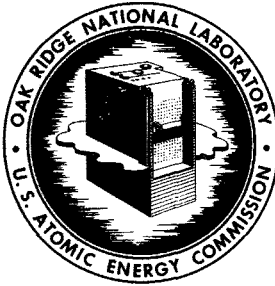


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TUBE VIBRATION IN MSRE PRIMARY HEAT EXCHANGER

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ABSTRACT

The primary heat exchanger for the Molten-Salt Reactor Experiment was completed in 1963. Preoperational tests with water revealed excessive tube vibrations and high fluid pressure drop on the shell side of the exchanger. Modifications were made to correct these deficiencies. From January 1965 through November 1967 the heat exchanger has operated for about 14,000 hours in molten salt without indications of leakage or change in performance.

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INTRODUCTION

In October 1967, the Division of Reactor Development and Technology of the AEC began a survey of heat exchangers in the primary circuits of nuclear reactor facilities for which the Division has technical responsibility.^{1,2} The heat exchanger in the fuel circuit of the Molten-Salt Reactor Experiment (MSRE) was included in the survey, and this report is intended to provide the information requested.

The heat exchanger was designed in 1961. Fabrication was completed early in 1963. Difficulties with excessive vibrations in heat exchangers at other nuclear reactor facilities prompted a review of the design of the unit that had been built for the MSRE. This review indicated that vibration could be a problem and that flow tests should be conducted with the heat exchanger. Flow tests with water were performed on the exchanger during the winter of 1963-1964. The tests revealed excessive vibration of the tubes and excessive pressure drop through the shell side of the heat exchanger. Its faults were corrected, and the modified component was installed in the primary loop of the reactor system, Fig. 1, in the spring of 1964. From January 1965 through November 1967 the heat exchanger has been operated for approximately 14,000 hours with molten salt at temperatures from 1000 to 1225°F without indications of leakage or change in performance.

DESIGN CONSIDERATIONS OF PRIMARY HEAT EXCHANGER

The MSRE primary heat exchanger is used to transfer heat from the fuel salt to the coolant salt. It was designed for low holdup of salts, simplicity of construction, and moderately high performance. The space limitations within the containment and other considerations dictated a fairly compact unit.³ A U-tube configuration as shown in Fig. 2 best satisfied the requirements and also minimized the thermal-expansion problems in the heat exchanger.

Molten salt discharged by the fuel pump flows at 1200 gpm through the shell side of the primary heat exchanger where it is cooled from

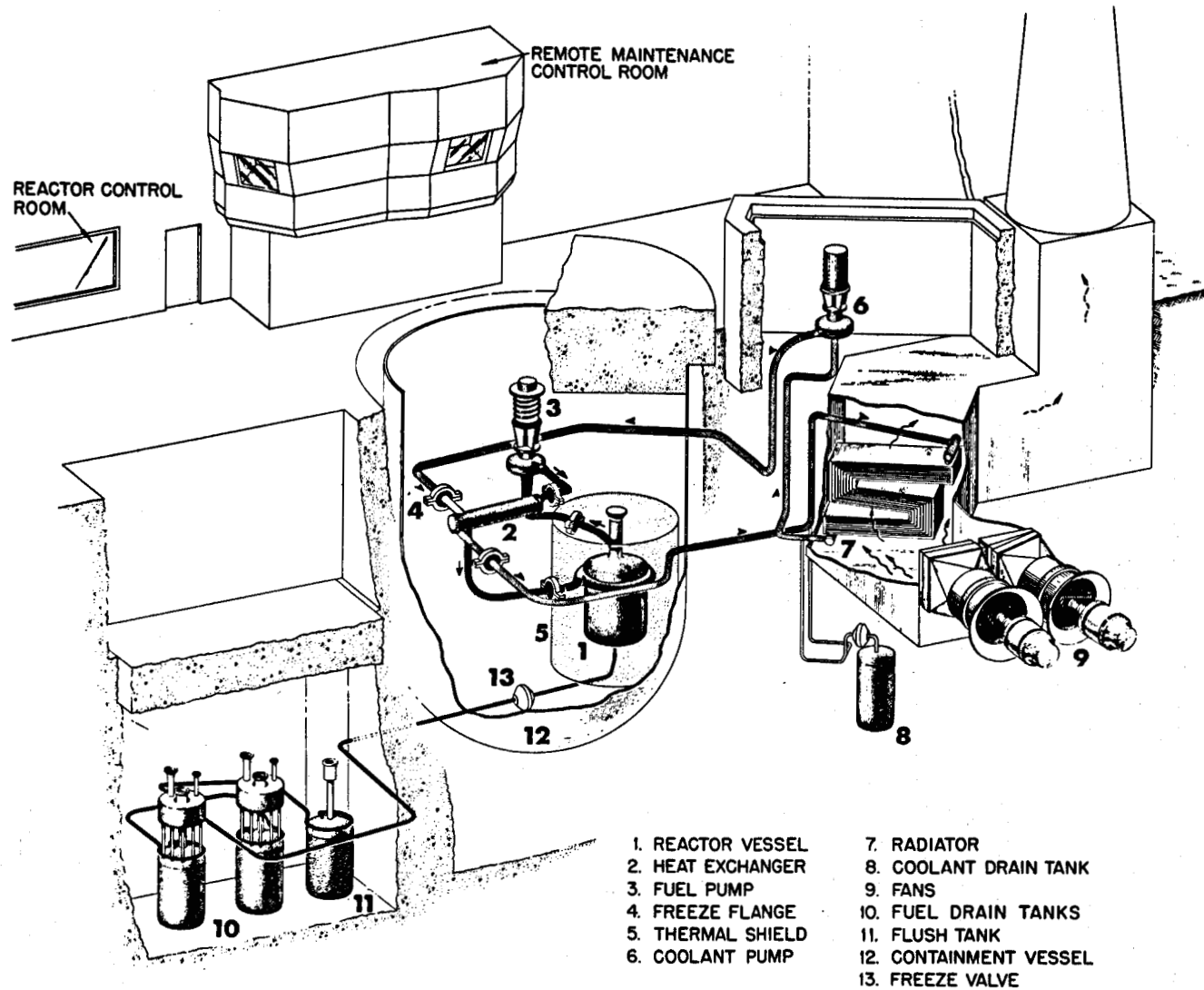
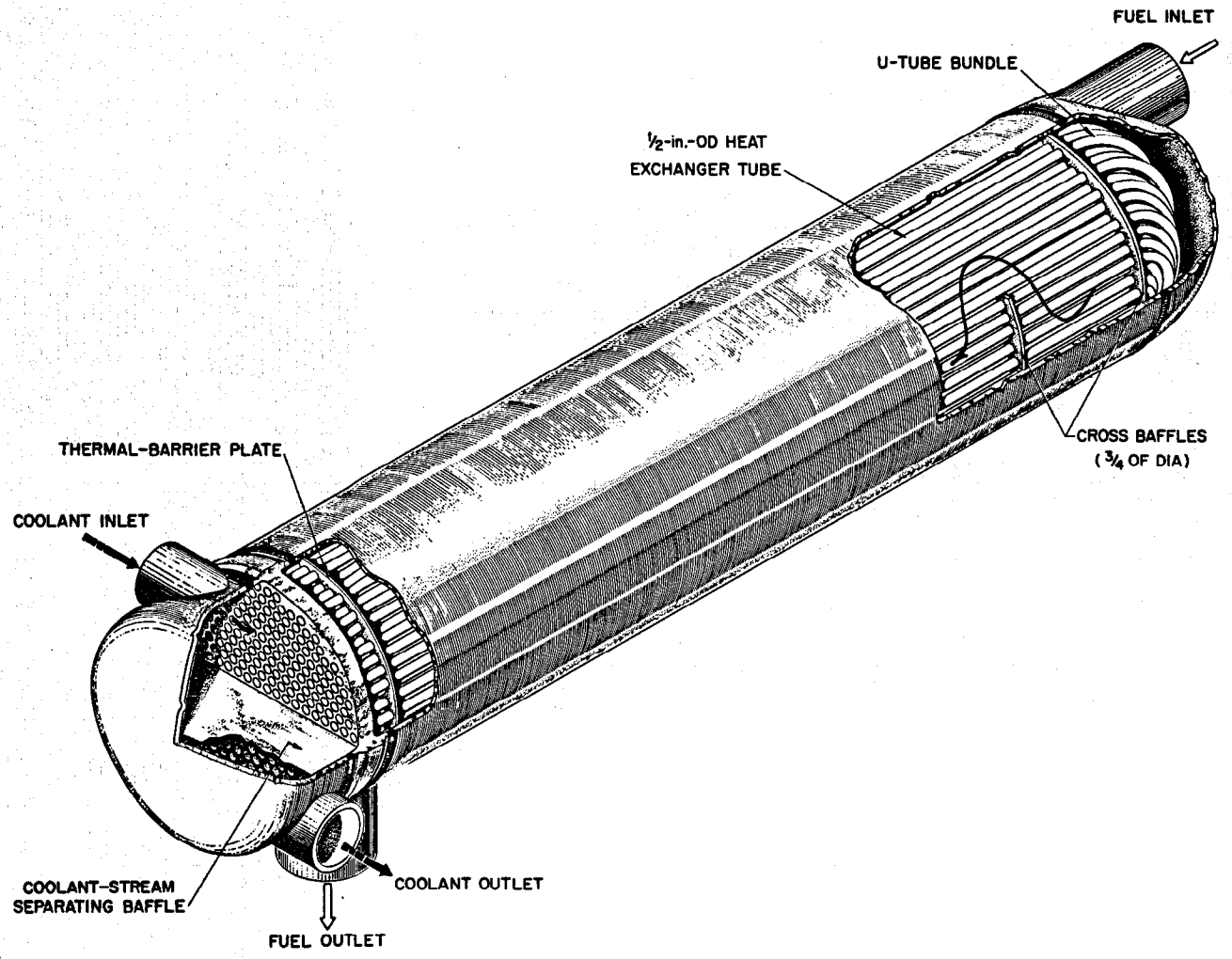


Fig. 1. MSRE Flow Diagram.



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Fig. 2. Primary Heat Exchanger for MSRE.

1225°F to 1175°F.* The coolant salt circulates through the tubes at a rate of 850 gpm, entering at 1025°F and leaving at 1100°F. From the heat transfer and drainability standpoints, it was better to pass the fuel salt through the shell and the coolant salt through the tubes. The shell side also presents less opportunity for retention of gas pockets during fuel salt filling operations.

The design data are given in Table 1 and the design basis physical properties of the fuel and coolant salts and container material are given in Tables 2 and 3. Stresses in the shell, tubes, and tube sheet were evaluated for the design point conditions and reported in design reports.^{4,5} Design of the heat exchanger was based on formulae and correlations of Kern,⁶ requirements of the ASME Unfired Pressure Vessel Code, Section VIII,⁷ Interpretations of ASME Boiler and Pressure Vessel Codes,^{8,9,10,11} and Standards of Tubular Exchanger Manufacturers Association.¹² The exchanger was of a common design; applicable ASME and TEMA standards did not require a vibration analysis and none was made.

The TEMA standards do require that means be provided to protect the tube bundle against impinging fluids at the entrance to the shell if the velocity of the entering fluid exceeds 3 ft/sec. Since the fluid enters the MSRE heat exchanger at 19.3 ft/sec, an impingement baffle was needed to satisfy TEMA standards. This impingement baffle was omitted from the design in order to keep the hold-up of fuel salt to a minimum.

Tube holes in cross baffles were drilled 1/32 in. larger in diameter than the outside diameter of the tubes as indicated by TEMA standards. This large clearance contributed to a tube vibration problem that was discovered during preoperational testing and is discussed in a later section of this report.

*The design basis performance is discussed here. The capacity is actually about 7.5 Mw with the design fuel and coolant flows and inlet temperatures.

Table 1
Design Data for Primary Heat Exchanger

Construction Material	Hastelloy-N
Heat Load, Mw	10
Shell-side Fluid	Fuel Salt
Tube-side Fluid	Coolant Salt
Layout	25% cut, cross-baffled shell with U-tubes
Baffle pitch, in.	12
Tube pitch, in.	0.775 triangular
Active shell length, ft	~ 6
Overall shell length, ft	~ 8
Shell outside diameter, in.	~ 17
Shell thickness, in.	1/2
Average tube length, ft	~ 14
Number of U-tubes	163 ^a 159 ^b
Tube size, in.	1/2 OD; 0.042 wall
Effective heat-transfer surface, ft ²	~ 254 ^c
Tubesheet thickness, in.	1-1/2
Fuel salt holdup, ft ³	6.1
Design temperature: shell side, °F	1300
tube side, °F	1300
Design pressure: shell side, psig	55
tube side, psig	90
Allowable working pressure:	
shell side, psig	75 ^d
tube side, psig	125 ^d

^aBefore modification.

^bAfter modification.

^cStraight section of tubes only.

^dBased on actual thicknesses

Table 1 (continued)
Design Data for Primary Heat Exchanger

Hydrostatic test pressure:		
Shell side, psig		800
tube side, psig		1335
Terminal temperature: fuel salt, °F		1225 inlet; 1175 outlet
coolant, °F		1025 inlet; 1100 outlet
Effective log mean temperature difference, °F		133
Pressure drop: shell side, psi		24
tube side, psi		29
Nozzles: shell, in. (Sched-40)		5 inlet & outlet; ^a 5 inlet, ^b
tube, in. (Sched-40)		5 " " " 7 outlet ^b
Fuel-salt flow rate, gpm		1200 (2.67 cfs)
Coolant-salt flow rate, gpm		850 (1.85 cfs)
Overall heat transfer coefficient, Btu/hr-ft ² -°F		~ 1100, ~ 600 ^e
Average Heat Transfer Coefficient		
Tube Side, Btu/ft ² -hr-°F		~ 5000
Shell Side, Btu/ft ² -hr-°F		~ 3500

^aBefore modification.

^bAfter modification.

^eAs measured.

Table 2
Properties of Fuel and Coolant Salts

	Fuel Salt	Coolant Salt
Composition, mole%:		
LiF	70	66
BeF ₂	23	34
ThF ₄	1	
ZrF ₄	5	
UF ₄	~ 1	
Average Physical Properties:		
	@ <u>1200°F</u>	@ <u>1065°F</u>
Specific heat, Btu/lb-°F	0.46	0.57
Thermal conductivity, Btu/ft ² -hr-°F/ft	2.8*	3.5*
Viscosity, lb/ft-hr	18	20
Density, lb/ft ³	154	120
Prandtl number	3.00	3.26
Liquidus Temperature, °F	840	850

* These are estimated values that were used in the design. Values obtained from measurements in 1967 are about 0.8 Btu/ft²-hr-°F/ft.

Table 3

Composition and Properties of Hastelloy-N^a

Chemical Properties:

Ni	66-71%	Mn, max	1.0%
Mo	15-18	Si, max	1.0
Cr	6-8	Cu, max	0.35
Fe, max	5	B, max	0.010
C	0.04-0.08	W, max	0.50
Ti + Al, max	0.50	P, max	0.015
S, max	0.02	Co, max	0.20

Physical Properties:

Density, lb/in. ³	0.317
Melting Point, °F	2470-2555
Thermal conductivity, Btu/hr-ft ² -°F/ft at 1300°F	12.7
Modulus of elasticity at ~ 1300°F, psi	24.8 x 10 ⁶
Specific heat, Btu/lb-°F at 1300°F	0.135
Mean coefficient of thermal expansion, 70-1300°F range, in./in.-°F	8.0 x 10 ⁻⁶

Mechanical Properties:

Maximum allowable stress, ^b psi: at 1000°F	17,000
1100°F	13,000
1200°F	6,000
1300°F	3,500

^aCommercially available from Haynes Stellite as "Hastelloy-N" and International Nickel Co. as INCO-806.

^bASME Boiler and Pressure Vessel Code, Case 1315.

DESCRIPTION OF HEAT EXCHANGER

The heat exchanger is a conventional shell and U-tube exchanger with a cross-baffled tube bundle. It is of all-welded construction and is fabricated from Hastelloy-N throughout, except for the alloy used to back-braze the tube sheet joints. The dished heads were cold-pressed by the Paducah Plant of Union Carbide, the tube sheet was forged by Taylor Forge Co., the tube-to-tube sheet joints were back-brazed by Wall Colmonoy Co., and the remainder of the fabrication was done in machine shops of the Y-12 Plant of Union Carbide. All work was covered by ORNL Specifications.¹³

The shell is ~ 17 in. OD and about 8-ft 3-in. long, including the 8-3/4-in. long coolant salt header and the ASME flanged and dished heads at the ends. (See ORNL Drawings D-EE-A-40869, -72, -74.) The shell is 1/2-in. thick in the cylindrical portion and the heads. The fuel enters at the U-bend end of the shell through a 5-in. Schedule-40 pipe nozzle, near the top of the dished head. Before modifications, the fuel salt left through a 5-in. Schedule-40 pipe nozzle at the bottom of the shell at the tube sheet end. (See ORNL Drawings D-EE-A-40873, -74.)

Six 25%-cut cross baffles of 1/4-in. plate, spaced at 12-in. intervals, direct the fuel salt flow across the tube bundle (see ORNL Drawings D-EE-A-40864, -65, -66). A barrier plate, similar to the baffle plates but with no cutaway segment, is located 1-7/8 in. from the tube sheet to provide a more-or-less stagnant layer of fuel salt and reduce temperature differences across the tube sheet. The baffles and the barrier plate are held in position by spacer rods, screwed and tack-welded together, to the tube sheet, and to each baffle.

A divider separates the entering and leaving coolant salt streams in the coolant header. It is fabricated of 1/2-in. plate and extends from the tube sheet to the dished head. It is positioned by guide strips on the shell wall, and a groove in the edge fits over a 1/4-in. pointed, horizontal projection on the tube sheet. This arrangement provides a labyrinth-type seal between the channels without stiffening the tube sheet.

Before modifications to the heat exchanger, there were 163 tubes, 1/2-in. OD by 0.042-in. wall thickness, affording an effective transfer surface of $\sim 254 \text{ ft}^2$. See ORNL Drawing D-EE-40867. The tubes are arranged on a 0.775-in. equilateral triangular pitch. The tube holes through the 1-1/2-in. thick tube sheet had trepanned grooves on both sides of the sheet. See ORNL Drawing D-EE-A-40865.

The grooves on the coolant salt side were to permit the tube-to-tube sheet welds to be made between the tube and a lip of about equal wall thickness in the tube sheet (see Figure 3). The tubes were expanded at the tip end into the holes before welding. After welding, the tube openings were reamed to the inside diameter of the tubes. The trepanned grooves on the fuel-salt side were to permit back-brazing of the joints. The back-brazing operation was performed in a furnace with a hydrogen atmosphere using a ring of gold-nickel brazing alloy.

The heat exchanger is installed horizontally, pitching toward the fuel-salt outlet at a slope of about 3° . Each U-tube is oriented so that the coolant salt will also drain. The unit weighs about 2060 lbs when empty and 3500 lbs when filled with fuel and coolant salts. The fuel-salt holdup is $\sim 6.1 \text{ ft}^3$, and the coolant-salt holdup is about 3.7 ft^3 .

PRE-OPERATIONAL TESTING AND MODIFICATIONS

Difficulties with excessive vibrations in heat exchangers at the Enrico Fermi Atomic Power Plant and the Hallam Nuclear Power Facility prompted a review of the MSRE heat exchanger design in the fall of 1963. This review, together with some exploratory tests of a single tube mockup, indicated that fluid induced vibrations could be a problem, and that flow tests should be conducted on the heat exchanger.

Water was the fluid used for these tests for the following reasons:

1. It is convenient to use and readily available at the necessary flow rates.

2. The Strouhal Number $\left(\frac{(\text{frequency})(\text{length})}{(\text{fluid velocity})} \right)$ which is the characteristic number used to correlate fluid-induced vibrations from vortex shedding, is independent of fluid properties such as density and viscosity.

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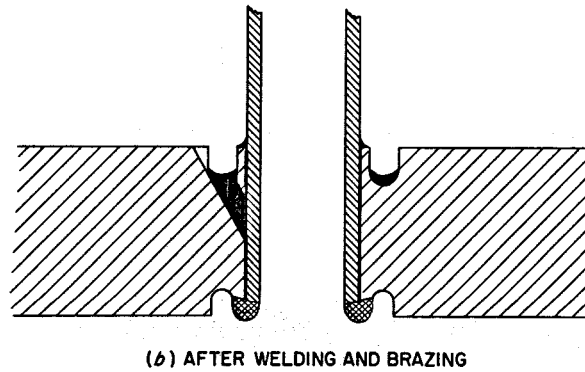
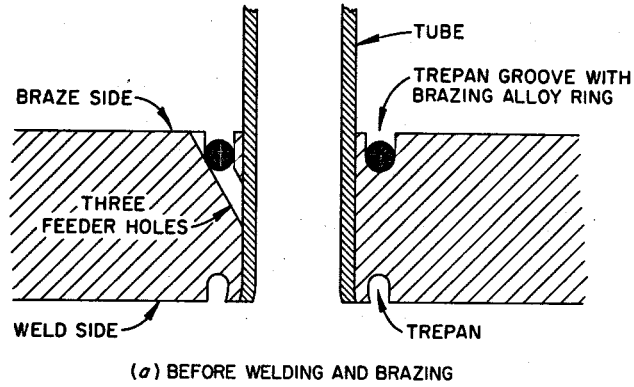


Fig. 3. Tube-to-Tube Sheet Joint MSRE Primary Heat Exchanger.

3. Fluid pressure drop measurements were also taken during the tests and are readily convertible from a water system to a molten salt system.

Accordingly, an outdoor test installation was built as shown schematically in Figure 4. Water was supplied from a large capacity water main. A once-through system was used and the water discharged into a drainage ditch. Before installing the MSRE heat exchanger, the line without the strainer installed was flushed out for about 20 minutes at a flow rate of 2800 gpm. The strainer was then inserted and the system was flushed again for about 1 hour at 2600 gpm. Sediment collected by the strainer consisted of several small pieces of paper gasket material, and a very small piece of lead. The system was now considered clean and the heat exchanger was installed. During each successive run, the system was flushed for a few minutes before water was run through the heat exchanger.

Hydraulic testing of the heat exchanger can be conveniently divided into 4 chronological phases as follows:

1. Initial test of the heat exchanger as built.
2. Testing the heat exchanger as designed, but with the Hastelloy-N shell replaced by a special stainless steel shell featuring observation windows.
3. Testing the heat exchanger as modified, and with the special stainless steel shell.
4. Final testing of the heat exchanger as modified, and with the Hastelloy-N shell.

Initial Test of Heat Exchanger, As-Built

The heat exchanger, as built, was installed in the water test facility and tested in December of 1963. Results of this test are as follows:

1. The most dramatic results were audible. At flow rates of 800 to 900 gpm ($\sim 2/3$ design flow) through the shell side, an intermittent rattling noise came from the heat exchanger. This noise is hard to describe but it impressed us as the kind of noise one might hear if tubes were rattling in the baffle plates. As the flow rate was increased, the

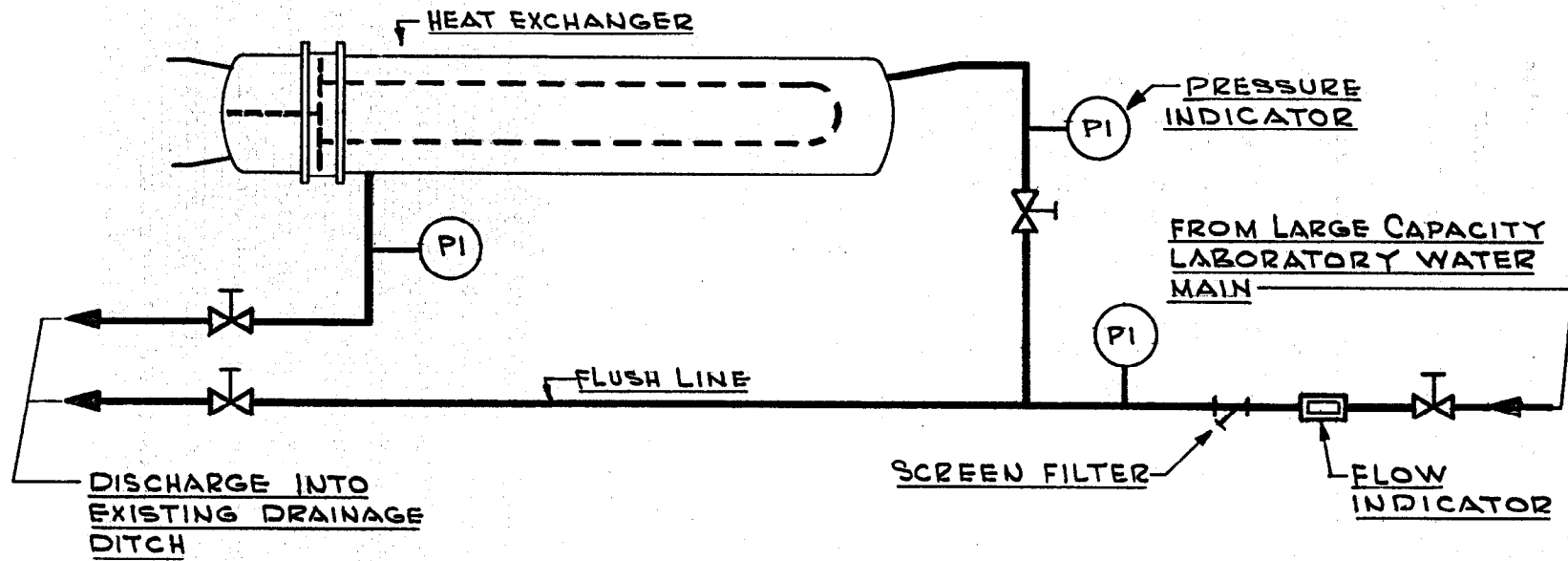


Fig. 4. Hydraulic Test Installation MSRE Primary Heat Exchanger.

fraction of time that the rattling noise was heard also increased and it seemed to get louder. At about 1100 gpm the noise was continuous. The rattling continued to get louder to the maximum flow rate tested, 1300 gpm. The character of the noise heard differed little whether the tubes were empty or full of water.

Measurements were taken with an International Research and Development Corporation, Model 600B, external pick-up vibrometer at intervals of 200 gpm from 500 to 1300 gpm. The results were hard to interpret. Generally at flow rates above 900 gpm, more instrument activity in the range of 450-3500 cpm was observed, however, no discrete and continuous frequencies could be detected. The audible rattling noise was the best indication we had that the tubes were vibrating. To assure ourselves that the noise was not due to cavitation, we increased back pressure to 55 psig at 1000 gpm. There was no obvious change in the character of the noise. The conclusion from these tests was that the tubes were probably vibrating excessively.

2. The overall pressure drop through the tube side and the shell side of the heat exchanger was measured. The pressure drop through the tube side was almost exactly the estimated value. The pressure drop through the shell side was about twice the estimated value.

From these tests, it appeared that we had two serious problems, tube vibrations and excessive pressure drop on the shell side. To investigate these problems more thoroughly, we cut off the Hastelloy-N shell and replaced it with a special stainless steel shell incorporating 16 windows. The vibrations could then be viewed directly, also the windows could be fitted with pressure taps to determine the pressure drop distribution. This special shell is shown in Figure 5.

When the Hastelloy-N shell was removed, we noted that 2 tubes in the outermost row of 4 tubes (longest tubes) had vibrated against a seam weld in the shell wearing a notch ~ 0.0025-in. deep in the wall of Tube A and ~ 0.005-in. deep in Tube B. A photograph of this is shown in Figure 6. No worn places could be found on the tubes where they penetrated the baffle plates.

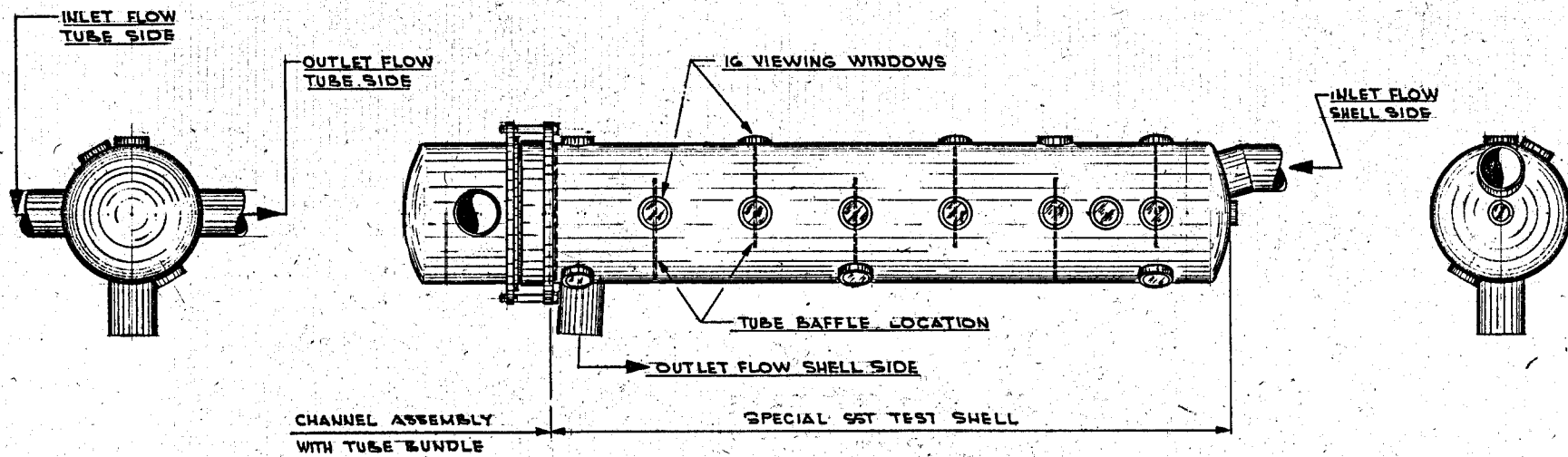


Fig. 5. Hydraulic Test Shell Assembly, Primary Heat Exchanger.

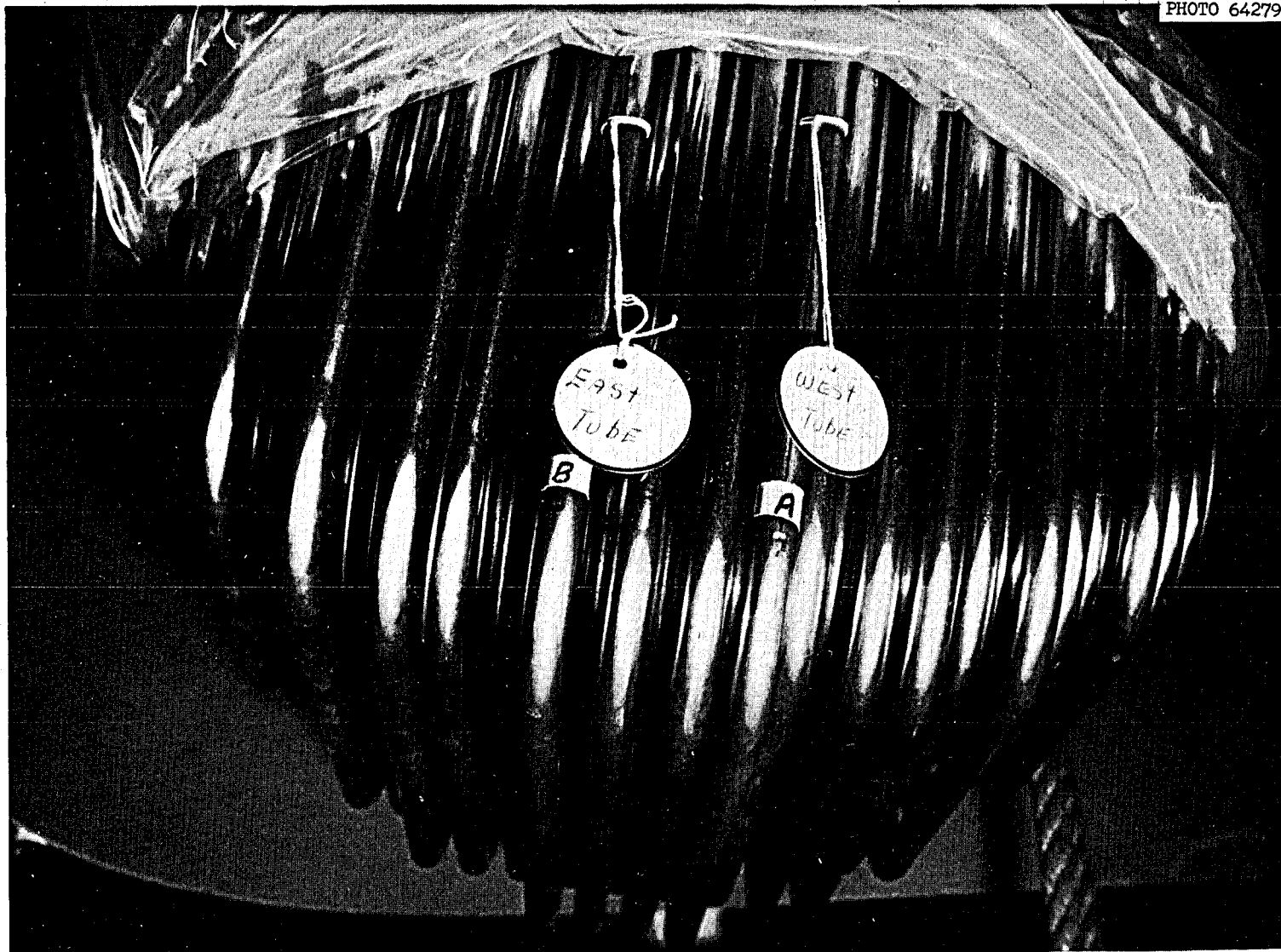


Fig. 6. MSRE Primary Heat Exchanger Tube Damage.

Test of Heat Exchanger, As-Designed but with Special Shell

The heat exchanger, as designed but with its new shell, was then tested with flow rates up to 1200 gpm. Results of this test are as follows:

1. The "U" bends vibrated quite severely with estimated frequencies from 5 to 10 cps, and with peak-to-peak amplitudes as high as 1/4 in.

2. In the bulk of the heat exchanger, some of the tubes that penetrate every baffle plate vibrated, and most of the tubes that penetrate every other baffle plate vibrated. The sections of tubes between baffles vibrated with much less amplitude than did the U bends.

3. In the bulk of the heat exchanger the tubes in the interior of the bundle seemed to vibrate less severely than those near the edge. This may be because most of the tubes in the interior of the bundle penetrate every baffle plate. It may also have been an illusion because the tubes on the interior of the bundle were difficult to see.

4. In the vicinity of the tube sheet where the tubes are brazed in, there was no visible vibration.

5. The character of the rattling noise in this test was the same as in the previous test and could definitely be correlated with tube vibration.

6. The excessive fluid pressure drop through the shell side was determined to be where the tubes passed very close to the inlet and outlet pipes and tended to choke them off.

Based on the above observations, the following corrective actions were taken:

1. The 4 outermost U tubes and 4 associated tie bars were removed. Plugs were welded into the 8 resulting tube stub ends, and into all the resulting holes in the baffle plates. (See ORNL Drawing M-10329-RE-003E2.) The intent of this change was two-fold. First, it helped alleviate the tube vibration problem because two of these tubes had the worn spots shown in Figure 6. Second, it helped lower the shell side pressure drop because these tubes and tie bars contributed greatly to choking the shell side inlet and outlet.

2. Bars were laced between the tubes on the downstream side and adjacent to each baffle plate as shown in ORNL Drawing M-10329-RE-003E2. Note that the lacing is in two directions. It was believed that lacing in one direction would not be adequate. It also seemed that lacing in the third direction would be redundant because the holes in the baffle plates could serve as contact points. The lacing bars were sized so that they fit snugly between the tubes, and were tack-welded to the baffle plates. Other methods of tightening the tubes in this structure were considered, such as expanding the tubes into the baffles and bending, twisting or in some other way deforming the bundle. All were discarded however, in favor of this lacing method.

3. A similar lacing was built across the middle of the U bends as shown in ORNL Drawing M-10329-RE-002E1. In this structure the lacing bars are threaded through the tubes in two directions and welded to the outer band. This makes all the tubes in the U bend behave as a single member. The structure is supported by the tubes. This arrangement probably affects only a small increase in fluid pressure drop through the region of the U bends.

4. The special stainless steel heat exchanger shell was lengthened 1.0 in. and an impingement baffle was installed in the inlet as shown in ORNL Drawing M-20794-RE-030E1 for the Hastelloy-N shell.

5. The 5-in. outlet pipe was replaced by a 7 x 5 in. conical reducer as shown in ORNL Drawing M-20794-RE-030E1 to reduce the exit pressure drop.

6. An accelerometer (Endevco Corp., Model 2220) was mounted on one of the centermost tubes in the U bend just below the midplane of the heat exchanger.

Testing Heat Exchanger, As-Modified but with Special Shell

With the above modifications incorporated into the tube bundle and the special, the heat exchanger was again installed into the test facility. Results of this series of tests with flow rates up to 1700 gpm are as follows:

1. Tube vibrations were reduced to a negligible amount. No tube vibrations were visible anywhere in the tube bundle. No noise attributable to tube vibrations (metal-to-metal contacting) could be detected. The accelerometer detected a very high frequency vibration of 2000-3000 cps. The amplitude was not accurately measurable but appeared to be less than 0.001 in.

2. The overall fluid pressure drop on the shell side was reduced and almost exactly equaled the predicted value.

At this point, the vibrational and pressure drop problems were considered adequately solved.

Final Test of Modified Heat Exchanger

All modifications were now incorporated into the Hastelloy-N shell, and the heat exchanger was reassembled. The unit was installed in the test facility and tested to flow rates as high as 1650 gpm. The results of this test were identical to those of the previous test, that is, fluid induced tube vibrations were reduced to a negligible level and the shell side pressure drop was adequately low. Figure 7 shows the final overall pressure drop through the tube side and shell side. The tube side pressure drop is based on data taken during the initial test and the shell side pressure drop was measured during the final test.

OPERATIONAL HISTORY

Installation of the heat exchanger in the reactor was completed late in the spring of 1964. Fuel and coolant salt were first circulated through the reactor systems in January 1965. The reactor reached criticality on June 1, 1965, and low levels (0 - 50 kw) of nuclear power were first generated in December 1965. (See Figure 8.) Full-power (7-1/2 Mw) operations began in April 1966 and are continuing at the present time.

During the past three years the heat exchanger has operated for more than 14,000 hours with molten salt without any indication of a leak between fuel and coolant salts or into the reactor cell. There has been no evidence either of gas filming of the heat exchanger tubes or of a decrease in performance by a buildup of scale. Accumulated operating data are given in Table 4.

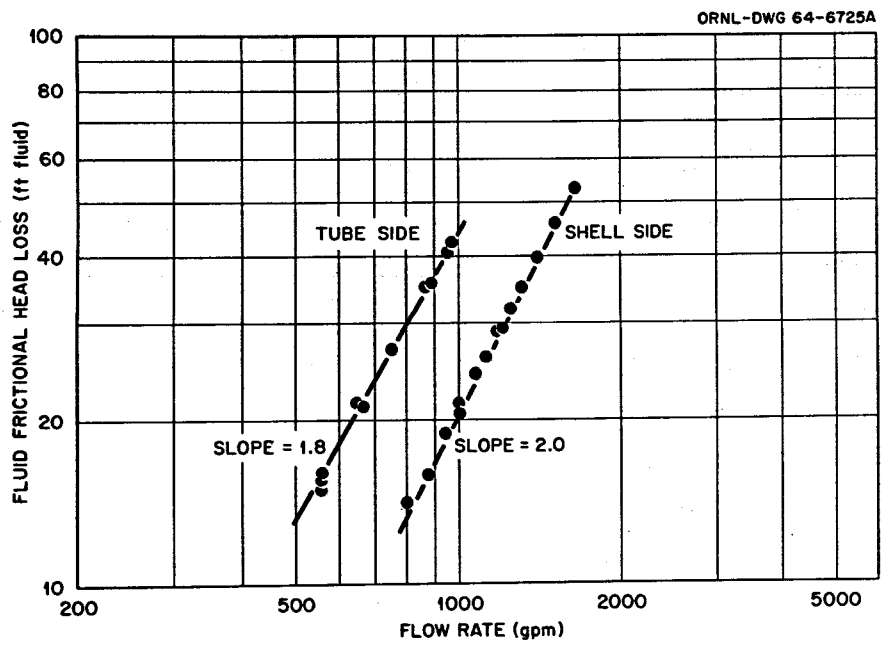


Fig. 7. Fluid Frictional Head Loss in Primary Heat Exchanger.

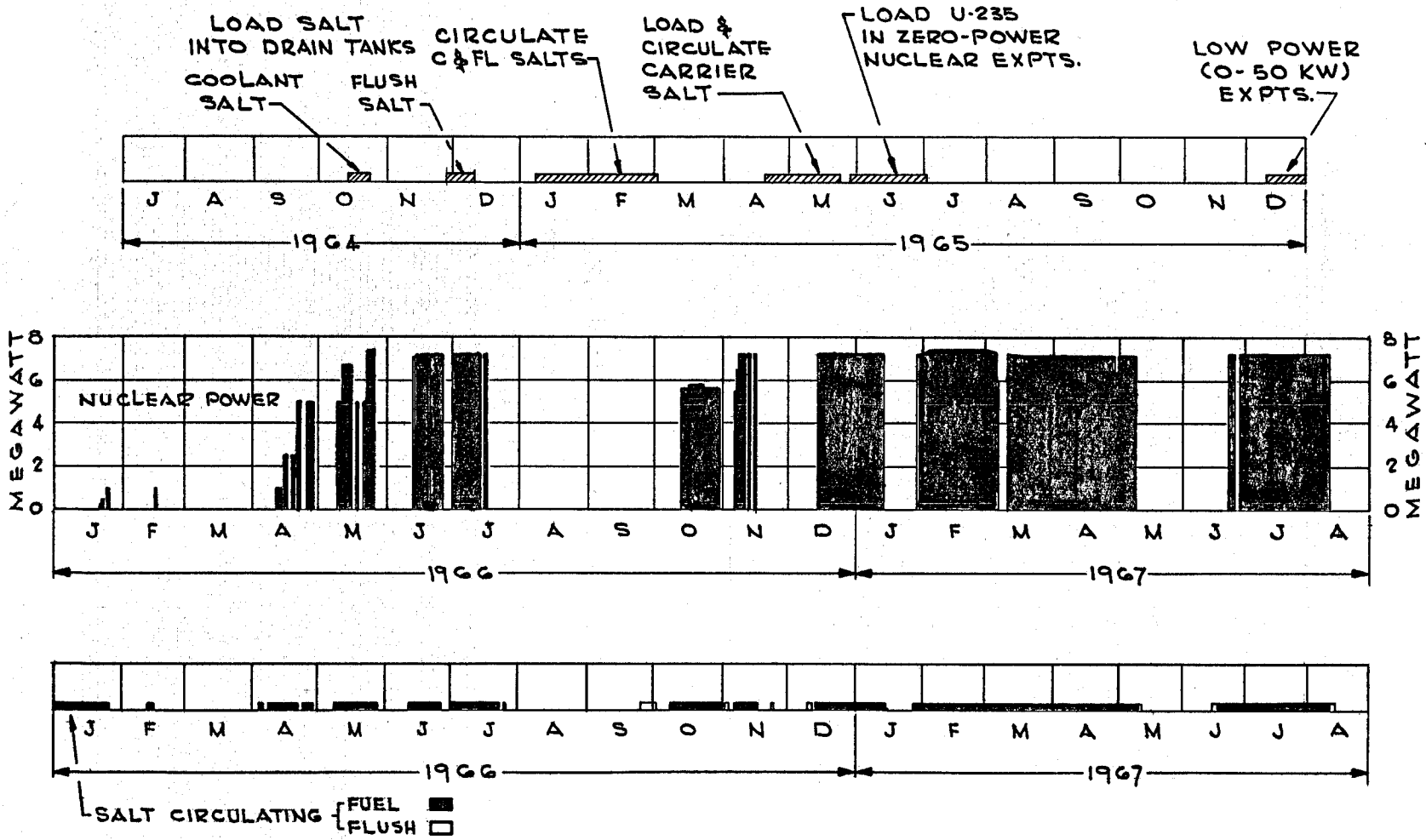


Fig. 8. MSRE Operational History.

Table 4

Reactor Accumulated Operating Data^a

Time Critical (hrs)	8,830
Fuel Loop Time Above 900°F (hrs)	18,021
Fuel Pump Time Circulating Helium (hrs)	3,985
Fuel Pump Time Circulating Salt (hrs)	12,334
Coolant Loop Time Above 900°F (hrs)	15,684
Coolant Pump Time Circulating Helium (hrs)	3,082
Coolant Pump Time Circulating Salt (hrs)	14,149
Heating Cycles (70 - 1200°F) Fuel/Coolant Systems	9/8
Fill-Drain Cycles (Fuel/Coolant Systems)	30/13
Nuclear Power Cycles (Fuel/Coolant Systems)	63/59
Equivalent Full-Power Hours	7,124

^aTotal to December 5, 1967

Soon after the operating power of the MSRE was raised to a significant level, the heat-transfer capability of the main heat exchanger and the coolant radiator was found to be less than predicted and, in fact, limited the attainable heat removal to about 7-1/2 Mw.¹⁴ The nominal power chosen for the design of the MSRE was 10 Mw. The overall heat-transfer coefficient of the primary heat exchanger was below the predicted value, resulting in somewhat larger fuel to coolant temperature differences than had been planned. The performance of the main heat exchanger was explained by recent measurements of the fuel salt thermal conductivity which indicated a value of $0.83 \frac{\text{Btu}}{\text{Hr-Ft-}^\circ\text{F}}$ rather than $2.75 \frac{\text{Btu}}{\text{Hr-Ft-}^\circ\text{F}}$ which was used in the calculations.

The fuel salt that circulates through the heat exchanger in the MSRE is highly radioactive. Noble metal fission products are reduced to metals in the salt, and some of them deposit on surfaces in the heat exchanger so it too becomes highly radioactive. The heat exchanger is of all-welded

construction and is covered by heater-insulation boxes that are difficult to remove and reinstall remotely. Any meaningful nondestructive inspection of the interior is impossible and of the exterior is extremely difficult. No inspection is planned, at least until the experiment is completed or the heat exchanger must be removed because it develops a leak. Leakage through failure of one or more tubes by vibration should be detectable by a small increase in salt inventory in the fuel system and decrease in salt inventory in the coolant system. The reactor is designed on the basis that such a leak or a leak from the fuel system into the coolant system might someday occur. The fuel and coolant salt systems are tested separately at pressures above the normal operating pressures at intervals of 6 to 12 months.¹⁵ No leakage has ever been indicated.

Because the heat exchanger operates at temperatures above 1000°F in a highly radioactive environment, no equipment is installed to monitor vibrations. However, we believe it unlikely that the vibration has increased since the final preoperational hydraulic flow tests. For vibration to reoccur, the rigidity of the tube bundle would have to be reduced. This could happen if the clearances between the tubes and lacing were increased by corrosion of the salt container material, however, this is unlikely. Chemical analysis of the fuel and coolant salt show that general corrosion of Hastelloy-N in the system has been practically nil (~ 0.1 mil).¹⁶

Vibration could also reoccur if the flow rate of the fuel salt entering the shell side of the heat exchanger were substantially increased. This is also unlikely as the fuel and coolant salt flow rates are fixed and cannot be varied unless the impellers of the pumps are modified. The original pumps are still in operation and there are no plans to replace these pumps before the MSRE is terminated in 1969.

CONCLUSIONS

1. Testing the MSRE heat exchanger with water indicated fluid flow induced tube vibrations and an excessive pressure drop on the shell side. The best indication we had of tube vibrations was a rattling noise emanating from the heat exchanger.

2. An extension of the above conclusion is that water is an adequate fluid to test molten salt heat exchangers for fluid-induced vibrations.

3. The fluid-induced tube vibrations were eliminated by lacing bars between the tubes at the baffle plates, by building a structure of bars around the U bend in the tube bundle, and by installing an impingement baffle at the inlet to the shell.

4. The excessive fluid pressure drop through the shell side was found to result from choking of the inlet and outlet pipes by the outermost row of tubes and tie bars. The pressure drop was reduced to an acceptable value by removing these tubes and tie bars and increasing the diameter of the outlet pipe.

5. After more than 14,000 hours of operation with salt in the system to date, the heat exchanger has shown no indication of leakage or change in operating performance.

6. We find no reasons why the primary heat exchanger should fail from vibration-induced damage before the planned termination of the MSRE in 1969.

REFERENCES

1. Memorandum from Milton Shaw to the Managers of the Operations Offices, September 29, 1967, Subject: Information on Primary Circuit Heat Exchangers - Damage from Tube Vibrations.
2. Letter from H. M. Roth to A. M. Weinberg, October 13, 1967, Subject: Information on Primary Circuit Heat Exchangers - Damage from Tube Vibrations.
3. J. H. Westsik, Oak Ridge National Laboratory, Heat Transfer and ΔP Design of MSRE Primary Heat Exchanger, CF-61-4-1, April 3, 1961. (Internal Distribution Only)
4. E. S. Bettis and J. H. Westsik, Oak Ridge National Laboratory, MSRE Component Design Report, Section V, Stress Analysis of Primary Heat Exchanger of the MSRE, MSR-61-67, June 20, 1961. (Internal Distribution Only)
5. R. C. Robertson, MSRE Design and Operations Report, Part I, Description of Reactor Design, USAEC Report ORNL-TM-728, Oak Ridge National Laboratory, January 1965.
6. D. Q. Kern, Process Heat Transfer, McGraw Hill Co., New York, 1st Ed., 1950.
7. Unfired Pressure Vessels, Section VIII ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, New York.
8. General Requirements for Nuclear Vessels, Case 1270N-5, Interpretations of ASME Boiler and Pressure Vessel Codes, American Society of Mechanical Engineers, New York.
9. Containment and Intermediate Containment Vessels, Case 1272 N-5, Case Interpretations of ASME Boiler and Pressure Vessel Codes, American Society of Mechanical Engineers, New York.
10. Nuclear Reactor Vessels and Primary Vessels, Case 1273N-7, Case Interpretations of ASME Boiler and Pressure Vessel Codes, American Society of Mechanical Engineers, New York.
11. Special Equipment Requirements, Case 1276N-1, Case Interpretations of ASME Boiler and Pressure Vessel Codes, American Society of Mechanical Engineers, New York.
12. Standards of Tubular Exchanger Manufacturers Association, 2nd ed., Tubular Exchanger Mfrs, Assn. Inc., New York 1949.

References (continued)

13. C. K. McGlothlan, Oak Ridge National Laboratory, Fabrication Specifications, Procedure and Records for MSRE Components, MSR-62-3, Rev. A, February 18, 1965. (Internal Distribution Only)
14. C. H. Gabbard, R. J. Kedl, and H. B. Piper, Oak Ridge National Laboratory, Heat Transfer of the MSRE Main Heat Exchanger and Radiator, CF-67-3-38, March 21, 1967. (Internal Distribution Only)
15. R. H. Guymon, MSRE Design and Operations Report Part VIII, Operating Procedures, USAEC Report ORNL-TM-908, Vol. II, Procedure 5H, Oak Ridge National Laboratory, January 1966.
16. Oak Ridge National Laboratory, MSRP Semiann. Progr. Rept. Feb. 1967, USAEC Report ORNL-4119, p. 120.

APPENDIX

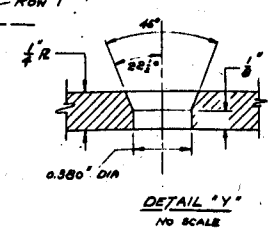
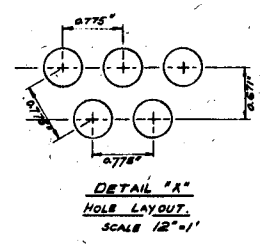
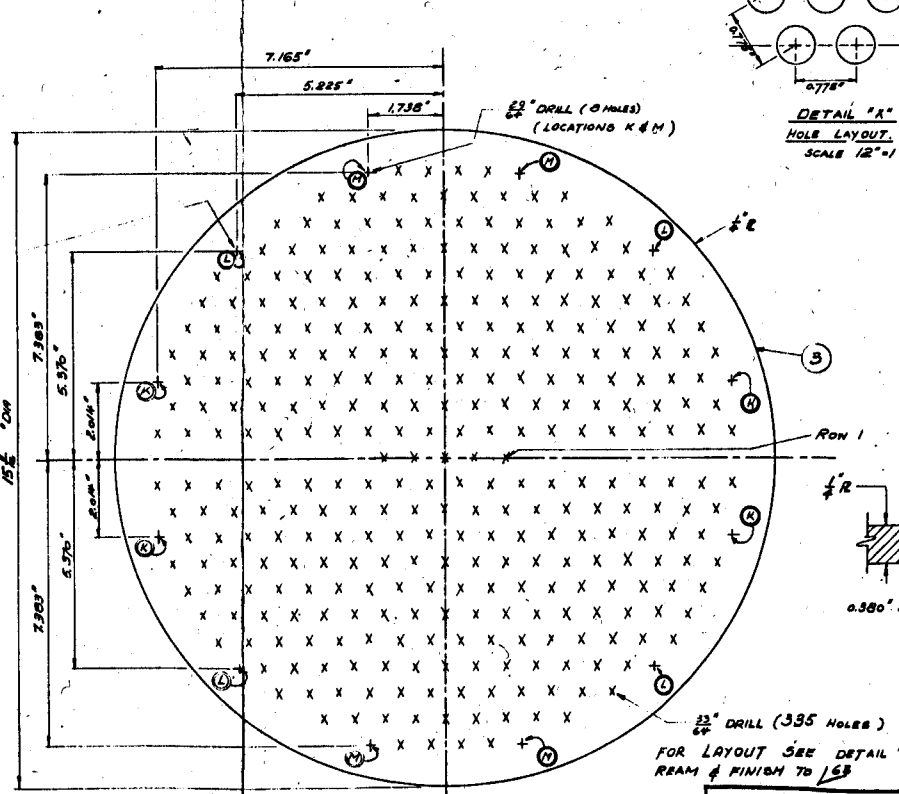
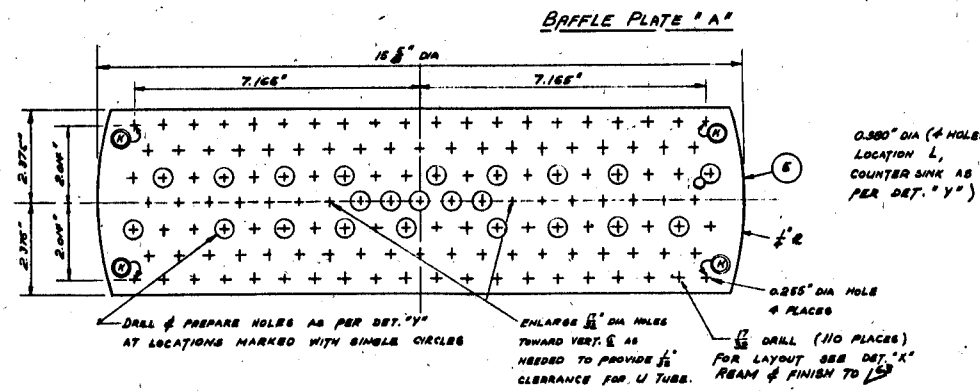
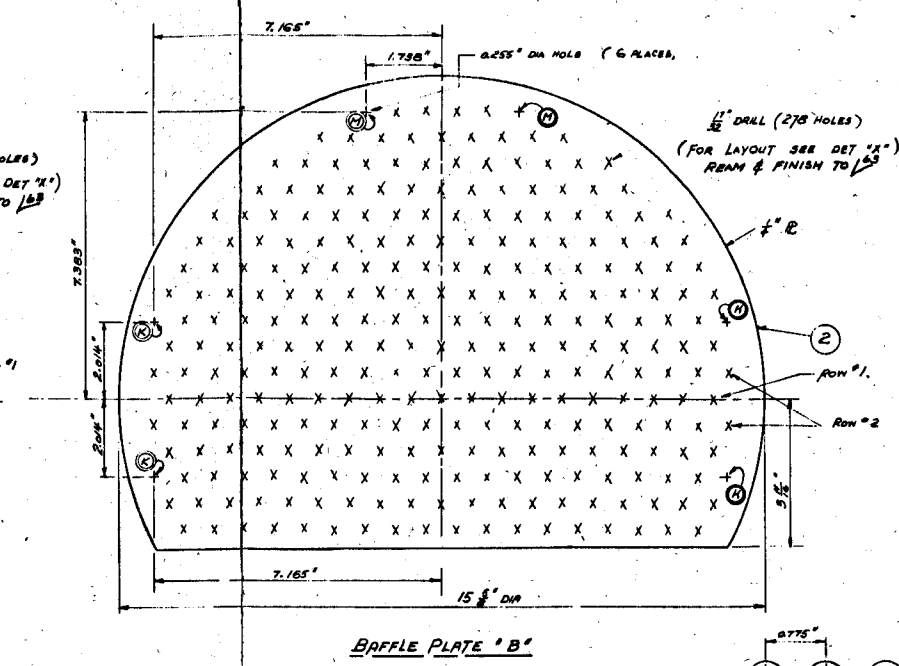
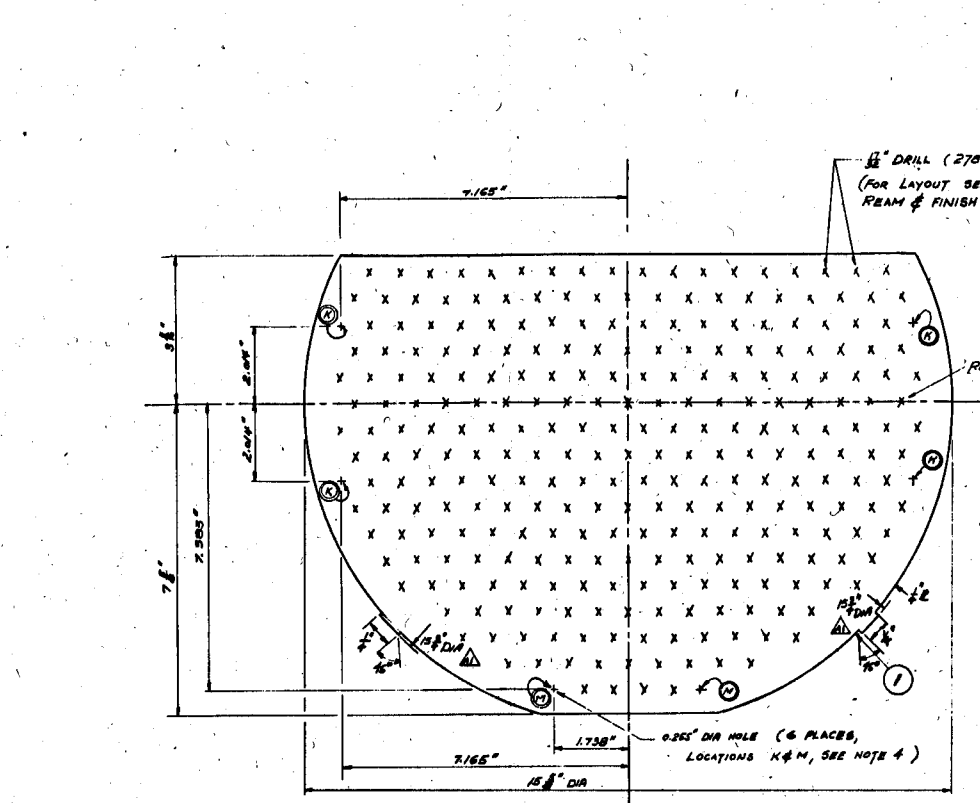
Fabrication Drawings - Primary Heat Exchanger

D-EE-A-40864	Baffle Plates
D-EE-A-40865	Tube Sheet
D-EE-A-40866	Baffle Assembly
D-EE-A-40867	Tube Bundle Assembly
D-EE-A-40869	Details
D-EE-A-40872	Channel Assembly
D-EE-A-40873	Assembly Sections
D-EE-A-40874	Assembly Elevation
M-10329-RE-003E2	Stabilizers - Details Return Bend
M-10329-RE-002E1	Stabilizer Details - Return Bend
M-20794-RE-030E1	Modifications

PARTS LIST				
PART NO.	DWG. NO.	NO. QUANT.	DESCRIPTION	MATERIAL
1	THIS DWG	3	BAFFLE PLATE "A" 1/2" THK PLATE, 15 1/2" DIA BLANK	INOR-B
2	"	2	BAFFLE PLATE "B" 1/2" THK PLATE, 15 1/2" DIA BLANK	INOR-B
3	"	1	BARRIER PLATE 1/2" THK PLATE, 15 1/2" DIA BLANK	INOR-B
4	"	1	STUB BAFFLE 1/2" THK 15 1/2" DIA BLANK	INOR-B

NOTES:

- DRILL ALL HOLES TO MATCH CORRESPONDING HOLES ON TUBE SHEET (DWG: D-EE-A-40865)
- LOCATIONS K, L & M ARE SYMMETRICAL ABOUT THE VERTICAL AXIS.
- COMPLETELY REMOVE ALL BURRS AFTER DRILLING.
- DRILL LOCATIONS "N" ON ONE TYPE "A" BAFFLE (ASSEMBLY POSITION "A") AS PER DETAIL "Y"
- PARTS TO BE FABRICATED AS PER USER GENERAL FABRICATION SPECIFICATION USER GE-B-285A
- MATERIAL SPEC. (ORNL) MET-RM-8334 INOR-B PLATE.
- ROUND ALL SHARP CORNERS TO 1/8" RADIUS UNLESS OTHERWISE SPECIFIED.
- FINISH MACHINED SURFACES TO 165 MICRO IN. AVG. ROUGHNESS HEIGHT, UNLESS OTHERWISE SPECIFIED.



THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9.24.64

CLASSIFICATION	NOT CLASSIFIED
DESIGNED BY	J. H. WESTRICK
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED	FRACTIONAL 1/32"
DECIMALS	0.005"
ANGLES	2°
TOLERANCE	0.001"

PRIM HEAT EXCH. ASSY ELEV	DEEA4087A
PRIM HEAT EXCH. BAFFLE PLATES, SHEET #2	D-EE-A-4087B
PRIM HEAT EXCH. BAFFLE ASSY.	D-EE-A-4086C
PRIM HEAT EXCH. TUBE SHEET	D-EE-A-4086E
REFERENCE DRAWINGS	DWG. NO.
MOLTEN SALT REACTOR EXPERIMENTAL UNIT 7503	
PRIMARY HEAT EXCHANGER; BAFFLE PLATES SHEET # 1.	
ORNL NATIONAL LABORATORY ORNL DIVISION OF UNION CARBIDE CORPORATION ONE RIDGE, TENNESSEE	
APPROVED	APPROVED
DATE 11/1/64	DATE 11/1/64
JOB 433-66	D-EE-A-4086C

NO.	REVISIONS	DATE	APPRO	APPRO
1	AS BUILT	9-24-64	J.H. Westrick	J.H. Westrick
2	SEE DCN #2217	1-16-65	J.H. Westrick	J.H. Westrick

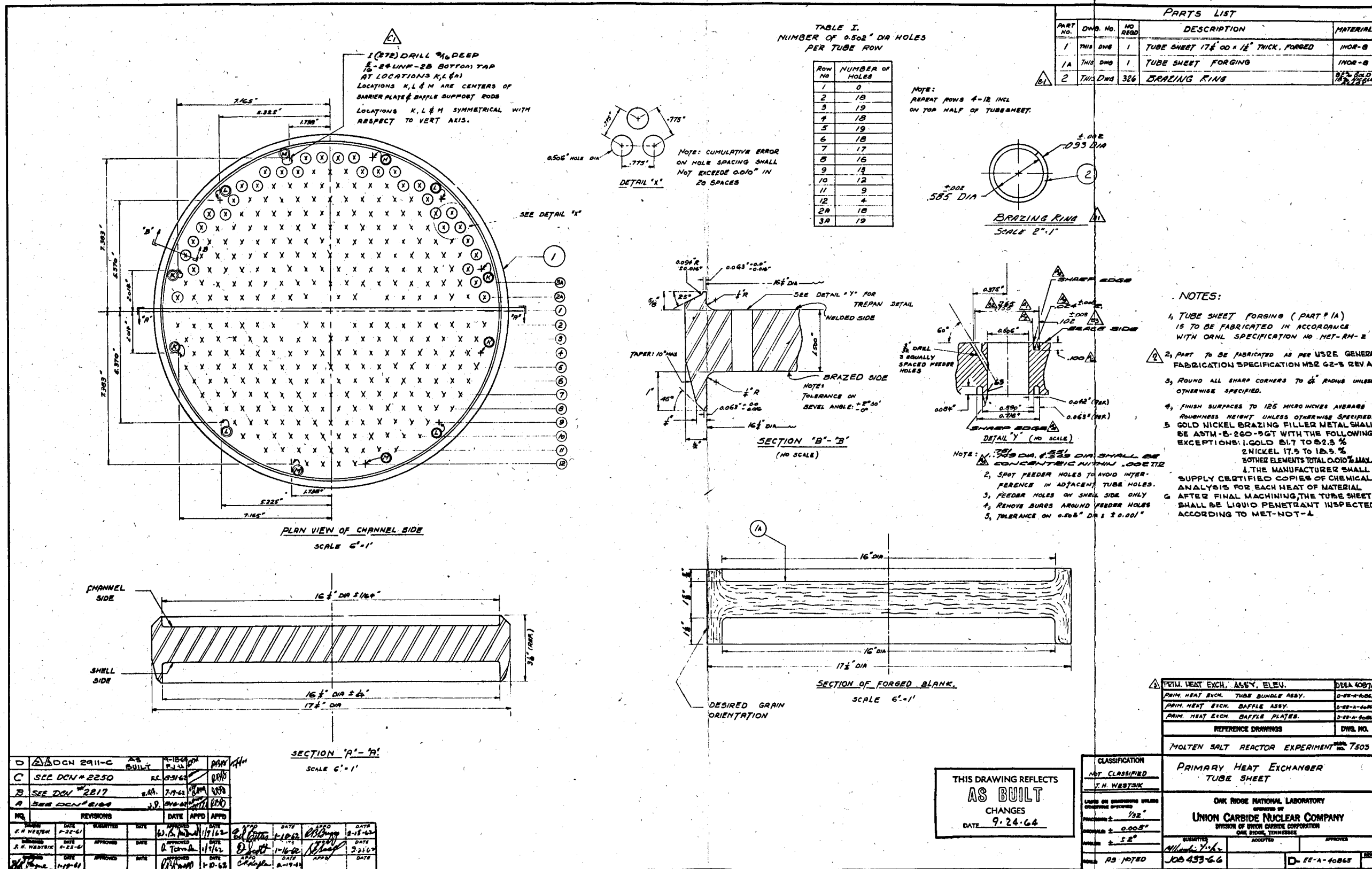


TABLE I.
NUMBER OF 0.502\"/>

ROW NO	NUMBER OF HOLES
1	0
2	18
3	19
4	18
5	19
6	18
7	17
8	16
9	14
10	12
11	9
12	4
2A	18
3A	19

PARTS LIST				
PART NO.	DWG NO.	NO RECD	DESCRIPTION	MATERIAL
1	THIS DWG	1	TUBE SHEET 17 1/2\"/>	
1A	THIS DWG	1	TUBE SHEET FORGING	INOR-B
2	THIS DWG	326	BRAZING RING	1/8\"/>

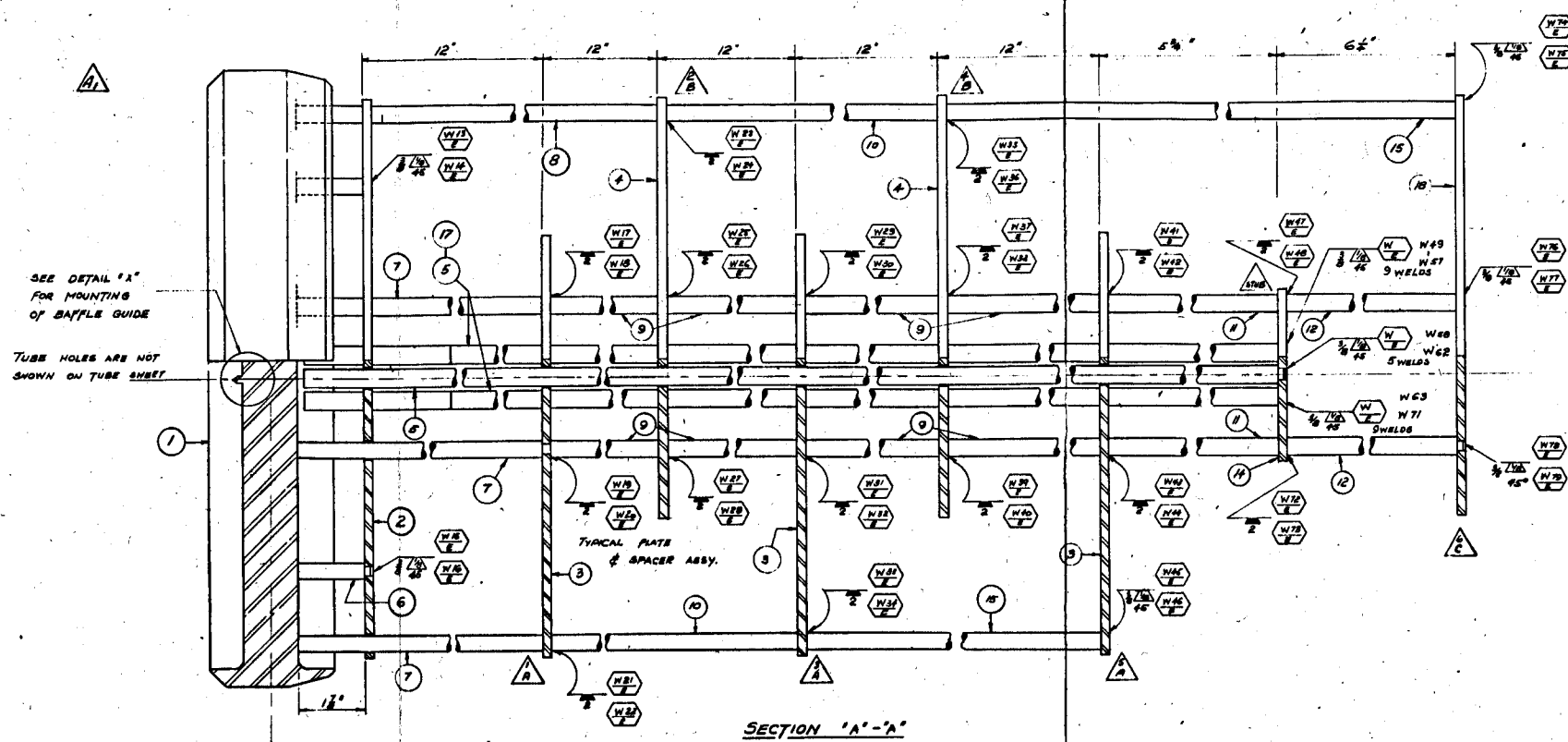
- NOTES:
- TUBE SHEET FORGING (PART # 1A) IS TO BE FABRICATED IN ACCORDANCE WITH ORNL SPECIFICATION NO. MET-RM-2
 - PART TO BE FABRICATED AS PER US2E GENERAL FABRICATION SPECIFICATION MS2 G2-3 REV A
 - ROUND ALL SHARP CORNERS TO 1/8\"/>
 - FINISH SURFACES TO 125 MICRO INCHES AVERAGE ROUGHNESS HEIGHT UNLESS OTHERWISE SPECIFIED.
 - GOLD NICKEL BRAZING FILLER METAL SHALL BE ASTM-B-260-5GT WITH THE FOLLOWING EXCEPTIONS: 1. GOLD 81.7 TO 82.3 % 2. NICKEL 17.5 TO 18.5 % 3. OTHER ELEMENTS TOTAL 0.010% MAX. 4. THE MANUFACTURER SHALL SUPPLY CERTIFIED COPIES OF CHEMICAL ANALYSIS FOR EACH HEAT OF MATERIAL
 - AFTER FINAL MACHINING, THE TUBE SHEET SHALL BE LIQUID PENETRANT INSPECTED ACCORDING TO MET-NOT-4

THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9.24.64

NO.	REVISIONS	DATE	APPROV	APPROV
D	ADDCN 2911-C AS BUILT	1-15-64	W.H.	W.H.
C	SEE DCN # 2250	8-31-63	W.H.	W.H.
B	SEE DCN # 2217	7-7-61	W.H.	W.H.
A	SEE DCN # 2184	5-16-61	W.H.	W.H.

REFERENCE DRAWINGS	DWG. NO.
PRIM. HEAT EXCH. ASSY. ELEV.	DEEA 4087A
PRIM. HEAT EXCH. TUBE BUNDLE ASSY.	D-EE-1-6067
PRIM. HEAT EXCH. BAFFLE ASSY.	D-EE-1-6064
PRIM. HEAT EXCH. BAFFLE PLATES	D-EE-1-6064

CLASSIFICATION	
NOT CLASSIFIED	BY T.H. WESTSIK
OAK RIDGE NATIONAL LABORATORY DIVISION OF UNION CARBIDE CORPORATION ONE BRIDGE, TENNESSEE	
DATE	9.24.64

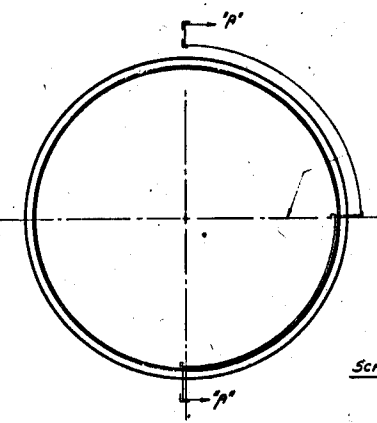


SEE DETAIL 'X' FOR MOUNTING OF BAFFLE GUIDE

TUBE HOLES ARE NOT SHOWN ON TUBE SHEET

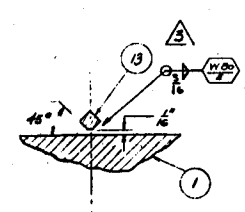
TYPICAL PLATE & SPACER ASSY.

SECTION 'A'-'A'

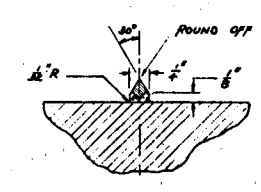


HORIZONTAL CENTER LINE, LOCATION OF BAFFLE GUIDE

SCHEMATIC FRONT ELEVATION
NO SCALE



WELD SETUP FOR BAFFLE GUIDE



MACHINING OF BAFFLE GUIDE

DETAIL 'X' BAFFLE GUIDE

PARTS LIST				
PART NO.	DWG. No.	QTY.	DESCRIPTION	MATERIAL
1	D-EE-A-4086A	1	TUBE SHEET 1/2" THK	INOR-B
2	D-EE-A-4086A	1	BARRIER PLATE 1/4" THK	"
3	"	3	BAFFLE PLATE 'A' 1/4" THK	"
4	"	2	BAFFLE PLATE 'B' 1/4" THK	"
5	D-EE-A-4086A	9	DUMMY RODS 1" 1/2 DIA	"
6	"	4	BARRIER PLATE SPACER ROD 1/2" DIA	"
7	"	6	BAFFLE PLATE SPACER ROD 'I' 1/2" DIA	"
8	"	2	BAFFLE PLATE SPACER ROD 'X' 1/2" DIA	"
9	"	16	BAFFLE PLATE SPACER ROD 'II' 1/2" DIA	"
10	"	4	BAFFLE PLATE SPACER ROD 'IV' 1/2" DIA	"
11	"	4	BAFFLE PLATE SPACER ROD 'V' 1/2" DIA	"
12	"	4	BAFFLE PLATE SPACER ROD 'VI' 1/2" DIA	"
13	THIS DWG	1	BAFFLE PLATE GUIDE 1/2" x 1/2" x 15 3/4"	"
14	D-EE-A-4086A	1	STUB BAFFLE 1/2" THK	"
15	D-EE-A-4086A	4	BAFFLE PLATE SPACER ROD 'II' 1/2" DIA	"
16	"	4	DUMMY ROD 'Z' 1/2" DIA	"
17	"	14	DUMMY ROD 'Z' 1/2" DIA	"
18	D-EE-A-4086A	1	BAFFLE PLATE 'C' 1/4" THK	"

- NOTES:
- WELD NUMBERING PROGRESSES FROM LEFT TO RIGHT, FROM TOP TO BOTTOM, AND FROM FRONT TO BACK OF SECTION 'A'-'A'
 - PARTS TO BE FABRICATED AS PER USRE GENERAL FABRICATION SPECIFICATION MSR G2-280-A
 - MATERIAL SPECIFICATIONS:
NET-RM-828G (INOR-B BAR)
NET-RM-8304 (INOR-B WELDING FILLER METAL)
 - UCNC FABRICATORS WELD PER SPECIFICATIONS PS-23, PS-25, PS-26, AS APPLICABLE. INSPECT PER WR-200.
 - WELD NUMBERS ASSIGNED W1-W50
WELD NUMBERS USED W1-W50
 - ROUND ALL SHARP CORNERS TO 1/8" RADIUS UNLESS OTHERWISE SPECIFIED.
 - FINISH SURFACES TO 125 MICROINCHES AVERAGE ROUGHNESS HEIGHT UNLESS OTHERWISE SPECIFIED.
 - BEFORE ASSEMBLY OF BAFFLE PLATES THREAD TUBES CODE I-B - CODE I-B THROUGH.

NO.	REVISIONS	DATE	APPD	APPRD	APPROVED	DATE	APPROVED	DATE
1	AS BUILT							
2	SEE DCN # 2250	02-13-64						
3								
4								
5								

THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64

REFERENCE DRAWINGS	DWG. NO.
PRIM. HEAT EXCH. ASSY. ELEV.	DCN 40814
PRIM. HEAT EXCH. BAFFLE PLATES, SHEET #2	D-EE-A-40877
PRIM. HEAT EXCH. TUBE SHEET	D-EE-A-40866
PRIM. HEAT EXCH. BAFFLE PLATES SHEET #1	D-EE-A-40866
PRIM. HEAT EXCH. TUBE & ROD DETAILS	D-EE-A-40866

MOLTEN SALT REACTOR EXPERIMENT
USA 7609

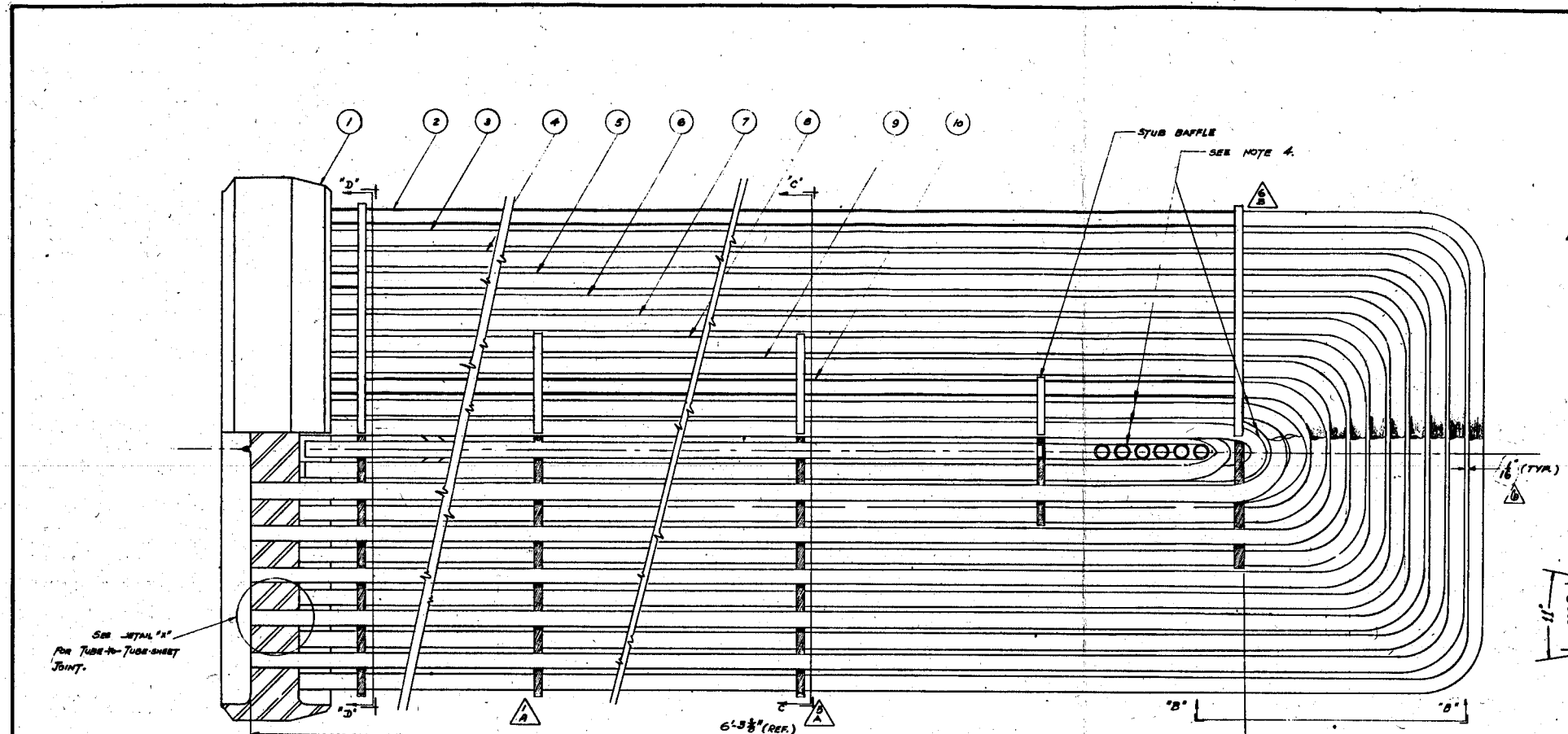
CLASSIFICATION
Not Classified
J. H. NEZYSIK

LIMITS OF DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/32"
DECIMALS ± 0.005"
ANGLES ± 2'0"
RADIUS ± 1'

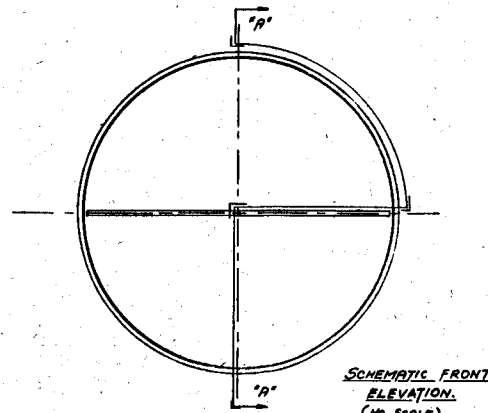
PRIMARY HEAT EXCHANGER
BAFFLE ASSEMBLY

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

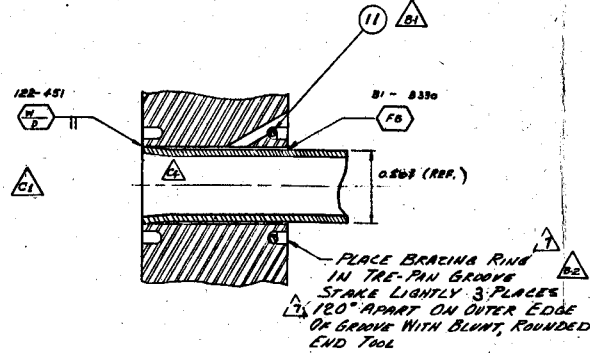
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D-EE-A-40866
M20744RE 007D 2



SECTION 'A'-'A'
(SIDE ELEVATION)



SCHEMATIC FRONT
ELEVATION
(NO SCALE)

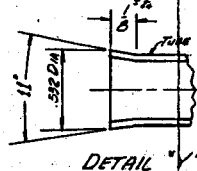


DETAIL 'X'
TYPICAL TUBE-TO-TUBE-SHEET JOINT

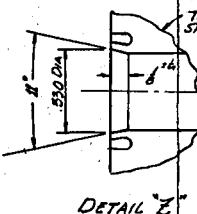
NOTE: SEE Dwg. No. D-EE-Z-40851 FOR
NUMBERING OF TUBE WELDS AND BRAZED JOINTS.

PARTS LIST				
PART NO.	DWG. NO.	NO. REQD.	DESCRIPTION	MATERIAL
1	D-EE-A-40866	1	BAFFLE ASSEMBLY	INOR-B
2	D-EE-A-40865	4	U TUBE, 5/16" O.D. x 0.002" WALL	FOR ROW 12
3	"	9	"	FOR ROW 11
4	"	18	"	FOR ROW 10
5	"	18	"	FOR ROW 9
6	"	18	"	FOR ROW 8
7	"	17	"	FOR ROW 7
8	"	18	"	FOR ROW 6
9	"	19	"	FOR ROW 5
10	"	18	"	FOR ROW 4
11	D-EE-A-40865	326	BRAZING RING	5028 BRASS ALLOY

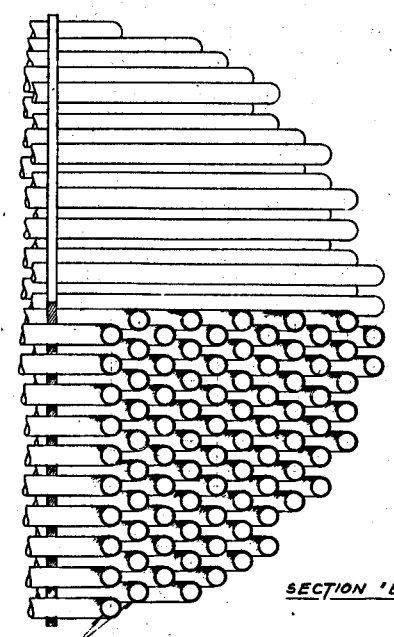
- NOTES:
- PARTS TO BE FABRICATED AS PER GENL SPEC. MS22 GE-3 REV. A (MS22 GENERAL FABRICATION SPEC.) U.S. 81-102 FABRICATION OF TUBE BUNDLE U.S. 80-102 BRAZING OF TUBE BUNDLE
 - MAKE TUBE TO TUBE SHEET WELD JOINTS AS PER MS22 METALLURGY MEMO GE-66
 -
 - FOR DETAILS AND PARTS LIST OF ROWS NO 1, 2 & 3 SEE DWG NO D-EE-A-40875
 - FOR SECTIONS 'C'-'C' AND 'D'-'D' SEE DWG NO D-EE-A-40876
 - FLARE TUBE AND TREPAN LIP ACCORDING TO DETAIL 'Y' & 'Z' BEFORE WELDING. FLARE HOLE IN TUBE SHEET AND INSERT TUBE THROUGH HOLE BEFORE FLARING THE TUBE.
 - A HELIUM LEAK CHECK SHALL BE PERFORMED AFTER WELDING AND BRAZING AS FOLLOWS: ENCLOSE THE TUBE BUNDLE IN A PLASTIC BAG AND COVER THE TUBE SHEET WITH A FLAT PLATE. FILL THE BAG WITH HELIUM AND EVACUATE INTERSTITIAL TUBES. THE HELIUM LEAK RATE SHALL BE LESS THAN 1x10⁻⁵/SEC.
 - COMPLETED HEAT EXCHANGER TUBE BUNDLE WAS MODIFIED IN THE FIELD AFTER WATER FLOW TESTS ACCORDING TO DRAWINGS E-10629-12-001 AND 002



DETAIL 'Y'



DETAIL 'Z'



SECTION 'B'-'B'

SEE NOTE 4.

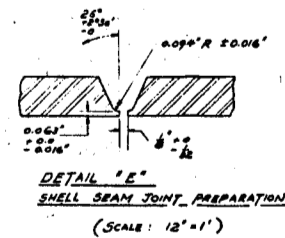
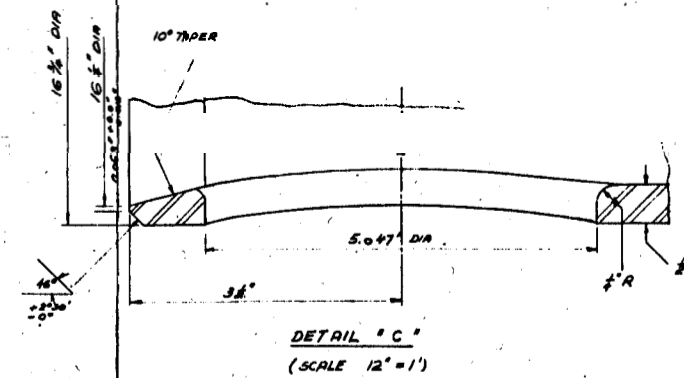
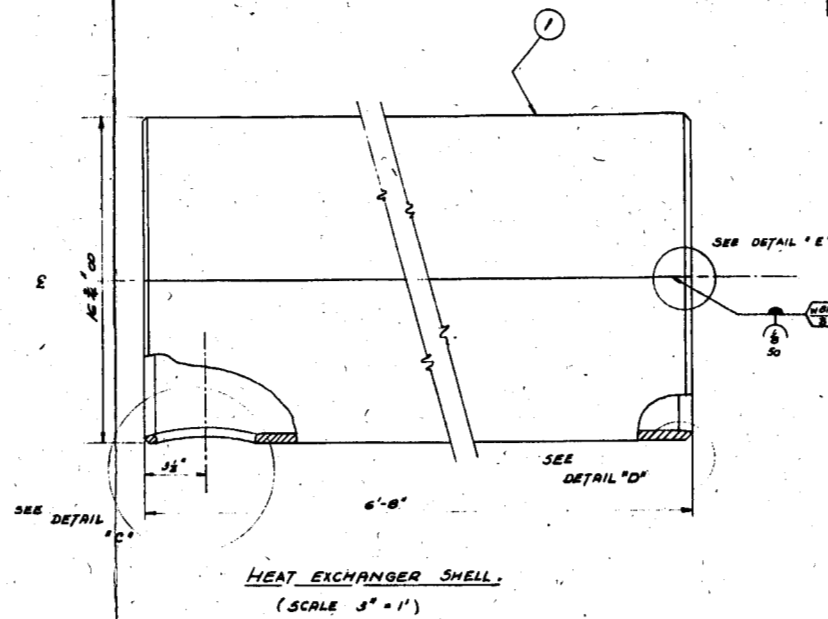
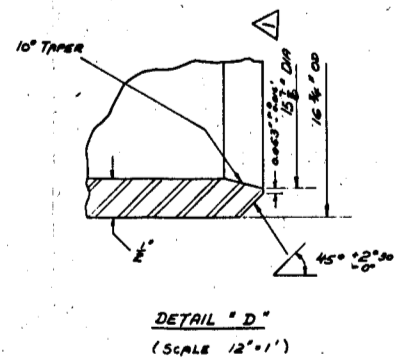
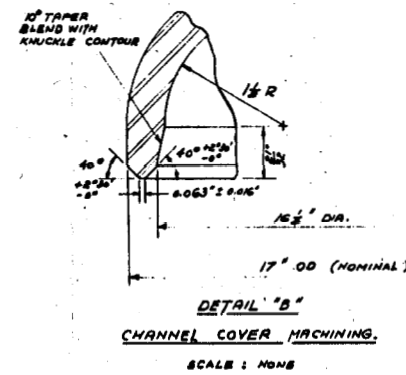
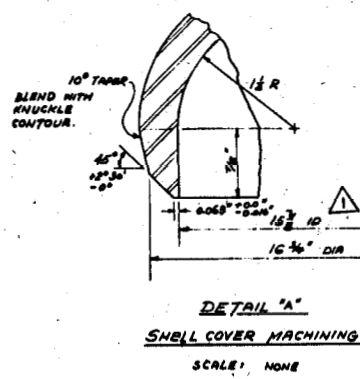
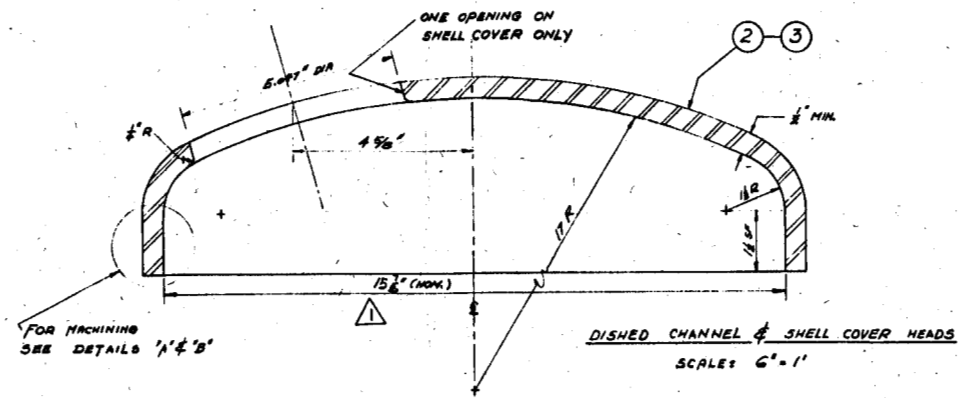
THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64

NO.	REVISIONS	DATE	APPROVED	DATE	APPROVED
1	AS BUILT	9-24-64	J.M. WESTSIK	9-24-64	J.M. WESTSIK
2					
3					
4					
5					
6					
7					
8					
9					
10					

CLASSIFICATION	NOT CLASSIFIED	J.M. WESTSIK
MOLTEN SALT REACTOR EXPERIMENT		
PRIMARY HEAT EXCHANGER TUBE BUNDLE ASSEMBLY		
ORR RIDGE NATIONAL LABORATORY DIVISION OF UNION CARBIDE CORPORATION		
DATE	9-24-64	D-EE-A-40867

NO.	REVISIONS	DATE	APPROVED	DATE	APPROVED
1	AS BUILT	9-24-64	J.M. WESTSIK	9-24-64	J.M. WESTSIK
2					
3					
4					
5					
6					
7					
8					
9					
10					

PARTS LIST				
PART NO	DWG. NO	NO QTD	DESCRIPTION	MATERIAL
1	THIS DWG	1	SHELL, 16 1/2" OD x 6" WALL PIPE, "LMB	INDE-B
2	"	1	SHELL COVER, 17" OD ASME DISHD HEAD & TAIL	"
3	"	1	CHANNEL COVER, 17" OD ASME DISHD HEAD	"



- NOTES:
1. PARTS TO BE FABRICATED AS PER MS&E GENERAL FABRICATION SPEC. MS&E GR-3 REV A
 2. UGHC FABRICATORS WELD PER PS-22, PS-25, PS-26 AS APPLICABLE. INSPECT PER WR-200
 3. MATERIAL SPECIFICATIONS:
 NET-RH-B304 (INOR-B PLATE)
 NET-RH-G (INOR-B FORMED HEADS)
 NET-RH-B304 (INOR-B WELDING FILLER METAL)
 4. ROUND ALL SHARP CORNERS TO 1/8" RADIUS UNLESS OTHERWISE SPECIFIED.
 5. FINISH ALL SURFACES TO 125 MICROINCHES AVERAGE ROUGHNESS HEIGHT UNLESS OTHERWISE SPECIFIED.
 6. WELD NUMBERS ASSIGNED: W#
 WELD NUMBERS USED: W#
 7. STRESS RELIEVE PART 101 AFTER 2 PHASES OF THE METAL AT 1600°F FOR 2 HOURS IN HELIUM ATMOSPHERE.

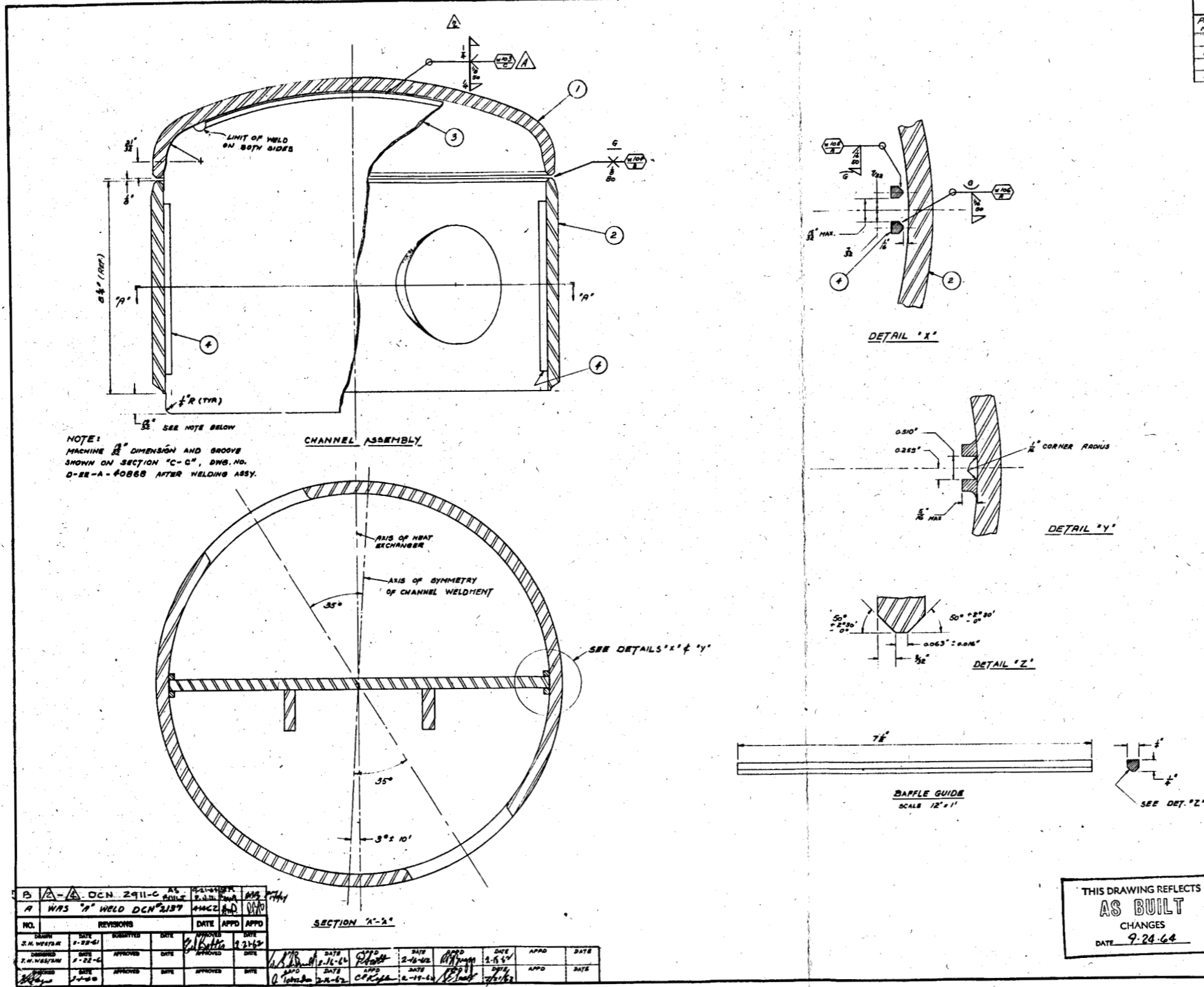
NO.	REVISIONS	DATE	APPD	APPD	APPROVED	DATE	APPROVED	DATE
1	DESIGN	1-11-64	J. N. NESTSIK		J. N. NESTSIK	1-11-64		
2	REVISED	2-11-64	J. N. NESTSIK		J. N. NESTSIK	2-11-64		
3	REVISED	2-11-64	J. N. NESTSIK		J. N. NESTSIK	2-11-64		

THIS DRAWING REFLECTS
AS BUILT
 CHANGES
 DATE 9-24-64

CLASSIFICATION
 NOT CLASSIFIED
 J. N. NESTSIK
 LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
 FINISHES: 1/2"
 DECIMALS: 0.005"
 ANGLES: 2"
 SOLD AS NOTED

PRINT HEAT EXCH. CHANNEL ASSY.	D-EE-A-4062
PRINT HEAT EXCH. ASSEMBLY ELEVATION	D-EE-A-4061
REFERENCE DRAWINGS	DWG. NO.
MOLTEN SALT REACTOR EXPERIMENT	7671
PRIMARY HEAT EXCHANGER DETAILS SHEET # 2	
OAK RIDGE NATIONAL LABORATORY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
DESIGNED	APPROVED
W. L. KILPATRICK	J. N. NESTSIK
DB 493-646	D-EE-A-4062

M20794RE 010D 1



NOTE:
MACHINE $\frac{1}{16}$ " DIMENSION AND GROOVE
SHOWN ON SECTION "C-C", DWG. NO.
D-EE-A-40888 AFTER WELDING ASSY.

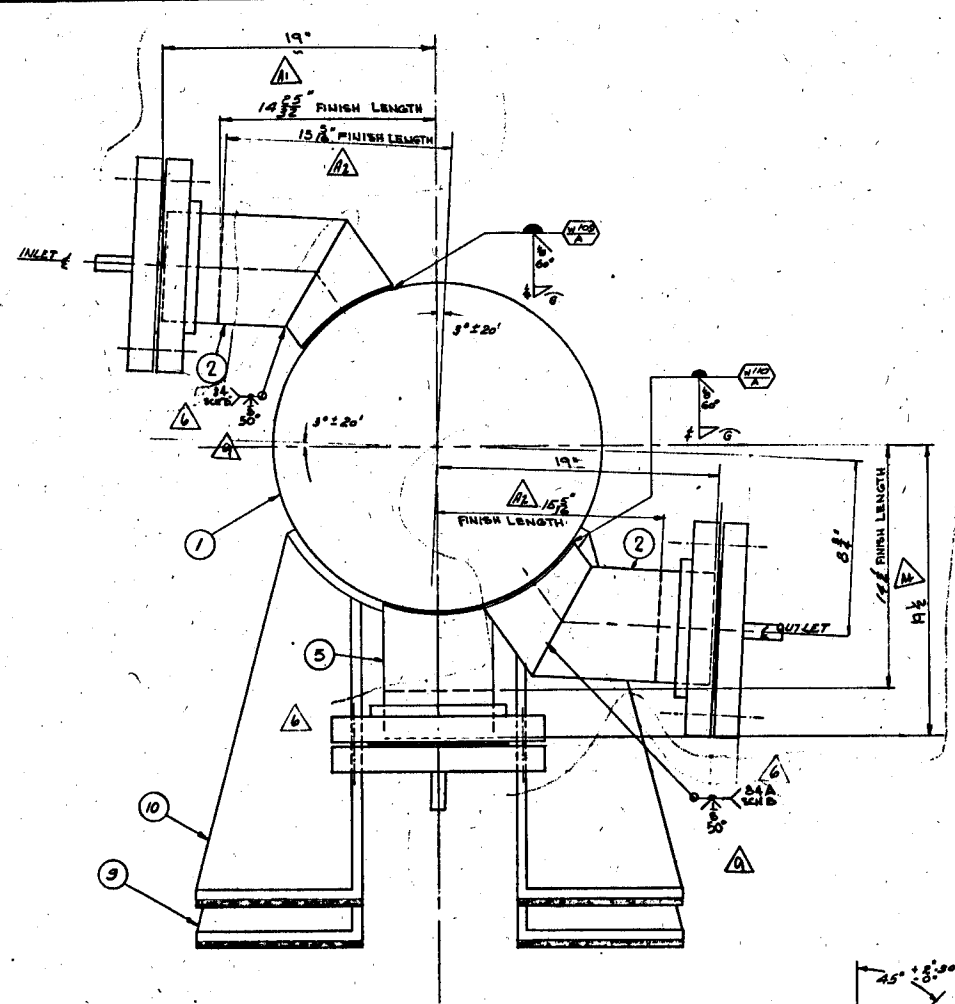
PARTS LIST				
PART NO.	QTY.	NO. REV.	DESCRIPTION	MATERIAL
1	1		ASME FLANGED & DISHED HEAD, 17 1/2" O.D. x 1/2" WALL	INOR-B
2	1		CHANNEL, 17 1/2" O.D. x 1/2" WALL, 24" LONG	"
3	1		CHANNEL SEPARATING BAFFLE, 1/2" THK. 2	"
4	1		BAFFLE GUIDE, 2 1/2" x 7 1/2"	"

- NOTES:
- FABRICATE ASSY AS PER MSTE GENERAL FABRICATION SPEC. M.S.R. G2-B. EBY A
 - MATERIAL SPECIFICATION:
NET-RN-B336 (INOR-B BAR)
NET-RN-B304 (INOR-B WELDING FILLER METAL)
 - ROUND ALL SHARP CORNERS TO $\frac{1}{8}$ " RADIUS UNLESS OTHERWISE SPECIFIED.
 - FINISH SURFACES TO 125 MICROINCHES AVERAGE RAUGHNESS HEIGHT UNLESS OTHERWISE SPECIFIED.
 - UCNC FABRICATORS WELD PER F1-25, F1-26, F1-26 AS APPLICABLE. INSPECT PER WR-200.
 - WELD NUMBERS ASSIGNED: W43 - W46
WELD NUMBERS USED: W43 - W46
 - STRESS RELIEVE CHANNEL ASSEMBLY AFTER WELDING PARTS 1, 2, & 4 IN POSITION AND AGAIN AFTER WELDING PART 3 IN POSITION AT 1600 \pm 25 \pm F FOR 2 HOURS EACH TIME IN INERT ATMOSPHERE.

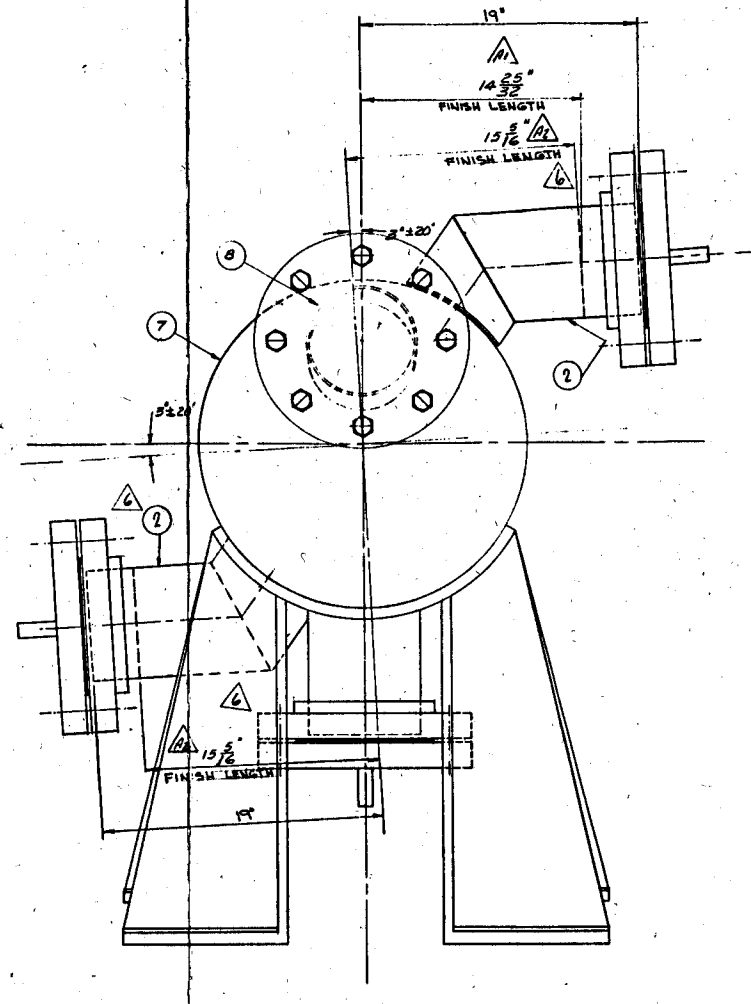
PRIM. HEAT EXCH. DETAILS SHEET # 1	D-EE-A-40887
" SHEET # 2	D-EE-A-40888
" SHEET # 3	D-EE-A-40889
PRIM. HEAT EXCH. ASSEMBLY ELEVATION	D-EE-A-40890
REFERENCE DRAWINGS	DWG. NO.
MOLTEN SALT REACTOR EXPERIMENT	EXP. NO. 7453

THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64

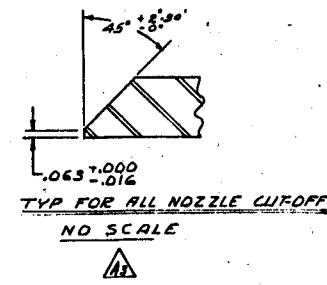
CLASSIFICATION NOT CLASSIFIED M. WESTSIK	PRIMARY HEAT EXCHANGER CHANNEL ASSEMBLY
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE	
DESIGNED BY E.N. WESTSIK	CHECKED BY M. WESTSIK
DATE 1-22-64	DATE 1-22-64
APPROVED BY [Signature]	APPROVED BY [Signature]
DATE 2-2-64	DATE 2-2-64
SCALE 6" = 1'	D-EE-A-4087E



SECTION 'A'-'A' OF DWG NO D-EE-A-40874



SECTION 'B'-'B' OF DWG NO D-EE-A-40874



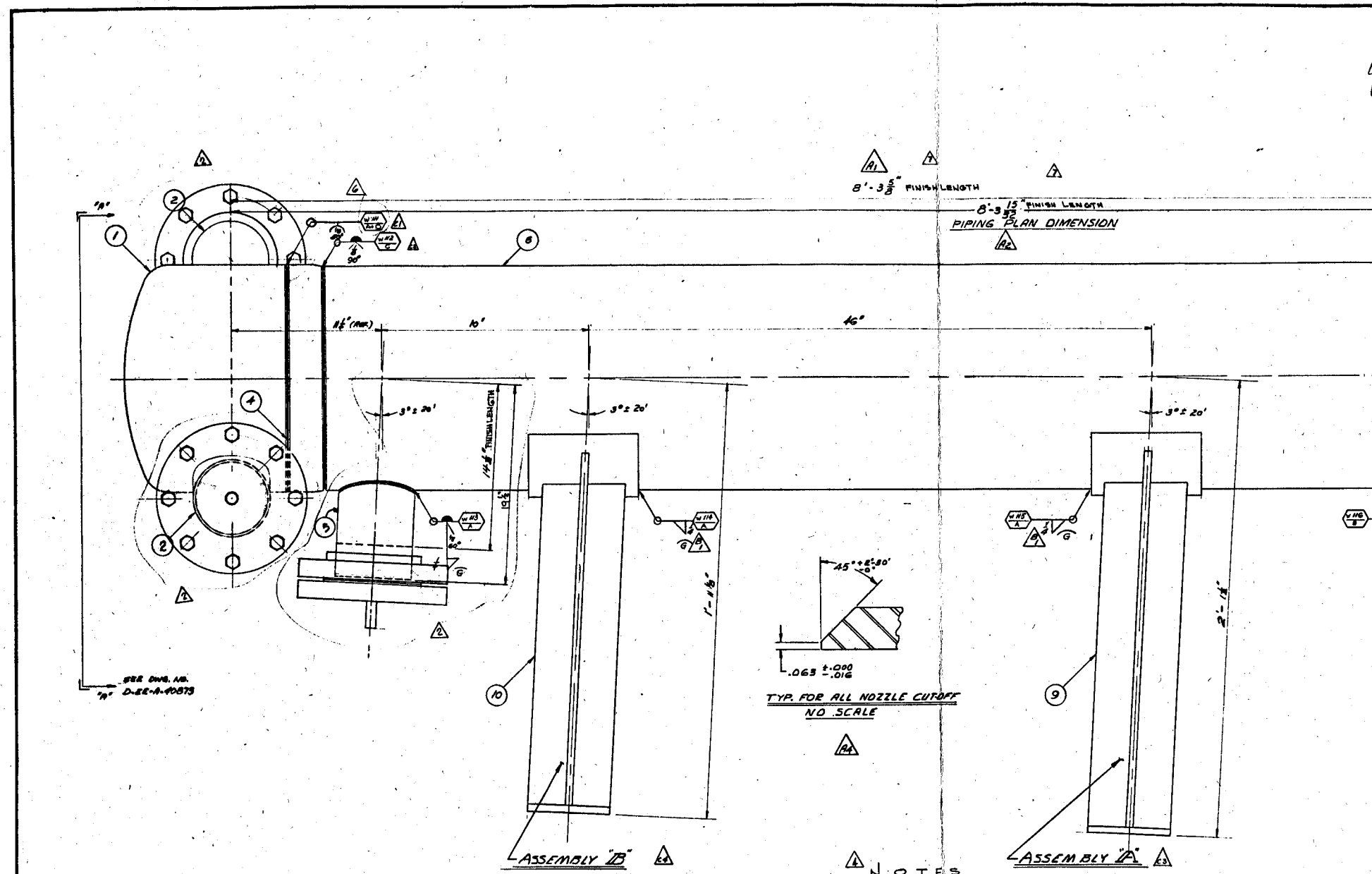
- NOTES:
1. FABRICATE HEAT EXCH AS PER USRE GENERAL FABRICATION SPEC. M.S.R. 02-2 REV. A.
 2. MATERIAL SPECIFICATION: MET-RM-8394 (MOR-B WELDING FILLER METAL)
 3. UGNC FABRICATORS WELD PER PW-23, PW-25, PW-26 AS APPLICABLE. INSPECT PER WR-200.
 4. WELD NUMBERS ASSIGNED: W49 - W10. WELD NUMBERS USED: W49 - W80.
 5. FOR PARTS LIST SEE DWG. NO. D-EE-A-40874.
 6. COMPLETED HEAT EXCHANGER SHELL WAS MODIFIED IN THE FIELD AFTER WATER FLOW TESTS ACCORDING TO DRAWING E-5649B.
 7. REMOVE LEAK TEST FLANGES AND CUT NOZZLES TO FINISH LENGTH IN FIELD.

NO.	REVISIONS	DATE	APPROVED	DATE	APPROVED	DATE
1	AS BUILT	9-24-64	J. H. WESTBICK			
2	...	...	...	...	...	...
3	...	...	...	...	...	...

THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64

CLASSIFICATION	NOT CLASSIFIED
DESIGNED BY	J. H. WESTBICK
DATE OF DIMENSION VALUES	...
SCALE	3" = 1'
PROJECT	MOLTEN SALT REACTOR EXPERIMENT
DESCRIPTION	PRIMARY HEAT EXCHANGER ASSEMBLY SECTIONS.
OWNER	OAK RIDGE NATIONAL LABORATORY
OPERATOR	UNION CARBIDE NUCLEAR COMPANY
DWG. NO.	D-EE-A-40874
JOB NO.	433-66

PARTS LIST				
PART NO.	DWG. NO.	NO. REQD.	DESCRIPTION	MATERIAL
1	D-EE-A-4087E	1	CHANNEL ASSEMBLY	INOR-B
2	D-EE-A-4087E	1	CHANNEL NOZZLE DETAIL	"
4	D-EE-A-4087E	1	TUBE BUNDLE ASSEMBLY	"
5	D-EE-A-4087E	1	SHELL OUTLET NOZZLE, 6" ID, SCH 40 PIPE	"
6	D-EE-A-4087E	1	SHELL, 18 1/2" OD, 1/2" WALL	"
7	D-EE-A-4087E	1	SHELL COVER, 17" OD ASME DIMED HEAD	"
8	D-EE-A-4087E	1	SHELL INLET NOZZLE, 6" ID, SCH 40 PIPE	"
9	D-EE-A-4087D	1	SUPPORT ASSEMBLY 'A'	"
10	D-EE-A-4087D	1	SUPPORT ASSEMBLY 'B'	"



NO.	REVISIONS	DATE	APPROVED	DATE	APPROVED	DATE
1	AS BUILT	2-11-64	[Signature]	2-11-64	[Signature]	2-11-64
2	SEE DCN # 2035	2-11-64	[Signature]	2-11-64	[Signature]	2-11-64
3	SEE DCN # 2217	2-11-64	[Signature]	2-11-64	[Signature]	2-11-64
4	SEE DCN # 2169	2-11-64	[Signature]	2-11-64	[Signature]	2-11-64
5	SEE DCN # 2137	2-11-64	[Signature]	2-11-64	[Signature]	2-11-64

- NOTES**
- FABRICATE HEAT EXCHANGER AS PER M.S.E.E. GENERAL FABRICATION SPEC. PART 4.020.
 - MATERIAL SPECIFICATION: MET-2M-B 304 (INOR-B WELDING FILLER METAL).
 - U.S.M.C. FABRICATORS WELD PER PS-23, PS-24, PS-25 AND PS-26 AS APPLICABLE. INSPECT PER WQ-200.
 - WELD NUMBER ASSIGNED. W-III THRU W-120 - WELD NUMBERS USED W-III THRU W-117 FOR SECTIONS 'A-A' & 'B-B' SEE DWG NO. D-EE-A-4087B.
 - EMPTY WEIGHT 2060 lbs.
 - COOLANT SALT WEIGHT 185 lbs.
 - FUEL SALT WEIGHT 95 lbs.
 - OPERATING WEIGHT 2300 lbs.
 - SHELL SUBASSEMBLY (PARTS 1 AND 2 WITH NOZZLES) AND SHELL SUBASSEMBLY (PARTS 5, 6, 7, 8 AND 10 WITH NOZZLES AND LEGS) SHALL BE STRESS RELIEVED AT 1000 PSI FOR 2 HOURS IN AIR ATMOSPHERE. VAPOR BLAST AFTER STRESS RELIEVING TO REMOVE OXIDE FILM.
 - LIQUID PENETRANT EXTERIOR SURFACES OF SHELL SUBASSEMBLIES ACCORDING TO SPECIFICATION MET-NDT-4 PRIOR TO INSTALLATION OF TUBE BUNDLE.
 - WELDED SUBASSEMBLIES MAY BE STRESS RELIEVED AS REQUIRED TO MAINTAIN DIMENSIONAL CONTROL.
 - DESIGN TEMP. DESIGN PRESS. HYDROSTATIC TEST PRESS.
SHELL SIDE 1500°F 75 PSI 800 PSIG.
TUBE SIDE 1500°F 125 PSI 800 PSIG.
THE TUBE SIDE SHALL NOT BE PRESSURIZED WHEN PERFORMING THE SHELL SIDE PRESSURE TEST AND THE SHELL SIDE SHALL NOT BE PRESSURIZED WHEN PERFORMING THE TUBE SIDE PRESSURE TEST. DRAIN WATER FROM HEAT EXCHANGER AND DRY WITH HOT INSTRUMENT AIR TO REMOVE ALL MOISTURE.
 - A HELIUM LEAK TEST SHALL BE PERFORMED AFTER THE HYDROSTATIC TEST AS FOLLOWS: ENCLOSE THE HEAT EXCHANGER IN A PLASTIC BAG. FILL THE BAG WITH HELIUM AND EVACUATE SHELL AND CHANNEL SUBASSEMBLIES. FILL SHELL ASSEMBLY WITH HELIUM AND EVACUATE CHANNEL ASSEMBLY. THE HELIUM LEAK RATE SHALL BE LESS THAN 1 x 10⁻⁶ CC/SEC.
 - LIQUID PENETRANT INSPECT EXTERIOR SURFACE OF COMPLETED HEAT EXCHANGER PRESSURE CONTAINING PARTS AFTER PRESSURIZED LEAK TESTING IN ACCORDANCE WITH SPEC. MET-NDT-4.
 - REMOVE LEAK TEST FLANGES AND CUT NOZZLES TO FINISH LENGTH IN FIELD.
 - COMPLETED HEAT EXCHANGER SHELL AND TUBE BUNDLE WERE MODIFIED IN THE FIELD AFTER WATER FLOW TESTS ACCORDING TO DRAWINGS E-56595, E-10329-2-001 AND COE.

THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64

CLASSIFICATION	NOT CLASSIFIED
DESIGNED BY	J.H. WESTER
DATE	2-11-64
SCALE	3" = 1'

NO.	DESCRIPTION	DATE
1	MOD. PRIM. HEAT EXCH. CHANNEL DETAIL	2-11-64
2	MOD. PRIM. HEAT EXCH. TUBE STABILIZER	2-11-64
3	MOD. HEAT EXCH. TUBE BUNDLE FOR PRESSURE	2-11-64
4	DETAILS SHIPPING SUPPORT FOR PRIM. HEAT EXCH. W/ CHANNEL	2-11-64
5	DETAILS SHIPPING SUPPORT FOR PRIM. HEAT EXCH. W/ CHANNEL	2-11-64
6	LOADING FIXTURE FOR PRIMARY HEAT EXCH. W/ CHANNEL	2-11-64
7	ASBY. SHIPPING SUPPORT FOR PRIM. HEAT EXCH. W/ CHANNEL	2-11-64
8	PRIMARY HEAT EXCH. DETAIL (LEG)	2-11-64
9	PRIMARY HEAT EXCH. TUBE BUNDLE SECTION	2-11-64
10	PRIMARY HEAT EXCH. TUBE BUNDLE COVER	2-11-64
11	PRIMARY HEAT EXCH. ASSEMBLY DETAIL	2-11-64
12	PRIMARY HEAT EXCH. CHANNEL DETAIL	2-11-64
13	PRIMARY HEAT EXCH. DETAIL (LEG)	2-11-64
14	PRIMARY HEAT EXCH. SUPPORT DETAIL	2-11-64
15	PRIMARY HEAT EXCH. DETAIL (LEG)	2-11-64
16	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
17	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
18	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
19	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
20	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
21	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
22	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
23	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
24	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
25	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
26	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
27	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
28	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
29	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
30	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
31	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
32	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
33	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
34	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
35	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
36	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
37	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
38	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
39	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
40	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
41	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
42	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
43	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
44	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
45	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
46	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
47	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
48	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
49	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64
50	PRIMARY HEAT EXCH. TUBE BUNDLE AND CHANNEL	2-11-64

REFERENCE DRAWINGS: D-EE-A-4087B, D-EE-A-4087C, D-EE-A-4087D, D-EE-A-4087E, E-56595, E-10329-2-001 AND COE.

MOLTEN SALT REACTOR EXPERIMENT, SER. NO. 7803

CLASSIFICATION: NOT CLASSIFIED

DESIGNED BY: J.H. WESTER

DATE: 2-11-64

SCALE: 3" = 1'

UNION CARBIDE NUCLEAR COMPANY

DIVISION OF UNION CARBIDE CORPORATION

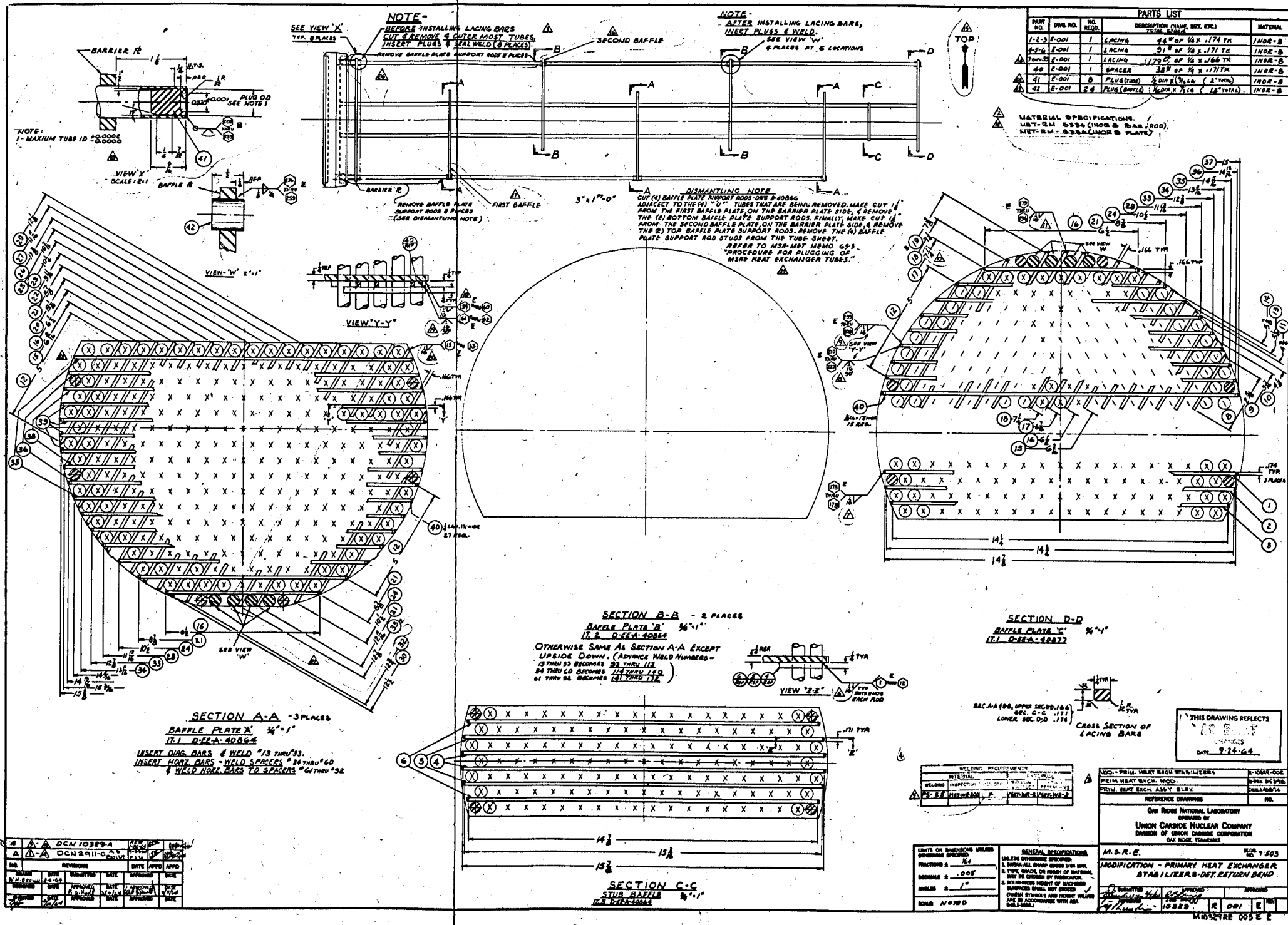
ONE MOORE, TENNESSEE

DATE: 9-24-64

NO. 100-433-G-6

D-EE-A-4087F

M20794RE 015D 5



PARTS LIST				
PART NO.	QTY.	NO. REQD.	DESCRIPTION (NAME, SIZE, ETC.)	MATERIAL
1-2-3	E-001	1	LACING 1/4" x 1/4" x .174 TH	INCR-B
4-5-6	F-001	1	LACING 5/16" x 5/16" x .171 TH	INCR-B
7-8-9	F-001	1	LACING 1/2" x 1/2" x .166 TH	INCR-B
40	E-001	1	SPACER 3/8" x 1/2" x .171 TH	INCR-B
41	F-001	2	PLUG (M) 1/2" DIA x 1/4" L (2" DIA)	INCR-B
42	E-001	24	PLUG (M) 1/2" DIA x 1/4" L (2" DIA)	INCR-B

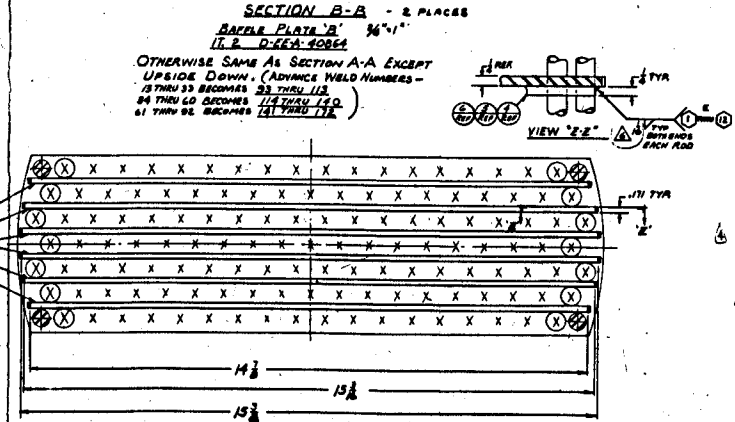
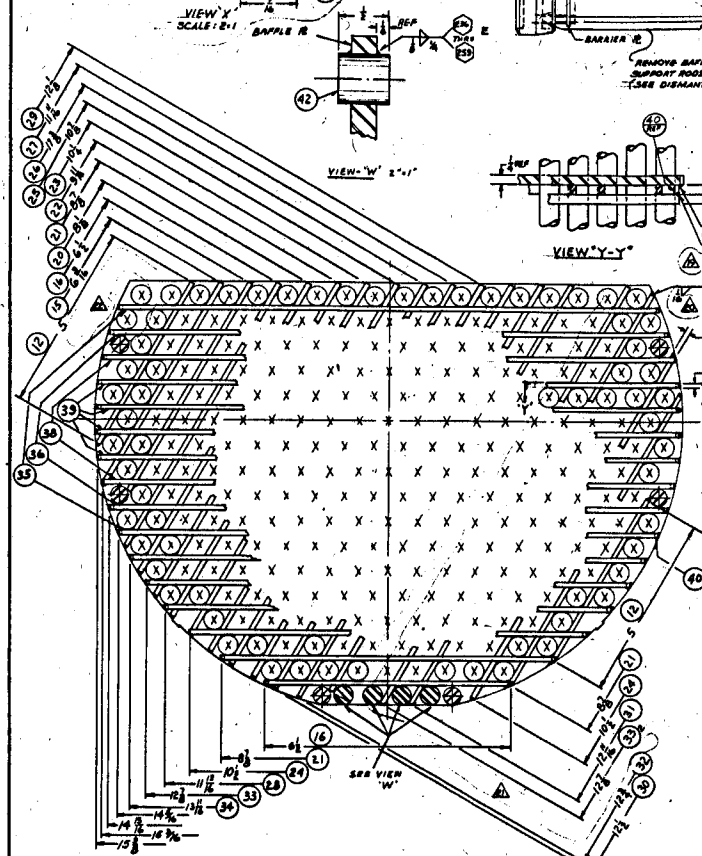
MATERIAL SPECIFICATIONS:
 INCR-BM - 304 (INCR-B - BAR (300))
 INCR-BM - 304 (INCR-B - PLATE)

NOTE: 1 - MAXIMUM TUBE ID .0005

NOTE - BEFORE INSTALLING LACING BARS CUT & REMOVE 4 OUTER MOST TUBES. INSERT PLUGS & SEALWELD (8 PLACES)

NOTE - AFTER INSTALLING LACING BARS, INSERT PLUGS & WELD. SEE VIEW 'X' & PLACES AT E LOCATIONS

DISMANTLING NOTE
 CUT (1) BAFFLE PLATE SUPPORT RODS ONE (2) TUBES ADJACENT TO THE (1) "U" TUBES THAT ARE BEING REMOVED. MAKE CUT FROM THE FIRST BAFFLE PLATE ON THE BARRIER PLATE SIDE, & REMOVE THE (2) BOTTOM BAFFLE PLATE SUPPORT RODS. FINALLY MAKE CUT FROM THE SECOND BAFFLE PLATE ON THE BARRIER PLATE SIDE, & REMOVE THE (2) TOP BAFFLE PLATE SUPPORT RODS. REMOVE THE (1) BAFFLE PLATE SUPPORT ROD STUDS FROM THE TUBE SHEET. REFER TO MSR-MET MEMO 65-3 "PROCEDURE FOR PLUGGING OF HEAT EXCHANGER TUBES."



WELDING REQUIREMENTS	
MATERIAL	304
WELDING	W-100
WELDING	W-100
WELDING	W-100

THIS DRAWING REFLECTS REVISIONS DATE 9-28-64

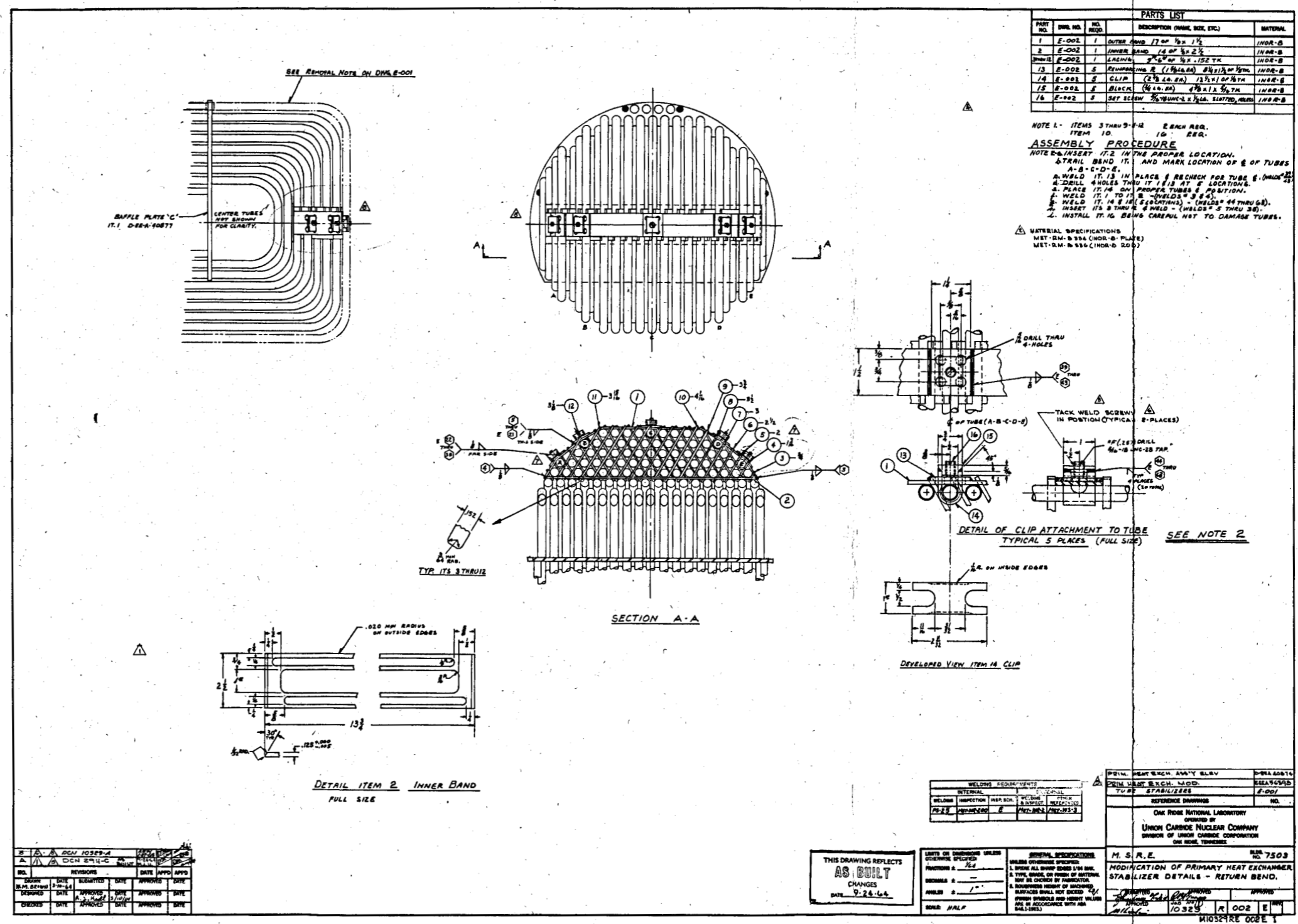
NO.	DESCRIPTION	DATE
1	AS SHOWN	9-28-64

ONE RISE NATIONAL LABORATORY
 OPERATED BY
 UNION CARBIDE NUCLEAR COMPANY
 DIVISION OF UNION CARBIDE CORPORATION
 ONE RISE, TENNESSEE

NO.	DESCRIPTION	DATE	APPROV.
1	AS SHOWN	9-28-64	[Signature]

GENERAL SPECIFICATIONS	
1. SERIAL NUMBER SPECIFIED	
2. TYPE GRADE OR FINISH OF MATERIAL	
3. DIMENSIONS INDICATED ON DRAWING	
4. DIMENSIONS SHALL NOT EXCEED	
5. DIMENSIONS SHALL NOT EXCEED	
6. DIMENSIONS SHALL NOT EXCEED	

✓
2



PARTS LIST				
PART NO.	QTY.	NO.	DESCRIPTION (DIM. WGT. ETC.)	MATERIAL
1	1	E-002	OUTER BAND 17 1/2" x 1 1/2"	INOR-B
2	1	E-002	INNER BAND 14 1/2" x 2 1/2"	INOR-B
3	1	E-002	LEAKING 2 1/2" x 1/2" x 1/2" TH	INOR-B
13	6	E-002	FRUSTRUMS 2 (1/2" DIA) 2 1/2" x 1/2" TH	INOR-B
14	6	E-002	CLIP (1/2" DIA) 1 1/2" x 1/2" TH	INOR-B
15	6	E-002	CLIP (1/2" DIA) 1 1/2" x 1/2" TH	INOR-B
16	6	E-002	SET SCREW 3/16" DIA x 1/2" L. SLTTD. W/FL	INOR-B

NOTE 1 - ITEMS 3 THRU 5 - 1 EACH REQ.
ITEM 10 16 EACH REQ.

ASSEMBLY PROCEDURE
NOTE 2 - INSERT IT 2 IN THE PROPER LOCATION.
& TACK WELD IT. AND MARK LOCATION OF 6 OF TUBES
A-B-C-D-E.
A. WELD IT 13 IN PLACE & RECHECK FOR TUBE 6. (HOLD 20)
B. DRILL HOLES THRU IT 13 AT E LOCATION.
C. PLACE IT 14 ON PROPER TUBES & POSITION.
D. WELD IT 1 TO B - (HOLDS 3 & 4).
E. WELD IT 14 IN 8 PLACES (WELDS 44 THRU 51).
F. INSERT IT 3 THRU 6 & WELD - (HOLDS 2 THRU 3).
G. INSTALL IT 16 BEING CAREFUL NOT TO DAMAGE TUBES.

MATERIAL SPECIFICATIONS
MET. 241-B 254 (INOR-B PLATE)
MET. 241-B 254 (INOR-B 200)

DETAIL OF CLIP ATTACHMENT TO TUBE
TYPICAL 5 PLACES (FULL SIZE) SEE NOTE 2

DETAIL ITEM 2 INNER BAND
FULL SIZE

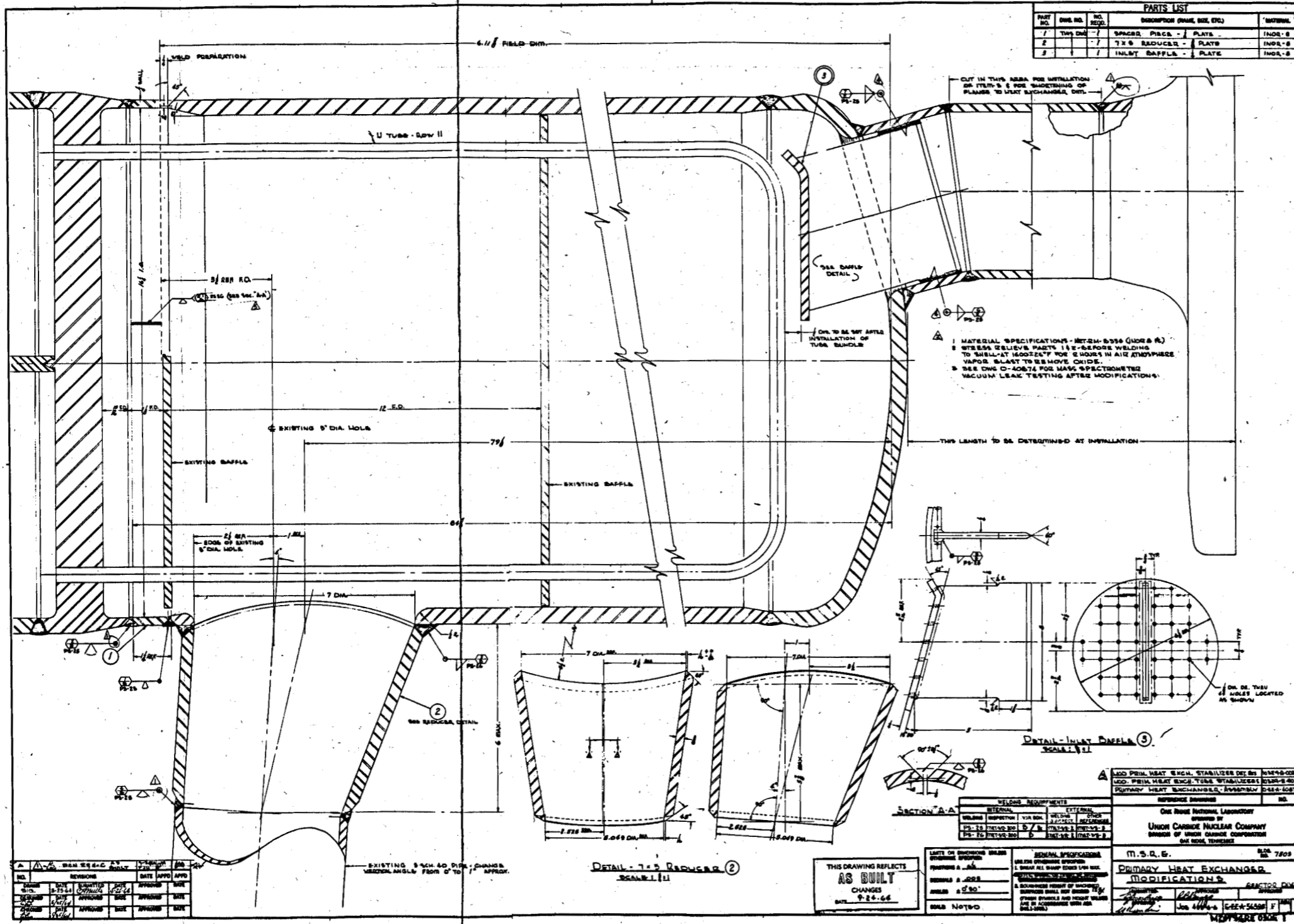
WELDING REQUIREMENTS			
WELDING	INSPECTION	WELDING	INSPECTION
WELDED	WELDED	WELDED	WELDED
WELDED	WELDED	WELDED	WELDED

ITEM	REVISION	DATE	BY	APP'D
1				
2				
3				
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6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				

THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64

M. S. R. E.
MODIFICATION OF PRIMARY HEAT EXCHANGER
STABILIZER DETAILS - RETURN BEND.
DATE 10-25-64
R 002 E 1
MIGUSTRE 000E 1

PARTS LIST			
PART NO.	QTY.	DESCRIPTION (SIZE, MAT., ETC.)	NOTES
1	1	SPACER, PIPES - PLATE	INCR. 8
2	1	7/8" REDUCER - PLATE	INCR. 8
3	1	INLET BAFFLE - PLATE	INCR. 8



1 MATERIAL SPECIFICATIONS - INCONEL 6000 (INCR. 8)
 2 STEELS (RELIEVE PARTS 1 & 2 - BEFORE WELDING TO BALLAST HOODS) FOR 6 INCHES IN AIR ATMOSPHERE VAPOR BLAST TO REMOVE OXIDE.
 3 SEE DWG D-40874 FOR MATE SPECIFICATIONS VACUUM LEAK TESTING AFTER MODIFICATIONS.

DETAIL - INLET BUNDLE 3
 SCALE: 1/2" = 1'

DETAIL - 7/8" REDUCER 2
 SCALE: 1/2" = 1'

THIS DRAWING REFLECTS AS BUILT CHANGES
 DATE: 9-26-66

NO.	REVISION	DATE	APPROV.
1	AS BUILT	9-26-66	[Signature]

ADD PRIN. HEAT EXCH. STABILIZER DEL BY 10/10/66
 ADD PRIN. HEAT EXCH. TUBE STABILIZER DEL BY 10/10/66
 PRIMARY HEAT EXCHANGER ASSEMBLY DATA SHEET

WELDING REQUIREMENTS	INTERNAL	EXTERNAL
WELDING INSPECTION	W/300	W/300
W/300	W/300	W/300
W/300	W/300	W/300

REFERENCE DRAWING NO. [Blank]
 ONE HOUR NATIONAL LABORATORY
 OPERATED BY
 UNION CARBIDE NUCLEAR COMPANY
 DIVISION OF UNION CARBIDE CORPORATION
 ONE HOUR, TENNESSEE

M.S.D.E. 7805
 PRIMARY HEAT EXCHANGER MODIFICATION
 DATE: 10/10/66
 JOB: 444-6 (EEN-5600) F
 DRAWING NO. 1

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