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TUBE VIBRATION IN MSRE PRIMARY HEAT EXCHANGER

R. J. Kedl

C. K. McGlothlan

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

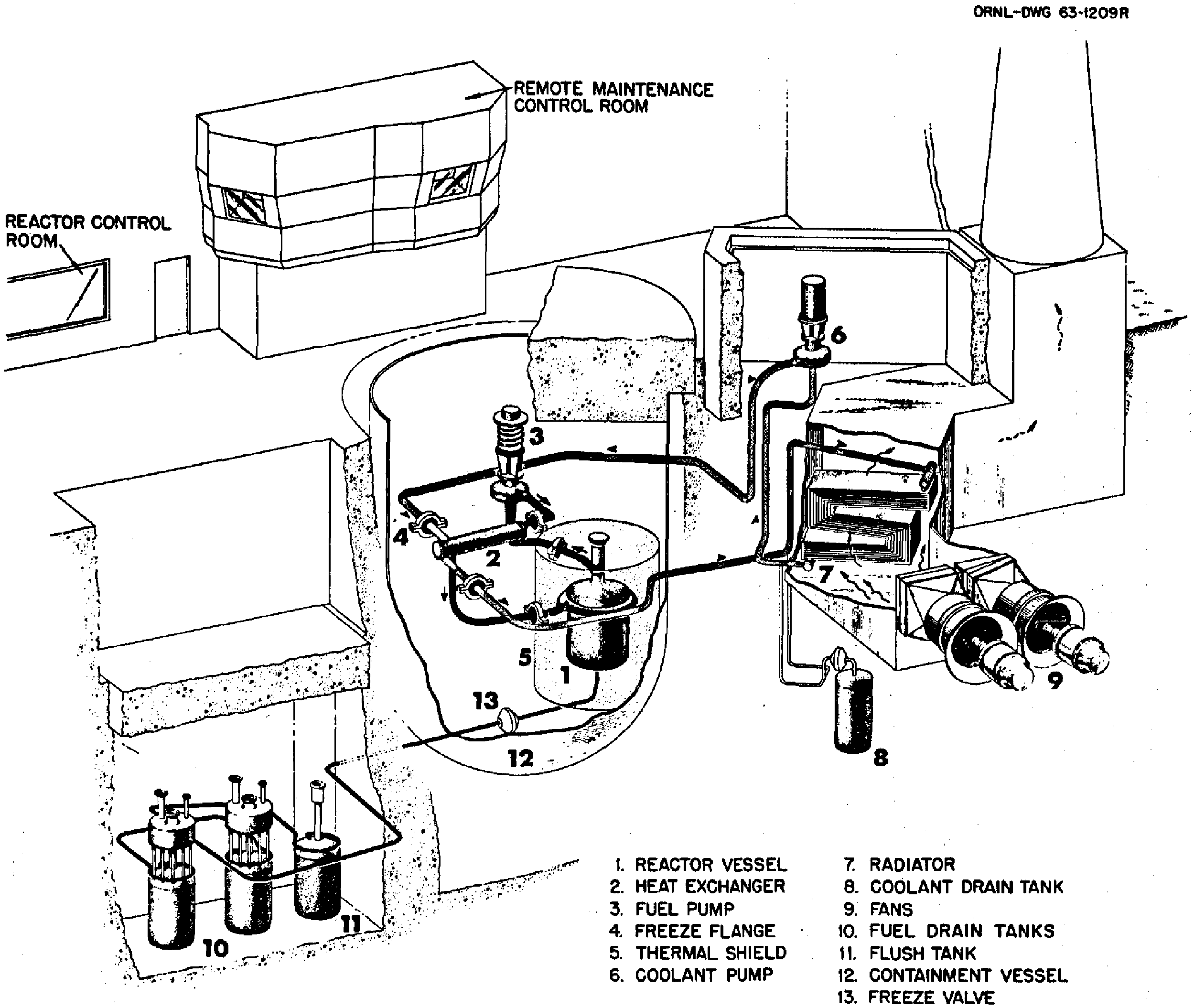

Fig. 1. MSRE Flow Diagram.

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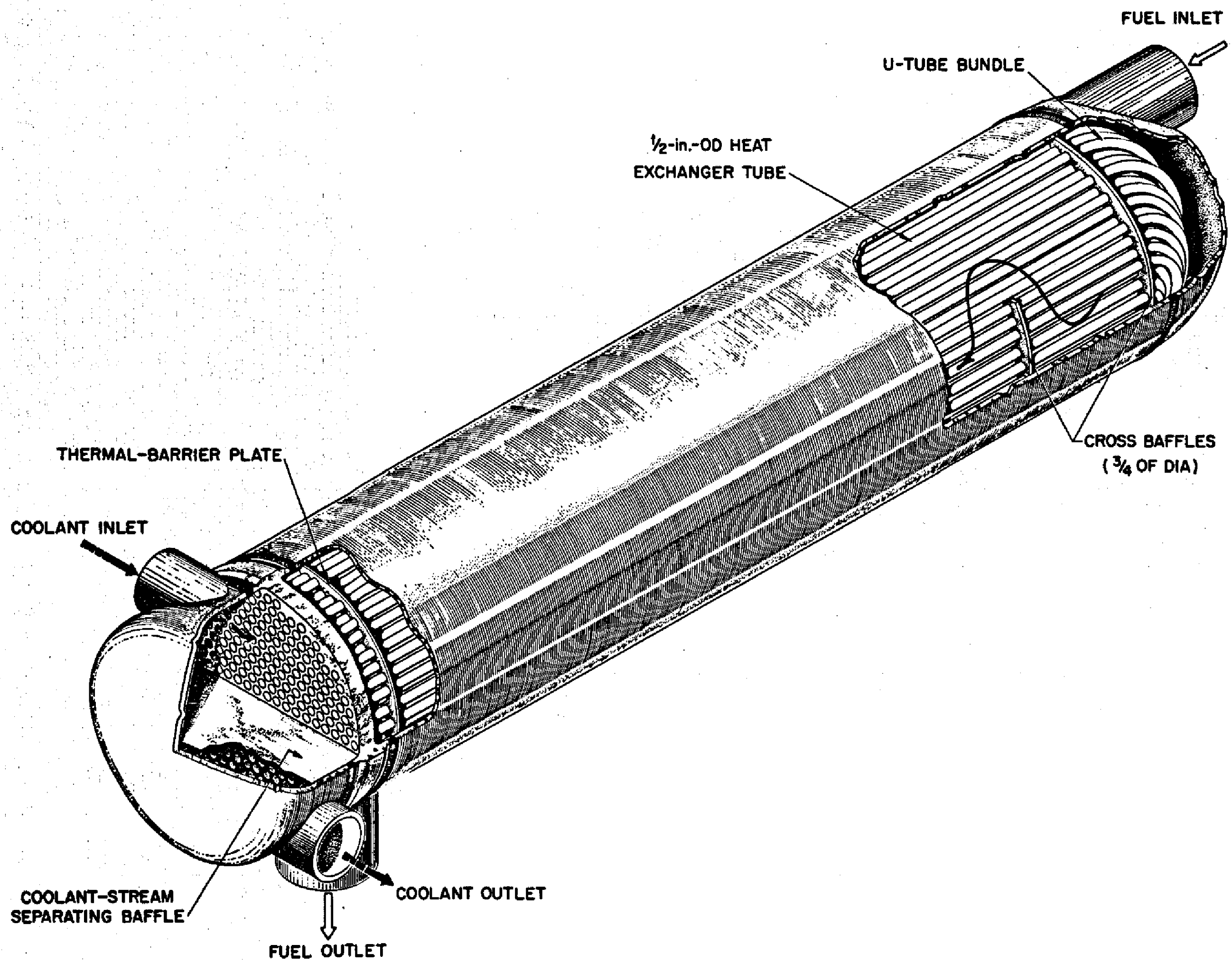

Fig. 2. Primary Heat Exchanger for MSRE.

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.

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*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]

[a]Before modification.

[b]After modification.

[c]Straight section of tubes only.

[d]Based 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, 7 outlet[b]
tube, in. (Sched-40)	5 " "
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

[a] Before modification.

[b] After modification.

[e] As 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:	@ 1200°F	@ 1065°F
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/ft^2-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, $Btu/hr\text{-}ft^2\text{-}°F/ft$ at 1300°F			12.7
Modulus of elasticity at ~ 1300°F, psi			24.8×10^6
Specific heat, Btu/lb-°F at 1300°F			0.135
Mean coefficient of thermal expansion, 70-1300°F range, in./in.-°F			8.0×10^{-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

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[a]Commercially available from Haynes Stellite as "Hastelloy-N" and International Nickel Co. as INCO-806.

[b]ASME 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 ~ 254 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 ~ 6.1 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 $\left(\frac{\text{(frequency)(length)}}{\text{(fluid velocity)}}\right)$ which is the characteristic number used to correlate fluid-induced vibrations from vortex shedding, is independent of fluid properties such as density and viscosity.

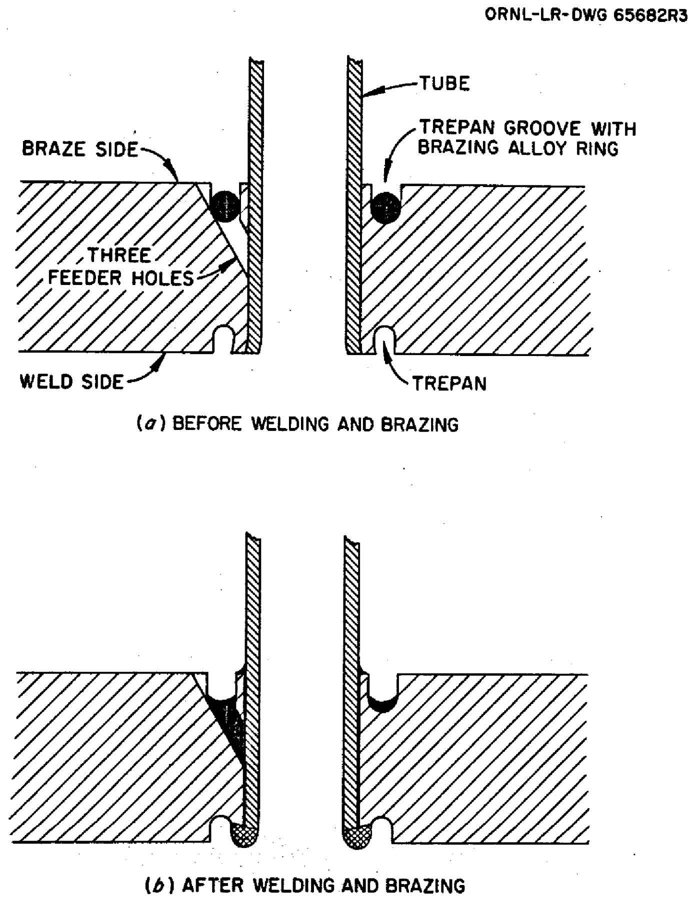

Fig. 3. Tube-to-Tube Sheet Joint MSRE Primary Heat Exchanger.

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.

<u>Initial Test of Heat Exchanger, As-Built</u>

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 (~ 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

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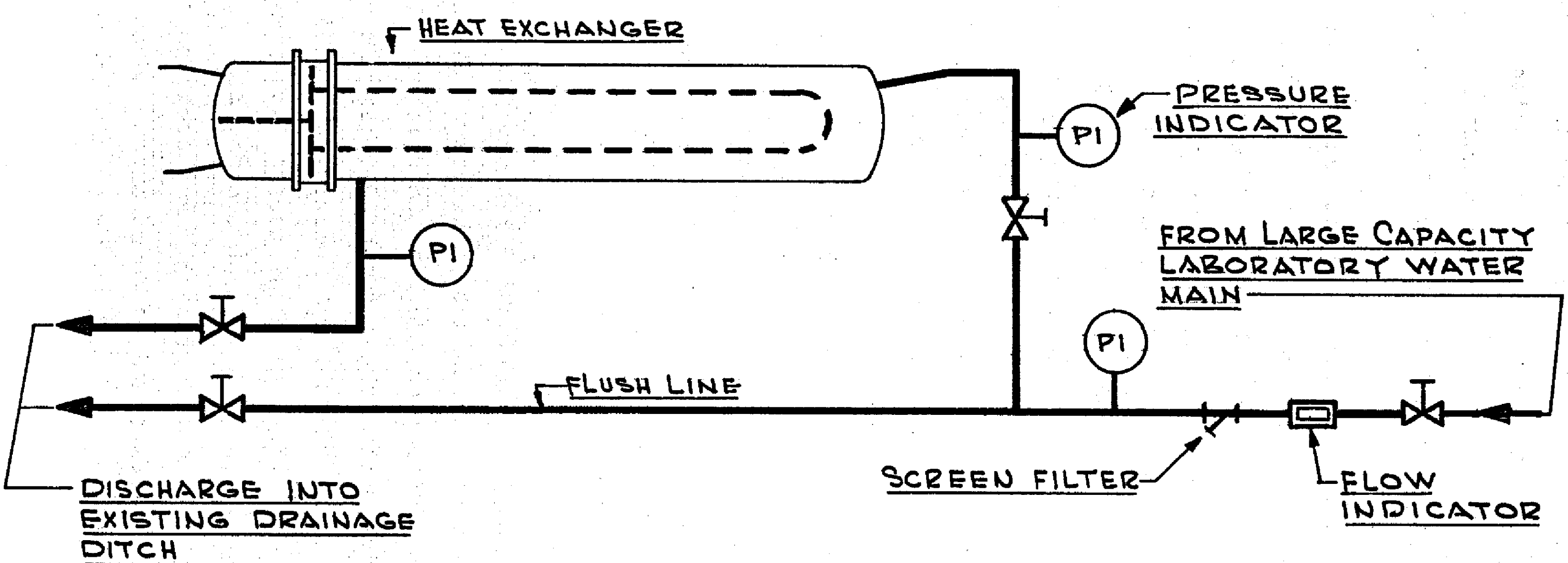

Fig. 4. Hydraulic Test Installation MSRE Primary Heat Exchanger.

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.

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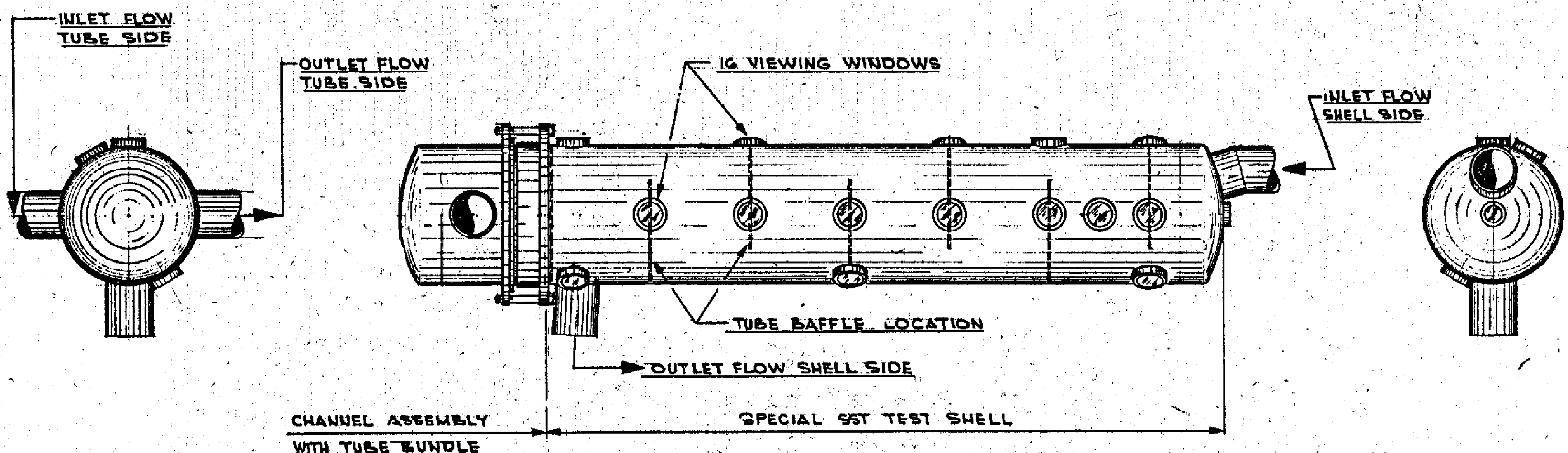

Fig. 5. Hydraulic Test Shell Assembly, Primary Heat Exchanger.

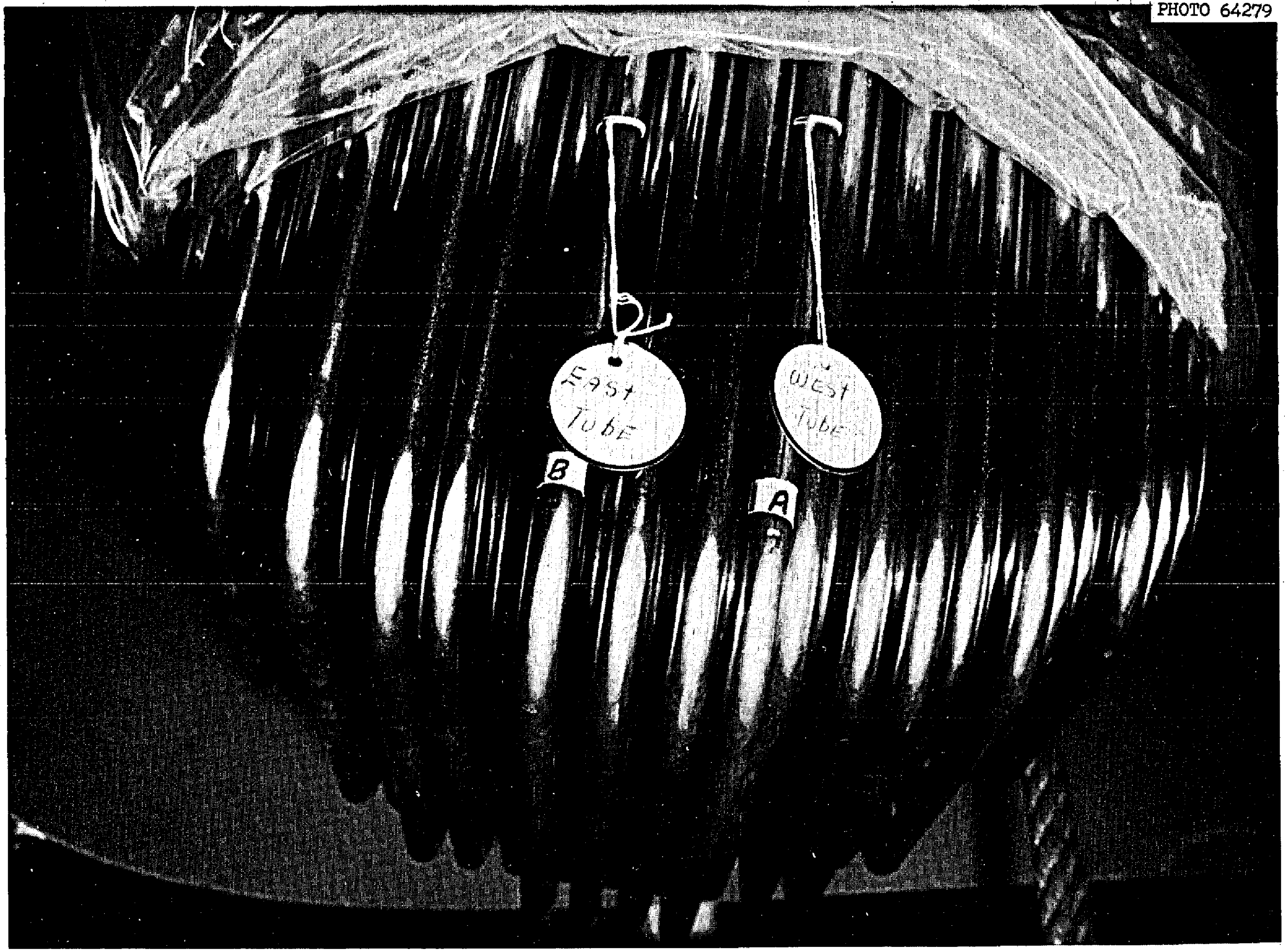

Fig. 6. MSRE Primary Heat Exchanger Tube Damage.

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.

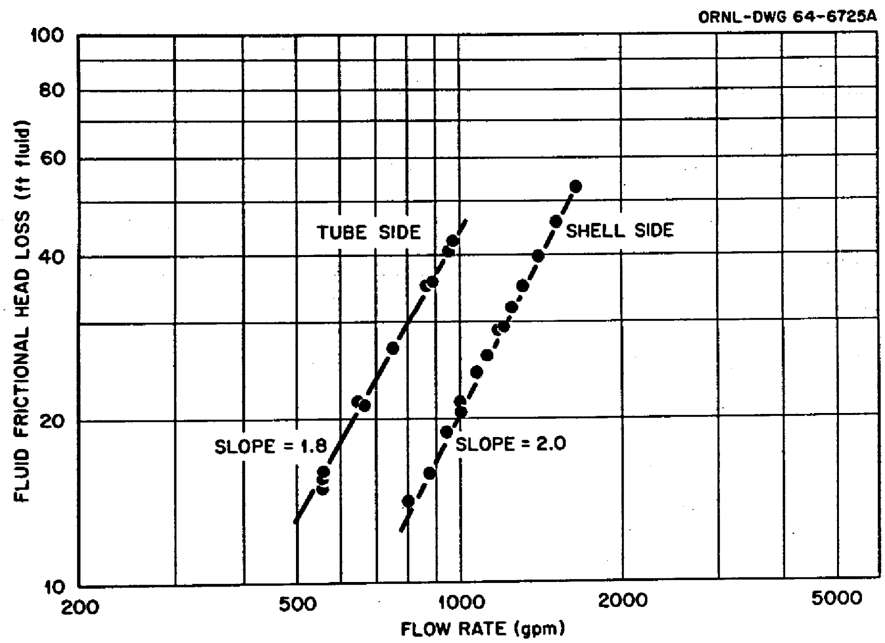

Fig. 7. Fluid Frictional Head Loss in Primary Heat Exchanger.

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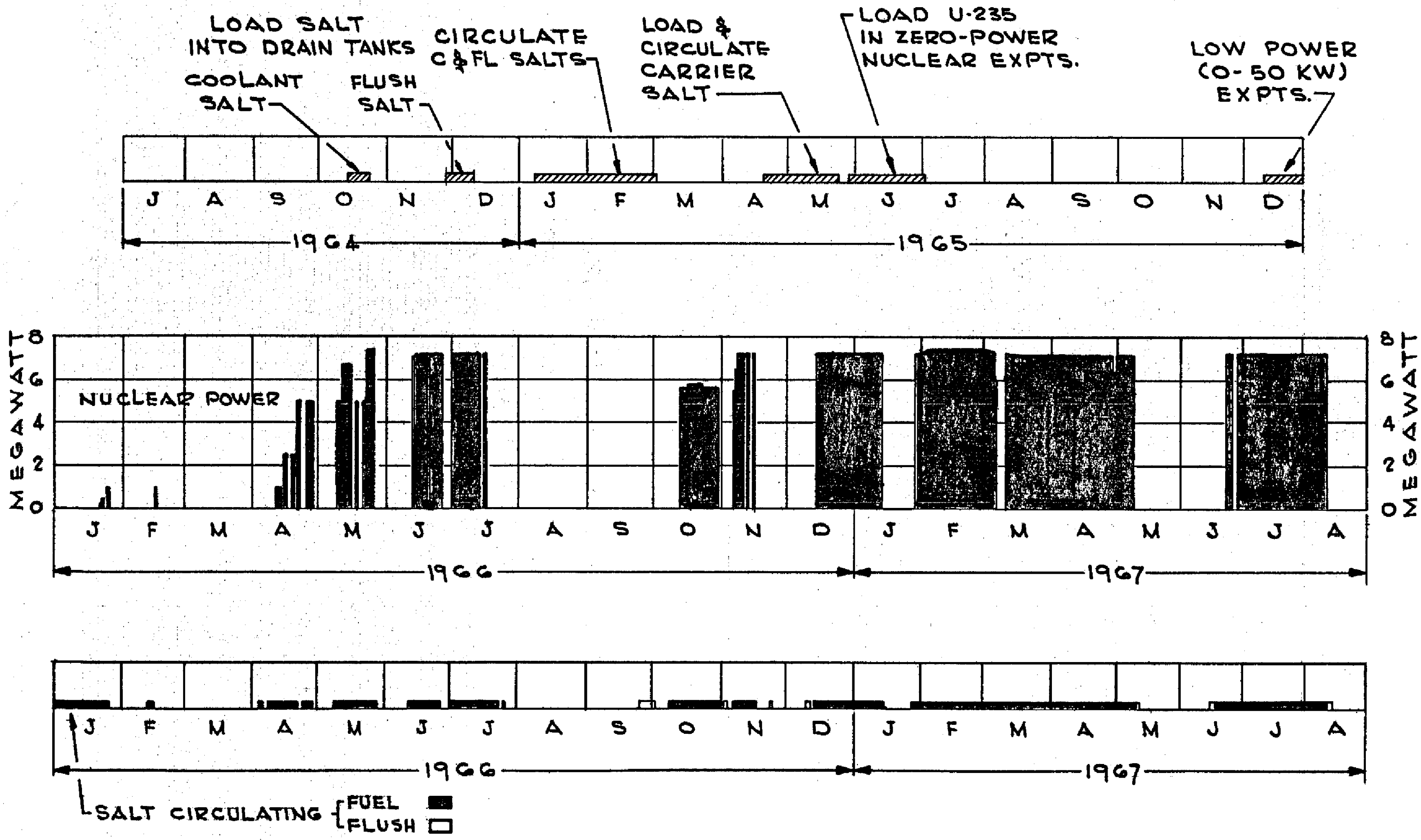


Fig. 8. MSRE Operational History.

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

[a]Total 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 $0.83 \frac{\text{Btu}}{\text{Hr-Ft-°F}}$ rather than $2.75 \frac{\text{Btu}}{\text{Hr-Ft-°F}}$ 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.

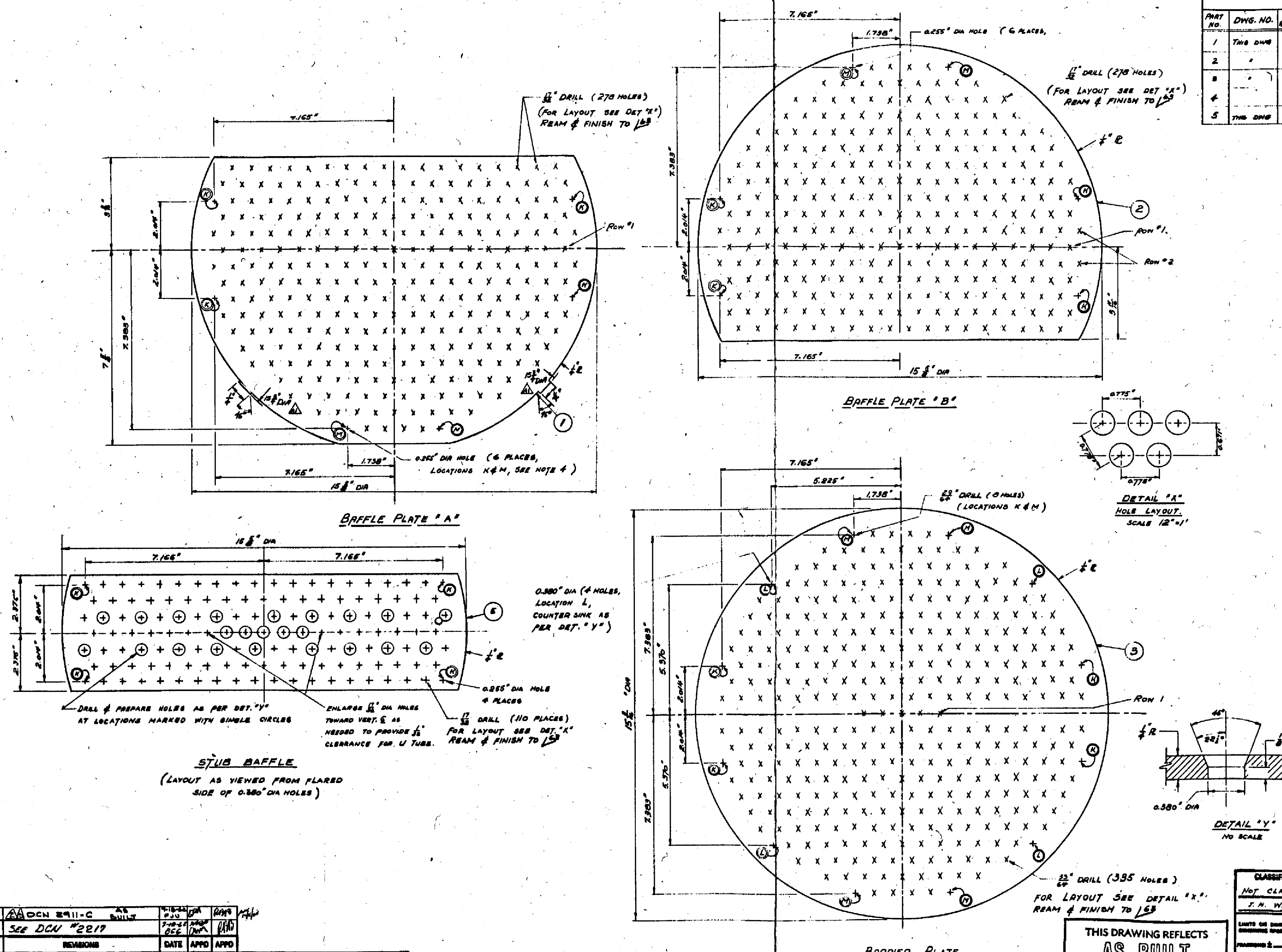
APPENDIX

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. REQD.	DESCRIPTION	MATERIAL
1	THIS DWG	3	BAFFLE PLATE "A" ¼" THK PLATE, 15¾" DIA BLANK	INOR-8
2	"	2	BAFFLE PLATE "B" ¼" THK PLATE, 16¾" DIA. BLANK	INOR-8
3	"	1	BARRIER PLATE ¼" THK PLATE, 16 ¾" DIA BLANK	INOR-8
4				
5	THIS DWG	1	STUB BAFFLE ¼" THK PL 5" x 15¾" BLANK	INOR-8



NOTES:

1. DRILL ALL HOLES TO MATCH CORRESPONDING HOLES ON TUBE SHEET (DWG: D-EE-A-40865)
2. LOCATIONS K, L & M ARE SYMMETRICAL ABOUT THE VERTICAL AXIS.
3. COMPLETELY REMOVE ALL BURRS AFTER DRILLING.
4. DRILL LOCATIONS "M" ON ONE TYPE "A" BAFFLE (ASSEMBLY POSITION 5A) AS PER DETAIL "Y"
5. (2) PARTS TO BE FABRICATED AS PER MSRE GENERAL FABRICATION SPECIFICATION MSR 62-3 REV. A
6. MATERIAL SPEC. (ORNL) MET-RM-B334 INOR-8 PLATE.
7. ROUND ALL SHARP CORNERS TO 1/64" RADIUS UNLESS OTHERWISE SPECIFIED.
8. FINISH MACHINED SURFACES TO 125 MICRO IN. AVG. ROUGHNESS HEIGHT, UNLESS OTHERWISE SPECIFIED.

REFERENCE DRAWINGS	DWG. NO.
(2) PRIM HEAT EXCH. ASSY ELEV	DEEA 40874
PRIM. HEAT EXCH. BAFFLE PLATES. SHEET #2	D-EE-A-40877
PRIM. HEAT EXCH. BAFFLE ASSY.	D-EE-A-40866
PRIM. HEAT EXCH. TUBE SHEET	D-EE-A-40865

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

CLASSIFICATION: NOT CLASSIFIED — J. H. WESTSIK

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED: FRACTIONS ± 1/32"; DECIMALS ± 0.005; ANGLES ± 2°

SCALE 6" = 1'

MOLTEN SALT REACTOR EXPERIMENT BLDG. NO. 7503

PRIMARY HEAT EXCHANGER; BAFFLE PLATES SHEET # 1.

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

SUBMITTED [illegible] — JOB 433-6.6 — D-EE-A-40864

NO.	REVISIONS	DATE	APPD	APPD
B	(2) DCN 2911-C AS BUILT	9-16-64 PJU	[illegible]	[illegible]
A	SEE DCN #2217	7-10-62 BCG	[illegible]	[illegible]

DRAWN J.H. WESTSIK	DATE 1-22-61	SUBMITTED	DATE	APPROVED [illegible]	DATE 2-21-62	APP'D [illegible]	DATE 2-16-62	APP'D [illegible]	DATE 2-19-62
DESIGNED J.H. WESTSIK	DATE 1-22-61	APPROVED	DATE	APPROVED	DATE	APP'D [illegible]	DATE 2-16-62	APP'D [illegible]	DATE 2-19-62
CHECKED [illegible]	DATE 2-1-62	APPROVED	DATE	APPROVED	DATE	APP'D [illegible]	DATE 2-16-62	APP'D [illegible]	DATE [illegible]

M20794RE 005D 2

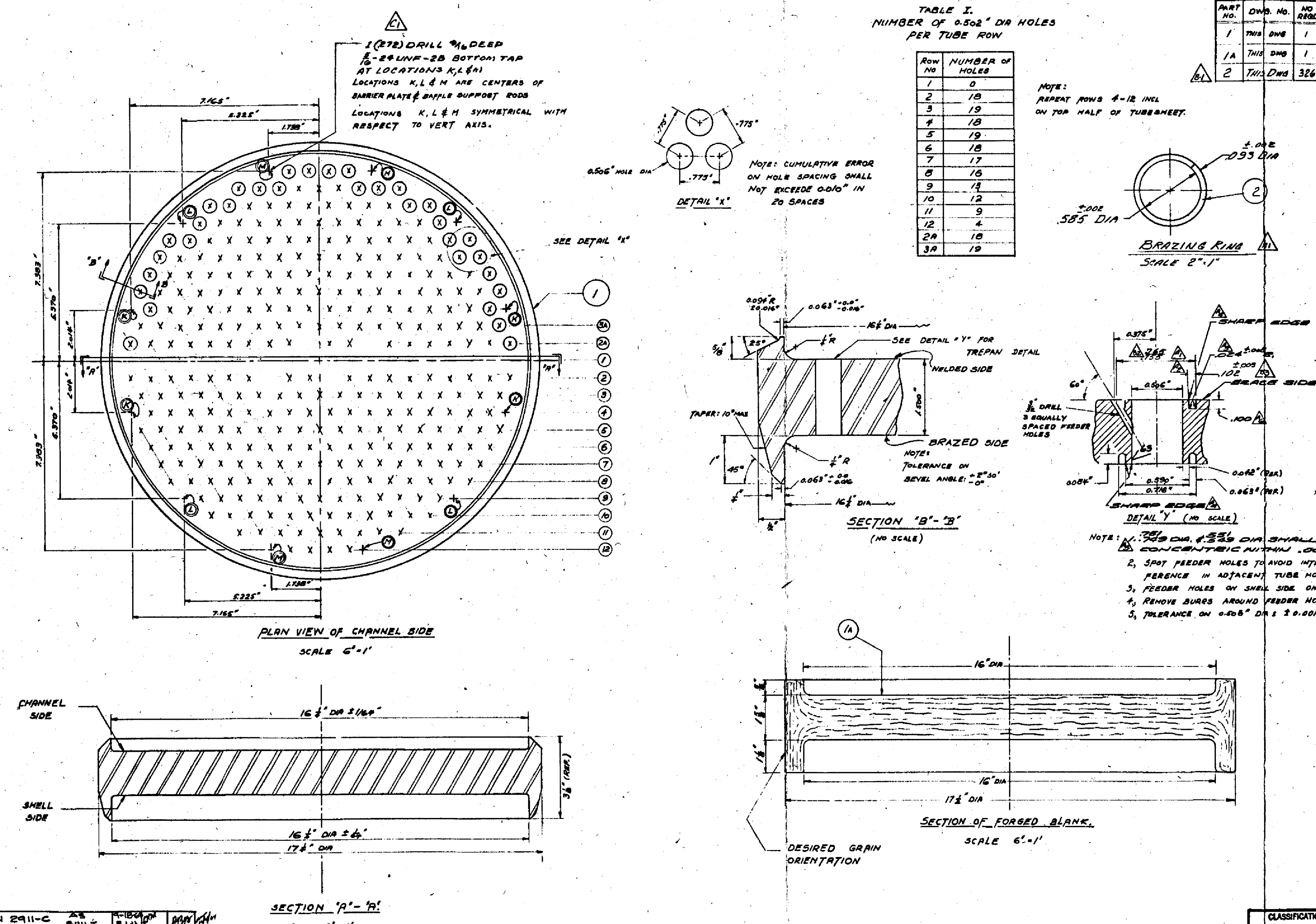


TABLE I.
NUMBER OF 0.502" DIA HOLES PER TUBE ROW

Row No	NUMBER OF HOLES
1	0
2	18
3	19
4	18
5	19
6	18
7	17
8	16
9	15
10	12
11	9
12	4
2A	18
3A	19

NOTE:
REPEAT ROWS 4-12 INCL ON TOP HALF OF TUBESHEET.

NOTE:
1. .761/.749 DIA. & .551/.549 DIA. SHALL BE CONCENTRIC WITHIN .002 TIR
2. SPOT FEEDER HOLES TO AVOID INTERFERENCE IN ADJACENT TUBE HOLES.
3. FEEDER HOLES ON SHELL SIDE ONLY
4. REMOVE BURRS AROUND FEEDER HOLES
5. TOLERANCE ON 0.506" DIA ± 0.001"

PARTS LIST

PART NO.	DWG. No.	NO REQD	DESCRIPTION	MATERIAL
1	THIS DWG	1	TUBE SHEET 17 1/2" OD x 1 1/2" THICK, FORGED	INOR-8
1A	THIS DWG	1	TUBE SHEET FORGING	INOR-8
2	THIS DWG	326	BRAZING RING	82% GOLD 18% NICKEL ALLOY

NOTES:

1. TUBE SHEET FORGING (PART # 1A) IS TO BE FABRICATED IN ACCORDANCE WITH ORNL SPECIFICATION NO MET-RM-2
2. PART TO BE FABRICATED AS PER USRE GENERAL FABRICATION SPECIFICATION MSR 62-3 REV A
3. ROUND ALL SHARP CORNERS TO 1/64" RADIUS UNLESS OTHERWISE SPECIFIED.
4. FINISH SURFACES TO 125 MICRO INCHES AVERAGE ROUGHNESS HEIGHT UNLESS OTHERWISE SPECIFIED.
5. GOLD NICKEL BRAZING FILLER METAL SHALL BE ASTM-B-260-56T 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
6. AFTER FINAL MACHINING, THE TUBE SHEET SHALL BE LIQUID PENETRANT INSPECTED ACCORDING TO MET-NDT-4

REFERENCE DRAWINGS	DWG. NO.
PRIM. HEAT EXCH. ASSY. ELEV.	D-EE-A-40874
PRIM. HEAT EXCH. TUBE BUNDLE ASSY.	D-EE-A-40867
PRIM. HEAT EXCH. BAFFLE ASSY.	D-EE-A-40866
PRIM. HEAT EXCH. BAFFLE PLATES.	D-EE-A-40864

NO.	REVISIONS		DATE	APPD	APPD
D	DCN 2911-C AS BUILT		9-18-64 F.J.W.		
C	SEE DCN # 2250	E.C.	8-31-62		
B	SEE DCN # 2217		7-19-62		
A	SEE DCN # 2164	J.P.	5-16-62		

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE	APPD	DATE	APPD	DATE
J. H. WESTSIK	9-22-61			W. B. McDonald	1/9/62		1-10-62		2-15-62
CHECKED J. H. WESTSIK	9-22-61	APPROVED		A. Taboada	1/9/62	D. Scott	1-16-62		2-21-62
TRACED	1-19-61	APPROVED			1-10-62		2-19-62		

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

CLASSIFICATION: NOT CLASSIFIED
J. H. WESTSIK

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/32"
DECIMALS ± 0.005"
ANGLES ± 1/2°
SCALE AS NOTED

MOLTEN SALT REACTOR EXPERIMENT BLDG. NO. 7503

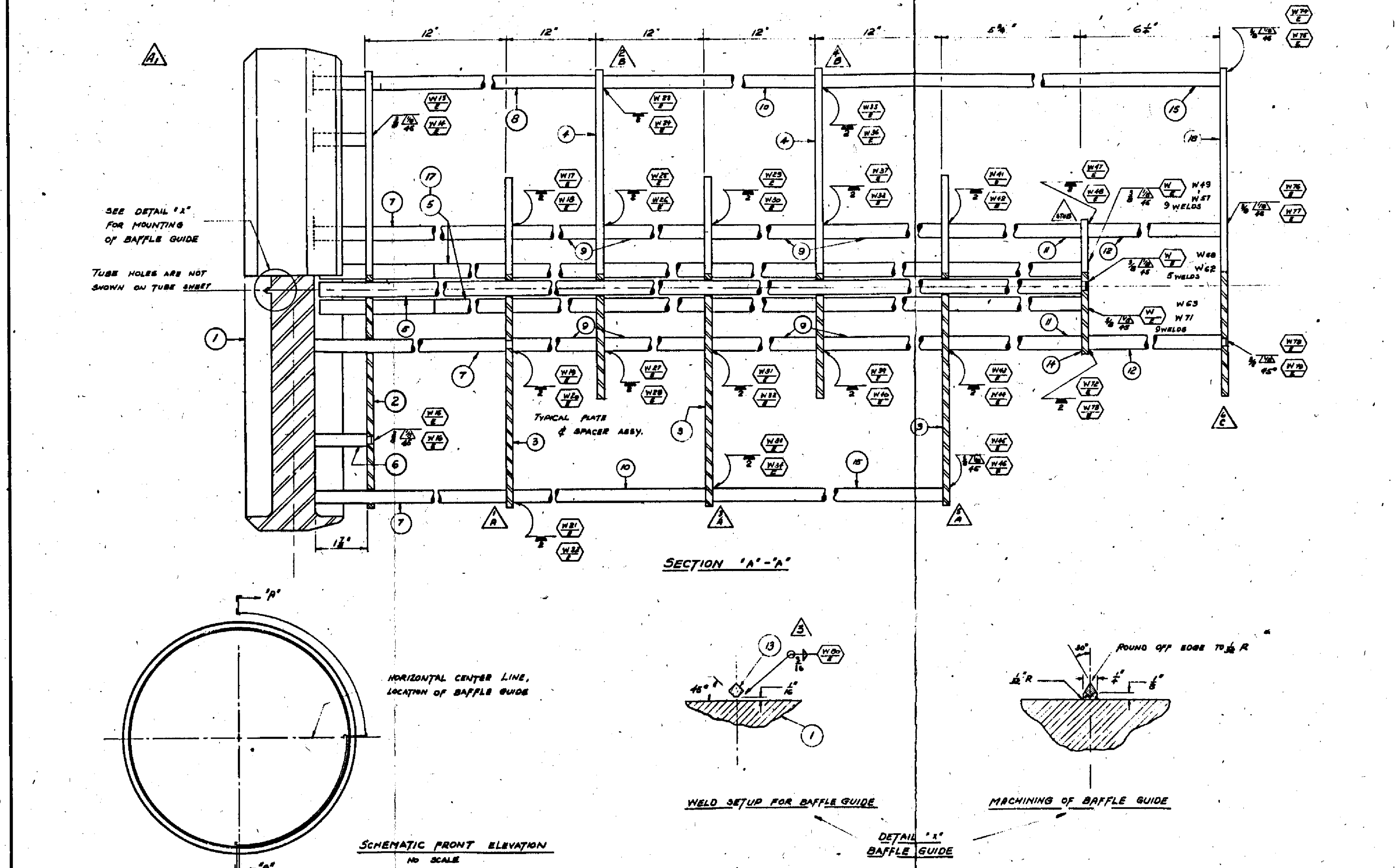
PRIMARY HEAT EXCHANGER
TUBE SHEET

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

SUBMITTED | ACCEPTED | APPROVED

JOB 433-6.6

D- EE-A-40865



PARTS LIST

PART No	DWG. No.	NO. REQD.	DESCRIPTION	MATERIAL
1	D-EE-A-40865	1	TUBE SHEET 1 1/2" THK	INOR-8
2	D-EE-A-40864	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-40863	9	DUMMY RODS "Y" 1/2" DIA	"
6	"	4	BARRIER PLATE SPACER ROD 7/16" DIA	"
7	"	6	BAFFLE PLATE SPACER ROD "I" 7/16" DIA	"
8	"	2	BAFFLE PLATE SPACER ROD "II" 7/16" DIA	"
9	"	16	BAFFLE PLATE SPACER ROD "III" 7/16" DIA	"
10	"	4	BAFFLE PLATE SPACER ROD "IV" 7/16" DIA	"
11	"	4	BAFFLE PLATE SPACER ROD "V" 7/16" DIA	"
12	"	4	BAFFLE PLATE SPACER ROD "VI" 7/16" DIA	"
13	THIS DWG	1	BAFFLE PLATE GUIDE 1/4" x 1/4" x 15 3/4"	"
14	D-EE-A-40864	1	STUB BAFFLE 1/4" THK	"
15	D-EE-A-40863	4	BAFFLE PLATE SPACER ROD "VII" 7/16" DIA	"
16				
17	"	14	DUMMY ROD "Z" 1/2" DIA	"
18	D-EE-A-40877	1	BAFFLE PLATE "C" 1/4" THK	"

NOTES:
1. WELD NUMBERING PROGRESSES FROM LEFT TO RIGHT, FROM TOP TO BOTTOM, AND FROM FRONT TO BACK OF SECTION "A"-"A"
2. PARTS TO BE FABRICATED AS PER MSRE GENERAL FABRICATION SPECIFICATION MSR 62-3 Rev. A
3. MATERIAL SPECIFICATIONS:
   MET-RM-B336 (INOR-8 BAR)
   MET-RM-B304 (INOR-8 WELDING FILLER METAL)
4. UCNC FABRICATORS WELD PER SPECIFICATIONS PS-23, PS-25, PS-26, AS APPLICABLE. INSPECT PER WR-200.
5. WELD NUMBERS ASSIGNED W1 - W80
   WELD NUMBERS USED W1 - W80
6. ROUND ALL SHARP CORNERS TO 1/64" RADIUS UNLESS OTHERWISE SPECIFIED.
7. FINISH SURFACES TO 125 MICROINCHES AVERAGE ROUGHNESS HEIGHT UNLESS OTHERWISE SPECIFIED.
8. BEFORE ASSEMBLY OF BAFFLE PLATES THREAD TUBES CODE 1-8 - CODE 1-8 THROUGH.

REFERENCE DRAWINGS	DWG. NO.
PRIM. HEAT EXCH. ASSY. ELEV.	D-EE-A-40874
PRIM. HEAT EXCH. BAFFLE PLATES, SHEET #2	D-EE-A-40877
PRIM. HEAT EXCH. TUBE SHEET	D-EE-A-40865
PRIM. HEAT EXCH. BAFFLE PLATES SHEET #1	D-EE-A-40864
PRIM. HEAT EXCH. TUBE & ROD DETAILS	D-EE-A-40863

NO.	REVISIONS	DATE	APPD	APPD
B	DCN 2911-C AS BUILT			
A	SEE DCN #2250	EC 8-31-62		

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

CLASSIFICATION: NOT CLASSIFIED — J. H. WESTSIK

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED: FRACTIONS ± 1/32"; DECIMALS ± 0.005"; ANGLES ± 2°0'

SCALE 6" = 1'

MOLTEN SALT REACTOR EXPERIMENT — BLDG. No. 7503

PRIMARY HEAT EXCHANGER BAFFLE ASSEMBLY

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

JOB 433-6.6

D-EE-A-40866

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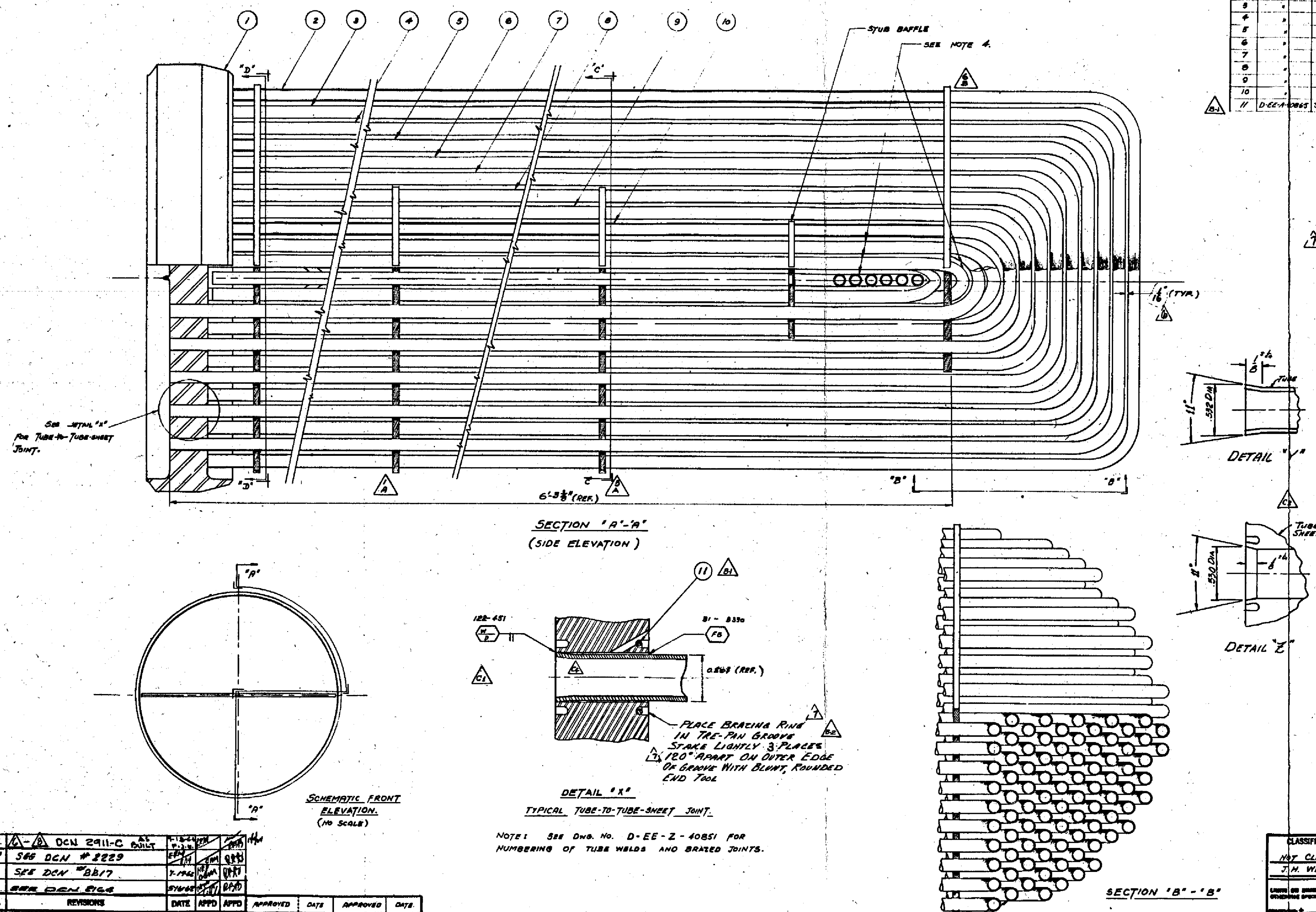


NOTE: SEE DWG. NO. D-EE-Z-40851 FOR NUMBERING OF TUBE WELDS AND BRAZED JOINTS.

PARTS LIST

PART NO.	DWG. NO.	NO. REQD.	DESCRIPTION	MATERIAL
1	D-EE-A-40866	1	BAFFLE ASSEMBLY	INOR-8
2	D-EE-A-40863	4	U TUBE, 1/2" OD × 0.042" WALL FOR ROW 12	"
3	"	9	" FOR ROW 11	"
4	"	12	" FOR ROW 10	"
5	"	13	" FOR ROW 9	"
6	"	16	" 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	GOLD-NICKEL ALLOY

NOTES:

1. PARTS TO BE FABRICATED AS PER ORNL SPEC. MSRE 62-3 REV-A (MSRE GENERAL FABRICATION SPEC.) J.S.-81-182 FABRICATION OF TUBE BUNDLE J.S. 80-167 BRAZING OF TUBE BUNDLE
2. MAKE TUBE TO TUBE SHEET WELD JOINTS AS PER. MSRE METALLURGY MEMO 62-66
3.
4. FOR DETAILS AND PARTS LIST OF ROWS NO 1, 2 & 3 SEE DWG NO D-EE-A-40875
5. FOR SECTIONS "C"-"C" AND "D"-"D" SEE DWG NO D-EE-A-40876
6. 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.
7. 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 INTERIOR OF TUBES. THE HELIUM LEAK RATE SHALL BE LESS THAN 1×10^{-8}/SEC.
8. COMPLETED HEAT EXCHANGER TUBE BUNDLE WAS MODIFIED IN THE FIELD AFTER WATER FLOW TESTS ACCORDING TO DRAWINGS E-10329-R-001 AND 002

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

REFERENCE DRAWINGS	DWG. NO.
MOD. PRIMARY HEAT EXCH. TUBE STABILIZER	E-10329-R-001
PRIMARY HEAT EXCHANGER ASSY.	D-40874
ASSY SHIPPING SUPPORT FOR PRIMARY HEAT EXCHANGER	41811
PRIM. HEAT EXCH. TUBE BUNDLE SECTIONS	D-EE-A-40876
PRIM. HEAT EXCH. TUBE BUNDLE DETAIL	D-EE-A-40875
PRIM. HEAT EXCH. TUBE & ROD DETAILS	D-EE-A-40863
PRIM. HEAT EXCH. TUBE SHEET LAYOUT	D-EE-Z-40851
PRIM. HEAT EXCH. BAFFLE ASSY.	D-EE-A-40866

NO.	REVISIONS
D	DCN 2911-C AS BUILT
C	SEE DCN #2229
B	SEE DCN #8817
A	SEE DCN 8166

MOLTEN SALT REACTOR EXPERIMENT BLDG. NO. 7503

CLASSIFICATION: NOT CLASSIFIED

J. H. WESTSIK

PRIMARY HEAT EXCHANGER
TUBE BUNDLE ASSEMBLY

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

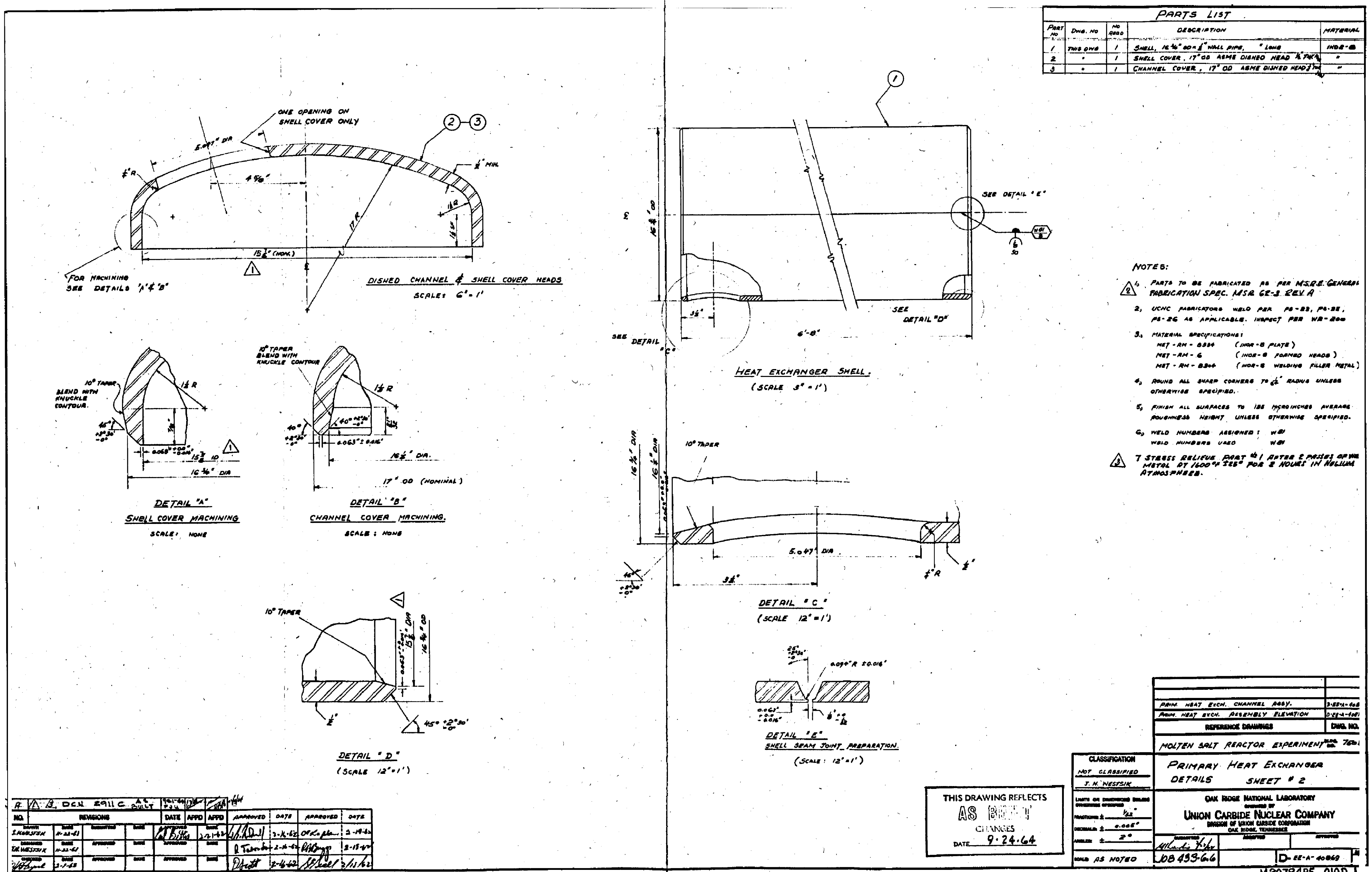
UNITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED: FRACTIONS ± 1/32; DECIMALS ± 0.001; ANGLES ± —

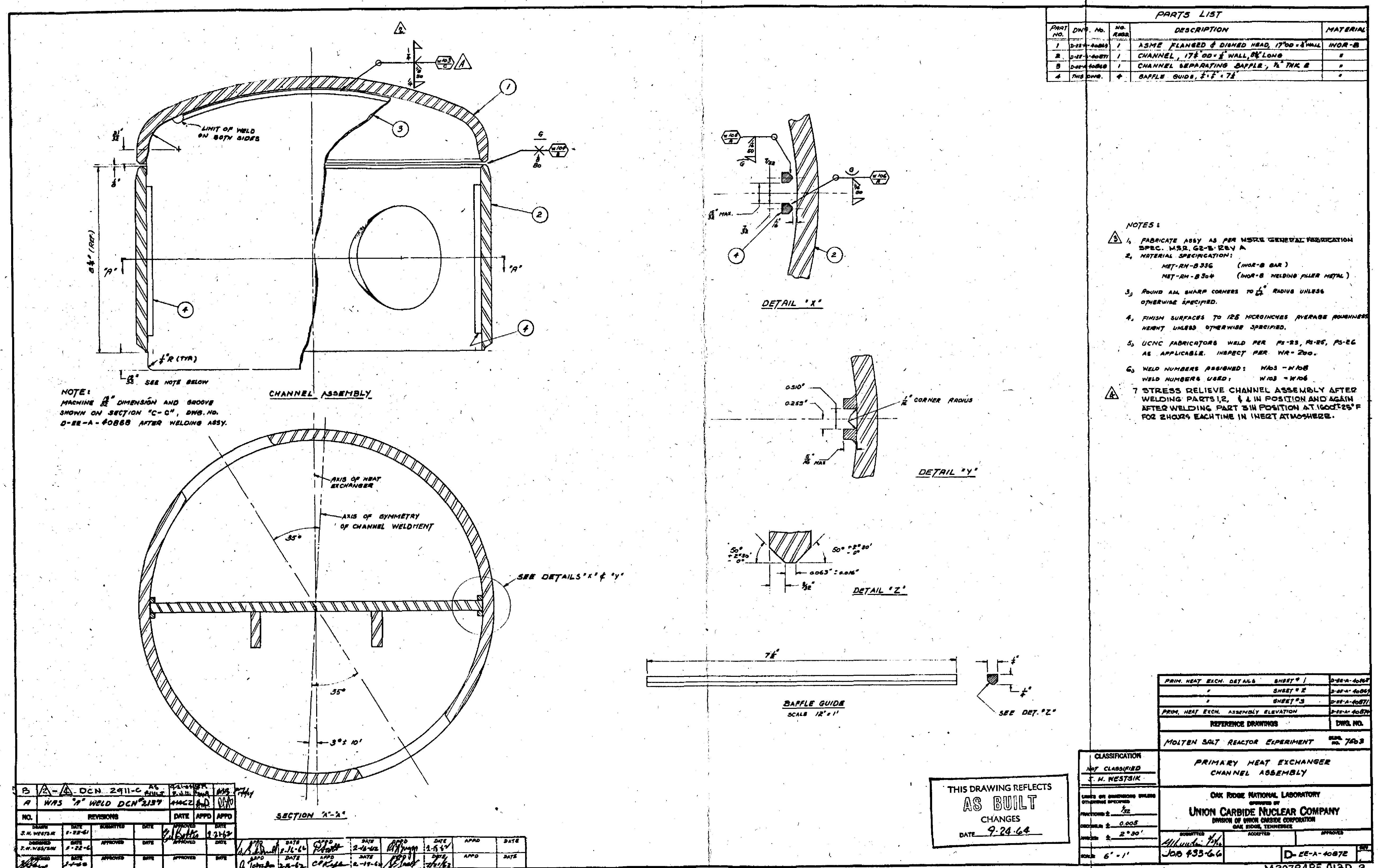
SCALE 6" = 1'

JOB 453-6.6

D-EE-A-40867

M20794RE 008D 4


PARTS LIST
PART NO | DWG. NO | NO REQD | DESCRIPTION | MATERIAL
1 | THIS DWG | 1 | SHELL, 16 1/4" OD x 1/2" WALL PIPE, " LONG | INOR-8
2 | " | 1 | SHELL COVER, 17" OD ASME DISHED HEAD 1/2" THK | "
3 | " | 1 | CHANNEL COVER, 17" OD ASME DISHED HEAD 1/2" THK | "
NOTES:
1. PARTS TO BE FABRICATED AS PER M.S.R.E. GENERAL FABRICATION SPEC. MSR 62-3 REV A
2. UCNC FABRICATORS WELD PER PS-23, PS-25, PS-26 AS APPLICABLE. INSPECT PER WR-200
3. MATERIAL SPECIFICATIONS:
MET-RM-B334 (INOR-8 PLATE)
MET-RM-6 (INOR-8 FORMED HEADS)
MET-RM-B304 (INOR-8 WELDING FILLER METAL)
4. ROUND ALL SHARP CORNERS TO 1/64" RADIUS UNLESS OTHERWISE SPECIFIED.
5. FINISH ALL SURFACES TO 125 MICROINCHES AVERAGE ROUGHNESS HEIGHT UNLESS OTHERWISE SPECIFIED.
6. WELD NUMBERS ASSIGNED: W81
WELD NUMBERS USED W81
7 STRESS RELIEVE PART #1 AFTER 2 PASSES OF WE METAL AT 1600°F ±25° FOR 2 HOURS IN HELIUM ATMOSPHERE.
ONE OPENING ON SHELL COVER ONLY
FOR MACHINING SEE DETAILS "A" & "B"
DISHED CHANNEL & SHELL COVER HEADS
SCALE: 6" = 1'
SEE DETAIL "E"
SEE DETAIL "D"
SEE DETAIL "C"
HEAT EXCHANGER SHELL.
(SCALE 3" = 1')
DETAIL "A"
SHELL COVER MACHINING
SCALE: NONE
DETAIL "B"
CHANNEL COVER MACHINING.
SCALE: NONE
10° TAPER
DETAIL "C"
(SCALE 12" = 1')
DETAIL "D"
(SCALE 12" = 1')
DETAIL "E"
SHELL SEAM JOINT PREPARATION.
(SCALE: 12" = 1')
THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64
PRIM. HEAT EXCH. CHANNEL ASSY.
PRIM. HEAT EXCH. ASSEMBLY ELEVATION
REFERENCE DRAWINGS
DWG. NO.
MOLTEN SALT REACTOR EXPERIMENT
PRIMARY HEAT EXCHANGER
DETAILS SHEET # 2
OAK RIDGE NATIONAL LABORATORY
UNION CARBIDE NUCLEAR COMPANY
CLASSIFICATION
NOT CLASSIFIED
J. H. WESTSIK
SCALE AS NOTED
JOB 433-66
D-EE-A-40869
M20794RE 010D



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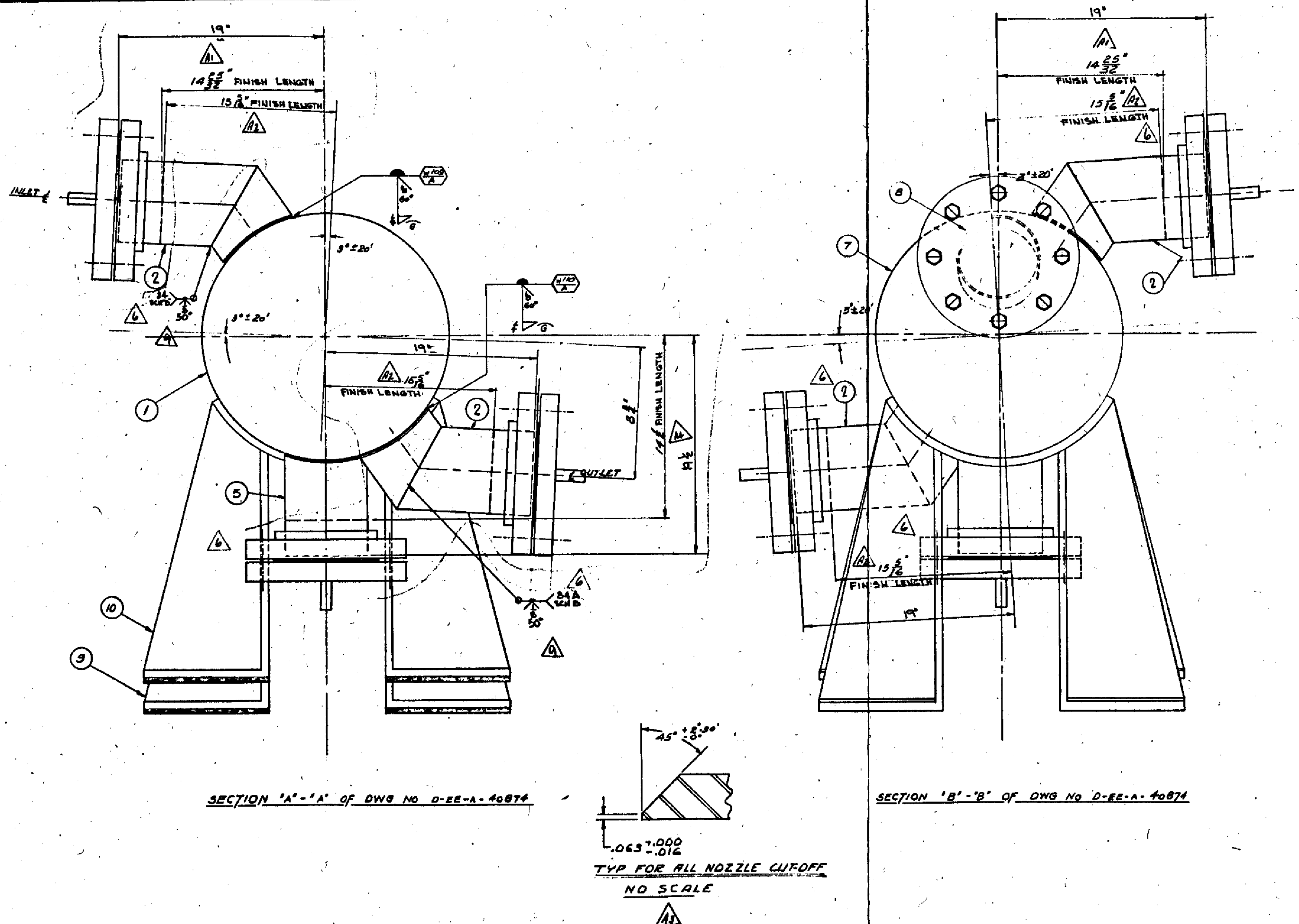


SECTION 'A'-'A' OF DWG NO D-EE-A-40874

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

TYP FOR ALL NOZZLE CUT-OFF
NO SCALE

NOTES:

1. FABRICATE HEAT EXCH. AS PER USRE GENERAL FABRICATION SPEC. MSR. 62-3 REV. A
2. MATERIAL SPECIFICATION:
   MET-RM-B304 (INOR-8 WELDING FILLER METAL)
3. UCNC FABRICATORS WELD PER PS-23, PS-25, PS-26 AS APPLICABLE. INSPECT PER WR-200.
4. WELD NUMBERS ASSIGNED: W109 - W110.
   WELD NUMBERS USED: W109 - W110.
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-56398
7. REMOVE LEAK TEST FLANGES AND CUT NOZZLES TO FINISH LENGTH IN FIELD.

NO.	REVISIONS	DATE	APPD	APPD
B	6 - 7 DCN 2911-C AS BUILT			
A	SEE DCN # 2137	4-16-62		

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

PRIM. HEAT EXCH. ASSEMBLY ELEVATION	D-EE-A-40873
REFERENCE DRAWINGS	DWG. NO.

MOLTEN SALT REACTOR EXPERIMENT BLDG. NO. 7503

PRIMARY HEAT EXCHANGER
ASSEMBLY SECTIONS.

CLASSIFICATION: NOT CLASSIFIED — J. H. WESTSIK

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/32"
DECIMALS ± —
ANGLES ± —
SCALE 3" = 1'

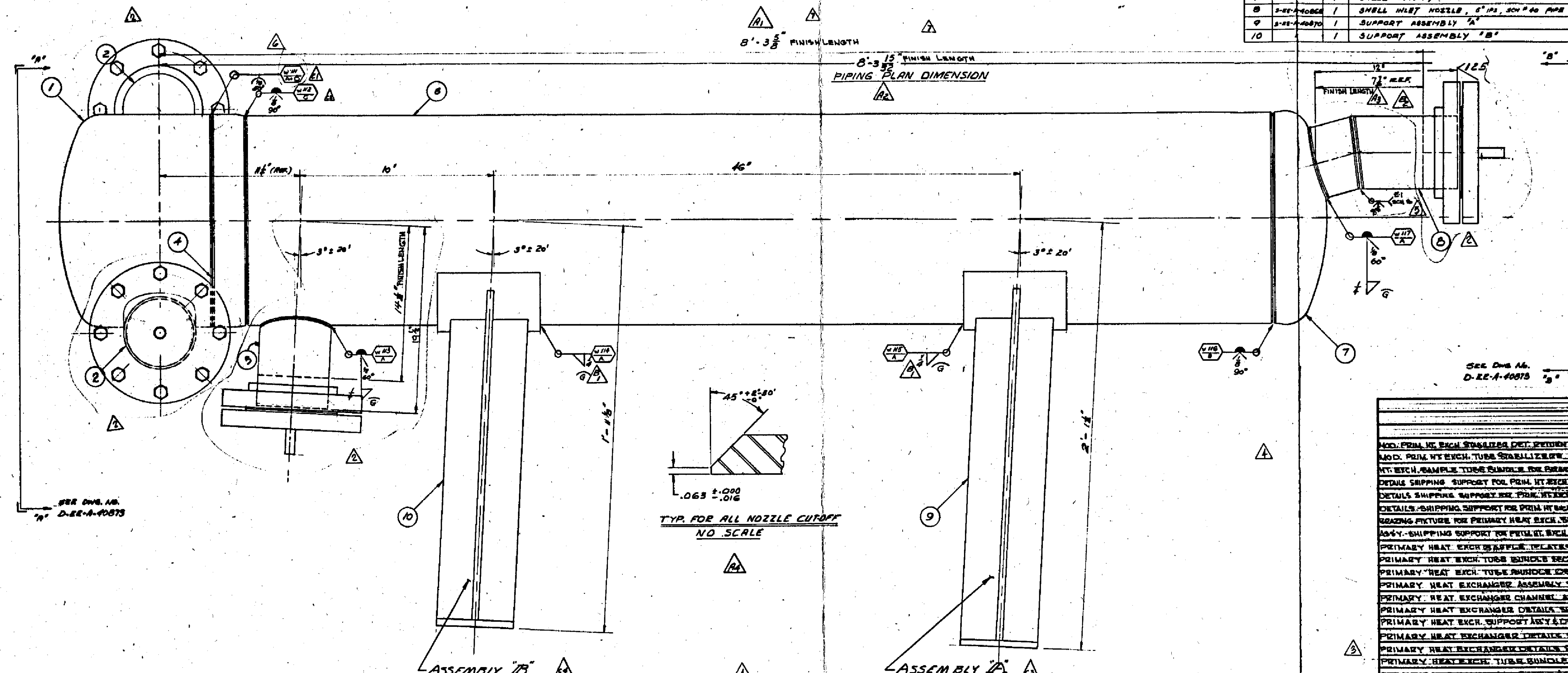
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

JOB 433-6.6 — D-EE-A-40875

M20194RE 014D 2

PART No.	DWG. No.	No. REQD	DESCRIPTION	MATERIAL
1	D-EE-A-40872	1	CHANNEL ASSEMBLY	INOR-8
2	D-EE-A-40864	1	CHANNEL NOZZLE DETAIL	"
4	D-EE-A-40867	1	TUBE BUNDLE ASSEMBLY	"
5	D-EE-A-40868	1	SHELL OUTLET NOZZLE 5" IPS, SCH# 40 PIPE	"
6	D-EE-A-40869	1	SHELL, 16 1/4" OD × 1/2" WALL	"
7		1	SHELL COVER, 17" OD ASME DISHED HEAD	"
8	D-EE-A-40868	1	SHELL INLET NOZZLE, 6" IPS, SCH # 40 PIPE	"
9	D-EE-A-40870	1	SUPPORT ASSEMBLY "A"	"
10		1	SUPPORT ASSEMBLY "B"	"

PARTS LIST



NOTES

1. FABRICATE HEAT EXCHANGER AS PER M.S.R.E. GENERAL FABRICATION SPEC MSR-62-3(Rev.A)
2. MATERIAL SPECIFICATION: MET-RM-B 304 (INOR 8 WELDING FILLER METAL)
3. U.C.N.C. FABRICATORS WELD PER PS-23, PS-24, PS-25 AND PS-26 AS APPLICABLE INSPECT PER WR-200
4. WELD NUMBER ASSIGNED. W-111 THRU W120 - WELD NUMBERS USED W-111 THRU W117
5. FOR SECTIONS 'A-A' & 'B-B' SEE DWG № D-EE-A 40873
6. EMPTY WEIGHT 2060 lbs
   COOLANT SALT WEIGHT 485 lbs
   FUEL SALT WEIGHT 955 lbs
   OPERATING WEIGHT 3500 lbs
7. SHELL SUBASSEMBLY (PARTS 1 AND 2 WITH NOZZLES) AND SHELL SUBASSEMBLY (PARTS 5,6,7,8,9 AND 10 WITH NOZZLES AND LEGS) SHALL BE STRESS RELIEVED AT 1600°±25°F FOR 2 HOURS IN AIR ATMOSHERE. VAPOR BLAST AFTER STRESS RELIEVING TO REMOVE OXIDE FILM.
8. LIQUID PENETRANT EXTERIOR SURFACES OF SHELL SUBASSEMBLIES ACCORDING TO SPECIFICATION MET-NDT-4 PRIOR TO INSTALLATION OF TUBE BUNDLE.
9. WELDED SUBASSEMBLIES MAY BE STRESS RELIEVED AS REQUIRED TO MAINTAIN DIMENSIONAL CONTROL.
10.

	DESIGN TEMP.	DESIGN PRESS.	HYDROSTATIC TEST PRESS.
SHELL SIDE	1300°F	75 PSI	800 P.S.I.G.
TUBE SIDE	1300°F	125 PSI	800 P.S.I.G.

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.

11. 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 RATES SHALL BE LESS THAN 1×10^{-8} CC/SEC.
12. LIQUID PENETRANT INSPECT EXTERIOR SURFACE OF COMPLETED HEAT EXCHANGER PRESSURE CONTAINING PARTS AFTER PRESSURIZED LEAK TESTING IN ACCORDANCE WITH SPEC. MET-NDT-4
13. REMOVE LEAK TEST FLANGES AND CUT NOZZLES TO FINISH LENGTH IN FIELD.
14. COMPLETED HEAT EXCHANGER SHELL AND TUBE BUNDLE WERE MODIFIED IN THE FIELD AFTER WATER FLOW TESTS ACCORDING TO DRAWINGS E-56598, E-10329-R-001 AND 002.

REFERENCE DRAWINGS	DWG. NO.
MOD. PRIM. HT. EXCH. STABILIZER DET. [illegible]	[illegible]
MOD. PRIM. HT. EXCH. TUBE STABILIZERS	E-10329-R-001
HT. EXCH. SAMPLE TUBE BUNDLE FOR [illegible]	[illegible]
DETAILS SHIPPING SUPPORT FOR PRIM. HT. EXCH. SHT. 3	[illegible]
DETAILS SHIPPING SUPPORT FOR PRIM. HT. EXCH. SHT. [illegible]	[illegible]
DETAILS-SHIPPING SUPPORT FOR PRIM. HT. EXCH. SHT. 5	[illegible]
BRAZING FIXTURE FOR PRIMARY HEAT EXCH. SHT. 2	[illegible]
ASSY.-SHIPPING SUPPORT FOR PRIM. HT. EXCH. SHT. 1	[illegible]
PRIMARY HEAT EXCH. BAFFLE PLATES	[illegible]
PRIMARY HEAT EXCH. TUBE BUNDLE SECTIONS	[illegible]
PRIMARY HEAT EXCH. TUBE BUNDLE [illegible]	[illegible]
PRIMARY HEAT EXCHANGER ASSEMBLY SEC.	[illegible]
PRIMARY HEAT EXCHANGER CHANNEL ASSY.	[illegible]
PRIMARY HEAT EXCHANGER DETAILS SHT. 3	[illegible]
PRIMARY HEAT EXCH. SUPPORT ASSY & DETS.	D-EE-A-40870
PRIMARY HEAT EXCHANGER DETAILS SHT. 2	[illegible]
PRIMARY HEAT EXCHANGER DETAILS SHT. 1	[illegible]
PRIMARY HEAT EXCH. TUBE BUNDLE ASSY	[illegible]
PRIMARY HEAT EXCHANGER BAFFLE ASSY	[illegible]
PRIMARY HEAT EXCHANGER TUBE SHEET	[illegible]
PRIMARY HEAT EXCHANGER BAFFLE PLATES	[illegible]
PRIMARY HEAT/EXCHANGER TUBE & ROD DETAILS	[illegible]
MSRE PRIM. HEAT EXCH. NOZZLE & SUPPORT LOCATION	[illegible]
MSRE PRIM. HEAT EXCH. TUBE SHEET LAYOUT	[illegible]

NO.	REVISIONS	DATE	APPD	APPD
E	E – A DCN 2911-C AS BUILT	[illegible]		
D	SEE DCN #2835	[illegible]		
C	SEE DCN #2217	[illegible]		
B	SEE DCN #2164	[illegible]		
A	SEE DCN #2137	4-16-62		

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

CLASSIFICATION: NOT CLASSIFIED — J. H. WESTSIK

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED: FRACTIONS ± 1/32; DECIMALS ± –; ANGLES ± 2°-0'

SCALE 3" = 1'

MOLTEN SALT REACTOR EXPERIMENT — BLDG. NO. 7503

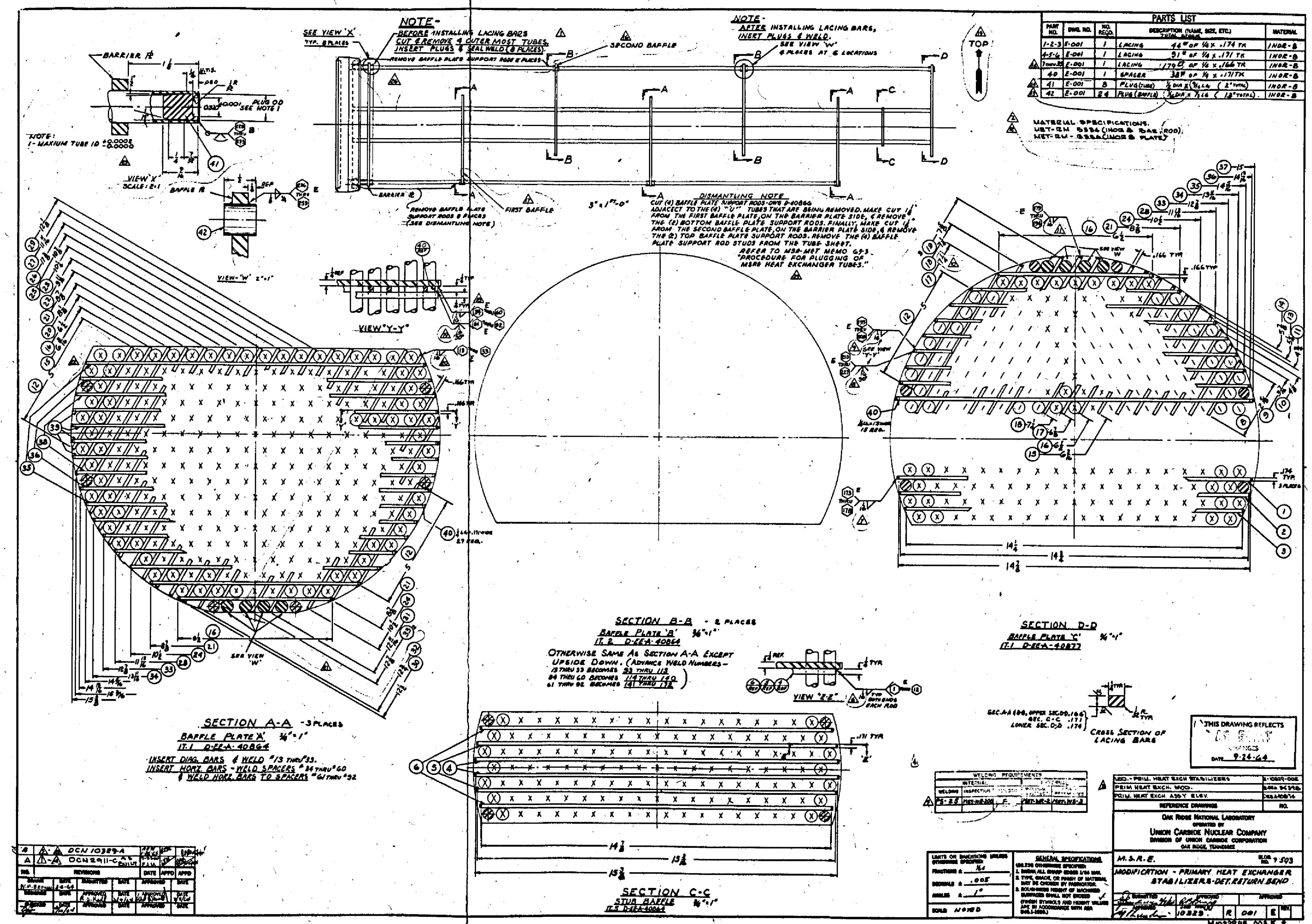
PRIMARY HEAT EXCHANGER
ASSEMBLY ELEVATION

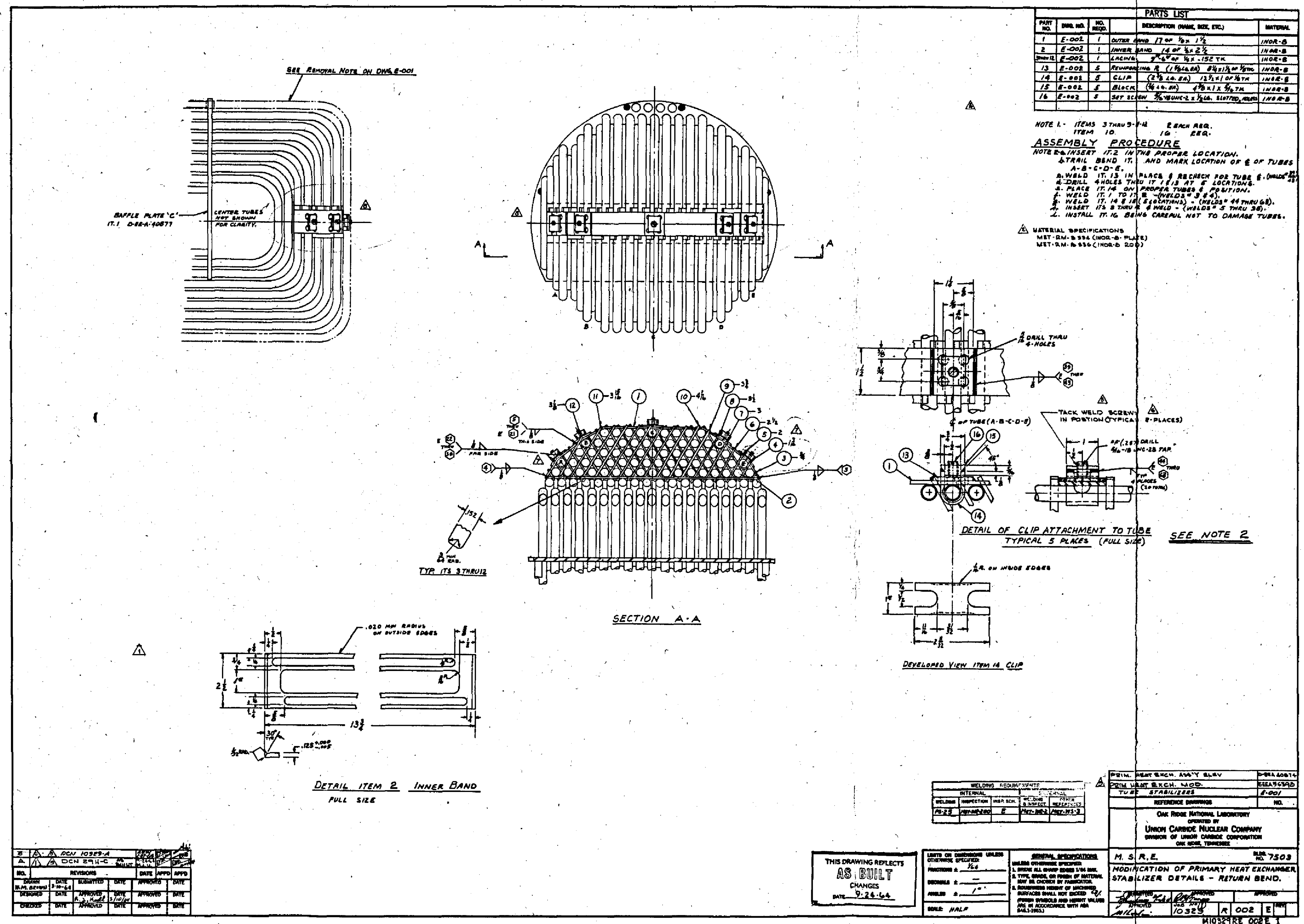
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

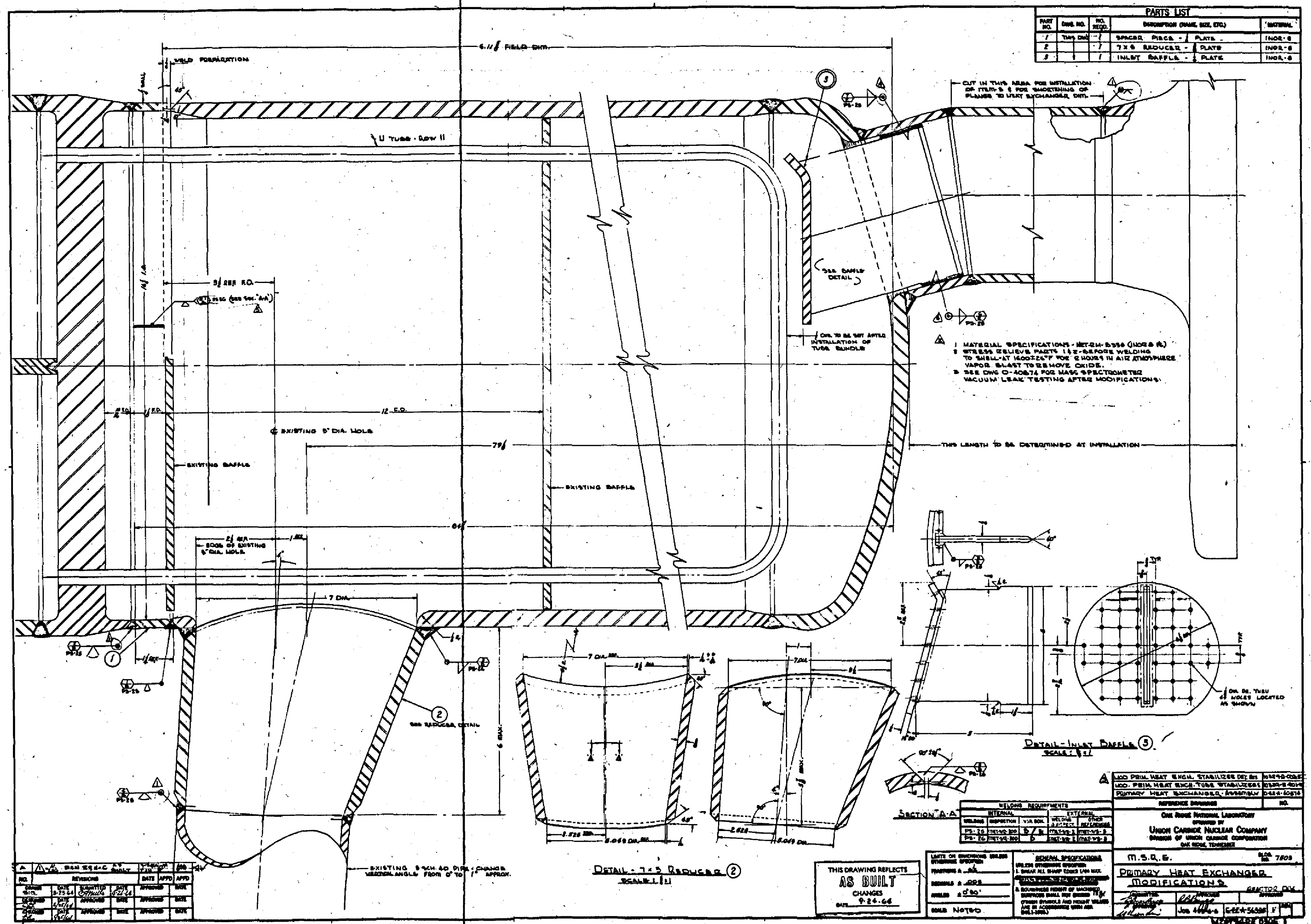
JOB 458-6.6

D-EE-A-40874

M20794RE 015D 5


PARTS LIST
1-2-3 E-001 1 LACING 44" OF 1/4 x .174 TK INOR-8
4-5-6 E-001 1 LACING 91" OF 1/4 x .171 TK INOR-8
7 THRU 39 E-001 1 LACING 1179" OF 1/4 x .166 TK INOR-8
40 E-001 1 SPACER 38" OF 1/4 x .171 TK INOR-8
41 E-001 8 PLUG (TUBE)
42 E-001 24 PLUG (BAFFLE)
MATERIAL SPECIFICATIONS.
TOP
NOTE -
AFTER INSTALLING LACING BARS, INSERT PLUGS & WELD.
DISMANTLING NOTE
SECTION A-A -3 PLACES
BAFFLE PLATE 'A'
SECTION B-B - 2 PLACES
BAFFLE PLATE 'B'
SECTION C-C
STUB BAFFLE
SECTION D-D
BAFFLE PLATE 'C'
VIEW 'X'
VIEW 'Y-Y'
VIEW 'Z-Z'
CROSS SECTION OF LACING BARS
FIRST BAFFLE
SECOND BAFFLE
THIS DRAWING REFLECTS
DATE 9-24-64
PRIM. HEAT EXCH. MOD.
PRIM. HEAT EXCH. ASSY. ELEV.
REFERENCE DRAWINGS
NO.
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE
M.S.R.E.
BLDG. NO. 7503
MODIFICATION - PRIMARY HEAT EXCHANGER STABILIZERS-DET. RETURN BEND
10329
R
001
E
M10329RE 003 E 2


PARTS LIST
PART NO. | DWG. NO. | NO. REQD. | DESCRIPTION (NAME, SIZE, ETC.) | MATERIAL
1 | E-002 | 1 | OUTER BAND 17 OF 1/8 x 1 1/2 | INOR-8
2 | E-002 | 1 | INNER BAND 14 OF 1/8 x 2 1/2 | INOR-8
3 thru 12 | E-002 | 1 | LACING 9'-6" OF 1/4 x .152 TK | INOR-8
13 | E-002 | 5 | REINFORCING R (1 5/8 LG. EA) 8 1/4 x 1 1/2 OF 1/8 THK | INOR-8
14 | E-002 | 5 | CLIP (2 1/2 LG. EA.) 12 1/2 x 1 OF 1/8 TK | INOR-8
15 | E-002 | 5 | BLOCK (3/4 LG. EA.) 4 3/8 x 1 x 5/16 TK | INOR-8
16 | E-002 | 5 | SET SCREW 5/16-18UNC-2 x 1/2 LG. SLOTTED, HDLESS | INOR-8
NOTE 1.- ITEMS 3 THRU 9-11-12 2 EACH REQ.
ITEM 10 16 REQ.
ASSEMBLY PROCEDURE
NOTE 2-a. INSERT IT. 2 IN THE PROPER LOCATION.
b. TRAIL BEND IT. 1 AND MARK LOCATION OF ℄ OF TUBES A-B-C-D-E.
c. WELD IT. 13 IN PLACE & RECHECK FOR TUBE ℄.
d. DRILL 4 HOLES THRU IT 1 & 13 AT 5 LOCATIONS.
e. PLACE IT. 14 ON PROPER TUBES & POSITION.
f. WELD IT. 1 TO IT. 2 -(WELDS # 3 & 4).
g. WELD IT. 14 & 15 (5 LOCATIONS) - (WELDS # 44 THRU 68).
h. INSERT ITS 3 THRU 12 & WELD - (WELDS # 5 THRU 38).
i. INSTALL IT. 16 BEING CAREFUL NOT TO DAMAGE TUBES.
MATERIAL SPECIFICATIONS
MET-RM-B 334 (INOR-8-PLATE)
MET-RM-B 336 (INOR-8 ROD)
SEE REMOVAL NOTE ON DWG E-001
BAFFLE PLATE "C" IT. 1 D-BB-A-40677
CENTER TUBES NOT SHOWN FOR CLARITY.
SECTION A-A
TYP ITS 3 THRU 12
DETAIL OF CLIP ATTACHMENT TO TUBE
TYPICAL 5 PLACES (FULL SIZE)
SEE NOTE 2
TACK WELD SCREW IN POSITION (TYPICAL 5-PLACES)
DEVELOPED VIEW ITEM 14 CLIP
DETAIL ITEM 2 INNER BAND
FULL SIZE
WELDING REQUIREMENTS
INTERNAL
EXTERNAL
WELDING | INSPECTION | INSP. SCH. | WELDING & INSPECT. | OTHER REFERENCES
PS-25 | MET-WR-200 | E | MET-WR-2 | MET-WS-3
PRIM. HEAT EXCH. ASS'Y ELEV
PRIM HEAT EXCH. MOD.
TUBE STABILIZERS
E-001
REFERENCE DRAWINGS
NO.
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE
THIS DRAWING REFLECTS
AS BUILT
CHANGES
DATE 9-24-64
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± 1/64
ANGLES ± 1°
SCALE: HALF
GENERAL SPECIFICATIONS
UNLESS OTHERWISE SPECIFIED:
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. TYPE, GRADE, OR FINISH OF MATERIAL MAY BE CHOSEN BY FABRICATOR.
3. ROUGHNESS HEIGHT OF MACHINED SURFACES SHALL NOT EXCEED
(FINISH SYMBOLS AND HEIGHT VALUES ARE IN ACCORDANCE WITH ASA B46.1-1955.)
M. S. R. E.
BLDG. NO. 7503
MODIFICATION OF PRIMARY HEAT EXCHANGER
STABILIZER DETAILS - RETURN BEND.
10329 R 002 E
M10329RE 002E 1


PARTS LIST
SPACER PIECE - PLATE
7 x 5 REDUCER - PLATE
INLET BAFFLE - PLATE
INOR-8
WELD PREPARATION
U TUBE - ROW 11
EXISTING BAFFLE
THIS LENGTH TO BE DETERMINED AT INSTALLATION
DETAIL - 7 x 5 REDUCER 2
DETAIL - INLET BAFFLE 3
SECTION A-A
WELDING REQUIREMENTS
THIS DRAWING REFLECTS
AS BUILT
CHANGES
9-24-66
OAK RIDGE NATIONAL LABORATORY
UNION CARBIDE NUCLEAR COMPANY
M.S.R.E.
PRIMARY HEAT EXCHANGER
MODIFICATIONS
REACTOR DIV.

ORNL-TM-2098

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