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APAE 122

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test program for 30 megawatt prototype sodium intermediate heat exchanger and steam generator

Submitted to
United States
Atomic Energy Commission

ALCO R&D

ALCO PRODUCTS, INC.
RESEARCH & DEVELOPMENT DEPARTMENT

DISCLAIMER

APAE 122

TEST PROGRAM FOR 30 MEGAWATT PROTOTYPE SODIUM INTERMEDIATE HEAT EXCHANGER AND STEAM GENERATOR

Submitted to:

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ALCO PRODUCTS, INC.
Research & Development
Schenectady, New York

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I - INTRODUCTION

This report presents the designer's concept of a test program for the 30 megawatt prototype intermediate heat exchanger and steam generator designed and fabricated for the United States Atomic Energy Commission as part of the Sodium Components Development Program.

The general objectives of the program are to obtain performance data which will serve to verify the thermal design, or allow application of improved techniques to future designs, give an improved basis for stress analysis in design of future units, and demonstrate the capability and limitations of the units in relation to the performance specifications for which they were designed.

This program was prepared in coordination with Atomics International and Baldwin-Lima-Hamilton. Atomics International will perform the test at the Atomic Energy Commission provided Sodium Components Test Installation, and Baldwin-Lima-Hamilton will complete a portion of the steam generator fabrication, and assume the role of designer in evaluation of the units during and after testing.

A complete design description of the prototype units is given in APAE 112, Volumes I through IV, published by Alco Products, Incorporated. These publications should be consulted as an integral part of this test program, and procedures given in the design manuals should be followed except where deviations are planned as part of the test.

The test program has been formulated to be consistent with the capability of the test installation.

II - TEST OBJECTIVES

1. Obtain performance data for the intermediate heat exchanger and steam generator which will serve to verify the thermal design of both units.

2. Determine the dynamic response characteristics of the intermediate heat exchanger and steam generator subjected to forced variations in operating parameters.

3. Obtain time-temperature recordings of internal sodium and steam temperatures during all transient operation (both normal and casualty) of both units, to support the thermal stress evaluation.

4. Obtain time-temperature recordings of fluid and metal temperatures for both units, to support the thermal stress evaluation.

5. Obtain strain gage data on the upper head of the steam generator during hydrostatic test, for pressure stress evaluation.

6. Obtain strain gage data on the steam generator sodium inlet nozzle and the nozzle reinforced region of the shell at ambient temperature to check the Bijlaard equations for stress evaluation and to determine the distance from the nozzle where shell reinforcement is necessary.

7. Obtain strain gage data at operating temperature and during transients from high temperature strain gages for thermal stress evaluation.

8. After evaluation of all transient operation (including both programmed transients and transients occurring during abnormal operation) demonstrate the structural integrity of the intermediate heat exchanger and steam generator by subjecting the units to the remaining number of specified cycles of thermal transients, to determine if the units can withstand the specified transients for which they were designed.

9. Determine the actual stresses induced by various rates of plant startup, in order to provide data to establish realistic normal startup limitations for future units of larger size.

10. Obtain additional test information to support the chemical evaluation of both units for determination of the compatibility of system materials with the test environment.

11. Evaluate test specimens attached in the intermediate heat exchanger to determine if the corrosion resistance and strength characteristics of weld metal deposited by Type 316 stainless steel and Type 316 modified (16% Cr-8% Ni-2% Mo) electrodes and Type 316 stainless steel base plate are adversely affected after a long-time exposure to high temperature sodium.

12. After completion of performance testing, and determination that the units have met functional specifications used as design conditions, the units may be further tested to determine their response to simulated reactor plant operating conditions for any remaining useful life, or until destruction.

13. After completion of all testing, the units are to be destructively examined for metallurgical evaluation.

III - AMBIENT TEMPERATURE PRESSURE STRESS EVALUATION OF STEAM GENERATOR

The tests herein described apply to the steam generator only, and are to verify the stress calculations for the upper and lower heads of the unit, and provide valuable data for nozzle reinforcement design. This section of the test program will be performed before and during hydrostatic testing of the unit at the place of fabrication.

A. STRESSES IN UPPER AND LOWER HEADS

Experimental data are required to verify the stress calculations of the heads of the steam generator. The heads are very thick and their irregular shape makes a stress analysis difficult. Calculated stresses are uncertain, due first, to the difficulty of correcting adequately for the effect of shearing deflections, and secondly, to the impossibility of predicting the true stresses adjacent to the steam outlet and large manway.

Strain gages will be placed on the exterior of the vessel only, as it is difficult to provide satisfactory seals during pressure test for lead wires from gages interior to the vessel. With a careful and studied evaluation of the results, strain gage readings on the vessel exterior will give significant and valuable information.

The upper head will be implemented with a cluster of one-quarter inch-three gage rosettes at locations shown on drawing D-666-4-9, Appendix D. All gages are to be high temperature (1200°F static) gages, so that after the pressure testing, these same gages may be used during the thermal stress evaluation testing. Gages are located radially and circumferentially with respect to the longitudinal axis of the vessel. A description of gage locations indicated on drawing D-666-4-9, Appendix D, and pertinent to this test follows:

1. To determine stresses in the head, place gages along Sections A-A and B-B, forty-five degrees away from the centerline of the steam outlet as follows:

SECTION A-A	SECTION B-B	LOCATION
SG-1	SG-5	Two inches below upper face of tubesheet.
SG-2	SG-6	Opposite upper face of tubesheet.
SG-3	SG-7	At weld centerline.
SG-4	SG-8	At surface discontinuity approximately ten inches above weld centerline.

2. Place the following gages along Section C-C to determine stresses in irregular regions of the steam outlet and manway, and other regions of the head:

Definition: The plane of the steam outlet nozzle coinciding with Section C-C is referenced as the vertical centerline, the plane perpendicular to Section C-C through the center of the steam outlet is the transverse centerline.

GAGE NUMBER	LOCATION
SG-9	At weld centerline.
SG-10	Three inches above weld centerline.
SG-11	At upper edge of steam nozzle weld.
SG-12	At edge of manhole reinforcement adjacent to weld.
SG-13	At edge of manhole reinforcement 180 degrees from SG-12.
SG-45	90 degrees from the vertical centerline of the steam outlet nozzle lying in the transverse centerline plane of the same nozzle.
SG-46 and SG-47	At weld joining the steam outlet nozzle to the head and lying diametrically opposite in the transverse centerline of the same nozzle. (See Plan View)
SG-67	At tapered tubesheet periphery approximately one inch below upper tubesheet surface in Section C-C.
SG-68	Two inches above weld center on lower lip of upper tubesheet in Section C-C.
SG-69	At center of weld directly under SG-68.
SG-70 and SG-71	At weld joining the steam outlet nozzle to the head and lying diametrically opposite in the vertical centerline of the same nozzle.
SG-72	At surface extending circumferentially a short distance from SG-47 and lying in the transverse centerline plane of the steam outlet nozzle. (See Plan View)

GAGE NUMBER	LOCATION
SG-73	Approximately half way up the nozzle taper extending from the weld joining the steam outlet nozzle to the head. (See Plan View)
SG-74	At end of steam outlet nozzle taper in line with SG-47 and SG-73. (See Plan View)
SG-75	At center of tubesheet to shell weld 180 degrees from SG-69.
SG-76	At weld centerline 180 degrees from SG-9.
SG-77	At tubesheet periphery 180 degrees from SG-67.
SG-78	At lower lip of upper tubesheet 180 degrees from SG-68.

3. Place the following gages on the upper face of the manhole cover:

GAGE NUMBER	LOCATION
SG-14	Center of cover.
SG-15	Five and one-half inches from center of cover.
SG-16	Five and one-half inches from center of cover, and 180 degrees from SG-15.

4. Two manhole studs are tobe implemented with gages to measure bolt tension with and without internal pressure. Two gages 180 degrees apart on each of two bolts are to be located as shown on drawing D-666-4-9, Appendix D, and are designated SG-17 through SG-20.

Compliance with the following practice will help to insure good and useful data for this test:

1. Strain gages for all tests and all locations will be one-quarter inch-three gage rosettes, in order to minimize confusion in placement.

2. All gages applied by the fabricator will be high temperature (1200^{O}F static) gages, and should be protected with temporary metal "huts" or wood blocks, or by other means, so as to minimize the possibility of damage during shipment to the test facility.

3. A three lead wire system should be used throughout. No smaller than 26 gage, three conductor, solid copper-stainless steel clad lead wires with fiber glass insulation and jacket shall be used.

4. The vessel is to be filled with test fluid sufficiently in advance to allow a reasonable state of temperature equilibrium to be reached prior to testing. Room, metal, and fluid temperatures are to be recorded during test.

5. The load (test pressure) is to be cycled from zero to maximum pressure and back until the zero shift of the gages is fifteen microinches, or less, prior to test.

6. A detailed test procedure shall be prepared by the fabricator (Baldwin-Lima-Hamilton) and reviewed with the acting customer (Atomics International) prior to testing.

The test is to include readings at one-quarter, one-half, three-quarters and full load (test pressure). Strain values are to be recorded on both increasing and decreasing pressure, and are to be tabulated during recording. In this manner, erroneous results can be eliminated and new readings taken immediately.

B. CHECK OF BIJLAARD EQUATIONS

The diameter of the sodium nozzles on the steam generator shell is large compared to the shell diameter and the ratio is beyond the range of the Bijlaard coefficients as given on the original charts. Experimental verification of extrapolations of the curves is required. Also, these curves give the thickness of the shell required in the vicinity of the nozzles, but do not indicate the length beyond the nozzle that the thickness must be maintained. This part of the test program is expected to answer this question also. This testing is to be performed after test described in III-A, and shall be done with the vessel filled with fluid.

Enough gages shall be applied to allow mapping of the stress contour on application of a moment to the nozzle. A description of gage locations, as shown on drawing D-666-4-9, Appendix D, follows:

GAGES ON VERTICAL (LONGITUDINAL) CENTERLINE OF SODIUM INLET NOZZLE

GAGE NUMBER	LOCATION
SG-24	Center of nozzle weld towards top of vessel.
SG-22	Center of nozzle weld towards bottom of vessel.
SG-53	One inch up nozzle from SG-24.
SG-51	One inch up nozzle from SG-22.

GAGE NUMBER	LOCATION
SG-58	One inch up shell from SG-24.
SG-56	One inch down shell from SG-22.
SG-61	Twelve inches up shell from horizontal centerline of nozzle.
SG-60	Twelve inches down shell from horizontal centerline of nozzle.
SG-28	Three inches above SG-61.
SG-29	Three inches below SG-60.
SG-63	Three inches above SG-28.
SG-62	Three inches below SG-29.
SG-27	Three inches above SG-63.
SG-30	Three inches below SG-62.
SG-26	Six inches above SG-27.
SG-31	Six inches below SG-30.
SG-25	Six inches above SG-26.
SG-32	Six inches below SG-31.

GAGES ON HORIZONTAL CENTERLINE OF SODIUM INLET NOZZLE

GAGE NUMBER	LOCATION
SG-21	Center of nozzle weld 90 degrees clockwise from SG-24.
SG-23	Center of nozzle weld 90 degrees clockwise from SG-22.
SG-54	One inch up nozzle from SG-21.
SG-52	One inch up nozzle from SG-23.
SG-59	On shell one inch from SG-21.
SG-57	On shell one inch from SG-23.

OTHER GAGES AROUND SODIUM INLET NOZZLE

GAGE NUMBER	LOCATION
SG-49	Center of nozzle weld 45 degrees clockwise from SG-21.
SG-48	Center of nozzle weld diametrically opposite from SG-49.
SG-50	One inch up nozzle from SG-49 in line with SG-48 and SG-49.
SG-55	One inch out on shell from SG-49 in same radial path.
SG-65	Center of nozzle weld and midway between SG-49 and SG-22.
SG-64	One inch up nozzle on radial line to SG-65.
SG-66	One inch out on shell from SG-65 in same radial path.

To obtain the required nozzle thrust, (thrust "A" in Figure 1) use a calibrated jack to apply a known force to the end of the nozzle. Varying the applied force will vary the nozzle thrust. The weight of the steam generator vessel is such that loads sufficient to give significant gage readings can be applied without lifting the vessel. The jack should be suitably blocked, so that the load acts uniformly over the nozzle. The maximum value of the thrust to be applied is not to exceed 13,300 pounds, which should not lift the end of the vessel, but is large enough to obtain significant values of strain. Readings shall be taken with the vessel full of hydrostatic test fluid, and following the general procedure listed in Section III-A. All gages around the nozzle are to be recorded during all testing done as a check on the Bijlaard equations.

In a similar manner, the required nozzle moments may be obtained by applying the thrust to the end of a beam welded to the blank over the inlet nozzle (thrust "B" in Figure 1). The beam used should be three feet, or more, in length to insure that a sufficiently long moment arm is used to obtain a nozzle moment. The moments are not to exceed the value of 40,000 foot-pounds (480,000 inch-pounds), as called for in the specifications, and the thrusts to create these moments are not to exceed 13,300 pounds.

The first moment is to be applied longitudinally with respect to the vertical axis of the jack and in the plane of the central axis of the unit. The strains induced by this moment are to be completely recorded.

The following moment is to be applied in a similar manner, except that the beam is rotated into a plane forty-five degrees away from the central axis plane and along the line of strain gages 48 and 49, which are placed on the vessel at forty-five degrees from the longitudinal and circumferential gages.

Initial nozzle moment tests are to be performed without hydrostatic pressure applied to the shell. The tests are then to be repeated with application of hydrostatic test pressure to the shell. This will allow comparision of gage data with calculated results for strains due to nozzle moments combined with hydrostatic pressure.

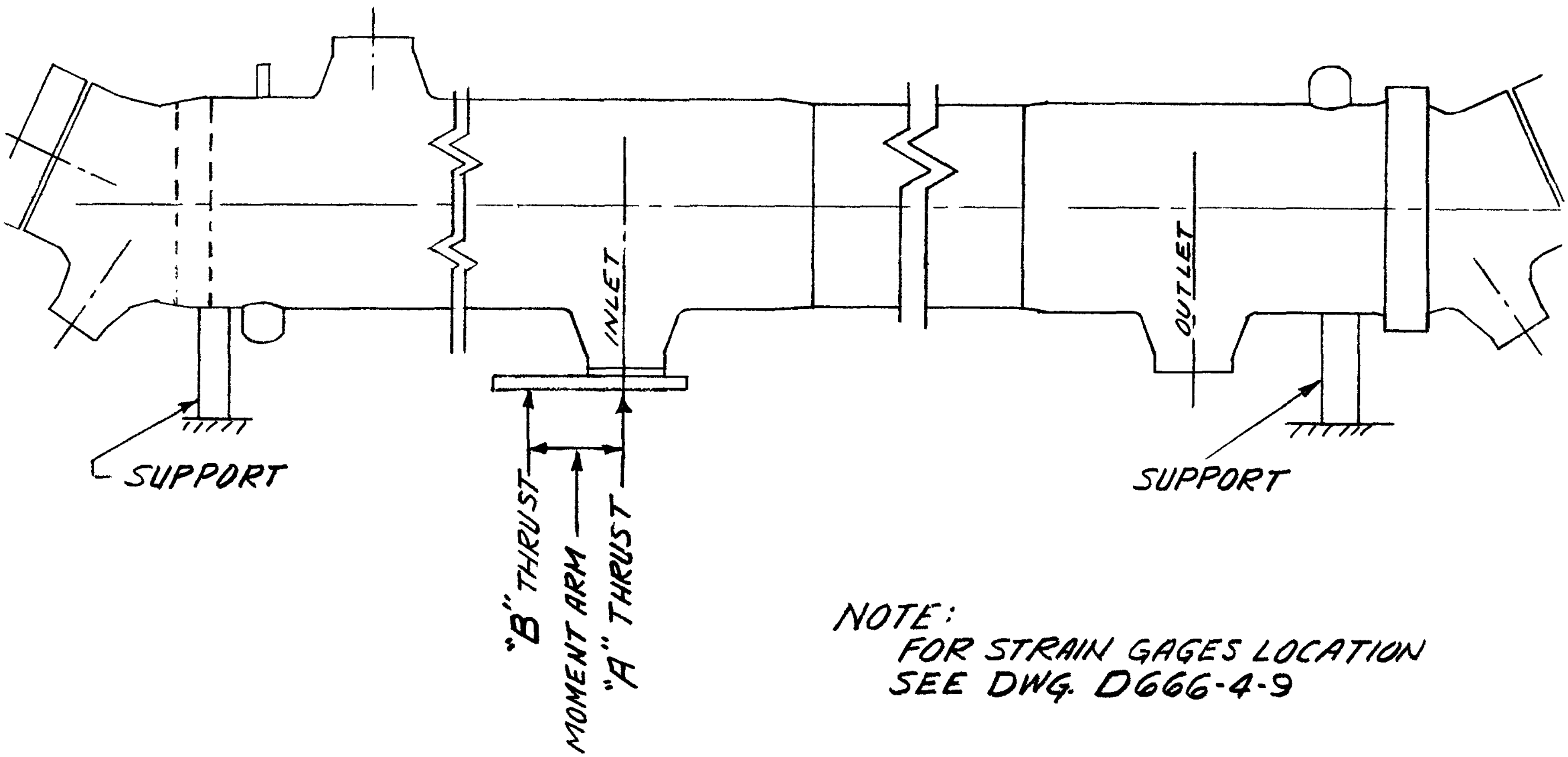


Figure 1 - Steam Generator Position and Location of Nozzle Thrusts

Each test (thrust, moment) is to be performed twice and the values obtained compared. Test values are to be recorded at both increasing and decreasing loads. Any erroneous data are to be discarded and new values obtained. The testing required under this section is to apply loads and record values at zero, twenty-five, fifty, seventy-five, and one hundred per cent of peak load.

IV - STEADY STATE THERMAL PERFORMANCE EVALUATION

This section of the test program outlines those tests which are related to obtaining performance data which will serve to verify the thermal design, or allow application of new techniques for future designs. It is proposed that both units should be tested in combined operation prior to testing the steam generator separately. The test data for combined operation is of more value since both components are involved.

A. INTERMEDIATE HEAT EXCHANGER AND STEAM GENERATOR IN COMBINED OPERATION

1. Test Data

The following test data are to be recorded for all steady state tests of the intermediate heat exchanger and steam generator in combined operation.

a. Primary inlet and outlet sodium temperatures.

b. Secondary inlet and outlet sodium temperatures of both units.

c. Feedwater inlet and steam outlet temperatures.

d. Primary to secondary sodium temperature difference at both ends of intermediate heat exchanger.

e. Secondary sodium to feedwater-steam temperature difference at both ends of steam generator.

f. Internal sodium temperatures of both units.

g. Primary inlet and outlet sodium pressure.

h. Secondary inlet and outlet sodium pressure of both units.

i. Feedwater inlet pressure.

j. Feedwater inlet to steam outlet pressure difference.

k. Primary and secondary sodium flow rate.

l. Feedwater-steam flow rate.

m. Exit steam quality.

n. Sodium gas blanket temperature and pressure.

2. Balanced Sodium Flow

The objective of this test is to obtain performance data for the units in combined operation with the primary sodium flow rate equal to, or balanced to, the secondary sodium flow rate. Another objective of this test is to compare the operative ability of the balanced sodium flow arrangement to the unbalanced sodium flow arrangement. This relates to the previous 70 Mw design which was a balanced sodium flow system. In going to the present 30 Mw design, the sodium flow was unbalanced to reduce the heat transfer surface required for the steam generator from an economic standpoint. As predicted, the prototype units, when operated with balanced sodium flow, should be capable of producing the design steam temperature up to and including 85% heat load or 25.5 Mw, versus 30 Mw which is the design heat load with unbalanced sodium flow.

The predicted operating conditions for this test are included in Table 1, Appendix B. This table includes the predicted conditions for heat loads of 117% (35 Mw) to 20% (6 Mw). It should be noted that the primary sodium inlet temperature to the intermediate heat exchanger, as predicted, must be varied downward from 1200°F to 1101°F for heat-loads of 85% to 20% to keep the steam outlet temperature from exceeding 1050°F. Likewise it should also be noted that for heat loads from 85% to 117% with 1200°F primary sodium inlet temperature, the steam temperature will decrease from 1050°F to 965°F. As specified by the feedwater-condenser system limitations, the feedwater temperature for the 115% and 117% heat load operation has to be reduced to 585°F.

3. Unbalanced Sodium Flow

The objective of this test is to obtain performance data for the units in combined operation with the primary sodium flow rate unbalanced in a 4 to 3 ratio to the secondary sodium flow rate. This is the final flow arrangement which resulted from the 30 Mw design evaluation study to establish the most economical combination of the heat exchanger and once-through steam generator. Another objective of this test is to compare the operation and control of the unbalanced flow arrangement to that of the balanced flow arrangement as presented in the previous test.

The predicted operating conditions for this test are included in Table 2, Appendix B. This table includes the predicted conditions for 117% (35 Mw) to 20% (6 Mw). It should be noted that the primary sodium inlet temperature to the intermediate heat exchanger, as predicted, must be varied downward from 1200°F to 1089°F for heat loads of 100% to 20% to keep the steam outlet temperature from exceeding 1050°F. Likewise it should be noted that for heat loads from 100% to 117% with 1200°F primary sodium inlet temperature, the steam temperature will decrease from 1050°F to 1007°F.

4. Confirmation of Part Load Thermal Design and Performance

The objective of this test is to obtain performance data for the units in combined operation which will help to confirm the design selected in order to minimize part load sodium stratification. This is a condition whereby the sodium will rapidly go isothermal during low flow rates and at shutdown conditions which causes the units to go inoperative and also creates severe temperature gradients. This condition has been experienced in shell and tube sodium to sodium heat exchangers and particularly ones horizontally installed.

The test procedure proposed is to vary the sodium velocity or flow rate from the design value downward on one side of the heat exchanger, holding the other side constant. With the units in combined operation, it is only practical to vary the secondary sodium flow rate while holding the primary sodium flow rate constant. It would be possible to perform the other version of this test had not the steam generator been used for the heat sink. The units are instrumented internally on the shell-side with a vertical arrangement of thermocouples to determine regions or areas of stratification.

The predicted operating conditions for this test are included in Table 3, Appendix B. The basic procedure for performing this test is to start with a heat load of 66-2/3% or 20 Mw and a balanced sodium flow arrangement of 1.14×10^6 lb/hr. Then, vary the secondary sodium flow rate and heat load downward, holding the primary sodium flow rate constant. It should be noted that the temperature range on the sodium side of the steam generator is held constant at 200°F or from 975°F to 775°F. In addition, the terminal temperature difference between the primary sodium inlet and secondary sodium outlet temperature will approach zero between heat loads of 30% (9 Mw) and 40% (12 Mw). It is hoped that operation can be continued, since this is only an indication that all of the heat transfer surface is not required. It should be possible to determine the approximate portion of ineffective surface from the vertical arrangement of internal sodium temperature measurements.

B. STEAM GENERATOR OPERATION WITHOUT INTERMEDIATE HEAT EXCHANGER

1. Test Data

The following test data are to be recorded for all steady state separate tests of the steam generator.

a. Sodium inlet and outlet temperatures to steam generator.

b. Feedwater inlet and steam outlet temperatures.

c. Sodium to feedwater-steam temperature difference at both ends of steam generator.

d. Internal sodium temperatures.

e. Sodium inlet and outlet pressures.

f. Feedwater inlet pressure.

g. Feedwater inlet to steam outlet pressure difference.

h. Sodium flow rate.

i. Feedwater-steam flow rate.

j. Exit steam quality.

k. Sodium gas blanket temperature and pressure.

2. Normal Load Variation

The objective of this test is to obtain performance data for the steam generator as tested without the intermediate heat exchanger. This test should isolate the operating characteristics of the steam generator and further confirm the thermal design analysis. It is anticipated that this test should duplicate the operating conditions of Section IV-A-3 as presented previously.

The predicted operating conditions for this test are tabulated in Table 4, Appendix B. This table includes the predicted design conditions for heat loads of 100% (30 Mw) to 20% (6 Mw) and overload conditions for heat loads of 117% (35 Mw) to 100% (30 Mw).

3. Reduced Superheat Operation at Pressures of 2200, 1800, 1400 and 100 psi

The objective of this test is to obtain basic design data for once-through steam generators. In predicting the heat transfer rate and surface requirements for the boiling region, pressure and corresponding saturation temperature have a definite effect upon establishing the design equation. In order to establish a reasonable curve or plot of the data, four pressures from 1000 psi to 2200 psi were selected. For each test the superheat of the effluent steam will be reduced gradually until the first trace of moisture appears in the outlet steam. The predicted temperature for this occurrence is approximately 50°F of superheat. The feedwater temperature is arbitrarily set at 50°F below the saturation temperature for each pressure concerned. The steam flow or heat load for each test pressure was limited by condenser - feedwater system considerations. These conditions were determined by Atomics International.

The predicted operating conditions for this test are tabulated in Table 5, Appendix B.

V - DYNAMIC PERFORMANCE OF INTERMEDIATE HEAT EXCHANGER AND STEAM GENERATOR IN COMBINED OPERATION

After startup, normal load changes in the operating range will be made by varying the sodium flow rate and power to match the demand. The objective of this test is to determine the response characteristics of the sodium intermediate heat exchanger and steam generator in combined operation during load changes. The actual procedure for this part of the test program is not presented in detail, since it depends highly upon the capabilities of the equipment available to measure the transient responses of temperatures, and possibly flow rates. Thus, the following is only the basis for this test.

It is proposed that the test procedure follow a transient study of long-term variations, and proceed slowly to short-term, or rapid variations of selected parameters, so as to approach ramp or step changes as specified for the design of both units. The following parameters should be included in this transient study:

1. Sodium flow variations (both primary and secondary).
2. Sodium inlet temperature variations(both units).
3. Combined sodium flow and temperature variations.
4. Feedwater-steam flow variations.

The ramp and step changes specified for the units are given in Appendix C. These transients should be performed as stated, or to the maximum capability of the test facility, if stated rates cannot be achieved. Where both increase and decrease of power demand is required, steady state metal temperatures shall be achieved before reversing the power demand change. Strains and temperatures are to be recorded as described in Section VI-A-1b.

The following parameters are to be continuously recorded during all these tests:

1. Primary and secondary sodium flow rates.
2. Sodium inlet and outlet temperatures (primary and secondary sides of both units).
3. Feedwater-steam flow rate.
4. Feedwater inlet temperature.

5. Exit steam temperature.

6. Exit steam quality.

7. Steam pressure or feedwater inlet pressure.

8. Sodium gas blanket pressure and temperature.

9. Internal sodium temperatures of both units.

VI - THERMAL STRESS EVALUATION IN TRANSIENT OPERATION

The thermal stress section of the test program consists of two parts: (a) intermediate heat exchanger test in combined operation with the steam generator, and (b) the steam generator tested separately.

All thermal performance tests will be completed prior to this part of the program. Sufficient temperature data shall be recorded during thermal performance testing to allow calculation of thermal stresses imposed on the units. Stress evaluation of the units will be completed to determine the transient cycles or equivalent stresses which have occurred during performance testing. The number of remaining cycles for various transients needed to meet design requirements can then be given. It may be necessary to reduce the number of cycles for various transients, in order to perform all of the tests in this section before the useful lives of the units are expended. Normal operation procedure limitations given in Volume IV of APAE 112 should be adhered to as closely as possible, except where intentional deviations are the subject for study. The units can thus be subjected to more planned transients.

Strains and temperatures (metal and fluid) to be recorded are given for each transient. Strain gage and thermocouple locations are given on instrumentation drawings in Appendix D.

Strain gages 34 and 35 on the intermediate heat exchanger and strain gages 36 through 44 and 79 through 86 on the steam generator are to be installed at the test facility. Lead wires from interior gages shall be fed through steam outlet piping. An attempt to install strain gage 33 on the interior lip of the heat exchanger tubesheet during fabrication was unsuccessful, and that gage has been eliminated. All other gages are to be installed before hydrostatic testing of the steam generator, and those which do not remain intact during shipment and installation should be replaced at the test facility.

A. HEAT EXCHANGER TEST WITH STEAM GENERATOR AS HEAT SINK

1. Effect of Intermediate Heat Exchanger Transients in Intermediate Heat Exchanger

The transients are those specified for the intermediate heat exchanger, as given in Appendix C, Part 2. Of necessity, they have an effect in the steam generator. This is discussed in Section VI-A-2. The following procedures will alleviate stresses in the steam generator, where possible, while allowing maximum stresses to be achieved in the heat exchanger.

a. Normal startup and shutdown cause high stresses in the thick metal areas of the unit. The normal maximum rate of either startup or shutdown is 100°F per hour, except that an initial change in fluid temperature of 150°F in fifteen minutes or longer is permissible only if the unit has been at some steady state level sufficiently long to attain steady state metal temperatures. Normal startups are a necessary prelude to other performance testing and are not required simply to record a given number of startup cycles.

For all startups (or shutdowns), metal temperatures are to be recorded at intervals of five minutes, or less, with sodium temperatures being continuously recorded. Strains are to be recorded at five minute intervals, or less.

b. Linear and step load-changes result in stresses below the endurance limit of the material and need not be considered. These load changes will be accomplished as part of the dynamic performance testing Section V, so that temperatures and strains may be recorded at that time. Temperatures are to be recorded continuously and strains are to be recorded at intervals of one-fifth the time of duration of the transient as a maximum interval of recording. All recording is to be maintained until steady-state metal temperatures are attained.

c. A reactor scram is to cause the following changes in primary sodium inlet temperature:

(1) Temperature drops 60°F in one-half second.

(2) It drops a total of 130°F in six seconds.

(3) At the end of the transient, the temperature is the normal outlet temperature (900°F).

The 60°F drop in the required time is beyond system capability. However, the same magnitude of stress will be achieved, if the drop in inlet temperature to 900°F is attained at a rate not to exceed 130°F per six seconds. When the inlet temperature reaches 900°F, this inlet temperature is to be maintained for five minutes, after which the inlet temperature may be brought back to 1200°F at the normal startup rate. Approximately two minutes after the 900°F inlet temperature is attained, the maximum stresses in the upper tubesheet are expected. Metal and sodium temperatures are to be continuously recorded until normal operation is resumed, after which temperatures may be recorded as desired for control. The number of cycles required will be specified after the thermal performance testing has been completed.

d. A stoppage of primary sodium flow with continued flow of secondary sodium creates high stresses in the upper tubesheet of the intermediate heat exchanger. Approximately one and one-half minutes after primary circulation is stopped, the primary sodium near the upper tubesheet will be 800°F. When this approximate temperature is reached, the secondary sodium circulation is to be stopped. About two minutes later, maximum stress values will be attained at the upper tubesheets, so that it is sufficient to hold this condition for five minutes. After this time, both sodium circulations will be resumed and normal startup procedure employed.

All metal temperatures in the vicinity of the upper tubesheet and necessary sodium temperatures, are to be recorded continuously until normal startup procedure is employed. It is not necessary to record strains or temperatures near the lower tubesheet as the temperature changes expected are small. The number of cycles to be performed will be specified after the thermal performance testing has been completed.

e. A stoppage of the secondary sodium flow with continued primary sodium flow creates high stresses at the lower tubesheet of the intermediate heat exchanger. Since this casualty condition causes a rise in the temperature of the primary sodium returning to the sodium heater, this test must be performed at reduced flow. Prior to performing this casualty, both sodium flows and feedwater flow are to be reduced to the sixty per cent level. Temperature levels are different from those at full flow, but gradients and resulting stresses obtained at reduced flow are not significantly different than those that would be obtained at full flow.

When the secondary sodium flow has been stopped, continue the flow of the primary sodium until the outlet sodium temperature approaches 1200°F. At this time, stop the primary flow and allow the system to remain at this condition for five minutes. After this period, the primary circulation is to be resumed and its temperature lowered to 900°F; at which point, the secondary sodium circulation may be resumed and the units returned to normal operation. Care shall be taken to avoid rapid temperature changes and unnecessarily large temperature differentials during return to normal operation. Limitations given in normal operating procedures, Volume IV of APAE 112, shall be adhered to, where possible.

Strain gages near the lower tubesheet and thermocouples in this area should be continuously recording. Other thermocouples are to record as required to maintain control.

The number of cycles to be performed will be specified after the thermal performance testing has been completed, and the unit has been evaluated from a stress viewpoint.

2. Effect of Intermediate Heat Exchanger Transients in the Steam Generator

a. Startup and shutdown rate in the steam generator will closely approximate the rate in the intermediate heat exchanger. Thus, the startups in the intermediate heat exchanger are also specified startups in the steam generator. The startup rate limitations are given in the operation procedure (APAE 112, Volume IV).

b. Linear and step-load changes are not to be performed, except as occur during thermal performance testing.

c. Upon a reactor scram, the secondary sodium entering the steam generator will drop in temperature, creating high stresses in the upper head as the steam temperature drops. The steam outlet temperature is not to be allowed to drop below 850°F. When the temperature approaches 850°F, the steam flow is to be slowed, or stopped if necessary, to maintain an 850°F steam outlet temperature. Strains and temperatures are to be recorded at ten to twenty second intervals in the vessel interior, and at two to three minute intervals on the exterior in the vicinity of the upper tubesheet and head. Continuous recording of interior strains and temperatures should be considered. It is necessary to record only temperatures at the lower end of the vessel, and then only as required to know the sodium temperature gradient along the length of the vessel.

d. A stoppage of the primary sodium flow will have the same effect in the steam generator as described in Section VI-A-2c. When the steam outlet temperature approaches 850°F, slow or stop steam flow to maintain 850°F temperature as long as possible. Secondary sodium flow is stopped as described in Section VI-A-1d. Record strains and temperatures as in Section VI-A-2c.

e. Treat a stoppage of secondary sodium flow as described in Section VI-A-2d.

B. STEAM GENERATOR TESTED SEPARATELY

Prior to imposing and transients on the steam generator, it is necessary to evaluate fully the effect of all transients imposed from the thermal performance testing, and those transients that occurred during the thermal stress testing of the intermediate heat exchanger. Some of the transients imposed upon the intermediate heat exchanger will have caused transients in the steam generator equal to those that are expected from specified steam generator transients. This means that prior to performing any testing under this section the steam generator will have already been exposed to many of the transients required by the specifications. The useful life of the unit should not have been expended by this time, so that the transients numerated in this section may be run a designated number of cycles to be determined by stress evaluation.

The following tests will be conducted to demonstrate the performance of the unit under transients given in design specifications, Appendix C, Part 1:

1. Normal startup and shutdown damage factors can be calculated from temperature and strain data obtained. Equivalent damage factors from more severe transients can then be substituted for the damage factor which would result from the specified number of cycles for startup and shutdown. This will preclude the necessity of performing one thousand startup cycles to demonstrate the capability of the unit.

   Although the 30 megawatt prototype steam generator is capable of startup rates consistent with present reactor plant requirements, there is a need for data to evaluate the capability of larger units. A major problem which will have to be faced in the design of larger units is that the thicker metal wall will necessitate more gradual temperature changes, in order to prevent prohibitively high thermal stresses. In consideration of this problem, data on actual temperature gradients which occur during various startup rates for the 30 megawatt prototype unit will give a sound basis for stress analysis of future larger units to determine their limitations.

   The controlling feature of a future design will probably be the thick-walled heads of the steam generator. The surface stresses developed in the thicker material, ignoring bending, will furnish a good measure of the severity of a transient. Typical calculated values of surface stresses (psi), as a result of various rates of temperature change are as follows:

Wall Thickness	30 Mw Unit 3-1/4 inches	30 Mw Unit 7 inches	Future Large Unit 11 inches
1000°F Change			
at 50°F per hour	-	-	32,000 psi
100°F per hour	-	24,600 psi	62,400 psi
200°F per hour	10,800 psi	57,100 psi	111,800 psi
400°F Change			
at 50°F per hour	-	-	30,000 psi
100°F per hour	-	24,200 psi	51,500 psi
200°F per hour	-	47,000 psi	71,900 psi
400°F Change			
400°F in ten minutes	57,900 psi	83,200 psi	95,300 psi
400°F in one minute	68,300 psi	87,700 psi	101,000 psi

Corresponding allowable stresses (psi) for Type 316 stainless steel are as follows:

Temperature °F	2500 Cycles	1000 Cycles	500 Cycles
70 to 650	45,000 psi	57,000 psi	66,000 psi
1050	34,000 psi	42,000 psi	48,000 psi

These allowable stresses must include pressure, as well as thermal stresses, and should contain an allowance for possible local stress concentration.

The following startup and shutdown tests will be performed to obtain temperature and strain data on the steam generator heads, which will aid in thermal stress evaluation for possible future startup requirements:

a. Start with an initial rise (or drop) in sodium temperature of 150°F in a relatively short period of time, approximately one-half hour.

b. Proceed to a steady rise (or drop) of 20°F per hour until the operating temperature is reached.

For a future unit of larger size, the initial change of 150°F could be maintained, but the steady change thereafter would have to be reduced to a lower figure than the normal startup rate (100°F per hour) for the 30 Mw unit. For this test, the given initial startup rate should be maintained, and then followed by progressively faster startups, increasing the rate in steps of 20°F per hour. The test should be repeated at progressively faster rates until a rate is reached for which the 30 megawatt unit will not withstand more than one thousand startup and shutdown cycles. This rate will be determined by stress analysis based on temperature and strain data obtained at conclusion of each cycle. During these tests, metal temperatures near the tubesheets are to be recorded at intervals sufficient to indicate any temperature change of 10°F, or less. Strains are to be recorded at five minute intervals, or less. Sodium temperatures are to be continuously recorded.

2. Normal step and ramp-load changes need not be considered here. Temperatures and strains shall be recorded during dynamic performance evaluations.

3. For a stoppage of the primary sodium flow with continued flow of the secondary sodium, the secondary sodium inlet temperature is to change at a maximum rate of 35°F per second for three seconds, and accomplish a drop from the normal sodium inlet temperature (1175°F) to the normal sodium outlet temperature (775°F) in fourteen seconds. The rate of

change, within limits, is not critical, so that, if the 400°F change takes fourteen seconds, or as much as thirty seconds, the resulting stresses in the upper head and tubesheet will be the same for either rate of temperature change. When the inlet sodium temperature drops to 775°F, the steam flow and sodium flow are to be stopped and the unit allowed to attain equilibrium. Maintain this condition for ten minutes as maximum stresses will have been attained within this time. After ten minutes or more at this condition resume secondary sodium circulation and feedwater flow raising the inlet sodium temperature as prescribed in the normal operation procedure.

Record temperatures and strains in the upper head at 15 to 20 second intervals (or continuously), and continuously on the sodium inlet nozzle during this transient. The number of cycles will be specified by stress evaluation to determine the remaining life of the unit.

4. For a stoppage of the secondary sodium flow with continued feedwater flow the above transient will be duplicated except for the rate of temperature change at the sodium inlet, which is fixed by the design of the unit. For this transient simply stop sodium flow and proceed as described in Section VI-B-3.

   The specifications call for a rate of change in sodium temperature at the sodium inlet which may or may not be attained with this unit. When the sodium flow is stopped, continue the feedwater flow until the inlet sodium temperature drops to 775°F. At this temperature, stop the steam flow and allow the unit to come to equilibrium. Strain and temperature recordings are to be handled as in Section VI-B-3.

5. A stoppage of the feedwater flow with continued secondary sodium flow must be accomplished with the sodium and feedwater flowing at their 60% level prior to cessation of the feedwater flow. After the feedwater flow has been stopped, the outlet sodium temperature will rise, eventually to 1175°F. When it has risen to 1175°F, allow the sodium flow to continue at this level for 45 minutes, after which, the sodium outlet temperature is to be lowered to approximately 775°F at a slow rate by resumption of feedwater flow.

   Metal and sodium temperatures, and strains, are to be continuously recorded in the vicinity of the lower tubesheet on the shell side with 2 to 3 minute intermittent recording on the tube side of the tubesheet and in the lower drum. Temperatures away from the lower tubesheet may be recorded as desired.

   The number of cycles will be specified by stress evaluation to determine the remaining life of the unit.

VII - CHEMICAL EVALUATION

As part of the design program to develop a more reliable sodium heat exchanger and steam generator, certain chemical considerations were made to establish specifications for materials, and procedures for fabrication, operation and maintenance. To further these considerations in establishing the design and operating specifications for future sodium components of this type, it is proposed that this test program include experimental procedures to determine certain chemical data and supporting test information.

Test data desired on both the steam generator and intermediate heat exchanger, tested separately or together, will include the following during all operations:

1. Periodic chemical analyses on both sodium systems, the frequency to be determined by the consistency of results. Analyses shall include determination of carbon, calcium, iron, nickel and chromium; in addition, oxygen and hydrogen content of the sodium shall be determined with sufficient frequency to detect significant fluctuations. A chronological log book of results is desirable.

2. Both sodium systems shall include a plugging indicator, which is set to give an indication when the desired sodium oxide operating level has been exceeded. This maximum operating level shall be no greater than 50 parts per million sodium oxide. A compact log book of all operational time in excess of allowable oxide concentration, indicating maximum oxide level attained, shall be kept for convenient reference.

3. The Atomics International developed hydrogen detector shall be included in the system.

4. Evidence of mass transfer, or accumulation, of sodium impurities at some point in either sodium system, and any operational difficulties which result, shall be recorded with chemical data.

5. The tube side of both units should be inspected for general condition in accordance with Volume IV, APAE 112. Inspection dates, and remarks concerning the appearance of the units, shall also be recorded chronologically with chemical data.

The following additional information is desired from the steam generator testing program:

1. Behavior of the gas blanket and the sodium liquid level are to be determined by simultaneous measurement of (1) gas blanket temperature,

(2) gas blanket pressure, and (3) liquid level versus flow rate from 0 to 117 per cent load. In addition, any evidence of gas entrainment in sodium, or entrapment at any point of the system should be noted. Variations of the liquid level with time at corresponding temperature, pressure, and flow conditions will give indication of any change in the quantity of gas present in the gas blanket.

2. Performance of the sodium liquid level indicator.

3. Complete drawings on design of the water system and water purification system are desired. Water chemistry data should include chemical analyses of feedwater and condensate for determination of total solids, conductivity, oxygen, silica, iron, copper, nickel, chromium, and pH as related to water treatment. Data on boiler shutdown conditions and on operation for transient periods under any abnormal feedwater conditions are also required.

VIII - METALLURGICAL EVALUATION

A. EFFECT OF HIGH TEMPERATURE SODIUM ON PROPERTIES OF WELD TEST PLATES

Design criteria for high temperature applications of materials are based primarily on stress-rupture and creep properties. These data, however, do not consider damage due to corrosive environments or microstructural changes influenced by constituents that may not be present in representative samples of the fabricated material.

The Type 316 weld metal and base plate of the intermediate heat exchanger and steam generator may undergo minor changes in microstructure after long-time exposure to the operating temperature of these units. At operating temperature of 1175°F, sigma phase can form from austenitic Type 316 stainless steel, as well as from the ferrite phase in Type 316 weld deposits. Since sigma is a harder and more brittle phase than either the austenite or the ferrite, it is conceivable the mechanical properties of both base metal and welded joints may be adversely affected after long-time exposure to the service temperature.

This program was initiated to compare the mechanical properties and microstructure of unexposed welded joints with welds subjected to 1175°F sodium for several thousand hours. The details relating to materials, welding procedures, mechanical properties, and representative microstructure of welded and tested joints, are included in Appendix A. These data are to be used in comparing results of the program, since both the "as-welded" test plates and exposure test plate were prepared from the same base metal and welding electrodes and were welded using an identical welding procedure.

1. Test Specimens

Four test specimens, as installed in the intermediate heat exchanger in accordance with drawing B-666-3-17, Appendix D, are identified as follows:

a. One Drilled Hole: Two samples were prepared using 16% Cr - 8% Ni - 2% Mo welding electrodes. The root pass was made with 5/32 inch diameter electrodes from heat No. 32167, lot 21. The joint was finished using 3/16 inch diameter electrodes from heat No. A61489, lot 7.

b. Two Drilled Holes: Sample was prepared using Type E316-15, 3/16 inch diameter electrodes from heat No. 34214-J.

c. Three Drilled Holes: Sample was prepared using Type E316, 3/16 inch diameter electrodes from heat No. 29032-H.

The welds are in the center of all specimens, and are transverse to the long dimension.

2. Test Procedure

At the first shutdown of the intermediate heat exchanger, which occurs after four thousand hours of accumulated service, the test plates shall be removed from the unit. Side bend tests and reduced section tensile tests shall be conducted in accordance with Section IX of the ASME Boiler and Pressure Vessel Code. Results obtained shall be compared with the data for the "as-welded", unexposed qualification test plates given in Appendix A of this report. The weld, fusion zones, heat-affected-zones, and base metal shall also be examined metallographically to determine the relative increase of sigma phase that may have formed during exposure to the service temperature. The corrosive effect of 1175^{O}F sodium on the weld deposits shall also be observed.

3. Discussion

Welded joints made in certain austenitic materials under high restraint have a propensity toward cracking in the weld metal and fusion zone, due to a resistance to plastic flow at temperatures normally encountered during welding or in service. These difficulties can be relieved by providing the weld metal deposit with a chemistry that will be conducive to the formation of a small per cent of delta ferrite, which has been found effective for increasing hot ductility. Therefore, the test plates were prepared with welding electrodes that would deposit zero per cent ferrite (AWS E316-15) and one to four per cent ferrite (Type 316 modified, 16% Cr - 8% Ni - 2% Mo). Cracks were not observed in any of the test plates prepared with each type of electrode. Since fully austenitic Type E-316-15 welds are more prone to fissuring, it was concluded that more reliable service could be expected by utilizing the modified Type 316 electrode for the intermediate heat exchanger and steam generator fabrication.

The hot ductility of welds containing small amounts of ferrite may be reduced after long-time exposure to 1175^{O}F sodium, due to a possible conversion of the ferrite to sigma. If this transformation occurs, the ferrite would no longer be available to enhance the hot ductility and the susceptibility to cracking may be increased, because of the presence of the hard and brittle sigma, as well as precipitated carbides.

Since no cracking occurred during welding of the test plates, it is not expected that cracks will develop in the weld, heat-affected zone, or base metal during exposure of the subject unrestrained test plates. Cracking that may develop during the 180 degree side bend tests would indicate that a change in metallurgical structure had occurred in the sample during exposure. This fact could be confirmed by metallographic examination and micro hardness determination of any new constituent found.

All reduced section transverse tensile test samples failed in the base metal well outside the weld heat-affected zone, indicating that the mechanical properties of the base metal were lower than the weld and heat-affected zones. Tensile strength averaged 78,400 psi for all samples. Sigma phase dispersed in a soft austenitic matrix will increase the room temperature yield strength, but will decrease the tensile strength and ductility. If the tensile test results of the exposed test plates indicate a reduction in ultimate tensile strength values, assuming failure takes place in the base metal, sigma formation could be the contributing factor to the loss in strength. If failure occurs in the weld or heat-affected-zone, then the amount of sigma that is formed may be less than that formed in the base metal. Other factors, such as the size and dispersion of the sigma phase, precipitated carbides and possible localized attack by sodium, naturally, would affect these conclusions. All results should be confirmed and evaluated by a complete metallographic examination.

If no cracking, or other defects, are revealed by the side bend tests, and tensile test results are comparable to tests of the "as-welded" specimens, it may be concluded that sigma and other metallurgical changes that may have occurred in the test plates during long-time exposure to 1175°F sodium had no effect on the mechanical properties of the welds or base material.

B. POST TEST EVALUATION OF UNITS

Upon completion of all scheduled tests to be conducted on both the prototype sodium steam generator and intermediate heat exchanger and prior to scrapping the units, the following destructive tests are proposed to determine what effect high temperature sodium and operating stresses had on the various areas within these units.

1. Tubes

Type 316 welded tubing was selected for the intermediate heat exchanger, and was ordered to commercial specification (ASTM A-249) with minor modifications to conform to the economical design provision in the contract. While the tubing, as received from the supplier, meets all provisions of the sodium components specification for Type 316 stainless steel welded tubing, the tubing surface was covered with macroscopic pits, which may have resulted from over pickling. A shallow longitudinal defect (0.001 to 0.002 inch deep) was also present on the outside diameter surface in the weld. This defect was intermittent along the length of many of the tubes, and may have been a result of lack of fusion and insufficient conditioning of the weld flash. The tubing was not structurally weakened, and was within specification in spite of this defect. However, the defect in an area where dirt, grease, or other residue could be entrapped, and may not be removed by subsequent cleaning. A hydrostatic test was conducted on a length of tubing containing the defect. A pressure of 15,000 psi was applied before the tube failed. The failure initiated in an area approximately 1/16 inch from the weld. Ultimate fiber stress in the wall was 107,000 psi.

Several tubes shall be selected when the intermediate heat exchanger is available for destructive evaluation, and shall be dye-penetrant and eddy-current inspected. Tubes containing weld defects shall be hydrostatically tested to destruction to determine if the "as-received" strength will be reduced by long-time exposure to high temperature sodium, and if the weld imperfection will become a focal point for failure. The weld areas and outside diameter surface shall also be examined metallographically to determine if the weld imperfection and pickling pits acted as initiation sites for subsequent corrosion. If any defects are observed by eddy-current inspection, the defective area shall be further inspected metallographically to determine the nature of these defects.

A destructive hydrostatic test is also recommended for the "as-received" steam generator composite tubes. A similar test program, as outlined above for Type 316 stainless steel tubing, shall also be conducted on the composite tubes.

Samples shall be selected at various locations along the length of the tubes to determine corrosion damage, pitting, deposits of scale and dimensional changes. Mass transfer, intergranular corrosion, sigma phase formation and structural changes shall be determined metallographically from these samples.

Erosion damage and excessive wear from the baffles shall also be investigated.

2. Tube-to-Tubesheet Welds

Tube-to-tubesheet welds and tubesheet, including the Inconel overlay, shall be dye-penetrant inspected to determine if cracking, or any other defects, have developed during service. The welds shall then be sectioned and examined for entrapment of sodium in the crevice, and excessive corrosion in these areas. The welds shall also be examined metallographically for microcracks and structural changes.

3. Inconel Overlay

The Inconel overlay on the tubesheets, and all other internal surfaces on the steam side of the steam generator, shall be inspected for attack by steam, which shall include scaling, cracking and erosion damage. All areas shall also be inspected for exposed stainless steel. If any cracks or exposed stainless steel are discovered, those areas in the stainless steel shall also be inspected metallographically for stress corrosion cracking.

4. Shell and Channels

The manway studs will be checked for increase in length resulting from relaxation, and shall also be dye-penetrant inspected for cracking, or other defects.

Damage to the shield and shroud, as well as baffle distortion, shall be checked.

Nozzles and other attachments shall be inspected for erosion and distortion.

IX - INSTRUMENTATION

This section of the test program describes the special instrumentation to be installed on the intermediate heat exchanger and steam generator for the purpose of making certain temperature and strain measurements. In addition to the special instrumentation as described below, both units should be instrumented to record the fluid temperature and pressure in the piping adjacent to each nozzle; the temperature difference of the fluids at both ends of each unit; the pressure difference from the feedwater inlet to the steam outlet; the flow in the primary sodium, secondary sodium and feedwater piping; the sodium gas blanket pressure; and the sodium level in the steam generator.

A. INTERMEDIATE HEAT EXCHANGER

1. Internal Sodium Temperatures

During fabrication, sixty thermocouples are to be installed inside the shell and on the primary sodium side of the intermediate heat exchanger. These thermocouples can be divided into four basic groups. The purpose of each group is as follows:

a. Upper and Lower Annulus Temperatures

In order to determine the relative heat transfer effectiveness of the entrance sine-wave bend region, central baffled region and exit region, thirty-six thermocouples are installed in the annular sodium passage outside three disc baffles, twelve at each baffle, and as shown in drawings C-666-3-9 and C-666-3-11 included in Appendix D.

By measuring the mean sodium temperature at the inlet and outlet of each major heat transfer region, it should be possible to make a heat balance and comparison for each region. The three levels selected include two adjacent levels at the inlet to the main or central baffled region. The purpose of the second level is to check the maldistribution of sodium flow that might exist from the entrance and sine-wave bend region.

b. Vertical or Axial Arrangement of Center Temperatures

A vertical arrangement of thirteen thermocouples are installed as shown in drawing D-666-3-7. Each of these thermocouples are located at the center of each doughnut baffle. The purpose of these thermocouples is basically to determine the effect of sodium stratification at low sodium flows. Sodium stratification is the effect of the unit going isothermal, thus, the designer would like to determine how the unit goes isothermal. This should be possible by a time-temperature recording of the axial or vertical sodium temperature gradient through the unit at low sodium flows approaching shutdown.

c. Crossflow Temperatures

An arrangement of ten thermocouples, as shown on drawing C-666-3-9, are installed between five tubes in the second row from the center and seven tubes in the fifth row from the center which all lie in a thirty degree sector of the tube bundle. Each thermocouple is placed midway between the tubes on the tube row centerline circle, in a plane midway between the second disc baffle and second doughnut baffle down from the sine-wave bend region.

The purpose for these temperature measurements is to study the crossflow heat transfer effect which relates to determining more accurate shell-side heat transfer coefficients. The results of these measurements will be compared to the results of small scale model studies that are in progress at other Atomic Energy Commission test facilities.

d. Upper Pipe Spacer Temperature

One thermocouple is installed, as shown on drawing D-666-3-7, directly underneath the center of the upper tubesheet inside the slotted portion of the center pipe, to measure the local sodium temperature. The pipe is slotted to allow sodium to circulate under the untubed region of the tubesheet. This should provide a more uniform tubesheet temperature during transients. To confirm this approach, it is necessary to record the sodium temperature at this location.

2. External Shell and Tubesheet Metal Temperatures

At the test facility, thirty-six thermocouples are to be installed at selected locations on the external metal surface of the intermediate heat exchanger shell, as shown on drawing D-666-3-7, which is included in Appendix D. These thermocouples can be divided into two basic groups. The purpose of each group is as follows:

a. Shell Metal Temperatures Adjacent to Internal Sodium Temperatures

At two levels, Section B-B and Section C-C of referenced drawing, six thermocouples (three at each level) are to be attached to the external metal surface of the shell. The time recording of these temperatures, in conjunction with the adjacent internal sodium temperatures are to be used to determine the effectiveness of the thermal shielding during transients.

b. Tubesheet Metal Temperatures

In the region of the tubesheet-to-shell connections and tubesheet-to-tubeside channel connections, thirty thermocouples are to be installed, as shown on drawing D-666-3-7. These thermocouples are located in vertical groups of five, each group positioned at one hundred-twenty degrees apart, on the upper and lower tubesheets. The purpose of these thermocouples is to record the metal temperature gradient in the region of the tubesheet during transients. This information will be used to predict thermal stresses, in order to confirm the thermal stress analysis.

3. Strain Gage Measurements

At the test facility, two strain gages are to be installed at the lower tubesheet, as shown on drawing D-666-3-7. The transients for which data are to be obtained from these gages are given in Section VI of this report.

B. STEAM GENERATOR

All special instrumentation for the steam generator is shown on drawing D-666-4-9, which is included in Appendix D.

1. Internal Sodium and Metal Temperatures

During fabrication, fifty-nine thermocouples are to be installed inside the shell and tubeside channels of the steam generator. These thermocouples can be divided into three general groups. The purpose of each group is as follows:

a. Vertical or Axial Arrangement of Center Temperatures

A vertical arrangement of thirty-three thermocouples is to be installed, as shown in drawings D-666-4-9 and C-666-4-10. Of these, twenty-six thermocouples are located in the baffled region, one at the center of every doughnut baffle, except the topmost baffle; three thermocouples located in the liquid level measurement region; and four thermocouples in the gas blanket region.

The purpose of the twenty-six thermocouples in the baffled region is to check for sodium stratification in much the same manner as described for the intermediate heat exchanger. The purpose for the three in the liquid level measurement region is to supplement and check the liquid level measurement device. The purpose of the four in the gas blanket region is to determine the temperature gradient between the sodium-free surface and the upper tubesheet.

b. Internal Metal Temperatures in Region of Tubesheets

In the region of the lower tubesheet, twelve thermocouples are installed, as shown on drawing D-666-4-9. Of these, nine thermocouples are attached to the upper face of the lower tubesheet to measure local metal temperatures, as required to confirm the thermal stress analysis of the lower tubesheet. The other three thermocouples are attached to the upper thermal shield, directly above three of the lower tubesheet face thermocouples. The recording of these six temperatures during transients should determine how effectively the group of thermal shields perform in protecting the lower tubesheet of the steam generator against transient sodium temperatures.

In addition to the above, twelve thermocouples are installed in the region of the upper tubesheet, as shown on drawing D-666-4-9. Of these, nine thermocouples are attached to the upper face of the upper tubesheet to measure local metal temperatures of the tubesheet, and three thermocouples are attached to the lower face of the tubesheet, directly underneath three of the upper face thermocouples, to measure the temperature gradient through the upper tubesheet. All of these temperatures are to be recorded during specified transients to confirm the thermal stress analysis of the upper tubesheet.

c. Upper Manway Cover Temperatures

Two thermocouples are located in one of the stud holes of the upper manway cover, as shown in drawing D-666-4-9, to determine the actual temperature of the manway cover. These temperatures are recorded during transients to confirm the thermal stress analysis.

2. External Shell and Tubesheet Metal Temperatures

At the test facility, thirty-six thermocouples are to be installed at selected locations on the external metal surface of the steam generator, as shown on drawing D-666-4-9, which is included in Appendix D. These thermocouples can be divided into two basic groups. The purpose of each group is as follows:

a. Shell Metal Temperatures

At two selected levels along the shielded portion of the steam generator shell, six thermocouples (three at each level) are to be attached to the external metal surface. The time recording of these temperatures in conjunction with the internal sodium temperature is to be used to determine the effectiveness of the thermal shielding during transients.

b. Tubesheet Metal Temperatures

In the region of the tubesheet-to-shell connections and tubesheet-to-tubeside channel connections, thirty thermocouples are to be installed, as shown on drawing D-666-4-9.

These thermocouples are located in vertical groups of five, each group positioned one-hundred and twenty degrees apart on both the upper and lower tubesheets. The purpose of these thermocouples is to record the metal temperature gradient in the region of the tubesheets during transients.

3. Strain Gage Measurements

The strain gage data for the steam generator will be obtained for three tests. The first test is described in Section III-A, and will require a cluster of gages on the upper head, to be applied prior to hydrostatic test, for pressure stress evaluation of the heads. The second test is described in Section III-B, and will require a cluster of gages around the sodium inlet nozzle, to be applied prior to hydrostatic test, for check of the Bijlaard equations as used for design of shell reinforcement in consideration of nozzle thrust and moment. The third test is the transient operation of the unit, as described in Section VI, and will require data from those gages previously used, as well as supplementary gages to be installed on the shell and interior of the upper head at the test facility.

X - APPENDIX A

EVALUATION OF QUALIFICATION TEST SAMPLES

Qualification plates were prepared using electrodes and base materials used on production of the intermediate heat exchanger to insure that these particular heats of material would meet all qualification requirements when evaluated in accordance with the ASME Boiler and Pressure Vessel Code, Section IX. At the time these qualification test plates were welded, duplicate specimens were also prepared using the same base metal, electrodes and welding procedure. These duplicate specimens are to be installed in the intermediate heat exchanger to determine the effect of high temperature sodium on the mechanical and corrosion resistance of the Type 316 base metal and weld deposits. The following data are the results of the evaluation of the qualification test plates. Since the duplicate test plates were prepared with identical materials and welding conditions, the results obtained also apply to these samples.

1. Test Materials

a. The base plate material was cut from a Type 316 stainless steel test tubesheet forging and conforms to ASTM A-182, Grade F316, and Specification NA-666-30Mw-3. It was supplied by Alco-Latrobe from heat No. 701407.

b. The modified E316 stainless steel electrodes (16% Cr-8% Ni-2% Mo) from heat Nos.32167-lot 21, and A61489-lot 7, were supplied by the Champion Rivet Company.

The E316 stainless steel electrodes from heat Nos.29032-H and 34214J were obtained from Alloy Rods Company.

c. The electrodes will deposit weld metal of the following analysis, per supplier's certified test report:

	%C	%Mn	%P	%S	%Si	%Ni	%Cr	%Mo	% Delta Ferrite
Type 316 Base Plate Heat 701407	.058	1.69	.020	.015	.14	12.01	17.90	2.46	0 to 1
E316 Electrode Heat 29032-H	.07	2.26	.028	.012	.34	13.38	18.60	2.42	0
E316 Electrode Heat 34214J	.06	2.09	.024	.014	.23	13.92	18.29	2.30	0
E316 Modified 16-8-2 Electrode Heat 32167, lot 21	.08	2.16	-	-	.27	8.02	15.91	2.41	4
E316 Modified 16-8-2 Electrode Heat A61489-lot 7	.07	1.90	-	-	.39	9.08	16.30	1.60	2

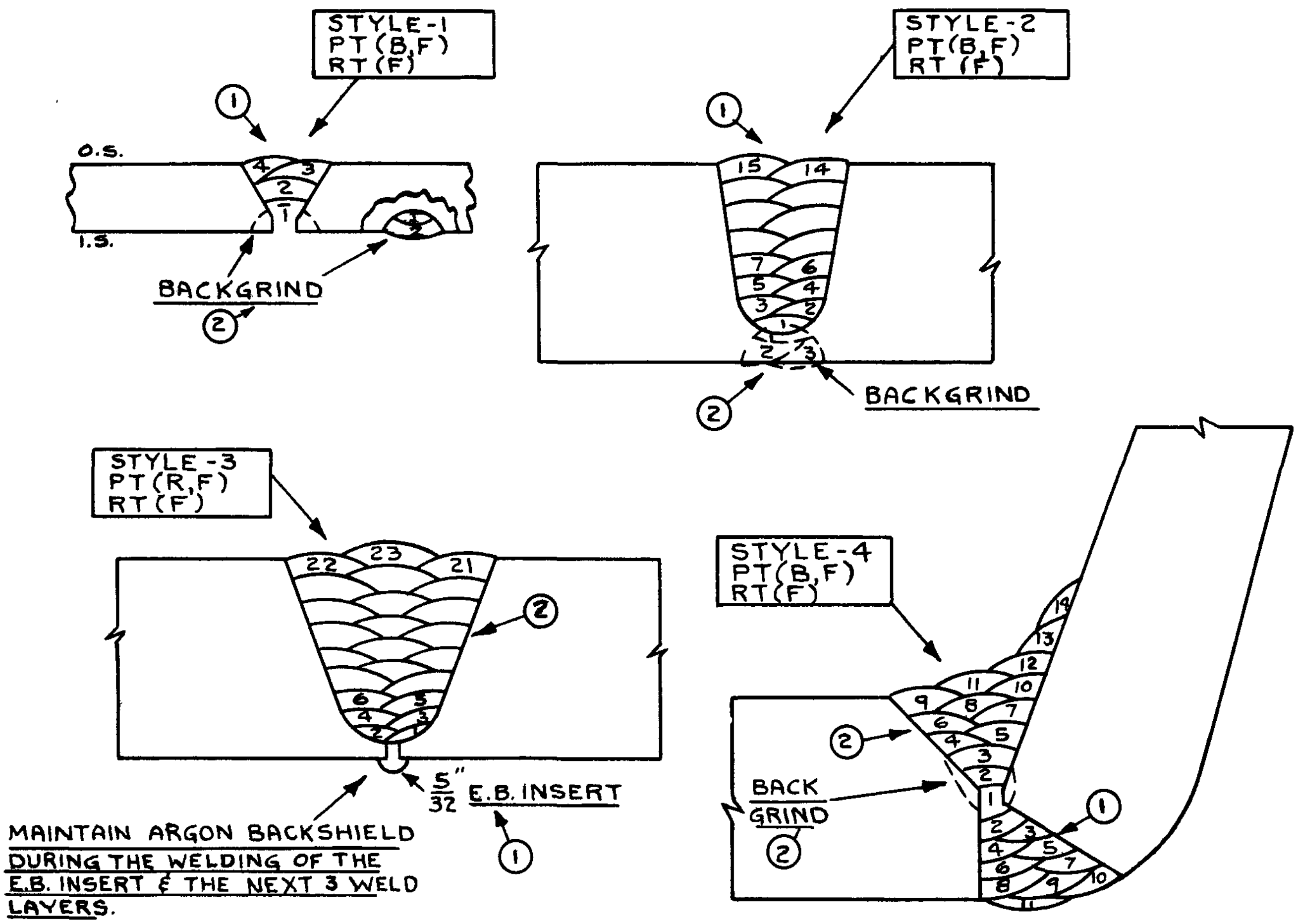
2. Welding Procedure

The qualification test and exposure test plates were welded in accordance with Welding Procedure Specification for Sodium-to-Sodium Intermediate Heat Exchanger No. 44228-W-1, Item 2, Style 2, as illustrated in Figure 2.

The 15/16 inch thick base plate was prepared with a single "U"-groove joint design, having a slope of nine degrees from the vertical, and bottom radius of 1/4 inch. The land thickness was 5/32 inch. Test plates were welded to a backing plate to provide full restraint. Thirteen weld passes were required to complete the joint.

Test plates, 12 x 10 x 15/16 inches were welded along the ten inch dimension, using Type 316 modified (16% Cr-8% Ni-2% Mo) electrodes. Three root passes were made with 5/32 inch diameter electrodes from heat No. 32167-lot 21. The joint was finished using 3/16 inch diameter electrodes from heat No. A-61489-lot 7. The weld qualification test plate was designated as sample No. 337. The exposure test plate was cut along the twelve inch dimension to produce two specimens 4-7/8 x 12 x 15/16 inches, and were identified by one drilled hole in each.

The other test plates, 12 x 12 x 15/16 inches, were welded using two heats of Type E316-15, 3/16 inch diameter electrodes that have been used for partial fabrication of the intermediate heat exchanger. Six inches of the weld was made with heat No. 29032H, and the remaining



BASE MATL. STAINL. STL. PL. SA-240 TP. 316 & FGD. STAINL. STL. SA-182 GR. F-316

FILLER METAL * COATED ELECTRODE E-316-15 MODIFIED (16CR-8NI.-2MO.)

STYLE NO.	SE-QUENCE	BEAD NO.	PROC.	FILLER MAT'L. SIZE	FILLER MAT'L. TYPE	CURRENT VOLTS	CURRENT AMPS	FLUX OR GAS SHIELD	PREHEAT TEMP.	MAX. INTERPASS TEMP.
1	1	1-2	MA	1/8" OR 5/32"	*E-316-15	23-24 24-26	90-110 125-150	—	70°F	350°F
1	1 2	3-4 1-2	MA	3/16" 5/32"	*E-316-15	25-28 24-26	155-195 125-150	—		
2	1	1-FIN.	MA	5/32" OR 3/16"	*E-316-15	24-26 25-28	125-150 155-195	—		
2	2	1-3	MA	5/32"	*E-316-15	24-26	125-150			
3	1	1	TIG	5/32" E.B.	ER-316	11-12	120-140	ARGON 20 CFH		
3	2	1-2 3-4	TIG MA	1/16" 1/8"	ER-316 *E-316-15	15-18 23-24	50-75 90-110	ARGON 20 CFH		
3	2	5-6 7-FIN.	MA	5/32" 3/16"	*E-316-15	24-26 25-28	125-150 155-195	—		
4	1	1-4	MA	1/8" OR 5/32"	*E-316-15	23-24 24-26	90-110 125-150	—		
4	1 2	5-FIN. 1-5	MA	3/16" 5/32	*E-316-15	25-28 24-26	155-195 125-150	—		
4	2	6-FIN.	MA	3/16	*E-316-15	25-28	155-195	—		

Figure 2 - Welding Specification for Shell Long and Girth Seams and 12" Nozzles to Shell

six inches with heat No.34214J. The qualification samples were designated as 336-A (Heat No.29032H) and 336-B (Heat No.34214J). The duplicate plate for the exposure test sample was cut transverse to the weld to produce two specimens 5-7/8 x 12 x 15/16 inches. The test plate made with electrodes from heat No.34214J was drilled with two identification holes, and the test plate welded with electrodes from heat No.29032H with three identification holes.

3. Test Results

a. Bend Tests

The side bend test samples are illustrated in Figure 3. No cracks, or weld defects, were observed in these samples. Metallographic examination of samples from the bend specimens did not reveal any cracks, porosity, microfissures, or other defects. Figure 4 illustrates the microstructure of the weld zone in a No.337 bend specimen.

b. Tensile Tests

Test No.	Filler Metal	Width Inch	Thickness Inch	Area Sq.In.	Load to Failure Pounds	Ultimate Tensile Strength psi
337	Champion	1.425	0.897	1.278	100,200	78,400
	16-8-2	1.420	0.871	1.237	97,200	78,600
336A	Alloy Rods E316-15	1.530	0.859	1.291	101,000	78,200
336B	Alloy Rods E316-15	1.487	0.875	1.301	102,000	78,400

(All failures took place in the base metal outside the heat-affected-zone)

These data are from reduced section tensile specimens; the weld being in the center of the reduced section and transverse to the loading direction. All failures took place in the base metal. No all-weld metal tensile specimens were tested.

c. Chemistry

Chemical analyses of the weld deposits taken from fractured tensile specimens are as follows:

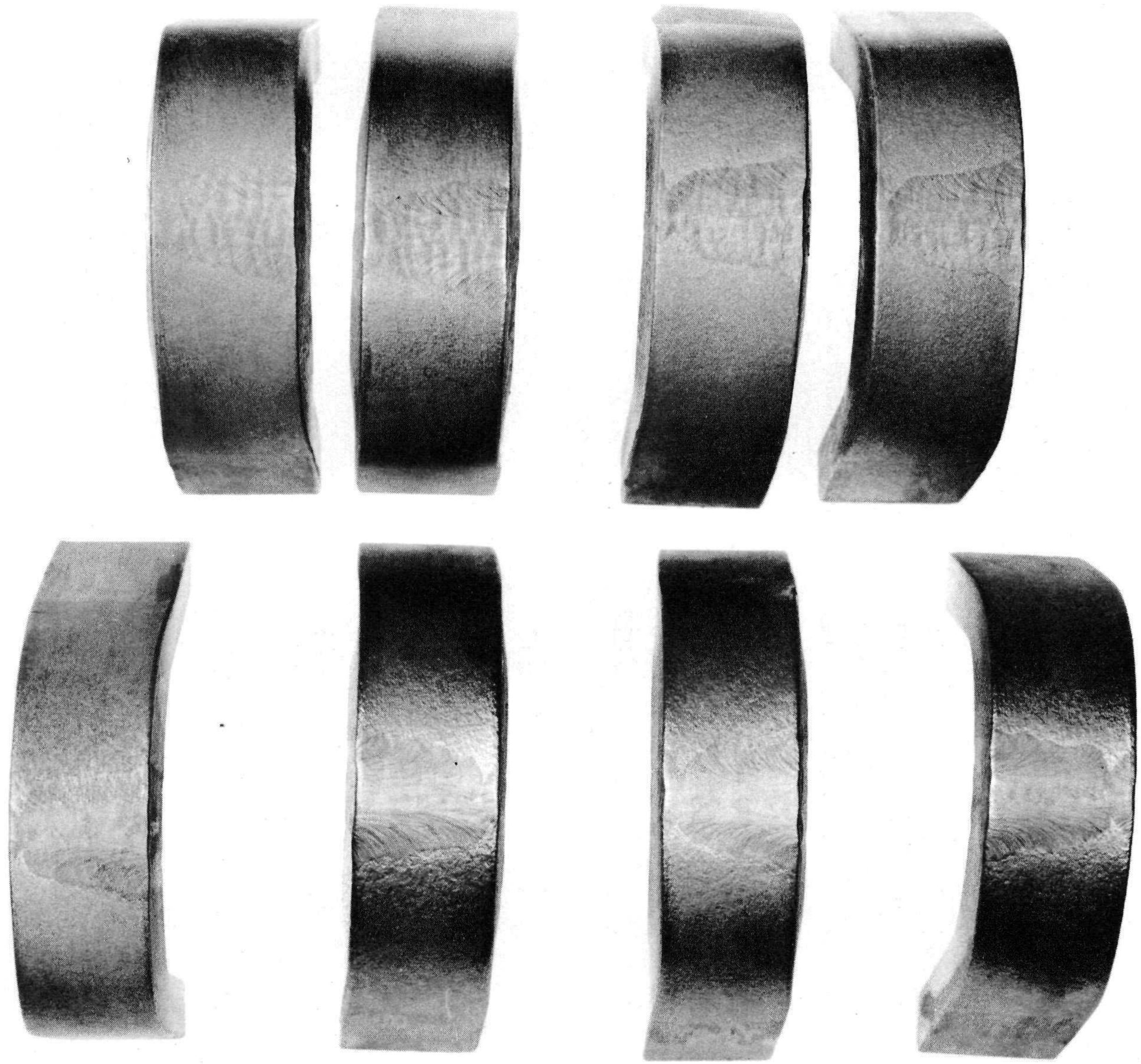


Figure 3 - Side Bend Weld Qualification Test Specimens

Two top left specimens are from sample 336-A. Two top right specimens are for sample 336-B. Bottom four specimens are for sample No.337.

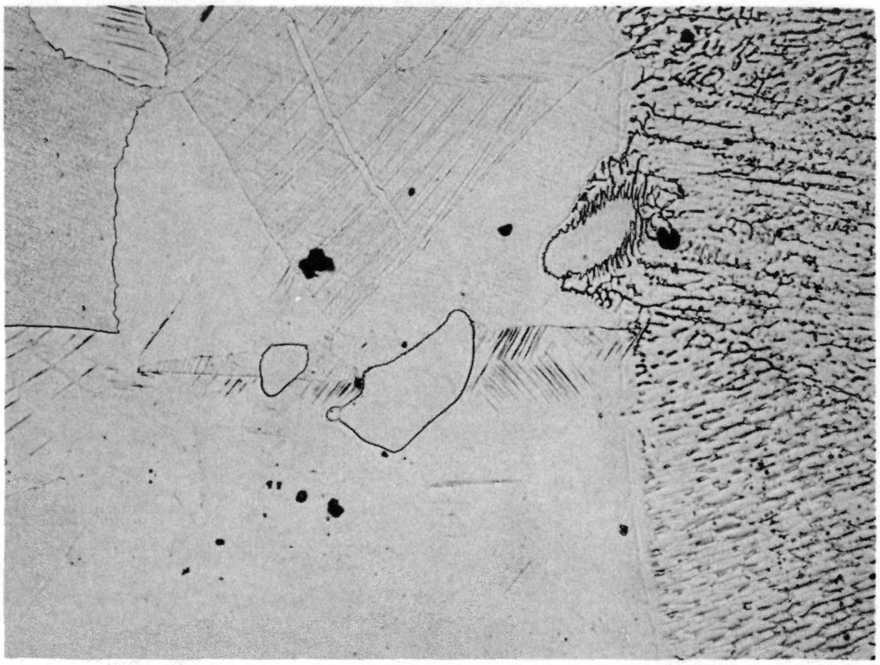


Figure 4 - Microstructure of Bend Test Specimen at Fusion Zone

250X ETCHING REAGENT: OXALIC ACID ELECTROLYTIC

Area on the left is the Type 316 base metal. Structure at the right is the weld metal. Three islands in the center have been identified as ferrite. Weld was made with 16CR- 8N- 2Mo electrodes.

Sample No.	337-1	337-2	336-A	336-B
Carbon	.072/.072	.078/.080	.072/.078	.07/.07
Manganese	2.20/2.20	2.26/2.28	1.94	1.78
Silicon	0.36	0.38	0.68	0.48
Nickel	8.68	8.70	13.33	13.23
Chromium	16.37	16.45	18.64	17.80
Molybdenum	1.53	1.73	2.07	2.07
Per Cent Ferrite	2	2	0	0

Weld deposits in samples 337-1 and 337-2 were made from two different heats of electrodes of slightly different chemistry.

X - APPENDIX-B

PREDICTED OPERATING CONDITIONS FOR STEADY STATE THERMAL PERFORMANCE TESTS

The predicted operating conditions for the steady-state thermal performance tests which are described in Section IV of this report are included in the following tables as listed below:

Table 1. Balanced Sodium Flow-Combined Units

Table 2. Unbalanced Sodium Flow-Combined Units

Table 3. Confirmation of Part Load Thermal Design and Performance-Combined Units

Table 4. Steam Generator Operation without Intermediate Heat Exchanger - Normal Load Variation

Table 5. Reduced Superheat Operation of Steam Generator without Intermediate Heat Exchanger at Pressures of 2200, 1800, 1400, 1000 psi

The following list of nomenclature is used in the above tables:

W_1 - Primary Sodium Flow Rate

W_2 - Secondary Sodium Flow Rate

W_S - Feedwater-Steam Flow Rate

T_1 - Primary Sodium Inlet Temperature to Intermediate Heat Exchanger

T_2 - Primary Sodium Outlet Temperature from Intermediate Heat Exchanger

T_3 - Secondary Sodium Inlet Temperature to Steam Generator

T_6 - Secondary Sodium Outlet Temperature from Steam Generator

T_7 - Feedwater Inlet Temperature to Steam Generator

T_8 - Saturation Temperature

T_9 - Steam Outlet Temperature from Steam Generator

The location of performance temperatures is shown in Figure 5.

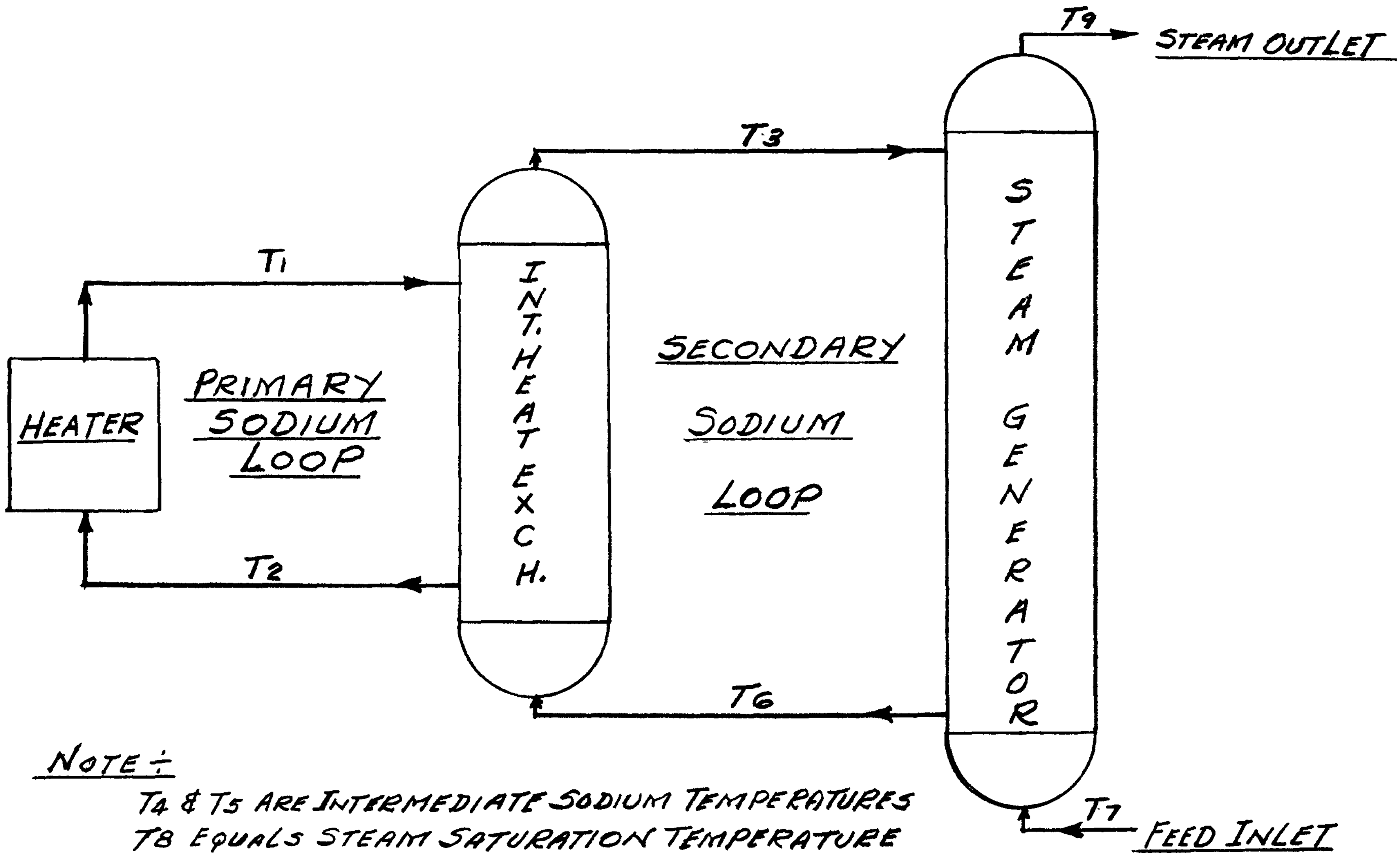


Figure 5 - Location of Predicted Performance Temperature

TABLE 1

BALANCED SODIUM FLOW - COMBINED UNITS

Heat Load %	W_1 Lb/Hr.	W_2 Lb/Hr.	W_s Lb/Hr.	T_1 °F.	T_2 °F.	T_3 °F.	T_6 °F.	T_7 °F.	T_8 °F.	T_9 °F.
117	1,110,000	1,110,000	141,000	1200	840	1128	768	585	650	965
115	1,090,000	1,090,000	138,000	1200	840	1129	769	585	650	970
110	1,045,000	1,045,000	134,000	1200	840	1131	771	600	650	986
105	997,000	997,000	126,000	1200	840	1133	773	600	650	1000
100	950,000	950,000	119,000	1200	840	1135	775	600	650	1014
95	902,000	902,000	112,000	1200	840	1137	777	600	650	1026
90	855,000	855,000	105,000	1200	840	1139	779	600	650	1038
85	807,000	807,000	98,300	1200	840	1141	781	600	650	1050
80	760,000	760,000	92,500	1194	834	1137	777	600	650	1050
60	570,000	570,000	69,400	1168	808	1120	760	600	650	1050
40	380,000	380,000	46,200	1134	774	1096	736	600	650	1050
20	190,000	190,000	23,100	1101	741	1074	714	600	650	1050

TABLE 2
UNBALANCED SODIUMFLOW - COMBINED UNITS

Heat Load %	W_1 Lb/Hr.	W_2 Lb/Hr.	W_s Lb/Hr.	T_1 °F.	T_2 °F.	T_3 °F.	T_6 °F.	T_7 °F.	T_8 °F.	T_9 °F.
117	1,333,000	1,000,000	140,000	1200	900	1170	770	600	650	1007
115	1,310,000	982,000	136,000	1200	900	1170	770	600	650	1015
110	1,255,000	940,000	129,000	1200	900	1173	773	600	650	1029
105	1,193,000	895,000	122,000	1200	900	1174	774	600	650	1041
100	1,140,000	855,000	116,000	1200	900	1175	775	600	650	1050
80	911,000	684,000	92,500	1174	874	1154	754	600	650	1050
60	683,000	513,000	69,400	1147	847	1134	734	600	650	1050
40	455,000	342,000	46,200	1119	819	1112	712	600	650	1050
20	228,000	171,000	23,100	1089	789	1087	687	600	650	1050

TABLE 3

CONFIRMATION OF PART LOAD THERMAL DESIGN AND PERFORMANCE - COMBINED UNITS

Heat Load M.W.	W_1 Lb/Hr.	W_2 Lb/Hr.	W_s Lb/Hr.	T_1 °F.	T_2 °F.	T_3 °F.	T_6 °F.	T_7 °F.	T_8 °F.	T_9 °F.
20	1,140,000	1,140,000	86,500	1016	816	975	775	600	650	908
18	1,140,000	1,026,000	77,200	1003	823	975	775	600	650	917
15	1,140,000	855,000	63,600	988	838	975	775	600	650	930
12	1,140,000	684,000	50,500	978	858	975	775	600	650	941
9	1,140,000	512,000	37,700	975	885	975	775	600	650	946
6	1,140,000	341,000	24,800	975	915	975	775	600	650	960
3	1,140,000	170,000	12,300	975	945	975	775	600	650	969

TABLE 4
STEAM GENERATOR OPERATION WITHOUT INTERMEDIATE HEAT EXCHANGER - NORMAL LOAD VARIATION

Heat Load %	W_2 Lb/Hr.	Ws Lb/Hr.	T_3 °F.	T_6 °F.	T_7 °F.	T_8 °F.	T_9 °F.
117	1,000,000	140,000	1170	770	600	650	1007
115	982,000	136,000	1170	770	600	650	1015
110	940,000	129,000	1173	773	600	650	1029
105	895,000	122,000	1174	774	600	650	1041
100	855,000	116,000	1175	775	600	650	1050
80	684,000	92,500	1154	754	600	650	1050
60	513,000	69,400	1134	734	600	650	1050
40	342,000	46,200	1112	712	600	650	1050
20	171,000	23,100	1087	687	600	650	1050

TABLE 5

REDUCED SUPERHEAT OPERATION OF STEAM GENERATOR WITHOUT INTERMEDIATE HEAT EXCHANGER AT PRESSURES OF 2200, 1800, 1400, AND 1000 PSI

Pressure Psi	Heat Load MW	W_2 Lb/Hr.	W_s Lb/Hr.	T_3 °F.	T_6 °F.	T_7 °F.	T_8 °F.	T_9 °F.
2200	25.5	1,370,000	145,000	922	710	600	650	700
1800	27.7	1,370,000	145,000	913	683	572	622	672
1400	26.4	1,370,000	128,000	869	649	538	588	638
1000	20.6	1,370,000	92,000	776	605	496	546	596

X - APPENDIX C

PART 1
FUNCTIONAL SPECIFICATIONS FOR STEAM GENERATOR

I. DESIGN DATA

A. STEAM SIDE

1. Temperature at Unit Outlet	1050°F
2. Pressure at Unit Outlet	2200 psig
3. Feedwater Inlet Temperature	600°F
4. Steam Quality at Outlet	99.75% at 125 per cent load
5. Steam Purity at Outlet	$<$1 ppm total solids
6. Rated Flow at 100 Per Cent Load	116,000 pounds per hour

B. SODIUM SIDE

1. Temperature at Unit Inlet	1175°F
2. Temperature at Unit Outlet	775°F
3. Pressure at Gas Blanket	100 psig
4. Rated Flow at 100 Per Cent Load	855,000 pounds per hour
5. Calculated Pressure Drop at 100 Per Cent Load *	12.6 psi

*APAE-112, Volume 1, Design value of 12.3 psi is based on nominal 1/2 inch O.D. tube. Above value based on tube O.D. of 0.523 inch.

C. MECHANICAL DESIGN

1. Tubes	2500 psig at 1200°F
2. Tubesheet, Channels	2500 psig at 1075°F
3. Shell	150 psig at 1200°F

II. STEAM GENERATOR OPERATION

A. GENERAL

1. The steam generator will be operated to give constant pressure at the turbine or sink inlet.

2. The sodium inlet temperature to the unit will be allowed to float, depending on the reactor or source outlet temperature, which may vary downward from peak temperature (1200°F), provided that 1050°F steam temperature is maintained at steam generator outlet.

3. The reactor or source outlet temperature is to be maintained at the level which will produce 1050°F steam, and permit linear variation of sodium flow rate with load.

4. The steam temperature at the unit exit must not be allowed to exceed 1075°F, which is the upper tubesheet and channel design temperature.

5. The sodium flow rate will vary approximately linearly with load.

B. NORMAL OPERATION

1. The normal startup and shutdown procedures are as specified in APAE 112, Volume IV, Section 3. The number of startups cycles used for design is one thousand.

2. After startup, or at any time within the range of fifteen to one hundred per cent load, load changes will be made by changing sodium flow rate and power to match demand. The normal rates of changes are:

a. Full Range Ramp:	± 5 per cent of full load value per minute from 20 to 100 per cent.
b. Short Time Ramp:	± 20 per cent of full load value in one minute.
c. Step Change:	± 10 per cent of full load value.

The number of operating cycles used for design is one million.

C. CASUALTY OPERATION

1. The steam generator shall be capable of withstanding the following thermal transient conditions:

Condition	Sodium Temp. at Start of Transient	Predicted Max. Rate of Change of Sodium Temp. for 3 Seconds	Predicted Duration of Transient *	Sodium Temperature at end of Transient
a. Primary pump stops. Secondary flow continues.	1175°F	-35°F/second	14 seconds	775°F
b. Sodium flow stops. Feedwater flow continues.	1175°F	-35°F/second	16 seconds	650°F
c. Feedwater flow stops. Sodium flow continues.	775°F	+50°F/second	9 seconds	1175°F

The predicted number of cycles of each above condition during the life of the equipment is twenty-five.

* The predicted duration of transients was set prior to establishing design characteristics of equipment. More detailed instructions and predicted durations are covered in the main body of the test report under the individual transient considerations.

X - APPENDIX C

PART 2
FUNCTIONAL SPECIFICATIONS FOR INTERMEDIATE HEAT EXCHANGER

I. DESIGN DATA

A. PRIMARY SIDE

1. Temperature at Unit Inlet (May vary downward at part load, provided 1050°F steam temperature is maintained at steam generator.)	1200°F
2. Temperature at Unit Outlet	900°F
3. Rated Flow at 100 Per Cent Load	1,140,000 pounds per hour
4. Calculated Pressure Drop at 100 Per Cent Load	9.0 psi

B. SECONDARY SIDE

1. Temperature at Unit Inlet	775°F
2. Temperature at Unit Outlet	1175°F
3. Rated Flow at 100 Per Cent Load	855,000 pounds per hour
4. Calculated Pressure Drop at 100 Per Cent Load	7.4 psi

C. MECHANICAL DESIGN

1. Shell Side	100 psig at 1200°F
2. Tube Side	150 psig at 1200°F

II. INTERMEDIATE HEAT EXCHANGER OPERATION

A. GENERAL

1. Power changes in the operating range will be accomplished by varying sodium flow approximately linearly with load.

2. The steam temperature at exit of steam generator must be sensed and the reactor or source outlet temperature of the primary sodium must be programmed downward to produce 1050°F steam.

B. NORMAL OPERATION

1. The normal startup and shutdown procedures are as specified in APAE-112, Volume IV, Section 3. The number of startup cycles used for design is one thousand.

2. After startup, or at anytime within the range of fifteen to one hundred per cent load, load changes will be made by changing sodium flow rates and power to match demand. The normal rates of change are:

   a. Linear increase in load from ten to one hundred per cent in three minutes. The number of cycles used for design is ten thousand.

   b. Step change in steam demand of ten per cent of rated steam flow in three seconds. The number of cycles used for design is one million.

C. REACTOR SCRAM

1. The intermediate heat exchanger shall be capable of withstanding the following thermal transient condition:

   The primary sodium inlet temperature drops 60°F in first one-half second and a total of 130°F in six seconds. At the end of the transient, the predicted sodium temperature is the normal sodium outlet temperature.

2. The number of cycles used for design is one thousand.

D. CASUALTY CONDITIONS

1. The intermediate heat exchanger shall be capable of withstanding the following thermal transient conditions:

   a. Primary pump stops, but secondary pump continues.

   b. Secondary pump stops, but primary pump continues.

2. The number of cycles used for design is twenty-five.

X - APPENDIX D

INSTRUMENTATION DRAWINGS

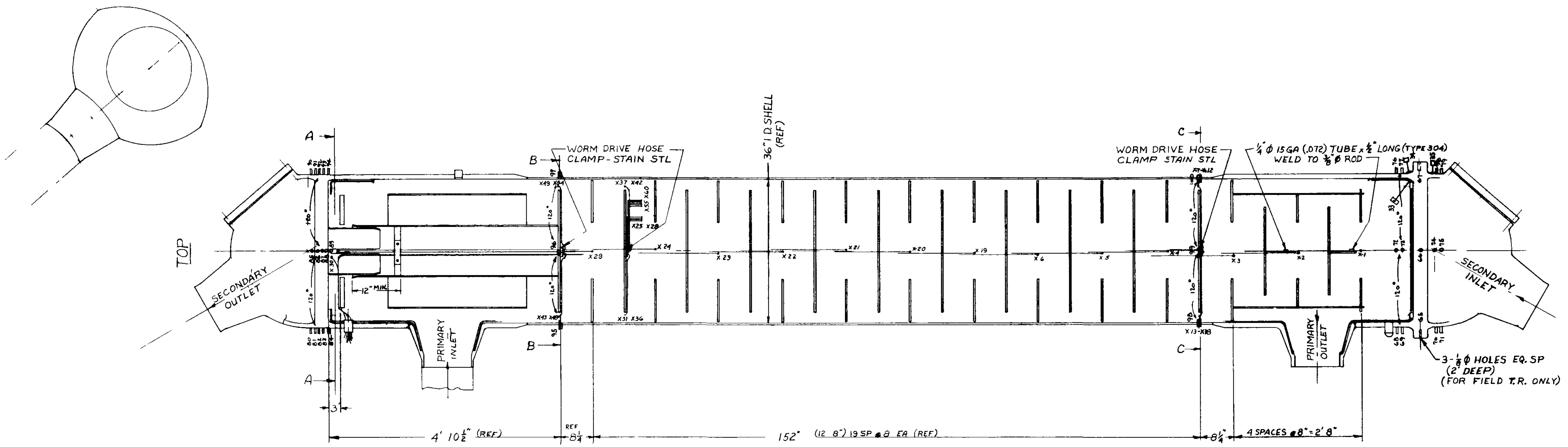
The following instrumentation drawings are included in Appendix D:

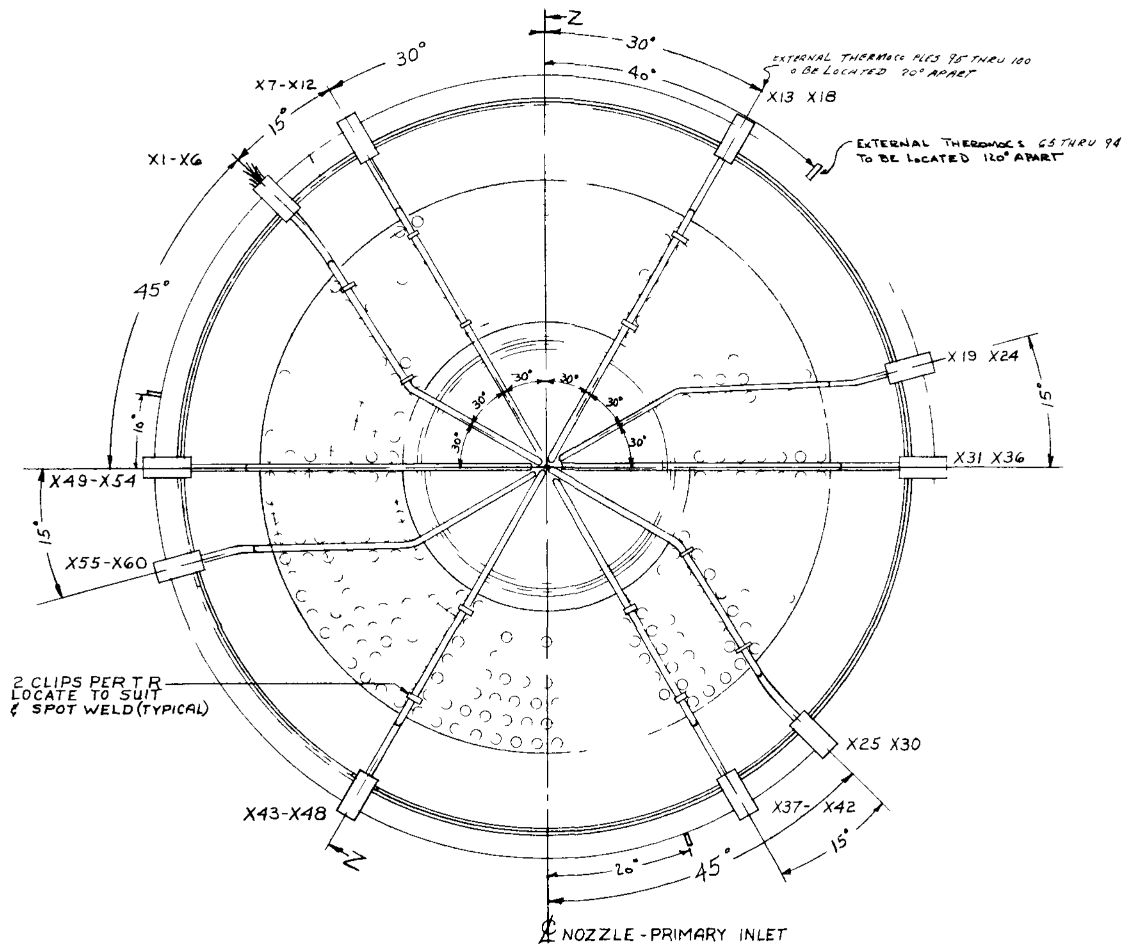
1. Intermediate Heat Exchanger

Drawing	Subject
D-666-3-7	Instrument Orientation
C-666-3-9	Detail - Section B-B
C-666-3-11	Detail - Section C-C
A-666-3-12	Thermocouple Assemblies
B-666-3-13	Thermocouple Assemblies
A-666-3-14	Thermocouple Support Clamp
B-666-3-17	Weld Test Plates

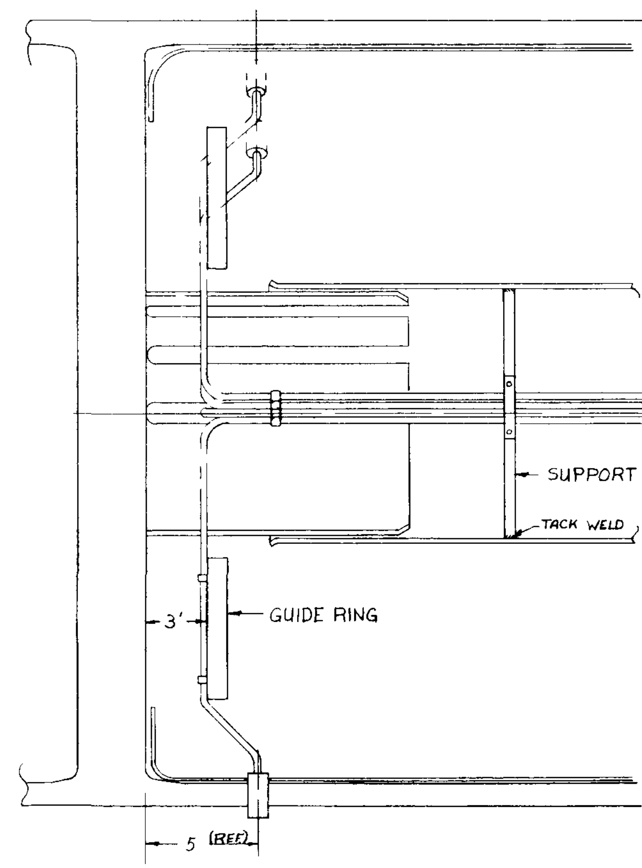
2. Steam Generator

Drawing	Subject
D-666-4-9	Instrument Orientation
C-666-4-10	Detail - Section Y-Y
B-666-4-11	Thermocouple Assemblies
A-666-4-12	Thermocouple Clips
A-666-4-13	Tube Sheet Thermocouples
A-666-4-14	Manway Cover Thermocouple





VIEW "A A" - TEMP RECORDER OUT-LETS



SECTION Z-Z

NOTES:

1- TEMP. RECORDER THERMOCOUPLES MARKED X1-X60 INCL. FURNISHED & INSTALLED BY ALCO.

2 61 64 IN NOZZLES (WELL TYPE)
65 67 1/8 ϕ x 2" DEEP (IMMERSION)
68 100 1/4" ϕ GASKET TYPE
} EXTERNAL THERMOCOUPLES TO BE INSTALLED BY ATOMICS INTERNATIONAL

3- SYMBOL ⊞ INDICATES STRAIN GAUGES SEE REF. DRGS FOR DETAILS. ALL GAUGES FURN'ED & INSTALL. BY TEST FACILITY. INTERIOR GAUGE INSTALL. DURING FABRICATION

REFERENCE DRAWINGS

C-666-3 9 INSTRUMENT ORIENTATION SECTION B B"
C-666-3 11 INSTRUMENT ORIENTATION SECTION C-C"
A 666 3 12 / B 666-3 13 } THERMOCOUPLE ARRG'T & LENGTHS OF BUNDLES
A-666 3 14 SUPPORT CLAMP
A 666 4 12 CLIPS FOR THERMOCOUPLES
* ~~B-666-3-15 STRAIN GAGE ASSY.~~
* ~~B 666-3-16 STRAIN GAGE INSTALLATION~~
* STRAIN GAGE #33 INSTALLATION COULD NOT BE ACCOMPLISHED THEREFOR THESE DRAWINGS ARE NOT APPLICABLE

D666-3-7

ISSUE	DATE	BY	CKD	REVISION	CERT
D	8/17/62	WLC	WJM	ORIENTATION OF TC'S 95 THRU 100 CHG'D DELETE SG 33	
C	7/3/62	WJ		THERMOS 61 100 ADDED	BFL
B	5/2/62	WJ	RHB	STRAIN GAUGES ADDED	
A	12/6/61	RDF		REDRAWN W/REVISIONS	

REVISIONS

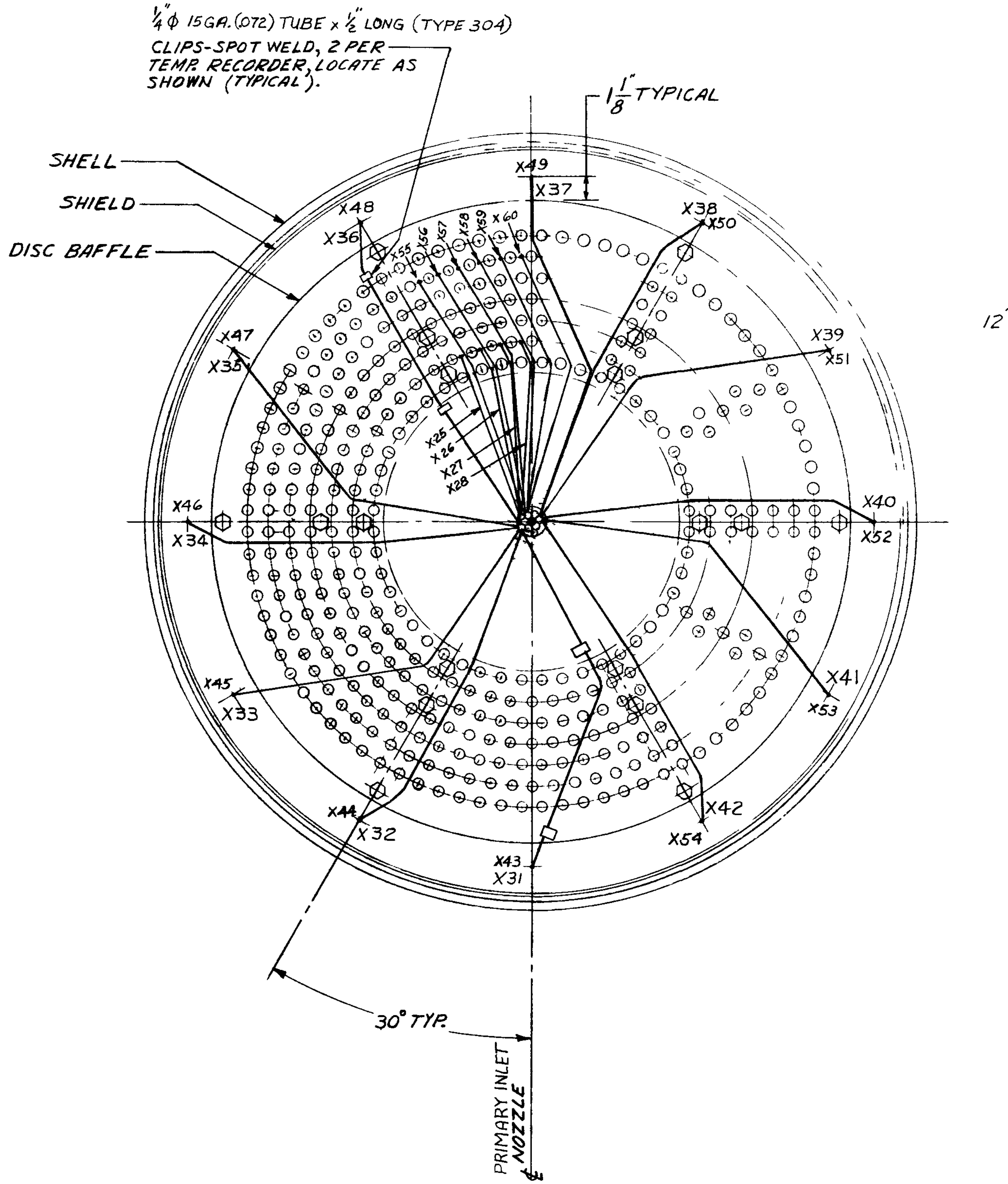
ALCO

ALCO PRODUCTS, INCORPORATED
RESEARCH & DEVELOPMENT — SCHENECTADY NEW YORK

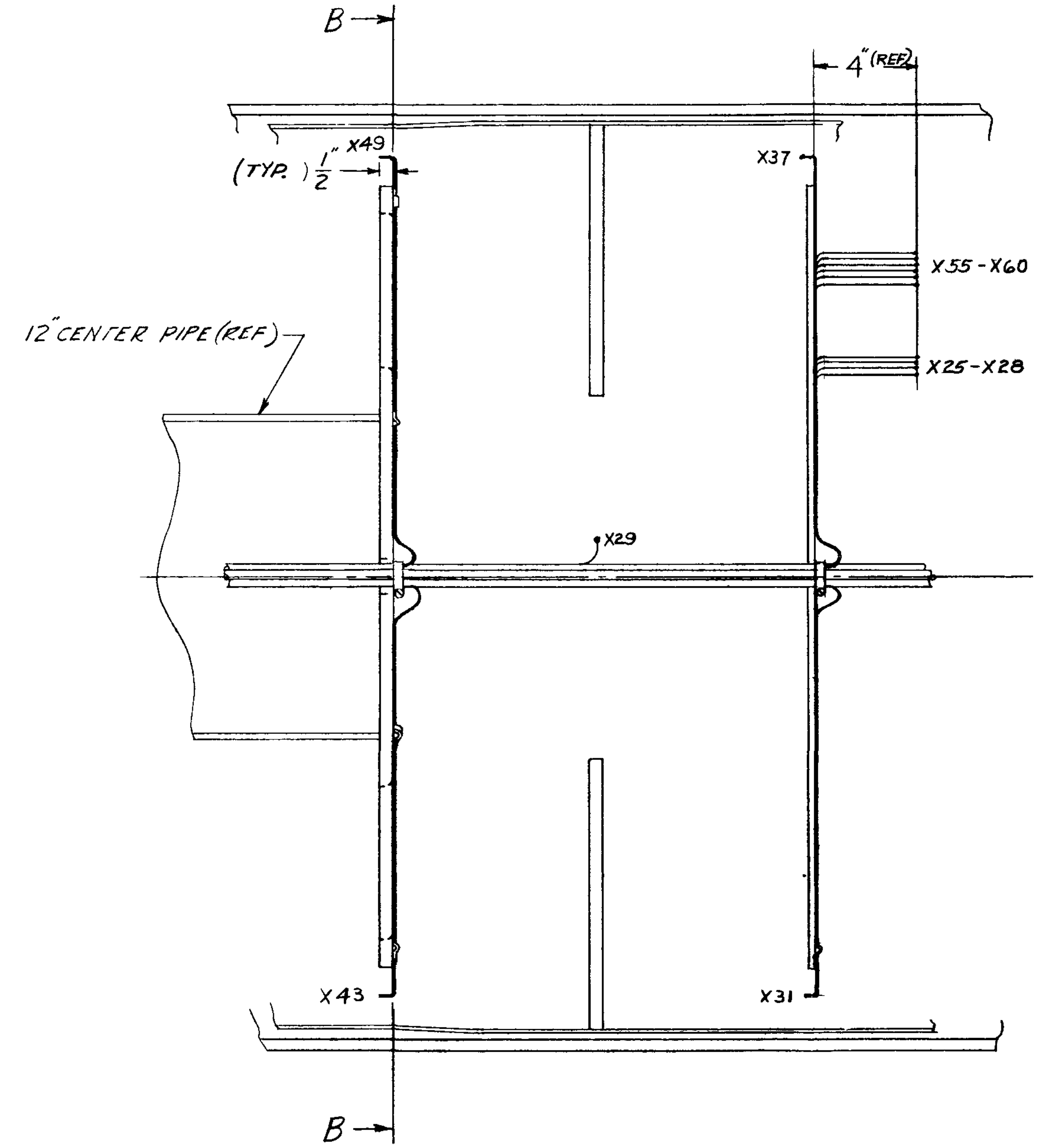
INSTRUMENT ORIENTATION
(30 MW INTERMED. HEAT X-CHR)

SCALE	MADE	CHK D	CERT	DATE	DRAWING NO	ORDER No	ITEM No	IDENT No
1" = 1' 0" / 3" = 1' 0"	[illegible]	WJM		6/26/61	D	666	3	7

NOTES:
1. REF DWG D666-3-7 (VIEW B-B)
2. ALL BENDS - MIN. 1/8 R.



VIEW "B-B (T.R.S. #X43 X54, X55 X60, X25 X28, X29 & X31 X42)
(REF.- FOR BUNDLE LENGTH'S - SEE DWG. A666 3-12 & B666-3-13



C666-3-9

ISSUE	DATE	BY	CKD	REVISION	CERT
B	8/17/62	WLC	[illegible]	LOCATION OF THERMO-COUPLES 31 TO 42	
A	12/12/61	RDF	WJM	GEN REV	

REVISIONS

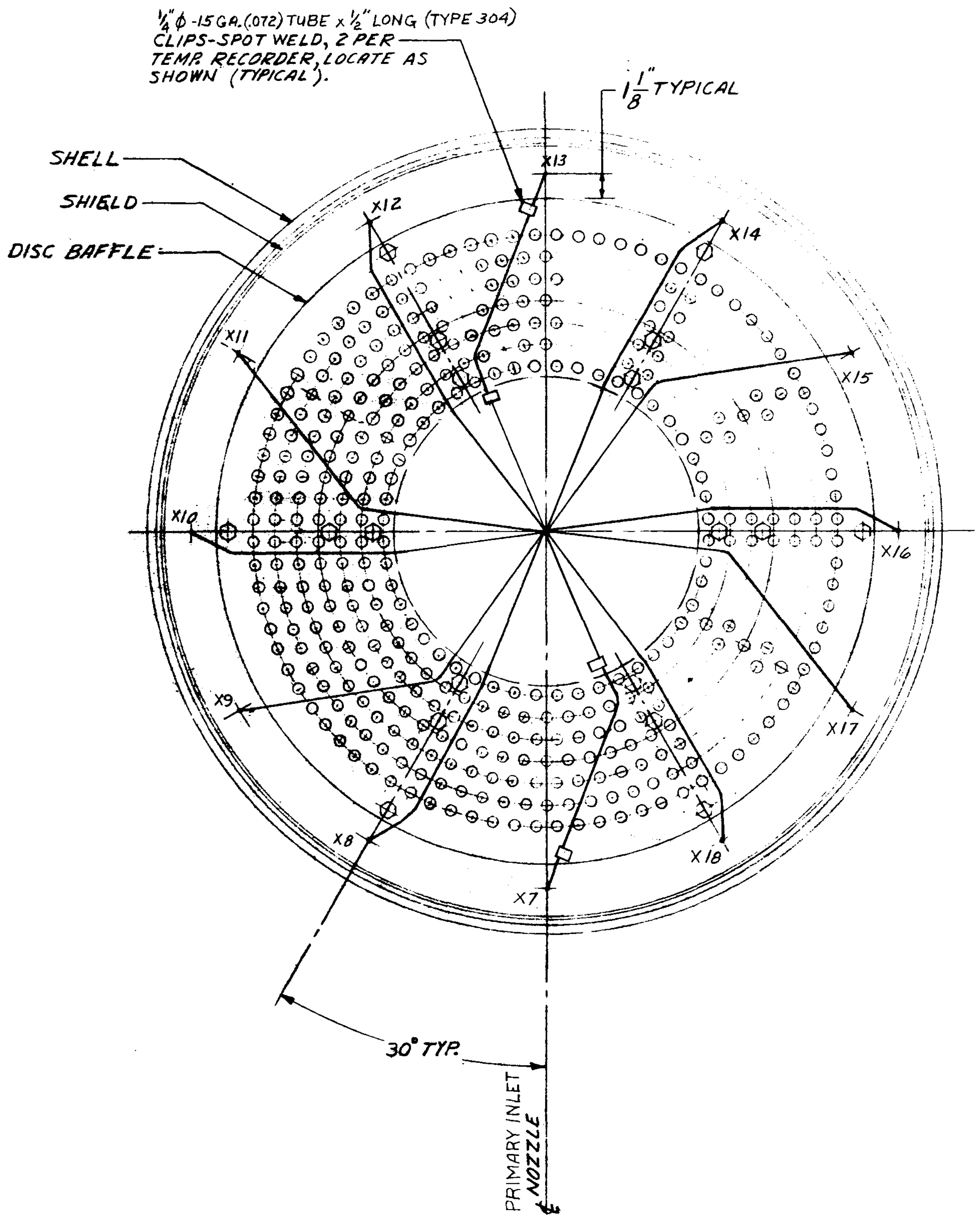
ALCO

ALCO PRODUCTS, INCORPORATED
RESEARCH & DEVELOPMENT — SCHENECTADY NEW YORK

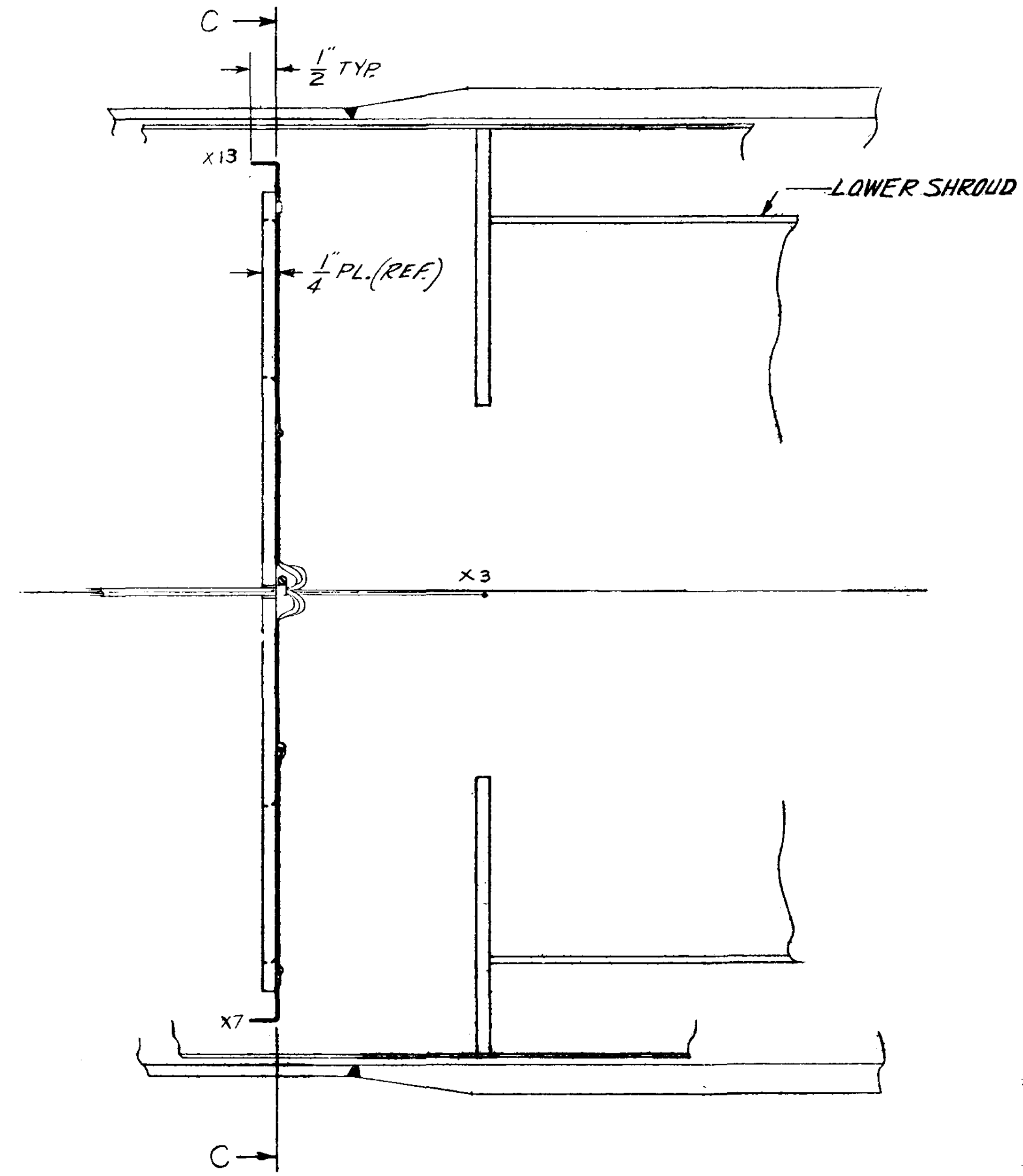
DETAIL-INSTRUMENT ORIENTATION (30 MW. - HT. X-CHR.) (VIEW "B-B")

SCALE	MADE	CHK'D	CERT	DATE		ORDER No	ITEM No.	IDENT. No
3"=1'-0"	MUNAFO	WJM		7/14/61	C	666	3	9

NOTES:
1. REF. DWG. D666-3-7 (VIEW "C-C")
2. ALL BENDS - MIN. 1/8 R.



VIEW "C-C" (T.R.'S # X7-X18)
(REF. - FOR BUNDLE "LENGTH'S. - SEE DWG. D666-3-12)



C666-3-11

ISSUE	DATE	BY	CKD	REVISION	CERT
A	10/11/61	KDF	WJM	GEN. REV.	

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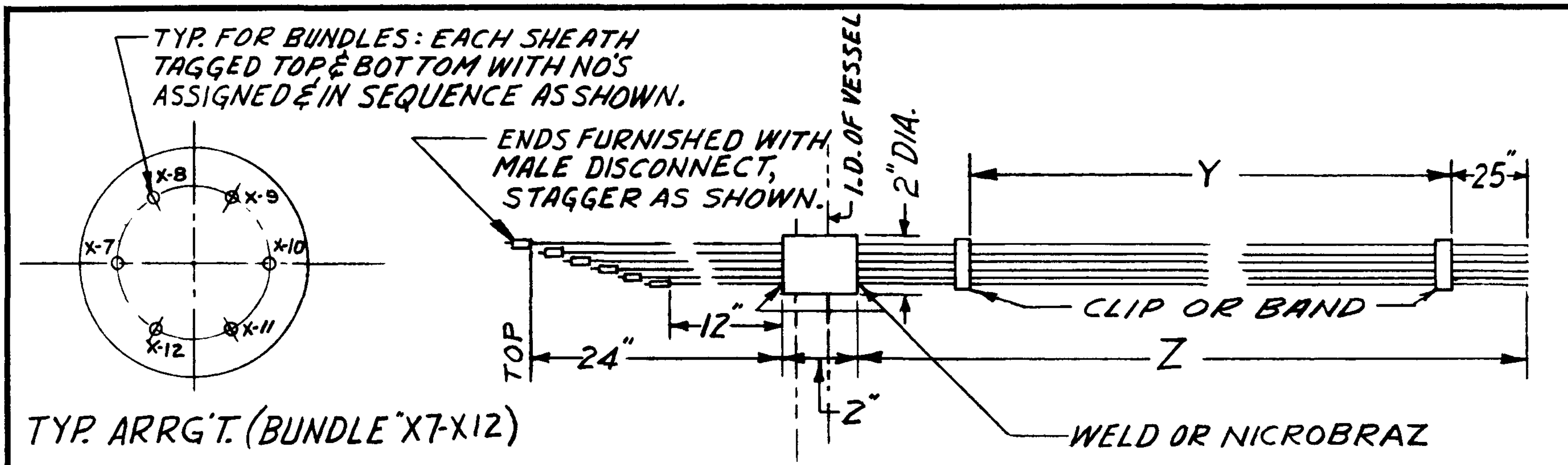
RESEARCH & DEVELOPMENT — SCHENECTADY, NEW YORK

DETAIL - INSTRUMENT ORIENTATION (30 M.W. - HT. X-CHR.) (VIEW "C-C")

SCALE	MADE	CHK'D	CERT.	DATE		ORDER No.	ITEM No.	IDENT. No.
3" = 1'-0"	McNAFO	WJM		7/10/61	C	666	3	11



BUNDLE NO'S.		LENGTH "Z"	"Y" (BANDS)
X7-X12	X13-X18	256"	6 EQ. SP. @ 32"
X31-X36	X37-X42	112"	32"-2 SPACES
X43-X48	X49-X54	96"	32"-1 SPACE
X55-X60		112"	2 EQ. SP. @ 32" ← (B)

MATERIAL-STAINLESS STEEL TYPE 316 SHEATH, VESSEL CONNECTION & BANDS.

DESIGN PRESS. 150 P.S.I. DESIGN TEMP. 1200°F. TEST PRESS. 413 P.S.I.

REF. DRWG.-INST. ORIENTATION D666-3-7

A666-3-12

ISSUE	DATE	BY	CKD	REVISION	CERT
C	1/5/62	RDF	WJM	REV. LGTHS. OF X55-X60	
B	12/1/61	RDF	WJM	X55-60 ADDED.	
A	10/20/61	MAm	WJM.	REDRAWN.	

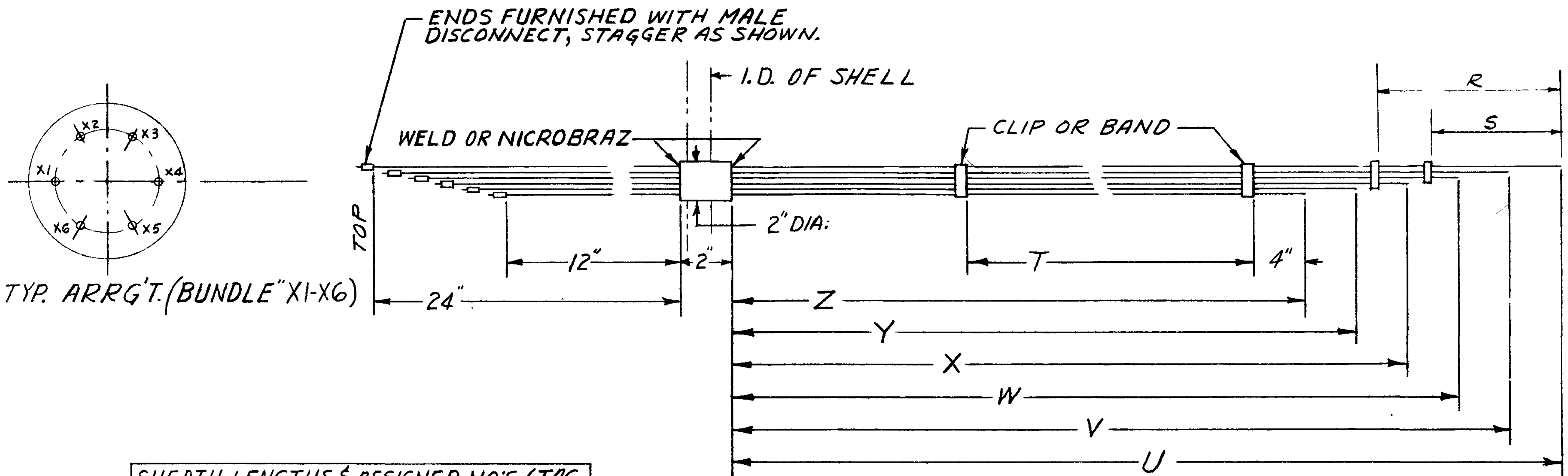
REVISIONS

ALCO

ALCO PRODUCTS, INCORPORATED
RESEARCH & DEVELOPMENT — SCHENECTADY, NEW YORK

TEMP. RECORDER'S ARRG'T. & LENGTHS OF BUNDLES (30 MW HT. X-CHR.)

SCALE	MADE	CHK'D	CERT.	DATE		ORDER No.	ITEM No.	IDENT. No.
—	MUNAFO	WJM		7/20/61	A	666	3	12



	SHEATH LENGTHS & ASSIGNED NO'S. (TAG SHEATHS WITH NO'S. TOP & BOTTOM)								
	U	V	W	X	Y	Z	"T" (BAND SPACING)	S	R
BUNDLE "X1-X6"	X1 276"	X2 260"	X3 244"	X4 228"	X5 212"	X6 196"	160"-5 EQ. SP. @ 32"	36"	—
BUNDLE "X19-X24"	X19 180"	X20 164"	X21 148"	X22 132"	X23 116"	X24 100"	64"-2 EQ. SP. @ 32"	36"	—
BUNDLE "X25-X30"	X25 109"	X26 109"	X27 109"	X28 109"	X29 88"	X30 24"	74"-2 EQ. SP. @ 37"	—	17"

MATERIAL - STAINLESS STEEL - TYPE 316, SHEATH, VESSEL CONNECTION & BANDS.

DESIGN PRESS.	DESIGN TEMP.	TEST PRESS.
150 P.S.I.	1200°F.	413 P.S.I.

REF. DWG.-INST. ORIENTATION D666-3-7 (HT. X-CHR.)

B666-3-13

ISSUE	DATE	BY	CKD	REVISION	CERT
C	1/5/62	RDF	WJM.	REV. LENGTHS & BAND SP.	
B	12/1/61	RDF	WJM	GEN. REVISION	
A	10/20/61	MAM	WJM	REDRAWN.	

REVISIONS

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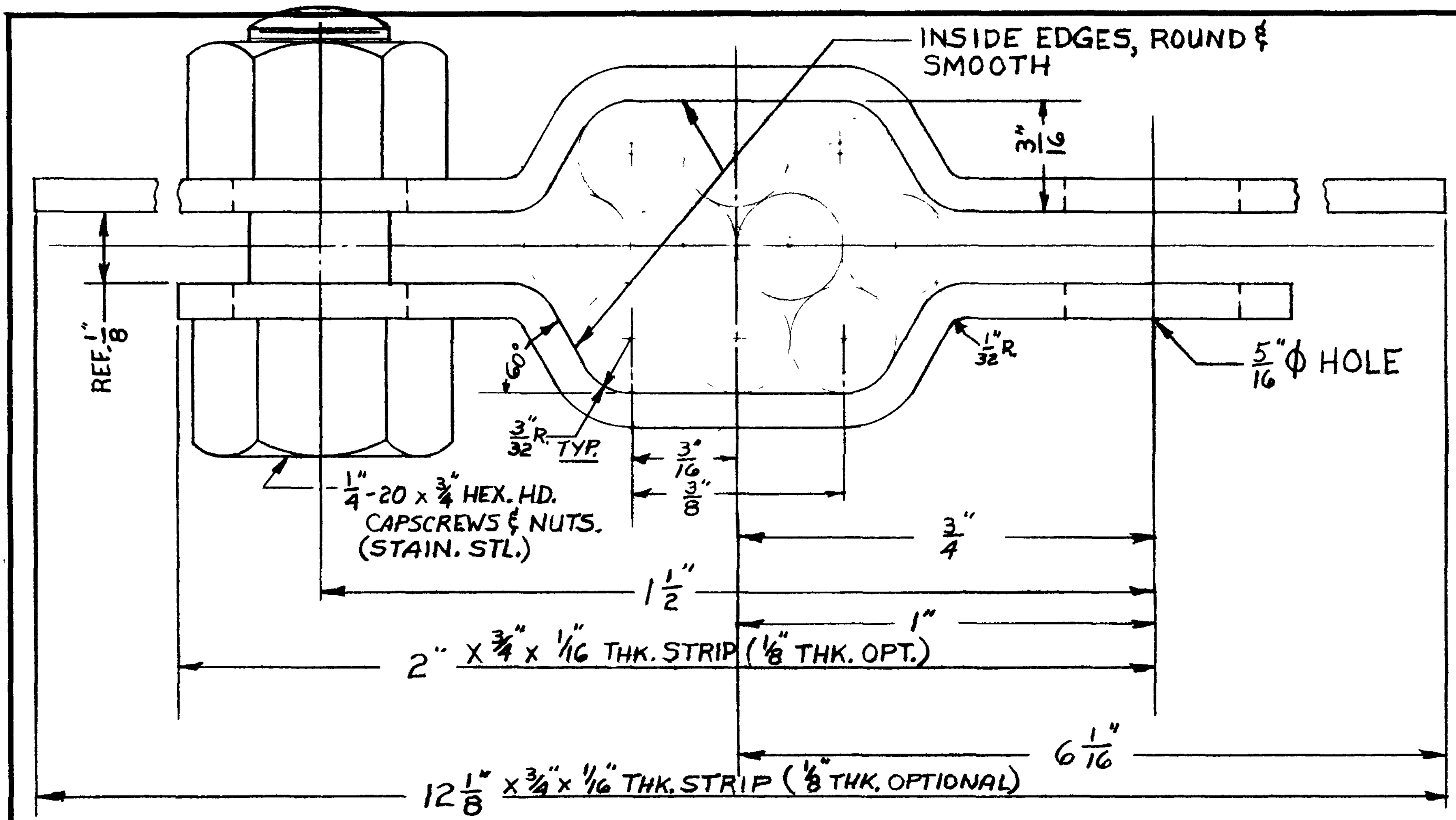
RESEARCH & DEVELOPMENT — SCHENECTADY, NEW YORK

TEMP. RECORDER LENGTHS & ARRG'T. OF BUNDLES (HT. X-CHR-30 MW.)

SCALE	MADE	CHK'D	CERT.	DATE	DRAWING NO.	ORDER No.	ITEM No.	IDENT. No.
—	MUNAFO	WJM		7/21/61	B	666	3	13



REF. DWG.-D666-3-7

MAT'L : STRIP, STAIN. STL.-TYPE 304

A666-3-14

ISSUE	DATE	BY	CKD	REVISION	CERT

REVISIONS

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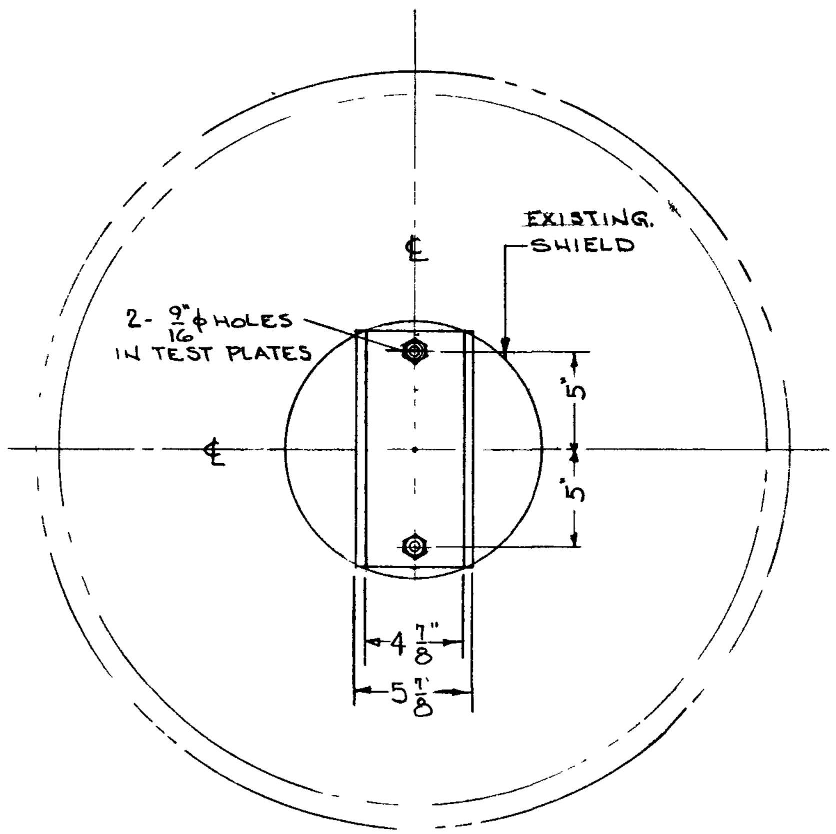
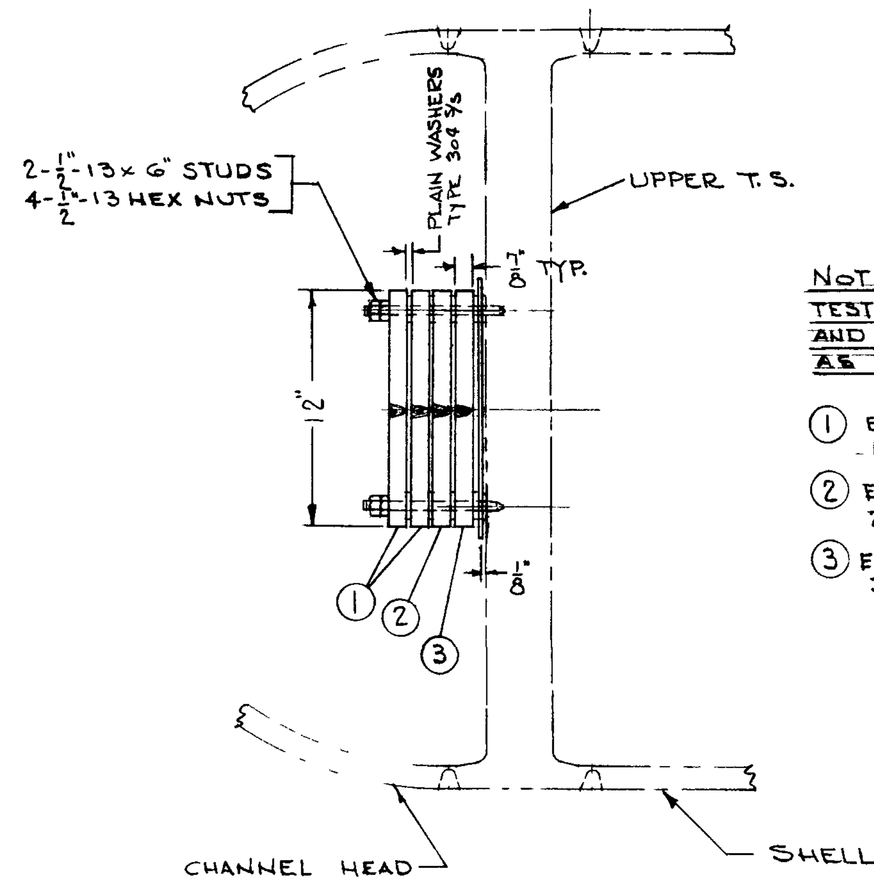
SUPPORT CLAMP-TEMP. RECORDER-30 M.W.-HEAT EXCHANGER

SCALE	MADE	CHK'D	CERT.	DATE		DRAWING NO. ORDER No.	ITEM No.	IDENT. No.
4X	RDF	WJM.		12/15/61	A	666	3	14





NOTE:
TEST PLATES WITH ELECTRODE #
AND HOLES ARE IDENIFIED
AS FOLLOWS:

(1) E.H.# 32167 LOT 21
1 HOLE DRILLED

(2) E.H.# 34214-J
2 HOLES DRILLED

(3) E.H.# 29032-H
3 HOLES DRILLED

MATERIAL SPECIFICATIONS

TEST PLATES:	FG'D. S/S SA-182 GR F 316
STUDS:	S/S TYPE 304
NUTS:	S/S TYPE 304
SPACERS:	S/S TYPE 304

REF. DRG. D-666-3-4

ISSUE	DATE	BY	CKD	REVISION	CERT
A	7/3/62	W.7		NOTE REVISED	REP

REVISIONS

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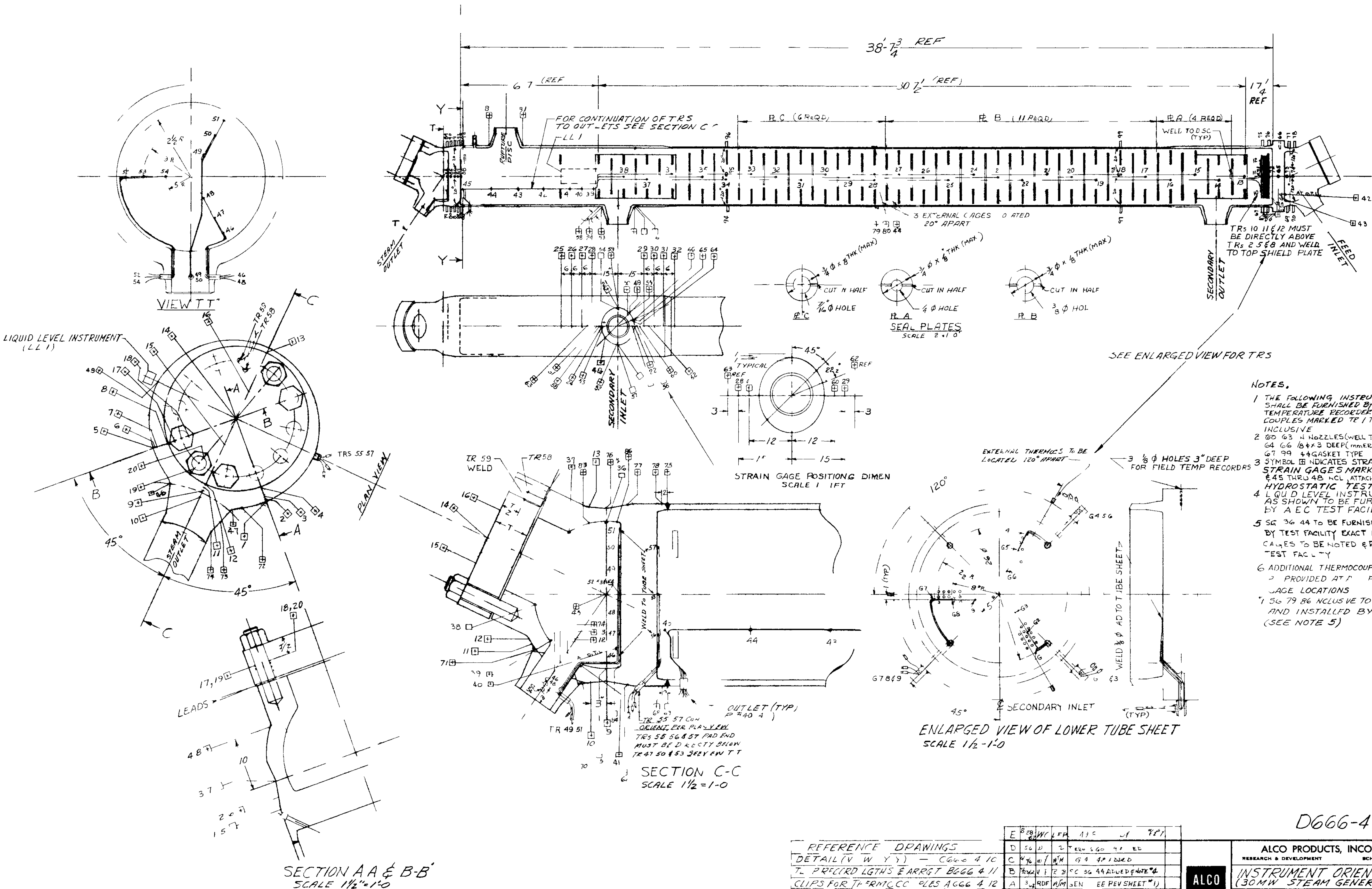
WELD TEST PLATES
(30MW INTERMEDIATE HEAT EXCHANGER)

SCALE	MADE	CHK'D	CERT	DATE		ORDER No	ITEM No	IDENT No
	W.7.	REP		7/3/62	B	666	3	17



NOTES.

1. THE FOLLOWING INSTRUMENTS SHALL BE FURNISHED BY ALCO PROD. INC TEMPERATURE RECORDER THERMOCOUPLES MARKED TR 1 TO TR 59 INCLUSIVE
2. 60 63 IN NOZZLES (WELL TYPE) / 64 66 1/8 ϕ x 3 DEEP (IMMERSION) / 67 99 4 ϕ GASKET TYPE — EXTERNAL THERMOS. TO BE INSTALLED BY ATOMICS INTERNATL
3. SYMBOL ⊞ INDICATES STRAIN GAGE (S G) STRAIN GAGES MARKED SG 1 TO SG 32 & 45 THRU 48 INCL ATTACHED PRIOR TO HYDROSTATIC TESTS
4. LIQUID LEVEL INSTRUMENT (LL 1) AS SHOWN TO BE FURNISHED BY A E C TEST FACILITY
5. SG 36 44 TO BE FURNISHED & INSTALLED BY TEST FACILITY EXACT LOCATION OF GAGES TO BE NOTED & RECORDED BY TEST FACILITY
6. ADDITIONAL THERMOCOUPLES SHOULD BE PROVIDED AT EXTERNAL STRAIN GAGE LOCATIONS
7. SG 79 86 INCLUSIVE TO BE FURNISHED AND INSTALLED BY TEST FACILITY (SEE NOTE 5)

D666-4-9

REFERENCE DRAWINGS

DETAIL (V W Y Y)	C666 4 10
TC PRECORD LGTHS & ARRGT	B666 4 11
CLIPS FOR THERMOCOUPLES	A666 4 12
TEMP REC LGTHS & ARRGT (TUBE SHT)	A666 4 3
TEMP REC LGTHS (TOP M H COVER)	A666 4 14

REVISIONS

ISSUE	DATE	B	CHD	REVISION	CERT
E	8 28 62	WC	LFP	[illegible]	
D	5 6	D	2	TERM 5 60 91 ED	
C	4 ¼	W	WJM	G 4 48 ADDED	
B	[illegible]	V F	R B	SG 36 44 ADDED & NOTE 4	
A	3 62	RDF	WJM	GEN SEE REV SHEET #1)	

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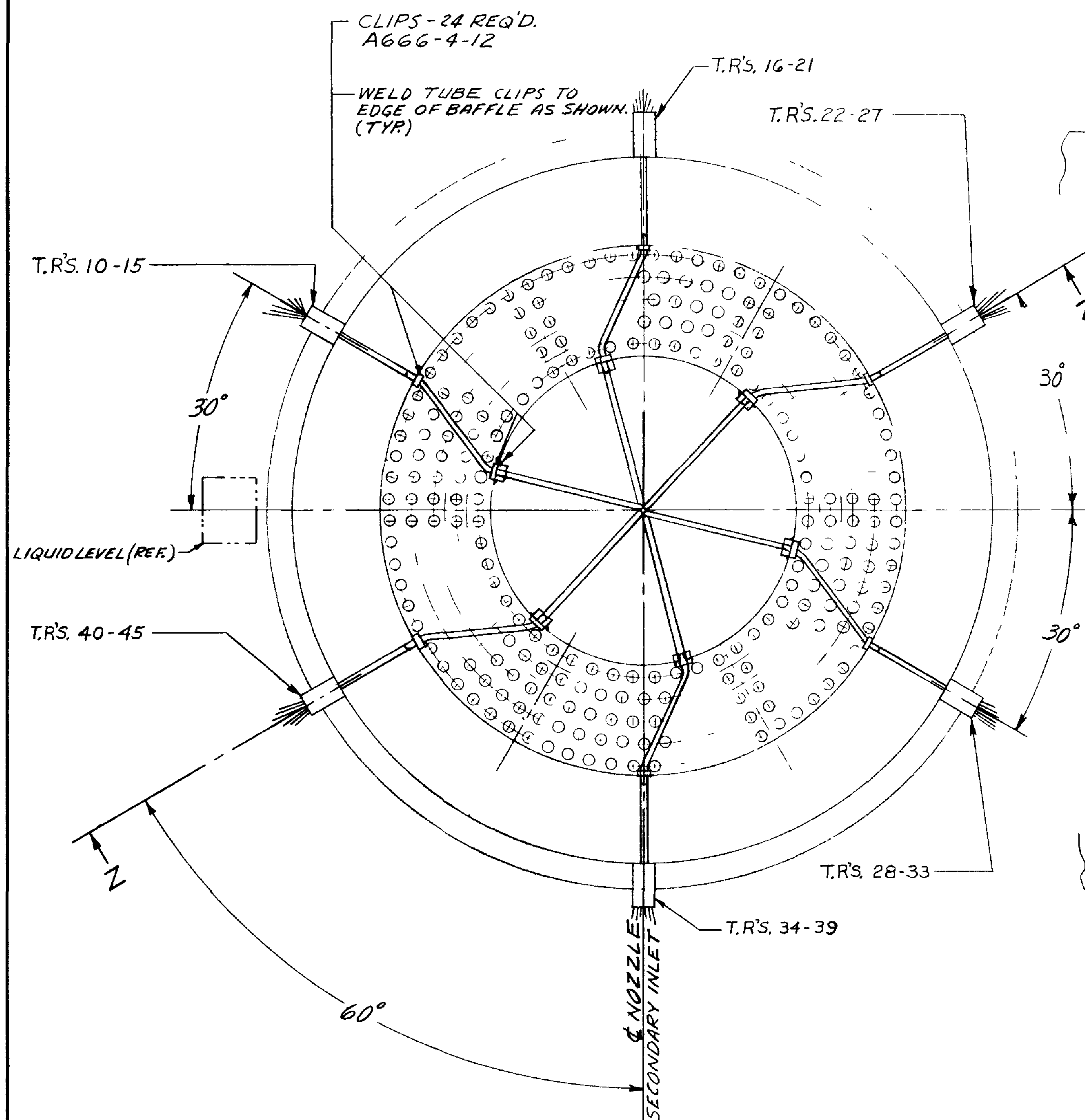
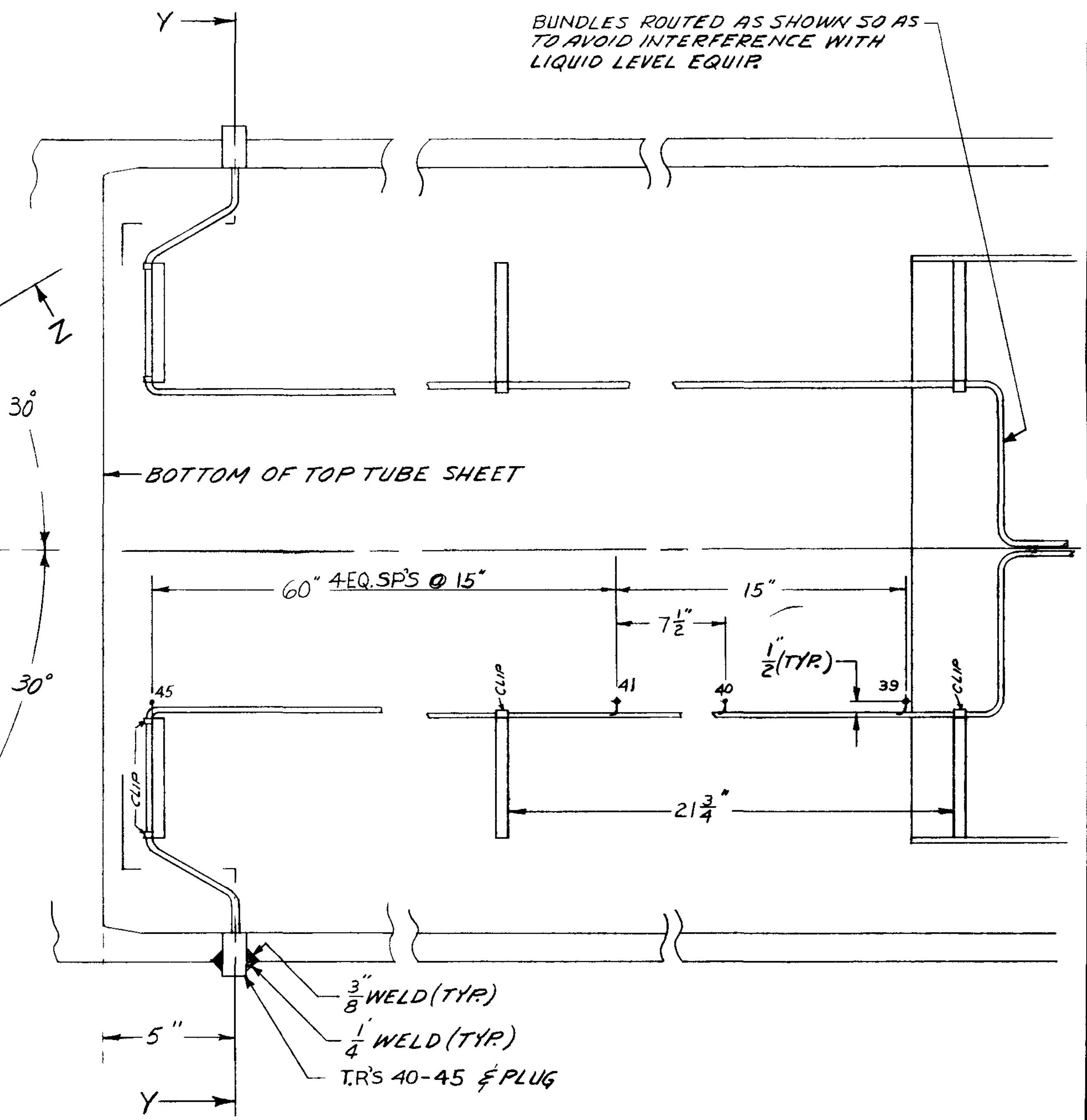
INSTRUMENT ORIENTATION
(30MW STEAM GENERATOR)

SCALE	MADE	CHK D	CERT	DATE		ORDER No	ITEM No	IDENT No
1/2=1-0	MUNAFO	WJM		6/30/61	D	666	4	9

NOTE: ALL BENDS - 1/4" R. MIN.



VIEW "Y-Y" - TEMP. RECORDER ARRG'T. & OUT-LETS



SECTION "Z-Z"

REF. DWG. - D666-4-9 (VIEW "A-A")

C666-4-10

ISSUE	DATE	BY	CKD	REVISION	CERT
A	1/31/62	RDF	WJM	GEN. (SEE REV. SHEET)	

REVISIONS

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RESEARCH & DEVELOPMENT — SCHENECTADY NEW YORK

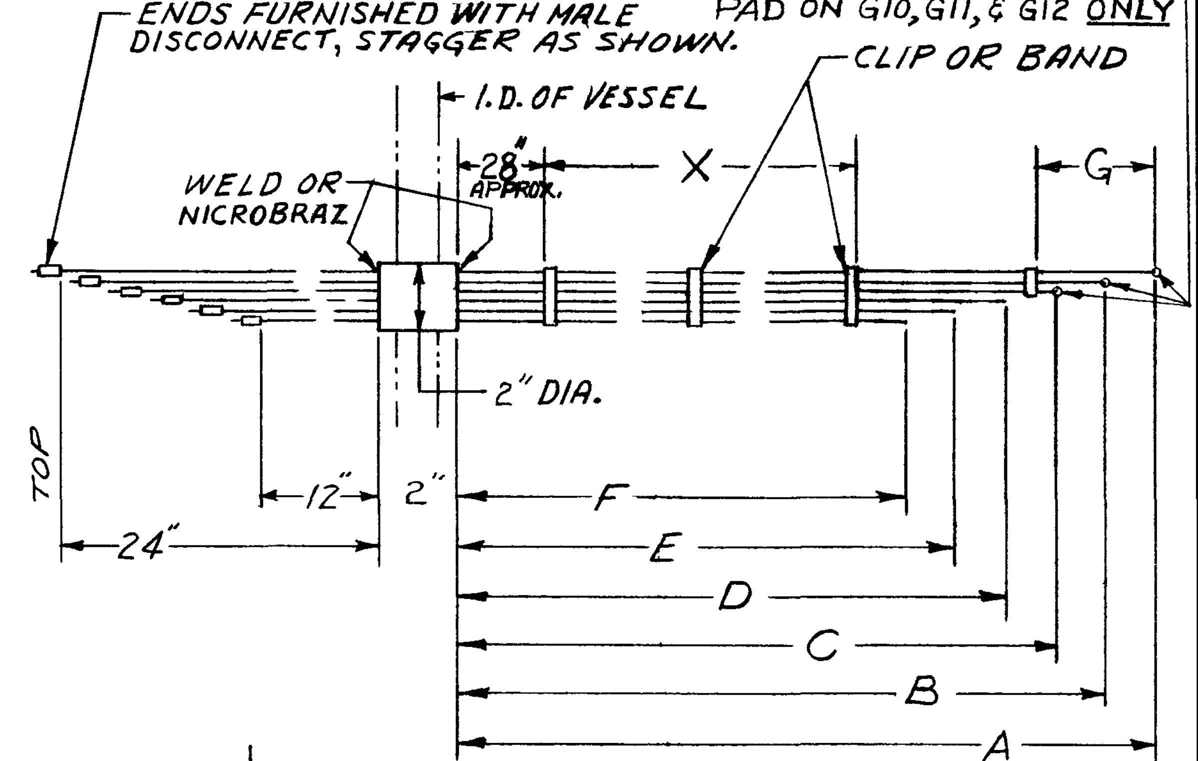
DETAIL - INSTRUMENT ORIENTATION - (VIEW "Y-Y") 30 M W. STEAM GEN.

SCALE	MADE	CHK D	CERT	DATE		ORDER No	ITEM No	IDENT No
3"=1'-0"	Munafo	WJM		7/26/61	C	666	4	10

SHEATH LENGTHS & ASSIGNED NO'S.
(TAG SHEATHS WITH NO'S.- TOP & BOTTOM)

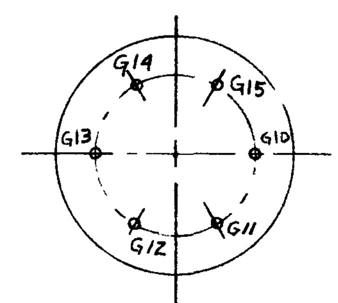
	A	B	C	D	E	F	G	
	488"	488"	488"	466"	452"	438"	12"	"X" (BANDS)
SHEATH NO'S. (BUNDLE "G10-G15)	G10*	G11*	G12*	G13	G14	G15	—	448"-16 EQ. SP. @ 28"
	424"	410"	396"	382"	368"	354"	30"	"X" (BANDS)
SHEATH NO'S. (BUNDLE "G16-G21)	G16	G17	G18	G19	G20	G21	—	364"-13 EQ. SP. @ 28"
	340"	326"	312"	298"	284"	270"	30"	"X" (BANDS)
SHEATH NO'S. (BUNDLE "G22-G27)	G22	G23	G24	G25	G26	G27	—	280"-10 EQ. SP. @ 28"
	256"	242"	228"	214"	200"	186"	30"	"X" (BANDS)
SHEATH NO'S. (BUNDLE "G28-G33)	G28	G29	G30	G31	G32	G33	—	196"-7 EQ. SP. @ 28"
	172"	158"	142"	128"	114"	92"	30"	"X" (BANDS)
SHEATH NO'S. (BUNDLE "G34-G39)	G34	G35	G36	G37	G38	G39	—	112"-4 EQ. SP. @ 28"
	85"	78"	72"	58"	44"	30"	19"	"X" (BANDS)
SHEATH NO'S. (BUNDLE "G40-G45)	G40	G41	G42	G43	G44	G45	—	38"-2 EQ. SP. @ 19"

*NOTE: 3/8" DIA. x .083" ± .010 THK. WELDING PAD ON G10, G11, & G12 ONLY



MATERIAL - STAINLESS STL. - TYPE 316
SHEATH, VESSEL CONN. & BANDS.

DESIGN PRESS. 150 P.S.I. DESIGN TEMP. 1200°F. TEST PRESS. 620 P.S.I.



TYP. ARRG'T. (BUNDLE "G10-G15)

REF. DWG.: INST. ORIENTATION D666-4-9

B666-4-11

ISSUE	DATE	BY	CKD	REVISION	CERT
B	12/1/61	RDF	WJM.	GEN. REVISIONS	
A	10-24-61	MAM	WJM.	REDRAWN	

REVISIONS

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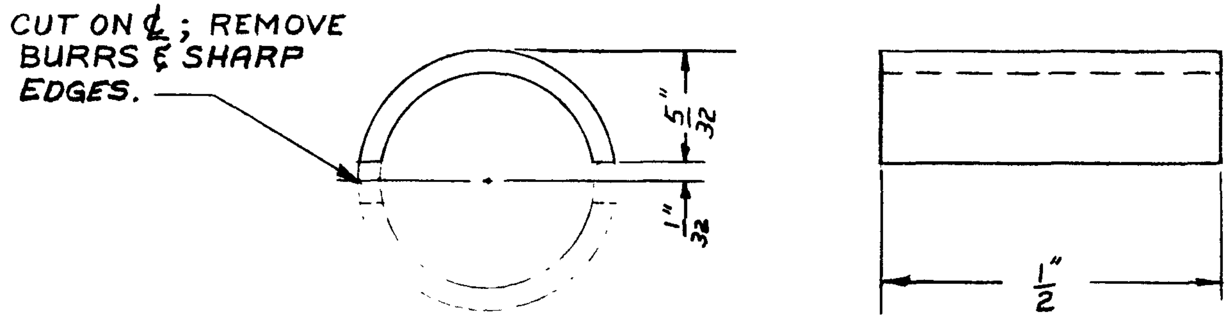
TEMP. RECORDER LENGTHS & ARRG'T. OF BUNDLES (30 MW. - ST. GEN.)

SCALE	MADE	CHK'D	CERT.	DATE		ORDER No.	ITEM No.	IDENT. No.
—	MUNAFO	WJM.		7/27/61	B	666	4	11



MAKE FROM 3/8" O.D. x 20 GA. (.035) TUBE OR EQUAL
STAIN. STL. - TYPE 304

ISSUE	DATE	BY	CKD	REVISION	CERT
A	1/5/62	RDF	WJM	REDRAWN W/REV.	

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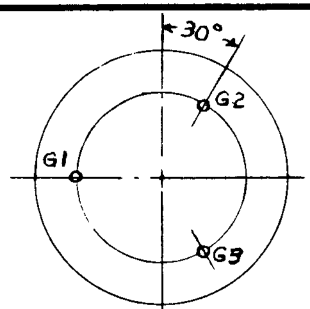
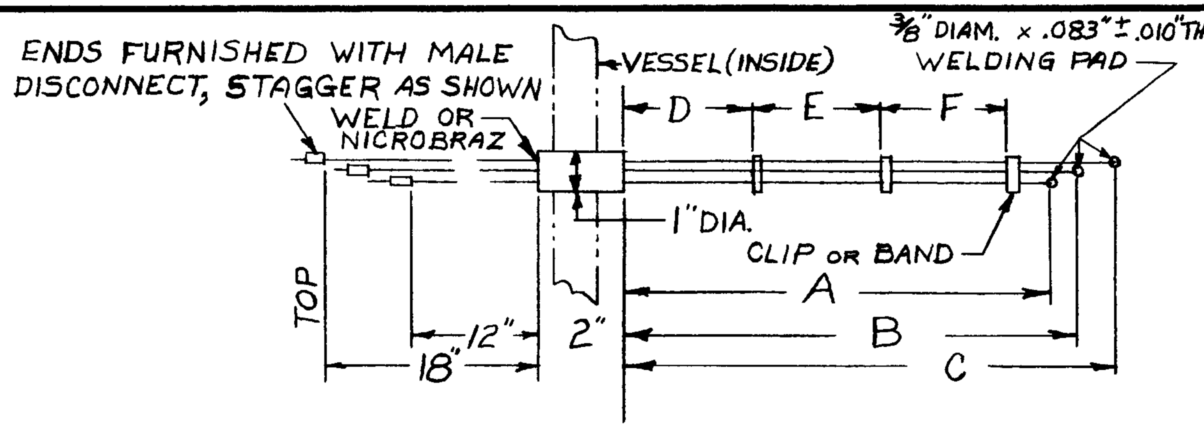
CLIPS FOR THERMOCOUPLES

SCALE	MADE	CHK'D	CERT.	DATE	DRAWING NO.	ORDER No.	ITEM No.	IDENT. No.
4x	RDF	WJM.		1/5/62	A	666	4	12



TYP. ARR'G'T.
(BUNDLE G1-G3)



SHEATH LGTH'S. & ASSIGNED NO'S. (TAG SHEATHS WITH NO'S. TOP & BOTTOM)

	A	B	C	D	E	F
	16"	19"	23"	—	—	—
SHEATH No's (BUNDLE G-1-G3	G1	G2	G3			
	17"	21"	25"	—	—	—
SHEATH No's. (BUNDLE G4-G6)	G4	G5	G6			
	23"	27"	31"	—	—	—
SHEATH No's (BUNDLE G7-G-9	G7	G8	G9			
	22"	22"	29"	11"	—	—
SHEATH No's. (BUNDLE G55-G57)	G55	G56	G57			
	24"	28"	32"	11"	—	—
SHEATH No's. (BUNDLE G46-G48)	G46	G47	G48			
	37"	41"	45"	11"	11"	9"
SHEATH No's. (BUNDLE G49-G51)	G49	G50	G51			
SHEATH No's. (BUNDLE G52-G54	G52	G53	G54			

MATERIAL - STAINLESS STEEL TYPE 316
SHEATHS, VESSEL CONN. & BANDS
DESIGN PRESS. - 150 P.S.I.
DESIGN TEMP. - 1200° F.
TEST PRESS. - 620 P.S.I.

REF. DWG. - INST. ORIENTATION D666-4-9

MATERIAL { WELDING PADS B-168 (INCONEL) / SHEATHS - B-163 (INCONEL)
MAT'L. - BANDS & VESSEL CONN. S.S. - TYPE 316
DESIGN PRESS. - 2500 P.S.I.
DESIGN TEMP. - 1075° F.
TEST PRESS. - 6220 P.S.I.

A666-4-13

ISSUE	DATE	BY	CKD	REVISION	CERT
B	12/29/61	RDF	WJM	CHANGED LENGTHS OF SHEATHS	
A	12/1/61	RDF	WJM	REDRAWN-GEN. REV.	

REVISIONS

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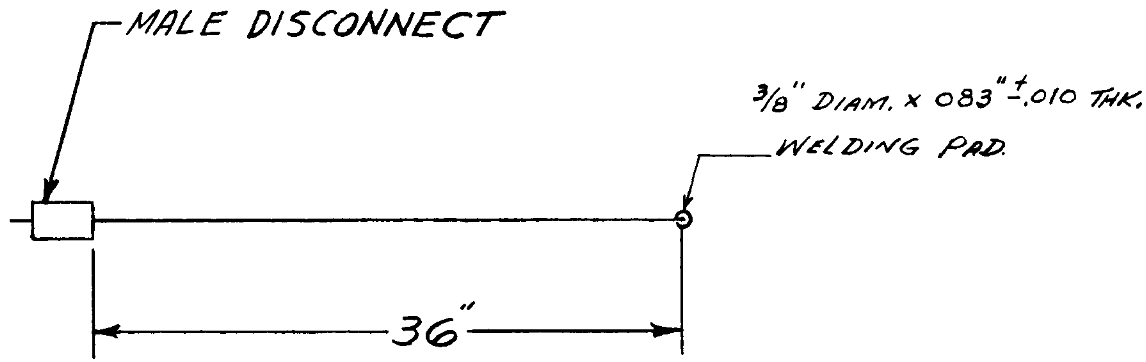
TEMP. RECORDER LGTH'S. & ARR'G'T. - BUNDLES (TUBE SHEETS - ST. GEN. - 30MW)

SCALE	MADE	CHK'D	CERT.	DATE		ORDER No.	ITEM No.	IDENT. No.
—	MUNAFO	WJM		10/26/61	A	666	4	13



NOTE:
ONE TEMP. RECORD. TAG WITH NO. G58 AND ONE T.R. TAG WITH NO. G59.

MATERIAL (SHEATH) - STAIN. STL. - TYPE 316. & PAD

REF. DRWG. - INST. ORIENTATION D666-4-9

A666-4-14

ISSUE	DATE	BY	CKD	REVISION	CERT
A	12/1/61	RDF	WJM	GEN. REV.	

REVISIONS

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TEMP. RECORDER (#G58 & G59)
TOP COVER - ST. GEN. - 30 M.W.

SCALE	MADE	CHK'D	CERT.	DATE	DRAWING NO.	ORDER No.	ITEM No.	IDENT. No.
—	MUNAFO	WJM.		10/27/61	A	666	4	14