NRC/EPRI/Westinghouse Report No. 2

PWR FLECHT SEASET
STEAM GENERATOR SEPARATE EFFECTS TASK
TASK PLAN REPORT

MARCH 1978

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L. E. Hochreiter H. W. Massie, Jr.

R. C. Howard M. C. Krepinevich
M. J. Loftus M. C. McGuire
W. Kavalkovich A. E. Tome

prepared for

United States Nuclear Regulatory Commission
Washington DC 20555

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94303

and

Westinghouse Electric Corporation

Nuclear Energy Systems
P.O. Box 355
Pittsburgh, Pennsylvania 15230

by

Westinghouse Electric Corporation

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Program Management Group

NRC — E. H. Davidson
EPRI — K. H. Sun
Westinghouse — H. J. Fix

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ABSTRACT

This report is a descriptive plan of tests for the Steam Generator Separate Effects Task of the Full-Length Emergency Cooling Heat Transfer for the Separate Effects and Systems Effects Test Program (FLECHT SEASET). These tests consist of a separate effects test to be conducted on the Full-Length Emergency Cooling Heat Transfer Systems Effects Test (FLECHT SET) phase B steam generator. This test is used to measure and to characterize the steam generator secondary side to primary side heat release under postulated inlet fluid conditions which apply during a hypothetical pressurized water reactor loss-of-coolant accident.

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PWR PROJECTS

H. J. Fix

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R. P. Vijuk
M. A. Emery
D. T. Kitzmiller

SAFEGUARDS ENGINEERING

T. Rago
D. F. Paddleford

FACILITIES ENGINEERING

L. R. Katz

TEST OPERATIONS

C. E. Fuchs
M. T. Mulligan
W. Ripple
J. Carovak

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SECTION 1

SUMMARY

As part of the Westinghouse/NRC/EPRI FLECHT SEASET reflood program, a series of separate effects tests will be conducted on the FLECHT SET phase B steam generator.[1] The purpose of these tests is to measure and to characterize the steam generator secondary side to primary side heat release under postulated inlet fluid conditions for a calculated hypothetical pressurized water reactor loss-of-coolant accident. This document is a description of data requirements, instrumentation plan, facility description, and current ideas on data reduction and analysis for this task in the FLECHT SEASET program.

In this test program, a special heat transfer facility will be constructed such that the steam generator primary side inlet two-phase flow conditions can be varied in a parametric fashion. Sufficient instrumentation will be placed in the steam generator and flow loop such that heat transfer rates within the steam generator tube bundle can be calculated from the data. In addition, a series of air/water tests will also be performed using the FLECHT SET phase B steam generator lower plenum to examine the radial flow distribution effects at the steam generator tube sheet and to help select the tube bundle instrumentation locations. The results of this program will then be used to develop a model or correlation which describes the FLECHT SEASET steam generator heat release characteristics.

1. Conway, C. E., et al., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/ERRI Westinghouse Report Number 1, December 1977.

SECTION 2
TASK OBJECTIVES AND BACKGROUND

The separate effects test described in the FLECHT SEASET Program Plan concentrated on the rod bundle heat transfer and thermal-hydraulic behavior. The systems effects tests will focus on the entire simulated thermal-hydraulic response of a pressurized water reactor primary system during reflood. However, the bundle inlet flooding rate in system effects tests is dependent upon hydraulic and heat transfer behavior of the bundle and different system components and their effect on the reflood transient.

Therefore, to understand the performance of the simulated primary system, the thermal-hydraulic behavior of the principal components of the system needs to be better understood. The objective of the steam generator separate effects task is to determine the heat release rate from a larger FLECHT SET steam generator for various known inlet fluid conditions and secondary side conditions.[1] To accomplish this objective, separate experiments on the main components of the simulated primary system, notably the steam generator and the simulated upper plenum, will be performed before the integral systems tests. In this fashion the thermal-hydraulic behavior of these important components will be better understood. This building-block approach is similar to the approach being used in the semiscale model experimental program.[2]

The first component to be examined in the FLECHT SEASET program is the steam generator. The FLECHT SET phase B tests indicated that during the reflood portion of a postulated loss-of-coolant accident (LOCA), not all the incoming entrained liquid flow would be vaporized in the steam generators, and that droplets could be carried out of the generator into the cold leg.[3] Carrying entrained liquid through the steam generators reduces superheating of the primary fluid. As the steam desuperheats, its density increases correspondingly. A larger mass flow can be vented through the loops for the same loop pressure drop as the steam density

1. Previous FLECHT SET phase B tests utilized two scaled steam generators. The larger one represented three pressurized water reactor steam generators of the unbroken loops during a postulated loss-of-coolant accident, and the smaller one represented the steam generator in the remaining broken loop.
2. Feldman, E. M. and Olson, D. J., "Semiscale MOD-1 Program and System Description for the Blowdown Heat Transfer Tests (Test Series 2)," ANCR-1230, August 1975.
3. Waring, J. P. and Hochreiter, L. E., "PWR FLECHT-SET Phase B1 Evaluation Report," WCAP-8583, August 1975.

increases. Hence, the venting capacity of the primary system is increased, and steam binding effects are less severe. The increased venting capacity results in larger core flooding rates and correspondingly increased core heat transfer and lower peak clad temperatures.

To model steam generator behavior during reflood, detailed knowledge of how the steam generator releases its heat, where the heat is transferred, and how the secondary side fluid behaves during the reflood transient must be known. Because the steam generator and the primary system interact, the easiest method of examining the steam generator behavior is to isolate it and perform separate component tests. This is the approach used in this experiment. Known inlet two-phase flows will be injected into the generator and the resulting two-phase mixture leaving the steam generator will be separated, collected, and measured. This will permit a primary fluid energy balance which can be related to the secondary side energy release.

A sufficient number of secondary fluid thermocouples, tube wall thermocouples, and shell wall thermocouples will be installed in the steam generator such that a secondary side heat release rate can be calculated. Selected tubes will be instrumented with primary side steam probes and differential pressure transducers (probes) to measure superheat of steam and liquid accumulation in the entrance region of the tubes. The steam probe data will allow an evaluation of thermodynamic nonequilibrium in the tubes, and the pressure drop transducers will allow an evaluation of the mass storage in the entrance region of selected tubes.

Prior to the steam generator separate effects tests, a series of tests will be run on the inlet plenum using air and water to simulate the two-phase steam mixture. The objective of these latter tests is to investigate the effect of the inlet plenum geometry on the flow distribution at the entrance to the steam generator tube bundle. In this test, two steam generator inlet plenum geometries will be tested. One of the plenums duplicates the FLECHT SET inlet plenum, and the other plenum resembles the hemispherical shape of a plenum in a typical pressurized water reactor plant with inverted U-tube steam generators.

SECTION 3
DATA REQUIREMENTS

To develop the data requirements for this task, the type of heat transfer and fluid flow processes in the steam generator must either be known or approximately known. A review of the FLECHT SET phase B data[1] and conversations with Kraft Werke Union personnel[2] who have been involved in analyzing the PKL reflooding systems effects data have indicated what the possible heat transfer and fluid flow processes are in the steam generator during reflood.

On the primary side, the heat transfer process is believed to be a two- or three-step convective film boiling process similar to that described by Iloeje[3] and Forslund and Rohsenow.[4] The vapor phase of the primary side dispersed flow is believed to be superheated easily by the hotter secondary side fluid temperature. The entrained droplets in the primary side fluid and the resulting vapor-to-droplet heat transfer limits the primary side vapor superheat from reaching the secondary side temperature. Primary side vapor superheating has been observed in the German PKL Tests. The heat transfer process going on in the secondary fluid is probably some combination of single-phase free convection and conduction. The secondary side fluid thermocouples in the FLECHT SET phase B tests indicated that a stratified relatively cold layer of water accumulates near the tube sheet on the secondary side. As secondary side cooldown continues, the stable cold layer becomes thicker, and reverse heat transfer can occur (that is, primary side to secondary side) within the cold layer on the outlet side of the steam generator.

The task data requirements can be developed from the previous description of the expected heat transfer and fluid flow processes postulated to occur in the steam generator. A summary of the basic thermal-hydraulic data which will be measured to meet the data requirements is given in table 3-1.

1. Waring, J. P. and Hochreiter, L. E., "PWR FLECHT-SET Phase B1 Evaluation Report," WCAP-8583, August 1975.
2. Documented in Westinghouse internal correspondence.
3. Iloeje, O. C., Rohsenow, W. M., and Griffith, P., "Three-Step Model of Dispersed Flow Heat Transfer (Post CHF Vertical Flow)," ASME Paper 75-WA-HT-1.
4. Forslund, R. P. and Rohsenow, W. M., "Dispersed Flow Film Boiling," *Trans. Am. Soc. Mech. Engrs. 90,* Series C, 399-407 (1968).

TABLE 3-1

BASIC DATA TO BE OBTAINED FOR THE STEAM GENERATOR SEPARATE EFFECTS TASK TO ACHIEVE DATA REQUIREMENTS FOR LOOP TESTS

Desired Data	Measuring Device	Location
Steam generator secondary fluid temperatures	Fluid thermocouples	Various radial locations at several different levels on the secondary side of the steam generator
Steam generator tube wall temperatures	Wall thermocouples	Various locations on the steam generator tube walls
Steam generator primary side vapor temperatures	Steam probes (aspirating)	Within the steam generator tubes
Water flow rate	Turbine meter	Mixer inlet line
Steam flow rate	Vortex meters	Mixer inlet line; steam separator outlet line
System pressure	Pressure transducers and transmitters	Steam generator secondary side, containment tank, and loop piping
Loop fluid temperatures	Thermocouples/RTDs[a]	In piping and steam generator plenum
Wall temperatures	Thermocouples	On piping, steam generator shell, and plenum
System pressure drops	Differential pressure transducers and transmitters	Steam generator inlet plenum, steam generator inlet tube, steam generator inlet to outlet plenum
Separator exit water mass rate	Differential pressure transducers	Steam separated collection tanks
Mass storage	Differential pressure transducer	Inlet plenum; water storage tanks
Secondary side fluid level	Differential pressure transducer	Secondary side of generator
Flow regimes	Photography	Inlet and outlet steam generator plenums

a. Resistance temperature detectors

A series of bench tests will be performed to aid in the design, selection, and placement of the steam generator instrumentation. Separate tests will be performed to examine tube wall thermocouple mounting, ability to measure pressure drop in a two-phase flow using static probes, and the two-phase flow inlet distribution at the steam generator tube sheet. These tests are detailed in section 6 and appendix C.

SECTION 4
PARAMETER RANGES AND REFERENCE CONDITIONS

4-1. JUSTIFICATION OF PARAMETER RANGES AND REFERENCE CONDITIONS

Parameter ranges and reference conditions for the steam generator separate effects test are given in table 4-1. Justification of parameters and conditions listed in table 4-1 is given in paragraphs 4-2 through 4-7. Note that all units in table 4-1 (and throughout this report) are given in metric units followed by English units in parentheses.

TABLE 4-1
PARAMETER RANGES AND REFERENCE CONDITIONS

Parameter	Reference Condition	Range
Primary side pressure	0.275 MPa[a] (40 psia)	0.138 to 0.414 MPa (20 to 60 psia)
Secondary side pressure	5.86 MPa (850 psia)	1.72 to 5.86 MPa (250 to 850 psia)
Primary side temperature	130.5°C (267°F)	109 to 145°C (228 to 293°F)
Secondary side temperature	274°C (525°F)	204 to 274°C (400 to 525°F)
Primary side mass velocity[b]	64.9 $kg/sec/m^2$ (13.3 $lb/sec/ft^2$)	64.9 to 129.9 $kg/sec/m^2$ (13.3 to 26.6 $lb/sec/ft^2$)
Inlet Quality	0.80	0.10 to 1.0
Secondary side water level	100%	25 to 100%

a. Megapascals

b. Based on hot leg flow area of 0.0035 m^2 (0.0375 ft^2)

4-2. Primary Side Pressure

The reference pressure of 0.275 MPa (40 psia) and the range of 0.138 to 0.414 MPa (20 to 60 psia) were chosen to maintain consistency with other separate effects and systems effects tests in the FLECHT SEASET program.[1] It includes the range of containment pressures from a typical pressurized water reactor plant in the reflood period of a hypothetical LOCA[2] after the blowdown of the primary loop.

4-3. Secondary Side Pressure

The maximum allowable secondary side pressure for the FLECHT SEASET steam generator is 5.86 MPa (850 psia). A steam generator secondary pressure typical of current-design plants is 6.894 MPa (1000 psia). The FLECHT SEASET steam generator maximum allowable secondary side pressure is typical of many currently-operating plants. The difference in saturation temperatures between these two pressures is only 11.1°C (20°F), and the cost of upgrading the steam generator because of this difference is not warranted.

The range of secondary side pressure, 1.72 to 5.86 MPa (250 to 850 psia) was chosen to yield a significant variation in secondary side temperature from the reference case. The information from this secondary side temperature variation run can be used to evaluate the effect of the 11.1°C (20°F) difference mentioned in the previous paragraph.

4-4. Primary Side Temperature

The reference primary side temperature of 130.5°C (267°F) is the saturation temperature corresponding to the reference primary pressure, and hence, varies with primary side pressure. FLECHT SET phase B test results show that the steam temperature at the steam generator inlet plenum is close to saturation and does not vary appreciably with time. The range of primary temperature is based on the saturation temperatures for the primary side pressure range.

4-5. Secondary Side Temperature

The range and reference values of the secondary side temperature are the saturation temperatures corresponding to the secondary side pressure.

1. Conway, E. E., et al., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI Westinghouse Report No. 1, December 1977.
2. Collier, G., et al., "Calculational Model for Core Reflooding After a Loss-of-Coolant Accident (WREFLOOD Code)," WCAP-8171, June 1974.

4-6. Primary Side Mass Velocity and Quality

The reference primary mass velocity given in table 4-1 was developed from a review of prior FLECHT SET tests[1] and LOCA design calculations[2] and is discussed below.

4-7. Secondary Water Level

The reference parameter for secondary water level is 100 percent (that is, the tube bundle is completely submerged). The selected range on secondary water level of 25 to 100 percent is intended to permit sensitivity studies to be run with secondary level as the single parameter variation.

4-8. REFERENCE STEAM AND LIQUID MASS FLOW RATE ESTIMATES FROM DESIGN CALCULATIONS

The bundle outlet steam and liquid flow rates can be calculated from known inlet flooding rates, the carryover fraction, and the outlet quality. These are expressed as equations as follows:

$$W_{out} = (W_{in})\ (F_{out}) \tag{4-1}$$

$$W_g = \chi\ W_{out}^* \tag{4-2}$$

$$W_f = (1 - \chi)\ W_{out}^* \tag{4-3}$$

$$W_{in} = (V_{in})\ (A_{core})\ (\rho_{in}) \tag{4-4}$$

where

W_{out} = mass flow rate out of the bundle

$*$ = assumes thermodynamic equilibrium in W_{out}

W_{in} = mass flow rate into the bundle

F_{out} = the inlet mass fraction from the design correlation or test data which is carried out of the bundle

W_g = steam mass flow rate out of the bundle

1. Waring, J. P. and Hochreiter, L. E., "PWR FLECHT-SET Phase B1 Evaluation Report," WCAP-8583, August 1975.
2. Collier, G., et al., "Calculational Model for Core Reflooding After a Loss-of-Coolant Accident (WREFLOOD Code)," WCAP-8171, June 1974.

W_f = liquid mass flow rate out of the bundle

χ = exit quality

V_{in} = core flooding rate

A_{core} = core or test bundle flow area

ρ_{in} = density of liquid at inlet conditions

For the bundle test reference inlet flooding rate of 25.4 mm/sec (1.0 in./sec), and a bundle flow area of 0.0145 m^2 (22.5 $in.^2$), the inlet mass flow rate is 0.369 kg/sec (0.813 lb/sec). Test data from WCAP-8838,[1] figures 3-30 and 3-40, indicate that the F_{out} fraction starts at zero and asymptotically approaches a value of approximately 0.80. The flow split between the broken and unbroken loops in past FLECHT SET tests is very nearly 3 to 1. Thus the unbroken loop steam generator receives three-quarters of the bundle effluent. The unbroken loop steam generator mass flow rate can be calculated by reducing the bundle inlet flow by the product (0.80 x 0.75) or 0.60. The above bundle flow rate that corresponds to a 25.4 mm/sec (1.0 in./sec) flooding rate equals a steam generator mass flow rate of 0.227 kg/sec (0.5 lb/sec). If the hot leg quality is known, the steam and liquid component flow rates can also be calculated from equations (4-2) and (4-3).

In a design reflood calculation,[2] the core outlet quality varies from 0.50 to 0.80 for the time period prior to core quench. This range of quality and the total flow of 0.227 kg/sec (0.5 lb/sec) corresponds to the following liquid and steam flow rates:

$$0.11 \text{ kg/sec} \leq W_g \leq 0.18 \text{ kg/sec}$$

or

$$0.25 \text{ lb/sec} \leq W_g \leq 0.40 \text{ lb/sec}$$

1. Lilly, G. P., et al., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.

2. Collier, G., et al., "Calculational Model for Core Reflooding After a Loss-of-Coolant Accident (WREFLOOD Code)," WCAP-8171, June 1974.

and

$$0.05 \text{ kg/sec} \leqslant W_f \leqslant 0.11 \text{ kg/sec}$$

or

$$0.10 \text{ lb/sec} \leqslant W_f \leqslant 0.25 \text{ lb/sec}$$

In the postcore quench period, a design calculation using the model described in WCAP-8312[1] predicted a core exit mass velocity as high as 76.5 kg/m^2/sec (15.66 lb/sec/ft^2) at a quality as low as 10 percent. These parameters correspond to a FLECHT SEASET steam generator inlet flow rate of 0.835 kg/sec (1.84 lb/sec). The corresponding liquid flow rate is 0.752 kg/sec (1.66 lb/sec).

4-9. STEAM AND LIQUID MASS FLOW RATE ESTIMATES FROM PRIOR FLECHT SET TESTS

The scale factor in the phase A test is 370.[2] The scale factor in the FLECHT SEASET test series is 327. Therefore, for the flow rates listed in table 4-2 to be applicable to FLECHT SEASET test conditions, they must be scaled by 370/327, or 1.13. The phase A test results for the hot leg liquid flow rate is assumed to be equal to the liquid flow rate into the steam generator tubes. This assumption neglects liquid storage in the steam generator inlet plenum. The phase B data for inlet plenum storage supports the assumption that the storage rate is negligible compared to the total flow through the steam generator.

A summary of the results of this study is presented in tables 4-3 and 4-4. For the steam generator separate effects test, the reference mass flow rate is taken to be 0.227 kg/sec (0.5 lb/sec) and the reference quality is 0.80. These parameters are representative of the portion of reflood transient prior to bundle quench. The range selected for the primary side mass velocity allows for a factor of 2 increase in mass velocity for sensitivity studies, the range of inlet qualities selected for the test program covers the range of qualities observed in prior FLECHT tests,[2,3] and the range of qualities found in the design calculation[1] for the period prior to core quench.

1. Shepard, R. M., et al., "Westinghouse Mass and Energy Release Data for Containment Design," WCAP-8312, March 1974.
2. Blaisdell, J. A., Hochreiter, L. E., and Waring, J. P., "PWR FLECHT-SET Phase A Report," WCAP-8238, December 1973.
3. Waring, J. P. and Hochreiter, L. E., "PWR FLECHT-SET Phase B1 Evaluation Report," WCAP-8583, August 1975.

TABLE 4-2
STEAM GENERATOR STEAM AND LIQUID FLOW RATES FROM FLECHT SET PHASE A TESTS[a]

Run No.	Pressure MPa (psia)	Time Interval[b] (sec)	$\dot{M}_B$ kg/sec (lb/sec) Bundle Accumulation	$\dot{M}_p$ kg/sec (lb/sec) Upper Plenum Accumulation	$\dot{M}_{SGB}$ kg/sec (lb/sec) SG Plenum Accumulation	W_{stm}[c] kg/sec (lb/sec)	W_{in}[d] kg/sec (lb/sec)	W_{liq}[e] kg/sec (lb/sec)
4923A	0.42 (61)	$0 \leq t \leq 150$	0.18 (0.40)	0.22 (0.50)	NA	0.22 (0.50)	0.68 (1.5)	0.0
4923A	0.42 (61)	$150 \leq t \leq 300$	0.05 (0.10)	0.0	NA	0.05 (0.10)	0.54 (1.2)	0.45 (1.0)
2919A	0.14 (20)	$0 \leq t \leq 300$	0.05 (0.10)	0.0[f]	NA	0.18 (0.40)	0.22 (0.5)	0.0
2919A	0.14 (20)	$300 \leq t \leq 600$	0.0	0.0[f]	NA	0.09 (0.20)	0.54 (1.2)	0.45 (1.0)

a. Blaisdell, J. A., Hochreiter, L. E., and Waring, J. P., "PWR FLECHT SET PHASE A Report," WCAP-8238, December 1973.
b. t = 0 corresponds to the beginning of bundle reflood.
c. W_{stm} refers to the steam mass flow rate in the hot leg.
d. W_{in} is the rod bundle inlet mass flow rate.
e. W_{liq} is the mass flow rate of the liquid in the hot leg.
f. Estimated due to inoperative d/p cell.

TABLE 4-3

STEAM GENERATOR INLET STEAM AND LIQUID MASS FLOW RATE ESTIMATES FROM DESIGN CALCULATIONS AND PRIOR TESTS

Source of Estimate	Steam Flow Rate Range	Liquid Flow Rate Range
Design calculations Reflood period[a]	0.23 to 0.36 kg/sec (0.5 to 0.8 lb/sec)	0.09 to 0.23 kg/sec (0.2 to 0.5 lb/sec)
Post reflood[b]	0.09 kg/sec (0.2 lb/sec)	0.77 kg/sec (1.7 lb/sec)
FLECHT SET tests[c,d]	0.05 to 0.23 kg/sec (0.1 to 0.5 lb/sec)	0 to 0.41 kg/sec (0 to 0.9 lb/sec)

a. Collier, G., Kelley, R. D., Spencer, A., and Waring, J. P., "Calculational Model for Core Reflooding After a Loss-of-Coolant Accident (W Reflood Code)," WCAP-8171, June 1974.

b. Shepard, R. M., Massie, H. W., Mark, R. H., and Docherty, P. J., "Westinghouse Mass and Energy Release Data for Containment Design," WCAP-8312, March 1974.

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

d. Blaisdell, J. A., Hochreiter, L. E., and Waring, J. P., "PWR FLECHT-SET Phase A Report," WCAP-8238, December 1973.

TABLE 4-4

SEPARATE EFFECTS TEST REFERENCE AND RANGE OF MASS FLOW RATES

Parameter	Reference	Range
Inlet flow rate	0.23 kg/sec (0.5 lb/sec)	0.23 to 0.45 kg/sec (0.5 to 1.0 lb/sec)
Inlet quality	0.8	0.2 to 1.0
Steam supply	0.18 kg/sec (0.4 lb/sec)	0.05 to 0.36 kg/sec (0.1 to 0.8 lb/sec)
Liquid supply	0.05 kg/sec (0.1 lb/sec)	0.05 to 0.41 kg/sec (0.1 to 0.9 lb/sec)

In the postcore quench period, the hot leg flow rate increases and the quality decreases. The data in tables 4-3 and 4-4 show that in prior FLECHT SET tests, the highest liquid flow rates measured are lower than the liquid flow rates specified for the separate effects test.

The parameter ranges for the separate effects test have been reviewed by other PWR vendors and are consistent with their calculated conditions. These items are documented in internal correspondence between Westinghouse and Combustion Engineering, and between Westinghouse and Babcock and Wilcox.[1]

1. Conway, C. E., et al., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI Westinghouse Report No. 1, December 1977, Appendix D.

SECTION 5
TEST FACILITY DESCRIPTION AND DESIGN

5-1. TEST LOOP DESIGN

Figure 5-1 illustrates a detailed schematic diagram of the separate effects test loop. The major components in the loop are the boiler, accumulator, steam/water mixer, steam generator, steam separator, and containment tank. The boiler and accumulator will supply steam and water to a mixing chamber which generates a two-phase flow regime to supply the steam generator. Steam separators in the steam generator discharge flow path will separate the two-phase effluent from the steam generator tube bundle to allow each component of the two-phase flow to be measured. A bypass line around the steam generator is provided to permit monitoring of the mixer effluent using the instrumentation downstream of the steam generator. Warmup lines are also provided to permit use of the boiler for loop warmup. Several drains are included in the loop to allow the two-phase mixture to be dumped while test parameters are being stabilized prior to running a test.

The steam-water mixer is shown in figure 5-2 and consists of a liquid spray nozzle located inside the steam flow line. Because most of these experiments will be conducted using high quality two-phase flows, the steam will be the continuous phase, and the liquid will be dispersed within the steam flow. This two-phase flow in the steam generator hot leg and lower plenum will then be generated by spraying liquid into the passing steam.

Preliminary air/water visualization tests on the steam generator inlet plenum indicated that the liquid flow distribution is not uniform. It is postulated that the liquid distribution is being determined by the geometry of the inlet plenum and the hot leg upstream of the inlet plenum. This geometry effect will be investigated in the air/water tests described in appendix C. The hot leg geometry downstream of the mixer will be preserved in the systems effects tests.

The drop size distribution generated by the spray nozzle is not believed to be an important parameter in the separate effects test. The expected flow regime in the hot leg is annular flow with the liquid phase predominately in a continuous film on the pipe wall. Also, prior phase B tests[1] show that liquid accumulation will occur in the inlet plenum. It is assumed that the

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

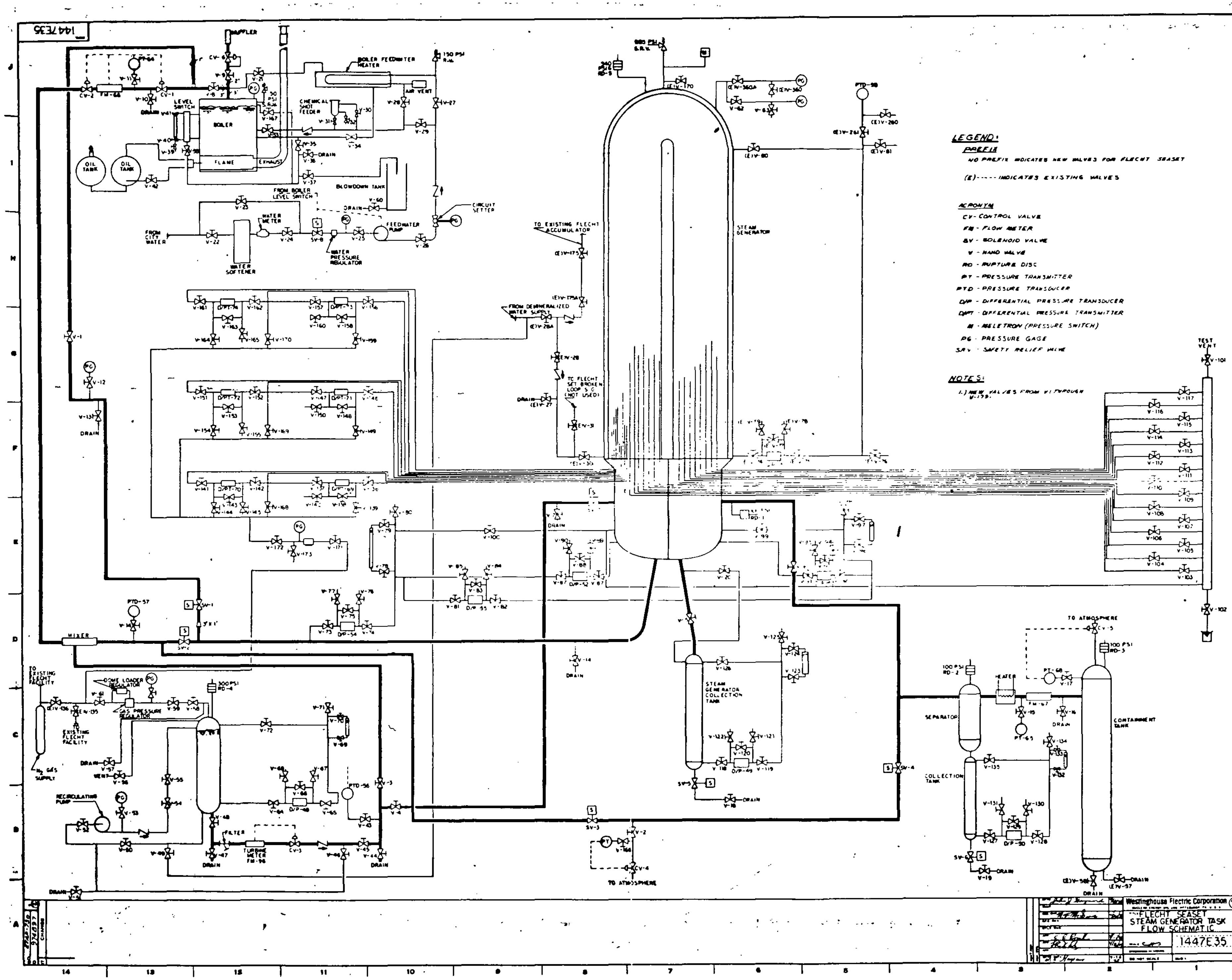


Figure 5-1. Schematic Diagram of the Separate Effects Test Loop

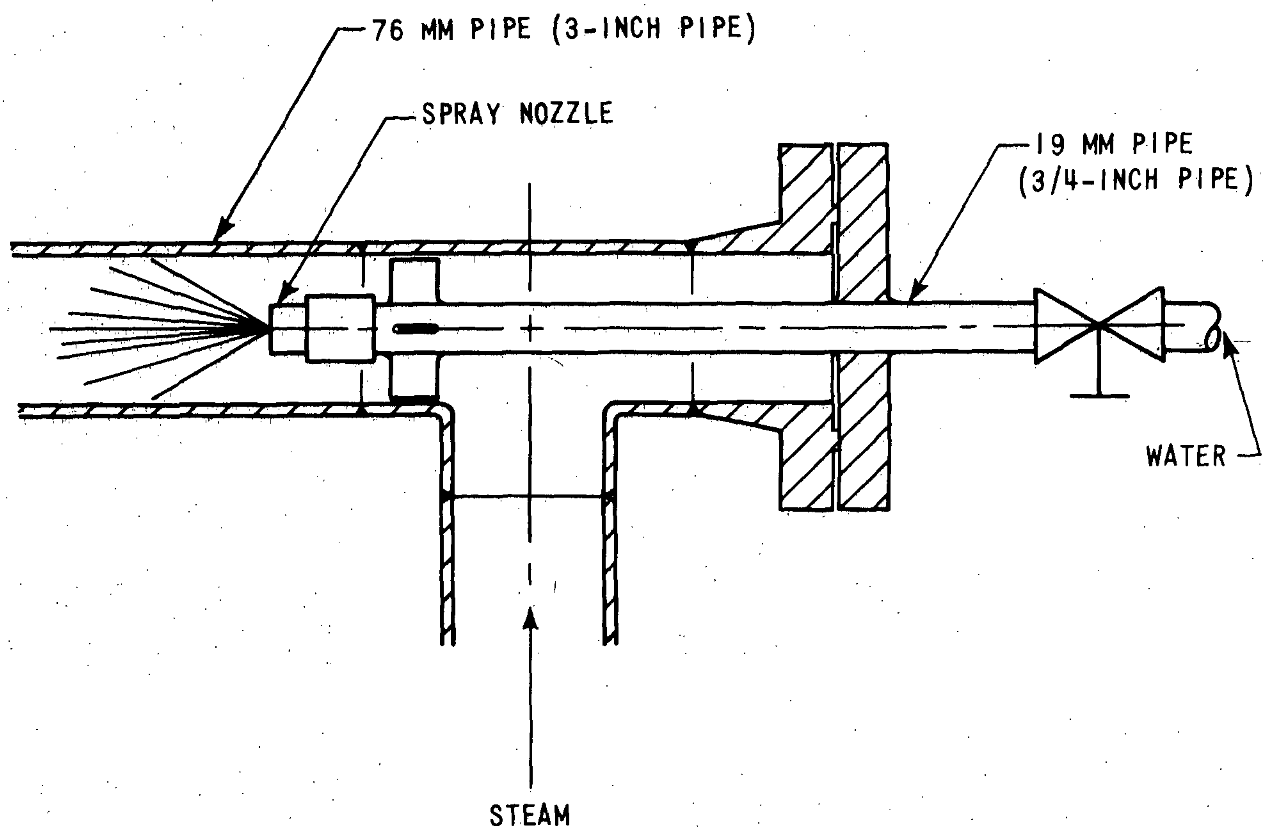


Figure 5-2. Diagram of the Steam-Water Mixer Section

drop size distribution at the tube sheet will be determined by the nature of the two-phase annular flow in the hot leg and the interaction between the stored liquid and flowing liquid in the inlet plenum rather than the drop size at the spray nozzle.

The macroscopic mixer characteristics will be checked by isolating the steam generator and discharging the mixer to the steam separator downstream of the steam generator. With this loop lineup, the steam and liquid flow rates upstream and downstream of the mixer can be measured and compared. After establishing the required test initial conditions, the test can be easily initiated by simply closing the valve in the bypass line (SV-3 in figure 5-1) and opening the isolation valve (SV-2 in figure 5-1) to the steam generator.

The FLECHT SET steam generator plenum will be modified by adding an integral steam separator in the outlet plenum which will minimize time delays and energy losses between the tube bundle exit and the separator. The inlet plenum will also be modified to the extent necessary to provide an alternate spray nozzle location for liquid injection just below the tube sheet.

The loop is designed to supply the steam generator with a steady-state two-phase mixture. The loop and steam generator response will be essentially steady state except for the secondary water which will cool down slowly. The test run will be terminated at a predetermined time limit which will correspond to the time when the rod bundle would have been quenched in a systems effect test.

5-2. FACILITY LAYOUT

The loop shown schematically in figure 5-1 will be built using as many of the FLECHT SET test series loop components as possible. This includes the steam generator, containment tank, and some connecting piping. The detailed piping layout drawings for the test loop are shown in appendix D.

The major loop components that must be procured for this test include a water supply tank, a boiler for supplying steam, a steam-water mixer section, a close-coupled water collection tank at the steam generator outlet, a steam separator and collection tank, and the necessary loop valves and piping.

5-3. FACILITY COMPONENT DESCRIPTION

Test loop components are described in paragraphs 5-4 through 5-10.

5-4. Description of the Boiler

The facility steam supply will be a 1.23 MW_t (125 bhp) steam boiler. The unit will have a thermal output rating of 1,225,500 W (4,184,000 Btu/hr) and an equivalent steam rating of 1956 kg/hr (4313 lb/hr) at 100°C (212°F). The boiler will be of the package firetube type equipped with a combination gas/oil burner, modulating fire capabilities, and automatic controls. Design and construction of the boiler will be in accordance with the ASME Code, section I. Design pressure will be 1.034 MPa (150 psig). The unit will be operated at approximately 0.69 MPa (100 psig) for all tests. At this operating condition, outlet steam quality will be rated as better than 99.5 percent.

5-5. Description of the Water Supply Tank

The water supply tank will provide the water for the mixer section. The tank will be constructed of 0.61-meter (24-inch) carbon steel pipe with elliptical head closures. The capacity will be approximately 946 liters (250 gallons). Design and construction will comply with section I of the ASME Code. The vessel will be designed for 2.06 MPa (300 psi) at 343°C (650°F). Strip heaters on the tank wall along with a mixing pump will be used to bring the water to the saturation temperature corresponding to the specified test pressure. A constant nitrogen gas overpressure will supply the driving head for injecting water into the mixer section.

5-6. Description of the Mixer

Water and steam will be combined in the mixer section to produce the two-phase flows entering the steam generator. Mixing will be accomplished by spray nozzle injection as shown in figure 5-2. The spray nozzles that will be used are commercially available and produce a full-cone spray pattern.

The nozzle size will be based on matching the known nozzle pressure drop versus flow characteristics with the required liquid flow rate for a given test run. A minimum nozzle pressure drop will be established to ensure a fully-developed spray pattern from the nozzle. A maximum nozzle pressure drop will be established to ensure that the pressure limits in the accumulator and piping upstream of the mixing nozzle will not be violated.

The spray nozzle will normally be installed in the horizontal run of hot leg pipe upstream of the steam generator. However, an alternate spray nozzle location in the inlet plenum just below the tube sheet will also be used to test the generator response to uniform inlet flow conditions.

5-7. Description of the Steam Generator

The steam generator which will be used for the separate effects task is the large steam generator simulator used in the FLECHT SET phase B Test Program.[1] Figures 5-3 and 5-4 show details of construction of the generator.

Certain modifications will be made to the generator for the separate effects task. All but one of the spare tubes previously plugged for the FLECHT SET phase B test series will be opened. A total of 32 of 33 tubes will be needed to preserve, as closely as possible, the flow area scaling relationship due to increasing the heater rod bundle flow area in the FLECHT SEASET systems effects task. The tube chosen for plugging is tube E shown in figure 5-3. This tube was selected for plugging because it would be most strongly affected by edge effects of the shell on the steam generator secondary side and edge effects of the inlet plenum on the primary side.

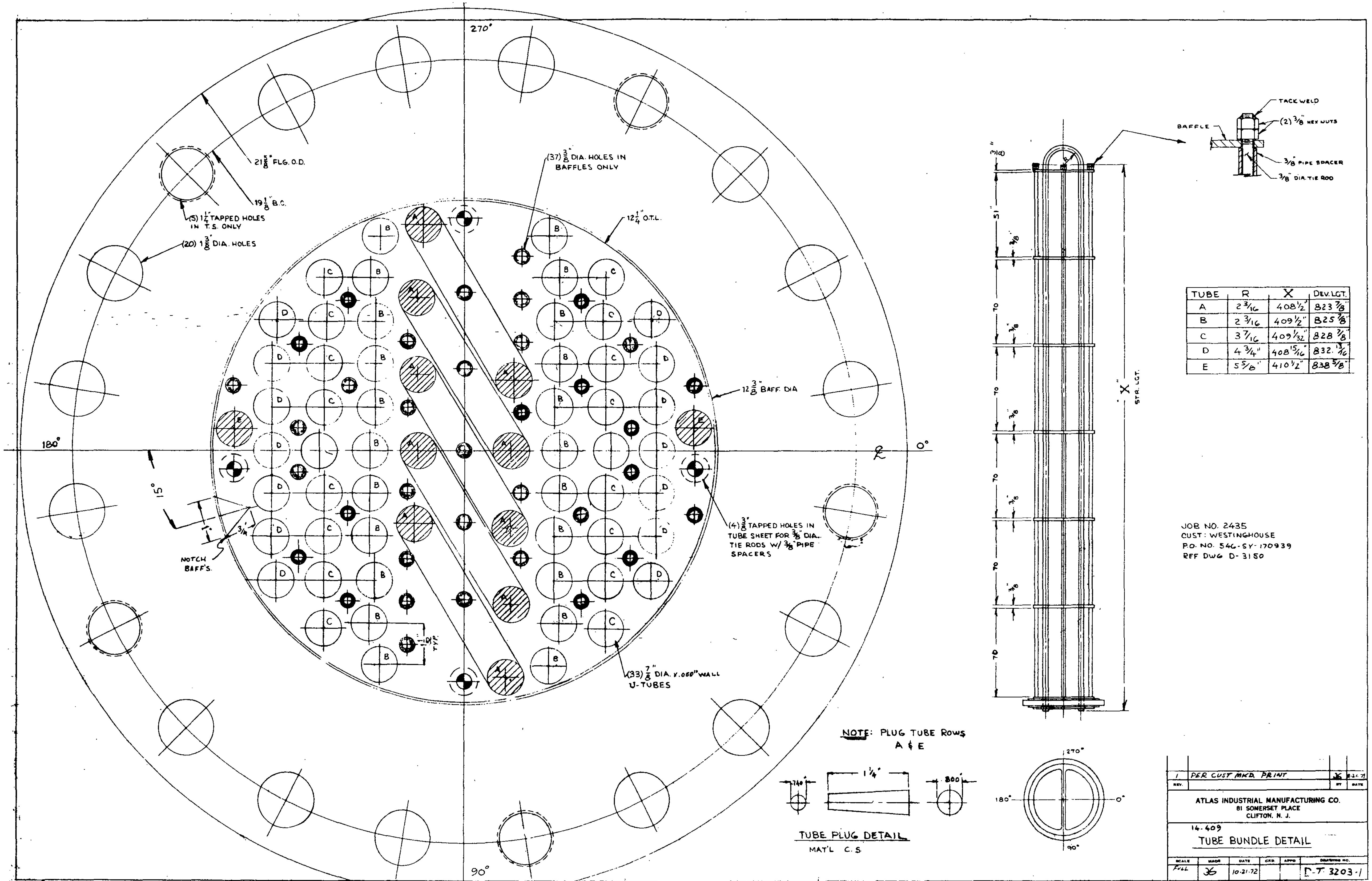
An instrumentation ring with multiple radial penetrations will be added between the tube sheet flange and the lower plenum flange to bring out primary side instrumentation. Two sight glass nozzles will be added to the discharge side of the lower plenum section for viewing and photographic study. An alternate 127-millimetre (5-inch) discharge nozzle will also be added to the lower plenum. This will serve as an outlet for steam and will also be used to support an internal baffle assembly. The baffle will help separate any entrained liquid carried through the generator. The separated liquid will drain through the old discharge nozzle to a new 3.05 metre-long (10-foot-long) collection tank made from 152-millimetre (6-inch) pipe.

The internal baffle in the outlet plenum will not be used in the systems effects tests because no attempt will be made to separate and collect the steam generator exit two-phase flow. This approach is the same as that used in FLECHT SET phase B tests. To minimize the effects of evaporation or condensation or any part of the loop, the loop piping and steam generator plenums are preheated to saturation temperature.

5-8. Description of the Steam Generator

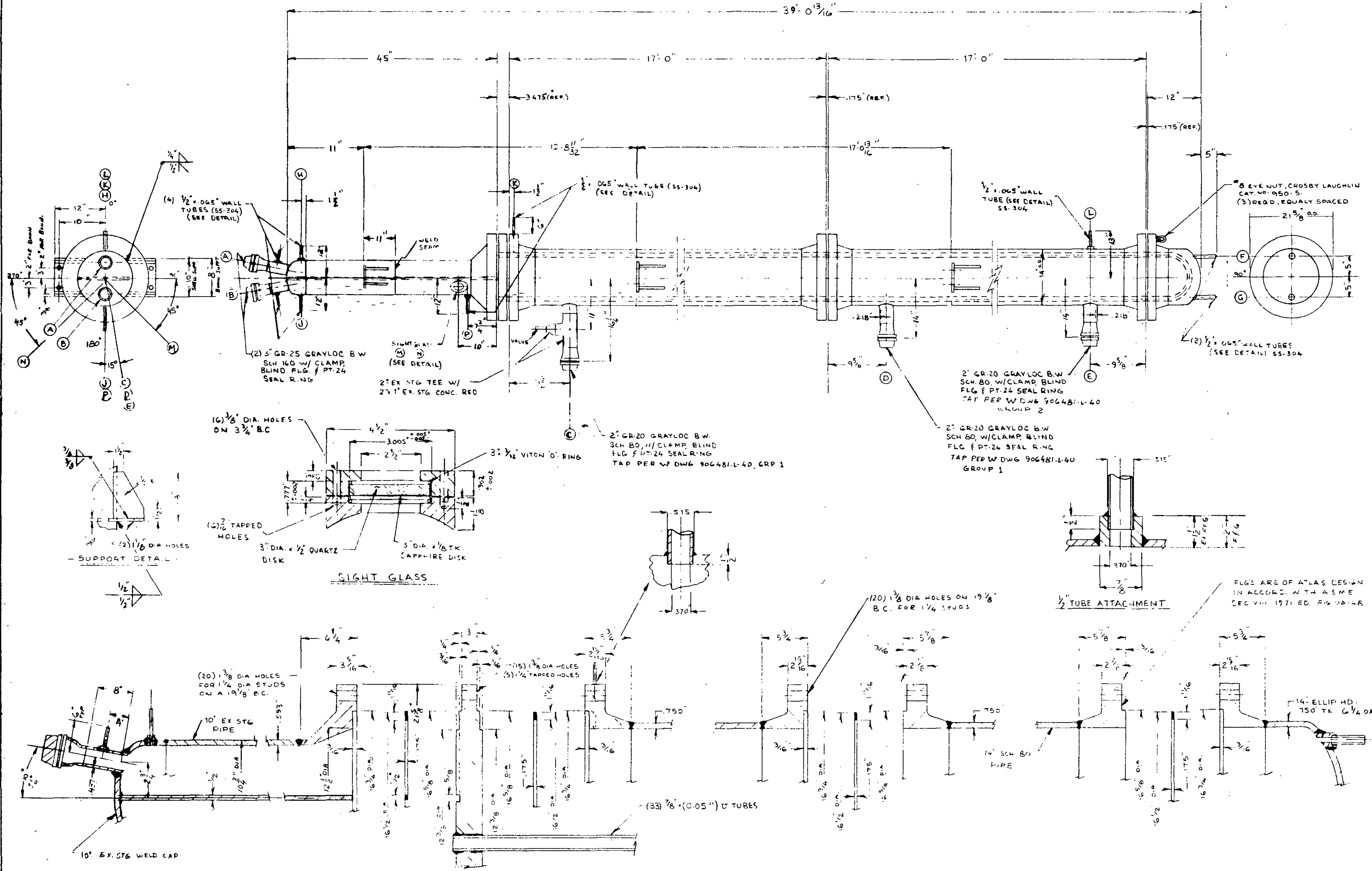
The close-coupled steam separator located downstream of the steam generator will be used to separate any remaining entrained liquid so that an accurate single-phase steam flow measurement can be made by the vortex meter located downstream of the separator. The separator is commercially available and uses centrifugal force to drive the heavier moisture against the walls of the vessel where it will drain to a 76.2-millimetre-diameter (3-inch-diameter) by 2.1-metre-long (7-foot-long) collection tank. The separator will be similar in design to the one

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



TUBE	R	X	DEV. LGT.
A	2 3/16	408 1/2"	823 7/8"
B	2 3/16	409 1/2"	825 7/8"
C	3 7/16	409 1/32"	828 7/8"
D	4 3/4"	408 15/16"	832 13/16
E	5 5/8"	410 1/2"	838 5/8"

Figure 5-3. Details of the Construction of Separate Effects Test Steam Generator (Sheet 1 of 2)



—CONSTRUCTION DETAILS—

NOTES

1. CONSTRUCTION TO COMPLY WITH ASME CODE SECTION VIII - 1971 ED. INCLUDING CERT. & STAMP. TEMA R FOR INSTALLATION IN STATE OF PA.
2. NAME PLATE STAMPING:

ATLAS INDUSTRIAL MFG. CO. CLIFTON, N.J.

NAT'L BD.	1906			
SERIAL	2522			
YEAR	1973			
SHELL	900	PSI AT	600	°F
TUBES	150	PSI AT	600	°F
JACKET		PSI AT		°F
PO NO. 546-SY-170939				

3.

	SHELL SIDE		TUBE SIDE	
TEST PRESSURE	1350	PSI	225	PSI
CORROSION ALLOW.	.065"		.065"	EX. TUBES

4. WEIGHTS:
   EMPTY — 8250 LBS.
   FULL OF WATER — 10,150 LBS.
5. PAINT: NOT REQ'D
   SANDBLAST: NOT REQ'D
6. [redacted]
7. STRESS RELIEVE: NOT REQ'D.
8. RADIOGRAPHY: SPOT TUBE SIDE & SHELL SIDE
9. SPECIAL TESTS: NONE
10. CUSTOMER'S INSPECTION: REQ'D. (SEE NOTE 14
11. TUBES TO BE SEAL WELDED TO T.S.
12. ALL TOL. PER TEMA "R".
13. THE NAME & DESIGN COND ARE SUBJECT TO CODE APPROVAL OF THE TUBE MATERIAL
14. INSPECTION POINTS
   A. TUBE SHEET AFTER DRILLING
   B. COMPONENT PARTS - BEFORE ASSEMBLY
   C. AT HYDRO-TEST.

CUSTOMER: WESTINGHOUSE ELEC. CO.
PO NO. 546-SY-170939
UNITS REQUIRED: (1) ONE
ATLAS JOB NO. 2435

REV		BY	DATE
7	REV. TEST PRESS. (SHELL SIDE)	JB	10-25-73
6	FINALIZED DWG	JB	5-15-73
5	REV. SUPPORT LOCATIONS	[illegible]	4-2-73
4	REV. PER CUST MKD PRINT	JB	[illegible]
3	REV. PER CUST MKD. PRINT	JB	[illegible]
2	REV. T.S. REF. & UNIT O.A.	JB	[illegible]
1	PER MEETING OF 10-16-72	JB	10-21-72

ATLAS INDUSTRIAL MANUFACTURING CO.
81 SOMERSET PLACE

ASME MATERIAL SPECIFICATIONS

SHELLS			FACINGS			BONNETS CHANNELS			NOZZLE NECKS	C/S	SA-33B
PIPE	C/S (SMLS)	SA-53-B	EXPANSION JOINT			WELD CAPS			FITTINGS		
ROLLED PLATE			END PLATE			FORMED HEADS	C/S	SA-516-70	COVERS ☐ FACED		
BAFFLES	C/S	SA-36	WELD CAPS			PIPE	C/S (SMLS)	SA-53-B	TUBE SHEETS	C/S	SA-515-70
TIE RODS	C/S	SA-36	FORMED HEADS			PLATE			TUBES SEAMLESS / WELDED	INCONEL	SB-163
SPACERS	C/S	SA-120	UNIT FLANGES	F/S	SA-105-II	UNIT FLANGES	F/S	SA-105-II			
NOZZLE FLG'S	F/S	SA-105-II	FITTINGS, SCREWED	F/S	SA-105	NOZZLE FLG'S	F/S	SA-105 II	PRESS TAPS	S/S 304	SA-249
NOZZLE NECKS	C/S	SA-53-B	SUPPORTS	C/S	SA-36	PASS PART.	C/S	SA-36	SIGHT GLASSES	C.S. -	SA-285-C

STUDS
☒ SA-193 GR B7
☐ SA-193 GR
NUTS
☒ SA-194 GR 2H
☐ SA-192 CL 2

GASKETS
☐
RIB ☒
☒
SEALING
☐

Figure 5-4. Details of the Construction of Separate Effects Test Steam Generator (Sheet 1 of 2)

used in the FLECHT Low Flooding Rate Test Series.[1] The pressure retaining shell will be made from 305-millimetre-diameter (12-inch-diameter) pipe with 102-millimetre (4-inch) flanged inlet and outlet steam connections. The unit will be designed for 1.03 MPa (150 psi) at 260°C (500°F) in accordance with the ASME Code, section VIII. The manufacturer rates the separator as being capable of removing 99 percent of all liquid and solid entrainment where the particle sizes exceed 10^{-5} metres (3.9 x 10^{-4} inches). Separator capacity varies with operating pressure. At 0.14 MPa (20 psia), the maximum recommended steam flow rate is 1134 kg/hr (2500 lb/hr), and at 0.41 MPa (60 psia), the capacity is 2132 kg/hr (4700 lb/hr). Up to half the above flow rates can be entrained water. Higher percentages of water can be tolerated by correspondingly reducing the saturated component of the total flow.

5-9. Description of the Containment Tank

The containment tank is the same vessel that was used in the FLECHT SET Test Program[2] to provide the containment backpressure simulation. The vessel is made from 0.61-metre-diameter (24-inch-diameter) pipe with elliptical head closures. Design and construction comply with the ASME Code, section I. The design rating is 0.7 MPa (100 psi) at 343°C (650°F). The tank has a volume of approximately 1703.3 litres (450 gallons). The containment tank will serve as a convenient point at which to control system pressure. Its large volume will help dampen any system pressure fluctuations in the test loop.

5-10. Description of the Loop Piping

The main loop steam piping from the boiler to the steam generator, including the bypass line, will be fabricated primarily from 76-millimetre (3-inch) standard weight pipe and weld fittings. The FLECHT SET steam generator inlet piping geometry will be maintained by using the inlet bend section of 76-millimetre (3-inch) schedule 160 piping from the FLECHT SET facility. A short section of pipe upstream of the separator and from the separator to the containment tank will be 102-millimetre (4-inch) standard weight. Water injection piping from the water supply tank to the mixer and any auxiliary steam piping will be primarily field run and consist of 25.4-millimetre (1-inch) standard weight pipe and screwed fittings.

1. Lilly, G. P., et al., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.
2. Blaisdell, J. A., Hochreiter, L. E., and Waring, J. P., "PWR FLECHT-SET Phase A Report," WCAP-8238, December 1973.

5-11. FACILITY OPERATION

To perform a steam generator separate effects experiment, the facility and the steam generator must be brought to the desired initial conditions. The steam generator secondary side is heated using electrical strip heaters on the steam generator shell and lower flanges. Previous FLECHT SET phase B experiments[1] have shown that this method of heating will produce a uniform temperature on the steam generator secondary side. During heatup, the secondary side temperature is monitored, and the strip heaters, at a given elevation, are deenergized when that elevation reaches the desired secondary side temperature.

The primary side piping will be heated to the primary side saturation temperature using bleed steam from the boiler (figure 5-1). While the system is being heated, the instrumentation channels will be checked, flowmeters and differential pressure transducer cells will be zeroed, and flow control valves will be aligned. Once the system is heated, the steam and liquid flows can be adjusted to their desired values at the mixer, and the resulting two-phase flow can be bypassed to the drain while these conditions are being established. Once the desired inlet flow conditions are established, the inlet two-phase flow can be directed into the steam generator by proper alignment of the loop solenoid valves.

Steam flow to the mixer will be measured by a vortex meter (FM-66 on figure 5-1). A pressure reducing valve, CV-1, will be used to control the upstream pressure at FM-66 and to minimize system instabilities caused by boiler pressure fluctuations. The pressure drop of 0.28 to 0.52 MPa (40 to 75 psid) across CV-1 will also help ensure a single-phase steam flow at FM-66 and the mixer. Steam flow control will be accomplished with control valve CV-2; feedback to the valve will be supplied by FM-66.

Water flow to the mixer will be controlled by valve CV-3. A turbine meter (FM-96) will be used to measure the flow and provide feedback to the control valve.

Two-phase fluid leaving the generator primary side tubes will go through a first stage of separation in the lower plenum section of the steam generator. An internal baffle assembly will be used to separate the liquid which will be drained and measured in a collection tank located below the plenum. The remaining steam will pass through a commercial separator of the same type as used in the FLECHT Low Flooding Rate Test Series.[2] The separator will remove any remaining entrained liquid which will then be collected and measured in the separator drain tank. During certain tests, the steam generator exit quality will be low and the liquid collection

1. Waring, J. P. and Hochreiter, L. E., "PWR FLECHT-SET Phase B1 Evaluation Report," WCAP-8583, August 1975.
2. Lilly, G. P., et al., "PWR FLECHT Cosine Low Flooding Rate Test Series Evaluation Report," WCAP-8838, March 1977.

tanks may fill up prior to the end of the test. Each collection tank will have a solenoid valve dumping to a drain or larger collection tank to allow the separator drain tank to be emptied during a test run.

Dry steam leaving the separator will pass through another vortex flowmeter (FM-67) prior to entering the containment tank. An immersion heater, inserted upstream of the flowmeter, will be used to ensure that single-phase flow is being measured by the meter. The exhaust valve (CV-5), located downstream of the containment tank, will be used to control the specified system backpressure. Control feedback to the valve will be supplied by a pressure transmitter located on the containment tank.

A bypass line around the steam generator will be used for shakedown and pretest setup. During shakedown, two-phase flow from the mixer will be diverted around the generator to the steam separator. The separator will be used as a backup check on the quality of the two-phase mixer. While establishing two-phase flow in the mixer section, the bypass line will be used to divert flow to atmosphere via backpressure control valve CV-4. A separate line will run from the boiler to the steam generator inlet. This line will be used to heat up the primary side of the steam generator and the piping and components downstream of the generator while two-phase flow is being established in the mixer.

The following is a simplified test operating procedure. Drawing number 8763D67 presented in appendix D shows the location of loop valves and components in a simplified manner.

(1) Begin with all valves closed.

(2) Fill the steam generator and accumulator with water and heat up to desired conditions.

(3) Fire boiler. Open V-1, SV-1, V-5, V-6, and CV-5. Use steam to heat up steam generator primary side, separator, collection tank, containment, and interconnecting piping. Adjust backpressure with CV-5, and control steam flow with V-1.

(4) Open CV-1, CV-2, SV-3, and CV-4, and use boiler steam to heat up piping from boiler through mixer and steam generator bypass line. Control flow with CV-2 and backpressure with CV-4.

(5) When all loop components have reached desired conditions, set the desired test steam flow through the bypass line by using CV-1 to control FM-1 upstream pressure and CV-2 to control steam flow. Control bypass line backpressure with CV-4.

(6) Open V-3 and set water flow to mixer by appropriate adjustment of CV-3.

(7) To run flow to separator and bypass steam generator, close V-6 and CV-4, and open SV-4. Maintain desired backpressure with CV-5.

(8) To run flow through the bypass line to the drain, open CV-4, and close SV-4.

(9) To establish flow through the steam generator, close SV-1, SV-3, SV-4, and CV-4, and open SV-2 and V-6. Control backpressure with CV-5.

(10) To terminate the test, isolate the system by closing SV-2 and opening SV-3 and CV-4. Close CV-3 and shut down the boiler.

5-12. AIR/WATER PLENUM TEST DESCRIPTION

A series of air/water tests are planned to investigate the effects of inlet plenum geometry on the inlet two-phase flow distribution at the tube sheet. FLECHT SET phase B test results suggest that a radially nonuniform mixture existed at the tube sheet, but the steam generator instrumentation was not sufficiently detailed to evaluate this effect. Air/water visual bench tests, performed to date with the FLECHT SEASET steam generator inlet plenum, have confirmed that conditions at the tube sheet are nonuniform with the tubes closes to the baffle plate getting the most liquid.

Instrumentation will be added for further air/water tests to include measurements of the air and water flow rates into the plenum and the air and water flow rates into selected individual tubes in the tube bundle. These instrumentated air/water tests will be run on the existing FLECHT plenum, the FLECHT plenum with an internal spray nozzle, and a hemispherical plenum that has the general shape of a typical pressurized water reactor steam generator plenum. The objective of these plenum tests is to measure the inlet flow distribution and to define the difference in two-phase conditions at the tube sheet between the FLECHT plenum and a hemispherical plenum. The test with the internal spray nozzle in the FLECHT plenum is intended to define the location of the spray nozzle such that mounting the spray nozzle in the plenum results in a uniform distribution to all the tubes. The test results from the FLECHT plenum air/water test will be used to define the inlet liquid distribution at the tube sheet in the steam generator separate effects loop test.

A detailed description of the air/water test is included in appendix C. A summary of the measurements that will be recorded during the air/water test is presented in Table 5-1.

TABLE 5-1

BASIC DATA TO BE OBTAINED FOR THE STEAM GENERATOR SEPARATE EFFECTS TASK TO ACHIEVE DATA REQUIREMENTS FOR PLENUM AIR/WATER BENCH TESTS

Desired Data	Measuring Device	Location
Inlet plenum liquid accumulation	Water manometer	Inlet plenum
Total liquid flow rate	Pressure gage	Liquid supply line upstream of spray nozzle
Total air flow rate	Flow orifice and presssure gage	Air compressor discharge
Liquid flow rate distribution at tube sheet	Calibrated liquid collection beaker and stop watch	Air/water separator downstream of the plenum tube sheet
Air flow rate distribution at tube sheet	Pitot-tube differential pressure	Air/water separator downstream of the plenum tube sheet

SECTION 6
INSTRUMENTATION PLAN

6-1. GENERAL INFORMATION

The bundle and loop instrumentation have been designed to achieve the data requirements discussed in section 3. Designing the required instrumentation for this task was particularly difficult because the steam generator tube bundle was already assembled and in place. The tube bundle was lowered out of the steam generator shell exposing approximately 8.2 metres (27 feet) of its 10.7 metre (35-foot) length. With this portion of the tube bundle exposed, fluid thermocouples could be placed in the desired locations between tubes. One of the principal problems is attaching wall thermocouples to the steam generator tube wall. Because the tubes constitute the primary pressure boundary, no machining or grooving should be performed on the tubes. Bench tests on tube wall thermocouple attachment are being performed to help determine the best attachment method. One particular problem is the attachment of the wall thermocouples on the interior tubes.

Another problem which occurs because machining cannot be done on the tubes is the installation of static pressure taps. Because taps cannot be placed on the tube wall, static pressure tubes will be inserted in the tube from the steam generator lower plenum. These probes are 1.6 millimetres (0.062 inches) in diameter and will only be inserted in the first 1.22 metres (4 feet) of tube. The three pressure probes in a tube represent a flow area reduction of less than 2 percent over the first 1.22 metres of tube length. The static probe measurement is felt to be more complex and less accurate for measuring mass accumulation rates in the steam generator tubes compared with standard static pressure taps. Again, a separate bench test will be conducted using air and water to verify that this measuring technique will yield valid data.

A third instrumentation problem which exists is the measurement of the primary fluid vapor superheat within the tube bundle. As indicated in earlier sections, vapor superheating has been detected along the steam generator tube length in other reflooding tests. The measuring technique which will be used in this experiment consists of using an aspirating steam probe which is inserted in the tube from the lower plenum. These steam probes are 2.4 millimetres (0.094 inches) in diameter and are installed at various elevations within the first and last 4.6 metres (15 feet) of tube. The reduction in the tube flow area due to the steam probes is less than 2 percent when the reduction is averaged over the entire tube length. The steam probes will aspirate less than 3 percent of the total loop mass flow rate. The aspirated steam is condensed, collected, and accounted for in the overall loop mass and energy balances.

If low quality mixtures are introduced into the steam generator tubes, a possibility exists that the steam probe thermocouple could become wet and only read the saturation temperature. This wetting effect is minimized by using small thermocouples and providing a tortuous flow path for the steam. Provision will be made to isolate steam probes that aspirate liquid.

6-2. INSTRUMENTATION DESIGN

Loop instrumentation (figure 6-1) is designed to measure mass and energy transport across the primary side inlet and primary side exit boundaries of the steam generator. Flowmeters in the boiler steamline, accumulator liquid line, and steam separator exhaust line will establish the mass flow rates of steam and liquid in these lines. The separator liquid flow rate is measured by the rate of change of liquid level in the liquid collection tanks. The energy content of the steam and liquid is calculated from measurements of the fluid temperature and pressure at the collection and flow measuring points. The difference between the steam generator primary side inlet quality and the primary side exit quality, for a given constant mass flow, represents the total energy exchange from the secondary to primary side of the steam generator. Any steam generator exit vapor superheat will also have to be considered in the overall energy balance.

Within the tube bundle, the heat transfer process is monitored by thermocouples in the secondary fluid, on the tube wall, and by steam probes inside the tubes. The steam generator bundle instrumentation locations are shown in figures 6-1, 6-2, 6-3, and 6-4. A summary of the bundle instrumentation is also presented in table 6-1. The tube bundle instrumentation is specifically designed to measure a radial variation in heat transfer rate due to expected nonuniform two-phase flow in the inlet plenum. The distribution of secondary fluid and tube wall thermocouples are skewed toward the bottom of the bundle because prior FLECHT SET phase B data shows that most secondary temperature variation occurs below the 0.61 metre elevation (2-foot elevation). The steam probe axial spacing is based on calculations of vapor temperature versus tube length from a model of the two-phase heat transfer process in the tubes. A typical calculation is shown in figure 6-4, and the calculational model is described in appendix B.

The tubes on the inlet side of the tube bundle will be instrumented with differential pressure probes to monitor differential pressure over the zero to 1.2 metre (4-foot) elevation. The differential pressure transducers have a range of zero to 6.9 kPa (zero to 1 psi), which is

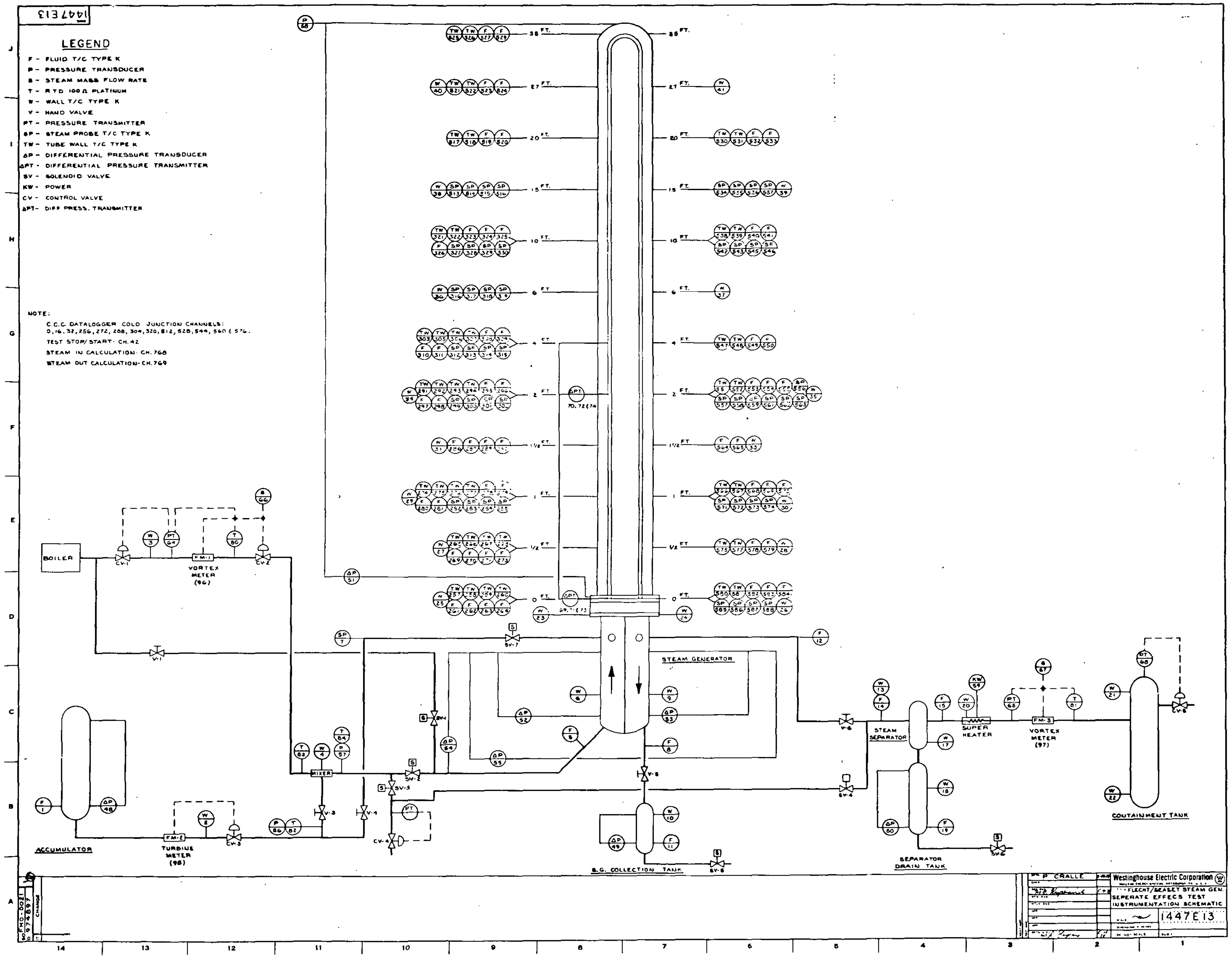


Figure 6-1. FLECHT SEASET Steam Generator Separate Effects Test Instrument Schematic Diagram

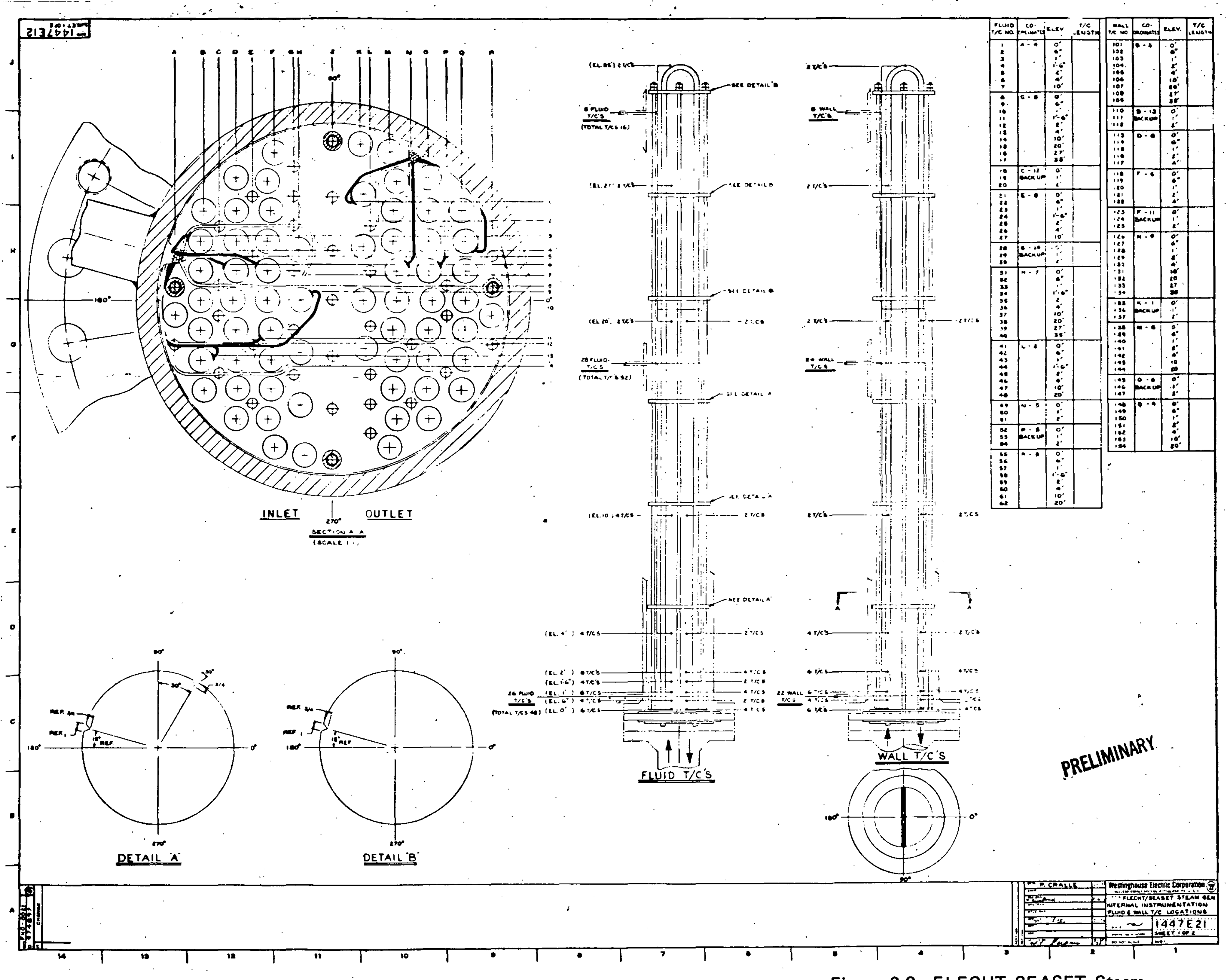


Figure 6-2. FLECHT SEASET Steam Generator Separate Effects Test Instrumentation Locations (Sheet 1 of 2)

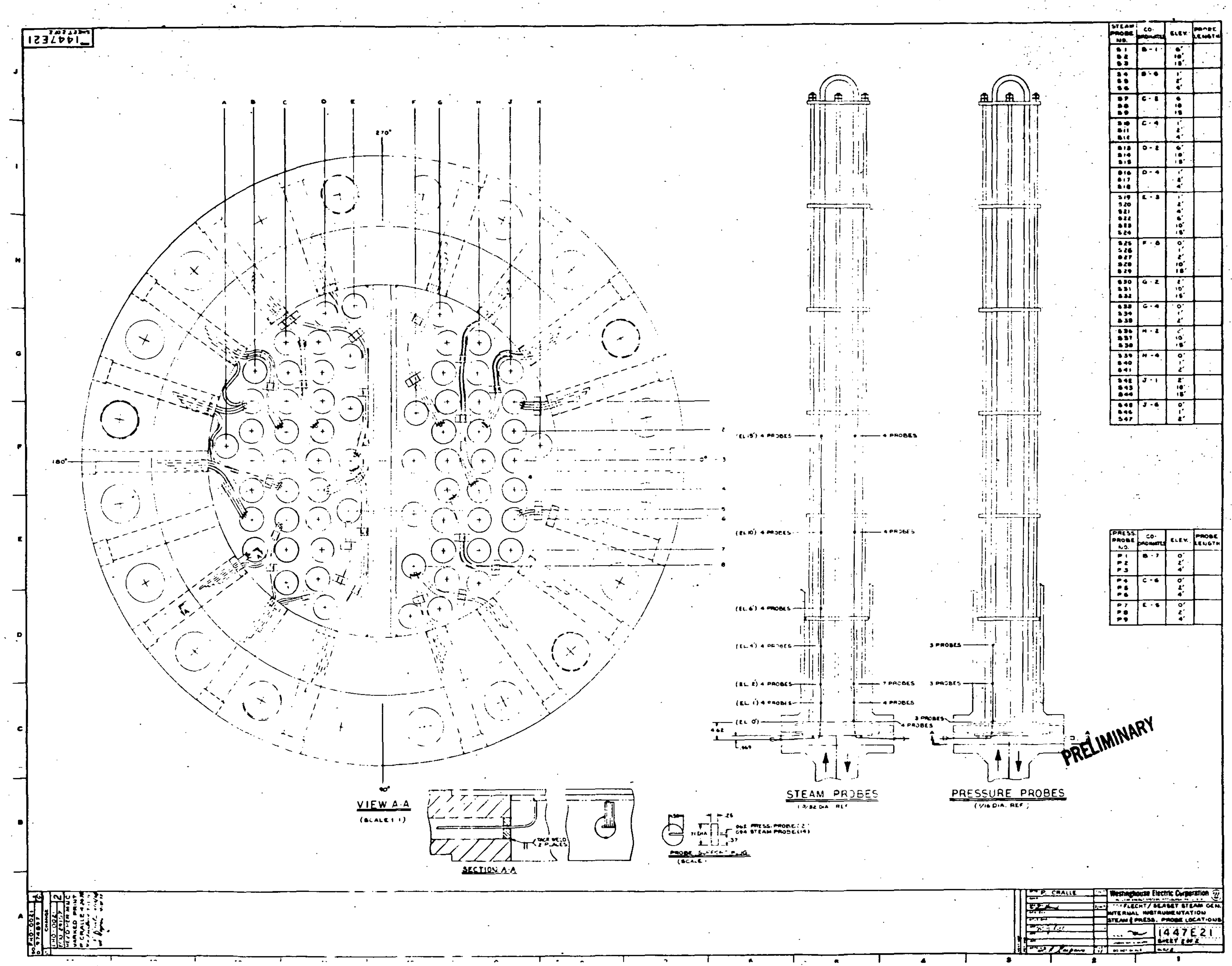
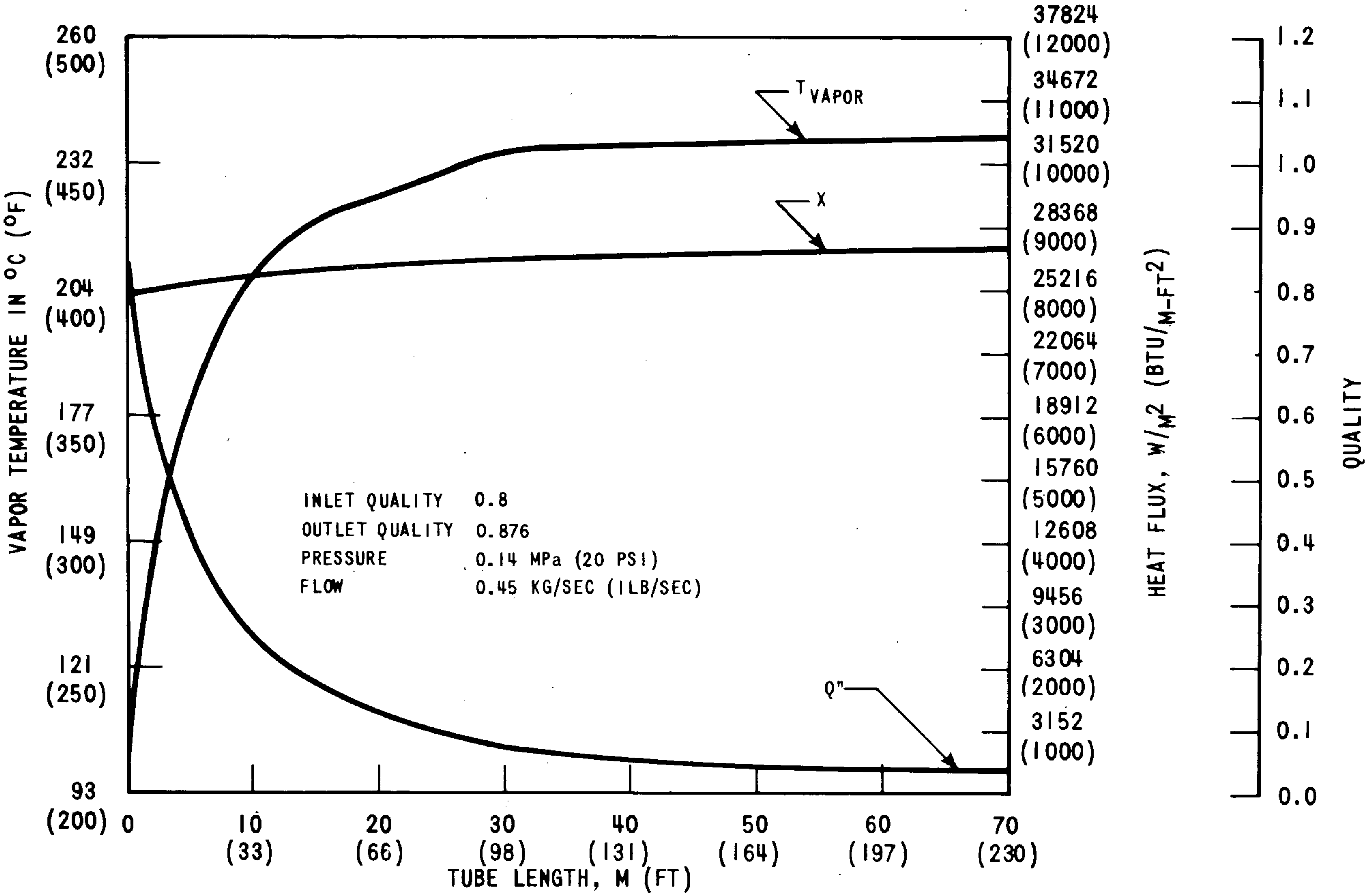


Figure 6-3. FLECHT SEASET Steam Generator Separate Effects Test Instrumentation Locations (Sheet 2 of 2)



13,020-7

Figure 6-4. Primary Side Tube Steam Temperature, Quality, and Heat Flux Versus Tube Length

TABLE 6-1

AXIAL DISTRIBUTION OF TUBE WALL, FLUID, AND STEAM PROBE THERMOCOUPLES

Elevation	Steam Generator Inlet					Steam Generator Outlet				
Meters	Tube Wall T/C[a]		Fluid T/C		Steam Probe	Tube Wall		Fluid		Steam Probe
(Feet)	Primary	Backup	Primary	Backup	Primary	Primary	Backup	Primary	Backup	Primary
0	4	2	4	2	—	2	2	3	1	4
0.153 (0.5)	4	—	4	—	—	2	—	2	—	—
0.305 (1)	4	2	4	2	4	2	2	3	1	4
0.458 (1.5)	—	—	4	—	—	—	—	2	—	—
0.610 (2)	4	2	4	2	4	2	2	3	1	7
1.220 (4)	4	—	4	—	4	2	—	2	—	—
1.830 (6)	—	—	—	—	4	—	—	—	—	—
3.050 (10)	2	—	4	—	4	2	—	2	—	4
4.575 (15)	—	—	—	—	4	—	—	—	—	4
6.100 (20)	2	—	2	—	—	2	—	2	—	—
8.235 (27)	2	—	2	—	—	—	—	—	—	—
10.675 (35)	2	—	2	—	—	—	—	—	—	—
Total T/Cs	28	6	34	6	24	14	6	19	3	23
Total tube wall + fluid = 116; total steam probe T/Cs = 47										

much larger than the calculated frictional or hydrostatic differential pressure within the tubes assuming uniform conditions at the tube entrance. However, a larger than expected differential pressure could develop in the tube entrance if significant mass accumulation occurs in a tube. The purpose of the differential pressure probes is to detect this mass accumulation if it occurs.

6-3. DATA ACQUISITION, CONTROL, AND PROCESSING SYSTEM

Data acquisition, control, and processing is described in paragraphs 6-4 and 6-5.

6-4. Data Acquisition and Control

The data acquisition instrumentation has been designed to meet the data requirements specified in section 3. The control instrumentation has been designed so that the facility can function to supply the parameters specified in the test matrix, and so that the facility operator will be able to monitor critical parameters during the test. The data acquisition system gives no operator indication of any data during a test; all data goes to the digital magnetic tape unit for recording. All operator indications during a test come from strip chart recorders. The data acquisition system monitors facility heatup by recording heatup data on a 21-column line printer.

The steam supply is controlled by valves CV-1 and CV-2.[1] CV-1 provides a constant pressure supply thus eliminating the effects of fluctuations in boiler pressure on steam flow. The pressure transmitter (Ch 64) is used for controlling CV-1. CV-2 controls the steam mass flow rate which is specified by the test matrix. The output of the flow computing electronics is recorded on Ch 66, used to control CV-1, and is recorded on the strip chart for operator indication. The steam mass flow is calculated from pressure transmitter (Ch 64), vortex meter (Ch 96), and resistance temperature detector (RTD) measurements (Ch 80). These three measurements are recorded by the data acquisition system separately which also computes steam mass flow rate using preprogrammed steam tables. These same three measurements are used by the steam mass flow computing electronics which control CV-1. A redundant steam mass flow calculation is made so the facility operator can monitor steam mass flow and so a control signal can be generated for CV-1.

The steam pressure (Ch 65) and temperature (Ch 81) are used to determine density and superheat from steam tables. The steam volumetric flow rate will be measured by a vortex meter (Ch 97). A vortex meter was chosen because it has the reliability of an orifice meter, the accuracy of a turbine meter, and flow computing electronics for control and operator indication. The vortex meter measures volumetric flow rate by sensing the vortexes shed by an obstruction in the steam flow. The output frequency of the vortex meter is reliable and

1. Figure 6-1 shows all instrument locations.

accurately proportional to volumetric flow over a specific range of steam velocities. The minimum velocity is defined by the following equation:

$$\rho V^3 = 500$$

where

ρ = steam density (lb/ft^3)

V = steam velocity (ft/sec)

This minimum velocity corresponds to the minimum momentum that the steam flow needs to shed vortexes reliably. The maximum velocity is 45.7 metres/second (150 feet/second), above which the vortex meter does not sense any change in flow. The steam mass flow range for any steam condition can be computed from maximum and minimum steam velocities using steam density and pipe cross-sectional area. The steam mass flow computing electronics (Ch 798) used for control also totalizes mass flow to aid in facility mass balance calculations.

The steam pipe wall temperature (Ch 3) is recorded to monitor facility heatup and to calculate steam pipe heat losses.

The accumulator and water injection system is used to measure and control the water flow spray mixing with the steam. The water level (Ch 48) measures mass flow for mass balance and gives the operator a level indication on a strip chart. The accumulator water temperature (Ch 1), injection line water temperature (Ch 82), and pressure (Ch 56) are recorded to determine the temperature and subcooling of the injection water.

The injection line wall temperature (Ch 2) is measured to monitor facility heatup and to help determine injection line heat loss. The water flow will be measured by a turbine meter and will be recorded directly by the data acquisition system (Ch 98). The output of the turbine meter electronics will be used to control valve CV-3 and give operator indication on the strip chart. The spray will go either into the hot leg mixer or the steam generator inlet lower plenum. The water flow will also be totalized for facility mass balance calculations.

The steam-water mixer is located upstream of the hot leg bypass. The steam temperature (Ch 83) just upstream of the mixer is recorded to determine steam superheat and steamline heat losses. Piping wall temperature (Ch 4) is also recorded to monitor heatup and to measure pipe heat losses. Mixture pressure (Ch 57) and temperature (Ch 84) are recorded and, by comparing these mixture parameters with steam and water properties, the mixture properties can be computed. Pressure is recorded on the strip chart for operator indication and for qualitative data on mixture pressure stability.

The steam generator bypass line is vented to atmosphere by CV-4. A pressure transmitter is located upstream of CV-4 to monitor system pressure while the steam-water mixture flow is established.

The hot leg and steam generator plenum are instrumented by differential pressure transducers to measure mass storage in the hot leg (Ch 54), plenum inlet (Ch 52), and plenum outlet (Ch 53). Overall steam generator tube pressure drop is measured by a differential pressure transducer (Ch 55). Inlet plenum fluid (Ch 5) and steam (Ch 7) temperatures are measured to determine the water temperature and steam temperature of the two-phase mixture just before it enters the tubes. The outlet plenum fluid temperature detector (Ch 8) is installed to measure the temperature of the fluid separated in the outlet plenum. Plenum inlet and outlet wall temperatures (Ch 6 and Ch 9), respectively) are recorded to monitor heatup and to help determine heat transfer from the two-phase mixture to the plenum walls.

The steam generator tubes are instrumented on both the inlet and outlet sides to determine heat transfer. The steam generator is instrumented to determine mass storage in the tubes. Steam probes are installed inside several tubes at different elevations on both the inlet and outlet side of the tube bundle. These probes will measure the primary side steam temperature at these elevations and locations to determine the heat transfer to the steam as it travels through the tube. The primary pressure is sensed at the zero meter, 0.61 metre (2-foot), and 1.22-metre (4 foot) elevation on three inlet tubes. Differential pressure transducers will be used to measure the pressure drop between these elevations to determine mass accumulation in the inlet tubes.

The secondary side of the steam generator will be instrumented at locations corresponding to primary side steam probes and at additional locations. The secondary side instrumentation is designed to measure tube wall and fluid temperatures. The tube wall temperatures will be measured by thermocouples silver-soldered to the wall. The tube wall measurements will aid in calculating heat transfer through the tubes. The secondary fluid measurements will also be used to measure the overall secondary side heat release.

Steam generator vessel outside wall and flange temperature will be recorded at elevations corresponding to some of the primary and secondary instrumentation. These temperatures are measured to monitor heatup and to measure secondary side heat release. Steam generator secondary side level is measured by a differential pressure transducer (Ch 51) and is used to determine the mass of the secondary side fluid. The level is also recorded on a strip chart recorder for operator indication. The secondary side pressure is measured by a pressure transducer (Ch 58) to determine the secondary side fluid conditions.

Plenum outlet and separator drain tanks are similarly instrumented. They both have a differential pressure transducer (Ch 49 and Ch 50, respectively) for fluid level. The plenum outlet and separator drain tank fluid level signals will be displayed on a strip chart recorder to assist the operator in controlling the test. This level measurement provides mass storage rates and is also used for mass balance. The fluid temperatures (Ch 10 and Ch 19, respectively) are recorded on the data acquisition system and are also used to monitor heatup. The drain tank wall temperatures (Ch 10 and Ch 18) are recorded to monitor heatup and to determine any heat transfer to the collected water.

The exhaust line from the plenum to the separator is instrumented to measure the fluid (Ch 14) and wall (Ch 13) temperatures. The fluid measurement is for steam temperature before the separator and the wall temperature is for heatup and pipe heat losses. The separator wall temperature (Ch 17) is used for heatup and heat losses.

The superheater downstream of the separator is designed to evaporate any liquid that leaves the separator before it goes through the exhaust vortex meter. The wall (Ch 20) and fluid (Ch 15) temperature of the superheater are recorded to monitor heatup, to measure pipe losses, and to measure steam superheat. The power delivered to the superheater will be measured by a watt transducer and recorded (Ch 59) on the strip chart recorder. Power input will be used to compute the system energy balance by measuring the energy added to the exhaust steam before it is measured by a vortex meter. A continuous recording on a strip chart is required because the temperature controller for the superheater will cycle the amount of power it supplies. The 5-second sampling rate of the data acquisition system is not fast enough to record the total power input to the superheater.

The exhaust steam mass flow rate will be measured by a pressure transmitter (Ch 65), vortex meter (Ch 97), and RTD (Ch 81) the same way the inlet steam mass flow rate is measured. The data acquisition system computes steam mass flow rate from pressure, volumetric flow rate, and temperature using the same equations as are used for steam supply. The vortex meter electronics also compute a steam mass flow rate (Ch 769) and totalizes exhaust steam mass flow rate. The vortex meter steam mass flow rate is recorded on the strip chart for operator indication.

The containment tank wall temperatures (Ch 22) are recorded to monitor loop heatup. The containment pressure (Ch 68) is recorded on the data acquisition system to verify test matrix conditions and is recorded on the strip chart for operator indication as well as providing qualitative data on facility pressure stability. The containment pressure is also used to control CV-5 which exhausts to atmosphere. The expected accuracy of the instrumentation described above is specified in table 6-2.

TABLE 6-2

TYPICAL EXPECTED ACCURACY OF INSTRUMENTATION TO BE USED FOR THE STEAM GENERATOR TASK[a,b]

Instrument	Sensor Accuracy	Signal Conditioning	Readout
Type K thermocouple	± 1.1°C zero to 294°C (± 2°F zero to 530°F)	NA[c]	± 0.72°C (± 1.3°F)
10052 platinum RTD	± 0.69°C (± 1.25°F)	NA	Linear ± 0.44°C (± 0.8°F) Repeat ± 0.22°C (± 0.4°F)
Pressure transducer	± 0.75% FS[d]	± 0.5% FS	± 0.05% FS
Pressure transmitter	± 0.25% FS	± 0.5% FS	± 0.15% FS
Flow transmitter	± 0.75% FS	± 0.5% FS	± 0.15% FS
Flowmeters			
Turbine meter	± 0.25% FS	NA	± 0.2% FS
Vortex meter	± 0.25% FS	NA	± 0.2% FS

a. The values listed are estimates and will be calculated from calibration data.

b. Instrument error components will be totalled in the data report.

c. NA indicates no conditioning hardware in the data path.

d. FS is the full scale reading of the device which will yield constant error values depending on the range of the device.

Photographic techniques will be used to identify the two-phase flow regime in the steam generator inlet and outlet plenum. Attempts will be made to obtain droplet size and velocity information from high speed movies and still photographs. The length of the movies will be determined by what data is required. First droplet information will require a relatively slow film speed 15.25 mps (50 fps) and should run for the entire test. Droplet velocity will be taken for short periods of time (typically 1 second) at very high film speeds 610 mps (2000 fps). The droplet velocity will be estimated by following a drop through several frames, measuring the distance it travels, and determining the time for this travel from film speed. It should be recognized that this data is difficult to obtain with precision in this type of a complex test. More approximate estimates of droplet size, velocity, and the different flow regimes will probably be sufficient to interpret the steam generator tube bundle data.

6-5. Data Processing Systems

The first stage of the data processing sequence is the data acquisition system. The hardware is a microprocessor-based data logger which can either record on 21-column paper or digital magnetic tape. The paper readout feature is used to monitor loop heatup, and the digital magnetic tape recorder stores data during a test. Data are recorded in engineering units from either standard conversion tables for thermocouples and RTDs or from preprogrammed calibration files for pressure and flow. Input signals from the loop sensors are conditioned so that the input to the A/D converter is a zero to 1 volt signal. These input conditioning cards are specialized for different types of sensors. Three A/D converters will be used simultaneously to get a system scan rate of 45 channels per second. With 212 channels, the data acquisition system will be able to scan each channel every 5 seconds. This scan rate is acceptable for the slow transient response expected in this task. This slow scan rate makes the strip chart recordings of system pressures and flows important for assuring process stability. The strip chart recorders are used for operator indication of loop operation during the test and for recording the cycling of the power to the immersion heater described in paragraph 5-11.

After each test, the digital magnetic tape will be processed on the existing FLECHT computer data acquisition system (a Digital Equipment Corporation PDP 11/20). A data correction for RTDs will be calculated to compensate for individual sensor deviations from a standard calibration value for each RTD will be used to adjust the recorded values. A printout of all the data will be made so that test director can evaluate the reliability of the data. A subroutine of the PDP 11/20 will compile specific data points so the test director can determine if the test met the requirements of the test matrix for a valid test. Finally, the PDP 11/20 will produce a data tape for the test which will transfer the data to the CDC 7600 analysis computer.

6-6. PROPOSED DATA VALIDATION METHODS

Data validation begins with instrumentation performance reliability. All the data collection instrumentation is periodically calibrated to assure the accuracy of the data. Gross equipment malfunctions will be checked as part of the operating procedure of each test. A pretest data recording of each channel will be taken and compared with expected values. Any discrepancies will be addressed before the test is run. If the discrepancy cannot readily be resolved, an assessment of the ability to make a valid test run without the defective channel will be made. Then, either the test will be run noting the defective channel, or testing will cease until the situation is corrected. The data printout of the PDP 11/20 computer will be used to qualitatively monitor the performance of the facility and instrumentation. Any anomalous behavior will be assessed and appropriate action will be taken either by functional checks or by calibrations to assure proper equipment operation.

Another criterion for the data validation is that test conditions must satisfy the test matrix. The data from each test will be evaluated to determine if the test meets the test matrix requirements. During the shakedown test program, the test operator's ability to control loop parameters will be established, and tolerances on control parameters will be defined consistent with this limit.

If excessive instrumentation failure occurs during the testing, and it becomes apparent that the original program objectives can not be met, the alternatives will be examined, and a decision will be made to do additional testing or to repair of the facility.

The following instrumentation will be considered the minimum desired for a valid test:

- Turbine flowmeter at the exit of the accumulator; two vortex meters at the boiler exit and at the superheater exit
- 5 differential pressure transducers located at the accumulator, the exit to the boiler, the exit of the mixer, the steam generator secondary shell side and the containment tank
- 5 fluid thermocouples located at the steam generator inlet plenum, the steam generator outlet plenum, at the superheater, at the accumulator exit, and at the boiler exit
- Pressure transducers at the steam generator inlet, across the tube bundle, and at both liquid collection tanks
- A minimum of 5 shell wall thermocouples, one each at the lower flange and the zero, 0.15 metre (0.5-foot) 0.30-metre (1-foot), 0.46 metre (1.5-foot), and 0.61-metre (2.0-foot) elevations.

- The following instrumentation in the steam generator tube bundle is required to be in operation:

  (1) A total of 17 steam probes should be available. On the inlet side, 4 probes will be at the 0.30-metre (1-foot) elevation, 4 probes will be at the 0.61-metre (2-foot) elevation, and 1 probe will be at each of the 1.2-metre (4-foot), 1.8-metre (6-foot), 3.0 metre (10-foot), and 4.6-metre (15-foot) elevations. On the outlet side, 1 probe will be at each of the zero, 0.30-metre (1-foot), 0.61 metre (2-foot), 3.0-metre (10-foot), and 4.6-metre (15-foot) elevations.

  (2) A total of 20 secondary side fluid thermocouples is needed. On the inlet side, 2 thermocouples will be located at each of these elevations: zero, 0.15 metre (0.5 foot), 0.30 metre (1 foot), 0.46 metre (1.5 feet), and 0.61 metre (2 feet). One thermocouple will be located at each of these elevations: 3.0 metres (10 feet) and 10.7 metres (35 feet). On the outlet side, 1 thermocouple will be located at each of these elevations: zero, 0.15 metre (0.5 foot), 0.30 metre (1 foot), 0.46 metre (1.5 feet), 0.61 metre (2 feet), 1.2 metres (4 feet), and 3.0 metres (10 feet).

  (3) A total of 18 wall thermocouples will be located on the tube walls. On the inlet side, 2 thermocouples will be located at each of these elevations: zero, 0.15 metre (0.5 foot), 0.30 metre (1 foot), and 0.61 metre (2 feet). One thermocouple will be located at each of these elevations: 1.2 metres (4 feet), 3.0 metres (10 feet), 6.1 metres (20 feet), and 10.7 metres (35 feet). On the outlet side, 1 thermocouple will be located at each of these elevations: zero, 0.15 metre (0.5 foot), 0.30 metre (1 foot), 0.61 metre (2 feet), 1.2 metres (4 feet), 3.0 metres (10 feet), and 6.1 metres (20 feet).

The above list of minimum instrumentation is based on a judgement of the minimum data required to fulfill the task objectives. Actual test data may indicate that a lesser subset of the instrumentation is needed to fulfill the task objectives. An absolute minimum subset of instrumentation required to achieve the task objective would include the steam and liquid mass flow rates and temperatures at the steam generator inlet and exit and secondary fluid temperature and level.

For each test conducted, a Run Specification and Validation Sheet is completed. This sheet specifies initial test conditions and validation requirements for each test. This table also provides space for comments on run conditions, causes for terminating and invalidating a run, instrument failures, preliminary selected thermocouple data, and the weight of water drained from collection tanks and the test section.

After the instrumentation checks out satisfactorily and the test is run, the data are transferred to the PDP 11/20 and printed out in engineering units. These test data are then examined to see if the system behaved as expected. Abnormal behavior of a data channel is investigated to determine if it is due to equipment malfunction or a physical phenomena. These procedures, along with periodic equipment calibration, are designed to assure that the data being recorded are accurate and reliable.

Once instrumentation reliability is determined, the actual test conditions are compared with the parameters specified by the test matrix to determine if the test run satisfies the test matrix. The facility conditions of mixture inlet quality and mass flow rate are calculated from the data to determine if the run conditions were within specification. The initial system pressure and temperature will also be compared with specific values. The instrumentation transient responses will be compared with their expected system behavior to determine if there are any data channel problems, system control problems, or deficiencies in the facility hardware. Conversion of the data to engineering units on the PDP 11/20 computer allows preliminary test validation to be done upon completion of running the test before the data analysis takes place. This preliminary validation provides for timely feedback on facility operation and data collecting equipment performance.

After the instrumentation is functionally checked and the test parameters and performance compared with the test matrix, the final data validation is performed during data reduction and analysis. In the process of data reduction and analysis, system mass and energy balance will be computed. These calculations determine if the data are within specified accuracy or whether the instrumentation is adequate for analyzing what is occurring in the system. The initial conditions of the test should be within the limits specified in table 6-3 prior to conducting a matrix test.

6-7 INSTRUMENTATION BENCH TESTS

As indicated at the beginning of this section, two bench tests are planned to demonstrate the adequacy of the tube bundle wall thermocouples and the primary side tube inlet region differential pressure taps. The two bench tests are illustrated in figures 6-5 and 6-6. The purpose of the bench tests is to verify the adequacy of the instrumentation concepts for measuring tube wall temperature and pressure drop. The results from the instrumentation bench tests will be reported in the steam generator separate effects test data report. An evaluation of the instrument error will also be included in the data report.

In the tube wall thermocouple bench test, several thermocouple mounting concepts are tested. They vary from a purely mechanical spring-loaded mounting concept to a typical sheathed-thermocouple mounted perpendicular to the tube wall to a pad type thermocouple

TABLE 6-3

STEAM GENERATOR TASK
VALIDATION CRITERIA

INITIAL TEMPERATURE	
Supply steam	±5.55°C (±10°F)
Injection water	±2.8°C (±5°F) plus maximum and minimum deviation from initial value during the test (±2.8°C)
Steam generator secondary side by elevation	±5.5°C (±10°F)
Lower plenum	±5.5°C (±10°F)
Plenum drain tank	±5.5°C (±10°F)
Steam separator	±5.5°C (±10°F)
Separator drain tank	±5.5°C (±10°F)
Superheater	±27.8°C (±50°F)
Containment tank	±5.5°C (±10°F)
Exhaust steam	±5.5°C (±10°F) plus minimum value for the test (5.5°C)
INITIAL LEVEL	
Steam generator secondary side	±5%
INITIAL PRESSURE	
Containment tank	±5% plus maximum and minimum deviation from initial value during the test
AVERAGE MASS FLOW RATE	
Steam supply	±10% } plus maximum and minimum deviation from initial value during the test
Water	±5% } plus maximum and minimum deviation from initial value during the test

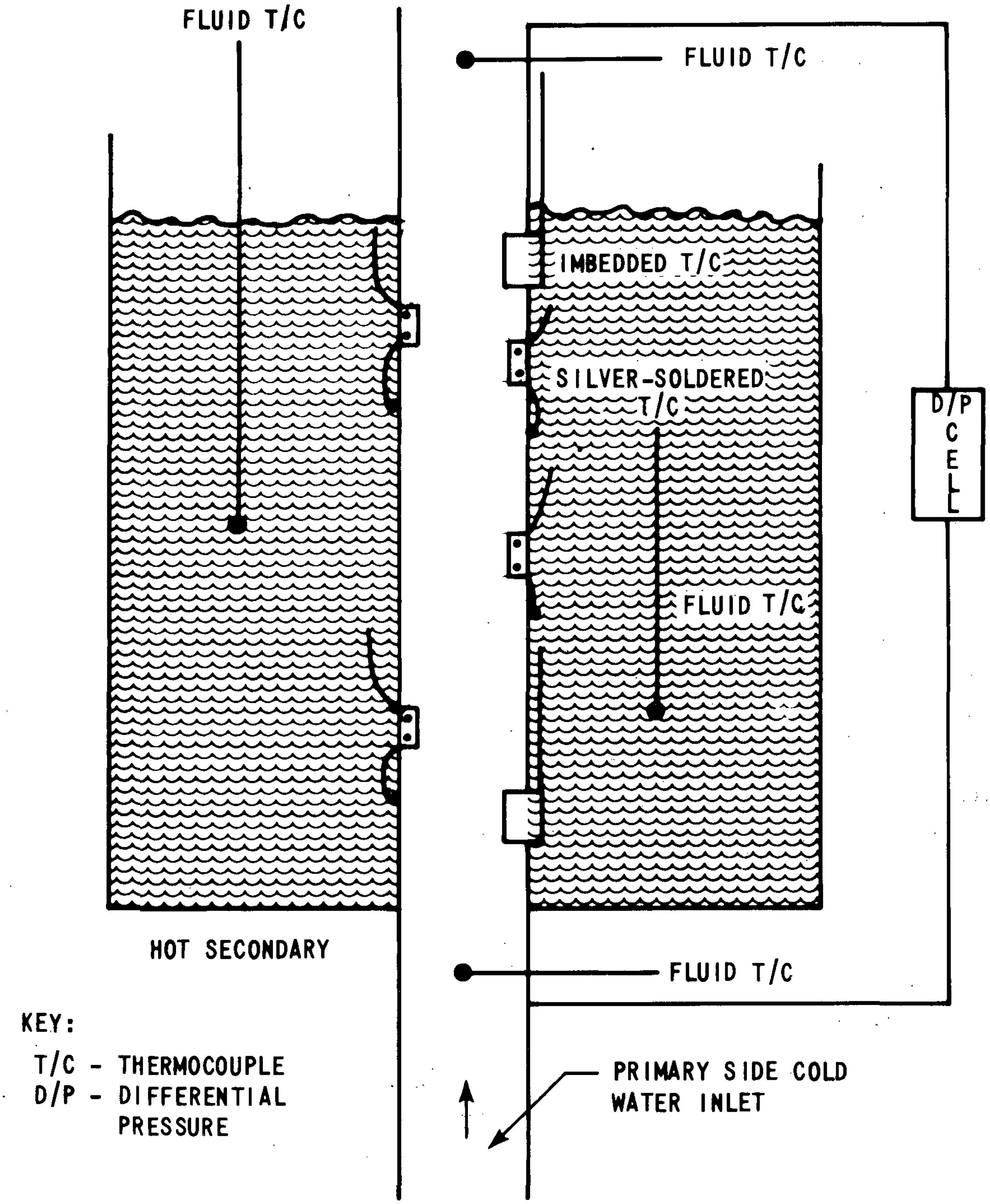


Figure 6-5. Schematic Diagram of the Thermocouple Bench Test

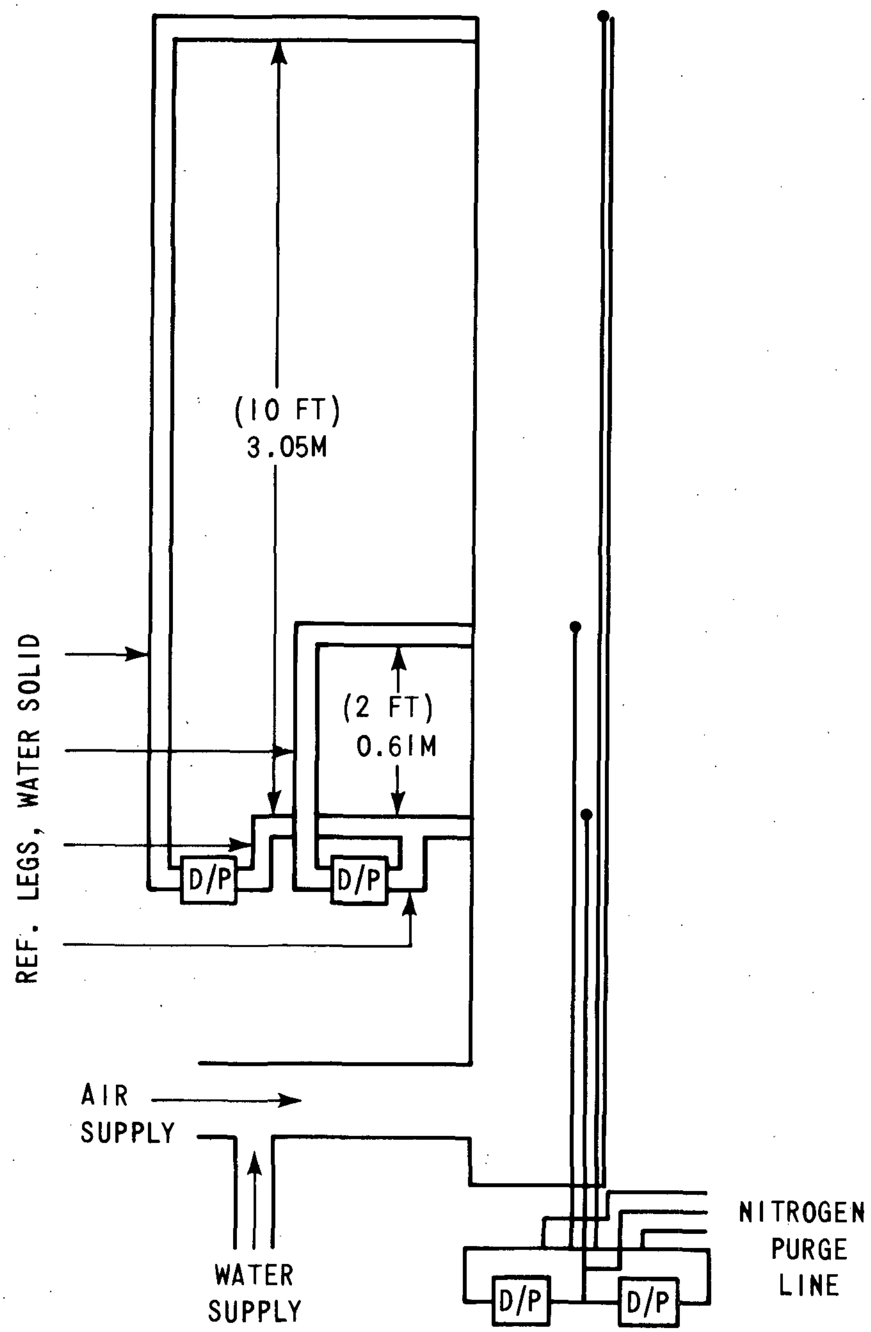


Figure 6-6. FLECHT SEASET Steam Generator Tube Pressure Probe Bench Test With Transparent Tube

tack-welded to the tube wall. These thermocouples are mounted to a short section of Inconel tube. Two thermocouples imbedded in the tube wall serve as references. A heat flux is imposed on the tube by passing cold water [10°C (50°F)] through the tube while it is immersed in a hot water bath [approximately 82°C (180°F)]. After steady-state conditions are reached, thermocouple output is recorded.

In addition to the thermocouple bench test, a TAP-A model of a section of the steam generator tube was developed. TAP-A is a general three-dimensional heat conduction code which will accept arbitrary boundary conditions.[1] The model simulated a pad-type thermocouple by taking four adjacent interior nodes and assigning a conduction coefficient of 1 percent of normal conduction to these nodes. The objective is to model a gap in the contact region between the pad and the tube wall. A second model simulated the thermocouple mounted perpendicular to the tube wall with the thermocouple sheath acting as a cooling fin. The results of these calculations indicate that both thermocouple configurations should produce reasonably small errors in determining tube wall temperature because of the thermocouple. The results of these calculations are summarized in table 6-4.

The objective of the differential pressure probe bench test is to demonstrate that such a probe inside the tube will function properly in a two-phase flow environment. In this test, the two-phase flow will be simulated with air and water. The simulated steam generator tube will be transparent to allow visual observation of the flow regime inside the tube. The concern is that the static tubes inside the two-phase mixture could collect liquid and would then give an erroneous reading.

A reference set of pressure taps will also be installed on the tube wall and will be connected to two differential pressure transducer cells. These reference differential pressure transducers will have a water solid external reference leg. The reference differential pressure will be compared to differential pressure readings from the cells with sensing lines inside the tube. The internal differential pressure cell will not use a water solid reference leg, but will use a nitrogen purge to ensure that the sensing lines are not water logged.

The nitrogen purge gas will exhaust into three steam generator tubes and mix in with the two-phase steam water flow to account for this gas. The mass flow rate of the purge gas will be measured or calculated. The purge flow rate will be throttled to minimize the amount of nitrogen that mixes with the steam phase and, in one of the replicate test runs, the purge flow will be isolated to show that the bundle heat transfer is not influenced by the nitrogen purge gas.

1. "TAP-A, A Program for Computing Transient or Steady-State Temperature Distributions," WANL-TME-1872, December 1969.

TABLE 6-4

TAP-A RESULTS OF TUBE WALL THERMOCOUPLE ERROR DUE TO GEOMETRY

TAP-A BOUNDARY CONDITIONS	
Assumed secondary side temperature	260°C (500°F)
Assumed secondary side film coefficient	568° $W/m^2/°C$ (100 $Btu/hr/ft^2/°F$)
Assumed primary side temperature	109°C (228°F)
Assumed primary side film coefficient	56.8° $W/m^2/°C$ (10 $Btu/hr/ft^2/°F$)
TAP-A RESULTS, PAD TYPE THERMOCOUPLE	
Overall heat flux	7881 W/m^2 (2500 $Btu/hr/ft^2$)
Tube wall temperature drop	0.4°C (0.8°F)
Tube wall surface temperature (sec)	246°C (474.2°F)
Tube wall temperature at pad thermocouple	247°C (476.2°F)
Thermocouple error	1°C (2°F)
TAP-A RESULTS, THERMOCOUPLE PERPENDICULAR TO WALL	
Overall heat flux	7881 W/m^2 (2500 $Btu/hr/ft^2$)
Tube wall temperature drop	0.4°C (0.8°F)
Tube wall surface temperature (sec)	246°C (474.2°F)
Tube wall surface temperature at thermocouple	245.6°C (473.5°F)
Thermocouple error	0.4°C (0.7°F)

SECTION 7
TEST MATRIX

7-1 BACKGROUND

The testing portion of this task can be broken down into facility and instrumentation shake-down testing and testing to achieve the data requirements given in section 3. Performance of the shakedown testing will verify that both the facility and instrumentation function as desired and that these tests will indicate the expected tolerances which can be obtained during the test matrix runs.

7-2. SHAKEDOWN TESTS

Two types of shakedown tests will be performed on the test facility. They include tests to help interpret the test matrix experiments and shakedown tests to verify that the instrumentation and test facility performs as desired.

Shakedown tests to verify the instrumentation performance and instrumentation hookup are currently being developed. Shakedown tests which will examine the facility performance are given in table 7-1. In tests 1 to 3, given in table 7-1, the steam generator will be isolated and bypassed, and the mixer effluent will be separated by the loop steam separator. These shakedown tests will establish mixer characteristics and will demonstrate the precision to which the test matrix parameters can be controlled. The demonstrated tolerances on the control parameters will be used in the test matrix to define the allowable tolerances on parameters in a valid run.

Shakedown tests have been identified which will help interpret the test matrix experiments. Interpretation of the test matrix experiments which have a two-phase flow inlet mixture entering the tubes will be complex because of the several heat transfer mechanisms which are present. To simplify the heat transfer process on the primary side and to allow easier interpretation of the secondary side heat transfer, two single-phase flow tests will be run during the shakedown period. These two tests will measure the heat transfer with single-phase steam and then single-phase liquid on the primary side of the tubes. In these two shakedown runs, the parameters are chosen to bracket the heat transfer rates expected during the test.

TABLE 7-1
SHAKEDOWN TEST MATRIX FOR STEAM GENERATOR SEPARATE EFFECTS TESTS

Run No.	Run Description	Flow Rate	Primary Pressure	Primary Temp	Secondary Temp	Secondary Level
1	Reference run 80% quality	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	149°C (300°F)	– –	– –
2	Reference run 50% quality	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	140°C (300°F)	– –	– –
3	Reference run 20% quality	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	149°C (300°F)	– –	– –
4	Single-phase steam	0.45 kg/sec (1.0 lb/sec)	0.28 MPa (40 psia)	149°C (300°F)	260°C (500°F)	100%
5	Single-phase liquid	0.45 kg/sec (1.0 lb/sec) (8 gpm)	0.28 MPa (40 psia)	10°C (50°F)	121°C (250°F)	100%

These two shakedown tests should also help indicate how to model the secondary side heat transfer process to accurately predict the local heat flux and local conditions on the primary side of the tube.

The single-phase steam shakedown run will have the lower heat transfer rate, and the heat flux should be localized at the tube bundle inlet. The single-phase liquid shakedown run will have a much higher heat transfer rate and could result in more distributed secondary to primary heat transfer. Conducting these tests should make interpretation of the two-phase flow primary side inlet tests easier.

7-3. TASK TEST MATRIX

Two types of tests are currently planned for the task test matrix with a provision for a third type of test. The two types of tests which are proposed consist of tests with the steam-water mixer located in the hog leg and tests with the spray nozzle located in the steam generator lower plenum. The tests with the spray nozzle located in the lower plenum are designed to provide for nearly uniform inlet two-phase flow and quality. Tests with a uniform inlet boundary condition are expected to maximize the steam generator's secondary side heat release because all tubes will have a two-phase mixture. Tests with the steam-water mixer located in the hot leg will yield the type of steam generator heat release which will be typical of the FLECHT SEASET systems effects tests.

Existing air/water visual tests indicate that the two-phase flow at the steam generator tube sheet is nonuniform with more water guided along the steam generator divider plate. These tests will be more difficult to analyze, and it is expected that the individual steam generator tube heat flux values will differ.

The steam generator bundle instrumentation is capable of detecting a radial variation in the bundle heat transfer. A maximum of four radial locations have been selected on both the inlet and outlet sections of the tube bundle to detect radial variation in the bundle heat transfer.

The third type of test depends on the results of the air/water tests which were described in paragraph 5-12. If sufficient differences exist between the tube sheet inlet two-phase flow distributions with the hemispherical inlet plenum and the FLECHT SET phase B plenum, additional tests will be conducted (if sufficient funding is available) using the spray nozzle in the lower plenum, such that the resulting two-phase flow at the tube sheet is similar to the hemispherical inlet plenum distribution.

The proposed test matrix for the steam generator separate effects test is shown in table 7-2. The first eight runs in the test matrix represent one reference run and seven single parameter variation runs where the test parameters are at their reference parameter values or are within the range of parameter variations specified in section 4. In the ninth run, the total flow will be increased and the quality will be reduced to approximate the postcore quench period of the reflood transient. Runs 10 and 11 are replicates of run 1.

Runs 12, 13, 14 and 15 will repeat the reference run and the single parameter perturbation runs for quality and mass flow rates with the spray nozzle in the inlet plenum. The inlet plenum nozzle spray tests should minimize any nonuniformity in the distribution of liquid to the tube bundle. Tests with uniform tube bundle inlet flow parameters will ensure that the heat transfer mechanisms in the bundle will be nearly one-dimensional, and therefore, easier to evaluate than tests with both radial and axial variation in the heat transfer.

TABLE 7-2

TEST MATRIX FOR STEAM GENERATOR SEPARATE EFFECTS TEST[a]

Run No.	Run Description	Flow Rate	Primary Pressure	Quality	Secondary Temp	Secondary Level
1	Reference run	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.80	274°C (525°F)	100%
2	Flow sensitivity	0.45 kg/sec (1.0 lb/sec)	0.28 MPa (40 psia)	0.80	274°C (525°F)	100%
3	Pressure sensitivity	0.23 kg/sec (0.5 lb/sec)	0.14 MPa (20 psia)	0.80	274°C (525°F)	100%
4	Pressure sensitivity	0.23 kg/sec (0.5 lb/sec)	0.41 MPa (60 psia)	0.80	274°C (525°F)	100%
5	Quality sensitivity	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.50	274°C (525°F)	100%
6	Quality sensitivity	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.20	274°C (525°F)	100%
7	Secondary temperature sensitivity	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.80	204°C (400°F)	100%
8	Secondary level sensitivity	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.80	274°C (525°F)	25%
9	Post bundle quench	0.45 kg/sec (1.0 lb/sec)	0.28 MPa (40 psia)	0.10	274°C (525°F)	100%
10	Replication of reference run	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.80	274°C (525°F)	100%
11	Replication of reference run	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.80	274°C (525°F)	100%

a. Tests will be run for a 2-month testing period only unless the Program Management Group determines that additional tests are required.

TABLE 7-2 (cont)

TEST MATRIX FOR STEAM GENERATOR SEPARATE EFFECTS TEST[a]

Run No.	Run Description	Flow Rate	Primary Pressure	Quality	Secondary Temp	Secondary Level
12[b]	Reference run	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.80	274°C (525°F)	100%
13[b]	Flow sensitivity	0.45 kg/sec (1.0 lb/sec)	0.28 MPa (40 psia)	0.80	274°C (525°F)	100%
14[b]	Quality sensitivity	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.50	274°C (525°F)	100%
15[b]	Quality sensitivity	0.23 kg/sec (0.5 lb/sec)	0.28 MPa (40 psia)	0.20	274°C (525°F)	100%
16 to 19	Possible additional runs using the spray nozzle to model the linearly-scaled inlet flow distribution at conditions which are the same as tests 12 to 15.					

a. Tests will be run for a 2-month testing period only unless the Program Management Group determines that additional tests are required.

b. Runs with a liquid spray nozzle in the steam generator inlet plenum

SECTION 8
DATA REDUCTION, ANALYSIS, AND EVALUATION PLAN

The objective of the steam generator separate effects task is to develop an analytical model of the steam generator which can be used in analyzing the FLECHT SEASET system effects tests to be conducted later in the test program.[1] The test data obtained in the steam generator separate effects tests will help identify the heat transfer mechanisms within the steam generator, from which the heat release from the secondary side to the primary side can be determined for various primary side inlet fluid conditions and secondary side conditions. The analytical model of the steam generator developed from the test data can subsequently be used to evaluate the system effects on core reflooding. The steam generator separate effects test facility and instrumentation, as described previously in sections 5 and 6, can be referred to for test initialization and operation.

To develop a steam generator model, the data from the separate effects tests will be reduced and evaluated to determine exactly how and where heat transfer takes place. Heat release to the primary side is the energy transmitted from the secondary side fluid and steam generator shell metal. The measurement of the two-phase flow inlet and outlet conditions on the primary side, and the measurement of temperature of fluid, wall, and steam on both the primary side and secondary side as functions of axial and radial position will permit the calculation of the secondary side energy release and the primary side energy increase.

The energy release of the secondary side and subsequent transfer to the tube wall will be evaluated using three methods. The first method consists of using an integral approach in which the energy release of the secondary side is assumed to be proportional to the time rate of change of average secondary side fluid and metal temperature. By calculating average secondary side fluid temperature and metal temperature from the available test data, the total heat release from the secondary side can be calculated as the product of the heat capacity and time rate of change of the average secondary side temperature. This is expressed by the following equation:

$$\dot{q}_{secondary} = \rho_{avg}\, C_p\, V_{fluid} \frac{d\bar{T}_{fluid}}{dt} + \rho_{avg}\, C_p\, V_{metal} \frac{d\bar{T}_{metal}}{dt} \qquad (8\text{-}1)$$

1. Conway, C. E., et al., "PWR FLECHT Separate Effects and System Effects Test (SEASET) Program Plan," NRC/EPRI Westinghouse Report No. 1, December 1977.

where

$$\dot{q}_{secondary} = \text{total rate of heat loss by secondary fluid and metal (Watts)}$$

$$\rho C_p = \text{heat capacity (W/sec/m}^3\text{/}^\circ\text{C)}$$

$$V = \text{volume (m}^3\text{)}$$

$$d\overline{T}/dt = \text{rate of decrease of secondary fluid or metal temperature (}^\circ\text{C/sec)}$$

This first method for calculating the secondary side energy release includes the inherent assumption that the entire steam generator secondary side behaves similarly and that the heat transfer to the tube wall is uniformly distributed across the tube length. This method will not be accurate when there are significant spatial and temporal differences in the secondary side temperature measurements. However, a simple check on the total secondary side energy release can be made by comparison with overall mass and energy balance on the primary side using known inlet and outlet conditions,

$$\dot{q}_{primary} = \dot{q}_{out} - \dot{q}_{in} + \dot{q}_{stored} \tag{8-2}$$

where

$$\dot{q}_{out} = (\dot{M}_{steam}\ C_p T_{steam} + \dot{M}_{liquid}\ C_p T_{liquid})_{out}$$

$$\dot{q}_{in} = (\dot{M}_{steam}\ C_p T_{steam} + \dot{M}_{liquid}\ C_p T_{liquid})_{in}$$

$$\dot{q}_{stored} = C_p T_{sat} \frac{d}{dt} (M_{tube\ bundle})$$

$$\dot{M}_{steam} = \text{mass flow rate of steam (kg/sec)}$$

$$\dot{M}_{liquid} = \text{mass flow rate of liquid (kg/sec)}$$

$$T_{steam} = \text{temperature of steam (}^\circ\text{C)}$$

$$T_{liquid} = \text{temperature of liquid (}^\circ\text{C)}$$

$$M_{tube\ bundle} = \text{mass of liquid accumulated in tube bundle (kg)}$$

The second method for evaluating the secondary side energy release consists of a discrete approach. This method accounts for spatial and/or temporal differences in the measured secondary side temperatures by calculating the heat release of the secondary side on a local basis. It is assumed that a representative volume of fluid, V_{cell}, can be associated with each secondary side thermocouple, T_{cell}. The energy release from each representative fluid cell or node can be subsequently calculated as the product of the cell density, heat capacity, cell volume, and time rate of change of the cell fluid temperature. This is shown in equation (8-3).

$$\dot{q}_{cell} = \rho_{cell}\, C_p\, V_{cell} \frac{dT_{cell}}{dt} \tag{8-3}$$

The steam generator shell metal heat release for each cell can also be calculated in this manner. This method for calculating the secondary side energy release includes the assumption that the internal resistance of the fluid is negligible and that the temperature measured by the cell thermocouple is representative of an average cell temperature. For cells having insignificant temporal changes in the measured secondary side fluid temperature and, where only the fluid in direct contact with the tube wall is transferring energy, the above method as described is inaccurate for determining the heat transfer to the tube.

The third method for evaluating the secondary side energy release accounts for the fluid resistance effects on a local basis. The local heat flow to the tube can be determined by utilizing the local secondary side fluid temperature and the local tube wall temperature measurements, such that

$$\dot{q}''_{secondary/wall} = \frac{1}{R} (T_{\substack{secondary\\fluid}} - T_{wall}) \tag{8-4}$$

where

$\dot{q}''_{secondary/wall}$ = tube wall heat flux (W/m^2)

T = secondary fluid or tube wall temperature (°C)

The thermal resistance, R, can be determined through available calculational techniques assuming the dominant heat transfer mechanism to be either pure conduction through the fluid and/or natural convection between the fluid and the wall. Thus, the heat flow from the secondary side to the tube can be determined for each cell. The total heat transfer to the tube can be calculated by integrating the heat flow for each cell over the total length of the primary side, such that

$$\dot{q}_{total} = \int_0^L n\pi D\, \dot{q}''_{secondary/wall}(z)\, dz \tag{8-5}$$

where

n = number of tubes

πD = tube circumference (metres)

L = tube length (metres)

z = distance from the tube inlet

This total heat transfer to the wall can be subsequently compared with overall mass and energy balance previously calculated for the primary side in equation (8-2).

Tests in the steam generator separate effects task will initially be conducted with single-phase steam flow through the primary side. These tests will significantly aid in identifying the heat transfer mechanism on the secondary side. The heat flow from the tube wall to the steam within the tube can be readily calculated knowing the measured wall and steam temperatures by

$$\dot{q}_{wall/vapor\text{-}1\phi} = h_{wall/vapor\text{-}1\phi}\, A\, (T_{wall} - T_{vapor}) \tag{8-6}$$

where

A = tube wall heat transfer area

The film coefficient, $h_{wall/vapor\text{-}1\phi}$ can be calculated knowing the steam velocity and using an available correlation for forced convection to single-phase steam flow.[1] This measured heat flow can subsequently be used to identify the heat flow from the secondary side to the tube wall, by

$$\dot{q}_{wall/vapor\text{-}1\phi} = \dot{q}_{secondary/wall\text{-}1\phi} \tag{8-7}$$

The measured heat flow from the secondary side to the tube wall, $q_{secondary/wall\text{-}1\phi}$ can now be used to identify which of the three methods previously described provides the most accurate method for determining secondary side energy release. It is postulated that various regions of the steam generator secondary will behave differently, and that some combination of the three methods will be used to develop the secondary side model. For those regions or individual fluid cells where the heat transfer mechanisms need be identified (because the lumped mass models of the first and second method do not accurately predict the heat flow), the local measurements of the secondary side fluid temperature and tube wall temperature can be used as follows:

$$\dot{q}_{secondary/wall\text{-}1\phi} = \frac{A}{R_{1\phi}}\,(T_{secondary} - T_{wall}) \tag{8-8}$$

1. This evaluation of the local heat flow neglects the tube wall temperature drop because the temperature difference between the inner and outer tube wall is approximately 1.8°C (1°F) for the heat flux expected.

then

$$R_{1\phi} = \frac{(T_{secondary} - T_{wall})A}{\dot{q}_{secondary/wall-1\phi}} \quad (8\text{-}9)$$

The thermal resistance, $R_{1\phi}$, can be subsequently compared with previously calculated values for conduction and natural convection to determine the dominant heat transfer mechanism on the secondary side for that particular fluid cell. The heat flow to the tube wall can be compared with axial increase in energy of the steam on the primary side as follows:

$$n\pi D \int_0^L \dot{q}''_{secondary\ wall}(z)\, dz = (\dot{M}_{steam}\ Cp\ T_{steam})_{out} - (\dot{M}_{steam}\ Cp\ T_{steam})_{in} \quad (8\text{-}10)$$

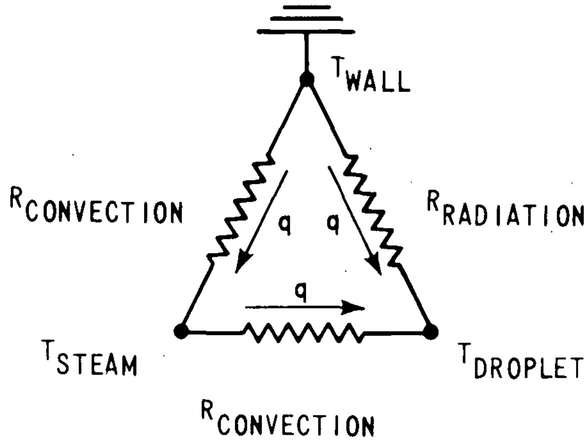
The heat transfer mechanism between the tube wall and the fluid within the tube will be evaluated by using measurements of primary side inlet and outlet flow conditions and wall and steam temperature as a function of axial and radial position. The steam temperature will be measured by means of the aspirating steam probes located in various tubes at different elevations. The steam probes will be inserted into the inlet and outlet of selected tubes at three elevations per tube. The design of the steam probe to be used in these tests is described in section 6.

The two-phase flow inlet conditions will be known by using the results from a series of air/water tests described in paragraph 5-12 and appendix C. The air/water tests will be conducted to determine the radial flow distribution into the steam generator tubes for the FLECHT SET inlet plenum, a hemispherical inlet plenum, and a spray nozzle used to distribute the two-phase flow uniformly across the tube inlet.

In the tests conducted with the two-phase flow through the primary side, the fluid within the tubes will consist of a mixture of water droplets and steam. The steam will increase in temperature, and in turn, give up some of its energy in evaporating droplets while traversing the tube bundle. The heat transfer mechanism from the wall to the steam and droplets within the tube is initially postulated to be the following:

- Convective heat transfer between the wall and the steam where either the water droplets wet the tube wall or film boiling occurs
- Convective heat transfer between the steam and the water droplets
- Radiation heat transfer between the tube wall and the water droplets

The heat transfer mechanisms as described above are analogous to an electrical resistance network shown here and are intended only to be an initial model which can be modified to incorporate other flow regimes and heat transfer mechanisms.



The heat flow to the droplets from the tube wall and the steam cannot be independently determined. The radiation heat transfer from the tube wall to the droplet can be estimated from the available calculational techniques, from the measured wall temperature, and from assuming the temperature of the droplet to be saturation temperature. Current scoping calculations performed using the technique detailed in appendix B have pointed out that the radiation heat transfer is negligible for high primary side inlet qualities; however, its contribution becomes more significant as the inlet quality decreases. The radiation heat transfer will be considered in the modeling of the primary side heat transfer until available data or analysis confirms that it is negligible.

The heat transfer from the steam to the droplet can be estimated from an available film coefficient correlation using measured wall and steam temperatures, estimating a droplet diameter from movies taken of the inlet and outlet flow in the respective steam generator plenums, and calculating droplet velocity from a force balance on the drop. The calculated heat flow to the droplet would subsequently be

$$\dot{q}_{\substack{\text{droplet}\\\text{calculated}}} = \dot{q}_{\text{wall/droplet}} + \dot{q}_{\text{steam/droplet}} \tag{8-11}$$

The heat flow to the tube wall from the secondary side can now be determined in the two-phase flow tests having previously identified the calculational method to be used for each region or individual fluid cell on the secondary side from the single-phase steam flow tests. The application of the methods determined in the single-phase steam flow tests is justified in the two-phase flow tests as long as the flow conditions on the secondary side is approximately the same for both tests.

For those secondary side regions or cells in which the lumped mass method is applicable, the heat flow to the tube wall can be determined by using the measured secondary side fluid temperature transient such that

$$\dot{q}_{wall\text{-}2\phi} = \rho\ CpV\ \frac{dT_{secondary}}{dt} \tag{8-12}$$

For those secondary side cells in which the lumped mass method is not applicable and the fluid internal resistance governs the heat flow, the heat flow to the tube wall can be determined by using the measured secondary side fluid and wall temperature and the thermal resistance as determined in the single-phase steam flow tests by

$$\dot{q}_{wall\text{-}2\phi} = \frac{A}{R_{1\phi}}\ (T_{secondary} - T_{wall}) \tag{8-13}$$

Therefore, knowing the wall heat flow as a function of elevation, the steam temperature as a function of elevation, the inlet conditions, and having an estimate of the radiation heat transfer, the steam mass flowrate as a function of elevation, $\dot{m}_{steam}$ (z) can be calculated by the following energy balance:

axial energy increase of steam phase	=	energy transferred directly to steam phase plus droplet evaporation

$$\dot{E}_{steam}\ (z) - \dot{E}_{steam\ in} = n\pi D \int_0^z (\dot{q}''_{wall/steam} - \dot{q}''_{steam\ drops})\ dz$$
$$+\ n\pi D \int_0^z (\dot{q}''_{steam/drops} + \dot{q}''_{wall/drops}) \left(\frac{hg}{h_{fg}}\right) dz \tag{8-14}$$

where

$\dot{E}_{steam} = \dot{M}_{steam}\ (z) \cdot h_{steam}\ (z)$ (Watts)

$h_{steam}\ (z) = F\ [T_{steam}\ (z),\ \text{pressure}]$ (W-sec/kg)

z = linear distance from tube inlet

$\dot{q}''_{wall\text{-}steam}$ = tube wall heat flux minus wall to drop heat flux (W/m^2)

After solving equation (8-14) for $\dot{M}_{steam}$ (z), the local quality can be determined by

$$\chi(z) = \frac{\dot{M}_{steam}(z)}{\dot{M}_{total}} \tag{8-15}$$

The local steam velocity can also be calculated by

$$V_{steam}(z) = \frac{\dot{M}_{steam}(z)}{\rho_{steam} A_{steam}} \tag{8-16}$$

where

$$A_{steam} \approx A_{total}$$

The void fraction, α, is approximately equal to 1 for a high quality mixture or can be calculated using available relationships between quality and void fraction.

A local convective heat transfer coefficient can be calculated from available correlations using the estimated quality or steam velocity and the measured wall and steam temperatures because

$$h_{wall/steam\text{-}2\phi} = f(T_{wall}, T_{steam}, \chi \text{ or } V_{steam})$$

The local heat flow from the tube wall to the steam within the tube can thus be calculated as

$$q_{wall/steam\text{-}2\phi} = h_{wall/steam\text{-}2\phi} A(T_{wall} - T_{steam}) \tag{8-17}$$

The assumption inherent in using the above convective film coefficient as to whether the liquid droplets wet the tube surface, or whether a vapor film insulates the tube surface, can now be verified by an energy balance

$$\begin{aligned} \int_0^z \dot{q}''_{wall/steam\text{-}2\phi}(z)\, n\pi D_{tube}\, dz = {} & \dot{E}_{steam}(z) - \dot{E}_{steam\,in} \\ & - n\pi D \int_0^z \dot{q}''_{wall/drops}(z)\left(\frac{hg}{h_{fg}}\right) dz \\ & - n\pi D \int_0^z \dot{q}''_{steam/drops}(z)\left(\frac{h_f}{h_{fg}}\right) dz \end{aligned} \tag{8-18}$$

Heat flow to the droplets from the wall and the steam as previously calculated can now be verified by computing the difference between the heat flow into the tube wall from the secondary side and the heat flow into the steam from the wall such that

$$\dot{q}_{droplet} = \dot{q}_{wall\text{-}2\phi} - \dot{q}_{wall/steam\text{-}2\phi} + \dot{q}_{steam/drops} \tag{8-19}$$

By comparing the measured droplet heat flow with the heat flow calculated previously in equation (8-11), the calculational techniques employed for the radiation heat transfer between the wall and the droplet and the convective heat transfer between the steam and the droplet can be appropriately modified if necessary. The amount of droplet evaporation as a function of tube length can be estimated knowing the heat flow to the droplets by

$$\dot{M}_{droplet\ evaporation}(z) = \frac{\dot{q}_{droplet}(z)}{h_{fg}} \tag{8-20}$$

A mass balance of the steam using the inlet flow conditions and droplet evaporation rate can provide an estimate of the steam flow as a function of length by

$$\dot{M}_{steam}(z) = \int_0^z \dot{M}_{droplet\ evaporation}(z)\, dz + \dot{M}_{steam\ in} \tag{8-21}$$

This steam mass flow rate can subsequently be compared with that calculated previously by equation (8-14) to close the loop. The calculated steam flow at the exit can also be compared with the measured steam flow at the exit.

SECTION 9
TASK SCHEDULE

Table 9-1 is a list of the major milestones for this task and figure 9-1 presents a more detailed task schedule. The critical items are the main loop steam piping, boilerhouse house fabrication, and the data acquisition system and associated software.

Based on the contract report review and publish cycle (consisting of 30 days for PMG review, 30 days for comment resolution, and 45 days for Westinghouse to publish reports) and the schedule presented in table 9-1, the final data report will be published by June 1, 1979 and the final data analysis and evaluation report will be published by September 15, 1979.

TABLE 9-1

FLECHT SEASET STEAM GENERATOR SEPARATE EFFECTS TASK MAJOR MILESTONES (TASK 3.2.6)

Milestone Number	Milestone	Months After Contract Start Date (7/1/77)	Calendar Date
E 1	Initiate test planning and facility design	3	10/1/77 Complete
E 2	Issue draft task plan for review	8	3/1/78 Complete
E 3	Complete facility construction and initiate shakedown testing	12.6	7/19/78
E 4	Complete testing	16.6	11/20/78
E 5	Complete draft data report	20	2/28/79
E 6	Complete draft data analysis and evaluation report	23	5/31/79

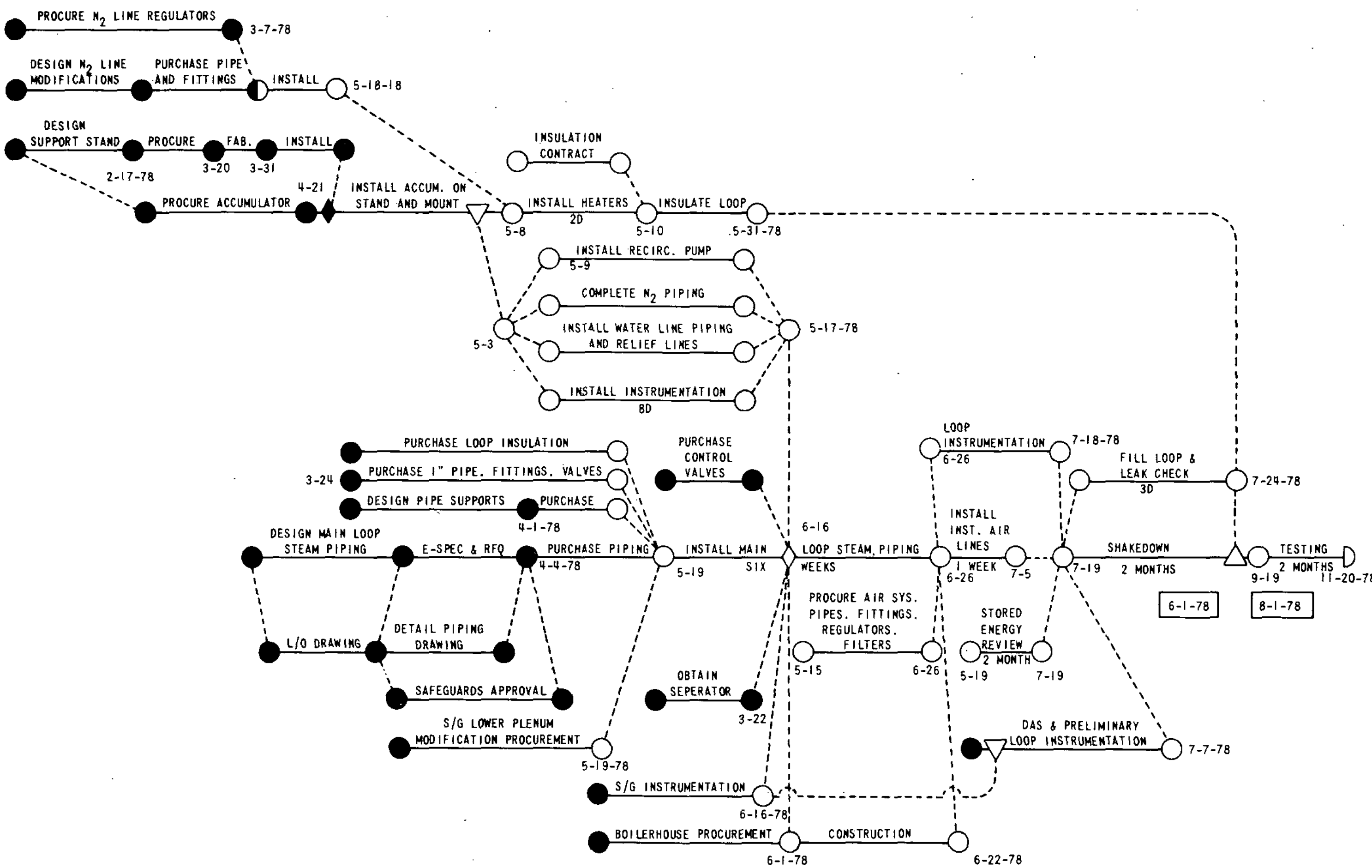


Figure 9-1. FLECHT SEASET Steam Generator Separate Effects Task 3.2.6. Main Path

13,020-6

APPENDIX A
WORK SCOPE FLECHT SEASET STEAM GENERATOR SEPARATE EFFECTS TASK 3.2.6

A-1. OBJECTIVE OF TASK 3.2.6

The objective of Task 3.2.6 is to determine the heat release rate from the larger FLECHT SEASET steam generator for various known inlet fluid conditions and secondary side conditions.

A-2. SCOPE OF WORK

The scope of FLECHT SEASET steam generator separate effects task 3.2.6 is as follows:

- Prepare a task plan.
- Design, procure, and construct a test facility to provide steam-water mixtures to the existing larger FLECHT SET steam generator.
- Procure and install necessary instrumentation to determine heat release rates from the primary and secondary sides of the steam generator.
- Perform system calibration, instrumentation calibration, facility checkout, and facility shakedown tests.
- Perform the agreed upon tests.
- Review and validate data.
- Reduce and analyze the data to obtain steam generator fluid and metal temperature histories for specified inlet flow and quality, steam generator outlet flow and quality, primary fluid vapor temperatures at the steam generator exit, inlet and exit pipe wall temperatures, primary and secondary side system pressures, secondary side initial temperature distribution and fluid level, two-phase level in the steam generator tubes using differential pressure transducers, and inlet plenum and exit plenum flow regimes from photographic studies.
- Process and store transducer data on computer tape.
- Prepare a data report.

- Analyze and evaluate the data to determine the heat release rate of the steam generator for a given range of inlet fluid conditions. Estimate the secondary to primary overall heat transfer coefficients and primary side heat transfer coefficients.
- Provide a FLECHT SEASET steam generator model or correlation for FLECHT SEASET tests.
- Prepare a data analysis and evaluation report.

APPENDIX B
STEAM GENERATOR PRIMARY SIDE HEAT TRANSFER MODEL

A preliminary heat transfer model of the primary side of the steam generator was developed to examine the evaporation of water droplets carried into the primary side tube bundle by the steam flow emanating from the core. This model accounts for the following heat transfer mechanisms within the tube:

- Forced convection between the wall and the steam assuming no wetting of the wall
- Convection between the steam and the droplet
- Radiation between the wall and the droplets

The convective heat transfer from the wall to the steam and from the steam to the droplets utilizes conventional convective film correlations. In the model, a constant tube wall temperature and a droplet temperature as saturation are assumed. For radiation heat transfer from the wall to the droplets, simple black body radiation is assumed. By performing an energy balance on the steam and on the droplets, the variation of the steam temperature and droplet diameter, respectively, were determined as a function of tube length.

Variation of steam temperature over tube length is calculated as follows.

$$\frac{dT_{steam}}{dZ} = \frac{1}{(V_{steam})(C_p M_{steam})}\Bigg[h_{wall}\, A_{wall}\, (T_{wall} - T_{steam}) - (T_{steam} - T_{sat}) \sum_{i=1} n_i\, h_i\, A_i$$

$$+ \frac{C_p \pi}{h_{fg}} \quad (T_{steam} - T_{sat}) \sum_{i=1} n_i D^2_{droplet\ i} \Bigg\{ h_i\, (T_{steam} - T_{sat})$$

$$+ 0.495 \left[\left(\frac{T_{wall} + 460}{1000}\right)^4 - \left(\frac{T_{sat} + 460}{1000}\right)^4\right]\Bigg\}\Bigg]$$

where

i = drops of a given diameter

n_i = number of drops in group i

h_i = heat transfer coefficient of drop group i

A_i = area of drop group i

Variation of droplet diameter over tube length is calculated as follows.

$$\frac{dD_{droplet\ i}}{dZ} = \frac{-2}{(\rho_{droplet\ i})(h_{fg})(V_{steam})} \left\{ h_{wall}\ (T_{steam} - T_{sat}) + 0.495 \left[\left(\frac{T_{wall} + 460}{1000} \right)^4 - \left(\frac{T_{sat} + 460}{1000} \right)^4 \right] \right\}$$

where the convective film coefficients are defined by wall-vapor and vapor-droplet calculations. Wall-vapor is calculated as follows.

$$h_{wall} = \left(\frac{0.023}{3600}\right)\left(\frac{K_v}{D}\right)\left(\frac{D\rho_v Q}{\mu_v A}\right)^{0.8} \left(Pr_v\right)^{0.4}$$

where

Q = volumetric flow

K_v = steam conductivity

Pr_v = steam Prandtl number

A = tube area

μ_v = steam viscosity

ρ_v = steam density

D = tube diameter

Vapor-droplet calculations are as follows:

$$h_i = \frac{K_v}{(3600)(D_{droplet\ i})}\left[2 + 0.55\ (Re_{droplet\ i})^{1/2}\ (Pr_v)^{1/3}\right]$$

By assuming the droplets reach terminal velocity, the droplet Reynold's number can be expressed as:

$$Re_{droplet\ i} = \text{minimum of} \left| (0.292 \frac{D_{droplet\ i}}{\mu_v} (g\rho_v (\rho_f - \rho_v) D_{droplet\ i})^{1/2} \right|^{1.7??}$$

or

$$\left| \left(\frac{4g(\rho_f - \rho_v) D_{droplet\ i}}{3\ \rho_v\ CD_{min}} \right)^{1/2} \left(\frac{\rho_v\ D_{droplet\ i}}{\mu v} \right) \right|$$

where

$D_{droplet\ i}$ = droplet diameter

ρ_f = water density

g = gravitational

CD_{min} = 0.5

A study on the initial droplet size utilizing both a log normal distribution of droplet diameters and a single droplet diameter showed (figure B-1) that the effect on exit quality was fairly insignificant.

In the event that the test data suggest that the above assumptions are inadequate for modeling the steam generator heat transfer, a more sophisticated model which includes variable wall temperatures and heat transfer regimes other than dispensed flow will be developed.

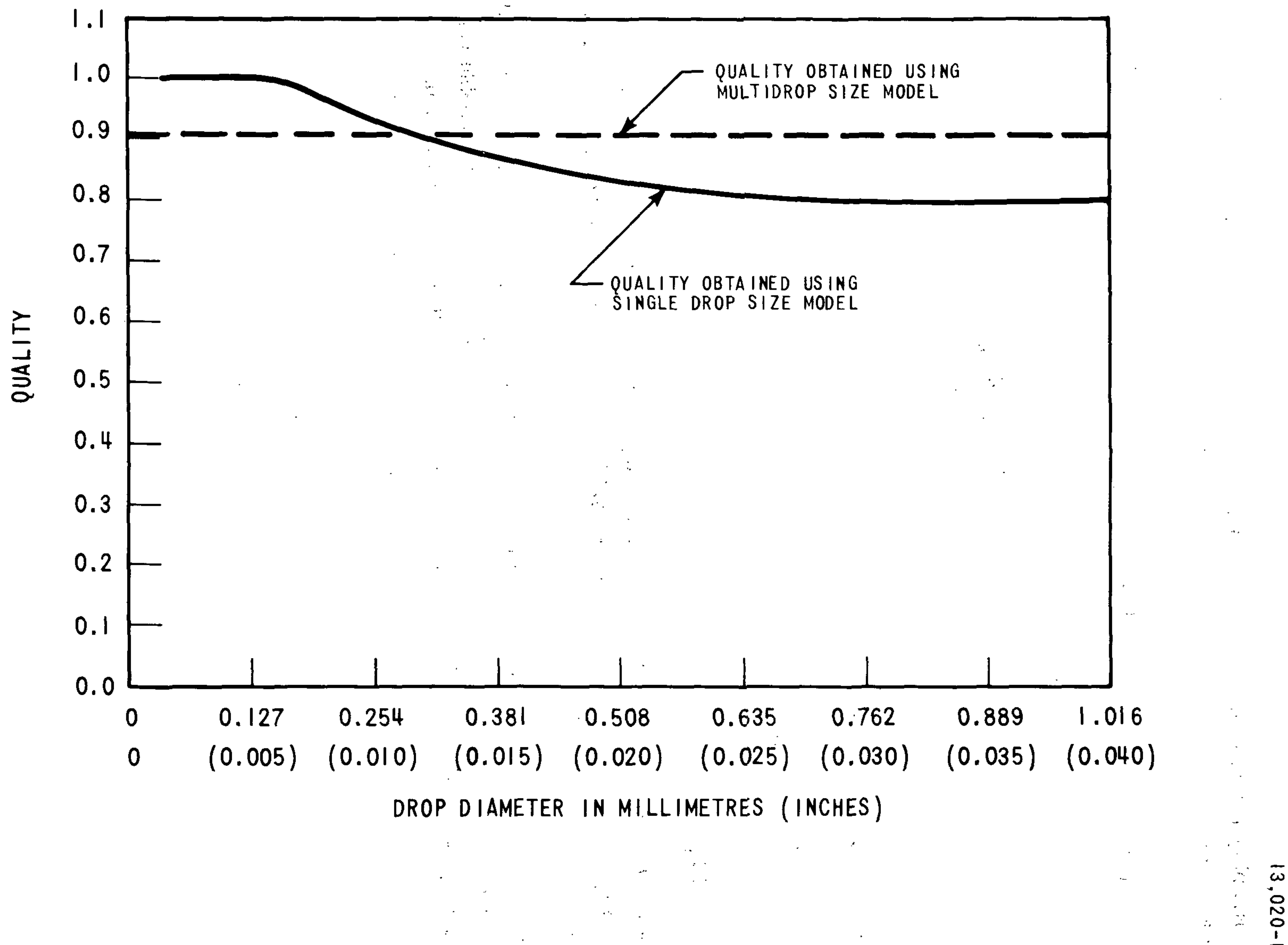


Figure B-1. Exit Quality Versus Drop Diameter

APPENDIX C

STEAM GENERATOR INLET PLENUM AIR/WATER FLOW DISTRIBUTION TEST

C-1. AIR/WATER PLENUM TEST OBJECTIVES

The objectives of the air/water plenum tests, in order of importance are as follows:

(1) Measure the radial variation in the liquid and air volumetric flow rates at the tube sheet of the FLECHT steam generator inlet plenum. The air and liquid volumetric flow rates will simulate steam and liquid volumetric flow rates from the test matrix in the task plan for the steam generator separate effects test.

(2) Measure the radial variation in liquid and air flow rates as specified in number 1 above with the spray nozzle mounted inside the FLECHT inlet plenum. The purpose of the internal spray nozzle is to ensure a uniform liquid distribution at the tube sheet.

(3) Measure the radial variation in liquid and air flow rates as specified in number 1 above using an inlet plenum that is geometrically similar to a typical pressurized water reactor plant steam generator inlet plenum.

(4) Experimentally determine a configuration for the internal nozzle that yields a flow rate distribution at the tubesheet that reproduces the scaled plenum distribution measured in number 3 above.

(5) Measure the single-phase air flow distribution at the tubesheet. This data will be used to verify the individual tube air flow rate measurement technique.

C-2. BACKGROUND

Some preliminary air/water visual tests were run on the FLECHT plenum and these tests indicate that a radially-nonuniform mixture will exist at the tube sheet during testing. Further tests, which are an extension of these earlier tests, will have the additional instrumentation required to measure the liquid and air flow rates in individual holes in the tubesheet.

C-3. TEST INSTRUMENTATION DESIGN

A calculation of the steam generator under reflood conditions, $f(L/D_e)$, shows that the tube, K_{eg}, $[K_{eg} = f(L/D_e)]$ is 24, and the variation in K_{eg} between tubes is less than 2 percent. Using relationships in the *Handbook of Hydraulic Resistance*[1] for orifice resistance, a 3.175-millimeter-thick (0.125-inch-thick) orifice with a 1.07-centimeter (0.421-inch) ID in a tube with a 1.97-centimeter (0.775-inch) ID will have the same hydraulic resistance as the FLECHT tube. Therefore, the simulated tubesheet to be used in the air/water tests should have a short section of tube with an orifice in the end of the tube at each tube hole location. A typical orifice simulating a steam generator tube is shown in Figure C-1.

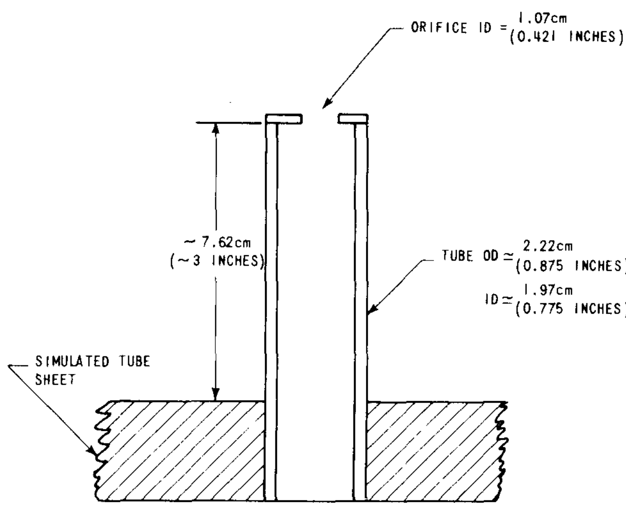


Figure C-1. Orifice Simulation of Steam Generator Tube Friction

During the air/water tests the air and liquid flow rates in the tube shown in figure C-1 will be measured. For this measurement, the orifice tube shown in figure C-1 will be removed, and the instrument shown in figure C-2 will be connected to the tube sheet. With this instrument and a pitot tube, the air/water mixture in a tube can be separated, and the flow rate of each component can be measured. During a test, the instrument will be moved from tube to tube sequentially to get the data necessary to map the flow distribution across the tubesheet. While the individual tube measurements are being made, the air and water flow to the inlet plenum will be held constant. The orifice size on the tube in the calibrated beaker is slightly larger than the orifices in the uninstrumented tubes to compensate for the added resistance of the instrument itself.

1. Idel'chik, I. E., *Handbook of Hydraulic Resistance*, AEC-TR-6630, 1966.

The only instruments needed to measure the individual tube air and liquid mass flow rates are the beaker, which should be approximately 500 cubic centimeters in volume, and the pitot tube, which will be sensing a total pressure of 2.76 kPa (0.4 psi), or 30.5 centimeters (1 foot) of water. A stop watch to measure the time to fill the beaker and a manometer to measure the pitot tube dynamic head will also be needed.

The pitot tube response is dependent on the orientation of the pitot tube relative to the orificed tube. The pitot tube dynamic probe should be approximately 1.27 centimeters (1/2 inch) above the orifice. To ensure that this relative orientation remains unchanged between the data collection from the individual tubes, the pitot tube and calibrated beaker should be attached to the same fixture. Also, during the single-phase test, the air flow distribution can be measured with the pitot tube placed over the orificed tubes in the tubesheet, provided the same relative orientation between orifice and pitot tube is preserved. Ideally, the same fixture could be used in both applications.

C-4. TEST LOOP DESIGN

An overall loop schematic diagram for the air/water test is shown in figure C-2. The control of the liquid flow rate will be accomplished with a throttling valve in the liquid supply line to control the pressure to the spray nozzle. A known nozzle characteristic curve will enable a flow rate determination from the pressure. The water source should be capable of supplying up to 0.00044 m^3/sec (7 gpm) at a pressure of at least 0.6894 MPa (100 psi).

The air flow will be supplied by the large air compressor and will be regulated by throttling to vary the backpressure or by bleeding a measured amount of air from the compressor supply line. The required air flow rates are from 0.0283 (60) to the maximum capacity of the compressor which is 0.1981 m^3/sec (420 cfm). To regulate the air flow to the plenum, a measured amount of air will be bled off the compressor supply line by adjusting valves V-2 and V-3 shown in figure C-2. The orifice flowmeter used in the bleed line is sized at 3.81 centimeters (1 1/2 inches) so that the pressure drop will always be less than or equal to 20.7 kPa (less than or equal to 3 psi). The minimum pressure which will be read on the pressure gage at the orifice will be approximately 4.82 kPa (0.70 psi).

C-5. TEST MATRIX

Tests with unique inlet plenum volumetric steam and liquid flow rates were selected for the air/water test from the test matrix in table 7-2 of this report. The assumption behind the air/water tests is that the fluid conditions at the tubesheet will be duplicated in the air/water test if the volumetric flow rates of the air and water are the same as the volumetric flow rates of steam and water in the loop test. The parameters from these runs are presented in table C-1.

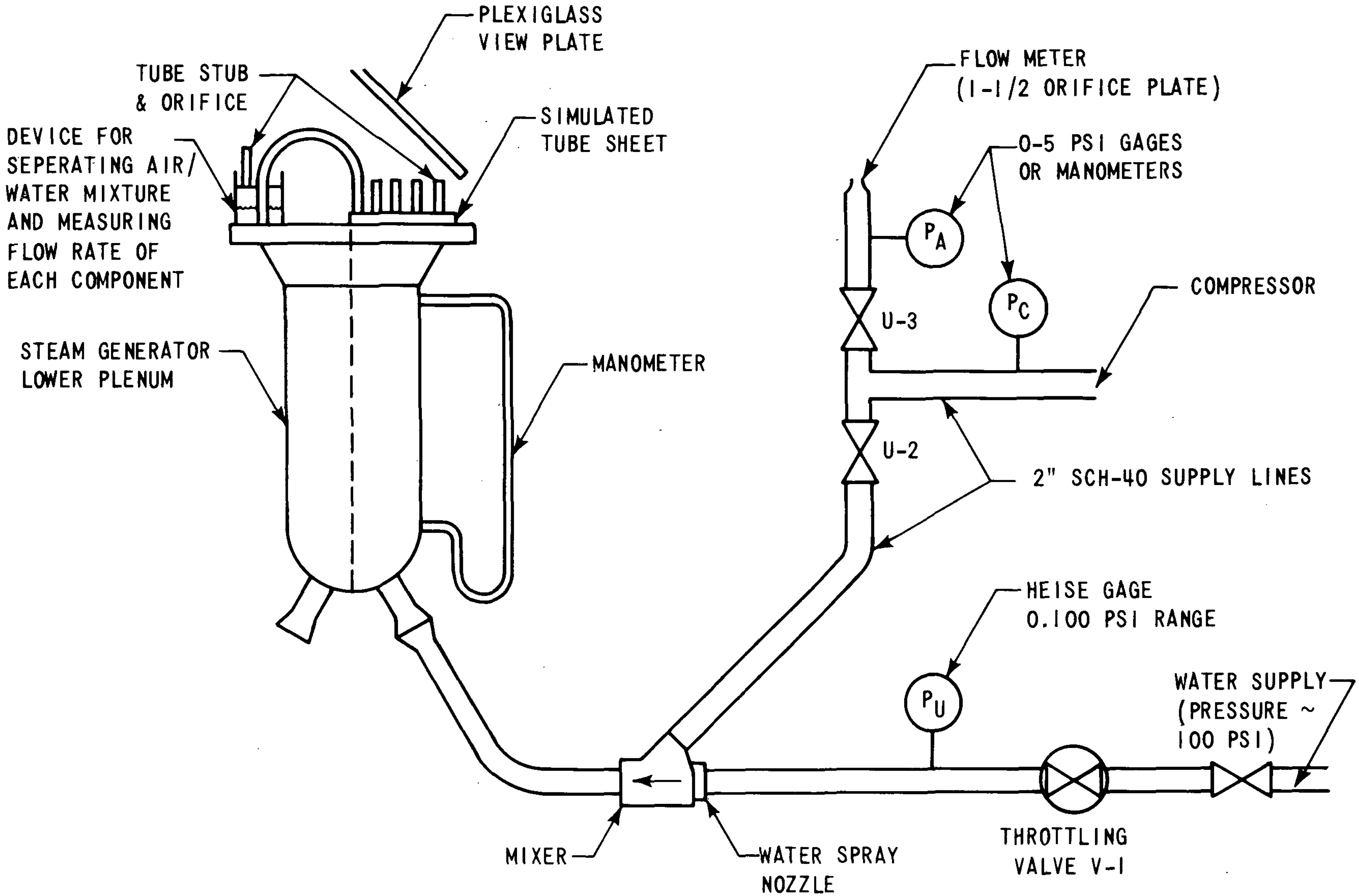


Figure C-2. Loop Schematic Diagram for the Plenum Air/Water Test

TABLE C-1
STEAM AND LIQUID VOLUMETRIC FLOW RATES
STEAM GENERATOR SEPARATE EFFECTS TEST

Run No.	Description	Pressure MPa (psia)	Quality	Total Flow kg/s (lb/sec)	Liquid Flow kg/s (lb/sec)	Liquid Flow m^3/sec (gpm)	Steam Flow kg/sec (lb/sec)	Steam Flow m^3/sec (cfm)
1	Reference run	0.276 (40)	0.80	0.227 (0.5)	0.0454 (0.10)	0.000045 (0.72)	0.182 (0.40)	0.1189 (252)
2	Flow sensitivity	0.276 (40)	0.80	0.454 (1.0)	0.0908 (0.20)	0.00009 (1.44)	0.363 (0.80)	0.2378 (504)
3	Pressure sensitivity	0.138 (20)	0.80	0.227 (0.5)	0.0454 (0.10)	0.000045 (0.72)	0.363 (0.80)	0.2275 (482)
4	Pressure sensitivity	0.414 (60)	0.80	0.227 (0.5)	0.0454 (0.10)	0.000045 (0.72)	0.363 (0.80)	0.0812 (172)
5	Quality sensitivity	0.276 (40)	0.50	0.227 (0.5)	0.114 (0.25)	0.00011 (1.8)	0.114 (0.25)	0.0746 (158)
6	Quality sensitivity	0.276 (40)	0.20	0.227 (0.5)	0.182 (0.40)	0.00018 (2.9)	0.0454 (0.10)	0.0297 (63)
7	Post bundle quench	0.276 (40)	0.10	0.454 (1.0)	0.409 (0.90)	0.00041 (6.5)	0.0454 (0.10)	0.0297 (63)

test if the volumetric flow rates of the air and water are the same as the volumetric flow rates of steam and water in the loop test. The parameters from these runs are presented in table C-1. To reproduce these conditions in the air/water plenum test, test loop conditions shown in table C-2 are required.

In the air/water plenum test, the seven test conditions shown in table C-1 will be run with the FLECHT inlet plenum. The hemispherical inlet plenum will be run with the conditions in runs 1, 2, 5 and 6. With the spray nozzle inside the inlet plenum, the run conditions from runs 1, 2, 5 and 6 will be run with the spray nozzle designed for a uniform inlet flow distribution. This sequence of four tests may be repeated with the internal spray nozzle modified to reproduce the inlet flow distribution measured in the hemispherical plenum test. The plenum air/water tests should be run in the sequence shown in table C-2.

The test in test sequence 1 (table C-2) is proposed to check out the individual tube air flow rate measurement method. In this test, the pitot tube used to measure air flow can be used on the stub tube (figure C-1) directly and as shown in figure C-3. For the same or symmetric tube locations, the air flow rate should be the same. Differences in air flow would be attributed to the flow measuring instrument in figure C-3. The individual tube air flow rates should add up to the compressor flow rate as determined from the compressor characteristic curve.

C-6. LOOP OPERATION

The air and liquid mass flow rates required (table C-2) can be readily established in the test loop as follows. For the liquid flow, throttle valve V-1 until the heise gage indicates the required pressure. For the air flow, required by runs 2 and 3, valve V-3 should be shut and valve V-2 should be wide open. This will provide the maximum air flow to the plenum. For the remaining test runs, valve V-3 should be opened progressively until the flowmeter upstream pressure is established. If the pressure can not be established with V-3 wide open, V-2 should be throttled until the required pressure is achieved.

C-7. TEST DATA

Test data will consist of indication of the total liquid and air flow rates, mass accumulation in the plenum, and the individual tube air and liquid flow rates. The liquid flow rate is determined from the spray nozzle pressure and the known spray nozzle pressure-flow characteristic curve. The plenum air flow rate is calculated by subtracting the bleed flow, measured by the orifice pressure drop, from the known compressor capacity. The maximum compressor output is 0.1981 m^3/s (420 cfm) at zero backpressure and decreased by approximately 0.0047 m^3/s (10 cfm) for each 68.94 kPa (10 psi) increase in the back-

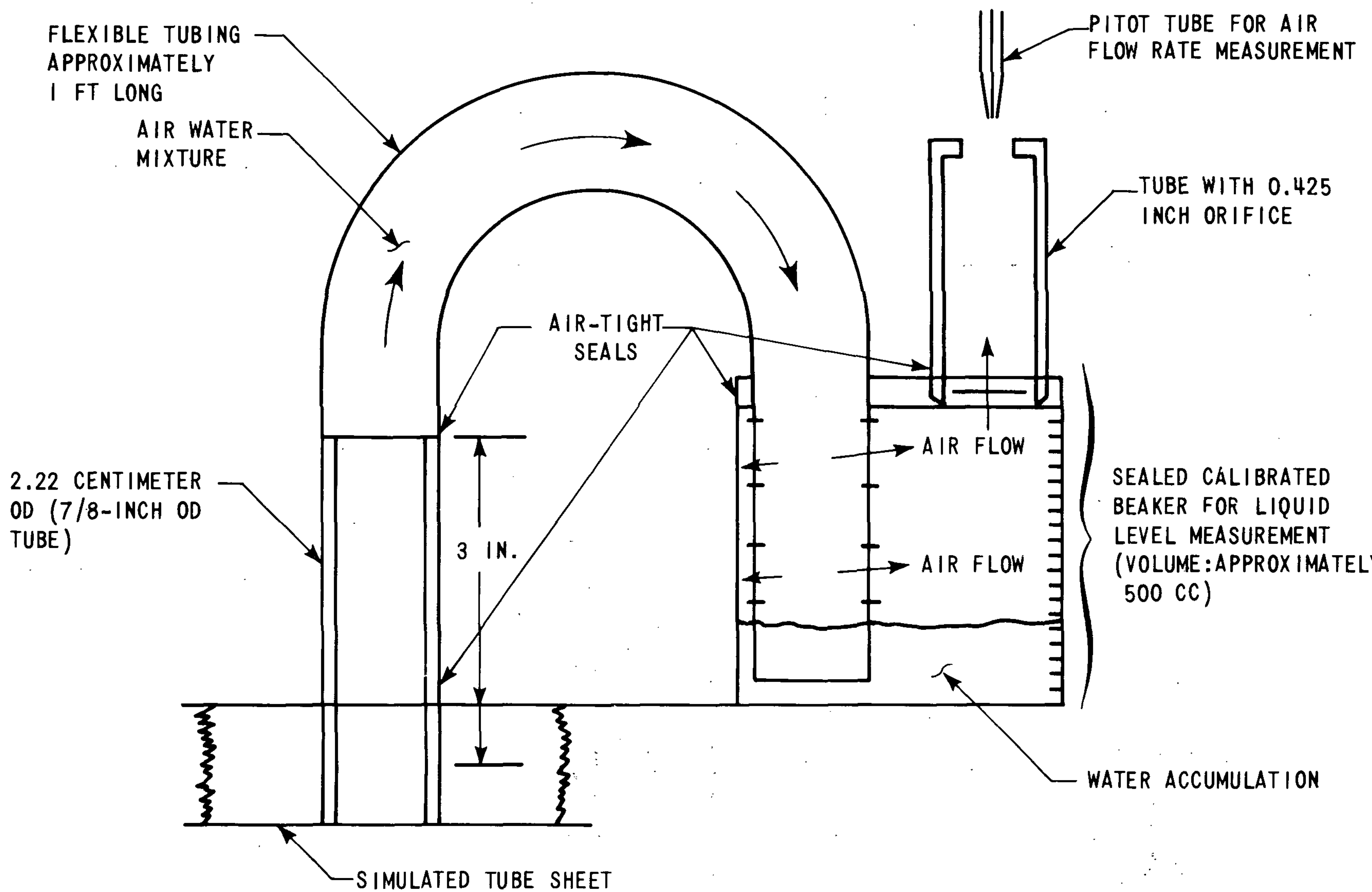
TABLE C-2
AIR/WATER PLENUM TEST SEQUENCE

Test Sequence	Plenum Configuration	Test Runs (From Table C-1)	No. of Tests
1	Scaled plenum	[a]	1
2	Scaled plenum	1,2,5,6	4
3	FLECHT plenum	1 thru 7	7
4	FLECHT plenum with internal nozzle for uniform flow	1,2,5,6	4
5[b]	FLECHT plenum with internal nozzle simulating scaled plenum distribution	1,2,5,6	4[c]
		Total runs	⩾ 20

a. Inst. verification run, air only

b. This sequence must be run after sequence 2

c. Due to possible iteration on the spray nozzle configuration, the number of runs in this sequence may be greater than four.



13,020-9

Figure C-3. Steam Generator Tube Air and Water Flow Rate Measurement presssure. For the air/water test, the maximum compressor backpressure will be approximately 2.68 kPa (3 psi) (table C-3), and the plenum air flow can be calculated by subtracting the bleed flow from 0.1981 m^3/s (420 cfm).

In individual tube air and water flow rates are measured with the instrument described in paragraph C-3. Data from the instrument shown in figure C-3 will consist of the liquid level versus time as measured in the calibrated beaker and the pressure drop as measured by the pitot tube. For the geometrically-scaled plenum, all tubes must be measured because the inlet nozzle is not symmetrically located.

TABLE C-3

AIR AND WATER FLOW RATES REQUIRED TO SIMULATE THE STEAM GENERATOR SEPARATE EFFECTS TEST

Run No.	Required Liquid Flow m^3/s (gpm)	Spray Nozzle Size[a]	Nozzle Pressure kPa (psi)	Required Air Flow m^3/s (cfm)	Bleed Flow m^3/s (cfm)	Pressure Upstream of Orifice kPa (psi)
1	0.000045 (0.72)	1/4-inch GD 6.5	82.8 (12)	0.1189 (252)	0.0793 (168)	4.69 (0.68)
2	0.000088 (1.44)	1/4-inch GD 6.5	379.2 (55)	0.2378 (504)[b]	0	—
3	0.000045 (0.72)	1/4-inch GD 6.5	82.8 (12)	0.2275 (482)[b]	0	—
4	0.000045 (0.72)	1/4-inch GD 6.5	82.8 (12)	0.0812 (172)	0.1170 (248)	9.996 (1.45)
5	0.000114 (1.8)	1/4-inch GD 6.5 or 3/8-inch GD 9.5	620.5 (90) 275.8 (40)	0.0746 (158)	0.1236 (262)	11.168 (1.62)
6	0.000183 (2.9)	3/4-inch HD 2.5	68.94 (10)	0.0297 (63)	0.1685 (357)	21.096 (3.06)
7	0.00041 (6.5)	3/4-inch HD 2.5	379.2 (55)	0.0297 (63)	0.1685 (357)	21.096 (3.06)

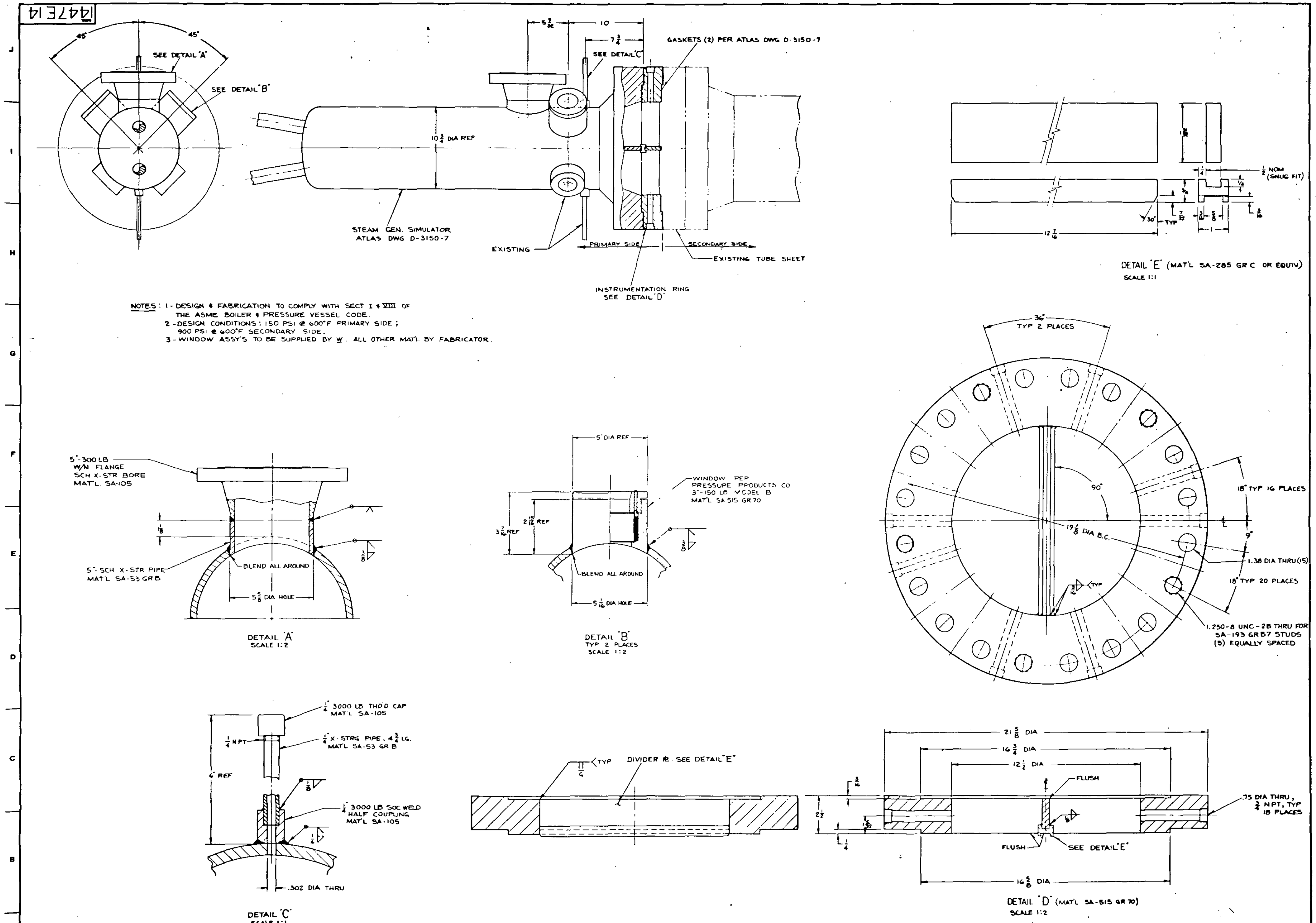
a. Nozzle size and pressure drop characteristic from Spraying Systems Co. Catalogue, p 19

b. Required flow rate exceeds compressor capacity of 0.1981 m^3/s (420 cfm).

APPENDIX D
ADDITIONAL FACILITY DRAWINGS FOR STEAM GENERATOR SEPARATE EFFECTS TASK

LIST OF DRAWINGS

	Title	Drawing Number
1.	FLECHT 14-inch Steam Generator Lower Plenum Modifications	1447E14
2.	FLECHT SEASET Steam Generator Task Piping Layout	1453E15 (3 sheets)
3.	FLECHT SEASET Steam Generator Test Water Supply Vessel	1463F31
4.	FLECHT SEASET Steam Generator Task Steam Piping Details	1447E32 (3 sheets)
5.	FLECHT SEASET Steam Generator Separate Effects Test – Simplified Flow Diagram	8763D67

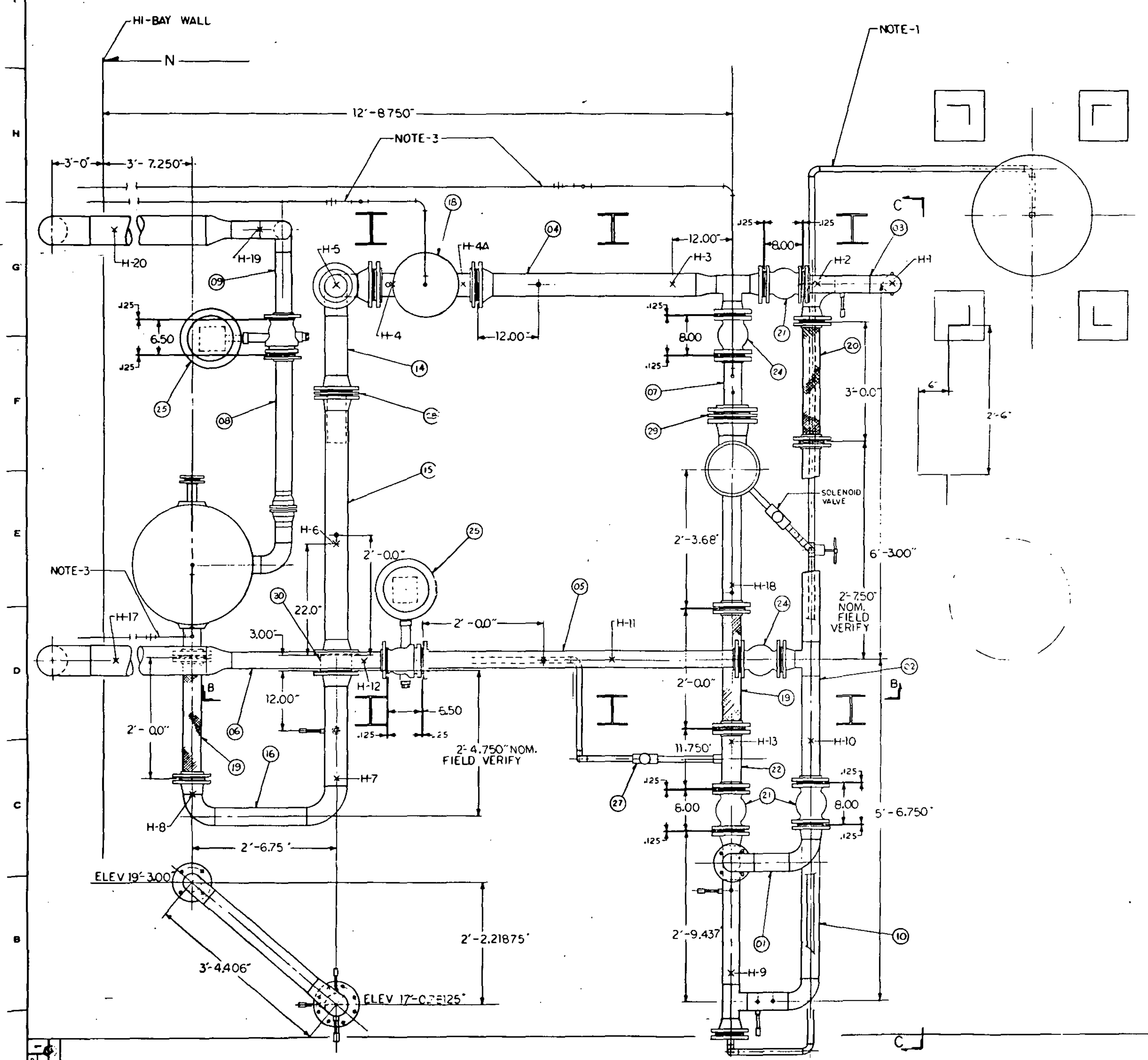


NOTES: 1 - DESIGN & FABRICATION TO COMPLY WITH SECT I & VIII OF THE ASME BOILER & PRESSURE VESSEL CODE.
2 - DESIGN CONDITIONS: 150 PSI @ 600°F PRIMARY SIDE; 900 PSI @ 600°F SECONDARY SIDE.
3 - WINDOW ASSY'S TO BE SUPPLIED BY W. ALL OTHER MAT'L BY FABRICATOR.

UNLESS OTHERWISE SPECIFIED THE FOLLOWING TOLERANCES APPLY
ALL DIMS ± .010

SEE PROCESS SPECIFICATION NO CAP505120 FOR SUPPLEMENTARY MANUFACTURING INFORMATION

Westinghouse Electric Corporation
FLECHT
14" STEAM GENERATOR
LOWER PLENUM MODIFICATIONS
SCALE 1:4
1447E14
DO NOT SCALE



ITEM		PART NAME	PART NO.	MATERIAL	NO. PER GROUP 01	02	03	04
01		PIPE SPOOL	1447E35G01		1			
02		PIPE SPOOL	1447E35G02		1			
03		PIPE SPOOL	1447E35G03		1			
04		PIPE SPOOL	1447E35G04		1			
05		PIPE SPOOL	1447E35G05		1			
06		PIPE SPOOL	1447E35G06		1			
07		PIPE SPOOL	1447E35G07		1			
08		PIPE SPOOL	1447E35G08		1			
09		PIPE SPOOL	1447E35G09		1			
10		PIPE SPOOL	1447E35G010		1			
11		PIPE SPOOL	1447E35G011		1			
12		PIPE SPOOL	1447E35G012		1			
13		PIPE SPOOL	1447E35G013		1			
14		PIPE SPOOL	1447E35G014		1			
15		PIPE SPOOL	1447E35G015		1			
16		PIPE SPOOL	1447E35G016		1			
17		PIPE SPOOL	1447E35G017		1			
18	Z	ENTRAINMENT SEPARATOR			1			
19	Y	3" 150# FLANGE FLEX HOSE			2			
20	Y	3" 150# FLANGE FLEX HOSE			1			
21	X	3" MISER FLANGED BALL VALVE			3			
22		PIPE SPOOL	1447E35G022		1			
23		PIPE SPOOL	1447E35G023		1			
24	W	3" 150# FLANGED GATE VALVE			1			
25	V	3" V-100 BALL VALVE			2			
26	Y	1½" NPT FLEX HOSE			1			
27	U	1" SOLENOID VALVE (MODEL 1580A)			1			
28	T	4" FLOW STRAIGHTENING VANE			1			
29		BAFFLE			1			
30	S	4" VORTEX FLOW METER			1			
31	S	3" VORTEX FLOW METER			1			
32	T	3" FLOW STRAIGHTENING VANE			1			

NOTES:

Z - B.O FR WRIGHT AUSTIN, DETROIT, MICHIGAN, 48207 4" ENTRAINMENT SEPARATOR TYPE TS

Y - B.O. FR UNIVERSAL METAL HOSE CO, CHICAGO, ILLINOIS

X - B.O FR WORCESTER CONTROLS, WEST BOYLSTON, MASSACHUSETTS

W - B.O FR VOGT MACHINE CO., LOUISVILLE, KY., 40201

V - B.O. FR FISHER CONTROLS, MARSHALLTOWN, IOWA

U - B.O. FR ATKOMATIC VALVE CO., INDIANAPOLIS, INDIANA

T - B.O FR DANIEL INDUSTRIES INC., HOUSTON TEXAS

S - B.O. FR NEPTUNE EASTECH, EDISON, N.J., 08817

NOTES:

1.) SEE DRAWING 1453E22 FOR WATER INJECTION SYSTEM PIPING DETAILS

2.) H-XX INDICATES HANGER LOCATION AND NUMBER, DETAILS TO BE SUPPLIED BY ENGINEERING

3.) FIELD ROUTED 1" RUPTURE DISC LINES

Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS PITTSBURGH U.S.A.

TITLE FLECHT SEASET STEAM GENERATOR TASK PIPING LAYOUT

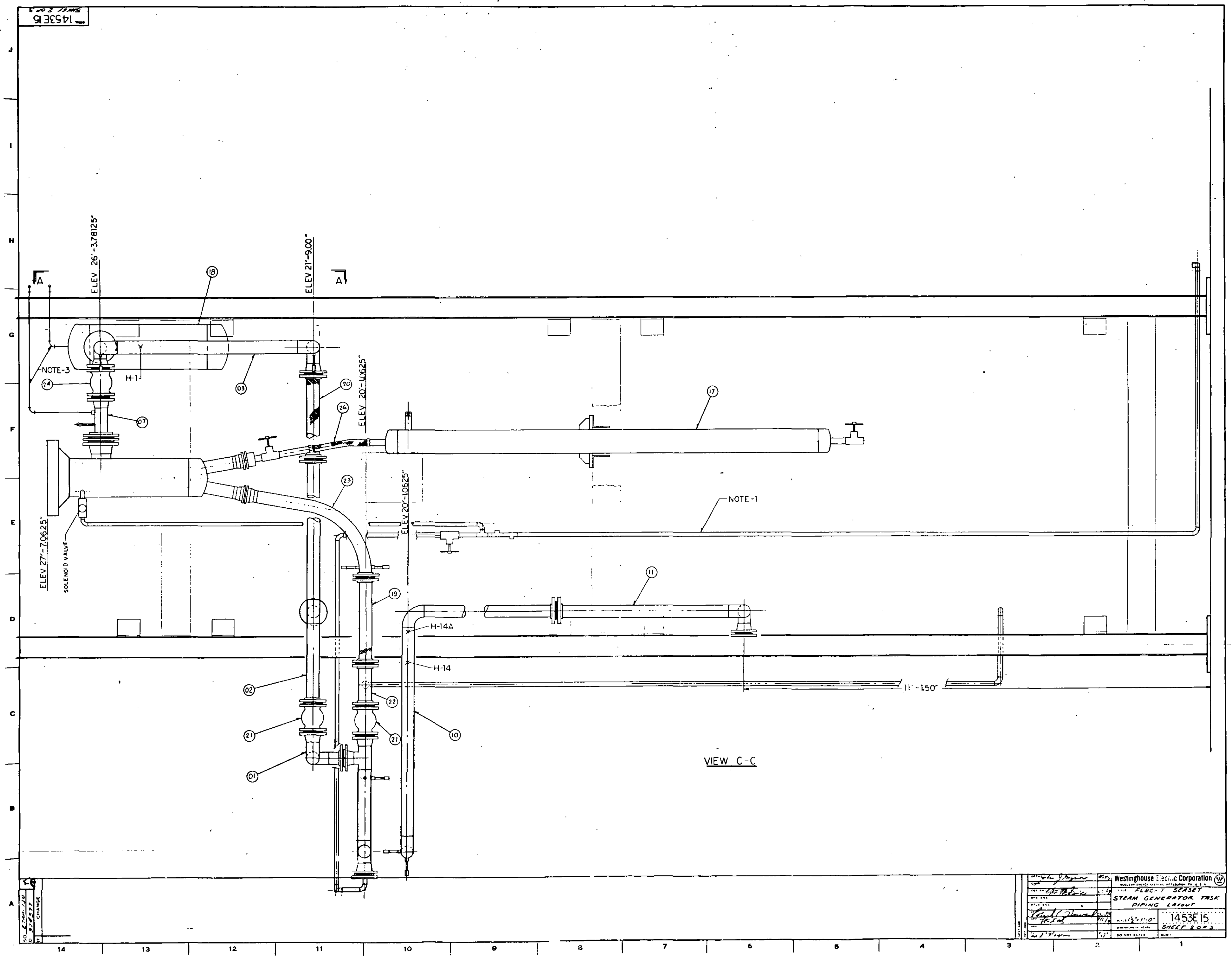
SCALE 1½" = 1'0"

DIMENSIONS IN INCHES

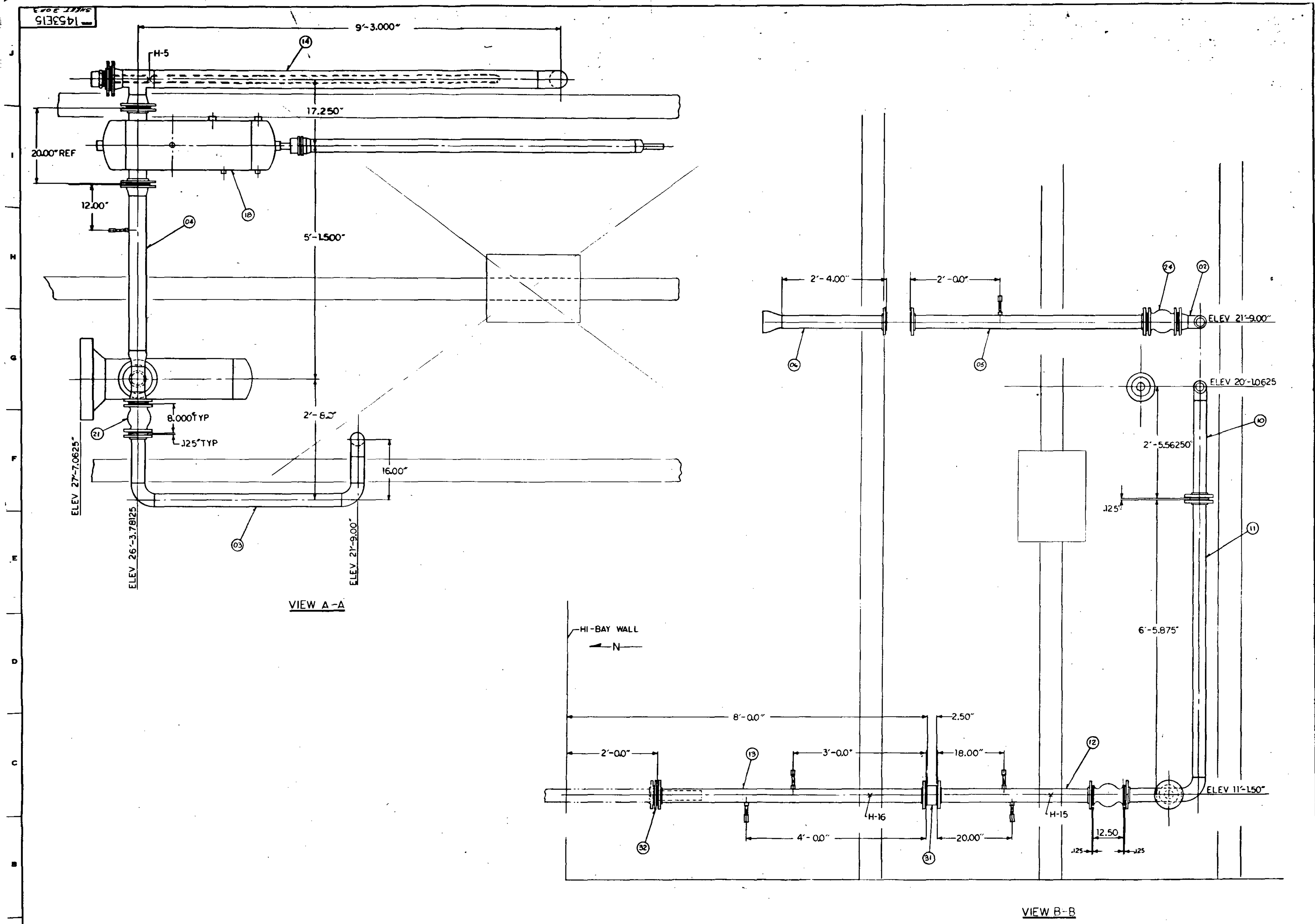
DO NOT SCALE

1453E15

SHEET 1 OF 3



1453E15
ELEV 26'-3.78125"
ELEV 21'-9.00"
A
A
18
NOTE-3
24
H-1
03
20
07
ELEV 20'-10625"
26
17
23
ELEV 20'-10625"
NOTE-1
ELEV 27'-7.0625"
SOLENOID VALVE
19
11
H-14A
H-14
02
22
11'-1.50"
21
21
10
01
VIEW C-C
Westinghouse Electric Corporation
ELECT SEASET
STEAM GENERATOR TASK
PIPING LAYOUT
DO NOT SCALE
1453E15
SHEET 2 OF 3



Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.

TITLE FLECHT SEASET STEAM GENERATOR TASK PIPING LAYOUT

SCALE 1½"=1'-0"

DIMENSIONS IN INCHES

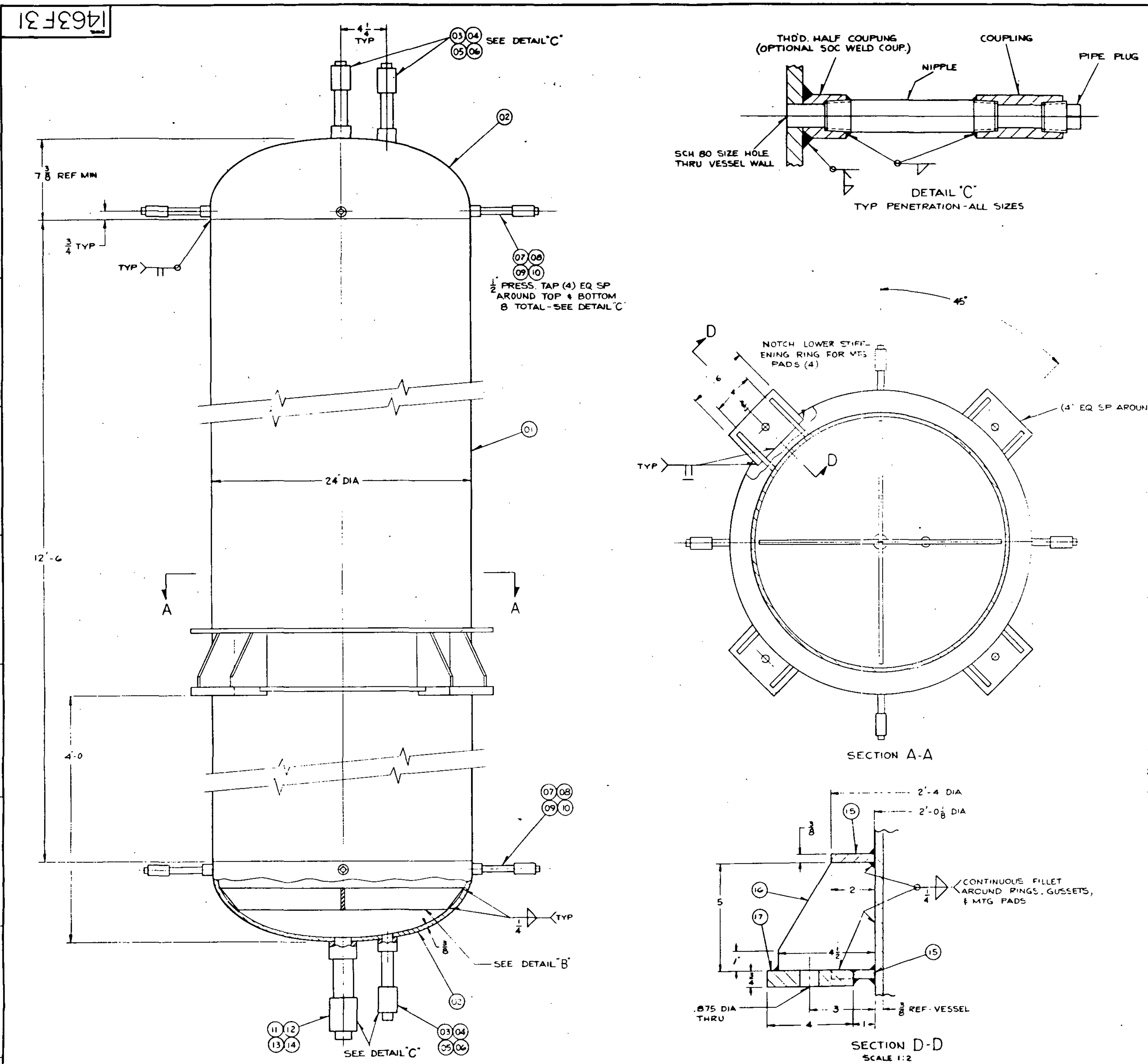
DO NOT SCALE

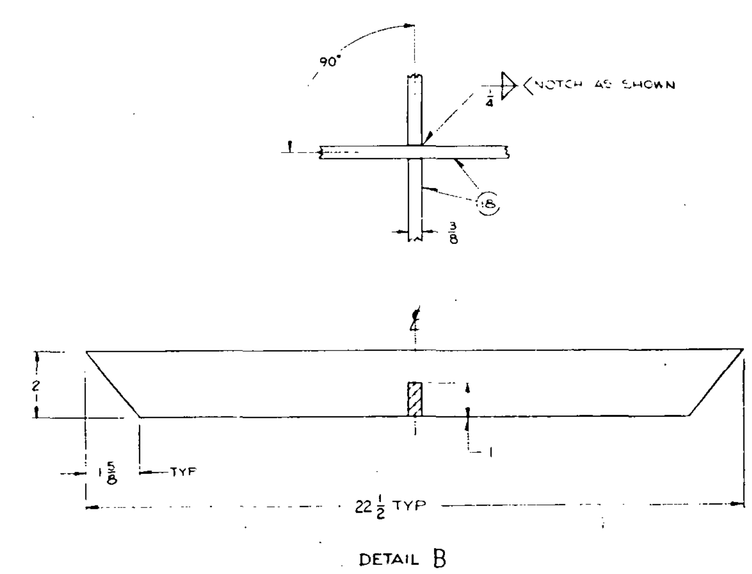
1453E15

SHEET 3 OF 3

SUB 1

1463F31





BILL OF MATERIAL								
ITEM		PART NAME	PART NO.	MATERIAL	REQ. PER GROUP 01	02	03	04
01		VESSEL BODY 24" STD WT PIPE		SA-106 GR B	1			
02		ELLIPTICAL HEAD 24" ASME	3/8 THK	SA 285 GR C	2			
03		HALF COUP 1" NPT 3000 LB		SA-105	3			
04		NIPPLE 1" SCH 80 4" LG		SA-106 GR B	3			
05		COUPLING 1" NPT 3000 LB		SA-105	3			
06		PIPE PLUG 1" NPT SQ HD		SA-105	3			
07		HALF COUP 1/2 NPT 3000 LB		SA-105	8			
08		NIPPLE 1/2 SCH 80 - 4" LG		SA-106 GR B	8			
09		COUPLING 1/2 NPT 3000 LB		SA-105	8			
10		PIPE PLUG 1/2 NPT SQ HD		SA-105	8			
11		HALF COUP 1 1/2 NPT 3000 LB		SA-105	1			
12		NIPPLE 1 1/2 SCH 80 4" LG		SA-106 GR B	1			
13		COUPLING 1 1/2 NPT 3000 LB		SA-105	1			
14		PIPE PLUG 1 1/2 NPT SQ HD		SA-105	1			
15		STIFFENING RING		ASTM A 36	2			
16		GUSSET			8			
17		MTG PAD			4			
18		ANTI-SWIRL VANE		ASTM A36	2			

NOTES:

1 - THE ASSY IS TO BE FABRICATED, TESTED, & STAMPED IN ACCORDANCE WITH SECT I OF THE ASME BOILER & PRESSURE VESSEL CODE.

2 - DESIGN PRESSURE 300 PSIG, DESIGN TEMP - 650°F

1 D STAP-730 974,827 CHANGE

DFTM.
CHKR.
DES. ENG.
MFG. ENG.
MTLS. ENG.
APP.
APP.
APP.
DFTG. SUPV.

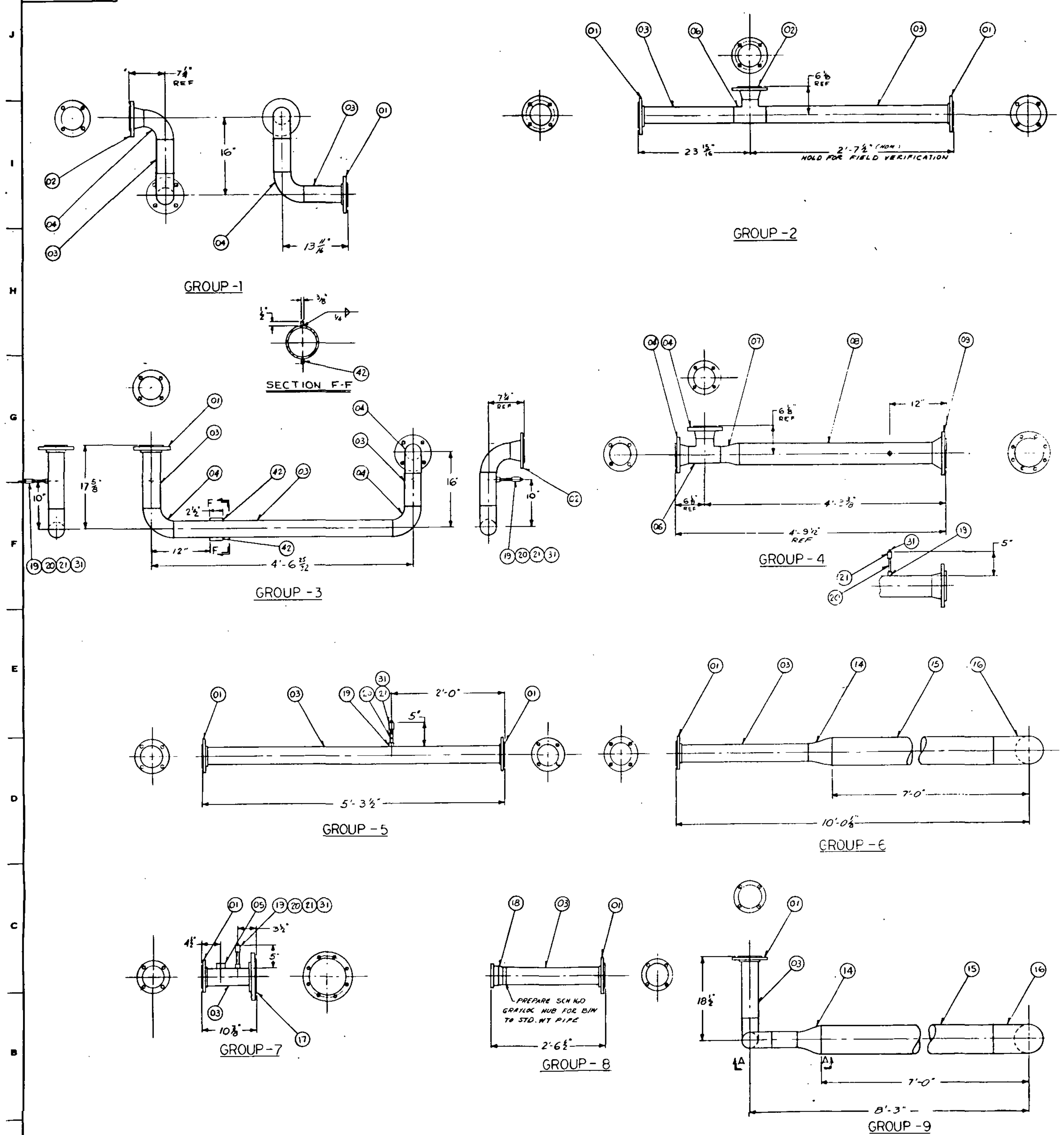
Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS PITTSBURGH, PA., U.S.A.

TITLE: FLECHT SEASET STEAM GEN TEST WATER SUPPLY VESSEL

SCALE 1:4
DIMENSIONS IN INCHES
DO NOT SCALE

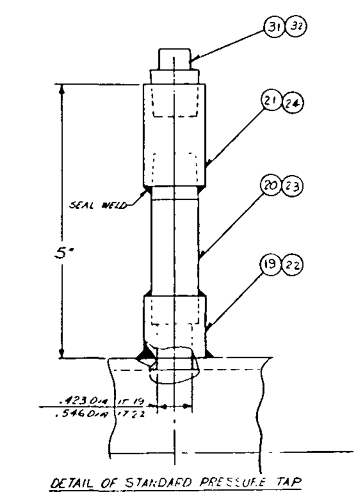
1463F31

SUB 1

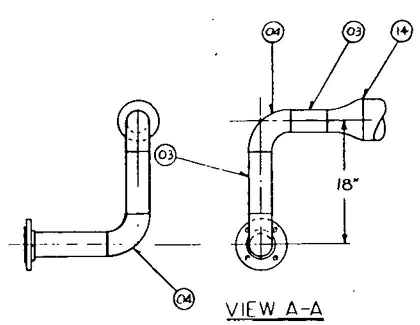


BILL OF MATERIAL

GR 23	GR 22	ITEM	NOTE	PART NAME	DRAWING & GR OR IT	MATERIAL	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
1	2	01		FLANGE 3" 150LB SLIP ON		SA-105	1	2	1	-	2	1	1	1	1	1	1	1	2	-	-	-	-	-		1	1
-	-	02		FLANGE 3" 150LB WELD NECK		SA 105	1	1	1	-		-	-	-	-	3	1	-	-	-	-	-	-	-	[illegible]		
-	AR	03		PIPE 3" STD WT		SA 106 GR B	AR	AR	AR	-	AR	AR	AR	AR	AR	AR	AR	AR	AR	-	-	AR	-	-		1	
-	-	04		ELBOWS 90 LR 3" STD WT		SA 234 WPB	2	1	3	2	-	-	-	-	2	2	1	-	-	-	-	1	-	-			1
-	1	05		HALF COUPLING 1" NPT 3000LB		SA 105	-	-	-	-	-	-	1	-	-	-	-	-	-		-	-	-	-		1	
-	-	06		TEE 3" STD WT. B W		SA 234 WPB	-	1	-	1	-	-	-	-	-	2	1	-	-	-	-	-	-	-	1		
-	-	07		REDUCER CONC. 3x4 STD WT.		SA-234 WPB	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-				
-	-	08		PIPE 4" STD WT		SA 106 GR B	-	-	-	AR	-	-	-	-	-	-	-	-	-	AR	AR	AR					
-	-	09		FLANGE 4" 150LB WELD NECK		SA-105	-	-		1	-	-	-	-	-	-	-	-	-	1	2	1					
-	-	10		FLANGE 3" 300LB SLIP ON		SA-105	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-					
-	-	11		TEE 4" STD. WT. B W		SA 234 WPB	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-			1		
-	-	12		ELBOWS 90° L.R 4" STD WT		SA-234 WPB	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-					
-	-	13		ELBOW 90° RED 4 x 3" STD WT		SA 234 WPB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1					
-	-	14		REDUCER CONC 3x5 STD WT		SA-234 WPB	-	-		-	-	1	-	-	1												
-	-	15		PIPE 5" STD WT		SA 106 GR B	-	-	-	-	-	AR	-	-	1								-				
-	-	16		ELBOW 90° LR 5 STD WT		SA 234 WPB	-	-	-	-	-	1	-	-	1							-	-				
-	-	17		FLANGE 5"x3" 300LB S.O. REDUCING		SA-105	-		-	-	-	-	1	-	-					-		-	-		-		
-	-	18		GRAYLOC 3" SCH 160 [illegible] BUTT WELD HUB		SA-105	-	-	-	-	-	-	-	1	-						-		-				
1	-	19		HALF COUPLING 3/8 3000LB SOC WELD		SA-105		-	2	1	1		1	-	-	5	-	1			1	2	-				
1	-	20		PIPE 3/8" SCH X STG		SA 106 GR B			AR	AR	AR		AR		-	AR	-	AR	AR		AR	AR					
1	-	21		COUPLING 3/8 NPT 3000LB		SA-105	-		2	1	1		-	-	-	5	-	1	-		1	2					
1	-	22		HALF COUPLING 1/2 3000LB SOC WELD		SA-105	-											-	-	-	-	-					-
1	-	23		PIPE 1/2" SCH X STG		SA-106 GR B	-											-	-	-		-					
1	-	24		COUPLING 1/2" NPT 3000LB		SA 105	-										-	1	1								-
-	-	25		PIPE 6" STD WT		SA 106 GR B	-	-	-	-	-		-										1				
-	-	26		PIPE CAPS 6" STD WT BW		SA-234 WPB	-	-														-	2				
-	-	27		PIPE 1 1/2 X-STG		SA 106 GR B	-	-	-		-	-		-	-		-	-		-			AR				
-	-	28		PIPE CAP 1 1/2" NPT 3000LB		SA-105	-		-												-	-	2	-			
-	-	29		PIPE 1" X-STG		SA 106 GR B	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	AR				
-	-	30		PIPE CAP 1" NPT 3000LB		SA 105	-	-		-		-	-	-	-		-	-	-	-	-	-	1				
1	-	31		PIPE PLUG 3/8 NPT		SA 105	-	-	2	1	1	-	1	-	-	5	-	1	1	-	1	2	4				
1	-	32		PIPE PLUG 1/2" NPT		SA-105	-	-	-		-	-				-		1	1	-	-	-	-	-			
-	-	33		BASE PLATE		SA-36	-	-	-	-	-									-	-		2	-			
-	-	34		GUSSET		SA 36									-	-		-				-	4	-			
-	-	35		TEE RED 3"x3"x2" STD WT		SA-234 WPB	-				-						-						-	-	1	-	
-	-	36		PIPE 2 STD WT		SA-106 GR B	-	-	-	-				-	-	-								-	AR		
-	-	37		REDUCER CONC 2x3 STD WT		SA 234 WPB	-	-		-		-			-	-				-			-	-	1	1	1
-	-	38		FLANGE 2" 300LB WN		SA 105	-																		-	1	1
-	-	39		PIPE 3" X-STG		SA-106 GR B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	AR	-	-	-
-	-	40		LAP JOINT STUB END 3" X-STG		SA-234 WPB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
-	-	41		FLANGE 3" 150LB LAP JOINT		SA-105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
-	-	42		STOP		SA-36	-	-	2	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-



NOTES:
1. DESIGN CONDITIONS ALL GROUPS: 150 PSI @ 500°F
2. GROUP 14 FABRICATED OUTSIDE BY HEAT ENGINEERING & SUPPLY CO., EL MONTE, CALIF. PER ASME BOILER & PRESSURE VESSEL CODE, SEC I.
3. GROUP 17: DESIGN, FABRICATE & STAMP PER ASME BOILER & PRESSURE VESSEL CODE, SECTION VIII. SEE W SPECIFICATION FEES-018 FOR ADDITIONAL REQUIREMENTS.
4. GROUPS 1 THROUGH 13, 15, 16, 18 THROUGH 23: DESIGN, FABRICATE PER ASME BOILER AND PRESSURE VESSEL CODE, SECTION I (BOILER EXTERNAL PIPING). SEE W SPECIFICATION FEES-017, REV. 1 FOR ADDITIONAL REQUIREMENTS
5. MODIFY EXISTING FABRICATION SUPPLIED BY WESTINGHOUSE BY CUTTING FLANGED END AND INSTALLING NEW S/O FLANGE & TWO PRESSURE TAP NOZZLES AS SHOWN.



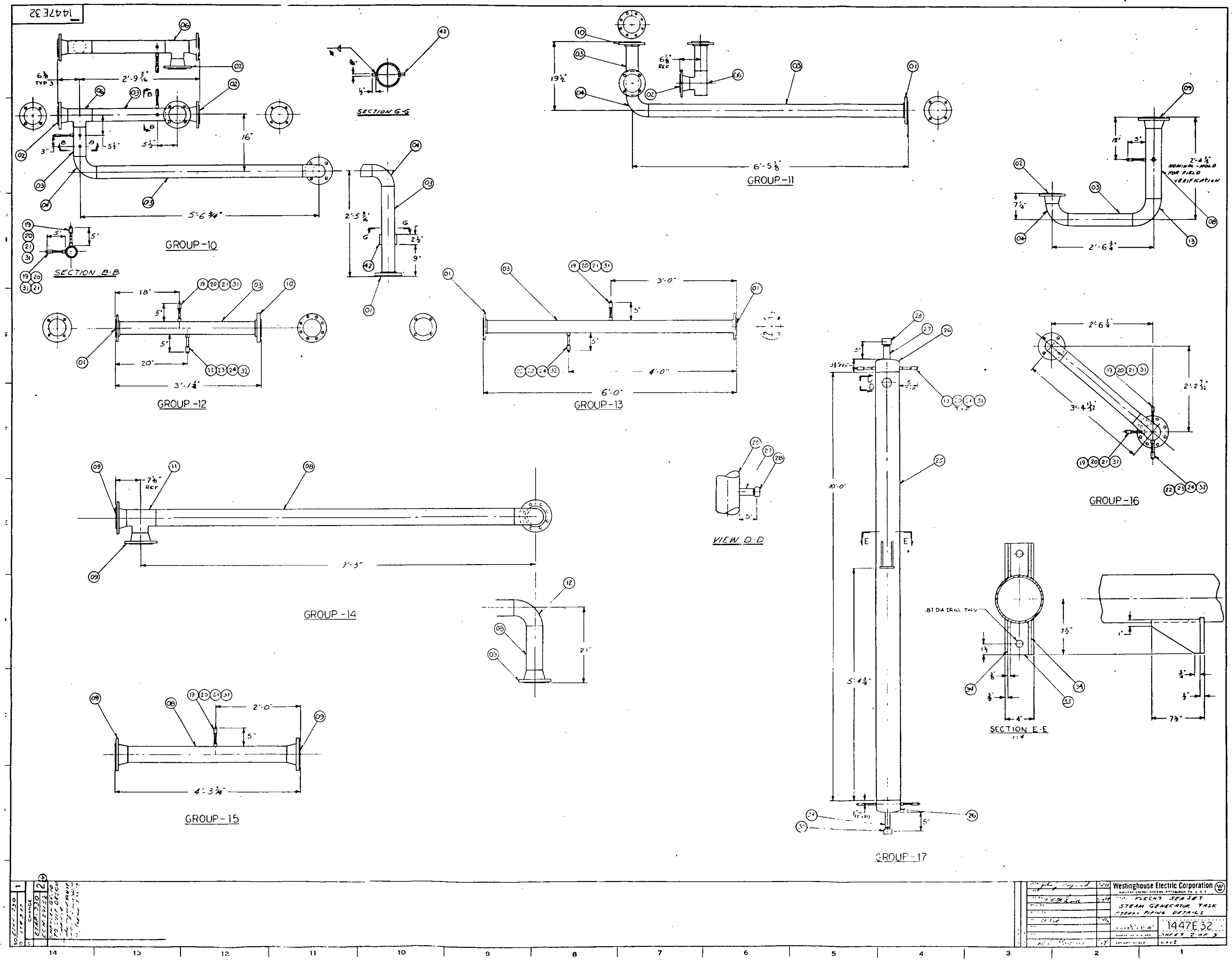
Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.

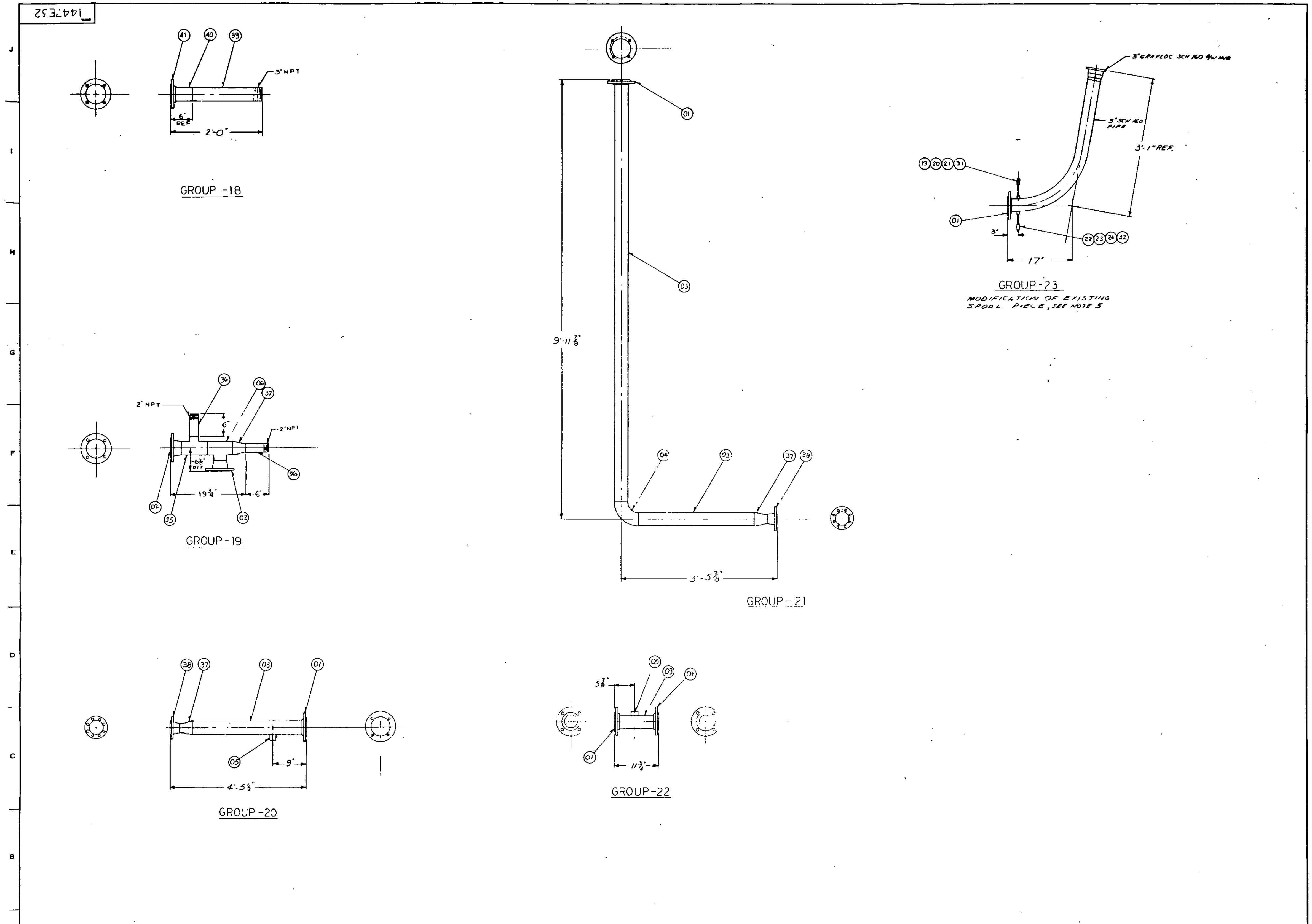
TITLE FLECHT SEASET STEAM GENERATOR TASK STEAM PIPING DETAILS

SCALE 1 1/2" = 1'-0"

1447E32

SHEET 1 OF 3


1447E32
GROUP-10
SECTION B-B
SECTION G-G
GROUP-11
GROUP-12
GROUP-13
GROUP-14
GROUP-15
GROUP-16
GROUP-17
VIEW D-D
SECTION E-E
.87 DIA DRILL THRU
NOMINAL - HOLD FOR FIELD VERIFICATION
Westinghouse Electric Corporation
FLECHT SEASET
STEAM GENERATOR TASK
STEAM PIPING DETAILS
1447E32
SHEET 2 OF 3



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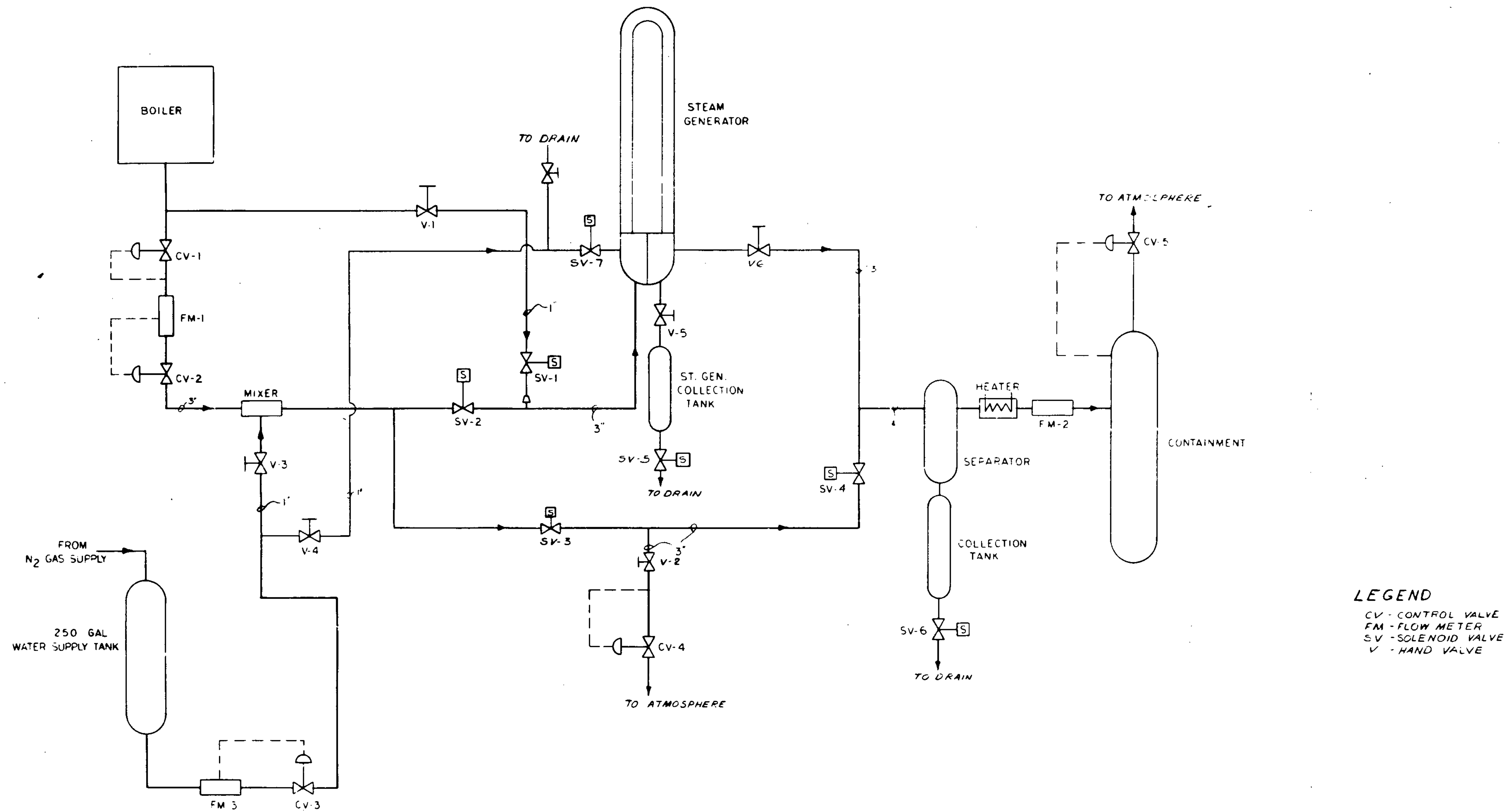
NUCLEAR ENERGY SYSTEMS PITTSBURGH PA U.S.A.

FLECHT SEASET
STEAM GENERATOR TASK
STEAM PIPING DETAILS

1447E32
SHEET 3 OF 3

8763D67



LEGEND
CV - CONTROL VALVE
FM - FLOW METER
SV - SOLENOID VALVE
V - HAND VALVE

Westinghouse Electric Corporation
NUCLEAR ENERGY SYSTEMS, PITTSBURGH, PA., U.S.A.

TITLE: FLECHT SEASET STEAM GENERATOR SEPARATE EFFECTS TEST ... FLOW DIAGRAM

8763D67

SCALE —
DIMENSIONS IN INCHES
DO NOT SCALE
SUB 2

CHANGE 2 ETAP-730