom of the test section and the pressure control valve will be closed.

When the test loop is empty and has reached atmospheric pressure, zero readings of all differential pressure cells will be checked. After the system is pressurized with nitrogen to 0.28 MPa (40 psia), all differential pressure cell zero shifts will be recorded. Then a steady state nitrogen flow selected between 0.09 to 0.45 kg/s (0.2 to 1.0 lbm/sec) will be developed with the pressure control valve maintaining upper plenum pressure at 0.28 MPa (40 psia). The nitrogen flow will then be varied several times between 0.09 to 0.45 kg/s (0.2 to 1.0 lbm/sec) to check the pressure control valve automatic response to changes in flow while maintaining 0.28 MPa (40 psia) system pressure.

B-12. Rotameters and Turbine Flowmeter Calibration, and Flow Control Valve Operation Checks – This test is intended to check the following items:

- A spot check of rotameters and turbine meter calibration for agreement with the "full flow range" calibrations performed prior to the shakedown tests will be conducted.

- The flowmeters will thus be checked for appropriate computer channel hookup.

- Flow control valve response to a continuously variable flooding signal will also be checked.

In preparation for this shakedown test, the turbine meter, rotameters, accumulator differential pressure cell, accumulator fluid thermocouple, and the flow control valve will be connected to the computer. The computer-activated flow control valve will be regulated by a signal from the turbine meter. The accumulator will be filled with water at 54°C (130°F) and will have a nitrogen back pressure of 2.76 ± 0.14 MPa (400 ± 20 psig). The injection line from the rotameters to the test section lower plenum will be replaced by a flexible hose.

With the facility prepared as outlined above, flow rate spot checks of each rotameter in series with the 3.8×10^{-5} to 3.8×10^{-3} m^3/s (0.6 to 60 gpm) turbine meter will be conducted for the steady state flooding rates listed in table B-1, Item A.

At first, the flow through the flowmeters will be run to the drain. After steady flow conditions have been established, the flow will be diverted to the weigh tank for the specified time interval shown in table B-1. The accumulator differential pressure cell, accumulator fluid thermocouple, and all flowmeter outputs will be monitored during the test. At the end of the test, the flow will be switched to the drain again and flow measurements will be terminated. The collected water will be weighed, the actual flow will be calculated and the flowmeter signals will be averaged. These readings are then compared to the "full flow range" calibration results for repeatability.

When the steady flow checks on the flowmeters are complete, a variable stepped flooding rate check will be conducted to evaluate the system response of all flowmeters in the forced reflood configuration. The system will be set up as for the previous flow checks and the test will be conducted as described above. However, for this test, the computer will be programmed to activate three solenoid control valves which work in conjunction with the three rotameters to follow the variable stepped flow pattern specified in table B-1, Item B.

TABLE B-1

FLOODING RATES FOR FLOW METER CALIBRATION AND FLOW CONTROL VALVE OPERATION CHECKS (UNBLOCKED BUNDLE TASK 3.2.1)

A. STEADY STATE FLOODING RATES – FORCED REFLOOD		
0. – 3.79 x 10^{-4} m^3/s	(0 – 6 gpm)[a]	Rotameter and Turbine Meter
6.31 x 10^{-5} m^3/s	(1 gpm)	for 5 min.
1.89 x 10^{-4} m^3/s	(3 gpm)	for 5 min.
3.15 x 10^{-4} m^3/s	(5 gpm)	for 5 min.
0 – 1.14 x 10^{-3} m^3/s	(0 – 18 gpm)	Rotameter and Turbine Meter
5.05 x 10^{-4} m^3/s	(8 gpm)	for 5 min.
7.57 x 10^{-4} m^3/s	(12 gpm)	for 3 min.
1.01 x 10^{-3} m^3/s	(16 gpm)	for 3 min.
0 – 6.31 x 10^{-3} m^3/s	(0 – 100 gpm)	Rotameter and Turbine Meter
1.26 x 10^{-3} m^3/s	(20 gpm)	for 2 min.
2.52 x 10^{-3} m^3/s	(40 gpm)	for 2 min.
3.79 x 10^{-3} m^3/s	(60 gpm)	for 2 min.
5.05 x 10^{-3} m^3/s	(80 gpm)	for 2 min.
B. VARIABLE STEPPED FLOODING RATES – FORCED REFLOOD		
2.33 x 10^{-3} m^3/s	(37 gpm) for 5 sec.	≈ 152. mm/s (6 in./sec) flood
6.31 x 10^{-4} m^3/s	(10 gpm) for 50 sec.	≈ 38.1 mm/s (1.5 in./sec) flood
2.52 x 10^{-4} m^3/s	(4 gpm) for 100 sec.	≈ 15.2 mm/s (0.6 in./sec) flood
C. CONTINUOUSLY VARIABLE FLOODING RATES – FORCED REFLOOD		
5.93 x 10^{-4} to 1.58 x 10^{-4} m^3/s (9.4 gpm to 2.5 gpm) in 400 sec		
38.1 to 10.2 mm/s (1.5 in./sec to 0.4 in./sec) in 400 sec		

a. Ranges and values enclosed in parenthesis represent the English equivalent of the SI engineering units.

The final flowmeter test for the forced reflood configuration, will be conducted to evaluate the system response of the flow control valve, coupled with the turbine meter and a rotameter. The flow control valve will respond to a programmed continuously variable flooding rate specified in table B-1, Item C. The system is set up as before and the test is conducted similarly.

B-13. Carryover Tank, Steam Separator Tank, and Connecting Piping Heatup Checks – This test is intended to evaluate the pretest heatup of the test facility's tanks and connecting piping. The heatup of this portion of the test facility is achieved initially by powering strip heaters attached to the external surfaces and then by circulating superheated steam through the facility. Loop thermocouple temperatures will be reviewed to determine temperature uniformity of the tanks and piping walls both before and after the steam is injected. The time needed for heating the facility components to the required temperatures will also be determined from this test.

In preparation for this shakedown test, selected wall and fluid thermocouple channels will be recorded by the computer and the FLUKE data acquisition systems. The boiler will be brought up to temperature and residual water will be drained from the tanks and piping prior to running the test. The wall heaters will be controlled manually as in the test program.

With the facility prepared as outlined above, the heaters will be powered until the tanks and piping thermocouples read 149 ± 11.1°C (300 ± 20°F). At this time all heaters except for those located on the steam separator downstream piping will be turned off and slightly superheated steam [T_{sat} + 11.1°C, (T_{sat} + 20°F)] from the boiler will be injected into the facility. The test vessel drain and all component drains, as well as the pressure control valve, are opened in order to circulate this steam for uniform heating. After the steam separator downstream piping wall thermocouples indicate 260 ± 11.1°C (500 ± 20°F), heaters on this section of piping will also be turned off. This shakedown test will continue until all facility thermocouples indicate approximately T_{sat} + 11.1°C (T_{sat} + 20°F) with the exception of the steam separator downstream piping thermocouples.

B-14. Motion Picture Check – Four motion picture cameras will be available for use in the test program. One camera can accommodate a 365.8 m (1200 ft) reel of film and the other three new high speed cameras can accommodate up to 122 m (400 ft) reels. This test is intended to examine the operation of one of the new high speed cameras and will be run in conjunction with the following Low Power and Low Temperature shakedown test. From this test it will be determined how much time is needed to reload these cameras for further filming and the quality of the movies will be reviewed for any changes needed in filming techniques.

For operation of this test the camera and lighting will be set up at the two housing windows at the 1.83 m (6 ft) elevation. The film speed will be set at 1000 frames/sec. Therefore, the 30.5 m (100 ft) reel, containing 4000 frames will last approximately 4 seconds. The first 4 seconds of filming will start at the initiation of reflood. Then the camera will be reloaded as quickly as possible and a second reel of film will be shot as soon as it is prepared. If, after reviewing the movies, major adjustments are necessary, another trial run will be scheduled during the test program.

B-15. Low Power and Low Temperature Test, Forced Reflood Configuration – This shakedown test is intended as a trial run for the complete test facility in the forced reflood configuration. The test will be conducted according to normal procedures (refer to paragraph 5-16), with care taken to meet all requirements for a valid run (refer to paragraph 5-27). Test conditions are the same as for Test Matrix No. 21, a nominal 0.28 MPa (40 psia) run having low power and low initial clad temperature.

All instrumentation will be connected to its specified recording system and all channels will be recorded. This test will be used to check all unconfirmed instrumentation for appropriate computer channel hookup and operation. Included in this review will be the operation of all bundle housing wall thermocouples. The complete data acquisition system and all facility control systems will be evaluated from this test.

For operation of this shakedown test, the initial conditions specified in table B-2 will be observed. Power decay will follow the ANS + 20 percent curve, and the over-temperature limit will be set at 816°C (1500°F). The motion picture equipment (high speed camera) will also be operated during this shakedown test. Refer to paragraph B-14 for motion picture shakedown test.

B-16. Test Facility Special Single Phase Testing

The shakedown tests outlined in paragraphs B-17 and B-18 will employ only single-phase steam flow through the facility in the forced reflood configuration.

B-17. Steam Cooling Shakedown Test – This unpowered shakedown test will be used to examine and adjust control procedures in preparation for the steam cooling tests described in paragraph 6-37. The following items are specific goals of this steam cooling shakedown test:

- Pressure control valve response to the initial steam injection into the lower plenum at about 0.31 MPa (45 psia) pressure will be observed.
- The value of the lower plenum pressure will be determined in order to achieve a 0.28 MPa (40 psia) upper plenum setpoint pressure when steady flow conditions are established.

TABLE B-2
LOW POWER AND TEMPERATURE SHAKEDOWN TEST
INITIAL CONDITIONS – FORCED REFLOOD
(UNBLOCKED BUNDLE TASK 3.2.1)

Upper Plenum Pressure, Constant	0.28 MPa	(40 psia)
Rod Initial Clad Temperature	260°C	(500°F)
Rod Peak Power	1.31 kW/m	(0.4 kw/ft)
Flooding Rate, Constant	38.1 mm/s	(1.5 in./sec)
Injection Water Subcooling	78°C	(140°F)
Bundle Radial Power Profile	Uniform	(Uniform)
Carryover Tank Wall Temperature	T_{sat} + 11.1°C	(T_{sat} + 20°F)
Steam Separator and Tank Wall Temperature	T_{sat} + 11.1°C	(T_{sat} + 20°F)
Separator Upstream Piping Temperature	T_{sat} + 11.1°C	(T_{sat} + 20°F)
Separator Downstream Piping Temperature	260 ± 11.1°C	(500 ± 20°F)

- The magnitude of pressure oscillations will be studied to determine how well automatic controls can maintain a 0.28 MPa (40 psia) static pressure in the upper plenum with the high steam flow velocity.
- After the test is completed any control adjustments needed to improve the results will be determined.

In preparation for this test, the facility will be modified by the connection of a 1814 kg/hr (4000 lbm/hr) boiler to the system. This larger boiler operating at 164°C, 0.69 MPa (328°F, 100 psia) will supply steam directly to a closed bypass loop as well as to the lower plenum injection line. When the test is initiated, a steady-state flow will be redirected from the bypass loop to the lower plenum. Saturated 0.69 MPa (100 psia) steam from the boiler will be throttled down to an approximate feedline exit pressure of 0.31 MPa (45 psia). A steady-state steam mass flow rate of 0.37 kg/s (0.81 lbm/sec) will be delivered to the test section for the duration of the test. This mass flow corresponds to a liquid flooding rate of 25.4 mm/s (1.0 in./sec).

The following instrumentation will be monitored and recorded:

- all test section differential pressure cells
- overall differential pressure cell

- upper plenum pressure transducer
- pressure control valve
- large and small boiler instrumentation
- all boiler feedline instrumentation
- lower plenum fluid thermocouples
- upper plenum fluid thermocouples

When the facility is prepared as outlined above, the steam separator and exhaust line will be heated to the pretest temperatures given in table B-2. The small boiler will be used to pressurize the facility to 0.28 MPa (40 psia) with superheated steam (T_{sat} + 11.1°C, T_{sat} + 20°F). The loop component drains and the pressure control valve will be opened to circulate the steam for uniform heating. During this preparation, steam from the large boiler will flow through the bypass loop in order to develop the desired steady-state flow conditions specified above. Then the test will be initiated by switching the large boiler steam flow from the bypass loop to the lower plenum. At this time, the small boiler will be valved-out, the pressure control valve will maintain the upper plenum pressure at 0.28 MPa (40 psia), and the feedline vortex meter will be used to reestablish desired steady-state flow conditions. After approximately 300 seconds of steady state operation, the boiler will be turned off and the system depressurized. This test may be repeated, if necessary, to evaluate any control adjustments.

B-18. Steam Probe Operation Checks – Two steam probe operation tests, one at 0.28 MPa (40 psia) and the other at 0.14 MPa (20 psia) upper plenum pressure, will be outlined in this paragraph. These shakedown tests will be run in conjunction with the Steam Cooling shakedown test (paragraph B-17) in order to utilize the modified facility layout. The 23 steam probes located in the test vessel are grouped by elevation into six manifold systems. Each manifold outlet empties into a separate ice-packed collection tank at atmospheric pressure. These tests will be unpowered and are intended to determine the following items:

- The amount of steam flow through each of the six manifolds.
- A reasonable response to changing flow conditions from all steam probe thermocouples.
- Operating procedure check for steam probe valving, manifolding, and condensate measurement.

- Operating pressures throughout the test vessel for steady-state flow conditions in order to determine the steam probe to atmosphere pressure differential.
- Differences in system response between the 0.28 MPa (40 psia) and 0.14 MPa (20 psia) shakedown tests.

In preparation for these tests, the test facility will remain in the Steam Cooling shakedown test configuration (paragraph B-17). Saturated 0.69 MPa (100 psia) steam from the large 1814 kg/hr (4000 lbm/hr) boiler will be throttled down to an approximate feedline exit pressure of 0.31 MPa (45 psia) or 0.16 MPa (23 psia) desired for the appropriate test. The steady-state mass flow rates to be developed by the boiler are 281 kg/hr (620 lbm/hr) for the 0.28 MPa (40 psia) test and 136 kg/hr (300 lbm/hr) for the 0.14 MPa (20 psia) test. These flow rates maintain the dynamic similarity (Reynolds number) between actual test conditions and the shakedown test conditions.

The instrumentation to be monitored and recorded is the same as that specified for the Steam Cooling test, with the addition of all 22 steam probe thermocouple outputs. As will be done with future tests, a 6 pen strip chart recorder will monitor one thermocouple from each of the six steam probe groupings to facilitate operator control of the test.

With the facility prepared as outlined above, the steam separator and exhaust line will be heated to the pretest temperatures given in table B-2. The small boiler will be used to pressurize the facility to 0.28 MPa (40 psia) or 0.14 MPa (20 psia) with superheated T_{sat} + 11.1°C (T_{sat} + 20°F) steam. The loop component drains and the pressure control valve will be opened to circulate the steam for uniform heating. During this preparation, steam from the large boiler will flow through the bypass loop in order to develop the desired steady-state flow conditions specified above. The initial weight of steam probe vapor collection tanks containing ice will be recorded. The valves between each manifold and collection tank will remain closed as the solenoid valves in each of the 22 steam probe vent lines are opened to atmosphere. Then the large boiler steam flow will be switched from the bypass loop to the lower plenum. At this time, the small boiler will be valved-out, the pressure control valve will maintain the desired upper plenum pressure setpoint and the feedline vortex meter will reestablish desired steady-state flow conditions in the facility. The steam probes will be bled to the atmosphere to heat the lines and eliminate any condensate, as well as to check that each line is clear.

As the test is initiated, all steam probe vent solenoid valves are closed and the manifold to collection tank valves are opened. The condensate will be collected from each manifold for about 5 minutes. All steam probe temperatures and test section differential pressures will be recorded during the test. After completion of the test, the amount of condensate will be determined by again weighing the collection tanks and subtracting the pretest weights.

B-19. Additional Shakedown Tests for Gravity Reflood Testing

Gravity reflood modifications and testing will be scheduled after completion of the forced reflood testing. The following list of shakedown tests will be conducted on the completely assembled facility after it has been modified for the gravity reflood configuration (paragraph 5-1).

B-20. High Range Turbine Flowmeter Flow Checks — With the facility modified for the gravity reflood testing, this shakedown test is intended to check the following items:

- The flowmeters will be checked for appropriate computer channel hookup.
- A spot check of the new high range 9.5×10^{-5} m^3/s to 9.5×10^{-3} m^3/s (1.5 to 150 gpm) turbine meter calibration will be made for agreement with the "full flow range" calibrations that will be conducted prior to the shakedown tests.

In preparation for this test, all flowmeters and the flow control valve will be connected to the computer. The computer-activated flow control valve will be controlled by a signal from the turbine meter. The accumulator will be filled with water at 54°C (130°F) and will have a nitrogen back pressure of 2.76 ± 0.14 MPa (400 ± 20 psig). The injection line from the rotameters to the downcomer elbow will be replaced with a flexible hose. Spot checks of the rotameters have been omitted from this shakedown test because their calibration was checked in the forced reflood configuration.

With the facility prepared as outlined above, flow rate spot checks of the turbine meter calibration will be conducted for the variable stepped injection rates specified in table B-3.

TABLE B-3
HIGH RANGE TURBINE FLOWMETER FLOW CHECKS
VARIABLE STEPPED INJECTION RATES — GRAVITY REFLOOD
(UNBLOCKED BUNDLE TASK 3.2.1)

6.52×10^{-3} m^3/s (103 gpm) for 14s ≈ 6.49 kg/s (14.3 lbm/sec)

7.82×10^{-4} m^3/s (12.3 gpm) for 60s ≈ 0.77 kg/s (1.7 lbm/sec)

This test will evaluate the system response of the flowmeters for the gravity reflood configuration and will be conducted as described previously (paragraph B-12). However, for this test the computer will be programmed to activate three solenoid control valves which work in conjunction with the three rotameters, to follow the specified stepped flow pattern.

B-21. Bidirectional Turboprobe Flow Checks – With the facility in the gravity reflood configuration, this shakedown test is intended to be a functional check of the bidirectional turboprobe calibration for agreement with it's "full flow range" calibrations. This test will be conducted in two phases; the first with the turboprobe oriented in its forward direction and the second with the turboprobe turned 3.14 rad (180°) to check the reverse flow measurements of the instrument. This test will also review the turboprobe instrumentation for appropriate computer channel hookup.

In preparation for this shakedown test, the turboprobe, the high range turbine meter, the flow control valve, and the accumulator instrumentation will be connected to and monitored by the computer. The turboprobe will be calibrated after installation in the downcomer crossover piping. The accumulator will be filled with water at 54°C (130°F) and will have a nitrogen back pressure of 2.76 ± 0.14 MPa (400 ± 20 psig). The flow control valve will be actuated by the computer using a signal from the turbine meter. Because of the high flow range of this test, all rotameters will be fully opened. Water will be injected into the bottom of the downcomer while the lower plenum drain is fully opened. An attempt will be made to establish a second reference flow measurement (turbine meter is the first) by collecting and weighing the flow discharge from the lower plenum drain.

With the facility prepared as outlined above, flow rate spot checks of the turboprobe calibration in both forward and reverse orientation will be conducted for the steady-state injection rates specified in table B-4.

TABLE B-4
BIDIRECTIONAL TURBO PROBE FLOW CHECKS
STEADY STATE INJECTION RATES – GRAVITY REFLOOD
(UNBLOCKED BUNDLE TASK 3.2.1)

9.46×10^{-3} m^3/s (150 gpm) for 2 min.

6.31×10^{-3} m^3/s (100 gpm) for 2 min.

3.15×10^{-3} m^3/s (50 gpm) for 2 min.

Steady-state flow rates are established in the loop prior to initiation of the test. The turbo-probe readings will be averaged and compared to the "full flow range" calibration results for repeatability.

B-22. Quick Drain Tests – This series of shakedown tests will be used to examine and adjust control procedures in preparation for the Series No. 11 tests described in paragraph 6-36. Two sets of tests will be conducted in this series; the first with an unpowered "cold" bundle and the second with a powered "hot" bundle. In these shakedown tests the bundle will be initially flooded to the 0.914 m (3 ft) elevation in order to simulate a partially quenched rod bundle at the beginning of reflood. The intended results of these tests will be as follows:

- The length of time required to drain the partially flooded bundle to the bottom of the heated length will be measured.
- After the water has been drained to the bottom of the heated length, the effect of partially quenched rods on the axial temperature profile in the bundle will be evaluated for the powered shakedown tests.
- The specified 0.914 m (3 ft) prefill elevation will be evaluated as to its suitability.
- After the tests are completed, it may be necessary to make control adjustments to improve the results.

In preparation for these tests, the test facility should be in the gravity reflood configuration. The following instrumentation will be monitored and recorded:

- test section incremental differential pressure cells between 0 m and 3.65 m (0-12 ft) elevations
- test section overall differential pressure cell
- accumulator differential pressure cell
- accumulator fluid thermocouple
- all heater rod thermocouples (hot tests only)
- steam separator pressure transducer (hot tests only)

For the cold tests, the loop may be pressurized either with the boiler or with the nitrogen supply; whereas only the boiler will be used for the hot tests. The accumulator will be filled with water at room temperature. In all tests the pressure control valve will be operative to maintain the steam separator pressure at 0.14 MPa (20 psia).

The subsequent paragraphs present procedural and descriptive aspects of cold and hot quick drain tests.

- **Cold Tests.** With the facility prepared as outlined above, the accumulator will be used to fill the test vessel and downcomer to the 0.914 m (3 ft) elevation. The test will be initiated by opening the lower plenum drain to atmospheric pressure. The time required to drain the water from the test section to the bottom of the heated length will be measured. When the test vessel water level reaches the bottom of the heated length, the drain valve will be closed in order to maintain this level in preparation for reflooding (for example, hot tests). The cold testing fill and drain sequence will be repeated three times to obtain an average drain time.

- **Hot Tests.** For operation of the hot tests, a uniform radial power profile will be used with the rod peak power at 1.31 kW/m (0.4 kw/ft). The bundle over-temperature setpoint will be set at 538°C (1000°F) for the initial hot test and at 816°C (1500°F) for the second hot test. Before initiation of the test, the loop will be pressurized to 0.14 MPa (20 psia) and the downcomer and test vessel will be filled again to the 0.914 m (3 ft) elevation. At this point the test will be initiated by applying power to the bundle. When the specified rod initial clad temperature (260°C (500°F) for the first test and 538°C (1000°F) for the second test) is reached at the 1.83 m (6 ft) elevation, the power will be turned off and the lower plenum drain will be opened to atmospheric pressure. The time required for the water level to reach the bottom of the heated length will be recorded. At this time, the lower plenum drain will be closed and the injection line from the accumulator will be manually opened. The test section will then be flooded at 38.1 mm/s (1.5 in./sec) until all rod thermocouples have quenched. After the first test having 260°C (500°F) initial clad temperature, it will be determined whether the test should be repeated before proceeding to the 538°C (1000°F) test. These shakedown tests are intended to supply some foresight to the 871°C (1600°F) initial clad temperature test that is found in the test matrix.

B-23. Low Power and Low Temperature Test, Gravity Reflood Configuration – This shakedown test is intended as a trial run for the complete test facility in the gravity reflood configuration. The test will be conducted according to normal procedures (paragraph 5-16), and will strive to meet all requirements for a valid run (paragraph 5-27). Test conditions are the same as for Test Matrix No. 36, a nominal 0.28 MPa (40 psia) run having low power and low initial clad temperature.

All instrumentation will be connected to its specified recording system and all channels will be recorded. This test will be used to check all unconfirmed instrumentation for appropriate computer channel hookup and proper operation. Included in this review will be the operational and data acquisition checks of the following instrumentation required by the gravity reflood configuration:

- hi-range turbine meter
- bidirectional turboprobe
- downcomer differential pressure cell
- downcomer fluid thermocouple
- downcomer wall thermocouple
- downcomer to steam separator differential pressure cell
- upper plenum to steam separator differential pressure cell
- steam separator tank pressure transducer
- pressure control valve

The complete data acquisition system and all facility control systems will again be evaluated from this test.

For operation of this shakedown test, the initial conditions specified in table B-5 will be observed. Power decay will follow the ANS + 20 percent curve, and the over-temperature limit will be set at 927°C (1700°F).

TABLE B-5

LOW POWER AND LOW TEMPERATURE SHAKEDOWN TEST INITIAL CONDITIONS – GRAVITY REFLOOD (UNBLOCKED BUNDLE TASK 3.2.1)

Steam separator pressure, (constant)	0.28 MPa	(40 psia)
Rod initial clad temperature	457°C	(855°F)
Rod peak power	1.64 kW/m	(0.5 kw/ft)
Injection rate (variable)	6.49 kg/s[a] 0.77 kg/s[b]	(14.3 lbm/sec)[a] (1.7 lbm/sec)[b]
Injection water subcooling	78°C	(140°F)
Bundle radial power profile	Uniform	Uniform
Carryover tank wall temperature	T_{sat} + 11.1°C	(T_{sat} + 20°F)
Steam separator and tank wall temperature	T_{sat} + 11.1°C	(T_{sat} + 20°F)
Separator upstream piping temperature	T_{sat} + 11.1°C	(T_{sat} + 20°F)
Separator downstream piping temperature	260 ± 11.1°C	(500 ± 20°F)
Downcomer and crossover piping temperature	T_{sat} + 11.1°C	(T_{sat} + 20°F)

a. For 0-14 seconds

b. For 14 seconds to end of test

APPENDIX C
INSTRUMENTATION PLAN

Appendix C describes the instrumentation plan for the FLECHT-SEASET Task 3.2.1. This package contains specifications for axial and radial positions of heater rod, steam probe, and thimble thermocouples in the bundle. In addition, a preliminary listing of the 256 channels, which are to be connected to the computer data acquisition system (CDAS), are included. Some channel connections to the computer may be revised if thermocouple failure is encountered either during manufacture or assembly of test section components.

To facilitate the location of desired information on the instrumentation plan, figures and tables in this appendix are presented in a listing as follows:

- Figure C-1 – This figure represents a bundle cross section illustrating radial placement of steam probe, thimble, and heater rod instrumentation. Numbers inside heater rods signify an instrumented heater rod by group (refer to figure 5-14) designation (axial thermocouple (T/C) distribution). Numbers inside a thimble signify elevation of steam probe instrumentation. The abbreviation T/C inside a thimble signifies location of thimble wall thermocouples.

- Figures C-2 through C-20 – These figures represent the location of instrumented heater rods, steam probes, and thimbles by specific elevation. The number inside a heater rod signifies an instrumented heater rod thermocouple, T/C, location at a given elevation. CHXXX signifies a T/C at that location which is to be monitored by the computer and designated as Channel XXX. SP CH XXX indicates location of a steam probe which is to be monitored by the computer as Channel XXX. T/C CH XXX indicated location of a thimble wall thermocouple to be monitored by the computer as Channel XXX. T/C S indicates location of a spare thimble wall thermocouple which is not connected to the computer.

- Table C-1 – This table presents a list of channels and identification of the quantity monitored by the computer data acquisition system. Information is also provided regarding the location of heater rod, steam probe, and thimble thermocouples with respect to power zones for each of the 5 different radial power profiles (refer to figures 6-2 to 6-5).

- Table C-2 – This table represents the axial distribution of heater rod thermocouples according to power zone for each of the 5 different radial power profiles.

- Table C-3 – This table lists thimble thermocouple instrumentation locations identifying spare and connected elevations.
- Table C-4 – This table summarizes quantities of connected and spare thimbles, steam probes, and heater rod thermocouples in the bundle.
- Table C-5 – This table summarizes the availability of bundle heater rod instrumentation.
- Table C-6 – This table presents a detailed steam probe instrumentation plan identifying those elevations which are to be manifolded along with the steam probe to be monitored on the strip chart recorder for each manifolded group.

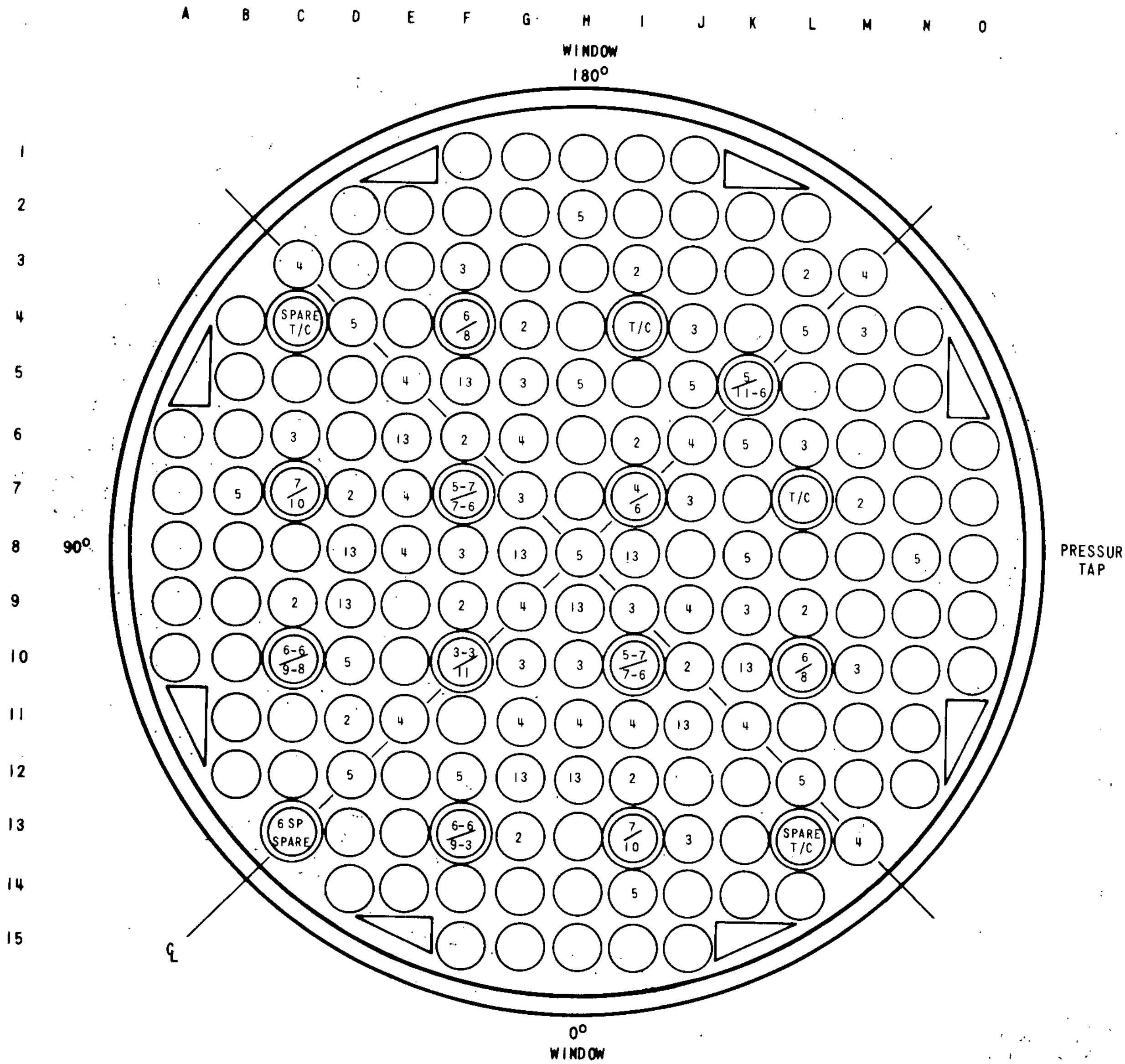
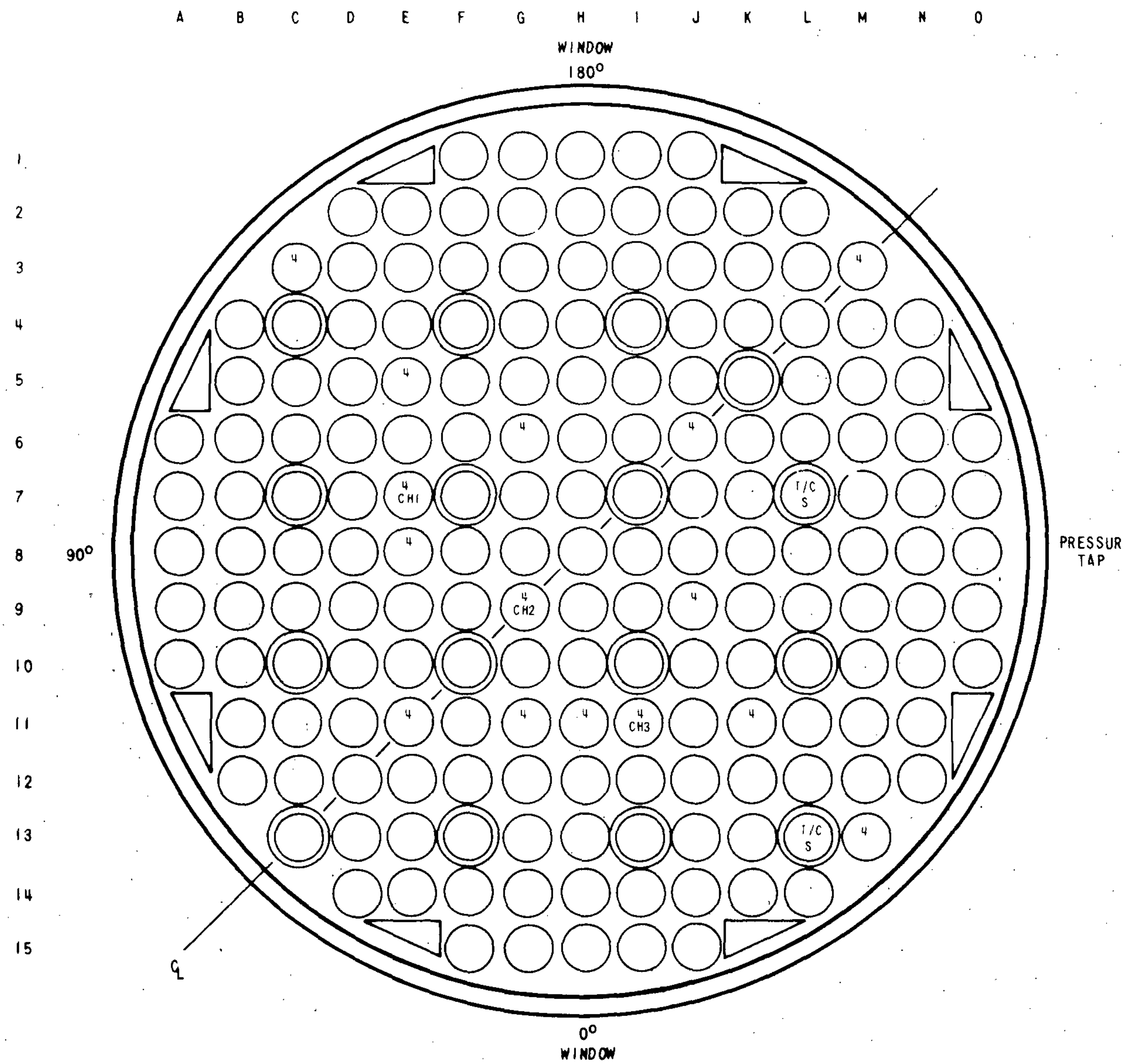


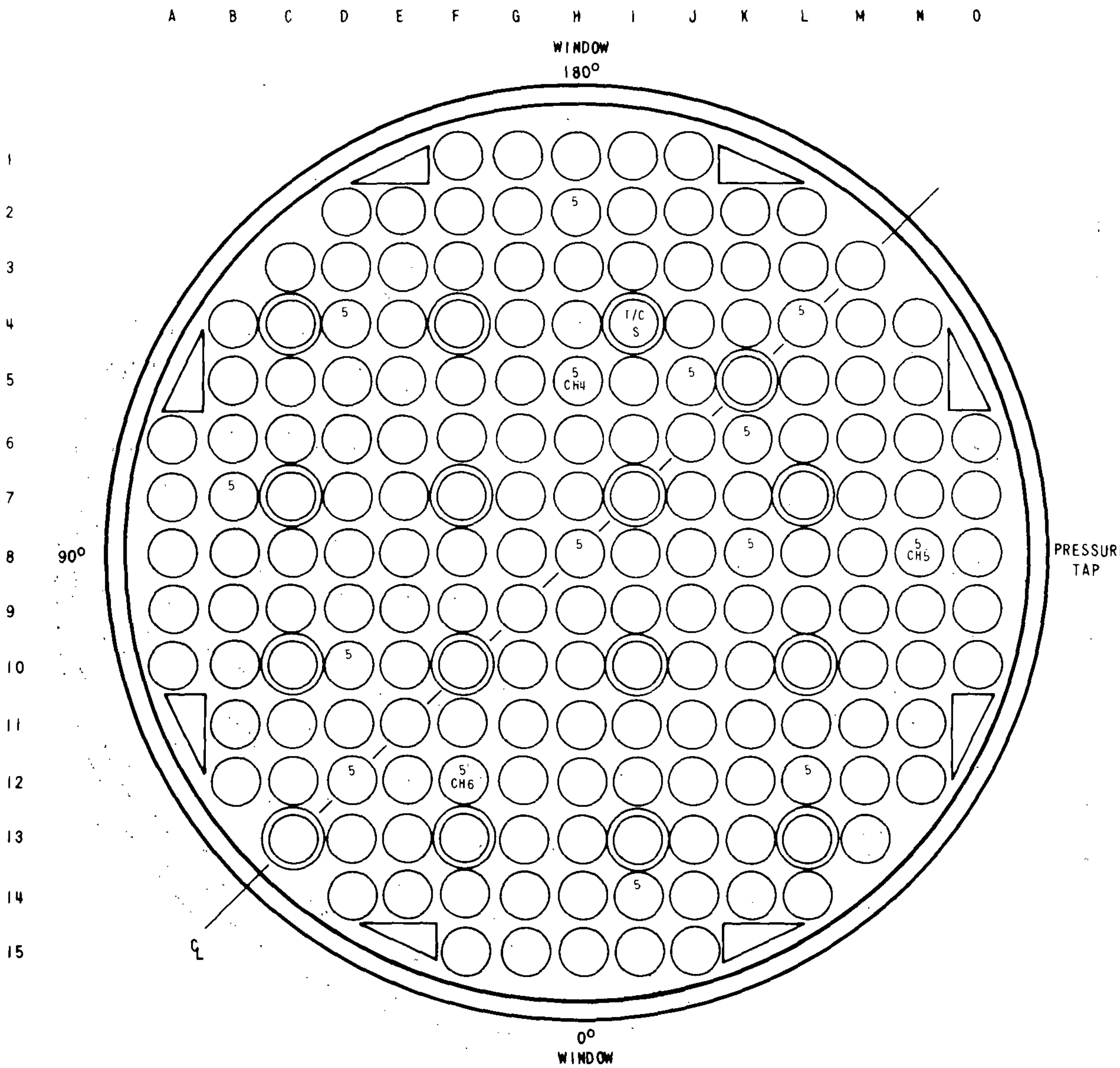
Figure C-1. Cross Section 17 x 17 Unblocked Bundle Instrumentation



(XX) CDAS CHANNEL NO. (X) HEATER ROD GROUP NO.

ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	3	12	15
STEAM PROBES	-	-	-
THIMBLE THERMOCOUPLES	-	2	2

Figure C-2. 17 x 17 Unblocked Bundle Instrumentation – 0.305m (1ft-0in.)

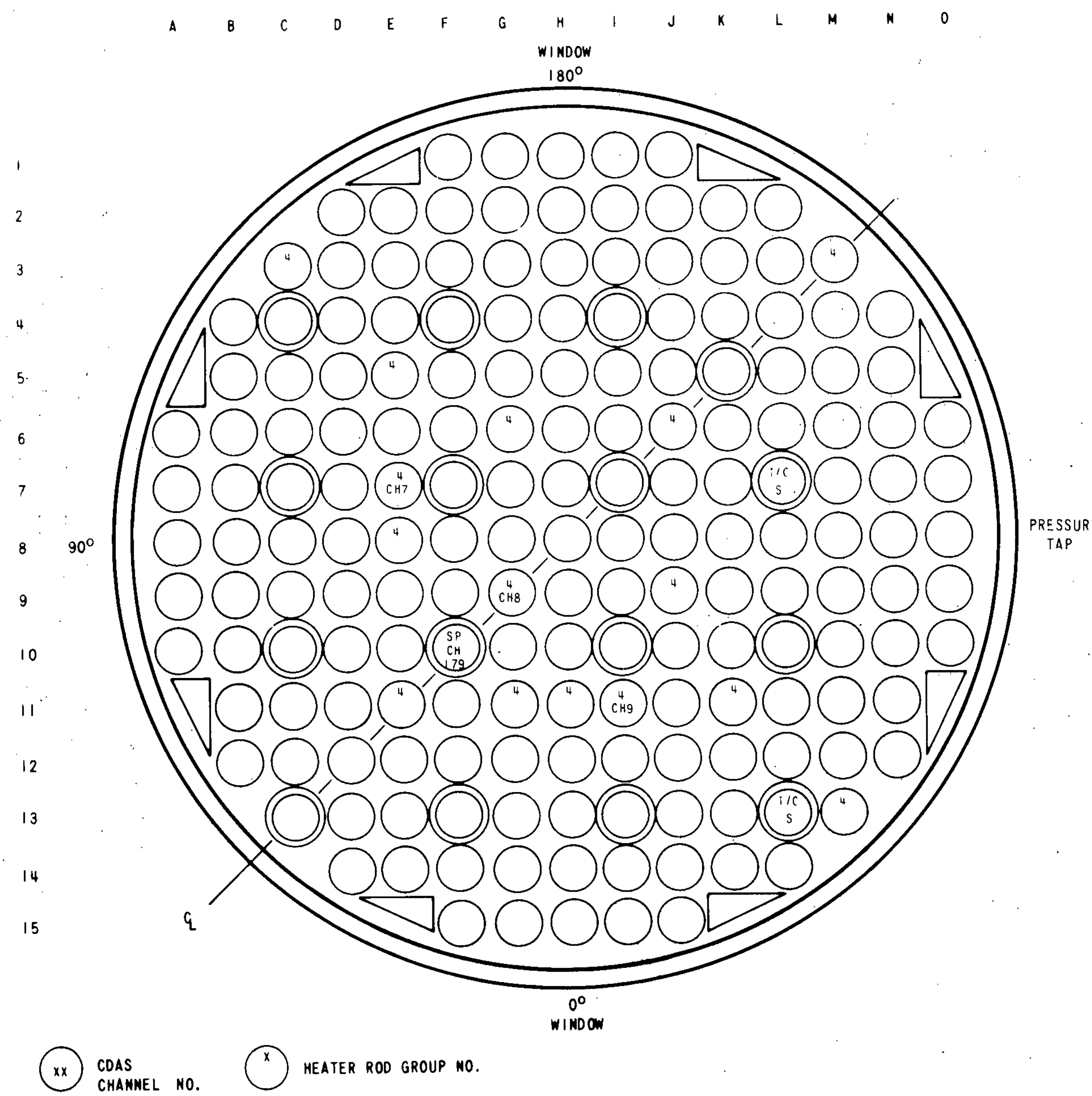


(xx) CDAS CHANNEL NO.

(x) HEATER ROD GROUP NO.

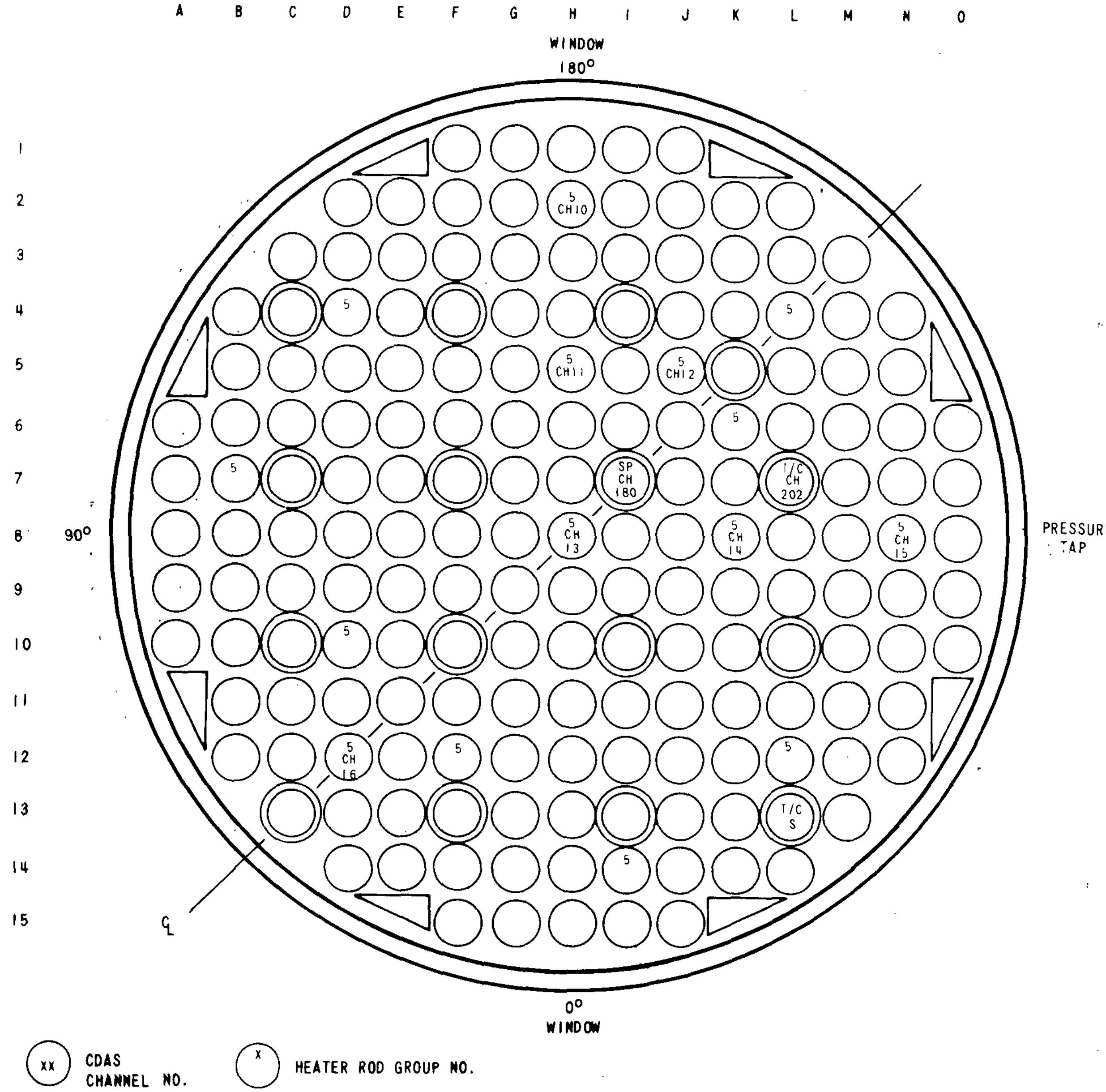
ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	3	12	15
STEAM PROBES	-	-	-
THIMBLE THERMOCOUPLES	-	2	2

Figure C-3. 17 x 17 Unblocked Bundle Instrumentation – 0.610m (2ft-0in.)



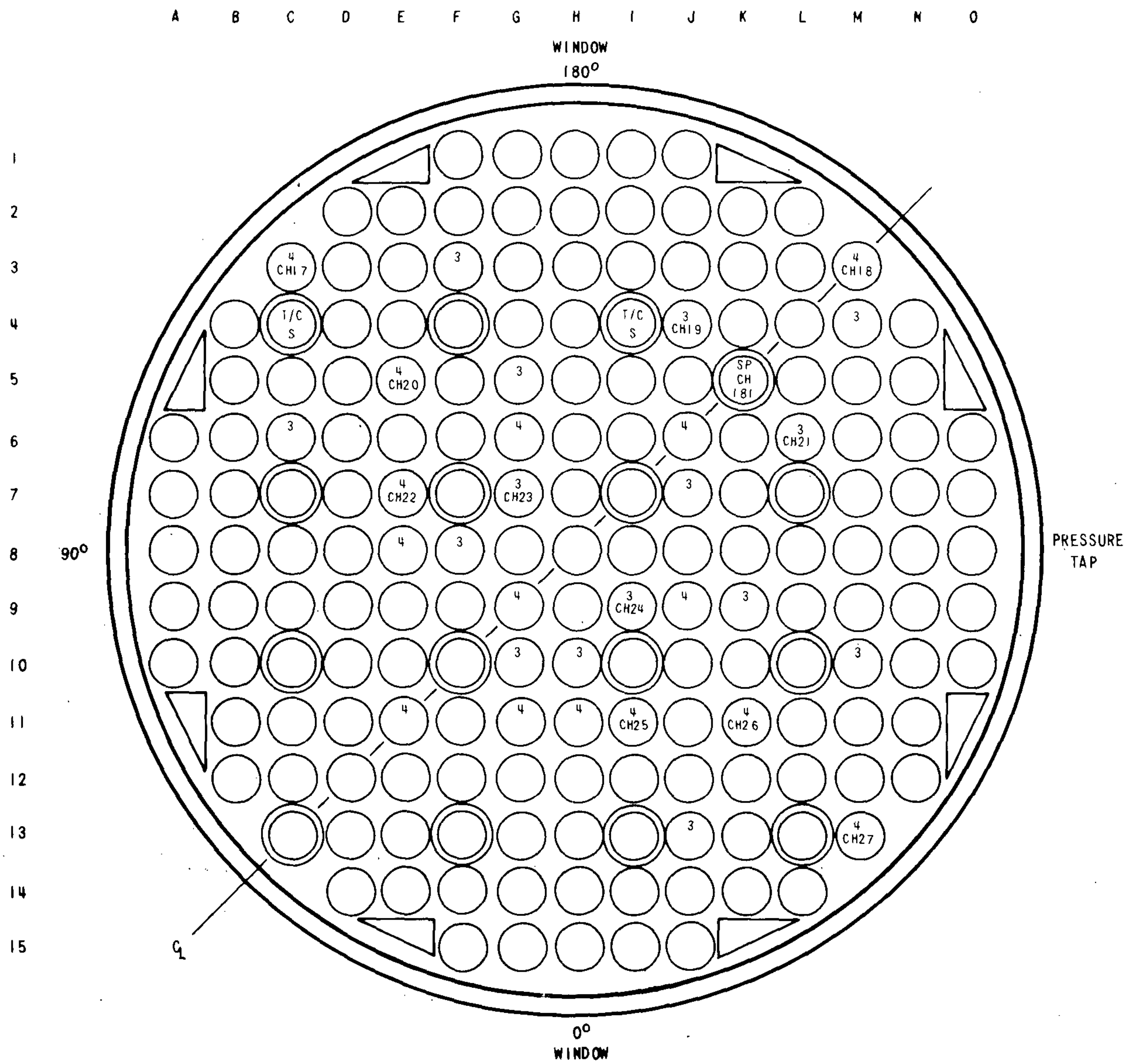
ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	3	12	15
STEAM PROBES	1	-	1
THIMBLE THERMOCOUPLES	-	2	2

Figure C-4. 17 x 17 Unblocked Bundle Instrumentation – 0.991m (3ft - 3in.)



ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	7	8	15
STEAM PROBES	1	-	1
THIMBLE THERMOCOUPLES	1	1	2

Figure C-5. 17 x 17 Unblocked Bundle Instrumentation – 1.22m (4ft - 0in.) Elevation

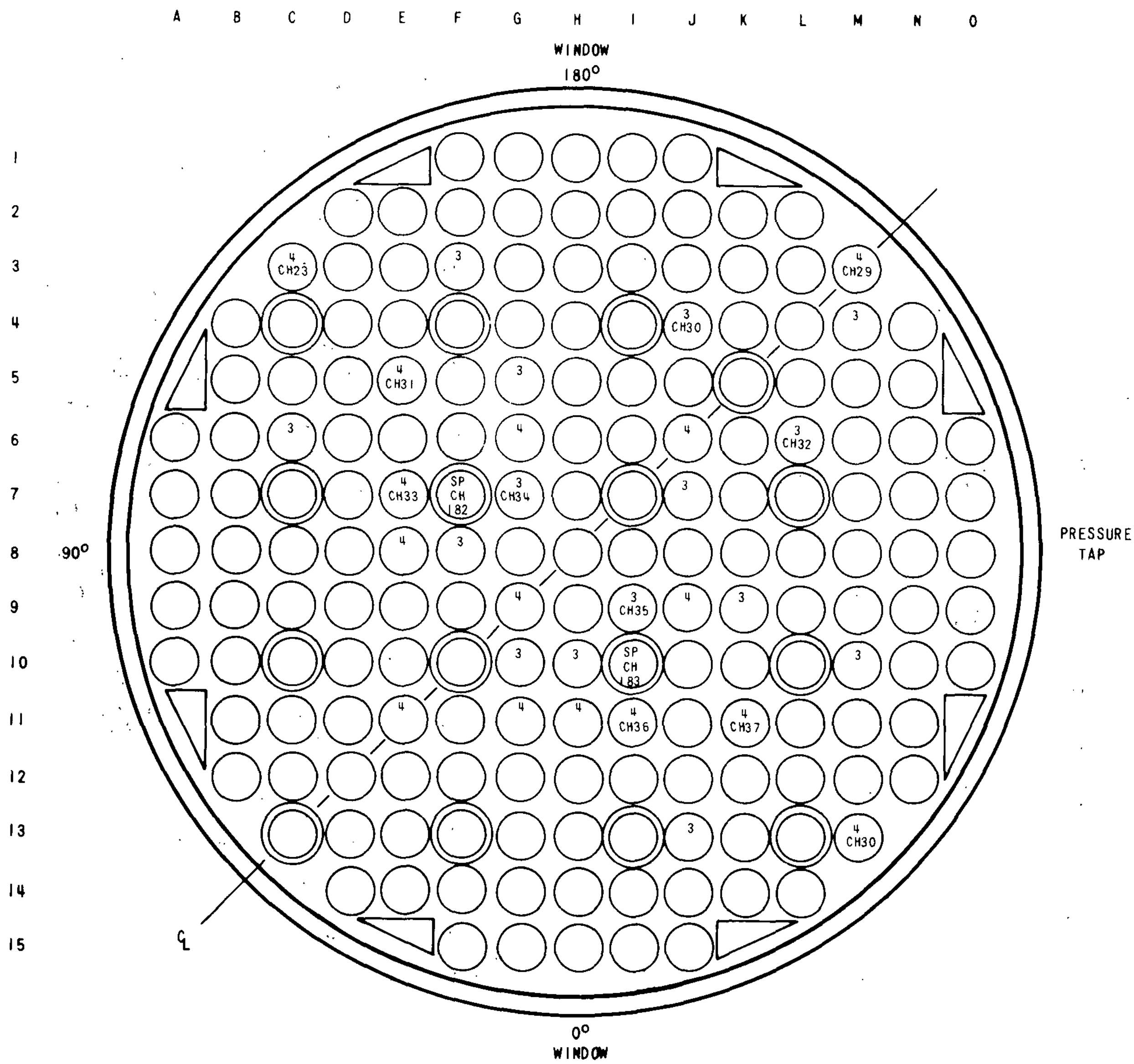


XX CDAS CHANNEL NO.

X HEATER ROD GROUP NO.

ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	11	19	30
STEAM PROBES	1	-	1
THIMBLE THERMOCOUPLES	-	2	2

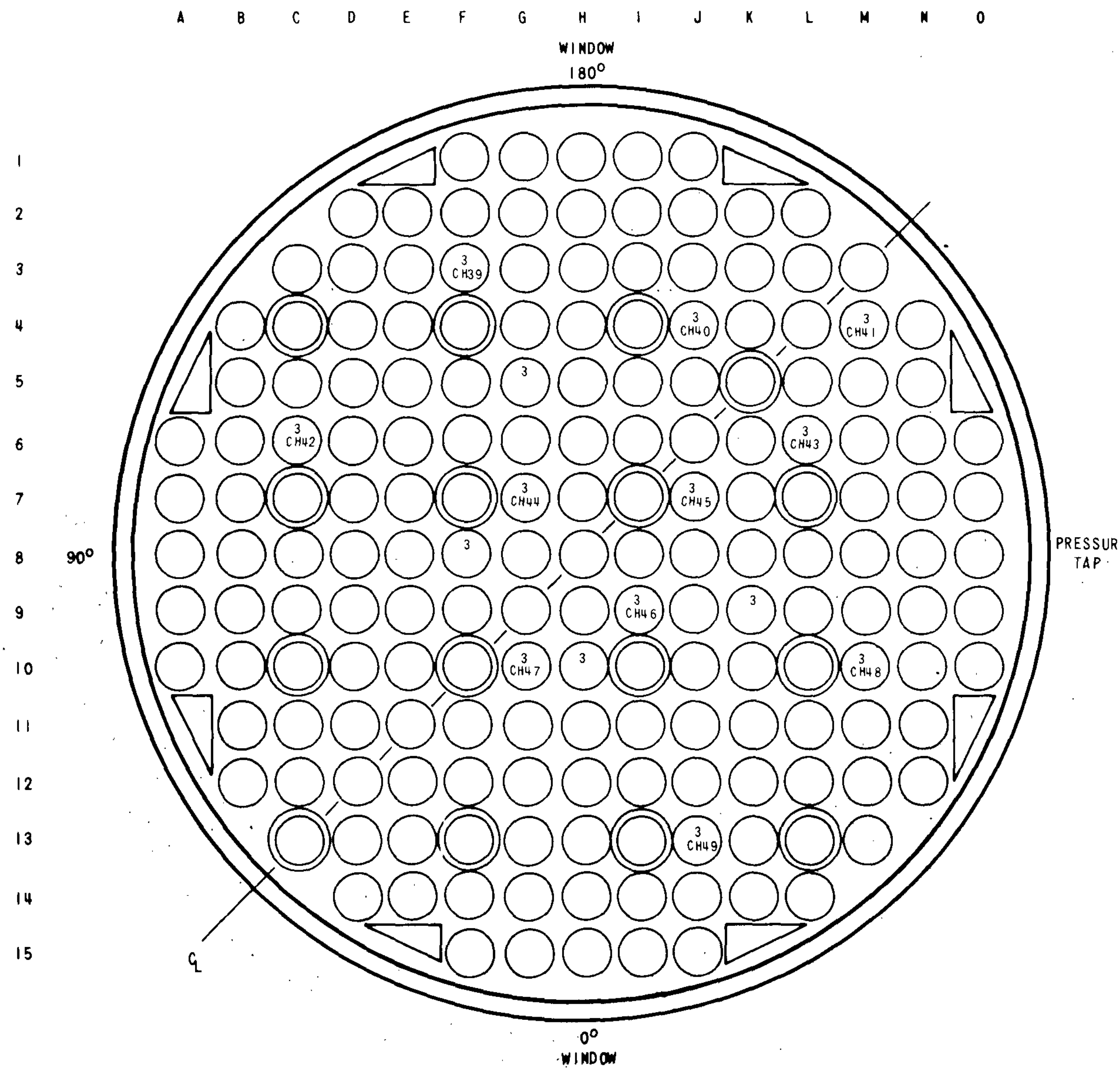
Figure C-6. 17 x 17 Unblocked Bundle Instrumentation – 1.52m (5ft - 0in.) Elevation



XX CDAS CHANNEL NO.   X HEATER ROD GROUP NO.

ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	11	19	30
STEAM PROBES	2	-	2
THIMBLE THERMOCOUPLES	-	-	-

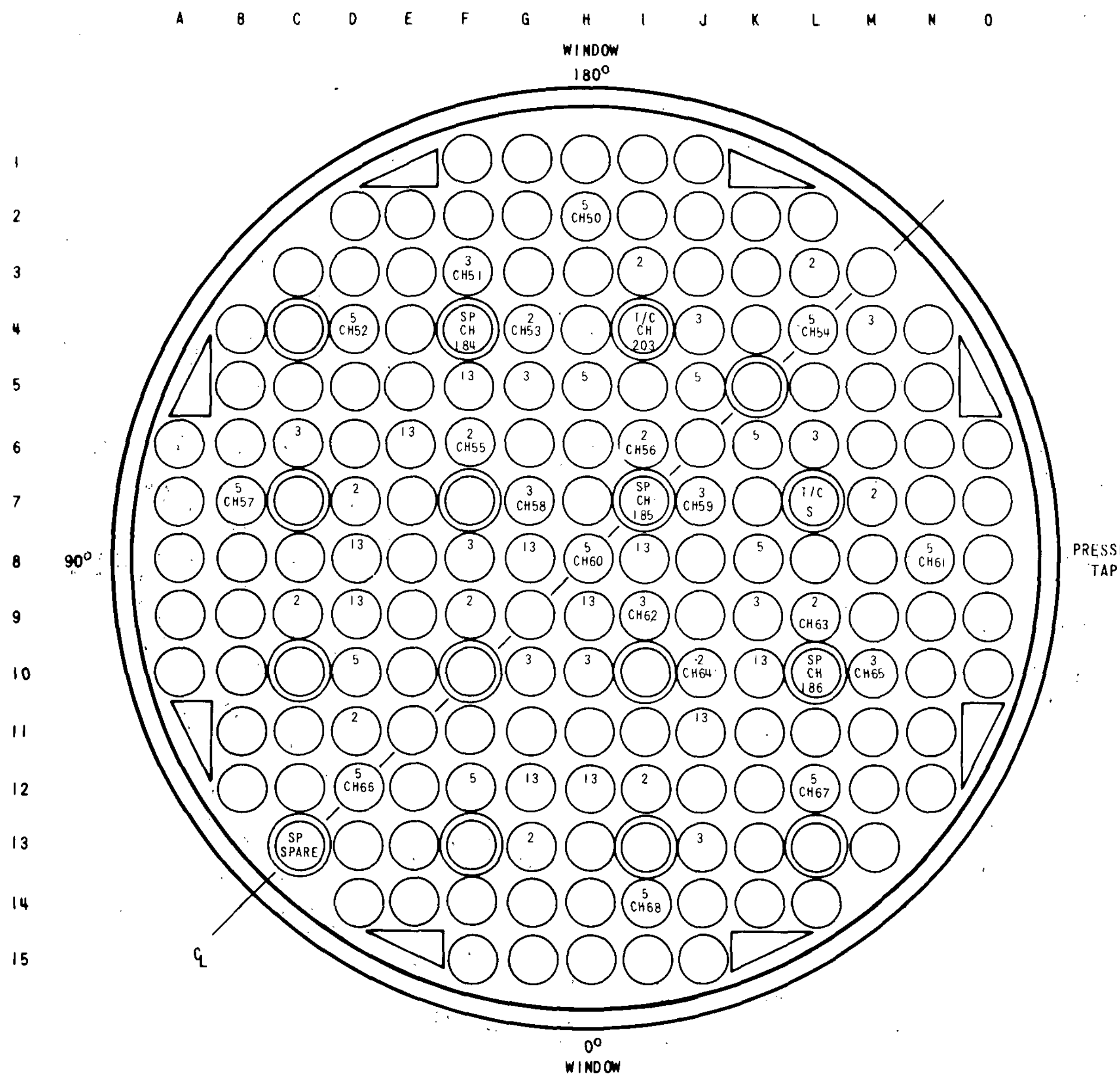
Figure C-7. 17 x 17 Unblocked Bundle Instrumentation — 1.70m (5ft-7in.) Elevation



CDAS CHANNEL NO. (xx) HEATER ROD GROUP NO. (x)

ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	11	4	15
STEAM PROBES	-	-	-
THIMBLE THERMOCOUPLES	-	-	-

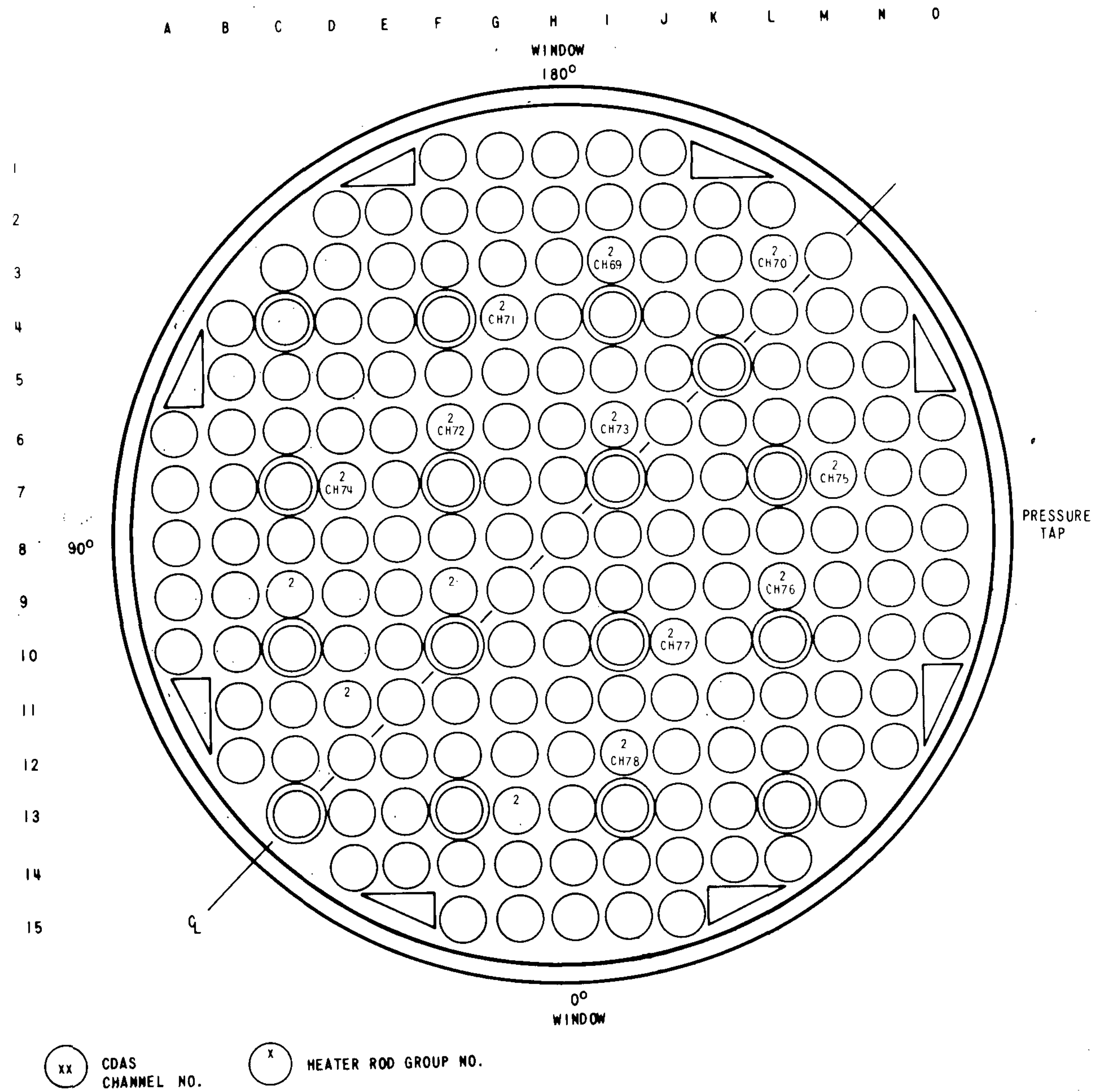
Figure C-8. 17 x 17 Unblocked Bundle Instrumentation – 1.78m (5ft-10in.) Elevation



CDAS CHANNEL NO. (XX) — HEATER ROD GROUP NO. (X)

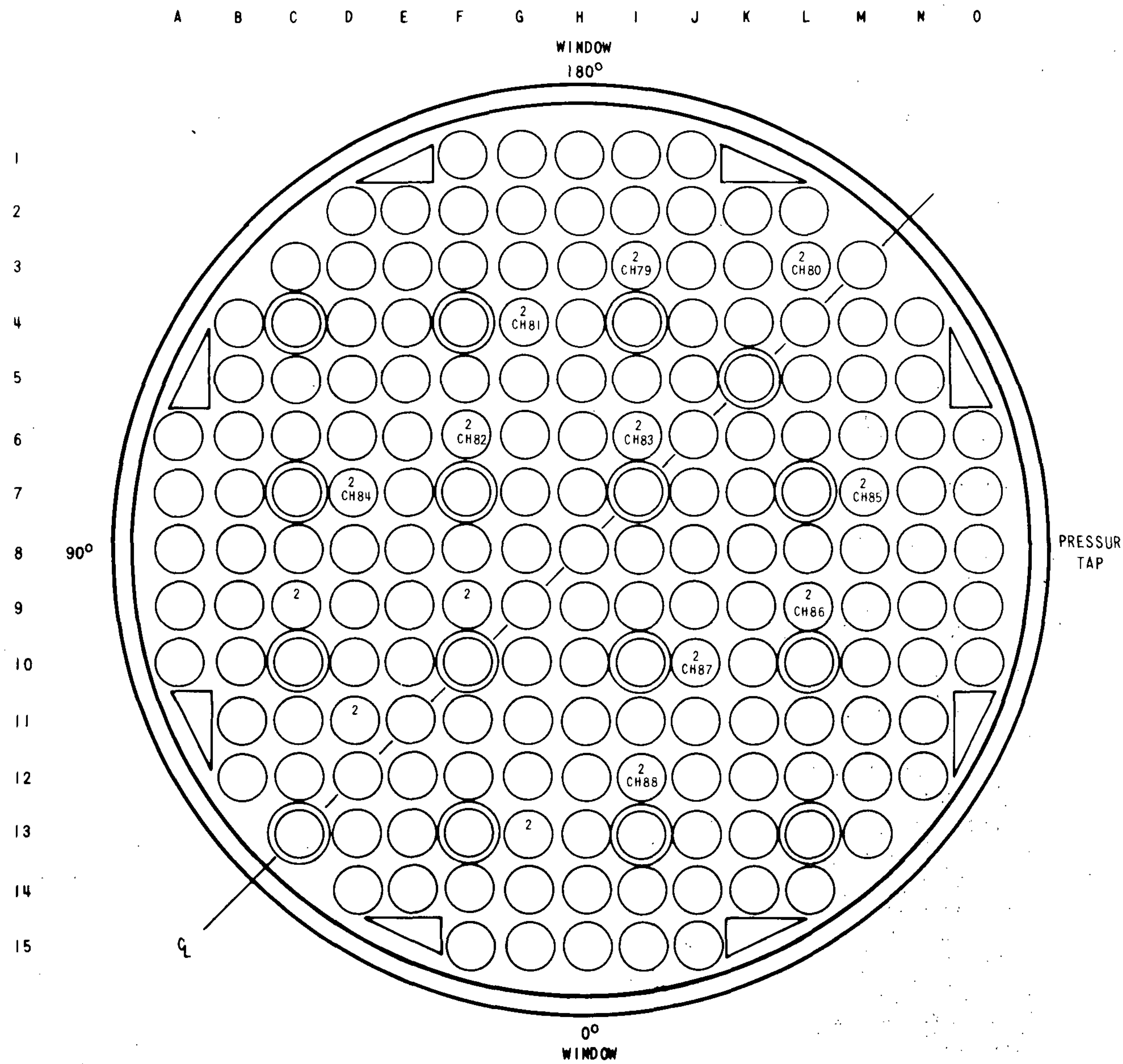
ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	19	36	55
STEAM PROBES	3	1	4
THIMBLE THERMOCOUPLES	2	2	4

Figure C-9. 17 x 17 Unblocked Bundle Instrumentation – 1.83m (6ft-0in.) Elevation



ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	10	4	14
STEAM PROBES	-	-	-
THIMBLE THERMOCOUPLES	-	-	-

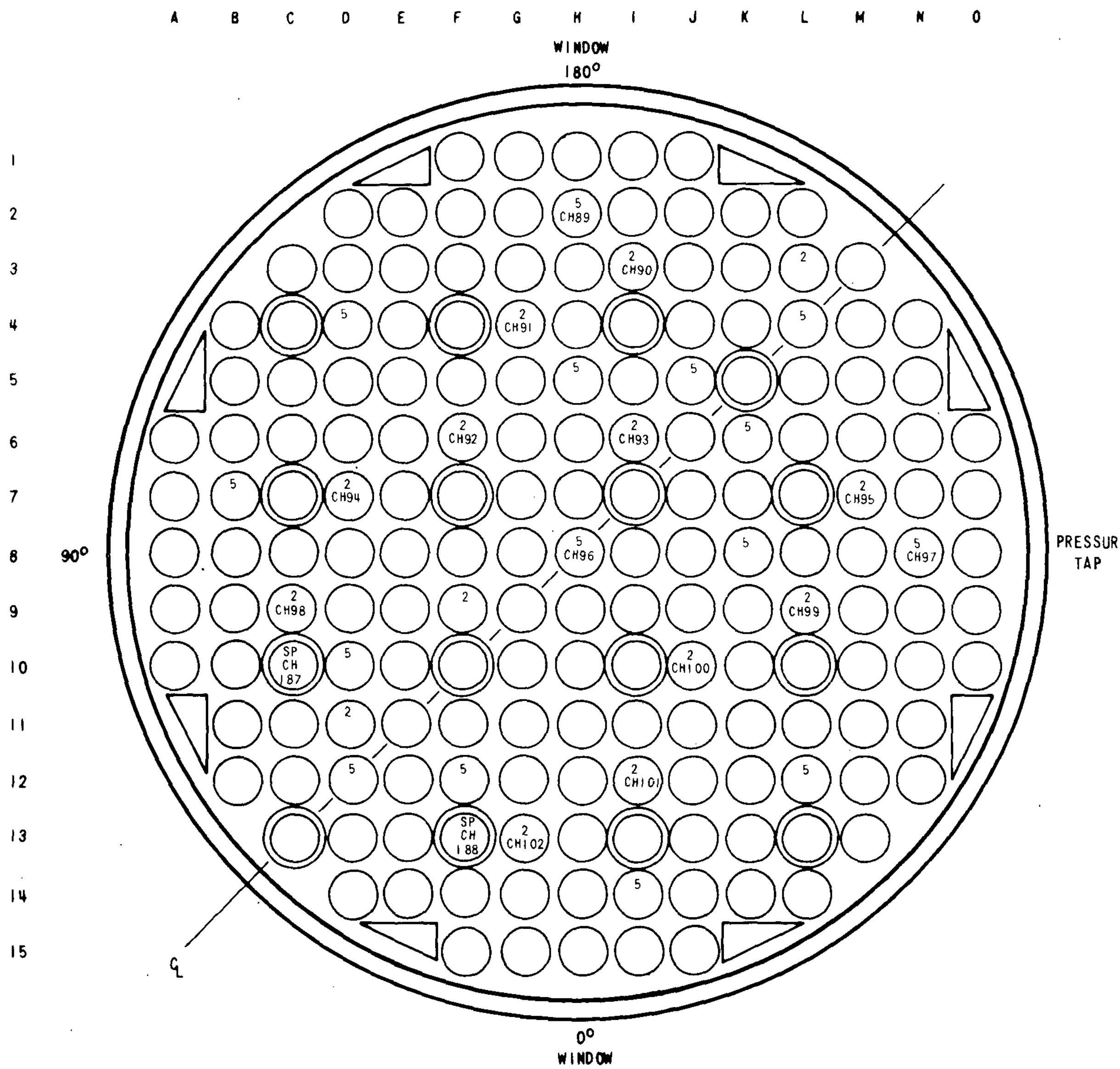
Figure C-10. 17 x 17 Unblocked Bundle Instrumentation – 1.88m (6ft-2in.) Elevation



(XX) CDAS CHANNEL NO. (X) HEATER ROD GROUP NO.

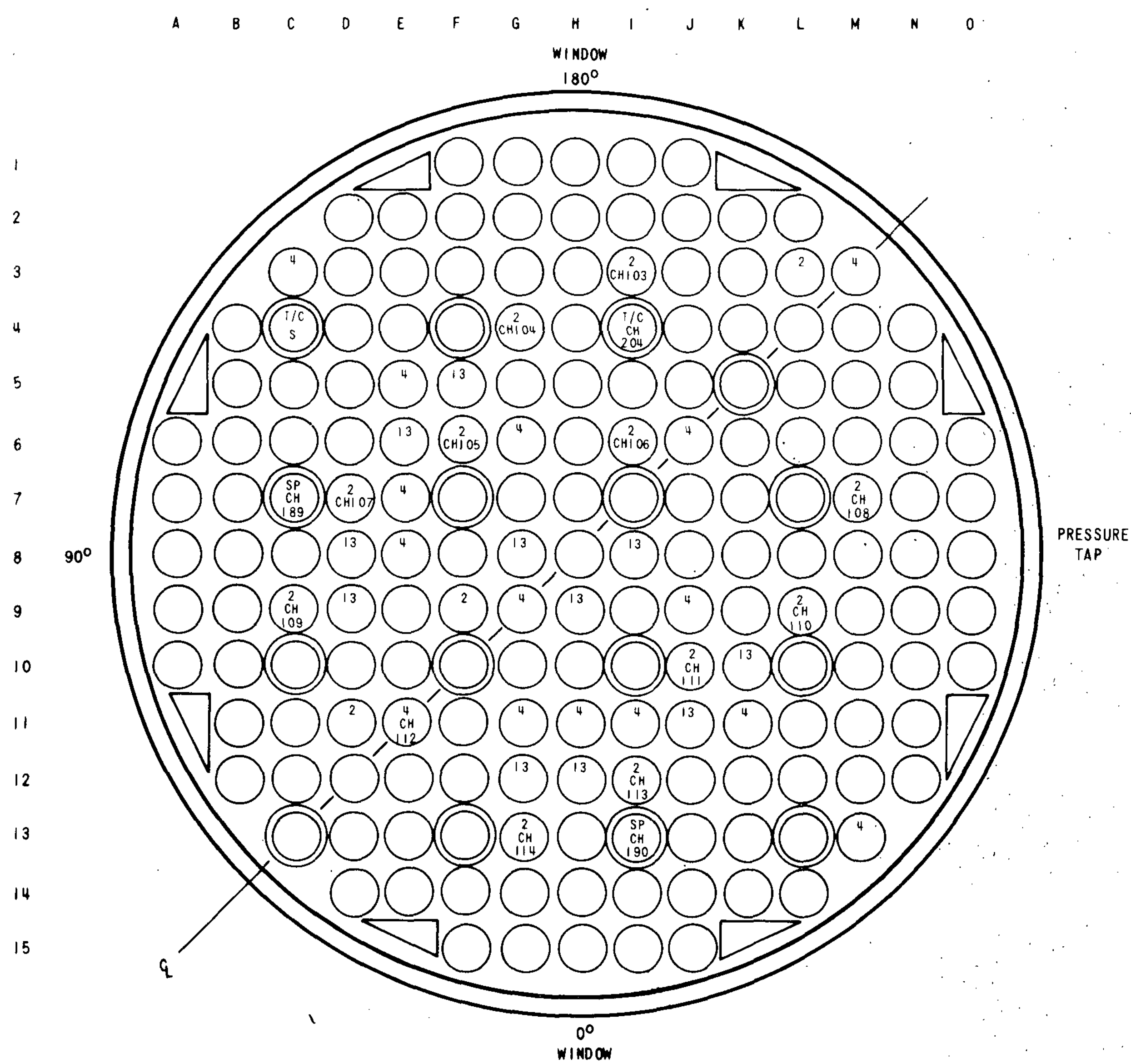
ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	10	4	14
STEAM PROBES	-	-	-
THIMBLE THERMOCOUPLES	-	-	-

Figure C-11. 17 x 17 Unblocked Bundle Instrumentation – 1.93m (6ft-4in.) Elevation



ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	14	15	29
STEAM PROBES	2	-	2
THIMBLE THERMOCOUPLES	-	-	-

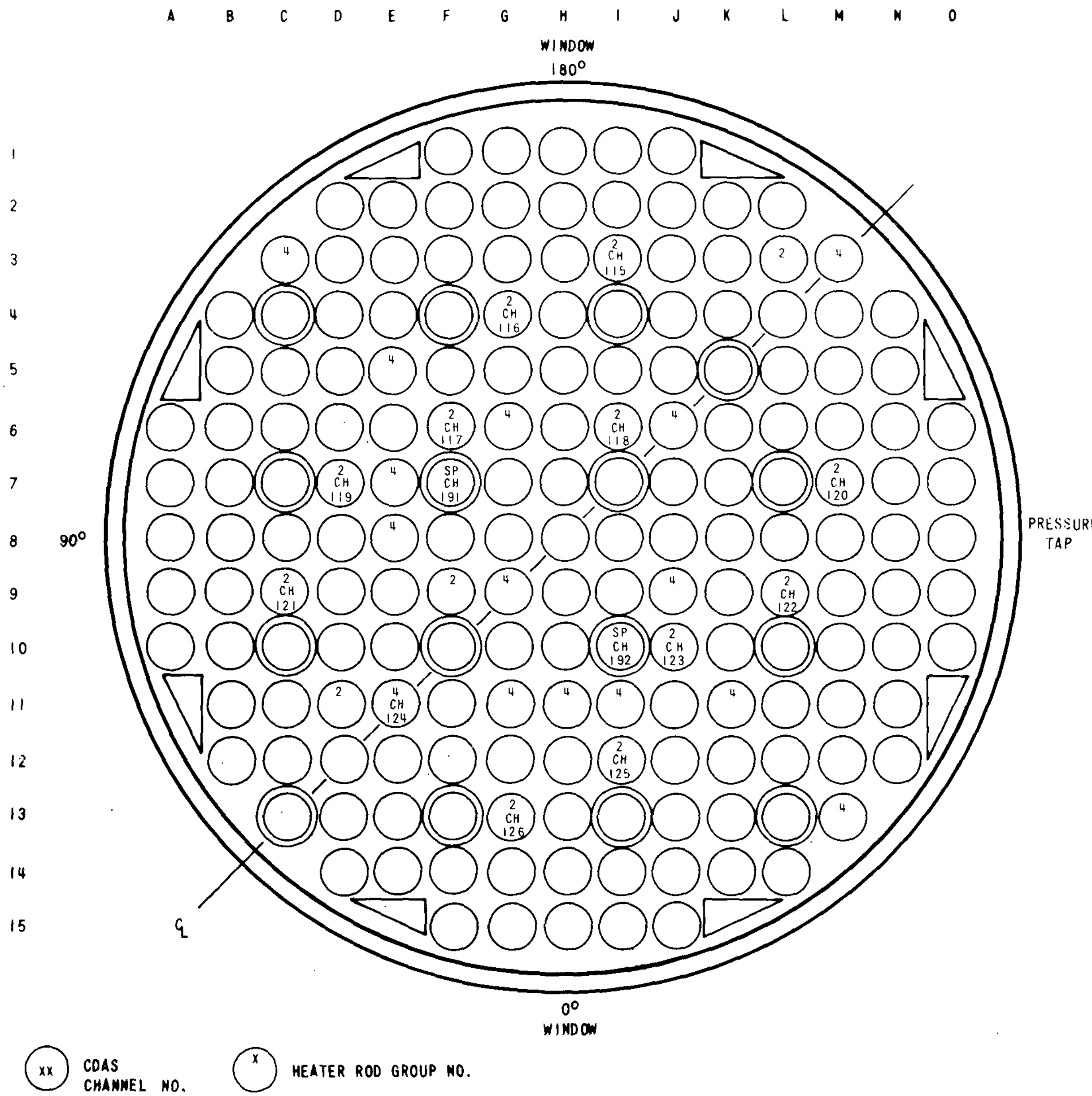
Figure C-12. 17 x 17 Unblocked Bundle Instrumentation — 1.98m (6ft-6in.) Elevation



(xx) CDAS CHANNEL NO. (x) HEATER ROD GROUP NO.

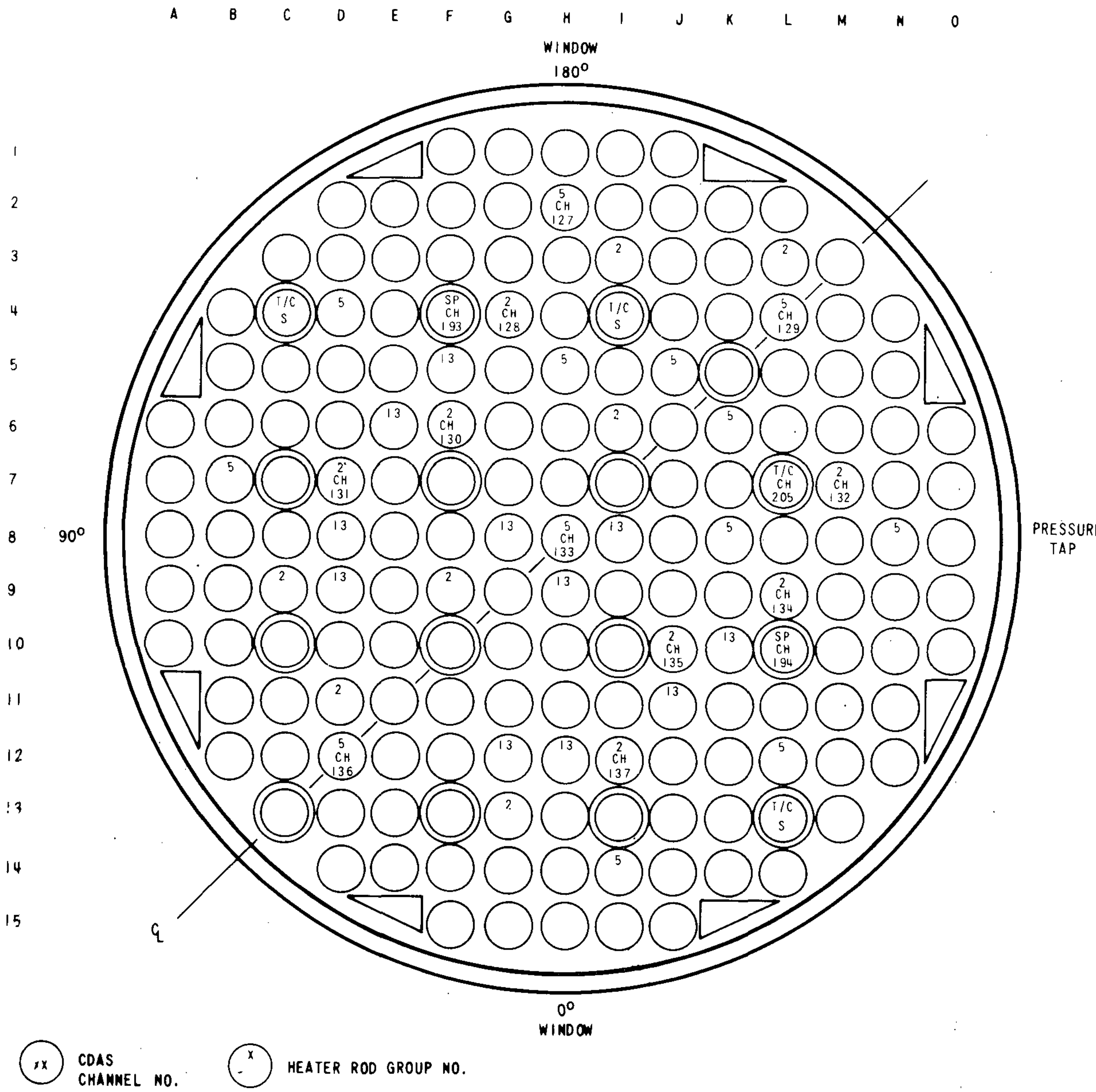
ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	12	28	40
STEAM PROBES	2	-	2
THIMBLE THERMOCOUPLES	1	1	2

Figure C-13. 17 x 17 Unblocked Bundle Instrumentation – 2.13m (7ft-0in.) Elevation



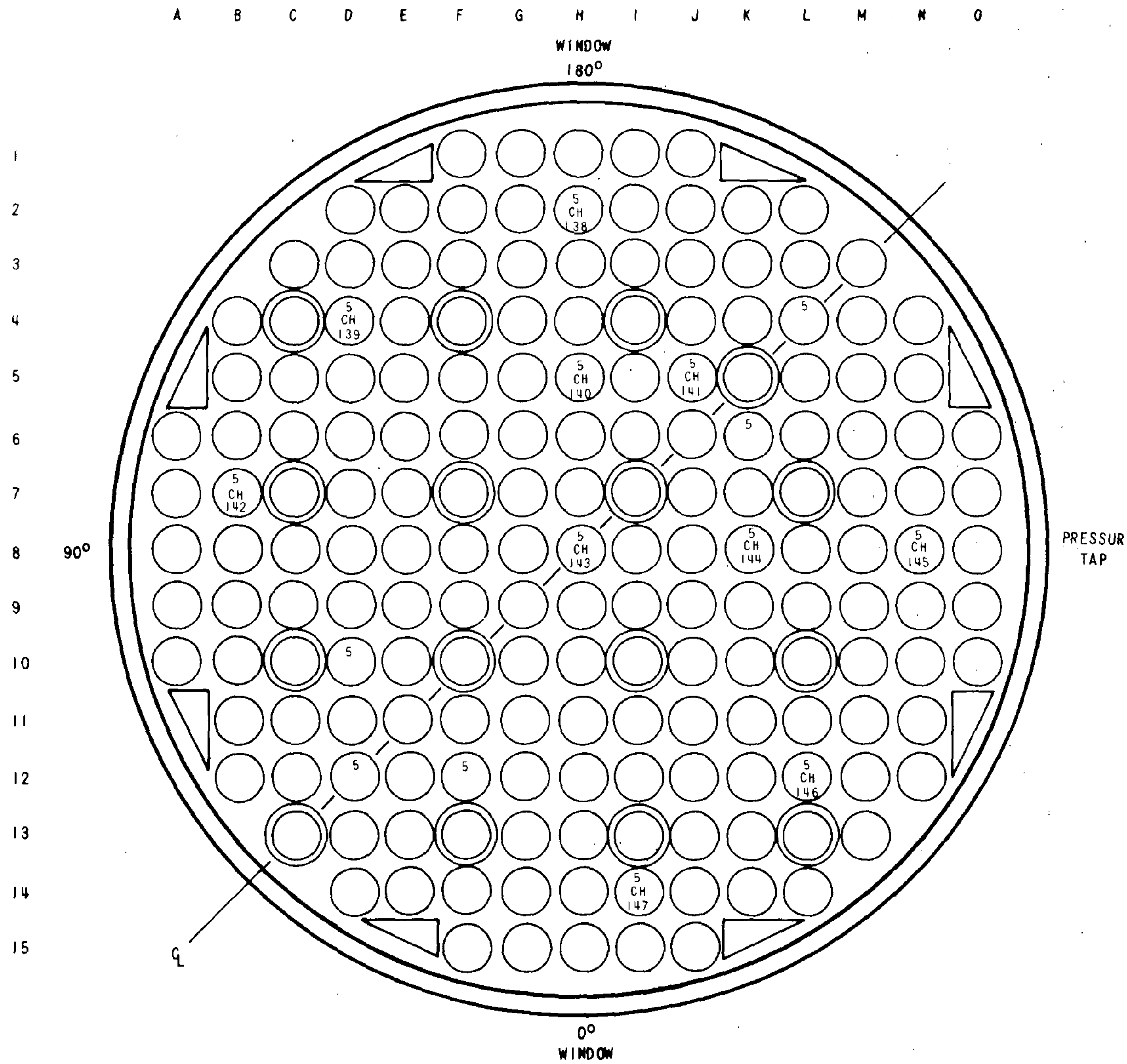
ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	12	17	29
STEAM PROBES	2	-	2
THIMBLE THERMOCOUPLES	-	-	-

Figure C-14. 17 x 17 Unblocked Bundle Instrumentation – 2.29m (7ft-6in.) Elevation



ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	11	29	40
STEAM PROBES	2	-	2
THIMBLE THERMOCOUPLES	1	3	4

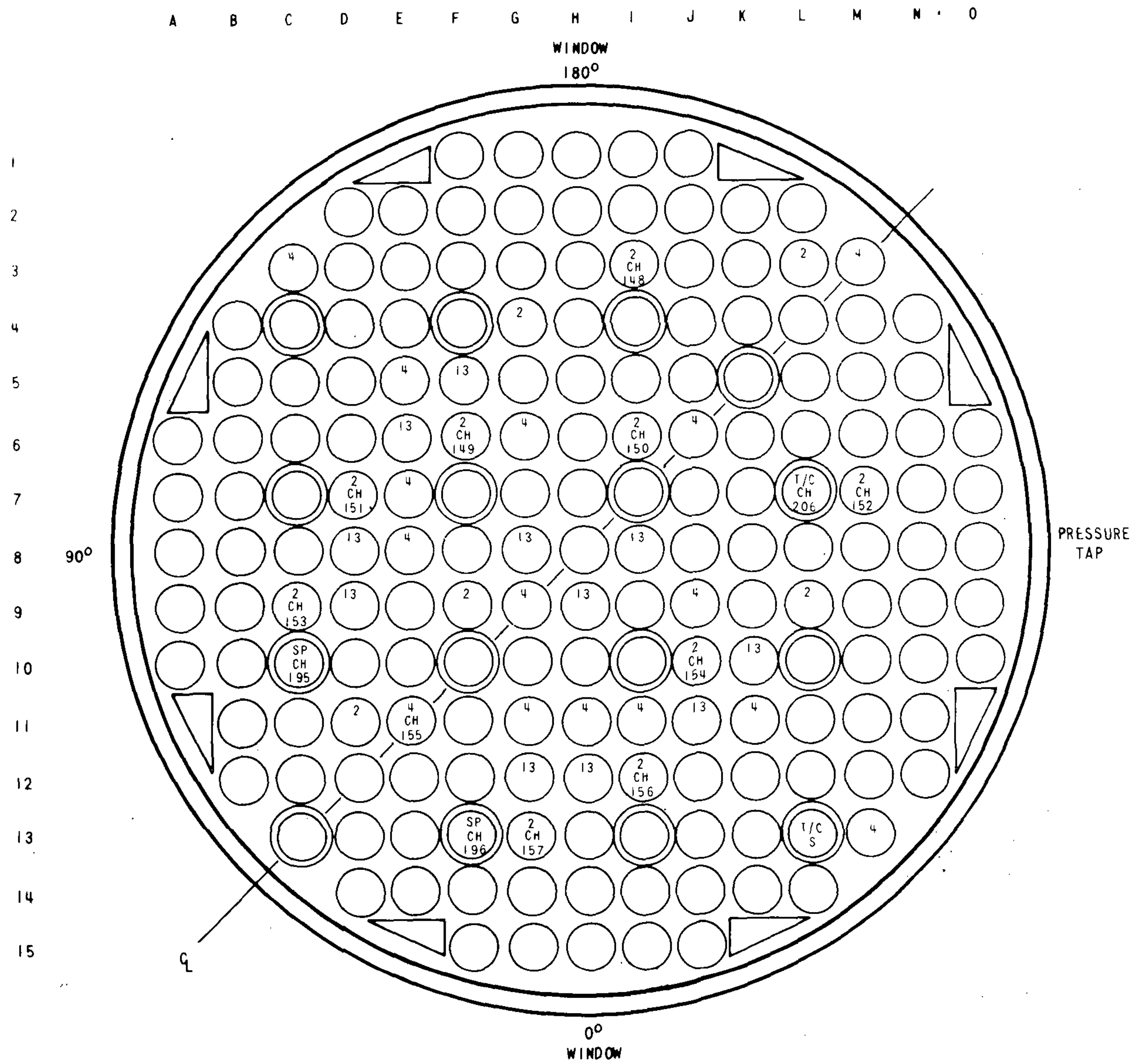
Figure C-15. 17 x 17 Unblocked Bundle Instrumentation – 2.44m (8ft-0in.) Elevation)



(XX) CDAS CHANNEL NO. (X) HEATER ROD GROUP NO.

ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	10	5	15
STEAM PROBES	-	-	-
THIMBLE THERMOCOUPLES	-	-	-

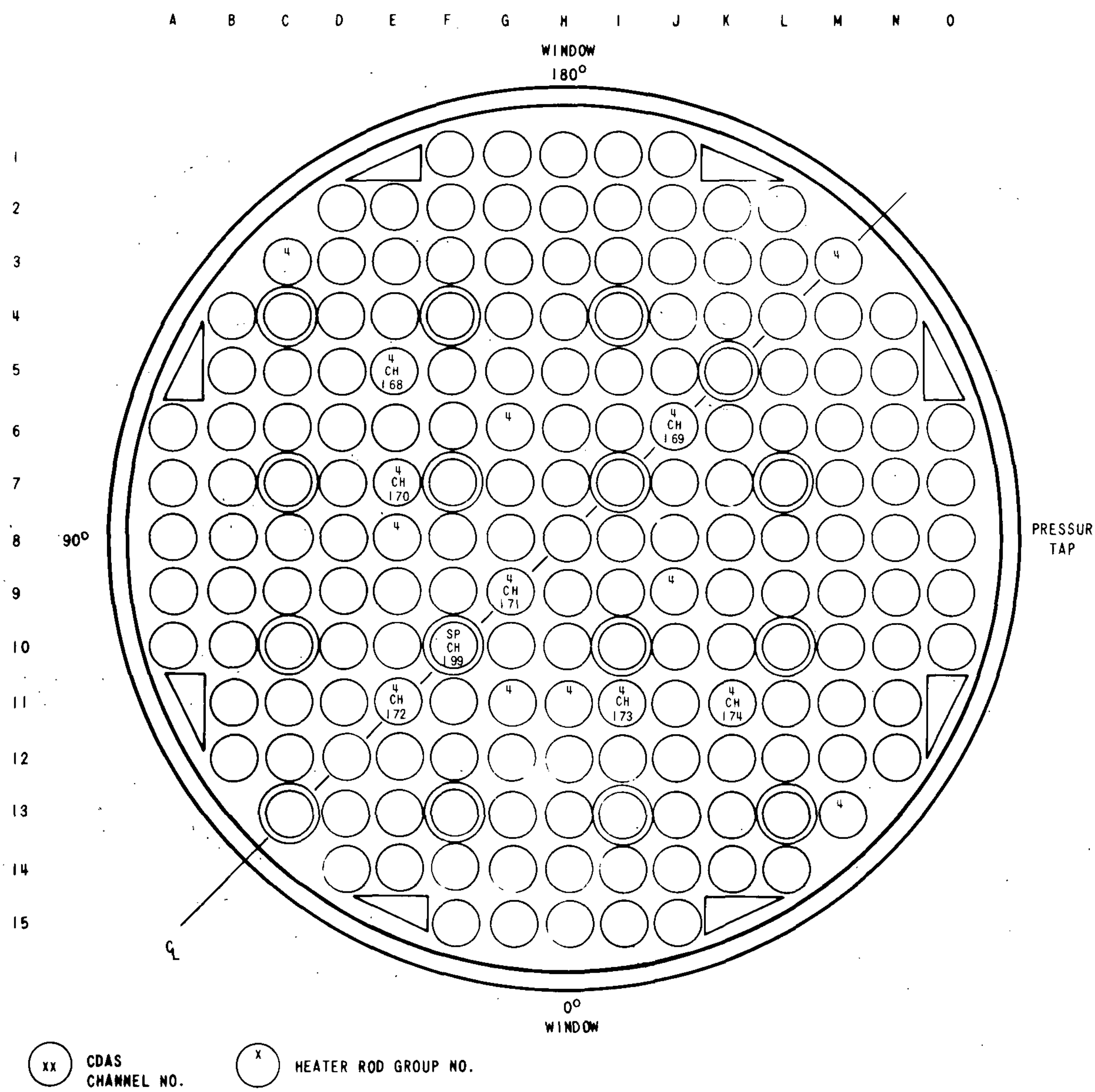
Figure C-16. 17 x 17 Unblocked Bundle Instrumentation – 2.59m (8ft-6in.) Elevation



(XX) CDAS CHANNEL NO. (X) HEATER ROD GROUP NO.

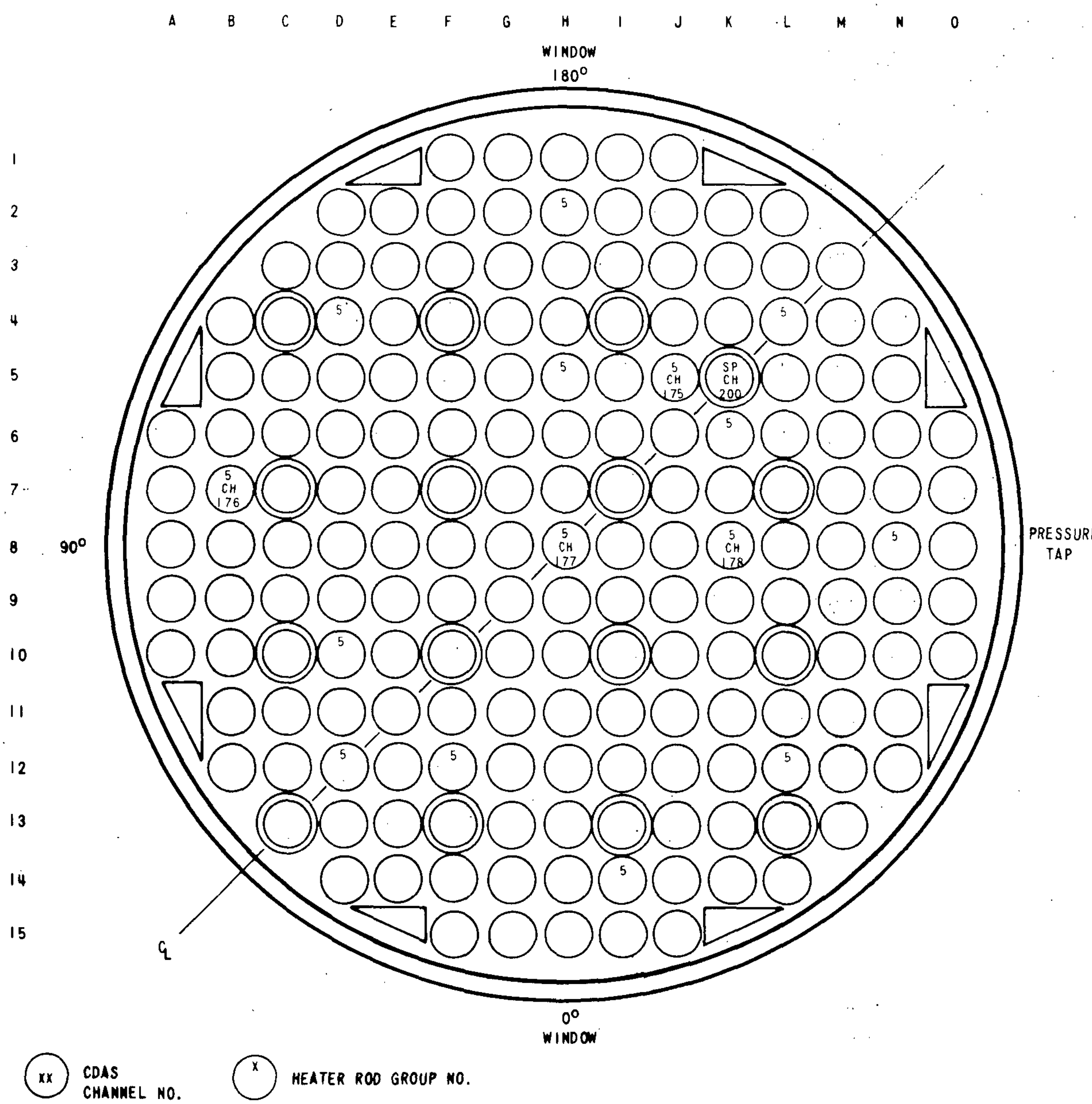
ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	10	30	40
STEAM PROBES	2	-	2
THIMBLE THERMOCOUPLES	1	1	2

Figure C-17. 17 x 17 Unblocked Bundle Instrumentation – 2.82m (9ft-3in.) Elevation



ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	7	8	15
STEAM PROBES	1	-	1
THIMBLE THERMOCOUPLES	-	-	-

Figure C-19. 17 x 17 Unblocked Bundle Instrumentation – 3.35m (11ft-0in.) Elevation



ITEM	CONNECTED	SPARE	TOTAL
HEATER ROD THERMOCOUPLES	4	11	15
STEAM PROBES	1	-	1
THIMBLE THERMOCOUPLES	-	-	-

Figure C-20. 17 x 17 Unblocked Bundle Instrumentation — 3.51m (11ft-6in.) Elevation

TABLE C-1

PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
1	7E-1	A	Hot	1.05	1.1	B
2	9G-1	A	Hot	1.0	1.0	B
3	11I-1	A	Hot	1.05	1.1	A
4	5H-2	A	Hot	1.0	1.0	C
5	8N-2	C	Cold	0.95	0.95	A
6	12F-2	B	Cold	1.05	1.0	A
7	7E-3-3	A	Hot	1.05	1.1	B
8	9G-3-3	A	Hot	1.0	1.0	B
9	11I-3-3	A	Hot	1.05	1.1	A
10	2H-4	C	Cold	0.95	0.95	C
11	5H-4	A	Hot	1.0	1.0	C
12	5J-4	A	Hot	1.05	1.0	C
13	8H-4	A	Hot	1.0	1.1	B
14	8K-4	A	Hot	1.0	1.0	A
15	8N-4	C	Cold	0.95	0.95	A
16	12D-4	B	Cold	1.0	1.0	B
17	3C-5	B	Cold	1.0	0.95	C
18	3M-5	C	Cold	0.95	0.95	C
19	4J-5	B	Cold	1.05	1.0	C
20	5E-5	A	Hot	1.0	1.0	C
21	6L-5	B	Cold	1.05	1.0	A
22	7E-5	A	Hot	1.05	1.1	B
23	7G-5	A	Hot	1.05	1.1	C
24	9I-5	A	Hot	1.05	1.1	A
25	11-I-5	A	Hot	1.05	1.1	A
26	11-K-5	A	Hot	1.0	1.0	A
27	13M-5	B	Cold	1.0	0.95	A
28	3C-5-7	B	Cold	1.0	0.95	C

TABLE C-1 (cont)
PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
29	3M-5-7	C	Cold	0.95	0.95	C
30	4J-5-7	B	Cold	1.05	1.0	C
31	5E-5-7	A	Hot	1.0	1.0	C
32	6L-5-7	B	Cold	1.05	1.0	A
33	7E-5-7	A	Hot	1.05	1.1	B
34	7G-5-7	A	Hot	1.05	1.0	C
35	9I-5-7	A	Hot	1.05	1.1	A
36	11I-5-7	A	Hot	1.05	1.1	A
37	11K-5-7	A	Hot	1.0	1.0	A
38	13M-5-7	B	Cold	1.0	0.95	A
39	3F-5-10	B	Cold	1.0	1.0	C
40	4G-5-10	B	Cold	1.05	1.0	C
41	4M-5-10	B	Cold	0.95	0.95	A
42	6C-5-10	B	Cold	1.05	1.1	B
43	6L-5-10	B	Cold	1.05	1.0	A
44	7G-5-10	A	Hot	1.05	1.1	C
45	7J-5-10	A	Hot	1.05	1.1	A
46	9I-5-10	A	Hot	1.05	1.1	A
47	10G-5-10	A	Hot	1.05	0.95	A
48	10M-5-10	B	Cold	1.0	1.0	A
49	13J-5-10	B	Cold	1.05	1.1	A
50	2H-6	C	Cold	0.95	0.95	C
51	3F-6	B	Cold	1.0	1.0	C
52	4D-6	B	Cold	1.05	1.0	B
53	4G-6	A	Hot	1.05	1.0	C
54	4L-6	B	Cold	0.95	0.95	C
55	6F-6	A	Hot	1.05	1.1	B
56	6I-6	A	Hot	1.05	1.1	C

TABLE C-1 (cont)
PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
57	7B-6	C	Cold	1.05	1.1	B
58	7G-6	A	Hot	1.05	1.1	C
59	7J-6	A	Hot	1.05	1.1	A
60	8H-6	A	Hot	1.0	1.1	B
61	8N-6	C	Cold	0.95	0.95	A
62	9I-6	A	Hot	1.05	1.1	A
63	9L-6	A	Hot	1.05	1.0	A
64	10J-6	A	Hot	1.05	1.1	A
65	10M-6	B	Cold	1.0	1.0	A
66	12D-6	B	Cold	1.0	1.0	B
67	12L-6	B	Cold	1.05	1.0	A
68	14I-6	C	Cold	1.05	1.1	A
69	3I-6-2	B	Cold	1.0	1.0	C
70	3L-6-2	B	Cold	0.95	0.95	C
71	4G-6-2	A	Hot	1.05	1.0	C
72	6F-6-2	A	Hot	1.05	1.1	B
73	6I-6-2	A	Hot	1.05	1.1	C
74	7D-6-2	A	Hot	1.05	1.1	B
75	7M-6-2	B	Cold	1.0	1.0	A
76	9L-6-2	A	Hot	1.05	1.0	A
77	10J-6-2	A	Hot	1.05	1.1	A
78	12I-6-2	A	Hot	1.05	1.1	A
79	3I-6-4	B	Cold	1.0	1.0	C
80	3L-6-4	B	Cold	0.95	0.95	C
81	4G-6-4	A	Hot	1.05	1.0	C
82	6F-6-4	A	Hot	1.05	1.1	B
83	6I-6-4	A	Hot	1.05	1.1	C
84	7D-6-4	A	Hot	1.05	1.1	B

TABLE C-1 (cont)
PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
85	7M-6-4	B	Cold	1.0	1.0	A
86	9L-6-4	A	Hot	1.05	1.0	A
87	10J-6-4	A	Hot	1.05	1.1	A
88	12I-6-4	A	Hot	1.05	1.1	A
89	2H-6-6	C	Cold	0.95	0.95	C
90	3I-6-6	B	Cold	1.0	1.0	C
91	4G-6-6	A	Hot	1.05	1.0	C
92	6F-6-6	A	Hot	1.05	1.1	B
93	6I-6-6	A	Hot	1.05	1.1	C
94	7D-6-6	A	Hot	1.05	1.1	B
95	7M-6-6	B	Cold	1.0	1.0	A
96	8H-6-6	A	Hot	1.0	1.0	B
97	8N-6-6	C	Cold	0.95	0.95	A
98	9C-6-6	B	Cold	1.0	0.95	B
99	9L-6-6	A	Hot	1.0	1.0	A
100	10J-6-6	A	Hot	1.05	1.1	A
101	12I-6-6	A	Hot	1.05	1.1	A
102	13G-6-6	B	Cold	1.05	0.95	A
103	3I-7	B	Cold	1.0	1.0	C
104	4G-7	A	Hot	1.05	1.0	C
105	6F-7	A	Hot	1.05	1.1	B
106	6I-7	A	Hot	1.05	1.1	C
107	7D-7	A	Hot	1.05	1.1	B
108	7M-7	B	Cold	1.0	1.0	A
109	9C-7	B	Cold	1.05	0.95	B
110	9L-7	A	Hot	1.05	1.0	A
111	10J-7	A	Hot	1.05	1.1	A
112	11E-7	A	Hot	1.0	1.0	B

TABLE C-1 (cont)
PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
113	12I-7	A	Hot	1.05	1.1	A
114	13G-7	B	Cold	1.05	0.95	A
115	3I-7-6	B	Cold	1.0	1.0	C
116	4G-7-6	A	Hot	1.05	1.0	C
117	6F-7-6	A	Hot	1.05	1.1	B
118	6I-7-6	A	Hot	1.05	1.1	C
119	7D-7-6	A	Hot	1.05	1.1	B
120	7M-7-6	B	Cold	1.0	1.0	A
121	9C-7-6	B	Cold	1.05	0.95	B
122	9L-7-6	A	Hot	1.05	1.0	A
123	10J-7-6	A	Hot	1.05	1.1	A
124	11E-7-6	A	Hot	1.0	1.0	B
125	12I-7-6	A	Hot	1.05	1.1	A
126	13G-7-6	B	Cold	1.05	0.95	A
127	2H-8	C	Cold	0.95	0.95	C
128	4G-8	A	Hot	1.05	1.0	C
129	4L-8	B	Cold	0.95	0.95	C
130	6F-8	A	Hot	1.05	1.1	B
131	7D-8	A	Hot	1.05	1.1	B
132	7M-8	B	Cold	1.0	1.0	A
133	8H-8	A	Hot	1.0	1.1	B
134	9L-8	A	Hot	1.05	1.0	A
135	10J-8	A	Hot	1.05	1.1	A
136	12D-8	B	Cold	1.0	1.0	B
137	12I-8	A	Hot	1.05	1.1	A
138	2H-8-6	C	Cold	0.95	0.95	C
139	4D-8-6	B	Cold	1.05	1.0	B
140	5H-8-6	A	Hot	1.0	1.0	C

TABLE C-1 (cont)

PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
141	5J-8-6	A	Hot	1.05	1.0	C
142	7B-8-6	C	Cold	1.05	1.1	B
143	8H-8-6	A	Hot	1.0	1.1	B
144	8K-8-6	A	Hot	1.0	1.0	A
145	8N-8-6	C	Cold	0.95	0.95	A
146	12L-8-6	B	Cold	1.05	1.0	A
147	14I-8-6	C	Cold	1.05	1.1	A
148	3I-9-3	B	Cold	1.0	1.0	C
149	6F-9-3	A	Hot	1.05	1.1	B
150	6I-9-3	A	Hot	1.05	1.1	C
151	7D-9-3	A	Hot	1.05	1.1	B
152	7M-9-3	B	Cold	1.0	1.0	A
153	9C-9-3	B	Cold	1.05	1.0	B
154	10J-9-3	A	Hot	1.05	1.1	A
155	11E-9-3	A	Hot	1.0	1.0	B
156	12I-9-3	A	Hot	1.05	1.1	A
157	13G-9-3	B	Cold	1.05	0.95	A
158	2H-10	C	Cold	0.95	0.95	C
159	4D-10	B	Cold	1.05	1.0	B
160	5H-10	A	Hot	1.0	1.0	C
161	5J-10	A	Hot	1.05	1.0	C
162	7B-10	C	Cold	1.05	1.1	B
163	8H-10	A	Hot	1.0	1.1	B
164	8K-10	A	Hot	1.0	1.0	A
165	8N-10	C	Cold	0.95	0.95	A
166	12L-10	B	Cold	1.05	1.0	A
167	14I-10	C	Cold	1.05	1.1	A
168	5E-11	A	Hot	1.0	1.0	C

TABLE C-1 (cont)

PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquistion System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
169	6J-11	A	Hot	1.05	1.1	C
170	7E-11	A	Hot	1.05	1.1	B
171	9G-11	A	Hot	1.0	1.0	B
172	11E-11	A	Hot	1.0	1.0	B
173	11I-11	A	Hot	1.05	1.1	A
174	11K-11	A	Hot	1.0	1.0	A
175	5J-11-6	A	Hot	1.05	1.0	C
176	7B-11-6	C	Cold	1.05	1.1	B
177	8H-11-6	A	Hot	1.0	1.1	B
178	8K-11-6	A	Hot	1.0	1.0	A
179	SP[a] 10F-3-3	A	Hot	1.05	1.0	B
180	SP 7I-4	A	Hot	1.05	1.1	C
181	SP 5K-5	B	Cold	0.95	1.0	C
182	SP 7F-5-7	A	Hot	1.05	1.1	B
183	SP 10I-5-7	A	Hot	1.05	1.1	A
184	SP 4F-6	B	Cold	1.05	1.0	C
185	SP 7I-6	A	Hot	1.05	1.1	C
186	SP 10L-6	B	Cold	1.05	1.0	A
187	SP 10C-6-6	B	Cold	1.05	1.0	B
188	SP 13F-6-6	B	Cold	1.05	1.0	A
189	SP 7C-7	B	Cold	1.05	1.1	B
190	SP 13I-7	B	Cold	1.05	1.1	A
191	SP 7F-7-6	A	Hot	1.05	1.1	B
192	SP 10I-7-6	A	Hot	1.05	1.1	A
193	SP 4F-8	B	Cold	1.05	1.0	C
194	SP 10L-8	B	Cold	1.05	1.0	A
195	SP 10C-9-3	B	Cold	1.05	1.0	B
196	SP 13F-9-3	B	Cold	1.05	1.0	A

a. Steam probe

TABLE C-1 (cont)

PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
197	SP 7C-10	B	Cold	1.05	1.1	B
198	SP 13I-10	B	Cold	1.05	1.1	A
199	SP 10F-11	A	Hot	1.05	1.0	B
200	SP 5K-11-6	B	Cold	1.0	1.0	C
201	SP test section exit					
202	TH 7L-4[a]	B	Cold	1.05	1.0	A
203	TH 4I-6	B	Cold	1.05	1.0	C
204	TH 4I-7	B	Cold	1.05	1.0	C
205	TH 7L-8	B	Cold	1.05	1.0	A
206	TH 7L-9-3	B	Cold	1.05	1.0	A
207	TH 4I-10	B	Cold	1.05	1.0	C
208	UP[b] fluid – bundle out					
209	UP fluid – 90°					
210	UP fluid – housing exit.					
211	LP[c] fluid – bundle in					
212	Accumulator fluid T/C[d] – 7.25 in.					
213	Carryover tank fluid T/C – 2.5 in.					
214	Steam separator drain tank fluid T/C – 3 in.					
215	Exhaust orifice fluid T/C					
216	Carryover tank wall T/C – 1 ft					
217	Steam separator wall T/C – middle					
218	Steam separator drain tank wall T/C – 3.5 ft					
219	Test section outlet pipe-wall T/C					
220	Pipe upstream orifice-wall T/C					

a. TH = thimble
b. UP = upper plenum
c. LP = lower plenum
d. T/C = thermocouple

TABLE C-1 (cont)

PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
221	Injection line near turbine meter fluid T/C (Forced Flooding Rate Tests); Downcomer fluid T/C (Gravity Reflooding Tests)					
222	Power 1.1 zone – primary					
223	Power 1.1 zone – redundant					
224	Power 1.0 zone – primary					
225	Power 1.0 zone – redundant					
226	Power 0.95 zone – primary					
227	Power 0.95 zone – redundant					
228	Turbine meter					
229	Low flow rotameter					
230	Medium flow rotameter					
231	High flow rotameter					
232	Turboprobe – Gravity Reflooding Tests)					
233	Bundle 0-1 ft D/P [a] (level)					
234	Bundle 1-2 ft D/P (level)					
235	Bundle 2-3 ft D/P (level)					
236	Bundle 3-4 ft D/P (level)					
237	Bundle 4-5 ft D/P (level)					

a. D/P = differential pressure

TABLE C-1 (cont)

PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
238	Bundle 5-6 ft D/P (level)					
239	Bundle 6-7 ft D/P (level)					
240	Bundle 7-8 ft D/P (level)					
241	Bundle 8-9 ft D/P (level)					
242	Bundle 9-10 ft D/P (level)					
243	Bundle 10-11 ft D/P (level)					
244	Bundle 11-12 ft D/P (level)					
245	Overall D/P 0-12 ft					
246	U.P. D/P (level)					
247	Carryover tank – 2 in.-13 ft D/P (level)					
248	Steam separator tank D/P (level)					
249	Steam separator drain tank D/P (level)					
250	Accumulator 0-20 ft D/P (level)					
251	Exhaust orifice D/P					
252	Upper plenum PT[a] pressure (Forced Flooding Rate Tests); Steam separator tank PT pressure (Gravity Reflooding Tests)					

a. PT = static pressure transducers

TABLE C-1 (cont)

PRELIMINARY DATA ACQUISITION SYSTEM – CROSS REFERENCE AND CHANNEL SYSTEM

Computer Data Acquisition System		Radial Power Distribution				
Channel No.	Location Radial – Axial (ft-in.)	Uniform	Hot/Cold Channel	17 x 17 FLECHT	15 x 15 FLECHT	Half Hot/ Half Cold
253	Exhaust orifice PT pressure					
254	UP – separator tank D/P – (Gravity Reflooding Tests					
255	Downcomer – separater tank D/P – (Gravity Reflooding Tests)					
256	Downcomer D/P (level) – (Gravity Reflooding Tests)					

TABLE C-2

HEATER ROD THERMOCOUPLE DISTRIBUTION (MONITORED BY THE COMPUTER BY ELEVATION AND POWER ZONE (UNBLOCKED BUNDLE TASK 3.2.1

Elevation m (ft-in.)	Uniform Power Zones[a]			Hot and Cold Power Zones[a]			FLECHT 17 x 17 Power Zones[b]			FLECHT 15 x 15 Power Zones[c]			Half Bundle Power Zones[d]			Total Number of Thermocouples
	A	B	C	A	B	C	A 1.05	B 1.0	C 0.95	A 1.1	B 1.0	C 0.95	A	B	C	
0.305 (1-0)	3	–	–	3	–	–	2	1	–	2	1	–	1	2	–	3
0.610 (2-0)	1	1	1	1	1	1	1	1	1	–	2	1	2	–	1	3
0.991 (3-3)	3	–	–	3	–	–	2	1	–	2	1	–	1	2	–	3
1.22 (4-0)	4	1	2	4	1	2	1	4	2	1	4	2	2	2	3	7
1.52 (5-0)	6	4	1	6	4	1	6	4	1	4	4	3	5	1	5	11
1.70 (5-7)	6	4	1	6	4	1	6	4	1	3	5	3	5	1	5	11
1.78 (5-10)	4	7	–	4	7	–	8	2	1	5	4	2	7	1	3	11
1.83 (6-0)	9	6	4	9	6	4	12	4	3	9	7	3	8	5	6	19
1.88 (6-2)	7	3	–	7	3	–	7	2	1	5	4	1	4	2	4	10
1.93 (6-4)	7	3	–	7	3	–	7	2	1	5	4	1	4	2	4	10
1.98 (6-6)	8	4	2	8	4	2	7	5	2	5	5	4	6	4	4	14
2.13 (7-0)	8	4	–	8	4	–	9	3	–	5	5	2	5	4	3	12
2.29 (7-6)	8	4	–	8	4	–	9	3	–	5	5	2	5	4	3	12
2.44 (8-0)	7	3	1	7	3	1	6	3	2	5	4	2	4	4	3	11
2.59 (8-6)	4	2	4	4	2	4	5	3	2	3	5	2	4	3	3	10
2.82 (9-3)	6	4	–	6	4	–	7	3	–	5	4	1	4	4	2	10
3.05 (10-0)	4	2	4	4	2	4	5	3	2	3	5	2	4	3	3	10
3.35 (11-0)	7	–	–	7	–	–	3	4	–	3	4	–	2	3	2	7
3.51 (11-6)	3	–	1	3	–	1	2	2	–	2	2	–	1	2	1	4
Totals	105	52	21	105	52	21	105	54	19	72	75	31	74	49	55	178

a. Refer to figure 6-2
b. Refer to figure 6-3
c. Refer to figure 6-4
d. Refer to figure 6-5

TABLE C-3

THIMBLE THERMOCOUPLE INSTRUMENTATION (UNBLOCKED BUNDLE, TASK 3.2.1)

Thermocouple Number	Thermocouple Location m (ft-in.)			
	4C	13L	4I	7L
1	0.610 (2) S[a]	0.305 (1) S	0.610 (2) S	0.305 (1) S
2	1.52 (5) S	0.991 (3-3) S	1.52 (5) S	0.991 (3-3) S
3	1.83 (6) S	1.22 (4) S	1.83 (6) C[b]	1.22 (4) C
4	2.13 (7) S	1.83 (6) S	2.13 (7) C	1.83 (6) C
5	2.44 (8) S	2.44 (8) S	2.44 (8) S	2.44 (8) C
6	3.05 (10) S	2.82 (9-3) S	3.05 (10) C	2.82 (9-3) C

a. S is spare thermocouple location.

b. C is connected thermocouple location.

TABLE C-4

SUMMARY OF QUANTITIES OF CONNECTED AND SPARE THIMBLE, STEAM PROBES, AND HEATER ROD THERMOCOUPLES IN THE BUNDLE

Item	Monitored By Computer	Spare[a]	Total
Instrumented heater rods	46	24	70
Noninstrumented heater rods	N/A	N/A	91
Thimbles	N/A	N/A	16
Steam probes	22	1	23
Instrumented thimble thermocouples	2	2	4

a. N/A = Not Applicable

TABLE C-5
SUMMARY OF BUNDLE HEATER ROD INSTRUMENTATION AVAILABILITY

Group	Thermocouple Locations[a] {m} [ft-in.]	Number of Rods In Bundle	Number of Rods With Thermocouples Connected to Computer	Locations of Heater Rods Not Connected to Computer
2	{1.83, 1.88, 1.93, 1.98 (Bottom) 2.13, 2.29, 2.44, 2.82 (Top)} [6, 6-2, 6-4, 6-6 (Bottom) 7, 7-6, 8, 9-3 (Top)]	14	13	11-D
3	{1.52, 1.70, 1.78, 1.83 (Bottom)} [5, 5-7, 5-10, 6 (Bottom)]	15	11	5-G 8-F 9-K H-10
4	{0.305, 0.991, 1.52, 1.70 (Bottom) 2.13, 2.29, 2.82, 3.35 (Top)} [1, 3-3, 5, 5-7 (Bottom) 7, 7-6, 9-3, 11 (Top)]	15	10	8-E 11-H 7-G 9-J 11-G
5	{0.610, 1.22, 1.83, 1.98 (Bottom) 2.44, 2.59, 3.05, 3.51 (Top)} [2, 4, 6, 6-6 (Bottom) 8, 8-6, 10, 11-6 (Top)]	15	12	10-D 12-F 6-K
13	{1.83, 2.13 (Bottom) 2.44, 2.82, 3.05 (Top)} [6, 7 (Bottom) 8, 9-3, 10 (Top)]	13	0	5-F 6-E 8-D 8-G 8-I 9-D 9-H 10-K 11-J 12-G 12-H

a. Top and bottom indicate end of heater rod from which thermocouple leads eminate.

TABLE C-6

DETAILED STEAM PROBE INSTRUMENTATION PLAN
(UNBLOCKED BUNDLE' TASK 3.2.1)

Steam Probe Elevation m (ft-in.)	Number of Probes	Steam Probe Manifolding Groups	Steam Probe Elevation and Location to be Monitored on Strip Chart Recorder
3.51 (11-6)	1		
3.35 (11)	1		10F
3.05 (10)	2		
2.82 (9-3)	2		13F
2.44 (8)	2		
2.29 (7-6)	2		10I
2.13 (7)	2		13I
1.98 (6-6)	2		
1.83 (6)	4 (Including 1 Spare)	Bottom[a] Top[a]	
1.70 (5-7)	2		10I
1.52 (5)	1		
1.22 (4)	1		7I
0.991 (3-3)	1		

a. Steam probes exhausting out the top and bottom of the bundle are connected to different manifolds at the 1.83 m (6 ft) elevation.

APPENDIX D
UNBLOCKED BUNDLE TEST RUN SPECIFICATION AND VALIDATION SHEET

This appendix contains the Run Specification and Validation Sheet which specifies the initial test conditions and the validation requirements for each FLECHT-SEASET, 17 x 17 Unblocked Bundle test. This table also provides space for comments on run conditions, causes for terminating and invalidating a run, instrumentation failures, preliminary selected thermocouple data, and drained water weights from collection tanks and the test section.

TABLE D-1

FLECHT-SEASET RUN SPECIFICATION AND VALIDATION SHEET – COSINE AXIAL POWER PROFILE BUNDLE (UNBLOCKED BUNDLE TASK 3.2.1)

RUN NO. ________________ FACILITY ENGINEERING ________________

DATE ________________ SAFEGUARDS DEVELOPMENT ________________

I. HEATER ROD POWER

Parameter	Specified Value	Actual Value Redundant Power
1. Initial Peak Linear Power	________ kw/ft ± 1%	________ kw/ft
2. Initial _____ Zone Power	________ kw ± 1%	________ kw
3. Initial _____ Zone Power	________ kw ± 1%	________ kw
4. Initial _____ Zone Power	________ kw ± 1%	________ kw

Note: The power decay should also be ± 1 of specified.

II. INJECTION FLOW

1. Injection Rate

	Specified Rate	Specified Duration	Actual Rate	Actual Duration
Step 1	______ gpm	______ sec	______ gpm	______ sec
Step 2	______ gpm	______ sec	______ gpm	______ sec
Step 3	______ gpm	______ sec	______ gpm	______ sec
Step 4	______ gpm	______ sec	______ gpm	______ sec

	Specified	Actual
2. Coolant Supply Temperature	________ °F ± 5°F	________ °F
3. Initial Temperature of Coolant Injection Line	________ °F ± 10°F	________ °F
4. Initial Temperature of Coolant in Lower Plenum	________ °F ± 10°F	________ °F

III. INITIAL TEST SECTION PRESSURE ________ psia ± 5% ________ psia

Note: The Test Section pressure should not vary by more than 1 psia during the test run, except for the first 20 seconds after flood.

IV. HOUSING TEMPERATURES AT FLOOD*

1. 2 ft. elevation ________ °F
2. 4 ft. elevation ________ °F
3. 5 ft. elevation ________ °F
4. 6 ft. elevation ________ °F
5. 7 ft. elevation ________ °F
6. 8 ft. elevation ________ °F
7. 10 ft. elevation ________ °F

*Location "E" Drawing 1453E50

V. LOOP PIPING AND COMPONENT TEMPERATURES

1. Lower Plenum ________ °F ± 10°F ________ °F
2. Upper Plenum ________ °F ± 20°F ________ °F
3. Carryover Tank ________ °F ± 20°F ________ °F
4. Steam Separator ________ °F ± 20°F ________ °F
5. Steam Separator Collection Tank ________ °F ± 20°F ________ °F
6. Exhaust Pipe
   a) Upstream of Separator ________ °F ± 20°F ________ °F
   b) Downstream of Separator ________ °F ± 20°F ________ °F

Note: Temperature should be an average of all working thermocouples, but each thermocouple should be within limits.

VI. DACPF INITIALIZATION

1. Maximum Acceptable Temperature __________ °F

2. Maximum Test Time __________ sec

3. Slow Scan Time __________ sec

4. Flood Temperature __________ °F

5. Power Decay Delay __________ sec

6. Delta T Time __________ sec

7. Termination Temperature __________ °F

8. Defective Temperature __________ °F

VII. DRPF INITIALIZATION

1. Maximum Power __________ kw/ft

2. Sink Temperature __________ °F

VIII. MOTION/STILL PICTURE CONDITIONS

LOCATION

1. 3′ Elevation Housing __________ frames/sec

2. 6′ Elevation Housing __________ frames/sec

3. 9′ Elevation Housing __________ frames/sec

IX. SPECIAL COMMENTS ON RUN CONDITIONS

X. CONDITIONS CAUSING RUN TERMINATION

XI. CONDITIONS CAUSING RUN TO BE INVALID

XII. INSTRUMENTATION FAILURES

XIII. GENERAL COMMENTS ON TEST RUN

XIV. PRELIMINARY RESULTS

1. Hottest Thermocouple Channel at Turnaround

Thermocouple Elevation	Initial Temp. at Flood	Maximum Temp.	Flood Time	Turnaround Time	Quench Time
_____ ft	_____ °F	_____ °F	_____ sec	_____ sec	_____ sec

2. Drained Water Weights

Carryover Tank	_______ lbm	at	_______ °F
Steam Separator and Collection Tank	_______ lbm	at	_______ °F
Steam Probe Tank – No. 1	_______ lbm	at	_______ °F
Steam Probe Tank – No. 2	_______ lbm	at	_______ °F
Steam Probe Tank – No. 3	_______ lbm	at	_______ °F
Steam Probe Tank – No. 4	_______ lbm	at	_______ °F
Steam Probe Tank – No. 5	_______ lbm	at	_______ °F
Steam Probe Tank – No. 6	_______ lbm	at	_______ °F
Steam Probe Tank – No. 7	_______ lbm	at	_______ °F
Test Section	_______ lbm	at	_______ °F

XV. HEATER ELEMENT INSULATION RESISTANCE CHECK

Heater No.	Prior to Test	Post Test

APPENDIX E
DATA REDUCTION AND ANALYSIS COMPUTER PROGRAMS

This appendix contains details of the various computer programs which will be used to reduce and analyze the test data from this task. The flow logic diagram for the data reduction methods was shown in figures 7-1 and 7-2 and is repeated here as figures E-1 and E-2. Each code is discussed in detail.

E-1. FVALID PROGRAM

The program FVALID provides a printout for the Validation Sheet and Day of Test Report (refer to appendix D). The validation sheet is a specific listing of the data recorded by the PDP 11/20 computer during a test one second before flooding. The listing of this data is used to compare specified values and actual values for the following quantities:

- Heater rod power
- Injection flow
- Initial test section pressure
- Flow housing temperature
- Loop piping and component temperatures

This information is used to determine run validity.

E-2. FLOOK PROGRAM

The FLOOK program permits the examination of selected analog/digital data from a FLECHT run. Data are taken directly from the disc file on the PDP 11/20 and printed in engineering units. Ten channels may be examined in one pass.

E-3. PLOT PROGRAM

Plot is a program which manipulates data that has been stored on the disc such that the necessary conversion, scaling, and formatting of data for the Plot-10 package is accomplished. Plot information is entered through the Tektronix 4010 which specifies the graphic functions to be

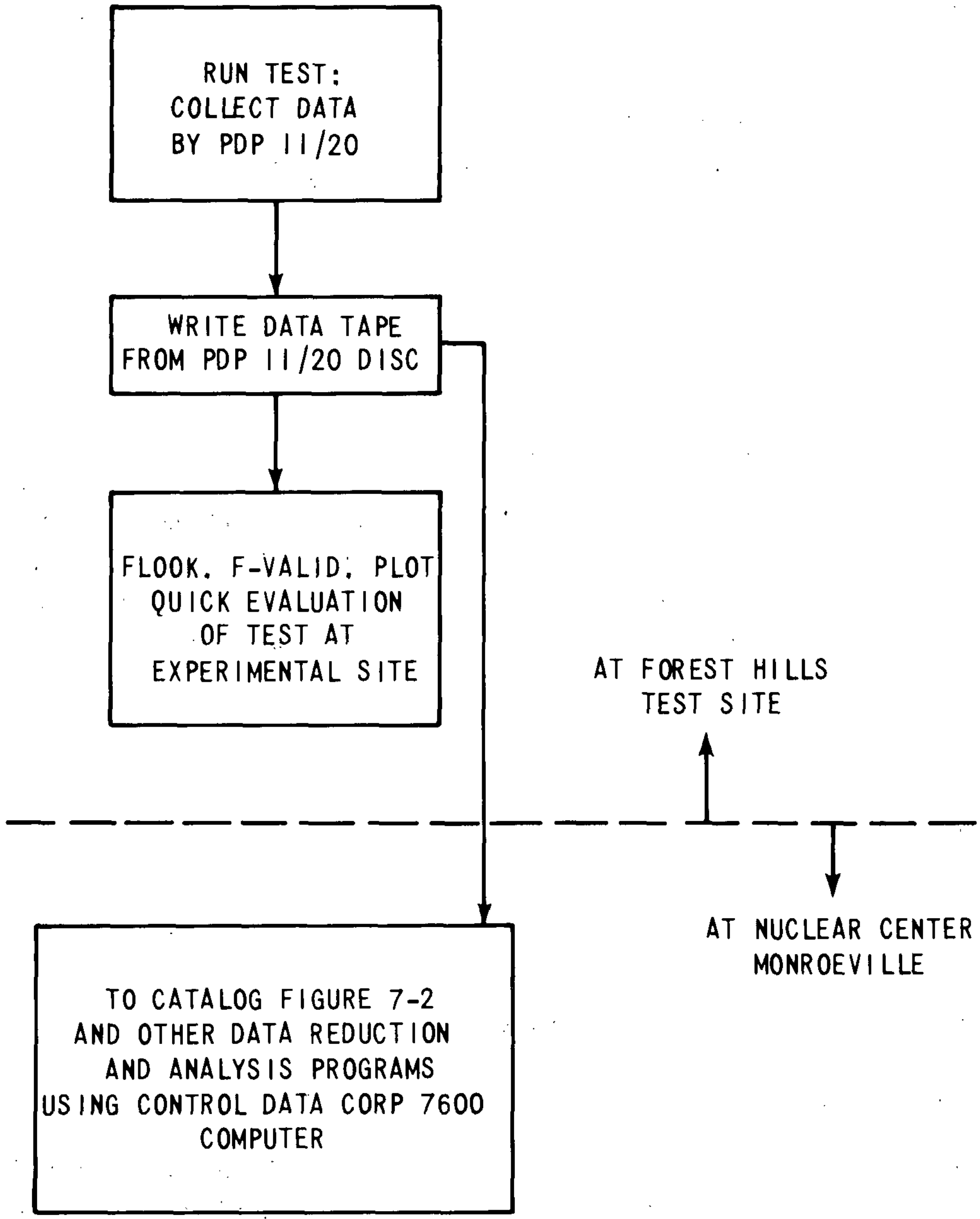


Figure E-1. Flow Logic of Computer Codes

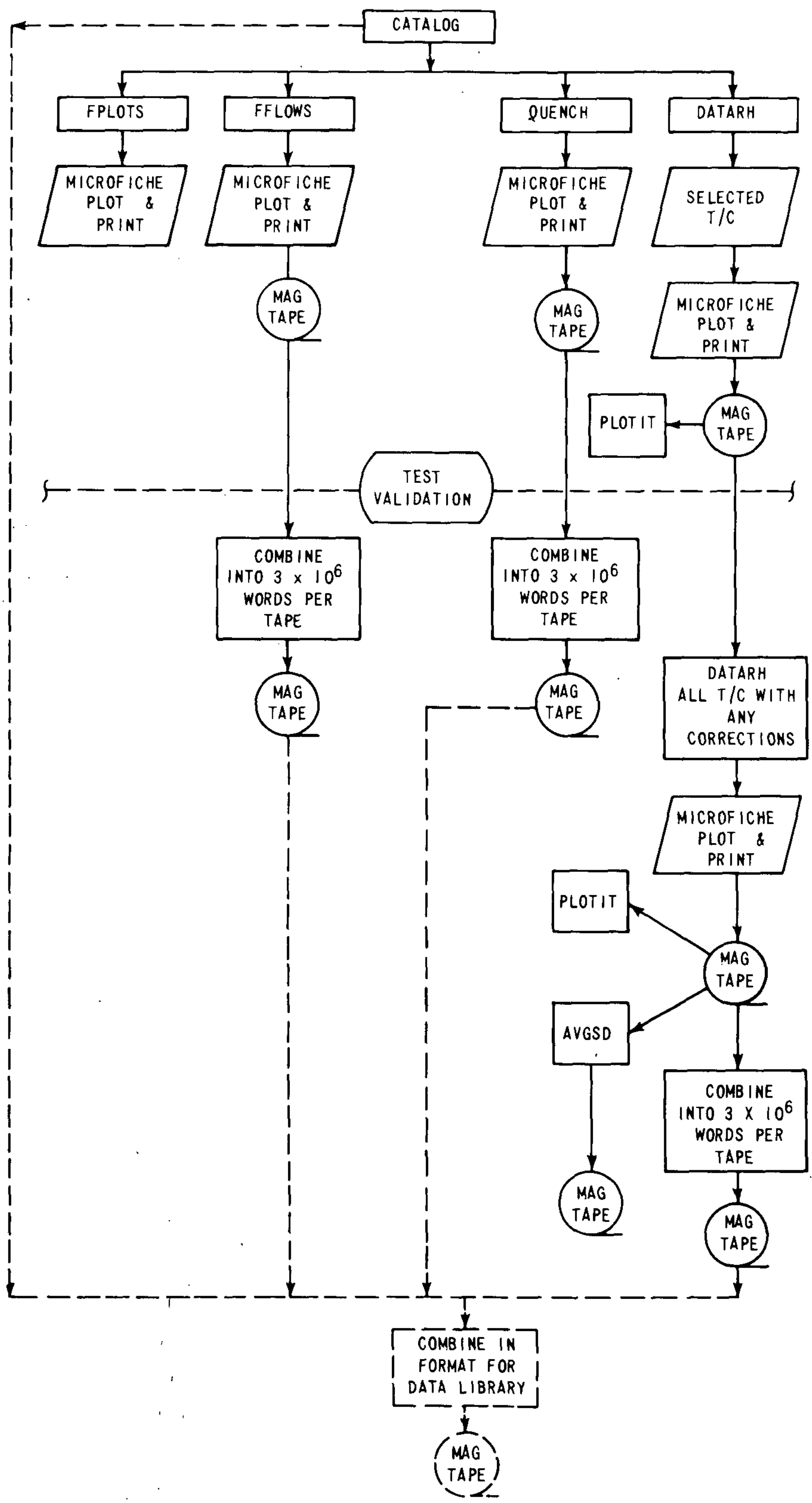


Figure E-2. FLECHT-SEASET Data Reduction Flow Chart performed. A dialog exists between the operator and computer in a question/answer format. Once the dialog has been completed a "Y" response to the "Run" command will cause plotting of the desired data. This information is also used in the data validation procedure.

E-4. CATALOG PROGRAM

CATALOG is the common name for two programs linked in series: FASTDRP and MAKEBIN. The purpose of CATALOG is to use data recorded at the test site and reduce it to a form that is compatible with the Control Data Corporation (CDC) 7600 System at the Westinghouse Nuclear Center.

FASTDRP takes input from the PDP-11/20 system and converts it to the 60 BIT per word CDC system. These data are then stored in updated form.

MAKEBIN, using the updated tape, corrects the appropriate channels for instrument shift. The data are then written in a compact form enabling 10 runs to be stored on each tape. (that is, each 60 BIT word is converted into 30 BIT words and then two 30 BIT words are stored per 60 BIT word).

The output is as follows:

- Raw data in update form
- Calibration file
- Time array (1 s – 0.5 s – 1 s)
- Bad channel list
- Data from each of 256 channels

E-5. FPLOT PROGRAM

FPLOT is a code that presents FLECHT data in tabular and graphical form using engineering units.

FPLOTS has several options for graphical output which are as follows:

- Plot any or all data with a predetermined scale or one that is supplied as test conditions warrant
- Plot any portion of a transient
- Multiplot up to 4 curves

Input to this code consists of data from all channels connected to the computer for a given test.

E-6. QUENCH PROGRAM

The QUENCH program determines key quantities associated with heatup and quenching of the heater rod bundle in the FLECHT facility. The quantities determined from QUENCH are heatup rates, initial temperature, turnaround temperature, turnaround time, quench time, and quench temperature. Statistical computations are performed for each quantity to determine maximum, minimum, mean and standard deviation.

A standard criteria is used in order to determine rod quench time and temperature. This criteria reduces the possibility of error and the injection of an individual's judgement into the computations. The criteria for heater rod quench is as follows:

- A slope greater than 10°C/s (50°F/sec) and a temperature greater than 149°C (300°F). A larger value of slope tends to call any thermocouple noise a quench and a smaller slope tends to miss the quench altogether.
- If the first criteria is not satisfied, the first time the thermocouple reaches saturation temperature.

The PDP 11/20 computer records data from the initiation of heatup sequence during which the bundle is pulsed on through reflood. This time scale is shifted such the bundle is pulsed on through reflood. This time scale is shifted such that time = 0s corresponds to the beginning of reflood. The heatup period prior to reflood is then rescaled with negative times. The QUENCH program linearly interpolates temperature data to determine the rod initial temperature at time = 0.

In most cases rods do not start to heat up at the same time the computer starts to scan channels. In these cases a time and temperature at the beginning of heatup is calculated. It is assumed that heatup begins when the first 1.1°C (2°F) difference is seen between any two consecutive scans of thermocouples. Heatup rates are found by calculating an average time and temperature over a given time increment. This heatup rate in degrees/second can be used to determine if the correct power is being supplied to the bundle through an energy balance calculation. A more detailed explanation of the QUENCH criteria and assumptions are contained within WCAPs-8651[1] and 9108.[2] For each valid thermocouple measurement, the output from QUENCH is as follows:

- Heatup rates
- Initial temperature

1. Rosal, E. R., Hochreiter, L. E., McGuire, M. F., Krepinevich, M. C., "FLECHT Low Flooding Rate Cosine Test Series Data Report, WCAP-8651, December 1975.
2. Rosal, E. R., Conway, C. E. and Krepinevich, M. C., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.

- Turnaround temperature
- Turnaround time
- Quench time
- Quench temperature

E-7. FFLOWS PROGRAM

The program FFLOWS calculates mass flow rate and mass storage for the FLECHT test section and accompanying loop components. A calculation of the fraction of inlet mass leaving the bundle is performed based on two criteria; 1) mass stored in the test section, 2) mass leaving the test section. An overall system mass balance is performed in order to account for system losses.

This mass balance takes into account the total mass stored in the test section, total mass leaving the test loop, and the total mass remaining in the loop after the test. The steam probe collection tanks, upper plenum and steam separator tank accounts for the mass remaining after the test. This sum is compared with the total measured mass (M) injected to otbain a mass balance. That is:

$$\Delta M = \frac{\Sigma M_{injected} - \left(\Sigma M_{\substack{stored\ in\\ bundle}} + \Sigma M_{out} + \Sigma M_{\substack{stored\ in\\ loop}}\right)}{\Sigma M_{injected}} \qquad \text{(E-1)}$$

The total mass injected is taken from the inlet turbine meter data. The collected liquid is calculated from the liquid collection tank differential pressure cells assuming saturated liquid conditions. The steam flow is calculated from the orifice meter differential cell using the measured steam temperature and local pressure to obtain a steam density. Mass stored in the test section is calculated from the 0-3.66 m (0-12 foot) differential pressure cell after a correction is made for frictional pressure drop.

Calculations are also performed to find the average void fraction using the measured pressure drop over each 0.3 m (1-ft) section of the bundle. The measured pressure drop consists of three effects; elevation head, frictional pressure drop and acceleration pressure drop due to vapor generation. That is:

$$\Delta P\ \text{measured} = \Delta P\ \text{elevation} + \Delta P\ \text{acceleration} + \Delta P\ \text{friction} \qquad \text{(E-2)}$$

WCAPs-8238[1] and 9108[2] contain detailed descriptions of the frictional pressure drop, measured pressure drop, and void fraction calculations.

Output from FFLOWS is presented both in tabular and graphical form. The following is a list of output quantities from FFLOWS.

- Two-phase pressure drop
- Void fraction
- Two-phase density
- Two-phase mass storage
- Two-phase frictional pressure drop
- Overall pressure drop 0-3.66 m (0-12 ft)
- Overall mass storage 0-3.66 m (0-12 ft)
- Mass difference
- 3.66 m (12 ft)–upper plenum pressure drop
- Mass in upper plenum
- Accumulator mass loss
- Mass injected into bundle (total and rate)
- Mass stored in bundle (total and rate)
- Mass out of bundle (total and rate)
- Mass difference (total and rate)
- Carryout fraction (total and rate)
- Test section mass (total and rate)
- Carryover tank mass (total and rate)[3]
- Steam separator mass (total and rate)
- Exhaust orifice mass (total and rate)

1. Blaisdell, J. A., Hochreiter, L. E., and Waring, J. P., "PWR FLECHT-SET Phase A Report," WCAP-8238, December 1973.
2. Rosal, E. R., Conway, C. E. and Krepinevich, M. C., "FLECHT Low Flooding Rate Skewed Test Series Data Report," WCAP-9108, May 1977.
3. Based on both mass stored and mass out.

- Overall mass balance
- Lower bound quality
- Upper bound quality

E-8. DATARH PROGRAM

The purpose of DATARH program is to calculate the heat transfer coefficient and wall heat flux for heater rods in the FLECHT-SEASET facility from temperature data (as read from CATALOG tape), as-built heater rod dimensions, and an inverse conduction mathematical model. The DATARH code consists of three overlays in order to reduce the computer field length required for code execution. These overlays consist of:

- The main program overlay together with those subroutines necessary to calculate film coefficients.
- The overlay which reads in appropriate data and calculates quantities such as rod powers.
- An overlay which plots the clad temperatures and heat transfer coefficients.

With the exception of plotting, the main program controls the flow of all input and output data read and generated by the program. A typical DATARH program is conducted using the following steps:

(1) Calculate heater rod material radial node positions based on as-built radii and power step interval information. Note that the code performs one-dimensional calculations in the radial direction only. Axial conduction is ignored.

(2) Calculate appropriate time values for each data point produced. The calibration file values are read via a call to the second overlay.

(3) Enter heater information on the output tape (run number, number of data scans, and the like). Read data tapes and position correctly. Calculate bundle power. The sink temperature is assumed to be the saturation temperature corresponding to the specified pressure for the test.

(4) Read temperature data for a rod thermocouple from the main data and miscellaneous information for that thermocouple (such as bundle position and axial and radial power factors) is read from a secondary data tape.

(5) Determine if a thermocouple is good. This is true if its channel number is not included in the bad channel list and the first temperature is greater than 65.6°C (150°F). If these 2 criteria are not met, a short entry is made on the output tape and data from the next channel is read.

(6) Calculate rod temperature profiles, surface heat flux and heat transfer coefficients by successively calling data reduction subroutines in the model. The number of future temperatures used is determined by the shape of the temperature versus time curve at the next time. This number is constrained to be between one and three and may be no more than one different from the previous value.

(7) Enter data results of calculations performed in step 6 on output. Plot clad temperature and heat transfer coefficient using a call to the third overlay.

(8) Repeat steps 4 through 7 for all bundle thermocouple channels and terminate data reduction.

DATARH uses 4 principal subroutines. The function of each of these is as follows:

(1) Calculate the coefficient matrix (solution-to-simultaneous equation set)

(2) Calculate the temperatures and surface heat flux given the coefficient matrix

(3) Invert the tri-diagonal coefficient matrix

(4) Smooth surface heat flux and heat transfer coefficient over a 10 second time window.

Several other subroutines perform miscellaneous calculations such as material property evaluation and data interpolation.

E-9. AVGSD PROGRAM

AVGSD is a statistical program used to evaluate the large volume of data produced by DATARH. Calculations are performed to obtain a time-dependent mean, one standard deviation, maximum and minimum for the measured temperature, calculated surface temperature, heat flux and heat transfer coefficient. This calculation is performed at each elevation for which valid data exist. In addition, at each elevation the data is grouped into power zones (for example, SCR hookup shown in figures 6-2 to 6-5). Input to this program consists of the output tape from DATARH.

The quantities below are output from AVGSD in both graphical and tabular form for measured temperature, heat flux and heat transfer coefficients.

- Time
- Group (a given set of heater rod thermocouples at an elevation)
- Average

- Standard deviation
- Maximum
- Channel number from which maximum value came
- Minimum
- Channel number from which minimum value came

E-10. ALLTURN PROGRAM

ALLTURN computes a heat transfer coefficients based on distance above the quench front. This is accomplished in two ways: 1) using reduced experimental data output from the QUENCH and DATARH programs 2) using a FLECHT type empirical correlation based on run conditions.

When DATARH results are reduced, thermocouples within an inner rod array are used for a uniform radial power distribution. When the power is a FLECHT radial distribution only, the high power (1.1 power factor) rods within the same array are used to eliminate any effects caused by the housing. At each time of interest a quench elevation is determined from the QUENCH code output. The difference between this elevation and the elevation of interest is the distance above the quench front. Average heat transfer coefficients at each time and elevation are calculated. These experimental results are compared with predicted heat transfer coefficients calculated by a trial correlation. A detailed description of this correlation and comparisons are contained in WCAP-9183.[1]

E-11. FLEMB PROGRAM

FLEMB performs a mass and energy balance on the FLECHT bundle. Input is taken from DATARH, FFLOWS, and CATALOG output tapes. FLEMB consists of a main program and two principal subroutines. The main program controls the input, output, and the user-selected method by which local mass flow, local quality, and local enthalpy are calculated. The local mass options are as follows:

- Without mass storage above quench front based on mass stored in the bundle
- Without mass storage above quench front based on mass out of the bundle

1. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.

- With mass storage above quench front based on mass stored in the bundle

- With mass storage above quench front based on mass out of the bundle

The basic equation for calculating the local mass flow at any differential pressure cell location i corresponding to 0.305, 0.610, 0.914, . . . 3.66 m (1, 2, 3, . . . 12 ft) is:

$$\dot{m}_i = \dot{m}_{i-1} - \frac{d}{dt}\,(m_{stored\ i-1,\ i}) \tag{E-3}$$

Local enthalpy options are as follows:

- Without mass and energy storage above quench front

- With mass and energy storage above quench front

The basic equation for calculating local quality is:

$$h(z) = xh_v(z) + (1-x)\,h_f(z) \tag{E-4}$$

where h(z) is the local enthalpy (refer to equation (E-5)).

Local vapor temperatures supplied by the steam probes are used to calculate a local nonequilibrium quality.

A detailed description and examples of code output is contained in WCAP-9183.[1]

The function of the two subroutines are as follows:

(1) To integrate heat flux data to find the heat release from the quench front to 3.66 m (12 ft) elevation. The basic form of the equation is

$$\dot{m}_{bundle\ exit}\left(h_{bundle\ exit} - h(z)\right) = \int_z^{bundle\ exit} Q'dz \tag{E-5}$$

where Q′ = bundle heat release rate per foot

(2) To extract needed data from input and arrange it into the form needed by the program

1. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP–9183, November 1977.

Calculations within FLEMB are based on the following assumptions:

- Quasi-steady state
- Liquid is at saturation temperature
- Negligible stored energy within a low mass housing

Output from FLEMB is in tabular and graphical form as follows:

- Mass flowrate
- Enthalpy
- Local quality
- Equilibrium quality
- Vapor temperature
- Rod wall temperature
- Local Reynolds number
- Void fraction
- Hot rod heat flux
- Radiation heat flux
- Nusselt number
- Total integrated heat flow
- Net heat flow to drops

E-12. HEAT II PROGRAM

HEAT II calculates the heat transfer to the entrained liquid droplets and the steam, using the method of Sun, Gonzalez-Santalo, and Tien,[1] along with a dynamic droplet model[2] developed in the FLECHT program.

1. Sun, K. H., Gonzalez-Santalo, J. M., and Tien, C. L., "Calculations of Combined Radiation and Connection Heat Transfer in Rod Bundles Under Emergency Cooling Conditions", *Trans. Amer. Soc. Mech. Engrs. 98,* Series C, 414-416 (1976).
2. Lilly, G. P., Yeh, H. C., Dodge, C. E., Wong, S., "PWR FLECHT Skewed Profile Low Flooding Rate Test Series Evaluation Report," WCAP-9183, November 1977.

Input to HEAT II is generated by the FLEMB program. This input includes mass flow rates, quality, steam temperature, wall temperature, and hot rod heat flux. When appropriate, a linear interpolation model is used to obtain the desired data. The calculations within HEAT II are based on the following assumptions:

- Quasi-steady state
- Constant system pressure
- Liquid is at saturation conditions
- Droplet velocity and acceleration is positive
- Slip (or void fraction) is given at quench front

A typical run contains the following steps:

(1) Calculate initial drop size

(2) Calculate slip and droplet volumetric density

(3) Determine the effect of initial void on slip

(4) Calculate the radiation-to-vapor and drops using the Sun, Gonzalez-Santalo and Tien method.[1]

Output from HEAT II contains the following quantities:

- Droplet diameter
- Droplet number density
- Droplet velocity
- Droplet Reynolds number
- Droplet Weber number
- Vapor velocity
- Slip ratio
- Void fraction
- Rod heat flux

1. Sun, K. H., Gonzalez-Santalo, J. M., and Tien, C. L., "Calculations of Combined Radiation and Connection Heat Transfer in Rod Bundles Under Emergency Cooling Conditions", *Trans. Amer. Soc. Mech. Engrs. 98,* Series C, 414-416 (1976).

- Radiation heat flux-to-vapor from heater rod wall
- Radiation heat flux-to-droplet from heater rod wall
- Surface-to-surface radiation heat flux
- Heater rod wall-to-vapor convection heat flux
- Heater rod wall-to-vapor heat transfer coefficient
- Vapor Nusselt number
- Quality
- Heater rod wall temperature
- Steam temperature

APPENDIX F

WORK SCOPE

This appendix discusses the work scope and objectives of the Unblocked Bundle, Forced and Gravity Reflood Task (Task 3.2.1).

F-1. TASK OBJECTIVE

The objective is to provide a data base which: 1) aids in the development or verification of computational methods used by others to predict the reflood thermal-hydraulic behavior of CRG rod arrays, 2) can be used as a baseline for comparison to Task 3.2.3 test data to determine the effect of blockage in CRG rod arrays, and 3) can be compared to previous FLECHT 15 x 15 unblocked tests to evaluate bundle geometry.

F-2. TASK SCOPE

The scope of this program is as follows:

(1) Prepare a Task Plan per section 4.0.[1]

(2) Modify the existing FLECHT facility to provide for both forced flooding and gravity reflood tests. If possible, simulation of initial conditions in which the fuel rods are partially quenched at the onset of reflooding should be provided.

(3) Procure 17 x 17 type heater rods, with a cosine axial power profile, for one bundle to be used in the modified FLECHT test facility.

(4) Recommend an appropriate test matrix based on best estimate and licensing calculations.

(5) Perform system calibration, instrumentation calibration, facility checkout, and facility shakedown tests.

(6) Perform the agreed upon tests.

(7) Review and validate the data.

(8) Reduce the data to obtain the histories of clad temperatures, fluid temperatures, and housing temperatures; inlet flow rate, inlet enthalpy, system pressure and pressure drops, steam and liquid flows out the bundle, mass storage in the test section as a function of elevation, and system temperatures. Review photographs and movies taken.

1. Conway, C. E., Hochreiter, L. E., Krepinevich, M., Massie Jr., H. W., Rosal, E. R. and Howard, R. C., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI/Westinghouse Report Number 1, December 1977.

(9) Process and store transducer data on computer tape.

(10) Prepare a Data Report per section 4.0.[1]

(11) Provide derived thermal-hydraulic quantities and bundle average fluid conditions at several axial positions from the test data, where applicable (that is, vapor temperatures, local rod heat fluxes, local heat transfer coefficients, bundle heat release rates, fluid mass storage in and effluent rate from the test section, quench front velocities, and void fractions).

(12) Identify the two-phase flow regimes occurring during reflood, using photographic methods and appropriate data. Where possible, identify the heat transfer regimes and mechanisms that occur during the reflooding process and compare the results to existing heat transfer correlations. If necessary and possible, propose improved heat transfer correlations.

(13) Correlate, in a FLECHT-type correlation, the resulting data to provide overlap with the previous FLECHT 15 x 15 unblocked heat transfer tests.

(14) Analyze suitable tests, using Westinghouse Proprietary Computer Code per Section 3.2.9.[1]

(15) Prepare a Data Analysis and Evaluation Report per section 4-0.[1]

1. Conway, C. E., Hochreiter, L. E., Krepinevich, M., Massie Jr., H. W., Rosal, E. R. and Howard, R. C., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI/Westinghouse Report Number 1, December 1977.

APPENDIX G
FACILITY DRAWINGS

An index of FLECHT-SEASET 17 x 17 Unblocked Bundle facility drawings with figure numbers is presented in table G-1. Code developers and data analysts may use these as-built dimensions on the assembly and working drawings to model the unblocked facility or to compare the FLECHT loop with other reflood testing installations.

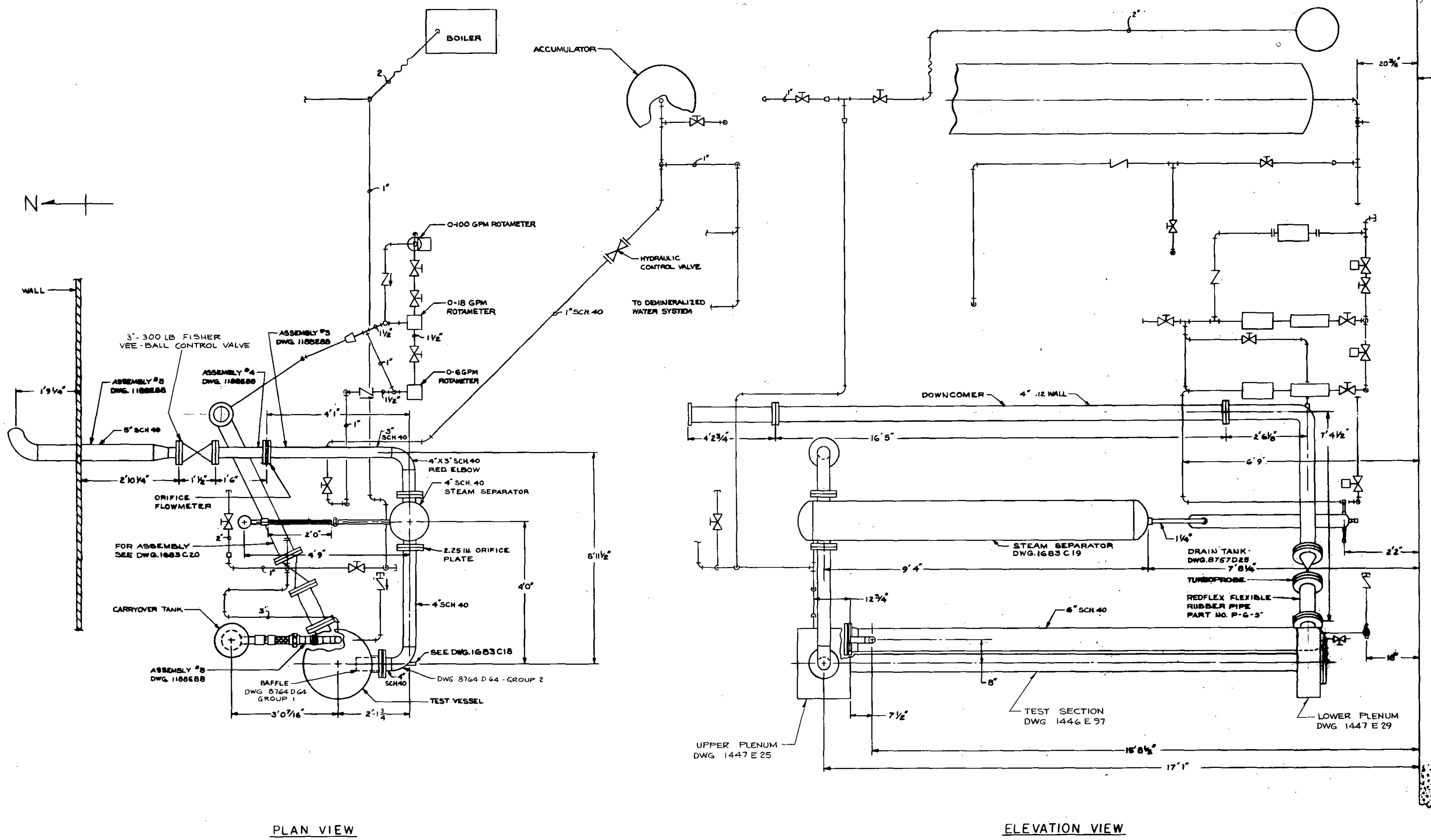
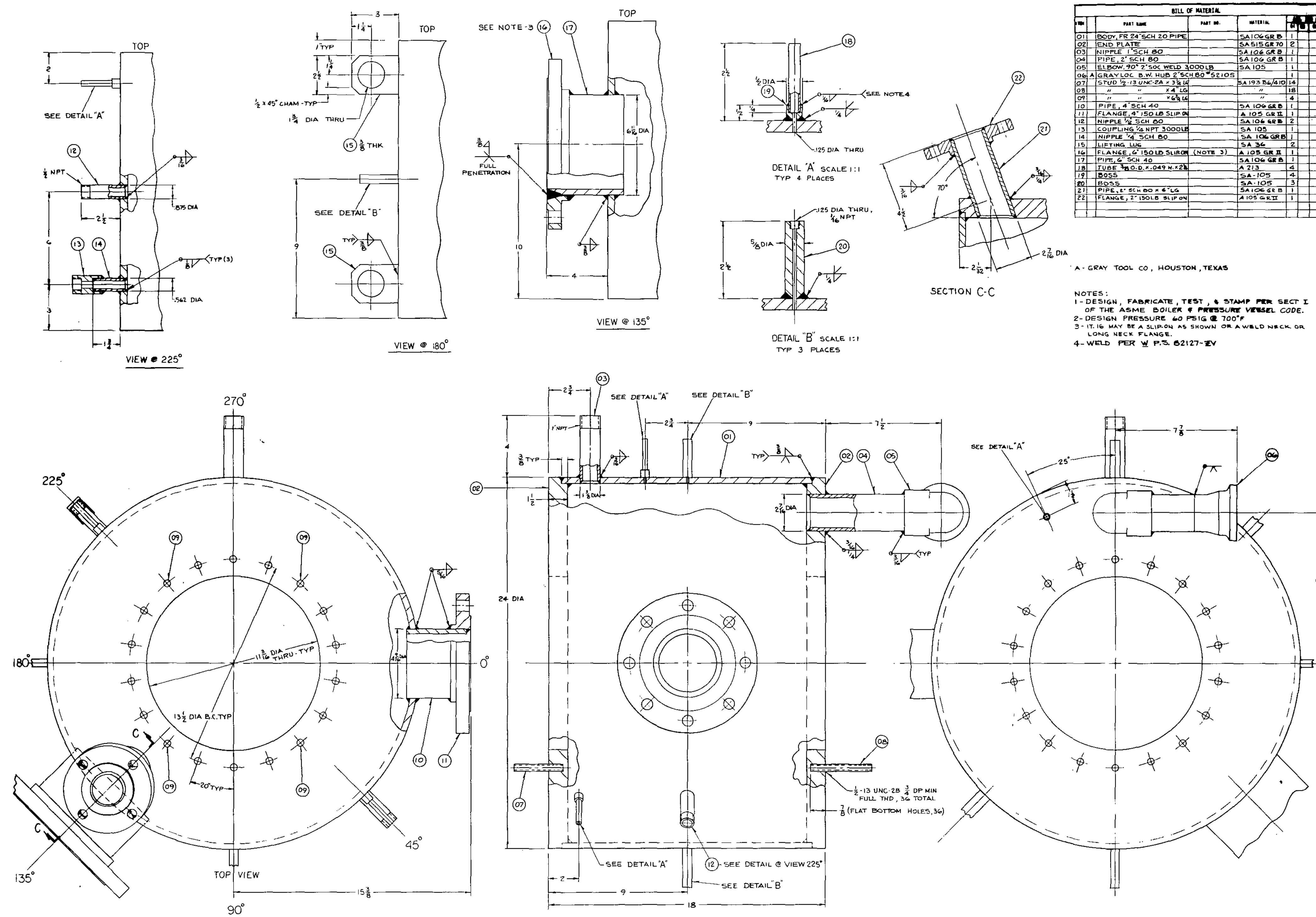


Figure G-1. Piping Diagram for the Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)



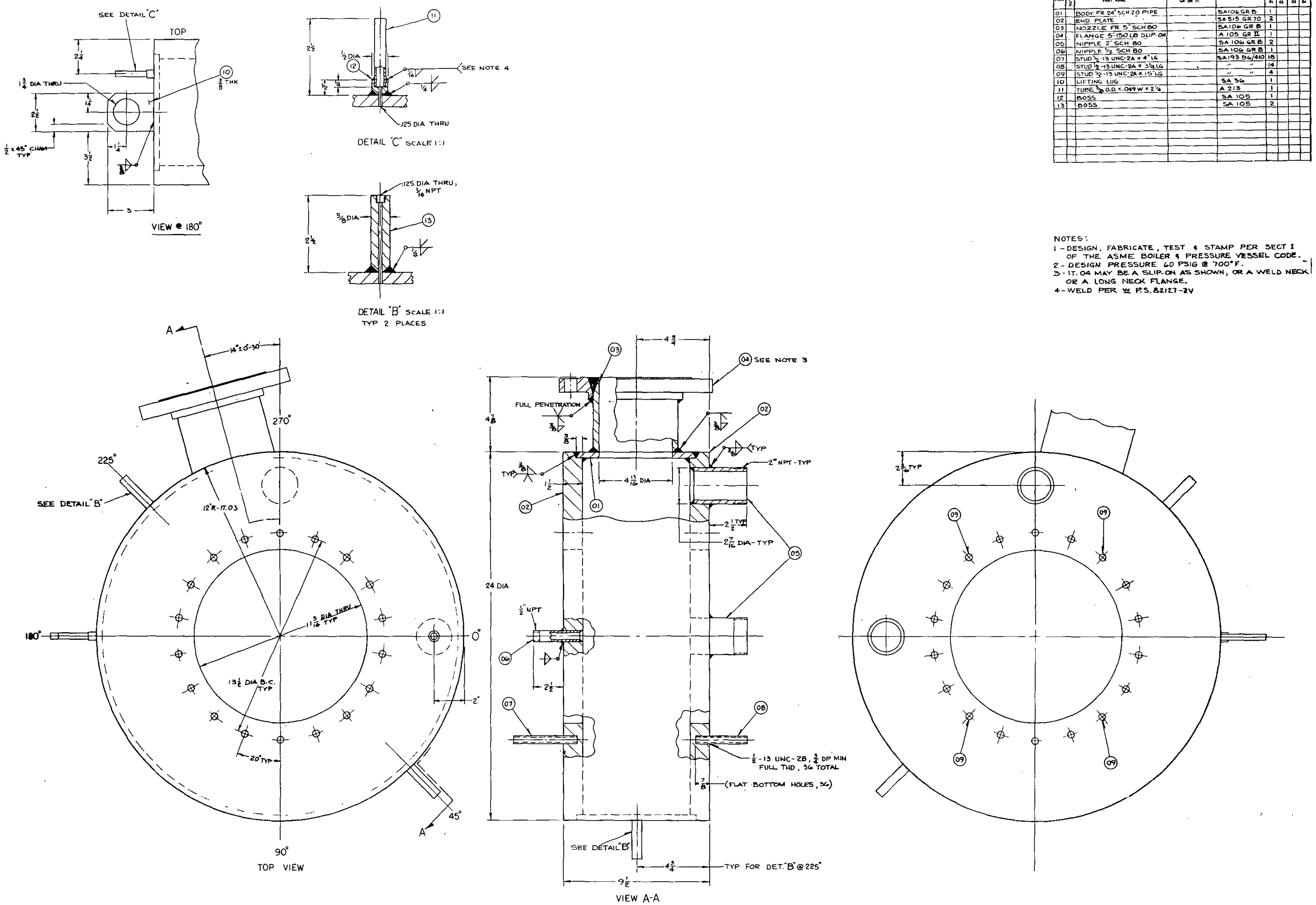
ITEM		PART NAME	PART NO.	MATERIAL	QTY			
01		BODY, FR 24" SCH 20 PIPE		SA106 GR B	1			
02		END PLATE		SA515 GR 70	2			
03		NIPPLE 1" SCH 80		SA106 GR B	1			
04		PIPE, 2" SCH 80		SA106 GR B	1			
05		ELBOW, 90° 2" SOC WELD 3000 LB		SA105	1			
06	A	GRAYLOC B.W. HUB 2" SCH 80 #52105			1			
07		STUD ½-13 UNC-2A × 3¼ LG		SA193 B6/410	14			
08		" " × 4" LG		"	18			
09		" " × 6¾ LG		"	4			
10		PIPE, 4" SCH 40		SA106 GR B	1			
11		FLANGE, 4" 150 LB SLIP ON		A105 GR II	1			
12		NIPPLE ½" SCH 80		SA106 GR B	2			
13		COUPLING ¼ NPT 3000 LB		SA105	1			
14		NIPPLE ¼" SCH 80		SA106 GR B	1			
15		LIFTING LUG		SA 36	2			
16		FLANGE, 6" 150 LB SLIP ON	(NOTE 3)	A105 GR II	1			
17		PIPE, 6" SCH 40		SA106 GR B	1			
18		TUBE 3/16 O.D. × .049 W. × 2½		A 213	4			
19		BOSS		SA-105	4			
20		BOSS		SA-105	3			
21		PIPE, 2" SCH 80 × 6" LG		SA106 GR B	1			
22		FLANGE, 2" 150 LB SLIP ON		A105 GR II	1			

A - GRAY TOOL CO, HOUSTON, TEXAS

NOTES:
1 - DESIGN, FABRICATE, TEST, & STAMP PER SECT I OF THE ASME BOILER & PRESSURE VESSEL CODE.
2 - DESIGN PRESSURE 60 PSIG @ 700°F
3 - IT. 16 MAY BE A SLIP-ON AS SHOWN OR A WELD NECK OR LONG NECK FLANGE.
4 - WELD PER W P.S. 62127-IV

UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
ALL DIMS ± 1/32
SEE PROCESS SPECIFICATION NO. CAPS05128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

Figure G-2. Upper Plenum Detail and Assembly (FLECHT-SEASET Unblocked Bundle)



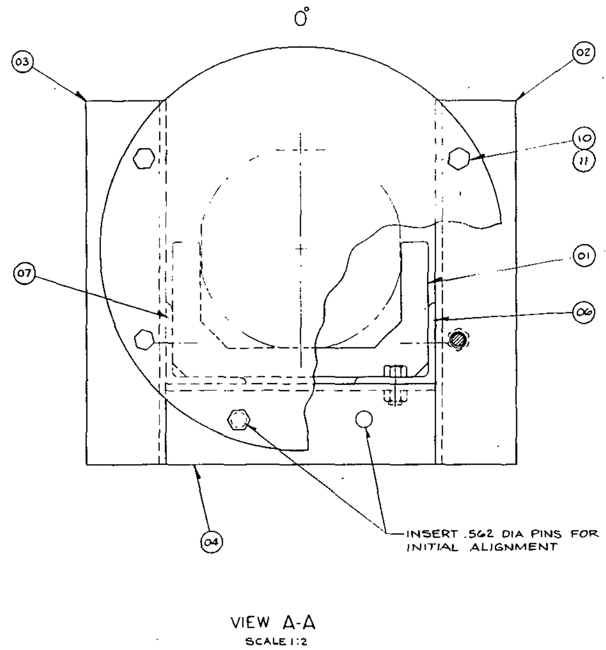
BILL OF MATERIAL								
ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ PER GROUP 01	02	03	04
01		BODY FR 24" SCH 20 PIPE		SA106 GR B	1			
02		END PLATE		SA 515 GR 70	2			
03		NOZZLE FR 5" SCH 80		SA106 GR B	1			
04		FLANGE 5"-150 LB SLIP-ON		A 105 GR II	1			
05		NIPPLE 2" SCH 80		SA 106 GR B	2			
06		NIPPLE 1/2 SCH 80		SA 106 GR B	1			
07		STUD 1/2-13 UNC-2A × 4" LG		SA193 B6/410	18			
08		STUD 1/2-13 UNC-2A × 3 1/4 LG		" "	14			
09		STUD 1/2-13 UNC-2A × 15" LG		" "	4			
10		LIFTING LUG		SA 36	1			
11		TUBE 3/8 O.D. × .049 W × 2 1/4		A 213	1			
12		BOSS		SA 105	1			
13		BOSS		SA 105	2			

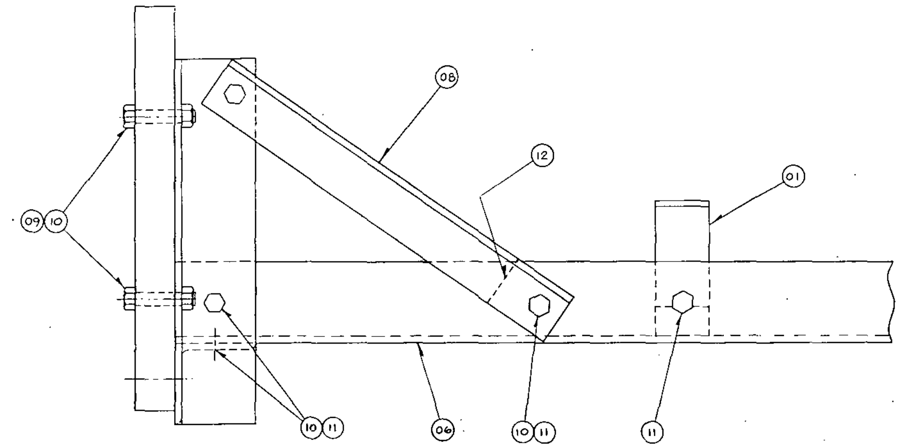
NOTES:
1 - DESIGN, FABRICATE, TEST & STAMP PER SECT I OF THE ASME BOILER & PRESSURE VESSEL CODE.
2 - DESIGN PRESSURE 60 PSIG @ 700°F.
3 - IT. 04 MAY BE A SLIP-ON AS SHOWN, OR A WELD NECK OR A LONG NECK FLANGE.
4 - WELD PER W P.S. 82127-ZV

Figure G-3. Lower Plenum Detail and Assembly (FLECHT-SEASET Unblocked Bundle)

BILL OF MATERIAL

ITEM	NOTE	PART NAME	DRAWING & GR OR IT	MATERIAL	REQ. PER GROUP 01	02	03	04
01		GRID SUPPORT		AL 6061-T6	8			
02		L 3 × ? × ¼		ASTM A36	1			
03		L			1			
04		L			1			
05		L			5			
06		L			1			
07		L 3 × 3 × ¼			1			
08		L 2 × 2 × ¼		ASTM A36	2			
09		.50-13 UNC-2A × 2.25 LG HEX HD BOLT		ALLOY STL	6			
10		.50-13 UNC-2B HEX NUT		ALLOY STL	24			
11		.50-13 UNC-2A × 1.00 LG HEX HD BOLT		ALLOY STL	34			
12		SPACER		ASTM A36	2			





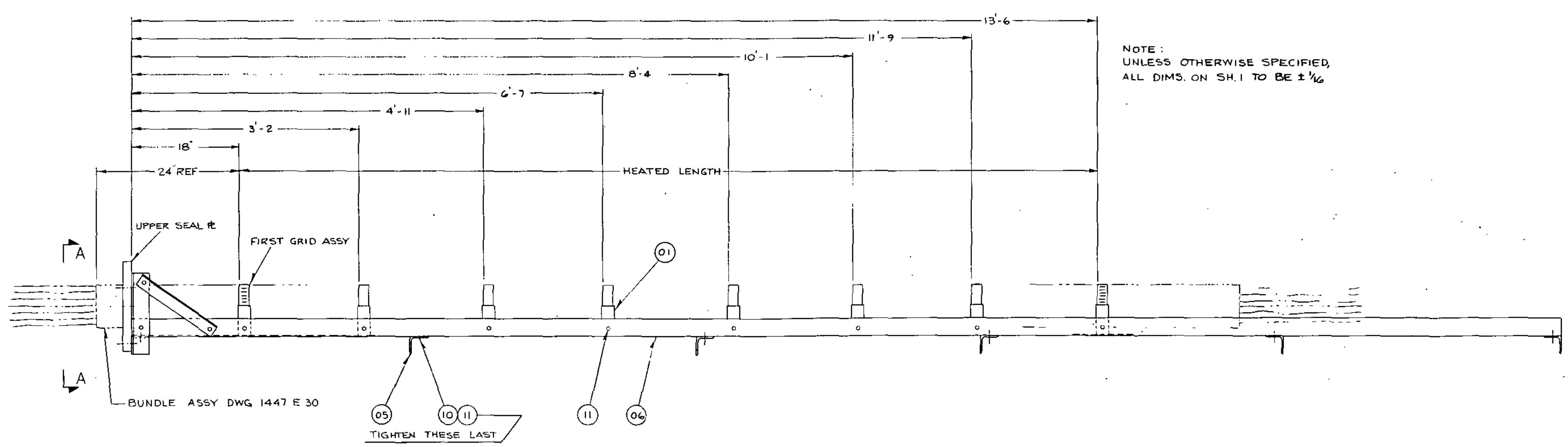


Figure G-4. Strongback and Assembly Fixture (FLECHT-SEASET Unblocked Bundle) Sheet 1 of 2

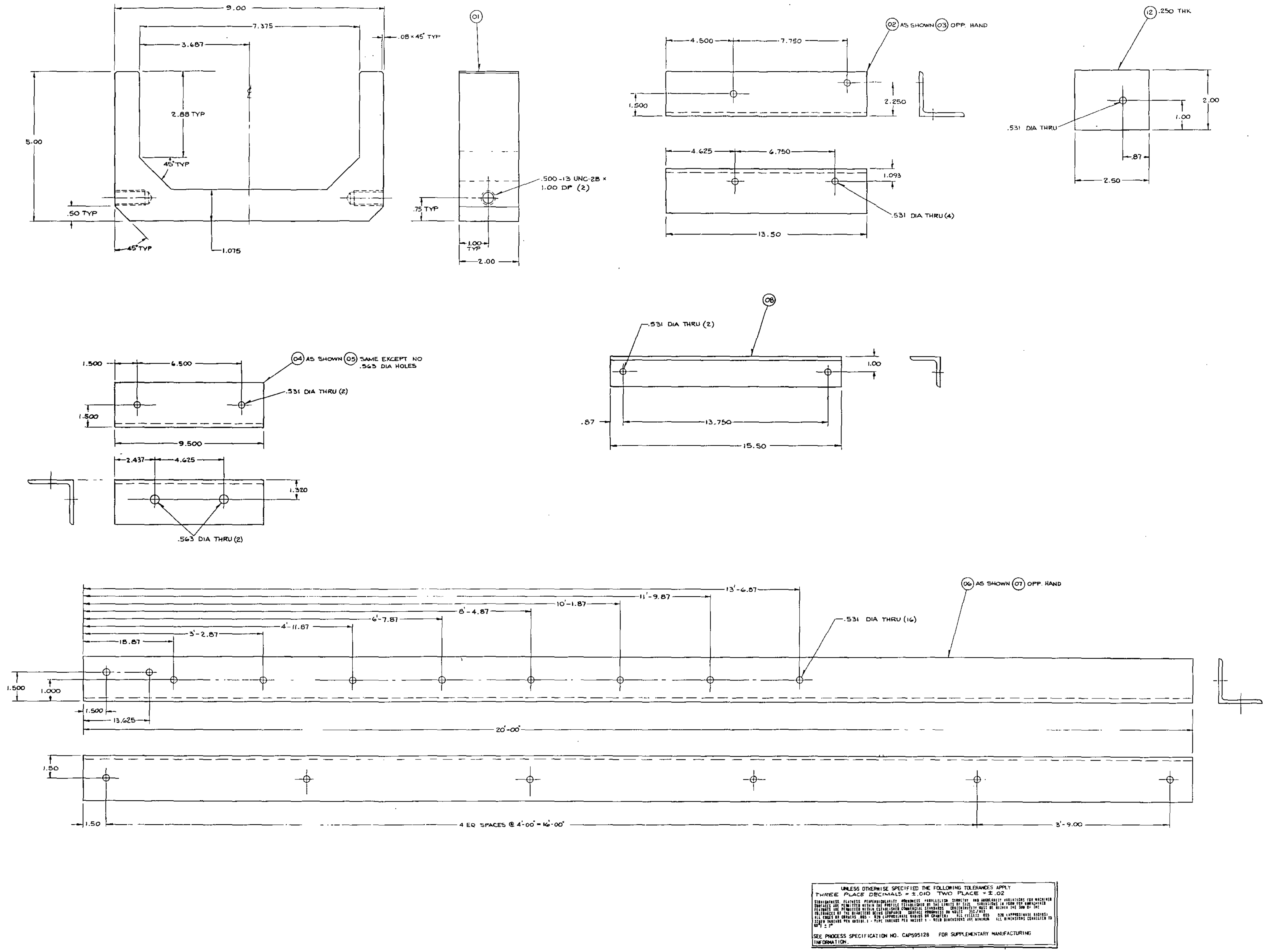
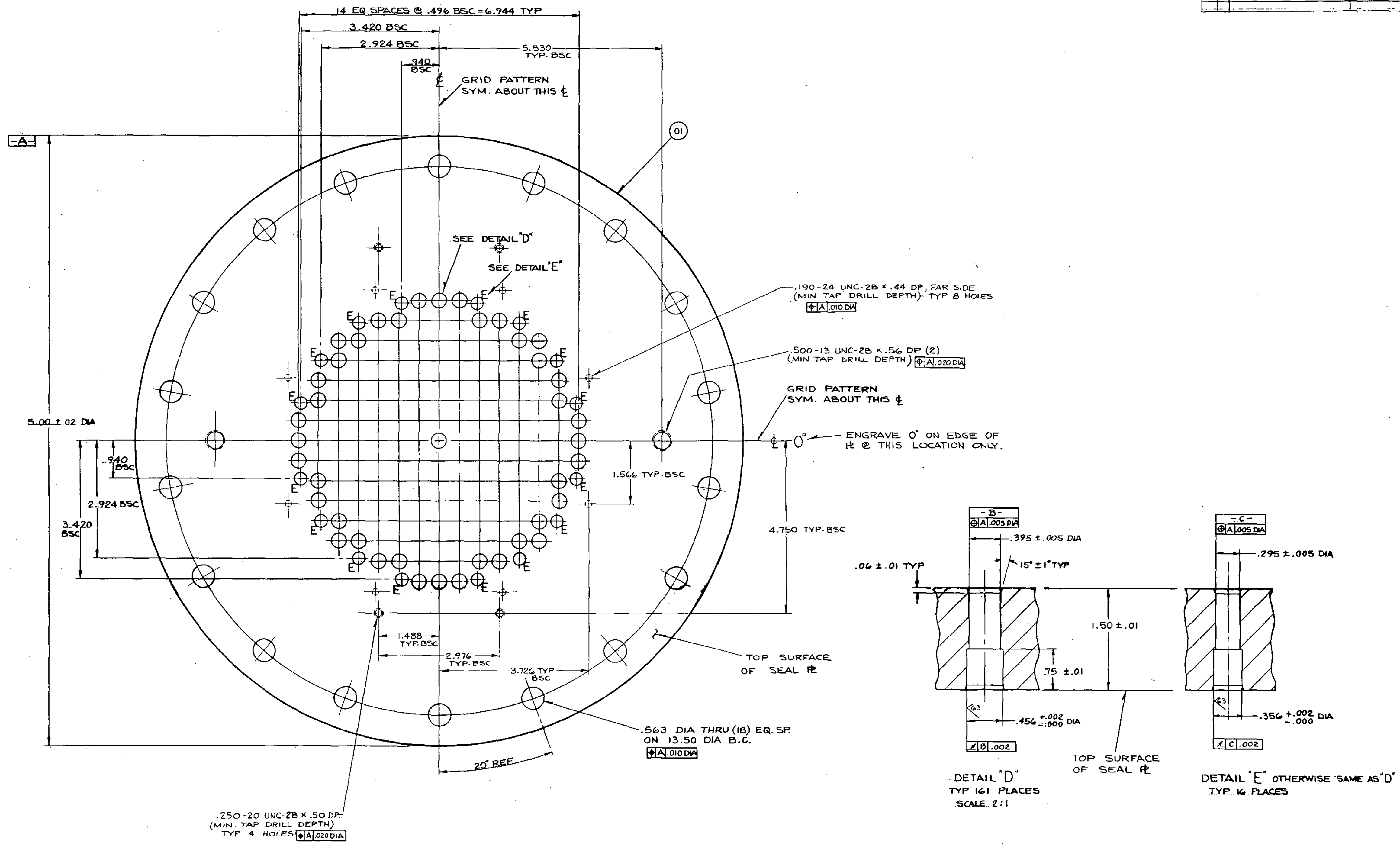


Figure G-4. Strongback and Assembly Fixture (FLECHT-SEASET Unblocked Bundle) Sheet 2 of 2

BILL OF MATERIAL								
ITEM		PART NAME	PART NO.	MATERIAL	REQ. PER GROUP			
					01	02	03	04
01		SEAL PLATE		ASTM 240 TYPE 304	1			



UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY

STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY, AND ANGULARITY VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE. VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. CONCENTRICITY MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES: 250√MAX. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER). - ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ANSI B1.1 - PIPE THREADS PER ANSI B2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°.

SEE PROCESS SPECIFICATION NO. CAP595128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION

Figure G-5. Upper Seal Plate for Low Mass Housing (FLECHT-SEASET Unblocked Bundle)

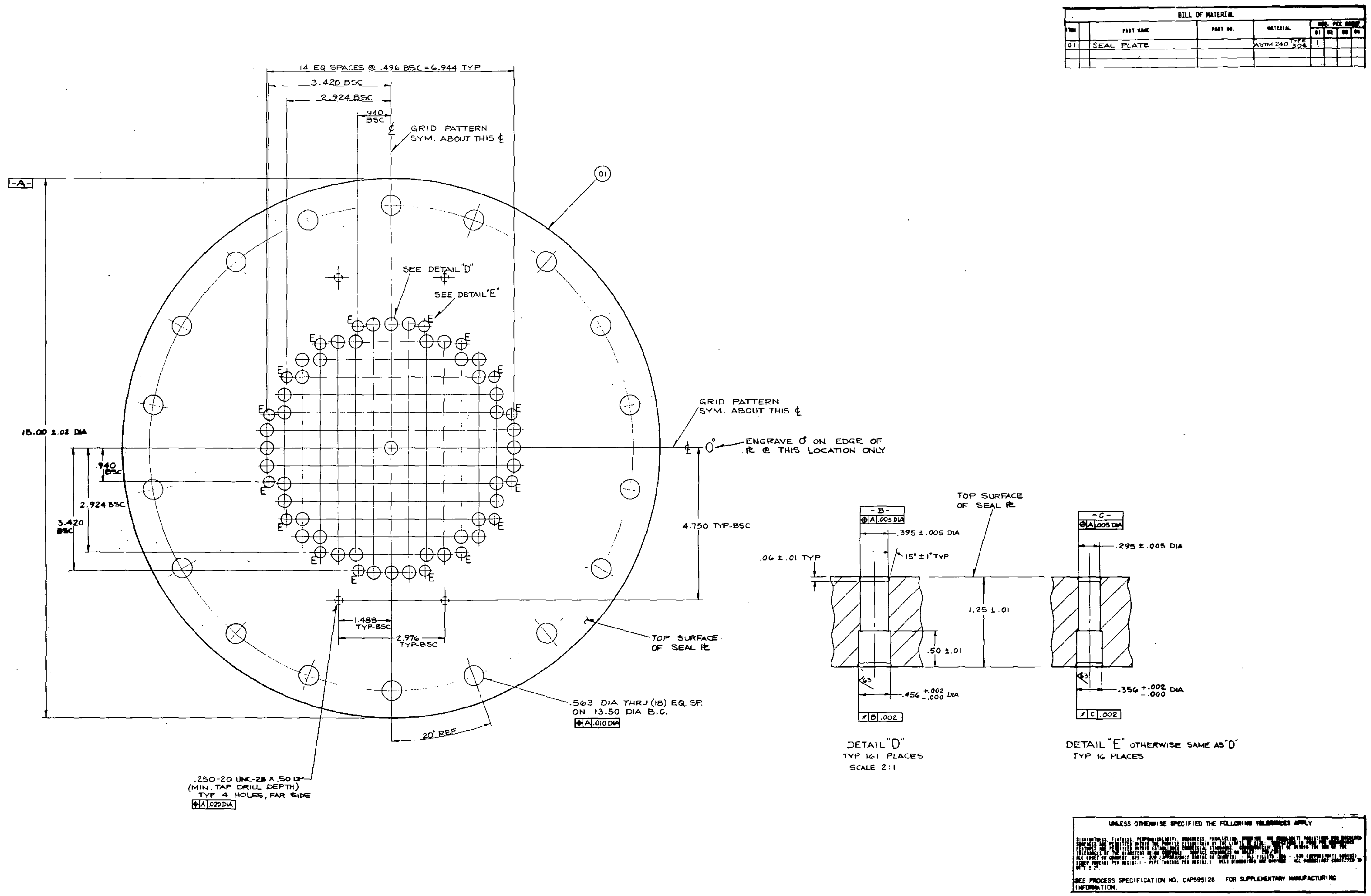
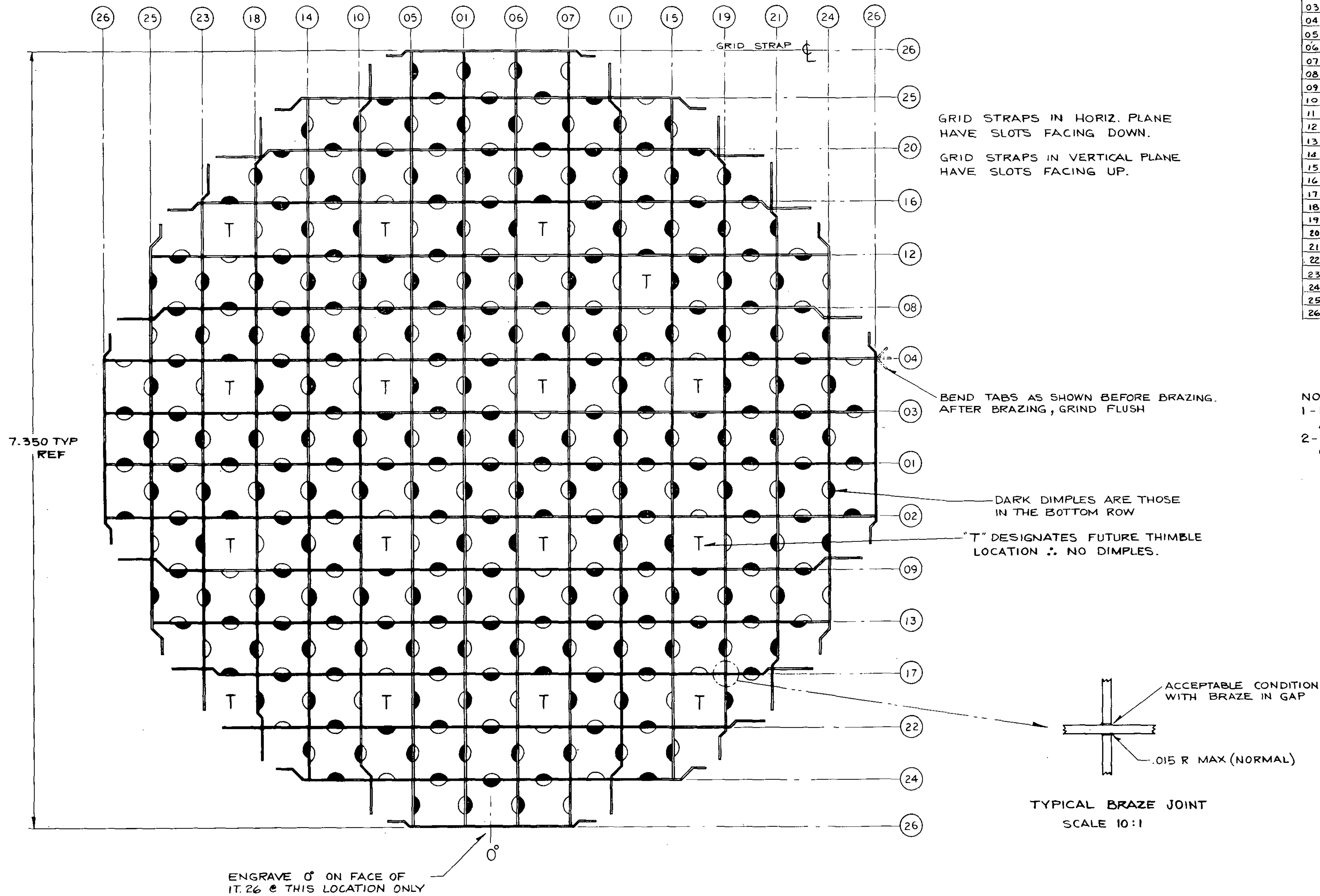


Figure G-6. Lower Seal Plate for Low Mass Housing (FLECHT-SEASET Unblocked Bundle)



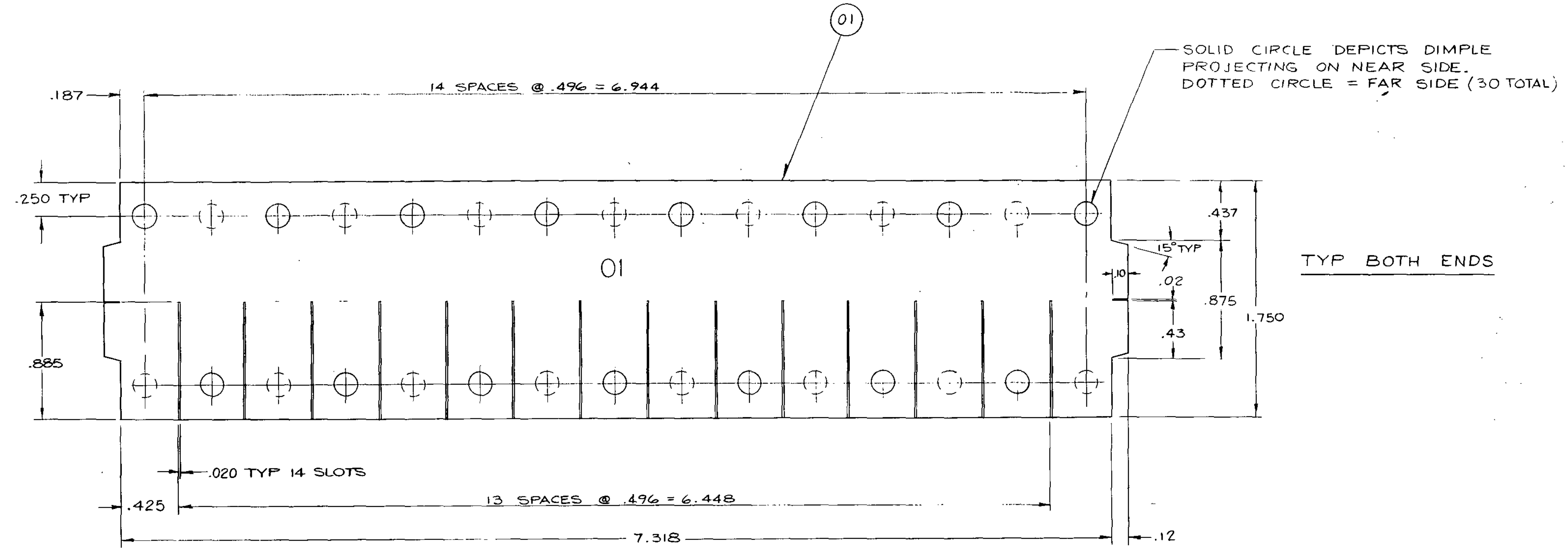
BILL OF MATERIAL								
ITEM		PART NAME	PART NO.	MATERIAL	REQ. PER GROUP			
					01	02	03	04
01		GRID STRAP	8763 D57-IT. 01		2			
02			02		1			
03			03		1			
04			04		1			
05			05		1			
06			06		1			
07			07		1			
08			08		1			
09			09		1			
10			10		1			
11			11		1			
12			12		1			
13			13		1			
14			14		1			
15			15		1			
16			16		1			
17			17		1			
18			18		1			
19			19		1			
20			20		1			
21			21		1			
22			22		1			
23			23		1			
24			24		2			
25			25		2			
26		GRID STRAP	8763 D57- IT. 26		4			

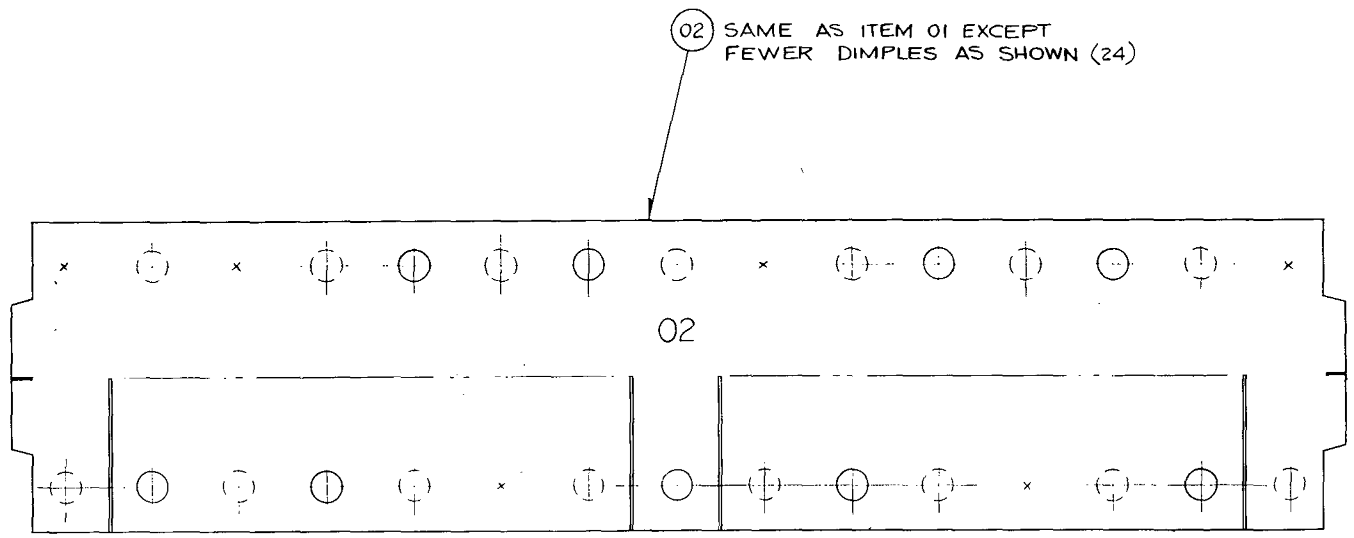
NOTES:

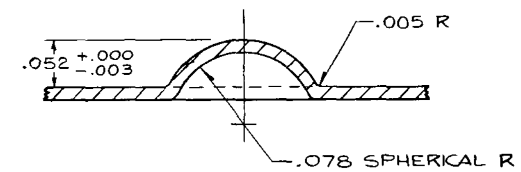
1 - BRAZE PER W PROC. SPEC. CAP 595151 - DELETE THE AGING CYCLE.

2 - GRID ASSY MUST PASS THRU AN INSPECTION ENVELOPE OF 7.525 DIA.

Figure G-7. Grid Strap Assembly (FLECHT-SEASET Unblocked Bundle)







TYPICAL DIMPLE
SCALE 10:1

BILL OF MATERIAL								
ITEM		PART NAME	PART NO.	MATERIAL	REQ. PER GROUP			
					01	02	03	04
01		GRID STRAP .015 THK		INCONEL 718				
02								
03								
04								
05								
06								
07								
08								
09								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26		GRID STRAP .015 THK		INCONEL 718				

NOTES:
1 - ALL GRID STRAPS ARE THE SAME HEIGHT, THICKNESS & HAVE THE SAME DIMPLE SIZE & SLOT SIZE. DIMPLE POSITIONS ARE AS SHOWN @ EACH VIEW.
2 - ENGRAVE .12 HIGH ITEM NO. AS SHOWN ON EACH STRAP.

Figure G-8. Grid Strap Details (FLECHT-SEASET Unblocked Bundle) Sheet 1 of 7

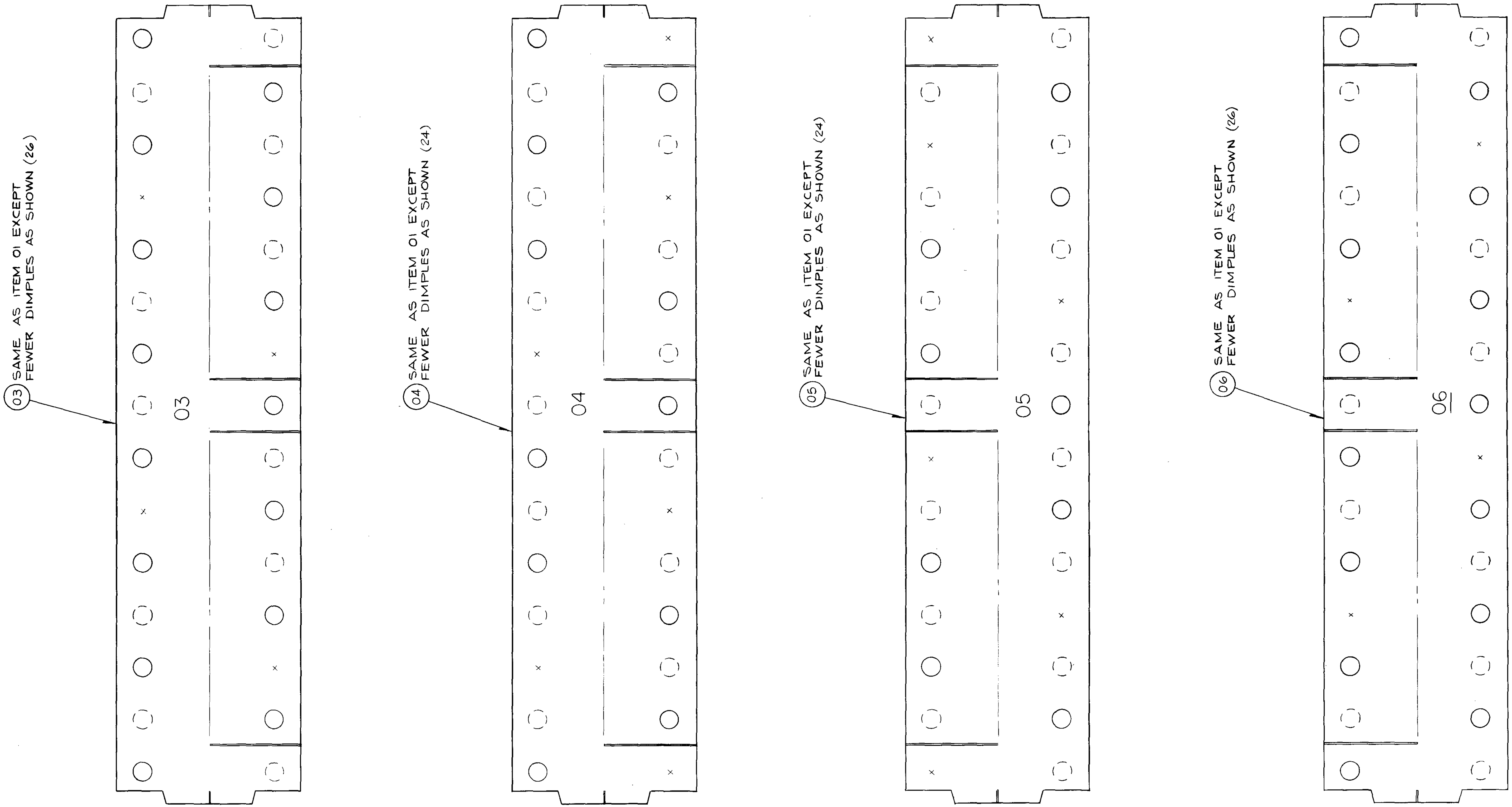


Figure G-8. Grid Strap Details (FLECHT-SEASET Unblocked Bundle) Sheet 2 of 7

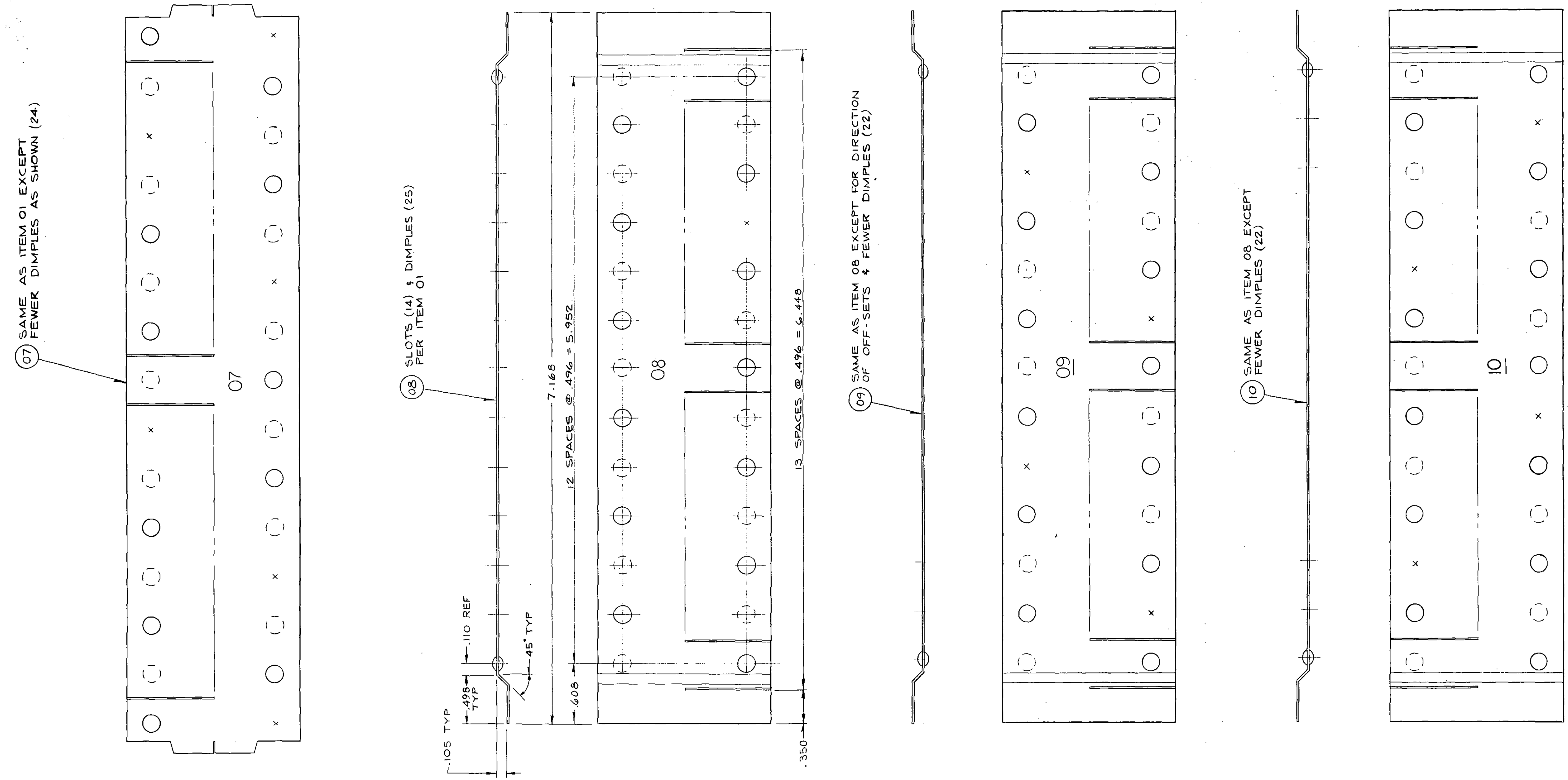


Figure G-8. Grid Strap Details (FLECHT-SEASET Unblocked Bundle) Sheet 3 of 7

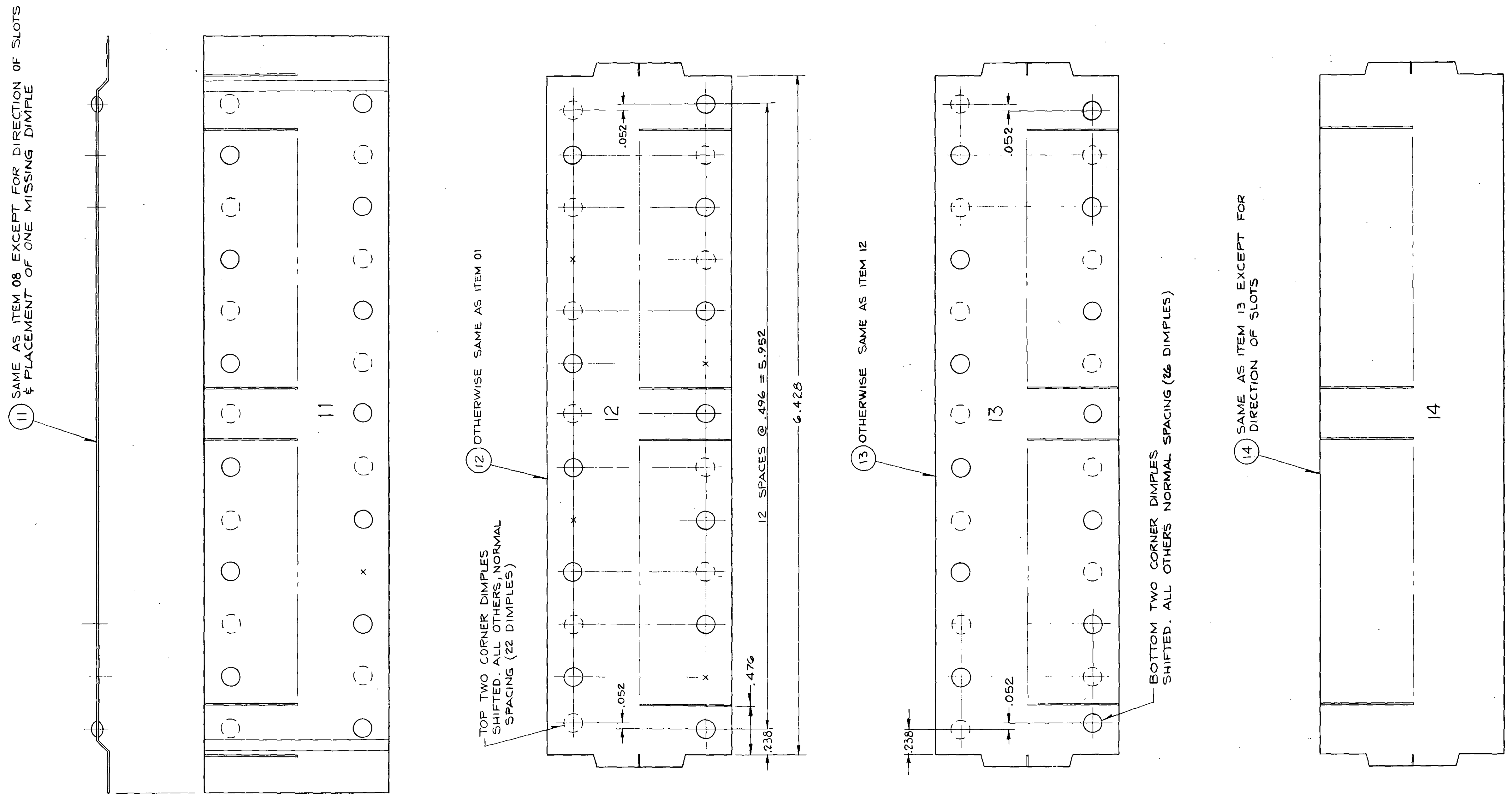


Figure G-8. Grid Strap Details (FLECHT-SEASET Unblocked Bundle) Sheet 4 of 7

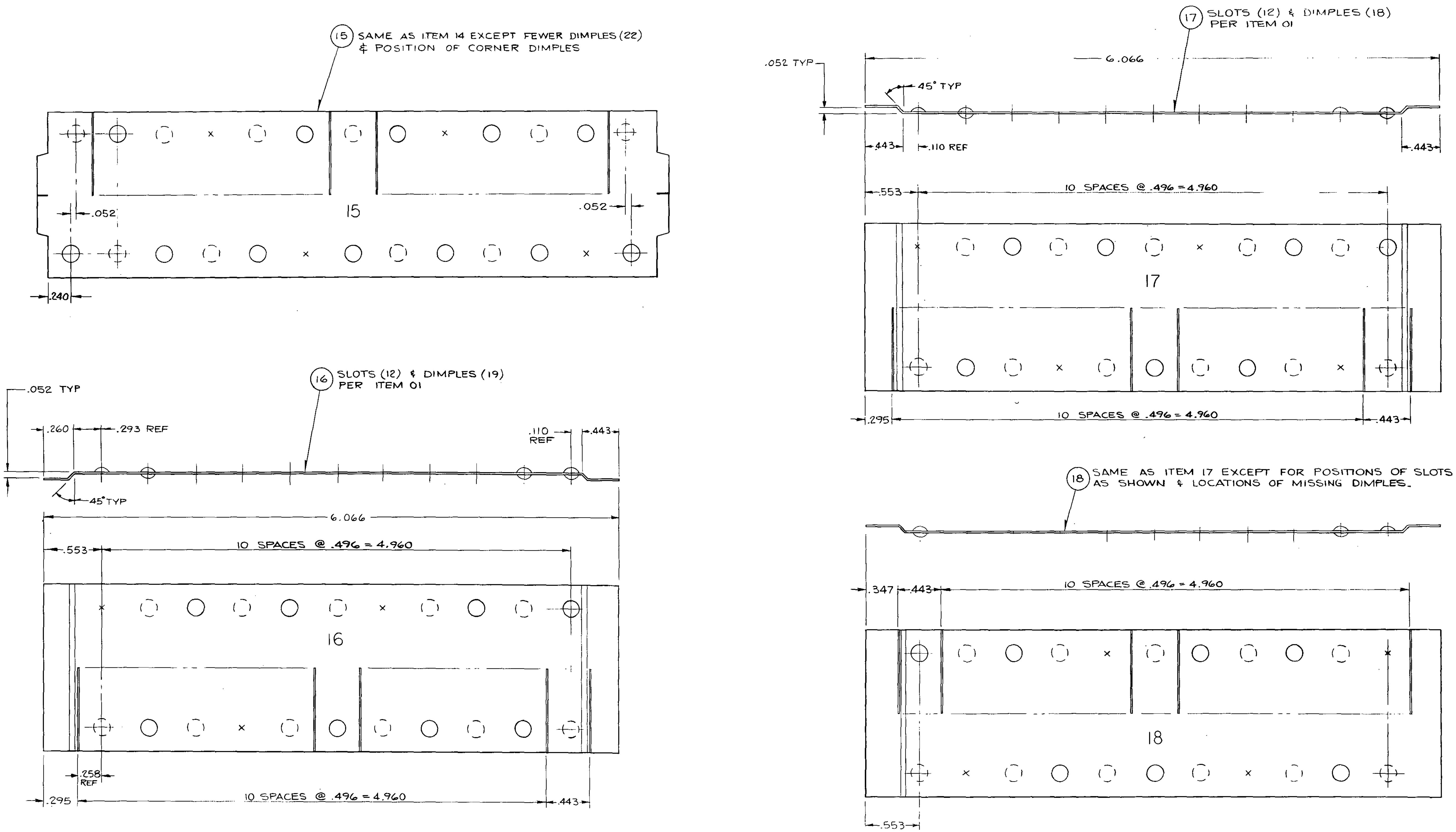


Figure G-8. Grid Strap Details (FLECHT-SEASET Unblocked Bundle) Sheet 5 of 7

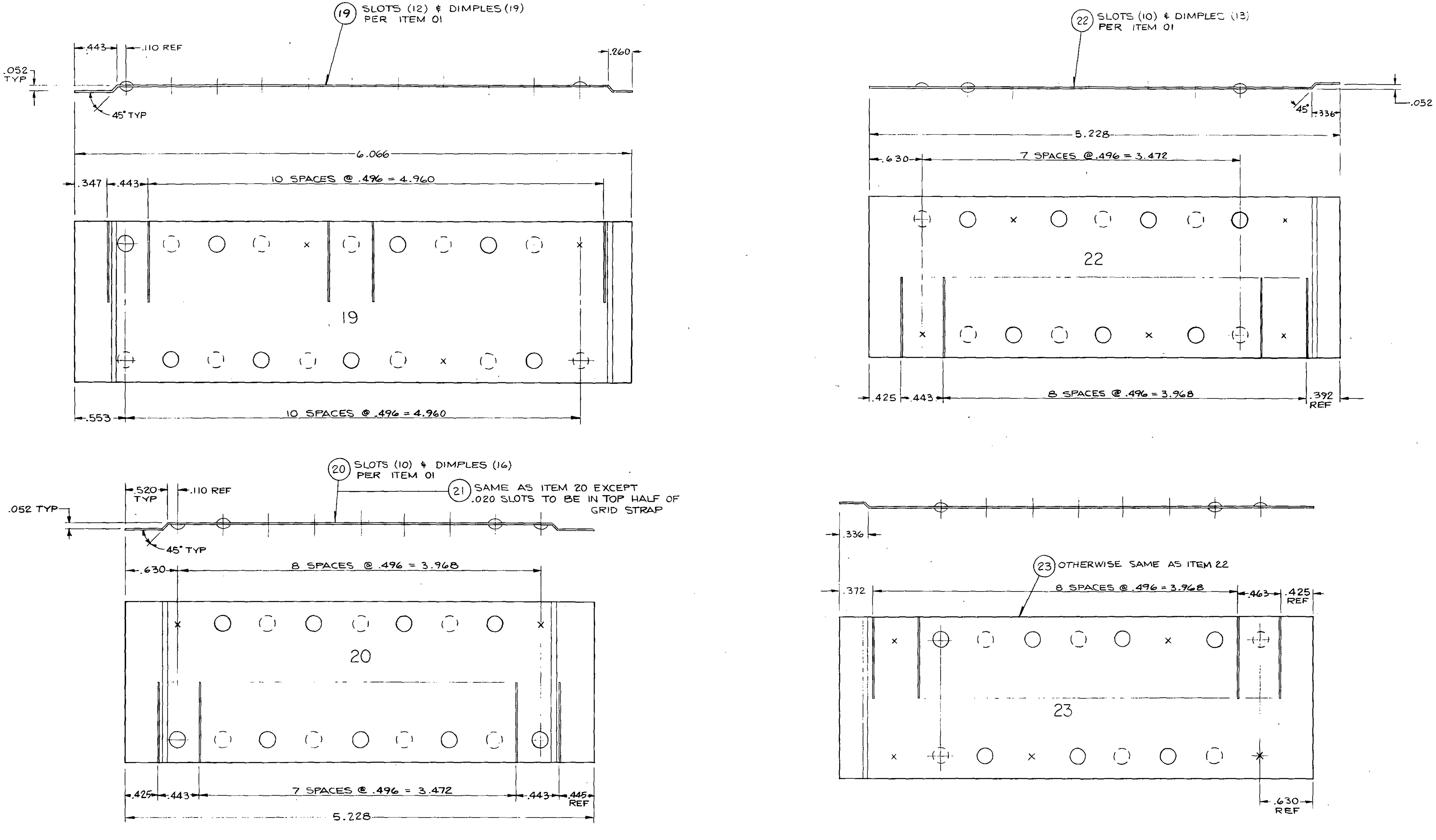


Figure G-8. Grid Strap Details (FLECHT-SEASET Unblocked Bundle) Sheet 6 of 7

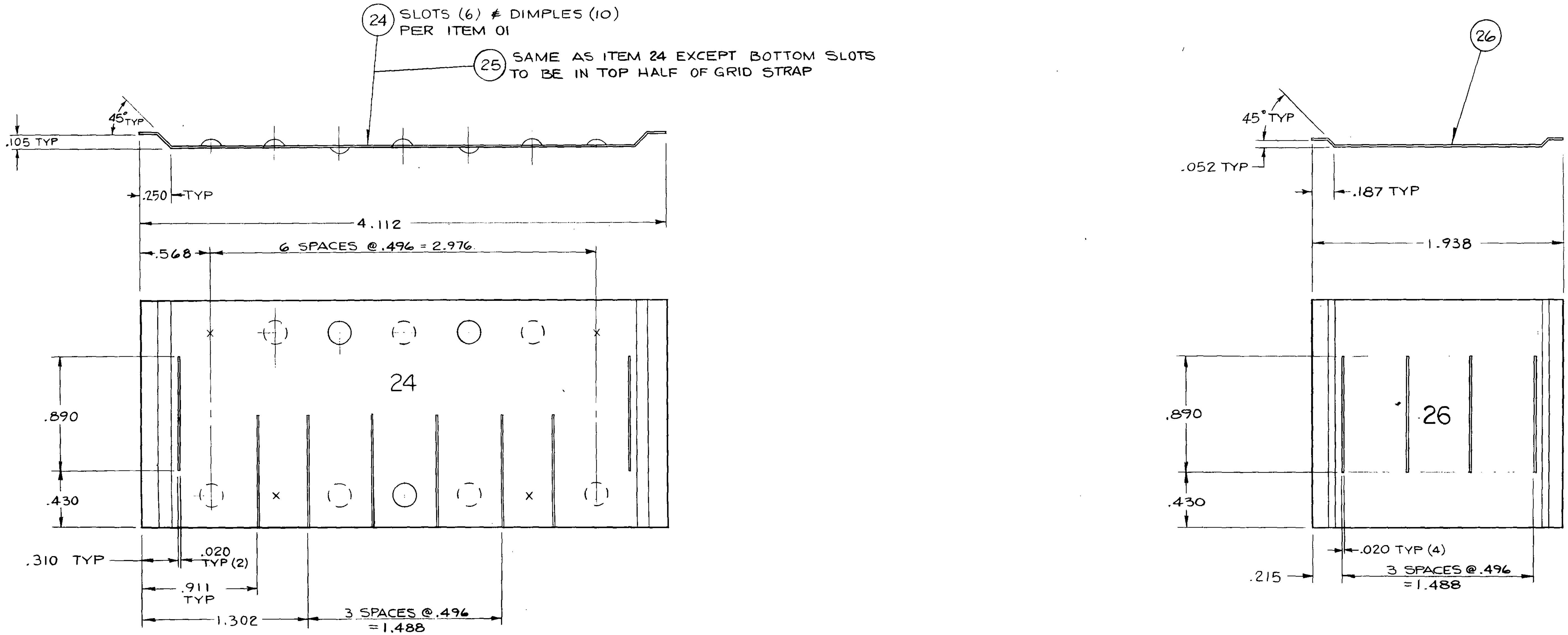
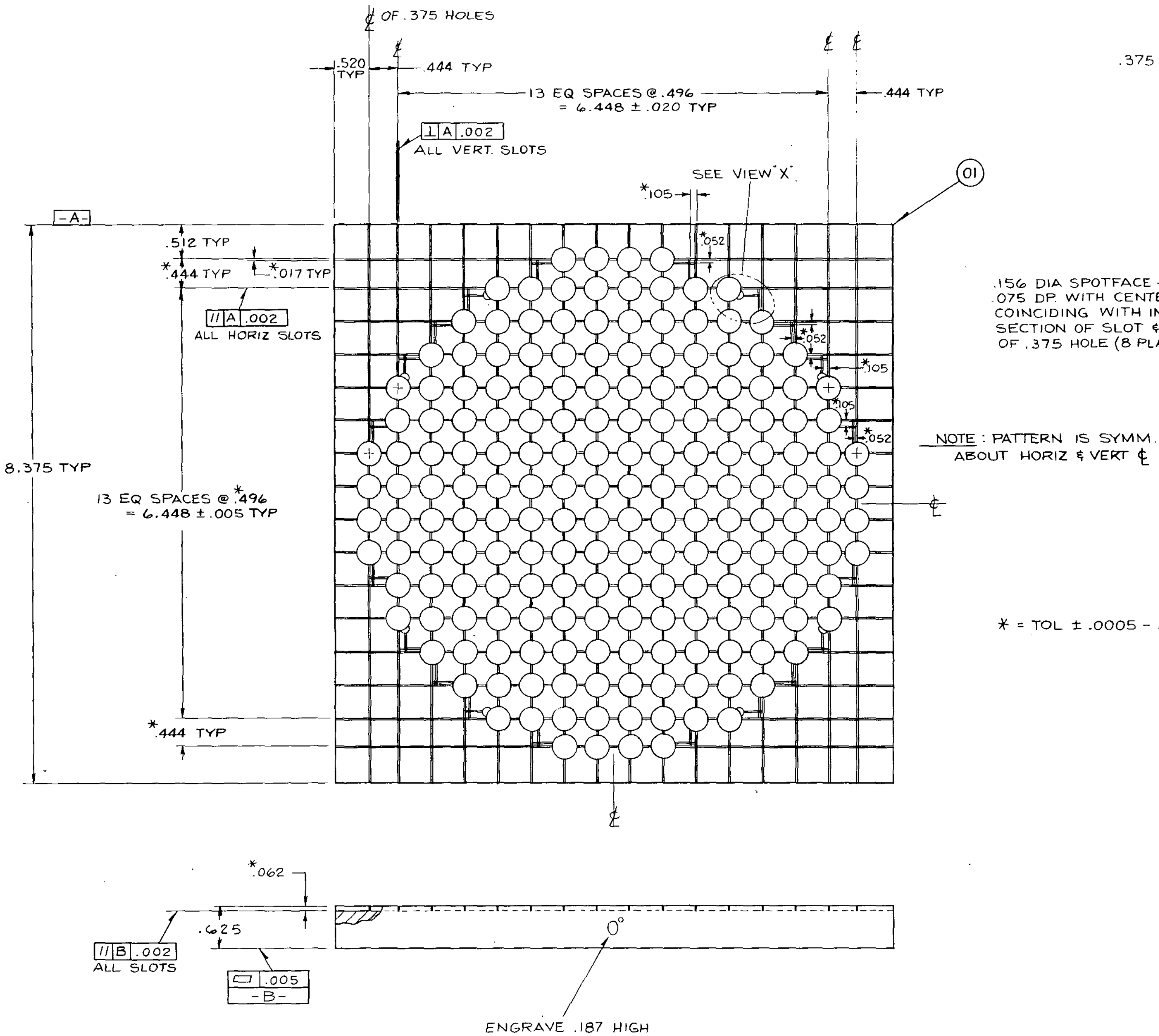
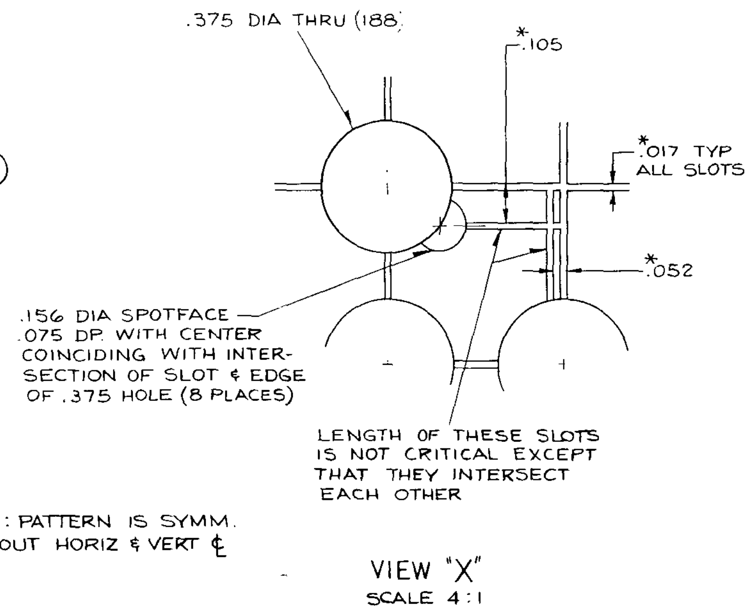


Figure G-8. Grid Strap Details (FLECHT-SEASET Unblocked Bundle) Sheet 7 of 7





* = TOL ± .0005 - ALL OTHER DIMS. ± .010

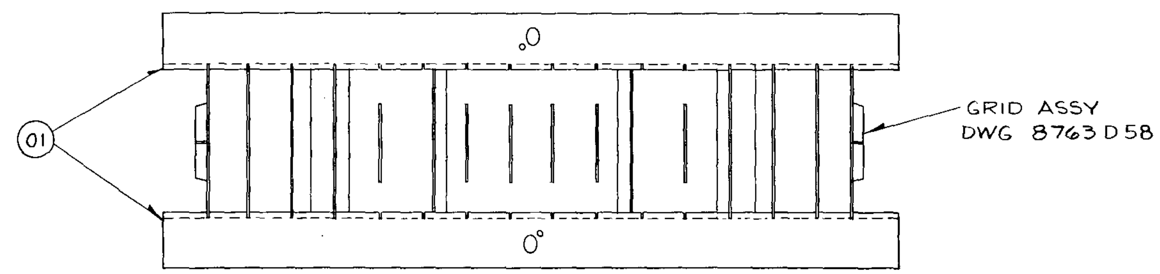
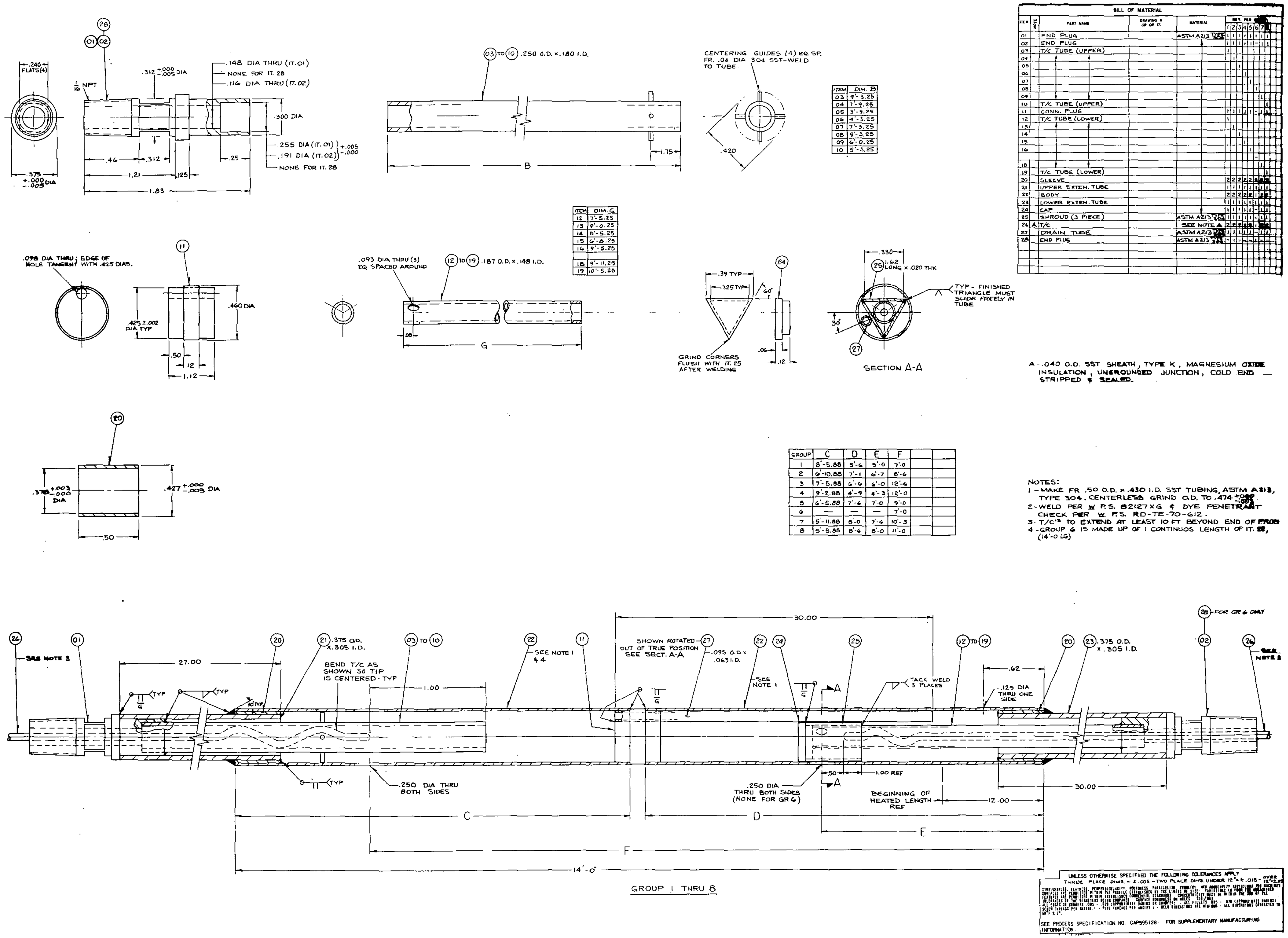
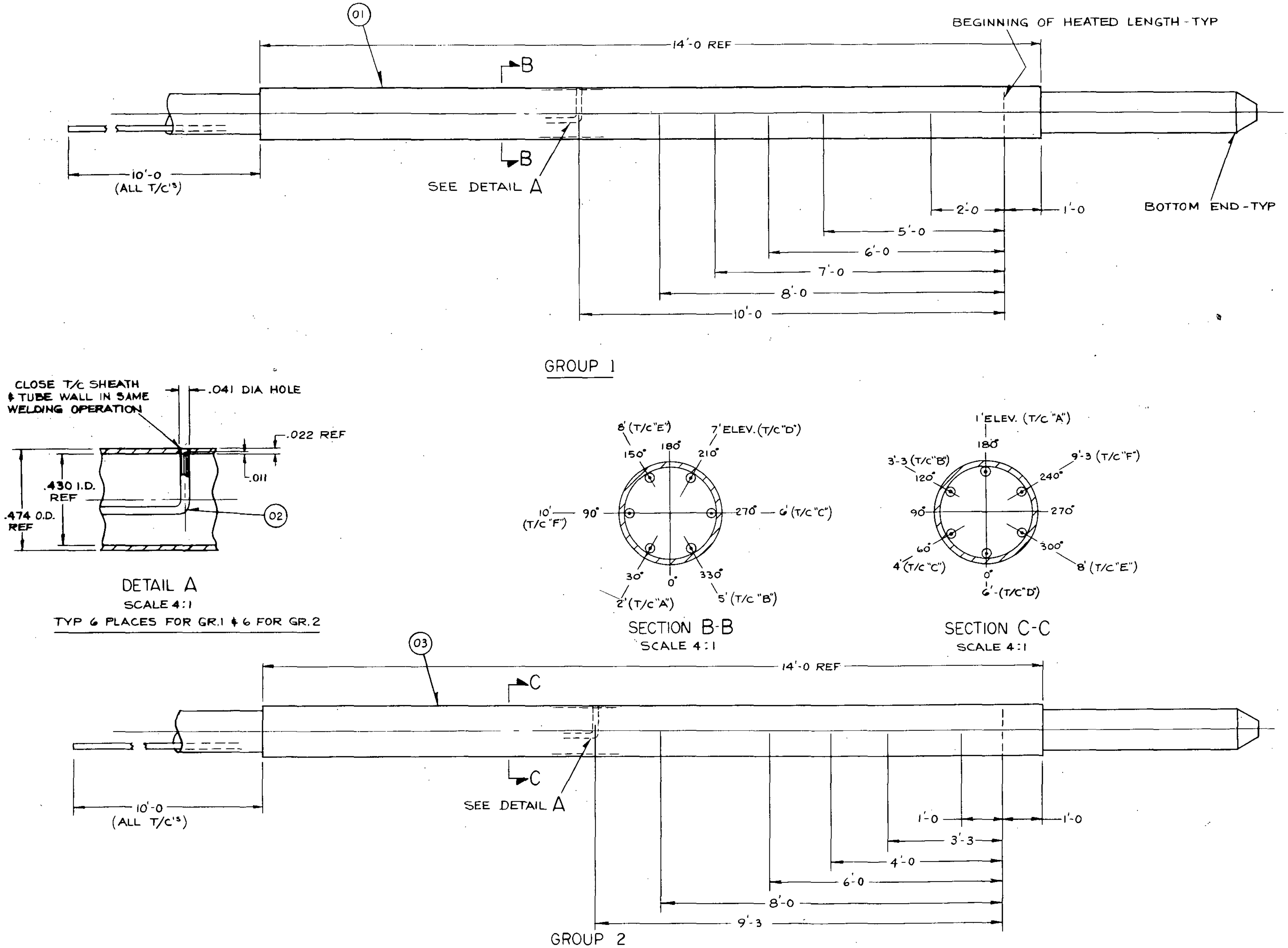


Figure G-9. Grid Brazing Fixture (FLECHT-SEASET Unblocked Bundle)



GROUP	C	D	E	F		
1	8'-5.88	5'-6	5'-0	7'-0		
2	6'-10.88	7'-1	6'-7	8'-6		
3	7'-5.88	6'-6	6'-0	12'-6		
4	9'-2.88	4'-9	4'-3	12'-0		
5	6'-5.88	7'-6	7'-0	9'-0		
6	—	—	—	7'-0		
7	5'-11.88	8'-0	7'-6	10'-3		
8	5'-5.88	8'-6	8'-0	11'-0		

Figure G-10. Steam Probe Detail and Assembly (FLECHT-SEASET Unblocked Bundle)



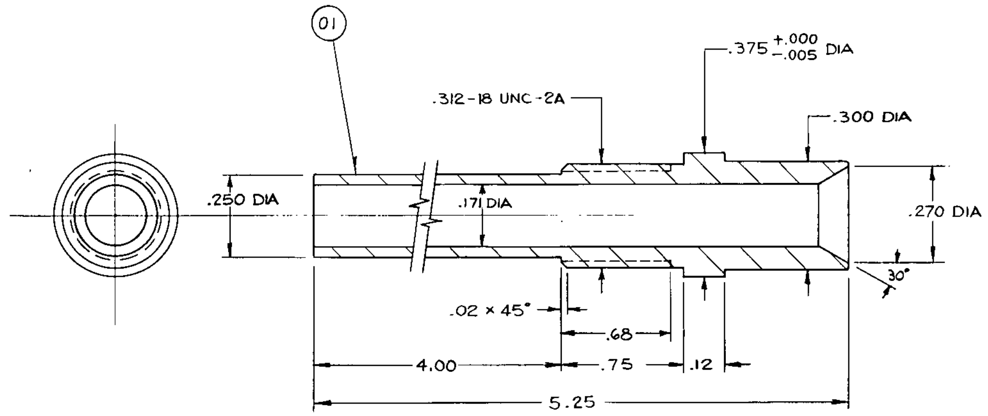
BILL OF MATERIAL								
ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ. PER GROUP			
					01	02	03	04
01		THIMBLE	8764D49-G01		1			
02	A	T/C			6	6		
03		THIMBLE	8764D49-G01			1		

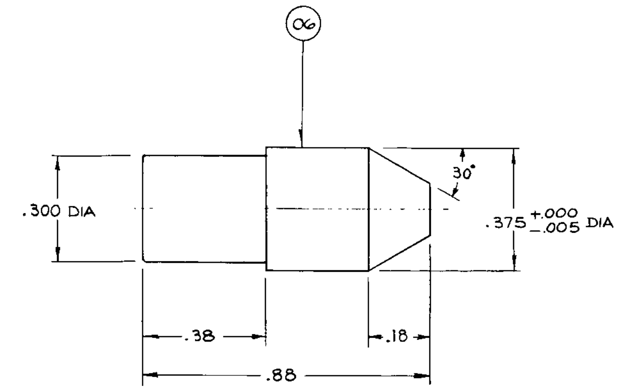
A - .040 O.D. SST SHEATH, TYPE K, MAGNESIUM OXIDE INSULATION, UNGROUNDED JUNCTION, COLD END STRIPPED & SEALED.

NOTES:

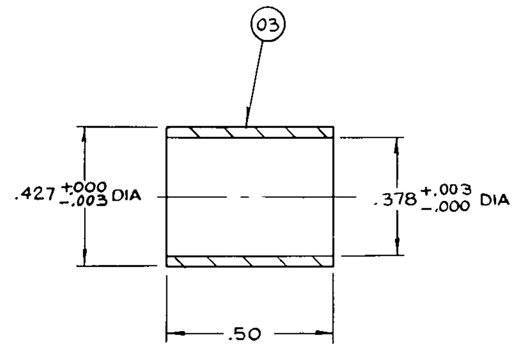
1 - WELD PER W P.S. 82127XG & DYE PENETRANT CHECK PER W P.S. RD-TE-70-612.
2 - ROUTE ALL T/C LEADS OUT SAME END OF TUBE AS SHOWN ALL T/C LEADS TO EXTEND 10 FT. BEYOND TUBE.
3 - POLISH TUBE SURFACE SMOOTH AFTER T/C INSTALLATION.
4 - LABEL ALL LEADS WITH APPROPRIATE IDENTIFICATION: (A - B - C - D - E - F)

Figure G-11. Thimble Instrumentation Details (FLECHT-SEASET Unblocked Bundle)





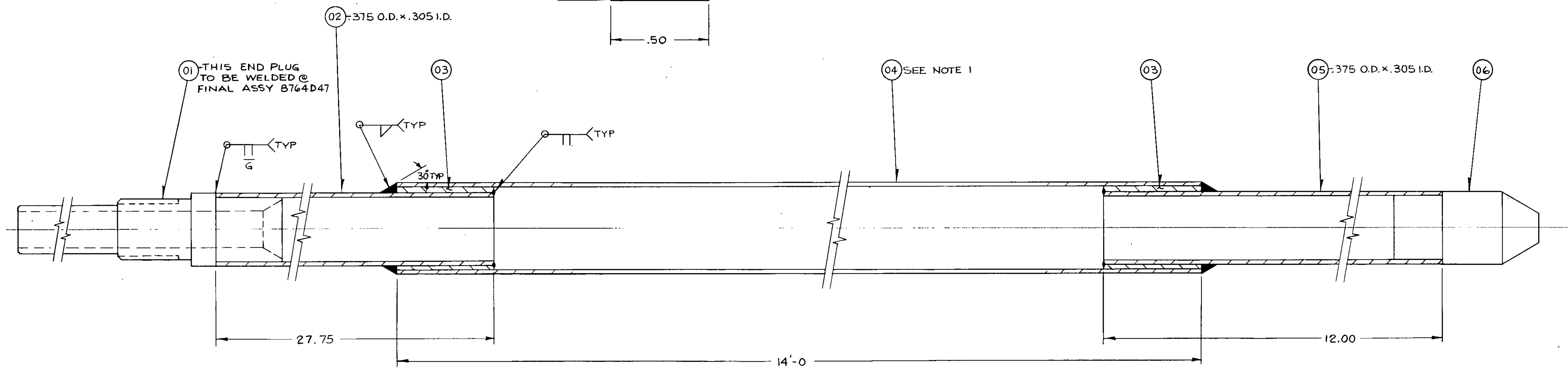
BILL OF MATERIAL								
ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ. PER GROUP 01	02	03	04
01		END PLUG		ASTM A213 TYPE 304	1			
02		UPPER EXTEN. TUBE		↕	1			
03		SLEEVE		↕	2			
04		BODY		↕	1			
05		LOWER EXTEN. TUBE		↕	1			
06		END PLUG		ASTM A213 TYPE 304	1			



NOTES:

1- MAKE FR. .50 O.D. × .430 I.D. SST TUBING. CENTERLESS GRIND O.D. TO .474 +.000 −.003

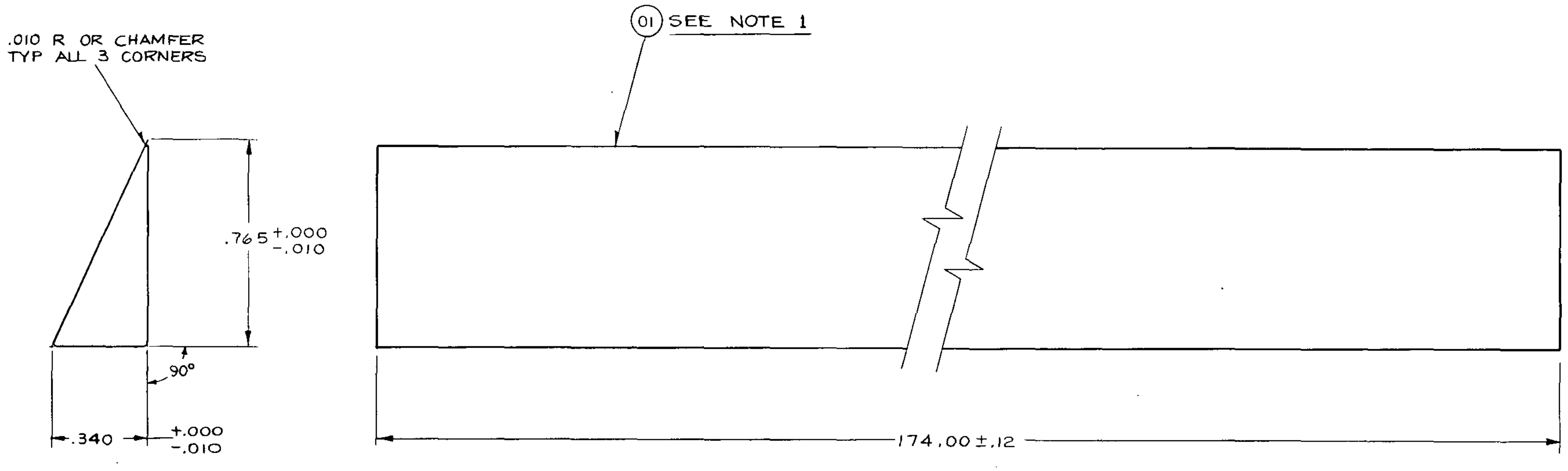
2- WELD PER W P.S. 82127 XG & DYE PENETRANT CHECK PER W P.S. RD-TE-70-612.



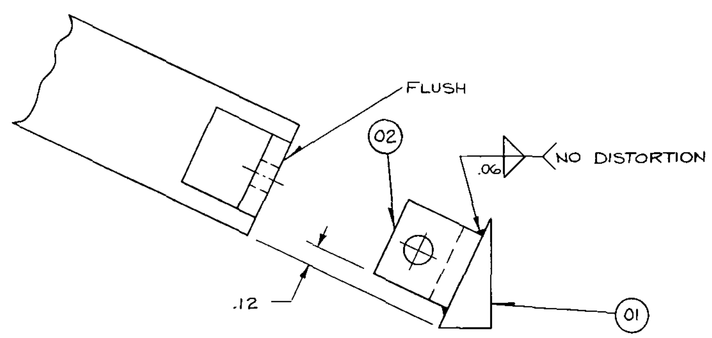
UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
THREE PLACE DIMS = ±.005 TWO PLACE DIMS UNDER 12" = ±.015 OVER 12" = ±.03
STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND ANGULARITY VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE: VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. CONCENTRICITY MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES: 250√MAX. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER). - ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ANSIB1.1 - PIPE THREADS PER ANSIB2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°.

SEE PROCESS SPECIFICATION NO. CAP595128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

Figure G-12. Thimble Detail and Assembly (FLECHT-SEASET Unblocked Bundle)



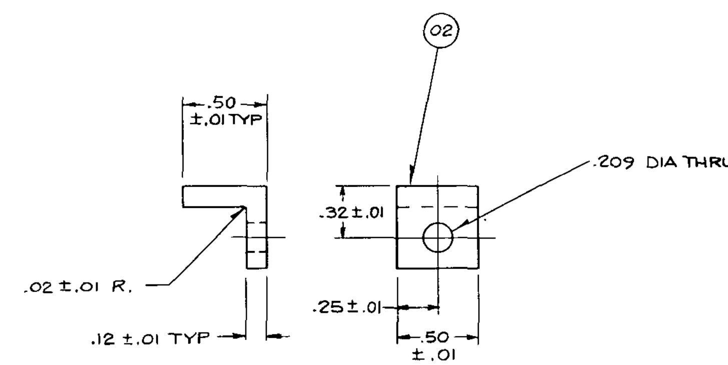
SCALE 4:1



GROUP 1

BILL OF MATERIAL								
ITEM		PART NAME	PART NO.	MATERIAL	REQ. PER GROUP			
					01	02	03	04
01		FILLER STRIP		AISI 304 SST	1			
02		CLIP		AISI 304 SST	1			

NOTE:
1 - FINISHED PART MUST PASS THRU AN INSPECTION ENVELOPE EQUIV. TO END VIEW. MAX. AXIAL DEVIATION & TWIST OF .06 OVER ENTIRE LENGTH.



UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY

STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND ANGULARITY VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE: VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. CONCENTRICITY MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES: 250√MAX. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER). - ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ANSIB1.1 - PIPE THREADS PER ANSIB2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°.

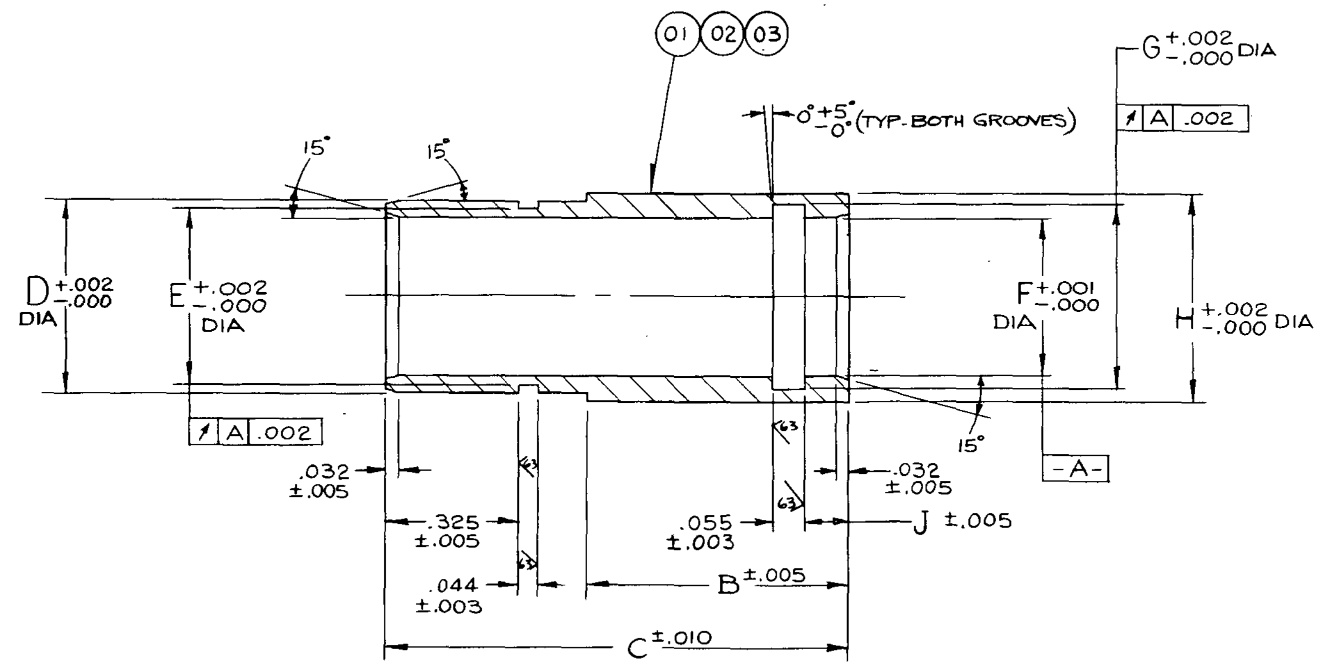
SEE PROCESS SPECIFICATION NO. CAP595128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

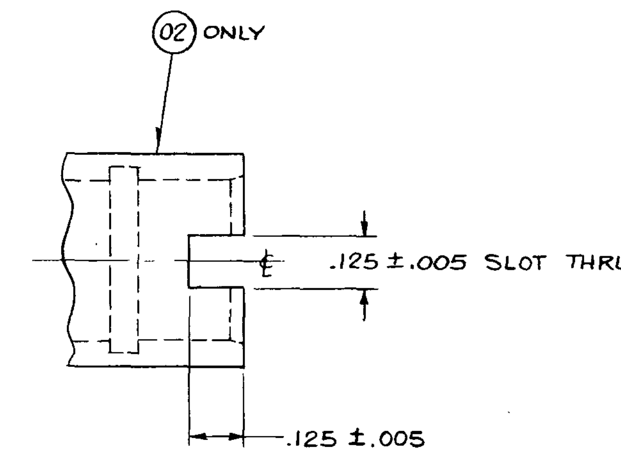
Figure G-13. Filler Strap Detail Assembly (FLECHT-SEASET Unblocked Bundle)

BILL OF MATERIAL								
ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ. PER GROUP 01	02	03	04
01	A	SLEEVE			1			
02	A	SLEEVE			1			
03	A	SLEEVE			1			

ITEM	B	C	D	E	F	G	H	J
01	.500	.975	.451	.410	.380	.435	.485	.100
02	.625	1.100	.451	.410	.380	.435	.485	.250
03	.625	1.100	.351	.310	.280	.335	.385	.100

A - MATERIAL - BERYLLIUM COPPER, BERYLCO 33-25, WILLIAMS & CO.





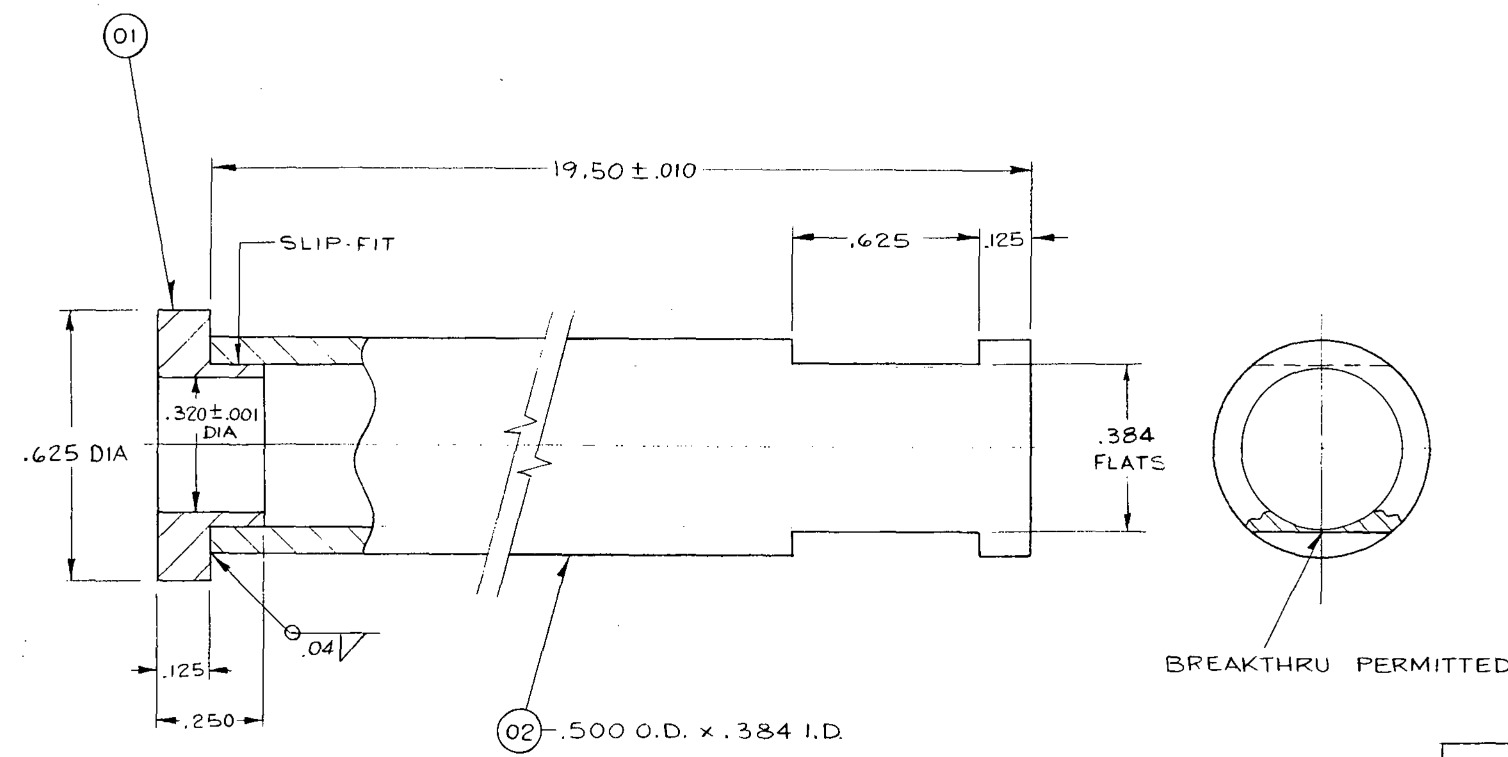
UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY

STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND ANGULARITY VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE: VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. CONCENTRICITY MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES: 250√MAX. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER). - ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ANSIB1.1 - PIPE THREADS PER ANSIB2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°.

SEE PROCESS SPECIFICATION NO. CAP595128- FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

Figure G-14. O-Ring Seal Sleeve (FLECHT-SEASET Unblocked Bundle)

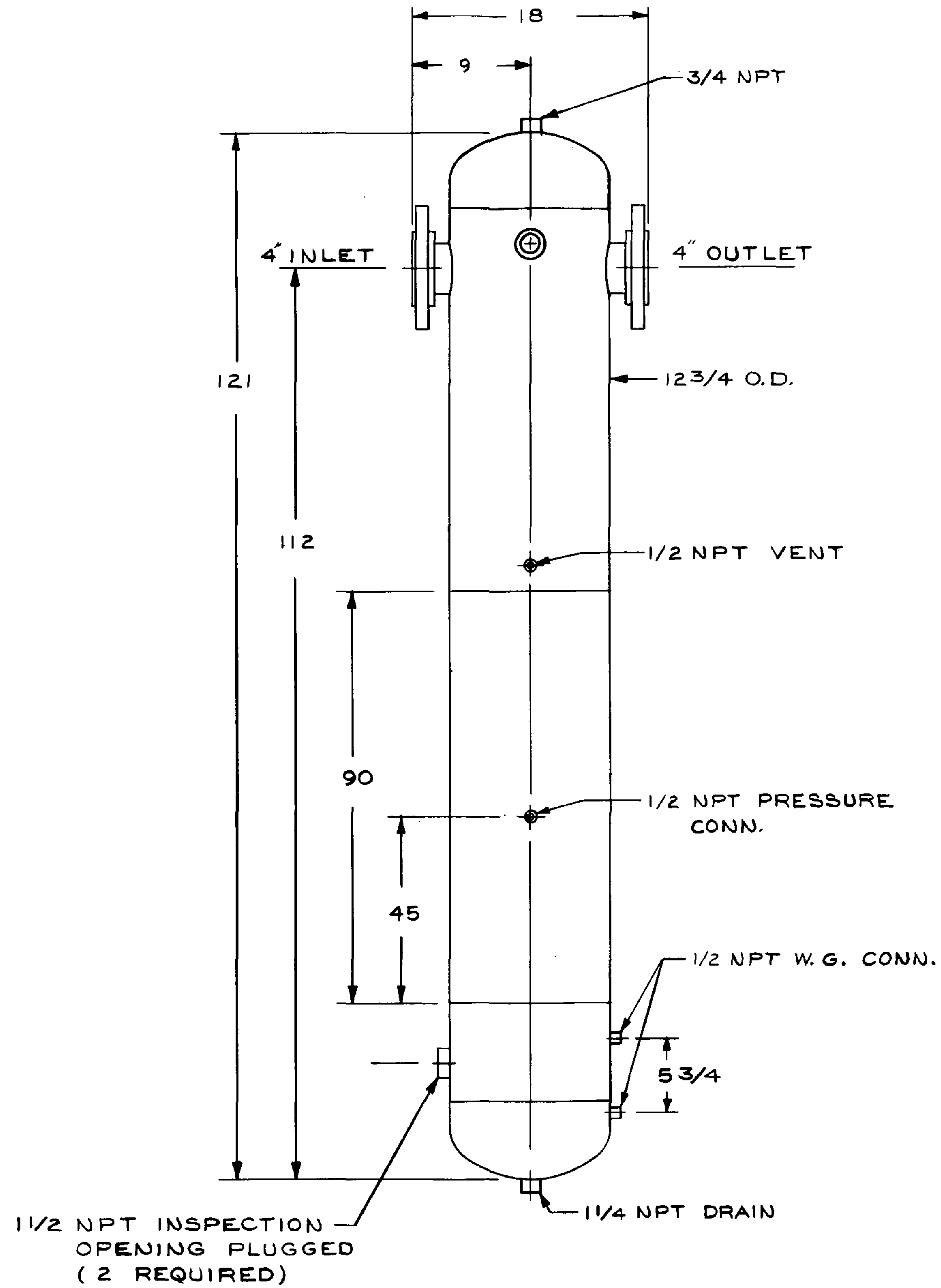
BILL OF MATERIAL								
ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ. PER GROUP			
					01	02	03	04
01		RIM		304 SST	1			
02		TUBE		304 SST	1			



UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
DIM TOL = ± .005
STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND ANGULARITY VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE: VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. CONCENTRICITY MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES 250√MAX. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER). - ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ANSIB1.1 - PIPE THREADS PER ANSIB2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°.

SEE PROCESS SPECIFICATION NO. CAP595128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

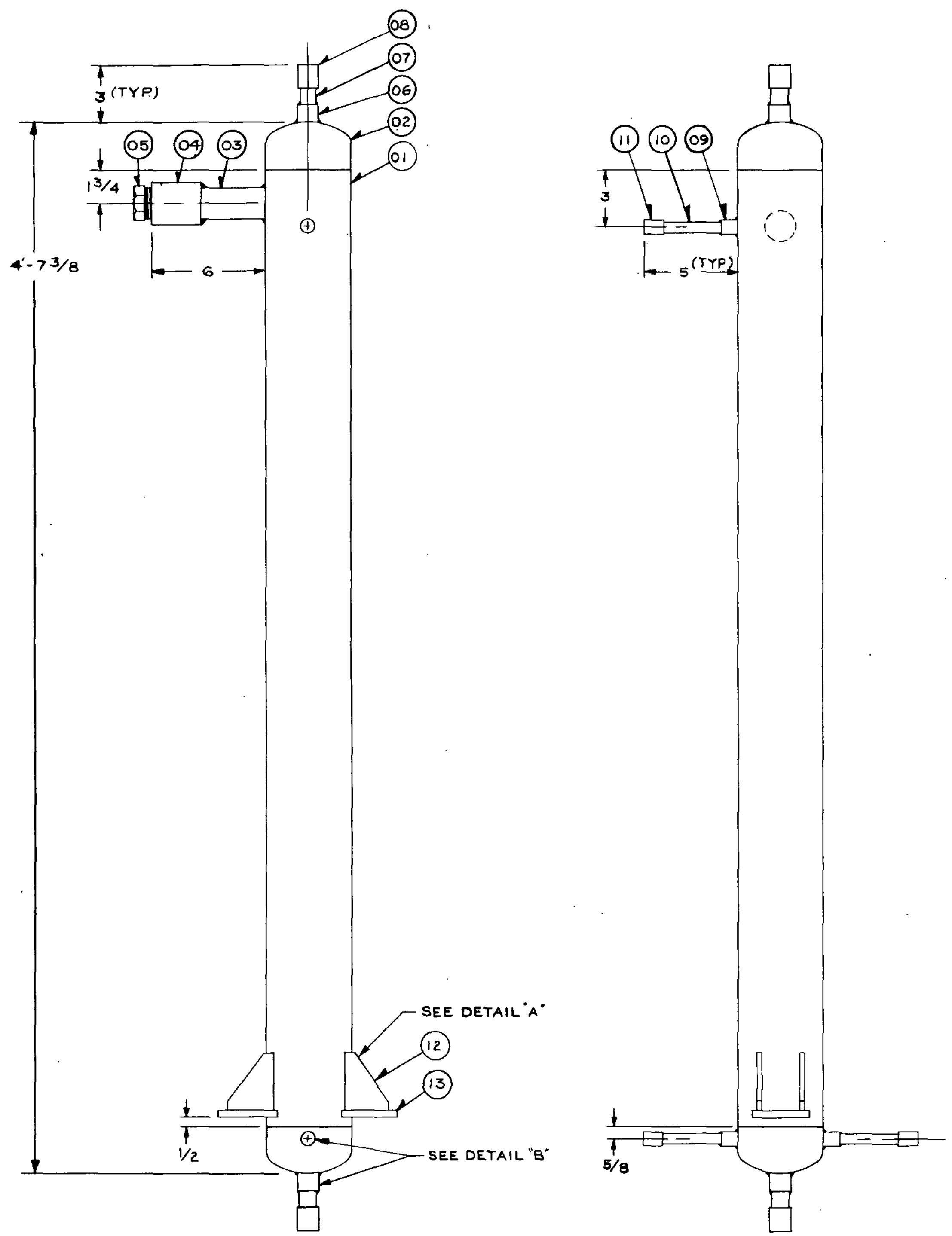
Figure G-15. Thimble Sleeve (FLECHT-SEASET Unblocked Bundle)



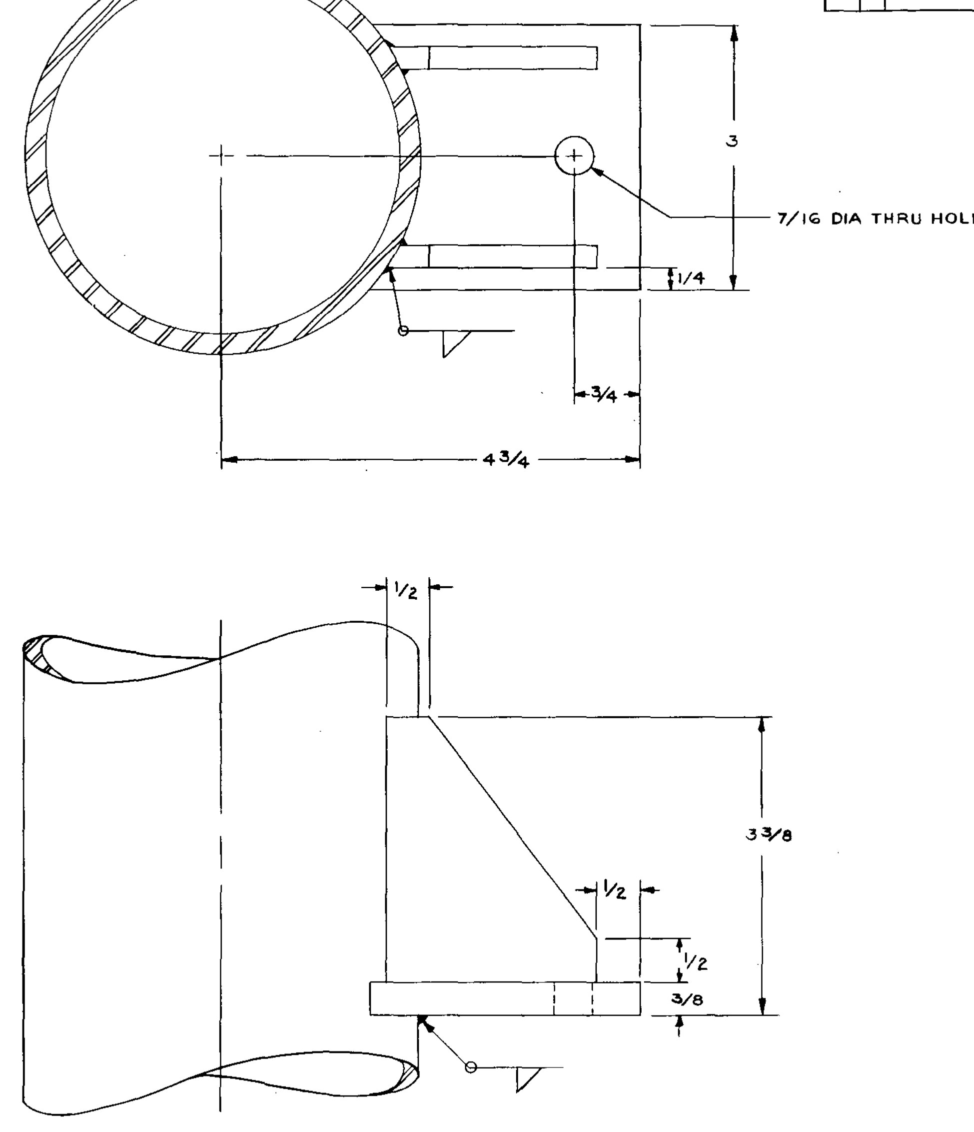
NOTE:

1. DESIGN: 180 PSIG @ 400°F
2. CONSTRUCTION, INSPECTION & STAMP PER ASME CODE, SECTION I "S" STAMP.
3. SEE WRIGHT-AUSTIN CO. DWG. 8578-17 FOR UNMODIFIED SEPARATOR.

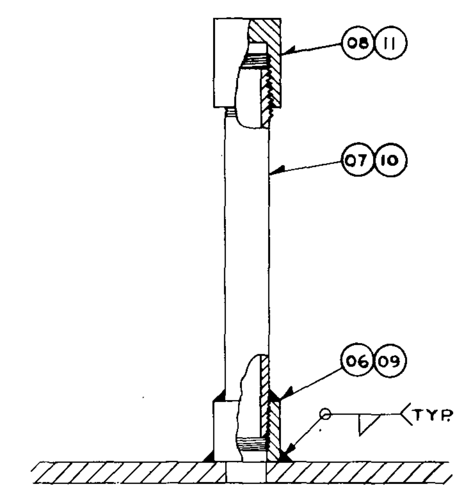
Figure G-16. Steam Separator (FLECHT-SEASET Unblocked Bundle)



(SCALE 1/4-1)



DETAIL "A"
(FULL SCALE)



DETAIL "B"

BILL OF MATERIAL

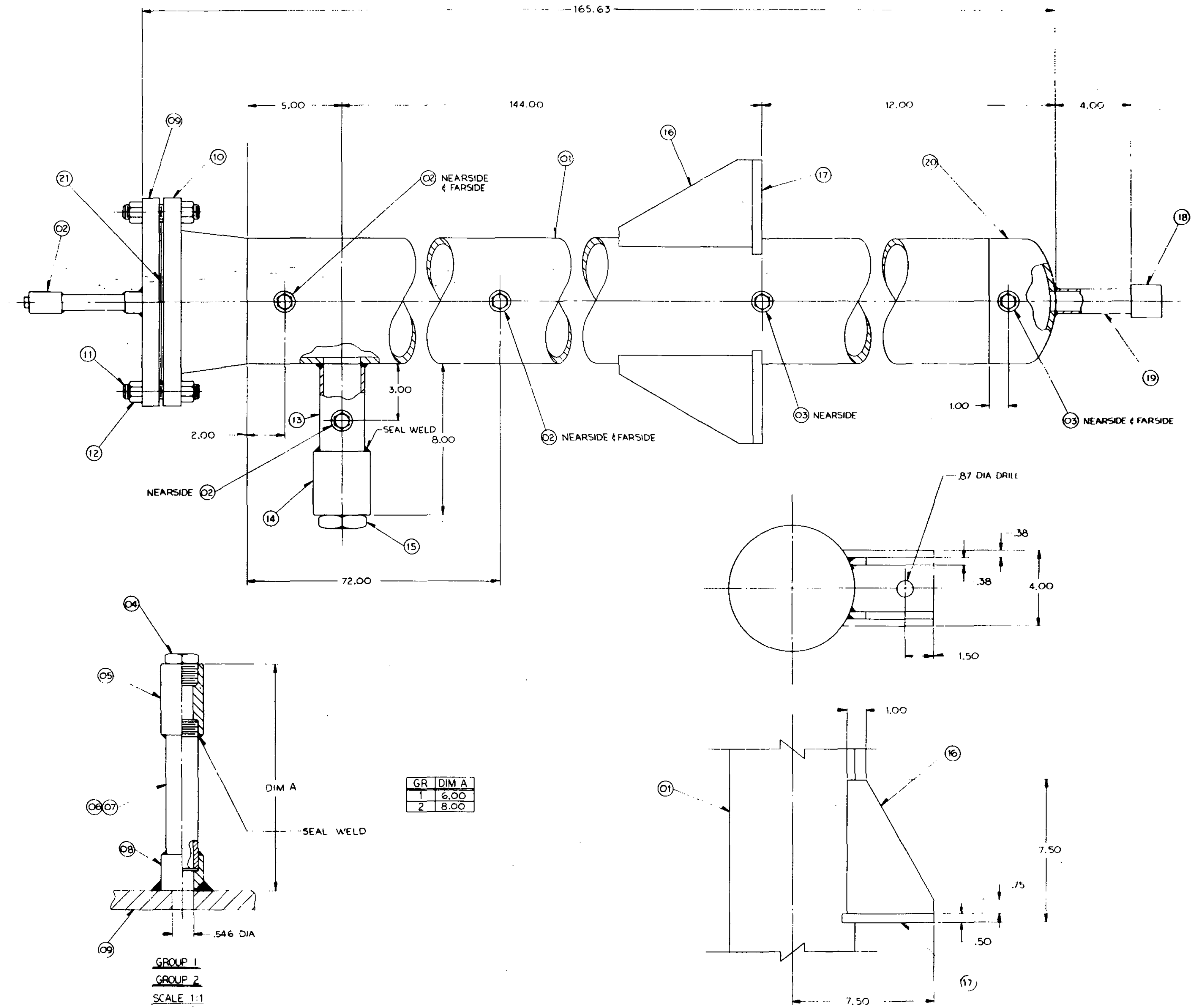
ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ. PER GROUP 01	02	03	04
01		4 STD. WT. PIPE (4-2 3/8 LG.)		SA-106 B	1			
02		4 STD. WT. B/W CAP		SA-234 B	2			
03		1 1/4 STD. WT. PIPE (6 LG.)		SA-106 B	1			
04		1 1/4 3000# THREADED CPLG.		SA-105	1			
05		1 1/4 THREADED PLUG		SA-105	1			
06		1/2 3000# S/W HALF CPLG.		SA-105	2			
07		1/2 X-STRONG PIPE (3 LG.)		SA-106B	2			
08		1/2 3000# THREADED CAP		SA-105	2			
09		1/4 3000# S/W HALF CPLG.		SA-105	3			
10		1/4 X-STRONG PIPE (5 LG.)		SA-106B	3			
11		1/4 3000# THREADED CAP		SA-105	3			
12		1/4 X 2 3/8 X 3 PLATE		SA-36	4			
13		3/8 X 3 X 3 3/32 PLATE		SA-36	2			

NOTES
1. THE ASSEMBLY IS TO BE FABRICATED, TESTED AND STAMPED IN ACCORDANCE WITH SECTION I OF THE ASME BOILER AND PRESSURE VESSEL CODE.
2. DESIGN PRESSURE - 100 PSI
DESIGN TEMPERATURE - 650°F
3. TOLERANCE ON DIMENSIONS ± 1/8 UNLESS OTHERWISE SPECIFIED.

Figure G-17. Separator Drain Tank (FLECHT-SEASET Unblocked Bundle)

BILL OF MATERIAL

01	6" STD WT SEAMLESS PIPE		SA 106 B	1	
02	PRESSURE TAP	GR 1		6	
03	PRESSURE TAP	GR 2			3
04	1/2 THD PLUG		SA 105	6	3
05	1/2 3000# THD CPLG			6	3
06	1/2 X-STG PIPE		SA 106 B	6	
07	1/2 X-STG PIPE		"		3
08	1/2 3000# S/W HALF CPLG		SA 105	6	3
09	6" 150# BLIND FLANGE		SA 105 B	1	
10	6" 150# W/N FLANGE		"	1	
11	3/4 x 4" STUDS		SA 193 GR B 7	8	
12	3/4 NUTS		SA 194 GR 2 H	16	
13	2" STD WT PIPE		SA 106 B	1	
14	2" 2000# SCR COUP		SA 105	1	
15	2" THD PLUG		"	1	
16	3/8 x 6" x 7" PLATE		SA 36	4	
17	1/2 x 4" x 6 PLATE			2	
18	1" 2000# THD CAP		SA 105	1	
19	1" STD WT PIPE		SA 106 GR B	1	
20	6" STD WT WELD CAP		SA 234	1	
21	FLEXITALLIC GASKET		NO. CG-IP	1	

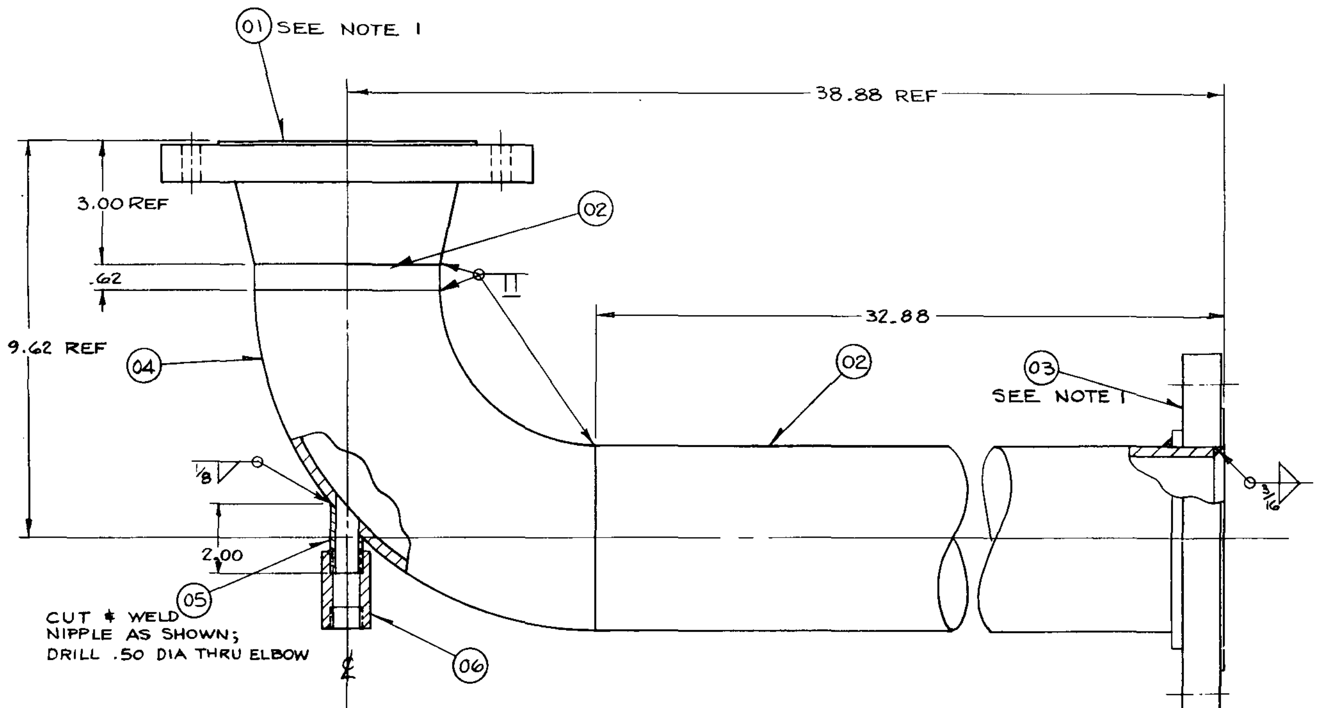


GR	DIM A
1	6.00
2	8.00

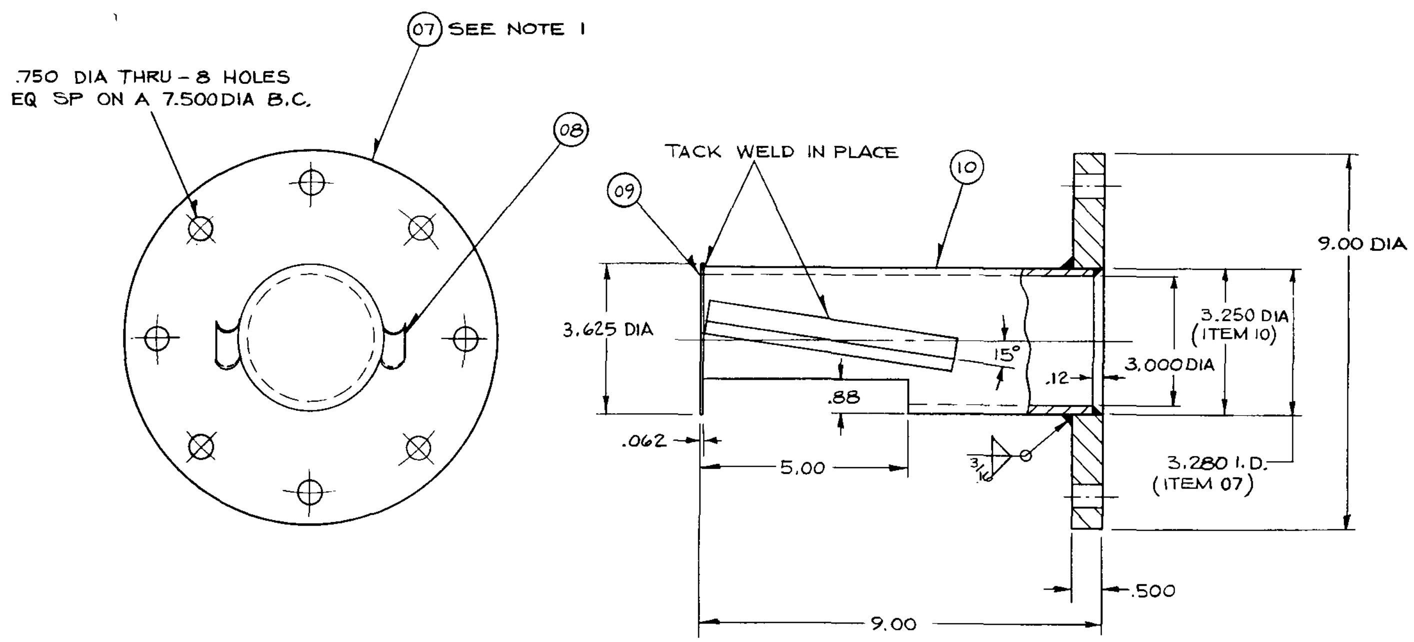
NOTES

1. THE ASSEMBLY IS TO BE FABRICATED TESTED, AND STAMPED IN ACCORDANCE WITH SECTION I OF THE ASME BOILER AND PRESSURE VESSEL CODE.
2. DESIGN PRESSURE - 100 PSI
   DESIGN TEMPERATURE - 650°F
3. SUPPORT LUGS TO SUSTAIN A STATIC VERTICAL LOAD OF 550 POUNDS.
4. TOLERANCE ON DIMENSIONS ± .125 UNLESS OTHERWISE SPECIFIED.

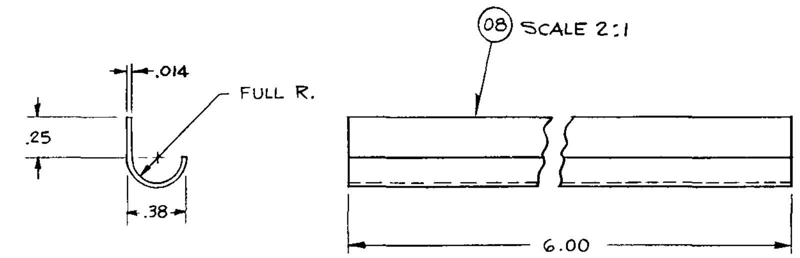
Figure G-18. Carryover Tank (FLECHT-SEASET Unblocked Bundle)



GROUP 2



GROUP 1



BILL OF MATERIAL

ITEM	NOTE	PART NAME	DRAWING & GR OR IT.	MATERIAL	REQ. PER GROUP 01	02	03	04
01		4IN 150 LB W/N FLANGE		SA-105 GR II		1		
02		4IN SCH 40 PIPE		SA-106 GR B		AR		
03		4IN 150 LB SLIP-ON FLANGE		SA-105 GR II		1		
04		4IN 90° L.R. ELL		SA-234		1		
05		1/2 NPT SCH 40 NIPPLE		C. STL		1		
06		1/2 NPT 3000 LB COUPLING		C. STL		1		
07		FLANGE PL		SA-285-GRC	1			
08		GUTTER		INCONEL	2			
09		COVER PL		C. STL	1			
10		3IN SCH 40 PIPE		SA-106 GR B	1			

NOTES:
1-ALIGN BOLT HOLES IN FIELD PRIOR TO WELDING.
2-DESIGN CONDITIONS: 100 PSI @ 650°F
3-FABRICATE PER ASME BOILER & PRESSURE VESSEL CODE, SECTIONS I & IX.
4-ALL PRESSURE WELDS TO BE DYE PENETRANT INSPECTED, BOTH ROOT & FINAL PASS.

UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
TWO PLACE DECIMALS = ±.06, THREE PLACE DECIMALS = ±.010.
STRAIGHTNESS, FLATNESS, PERPENDICULARITY, ROUNDNESS, PARALLELISM, SYMMETRY AND ANGULARITY VARIATIONS FOR MACHINED SURFACES ARE PERMITTED WITHIN THE PROFILE ESTABLISHED BY THE LIMITS OF SIZE. VARIATIONS IN FORM FOR UNMACHINED FEATURES ARE PERMITTED WITHIN ESTABLISHED COMMERCIAL STANDARDS. CONCENTRICITY MUST BE WITHIN THE SUM OF THE TOLERANCES OF THE DIAMETERS BEING COMPARED. SURFACE ROUGHNESS ON HOLES: 250√ MAX. ALL EDGES OR CORNERS .005 - .020 (APPROXIMATE RADIUS OR CHAMFER). - ALL FILLETS .005 - .020 (APPROXIMATE RADIUS). SCREW THREADS PER ANSIB1.1 - PIPE THREADS PER ANSIB2.1 - WELD DIMENSIONS ARE MINIMUM - ALL DIMENSIONS CORRECTED TO 68°F ± 2°.

SEE PROCESS SPECIFICATION NO. CAP595128 FOR SUPPLEMENTARY MANUFACTURING INFORMATION.

Figure G-19. Upper Plenum Extension and Baffle (FLECHT-SEASET Unblocked Bundle)

TABLE G-1
LIST OF DRAWINGS FOR THE FLECHT-SEASET UNBLOCKED BUNDLE TASK 3.2.1

Task Plan Figure No.	Engineering Drawing No.	Sub	Sheets	Task Plan Figure Title
5-1	1453E42	1	1	Flow Diagram for the Forced Reflood Configuration (FLECHT-SEASET Unblocked Bundle)
5-2	1453E43	1	1	Flow Diagram for the Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)
5-3	1453E32	1	1	Low Mass Housing Assembly (FLECHT-SEASET Unblocked Bundle)
5-4	1446E97	4	1	Low Mass Housing Details (FLECHT-SEASET Unblocked Bundle)
5-6	1224E16	5	1	Heater Rod Details (FLECHT-SEASET Unblocked Bundle)
5-7	1453E40	1	1	Piping Diagram for the Forced Reflood Configuration (FLECHT-SEASET Unblocked Bundle)
5-9	1188E88	2	1	Exhaust Line Details (FLECHT-SEASET Unblocked Bundle)
5-10	1683C20	1	1	Downcomer for Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)
5-12	1453E50	1	1	Instrumentation Schematic Diagram for the Forced Reflood Configuration (FLECHT-SEASET Unblocked Bundle)
5-13	1453E51	1	1	Instrumentation Schematic Diagram for the Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)
5-17	1683C18	1	1	Exhaust Line Steam Probe (FLECHT-SEASET Unblocked Bundle)
G-1	1453E41	1	1	Piping Diagram for the Gravity Reflood Configuration (FLECHT-SEASET Unblocked Bundle)

TABLE G-1
LIST OF DRAWINGS FOR THE FLECHT-SEASET UNBLOCKED BUNDLE TASK 3.2.1

Task Plan Figure No.	Engineering Drawing No.	Sub	Sheets	Task Plan Figure Title
G-2	1447E25	2	1	Upper Plenum Detail and Assembly (FLECHT-SEASET Unblocked Bundle)
G-3	1447E29	2	1	Lower Plenum Detail and Assembly (FLECHT-SEASET Unblocked Bundle)
G-4	1453E47	1	2	Strongback and Assembly Fixture (FLECHT-SEASET Unblocked Bundle)
G-5	1463F27	2	1	Upper Seal Plate for Low Mass Housing (FLECHT-SEASET Unblocked Bundle)
G-6	1463F33	2	1	Lower Seal Plate for Low Mass Housing (FLECHT-SEASET Unblocked Bundle)
G-7	8763D58	1	1	Grid Strap Assembly (FLECHT-SEASET Unblocked Bundle)
G-8	8763D57	1	7	Grid Strap Details (FLECHT-SEASET Unblocked Bundle)
G-9	8761D55	1	1	Grid Brazing Fixture (FLECHT-SEASET Unblocked Bundle)
G-10	1453E21	1	1	Steam Probe Detail and Assembly (FLECHT-SEASET Unblocked Bundle)
G-11	8764D47	2	1	Thimble Instrumentation Details (FLECHT-SEASET Unblocked Bundle)
G-12	8764D49	1	1	Thimble Detail and Assembly (FLECHT-SEASET Unblocked Bundle)
G-13	8763D64	2	1	Filler Strip Detail Assembly (FLECHT-SEASET Unblocked Bundle)
G-14	1680C97	3	1	O-Ring Seal Sleeve (FLECHT-SEASET Unblocked Bundle)
G-15	1680C98	1	1	Thimble Sleeve (FLECHT-SEASET Unblocked Bundle)

TABLE G-1

LIST OF DRAWINGS FOR THE FLECHT-SEASET UNBLOCKED BUNDLE TASK 3.2.1

Task Plan Figure No.	Engineering Drawing No.	Sub	Sheets	Task Plan Figure Title
G-16	1683C19	1	1	Steam Separator (FLECHT-SEASET Unblocked Bundle)
G-17	8757D25	1	1	Separator Drain Tank (FLECHT-SEASET Unblocked Bundle)
G-18	1144E64	1	1	Carryover Tank (FLECHT-SEASET Unblocked Bundle)
G-19	8764D64	1	1	Upper Plenum Extension and Baffle (FLECHT-SEASET Unblocked Bundle)

APPENDIX H
GLOSSARY

This appendix is included in this report as a referral appendix to explain definitions, acronyms, and symbols included in the text proper.

Analysis – refers to the examination of data to determine, if possible, the basic physical processes that occur and the interrelation of the processes. Where possible, physical processes will be identified from the data and will be related to first principles.

Average Fluid Conditions – average thermodynamic properties (for example, enthalphy, quality, temperature, pressure) and average thermal-hydraulic parameters (for example, void fraction, mass flow rate) which are derived from appropriately reduced data for a specified volume or a specified cross-sectional area.

Axial Peaking Factor – ratio of the peak-to-average power for a given power profile.

Blocked – refers to the situation where the flow area in the rod bundle or single tube is purposely obstructed at selected locations so as to restrict the flow.

Bottom of Core Recovery (BOCR) – a condition at the end of the refill period in which the lower plenum is filled with injected ECC water as the water is about to flood the core.

Bundle – a number of heater rods, including spares, which are assembled into a matrix with CRG type rods using necessary support hardware to meet the Task Plan design requirements.

Carryout – same as carryover.

Carryout Rate Fraction – the fraction of the inlet flooding flow rate which flows out the rod bundle exit by upflowing steam.

Carryover – refers to the process where the liquid is carried in a two-phase mixture out of a control volume, that is, the test bundle.

Computational Methods – refers to the procedure of reducing, analyzing and evaluating data or mathematical expressions, either by hand calculations or by digital computer codes.

Computer Code (or code) – refers to a set of specific instructions in computer languages to perform the desired mathematical operations utilizing appropriate models and correlations.

Computer Data Acquisition System (CDAS) – the system which controls the test and records data for later reduction and anlaysis.

Computer Tape – refers to magnetic tapes that store FLECHT-SEASET data.

Core Rod Geometry (CRG) – a nominal rod-to-rod pitch of 0.496 inches and outside "nominal" diameter of 0.374 inches representative of various nuclear fuel vendors' new fuel assembly geometrics commonly referred to as the 17 x 17 or 16 x 16 assemblies.

Correlation – a set of mathematical expressions, based on physical principles and experimental data but resting primarily on experimental data, which describes the thermal-hydraulic behavior of a system.

Cosine Axial Power Profile – refers to the axial power distribution of the heater rods in the CRG bundle that contains the maximum (peak) linear power (kilowatts/foot) at the midplane of the active heated rod length. This axial power profile will be used on all FLECHT-SEASET tests as a fixed parameter.

Data – means recorded information, regardless of form or characteristic, of a scientific or technical nature. It may, for example, document research, experimental, developmental or engineering work; or be usable or used to define a design or process or to procure, produce, support, maintain, or operate material. The data may be graphic or pictorial delineations in media such as drawings or photographs; text in specifications or related performance or design type documents; or computer printouts. Examples of data include research and engineering data, engineering drawings and associated lists, specifications, standards, process sheets, manuals, technical reports, catalog item identifications and related information, computer programs, computer codes, computer data bases, and computer software documentation. Data does not include financial, administrative, cost and pricing, and management data or other information incidental to contract administration.

Data Validation – refers to a procedure used to insure that the data generated from a test meets the specified test conditions, and that the instrumentation was functioning properly during the test.

Design and Procure – refers to the design of the system, including the specification (consistent with the appropriate Task Plan) of the material, component and/or system (of interest); and the necessary purchasing function to receive the material, component and/or system on the test site. This does not preclude Contractor from constructing components and systems on the test site to meet requirements of the Task Plan.

ECC – Emergency Core Cooling

Entrainment — refers to the process by which liquid, typically in droplet form, is carried into a flowing stream of gas or two-phase mixture.

Evaluation — refers to the process of comparing the data with similar data, other data sets, existing models and correlations, or computer codes to arrive at general trends, consistency, and other qualitative descriptions of the results.

Fallback — refers to the process whereby the liquid in a two-phase mixture flows countercurrently to the gas phase.

FLECHT — Full Length Emergency Core Heat Transfer test program

FLECHT-SEASET — Full Length Emergency Core Heat Transfer — Systems Effects And Separate Effects Test Program

FLECHT-SET — Full Length Emergency Core Heat Transfer — Systems Effects Tests

Heat Transfer Mechanisms — refers to the process of conduction, convection, radiation or phase changes (for example, vaporization, condensation, boiling) in a control volume or a system.

Hypothetical Loss-of-Coolant Accident — it is understood that this program is concerned with study of physical phenomena associated with reactor accidents that have an extremely low probability and are therefore termed hypothetical.

Loss-of-Coolant Accident — a break in the pressure boundary integrity resulting in loss of core cooling water.

Model — a set of mathematical expressions generated from physical laws to represent the thermal-hydraulic behavior of a system. A model rests mainly on physical principles.

PMG — Program Management Group

Pressurized Water Reactor (PWR) — a nuclear reactor type in which the system pressure exceeds saturation pressure thus preventing gross vapor formation under normal operating conditions.

Reduce Data — refers to the conversion of data from the measured signals to engineering units. In some cases the data are manipulated in a simple fashion to calculate quantities such as flows.

Separation — refers to the process whereby the liquid in a two-phase mixture is separated and detached from the gas phase.

Silicon Controlled Rectifier (SCR) — a rectifier control system used to supply DC current to the bundle heater rods.

Spacer Grids — refers to the metal matrix assembly (egg crate design) used to support and space the heater rods into a bundle array.

Test Section — consists of lower plenum, bundle, and upper plenum.

Test Site — the location of the test facilities where tests will be conducted.

Transducer — the devices used in experimental systems that sense the physical quantities, such as temperature, pressure, pressure difference, or power, and transform them into electrical outputs such as volts.

Unblocked — refers to the situation where the flow area in the rod bundle or a single tube is not purposely obstructed.

Upper Head Injection (UHI) — an emergency core coolant system whereby water from the upper head drains into the core through guide tubes and support columns.

$\bar{h}$ = average heat transfer coefficient from data of sample size n (pg 5-37)

n = number of thermocouples assigned per elevation (pg 5-41)

t_{n-1} = value from student t distribution tables having sample size n (pg 5-41)

σ = standard deviation (pg 5-37)

$\epsilon = \sigma/\bar{h}$ = coefficient of variance — a measure of relative error (pg 5-37)

μ = population mean heat transfer coefficient (pg 5-42)

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Date 9/15/78
SDP-78-493
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SUBJECT: FLECHT-SEASET Program – Unblocked Bundle Task Plan Submittal
(NRC/EPRI/Westinghouse Report No. 3)
Contract: NRC-04-77-127, EPRI No: RP959-1

Gentlemen:

Enclosed in NRC/EPRI/Westinghouse Report No. 3 entitled "PWR FLECHT SEASET Unblocked Bundle, Forced and Gravity Reflood Task – Task Plan Report." The specified number of copies (360) for category NRC-2 distribution have been sent to the NRC Division of Technical Information and Document Control along with a completed Form-426. EPRI was sent 423 copies. Also, the report has been sent to NRC Patent Counsel.

Sincerely,

H W Massie Jr

H. W. Massie, Jr.
FLECHT-SEASET Project Engineer
Strategic Development Projects

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