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SUBJECT: MSRE Radiator Design

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FROM: W. C. Ulrich

Abstract

An air-cooled radiator capable of rejecting 10 Mw of reactor thermal power to the atmosphere was designed for the MSRE. The design was based on utilizing in part equipment and facilities left from the ART program which were available for use in building 7503.

CONTENTS

Introduction

The design of a heat exchanger for removing MSRE thermal power was based on utilizing as much as possible the existing facilities and equipment in the Aircraft Reactor Test building 7503. Since these facilities included blowers, motors, ducting, and a stack for discharge of air to the atmosphere, an air-cooled coil or radiator seemed to be most feasible.

Because the secondary piping system of the MSRE, of which the radiator is a part, will contain a $LiF-BeF_2$ salt mixture from which the reactor heat is to be extracted, the design entailed determining the size and configuration of the radiator coil based on the physical properties of this salt and the amount of cooling air available. Also included in the design was an integral supporting frame work-insulated enclosure for the coil. Because the $LiF-BeF_2$ salt mixture freezes at about 850°F, provisions were made for supplying heat to the coil to keep this secondary salt fluid during reactor down periods.[1] Control of air flow rates over the coil, necessary baffling, and duct modifications were also determined.

Radiator Design

1. Secondary Salt Flow Rate

The secondary salt which will remove heat from the fuel solution in the primary heat exchanger and reject heat to the atmosphere in the radiator will consist of a mixture of 66 mol % LiF and 34 mol % BeF_2. For MSRE operation at 10 Mw thermal power, the secondary salt temperature drop through the coil was selected as 75°F. (1100°F inlet temperature, 1025°F outlet temperature.) The flow rate necessary for 10 Mw heat transference capacity was found to be 830 gpm.

2. Air Flow Rate

Air will be supplied by two 250 hp axial blowers left from the ART program. Each blower is rated at 82,500 cfm at 15 in. water static pressure, or 114,000 cfm free air delivery. For 10 Mw reactor power operation, the air temperature rise across the coil was set at 200°F. Assuming an air inlet temperature of 100°F, the temperature of the air leaving the coil would be 300°F. For this air temperature rise, 164,000 cfm of air will be required to reject 10 Mw of thermal energy to the atmosphere.

3. Coil Size and Configuration

The coil size and configuration depends on both the secondary salt and air flow rates. A first estimate of the coil area required was obtained by assuming an overall heat transfer coefficient of 55 Btu/hr-°F-ft^2 and solving for A in the equation

$$q = UA\Delta t_m ,$$

where

q = rate of heat transfer, Btu/hr

U = overall heat transfer coefficient, Btu/hr-°F-ft^2

A = heat transfer area, ft^2

Δt_m = log mean temperature difference, °F

$$\Delta t_m = \frac{(1025-100) - (1100-300)}{\ln \frac{1025 - 100}{1100 - 300}}$$

$$\Delta t_m = \frac{125}{\ln \frac{925}{800}} = \frac{125}{0.145} = 862°F \; .$$

$$(10 \text{ Mw})(3.415 \times 10^6 \text{ Btu/Mw-hr}) = (55 \text{ Btu/hr-ft}^2\text{-°F})(A \text{ ft}^2)(862°F)$$

A = 720 ft^2 of heat transfer surface area needed.

For $^3/_4$ in. OD x 0.072 in. wall tubing, the surface area is 0.1963 ft^2/ft length. Therefore,

$$\frac{720 \text{ ft}^2}{0.1963 \text{ ft}^2\text{/ft}} = 3670 \text{ ft}$$

of tubing would be required. An arbitrarily selected tube length of 30 ft gave a total of about 122 tubes. Because of space limitations in the existing ductwork and because of the physical layout of the reactor secondary salt system piping, an S-shaped coil of 120 tubes, each 30 ft long, was proposed for calculating the actual radiator performance. The 120 $^3/_4$ in. OD tubes were arranged in 10 rows with 12 tubes per row with a 1½ in. square pitch. Tube rows were staggered. See Figs. 1 and 2.

The salt film heat transfer coefficient, h_L, was calculated from the following equation[2], where the subscript b refers to the bulk temperature:

$$\frac{h_L D}{k_b} = 0.023 \left(\frac{DG}{\mu_b}\right)^{0.8} \left(\frac{c_p \mu}{k}\right)_b^{0.4} , \qquad (1)$$

where

h_L = liquid film heat transfer coefficient, Btu/hr-ft^2-°F

D = tube inside dia. ft

k_b = thermal conductivity, Btu/hr-ft^2-°F/ft

G = mass velocity, lb/hr-ft^2

μ_b = viscosity, lb/ft-hr

c_p = specific heat, Btu/lb-°F (at constant pressure)

$$\left(\frac{DG}{\mu_b}\right)^{0.8} = \left[\frac{(0.606\text{ in.})(830\text{ gpm})(60\text{ min/hr})(8.33\text{ lb/gal})(120\text{ lb/ft}^3)}{(12\text{ in./ft})(62.4\text{ lb/ft}^3)(22\text{ lb/ft-hr})(120\text{ tubes})(2\text{x}10^{-3}\text{ ft}^2\text{/tube})}\right]^{0.8}$$

$$\left(\frac{DG}{\mu_b}\right)^{0.8} = (7750)^{0.8} = 1290\ ,$$

$$\left(\frac{c_p\mu}{k}\right)_b^{0.4} = \left[\frac{(0.57\text{ Btu/lb-°F})(22\text{ lb/ft-hr})}{3.5\text{ Btu/hr-ft}^2\text{-°F/ft})}\right]^{0.4}$$

$$\left(\frac{c_p\mu}{k}\right)_b^{0.4} = (3.58)^{0.4} = 1.665$$

and

$$h_L = \frac{(0.023)(1290)(1.665)(3.4\text{ Btu/hr-ft}^2\text{-°F/ft})}{\frac{0.606\text{ in.}}{12\text{ in./ft}}}$$

$$h_L = 3420\text{ Btu/hr-ft}^2\text{-°F}\ .$$

The air film heat transfer coefficient, h_m, was found from the following equation[3] where the subscript f refers to the air film temperature, estimated to be 900°F:

$$\left(\frac{h_m D_o}{k_f}\right) = 0.33 \left(\frac{c_p \mu}{k}\right)_f^{1/3} \left(\frac{D_o G_{max}}{\mu_t}\right)^{0.6} , \qquad (2)$$

where

h_m = air film heat transfer coefficient, Btu/hr-ft^2-°F

D_o = tube outside diameter, ft

k_f = thermal conductivity Btu/hr-ft^2-°F/ft

c_p = specific heat, Btu/lb-°F (at constant pressure)

μ = viscosity, lb/ft-hr

G_{max} = air mass velocity through minimum flow area, lb/hr-ft^2

$$\left(\frac{c_p \mu}{k_f}\right)^{1/3} = \left[\frac{(0.2598 \text{ Btu/lb-°F})(0.0854 \text{ lb/ft-hr})}{0.0320 \text{ Btu/hr-ft}^2\text{-°F/ft}}\right]^{1/3}$$

$$\left(\frac{c_p \mu}{k_f}\right)^{1/3} = (0.693)^{1/3} = 0.885 ,$$

$$\left(\frac{D_o G_{max}}{\mu_f}\right)^{0.6} = \left[\frac{(0.750 \text{ in.})(692{,}000 \text{ lb/hr})}{(12 \text{ in./ft})(23.5 \text{ ft}^2)(0.0854 \text{ lb/ft-hr})}\right]^{0.6}$$

$$\left(\frac{D_o G_{max}}{\mu_f}\right)^{0.6} = (21{,}600)^{0.6} = 398$$

and

$$h_m = \frac{(0.33)(0.885)(398)(0.0320 \text{ Btu/hr-ft}^2\text{-°F/ft})}{\frac{0.750 \text{ in.}}{12 \text{ in./ft}}}$$

$$h_m = 59.5 \text{ Btu/hr-ft}^2\text{-°F} .$$

The overall heat transfer coefficient, U, was then determined.

$$\frac{1}{UA} = \frac{1}{h_L A_1} + \frac{1}{h_m A_2} + \frac{1}{kA_3}$$

where

$$\frac{X}{kA_3} = \text{thermal resistivity of tube wall, } \frac{\text{hr-°F}}{\text{Btu}}$$

$$A \cong A_1 \cong A_2 \cong A_3$$

$$\frac{1}{U} = 0.000292 + 0.0168 + 0.00171 = 0.0188 ,$$

and

$$U = 53.2 \text{ Btu/hr-ft}^2\text{-°F} ,$$

which agrees closely with the assumed value of 55 Btu/hr-ft^2-°F. Therefore, the assumed values for tube length, arrangement and configuration were acceptable.

The bulk secondary salt and air temperatures were taken as the arithmetic average, giving 1062.5°F for the salt and 200°F for the air. The temperature drops across each film and the pipe wall were then calculated.

$$\text{Salt film } \Delta t = \frac{0.000292}{0.0188} \times 862.5\text{°F} = 13.4\text{°F}$$

$$\text{Wall } \Delta t = \frac{0.00171}{0.0188} \times 862.5\text{°F} = 78.4\text{°F}$$

$$\text{Air film } \Delta t = \frac{0.0168}{0.0188} \times 862.5\text{°F} = 770.7\text{°F} .$$

The air film temperature was calculated to be 1062.5 - (13.4 + 78.4) = 970.7°F as against the assumed value of 900°F. The corrected air film heat transfer coefficient then becomes 58.4 Btu/hr-ft^2-°F, and the overall heat transfer coefficient 52.4 Btu/hr-ft^2-°F.

The secondary salt pressure drop through the coil was determined from the following equation:[4]

$$\Delta t_t = \frac{f G_t^2 L_n}{2 g \rho D \phi_t} \quad \text{psi} , \qquad (3)$$

where

Δp_t = pressure drop, psi

f = friction factor, ft^2/in.^{2}

G_t = mass velocity, lb/hr-ft^2

L_n = equivalent tube length, ft

g = acceleration of gravity, ft/hr^2

ρ = density, lb/ft^3

D = inside tube diameter, ft

ϕ_t = viscosity ratio, dimensionless

and was found to be

$$\Delta p_t = \frac{(0.00029 \text{ ft}^2/\text{in.}^2)(3.32 \times 10^6 \text{ lb/hr-ft}^2)^2(33.75 \text{ ft})(1)}{(2)(32.2 \text{ ft/sec}^2)(3600 \text{ sec/hr})^2(120 \text{ lb/ft}^3)(\frac{0.606}{12} \text{ ft})(1)} \quad \text{psi}$$

$$\Delta p_t = 21.4 \text{ psi} .$$

The air pressure drop across the coil was similarly determined, using the following two correlations,[5]

$$f = 0.75 \left(\frac{D_c V_{max} \rho}{\mu} \right)^{-0.2} , \qquad (4)$$

and

$$\Delta p = \frac{4fN_r \rho V_{max}^2}{2g_c} , \qquad (5)$$

where

f = friction factor, dimensionless

D_c = transverse clearance, ft

V_{max} = fluid velocity through minimum flow area, ft/sec

ρ = fluid density, lb/ft^3

μ = viscosity, lb mas/ft-sec

Δp = pressure drop, lb force/ft^2

N_r = number of rows of tubes normal to flow

g_c = conversion factor, 32.174 lb mass ft/lb force-sec^2 .

$$f = 0.75 \left[\frac{\left(\frac{0.750}{12} \text{ ft} \right) (4.19 \times 10^5 \text{ ft/hr})(0.0692 \text{ lb/ft}^3)}{0.0521 \text{ lb/ft-hr}} \right]^{-0.2} = 0.093$$

$$\Delta p = \frac{(4)(0.093)(12)(0.0692 \text{ lb/ft}^3)(4.19 \times 10^5 \text{ ft/hr})^2}{(2)(32.2 \text{ ft/sec}^2)(3600 \text{ sec/hr})^2(144 \text{ in.}^2/\text{ft}^2)}$$

Δp = 0.45 psi or 12.5 in. water.

4. MSRE Operation at Power Levels Less than 10 Mw

Because the MSRE will not always operate at 10 Mw, it was necessary to determine the radiator operating characteristics for all reactor power levels.

By use of the variable-speed fuel-circulating pump, the flow rate of the fuel through the primary heat exchanger may be varied. The secondary salt flow rate, however, is to be maintained constant. The amount of heat extracted from the secondary salt as it passes through the radiator is thus controlled by the amount of air forced over the radiator coil. Control of the air flow rate then will be the most sensitive reactor power level control.

The effective Δt's between the fuel and secondary salt in the primary heat exchanger for various reactor power levels have been estimated, and are given below.[6] From these figures, and assuming that the secondary

Fraction Reactor Design Power	Δt_{eff} °F	Corresponding Secondary Salt Δt in Radiator °F
1.0	130	75
0.8	117	60
0.6	103	45
0.4	89	30
0.2	73	15
0.1	62	7.5

salt flow rate will be constant, the corresponding secondary salt temperature changes in the radiator were calculated. The air mass-flow rates to achieve these secondary salt temperature changes in the radiator were then calculated by assuming a constant air inlet temperature of 100°F and using the correlations given above. (Equations 1 and 2.) The results are shown in Fig. 3 along with the air temperature rise through the radiator.

5. Cooling Air

Air for cooling the radiator will be supplied by two 250 hp vane-axial blowers left from the ART program. Each blower is rated at 82,500 cfm at 15 in. water static pressure, or 114,000 cfm free air delivery. The blowers are provided with horizontal multibladed dampers, gang-operated by air-operated motors, to prevent "blow-back" when a blower is not in operation.

A bypass duct with a controlled damper will be provided to short-circuit part of the air flow around the radiator. The purpose of the duct is threefold:

1. At low reactor power levels, the air leaving the radiator will be at very high temperatures as shown in Fig. 3. During these periods, the bypass damper will be open allowing cooler air to mix with the high temperature air to keep the duct at a temperature below 300°F. At higher reactor power levels when the air leaving the radiator is at a lower temperature, the bypass damper will be closed.

2. The bypass duct will be used to reduce the wind force on the radiator and radiator door in event of power failure or reactor scram. In either of these occurrences, the radiator doors will be closed and the fans will be running down, still delivering air. This air will then be routed around the radiator through the open bypass duct reducing the air static pressure on the radiator.

3. During reactor-down periods when heat is being supplied to the radiator coil in the enclosed radiator frame, the bypass duct will be open to reduce the stack effect across the radiator.

6. Radiator Frame and Doors

The radiator frame will be mainly structural steel; members exposed to high temperatures will be stainless steel. The radiator frame will be completely enclosed, insulated, and equipped with radiant heat shields to protect the structural members from high temperatures. The radiant heat shields and insulation will also limit radiator heat loss during reactor-down periods while maintaining the secondary salt in the fluid state by supplying heat from an external source. Baffles will be made integral with the frame to direct the air over the radiator coil.

The secondary salt inlet header of the radiator coil assembly will be anchored to the frame; the secondary salt outlet header will be allowed to move in the horizontal direction to allow for thermal expansion of the secondary piping and the radiator coil.

The coil will be suspended from hangers which will allow thermal expansion, support the weight of the coil, and maintain coil tube spacing.

The radiator frame will also contain provisions for two vertically-operating insulated doors. The doors will close off the air passage over the coil to reduce heat loss from the coil during reactor-down periods.

The doors are suspended from roller chains which run over sprockets to a single counter-weight which weighs less than the combined weights of the two doors. When the doors are in the up (open) position, the counter-weight is held down by three magnets, any two of which are capable of holding this weight. In event of power failure or reactor scram, the magnets release the counter-weight and the doors are allowed to fall freely. At other times the doors will be lowered by an electric motor through a magnetic clutch-brake arrangement. This same arrangement will also be used to raise the doors. The doors will normally be either fully open or closed; however, it will be possible with the magnetic clutch-brake to position them at any point in between. The doors will be guided by means of rollers that travel in a machined track so that "cocking" of a door is prevented.

7. Duct

The existing duct will be modified to provide as smooth a transition as possible from the fan outlet to the radiator coil inlet. A bypass duct, described above, will also be installed.

8. Heating

During periods when the reactor is not operating, it will be necessary to supply heat to the radiator coil to keep the secondary salt in the fluid state. When this heating is required, the radiator doors will be closed, the bypass duct will be open, and the radiator coil essentially isolated from the ambient atmosphere.

Heat will be supplied to the radiator coil by means of panels containing electric resistance heating elements embedded in a ceramic material. These panels will be located on the horizontal and vertical surfaces of the air baffles adjacent to the tubes of the radiator coil. Heat transmission from the panels to the coil will be primarily by radiation, with some convection caused by the air heated within the enclosure.

9. Conclusions

The radiator will contain a coil which consists of 120 $^3/_4$ in. OD x 0.072 in. wall tubes spaced $1\frac{1}{2}$ in. apart on centers in a square pitch arrangement. (Fig. 1) Each S-shaped tube is approximately 30 ft in length and terminates in a $2\frac{1}{2}$ in. pipe manifold which is connected to an 8 in. ID header. Total heat transfer surface area is about 706 sq. ft. The headers are connected to the 5 in. secondary salt circulating piping. (Fig. 2) Tubes, manifolds, headers, and secondary piping are all INOR-8.

The secondary salt mixture of 66 mol % LiF and 34 mol % BeF_2 will be circulated through the radiator at 830 gpm and will undergo a 75°F temperature drop as it loses 10 Mw of heat. Cooling air will be supplied by two 250 hp vane-axial blowers each capable of delivering 82,500 cfm of air at 15 in. water static pressure, or 114,000 cfm free air delivery.

For 10 Mw heat removal, 164,000 cfm of air with a temperature rise of 200°F across the radiator will be required. The air pressure drop across the radiator was calculated to be 12.5 in. water static pressure, and the overall heat transfer coefficient was calculated to be 52.4 Btu/hr-ft^2-°F under these conditions.

A curve of cooling air required and air temperature rise for various reactor power levels is shown in Fig. 3.

The radiator coil will be enclosed in an insulated frame equipped with vertically operating insulated doors. During periods when it is necessary to supply heat to the radiator to maintain the secondary salt in a liquid state, the doors will be closed forming a reasonably air-tight enclosure.

Heat will be supplied to the radiator coil during reactor-down periods by panels of electrical resistance heaters installed in baffles adjacent to the tube rows.

References

1 R. C. Robertson and S. E. Bolt, MSRE Heaters — Summary of Preliminary Studies, August 11, 1960, p. 20.

2 W. H. McAdams, Heat Transmission, 3d ed., p. 219, McGraw Hill Book Company, Inc., New York, 1954.

3 Ibid, p. 272.

4 Donald Q. Kern, Process Heat Transfer, 1st ed., p. 148, 836, McGraw Hill Book Company, Inc., New York, 1950.

5 J. H. Perry (Editor), Chemical Engineers Handbook, 3d ed., p. 391, McGraw Hill Book Company, Inc., New York, 1950.

6 J. H. Westsik, Personal Communication.

Unclassified
ORNL-LR-Dwg. 54696

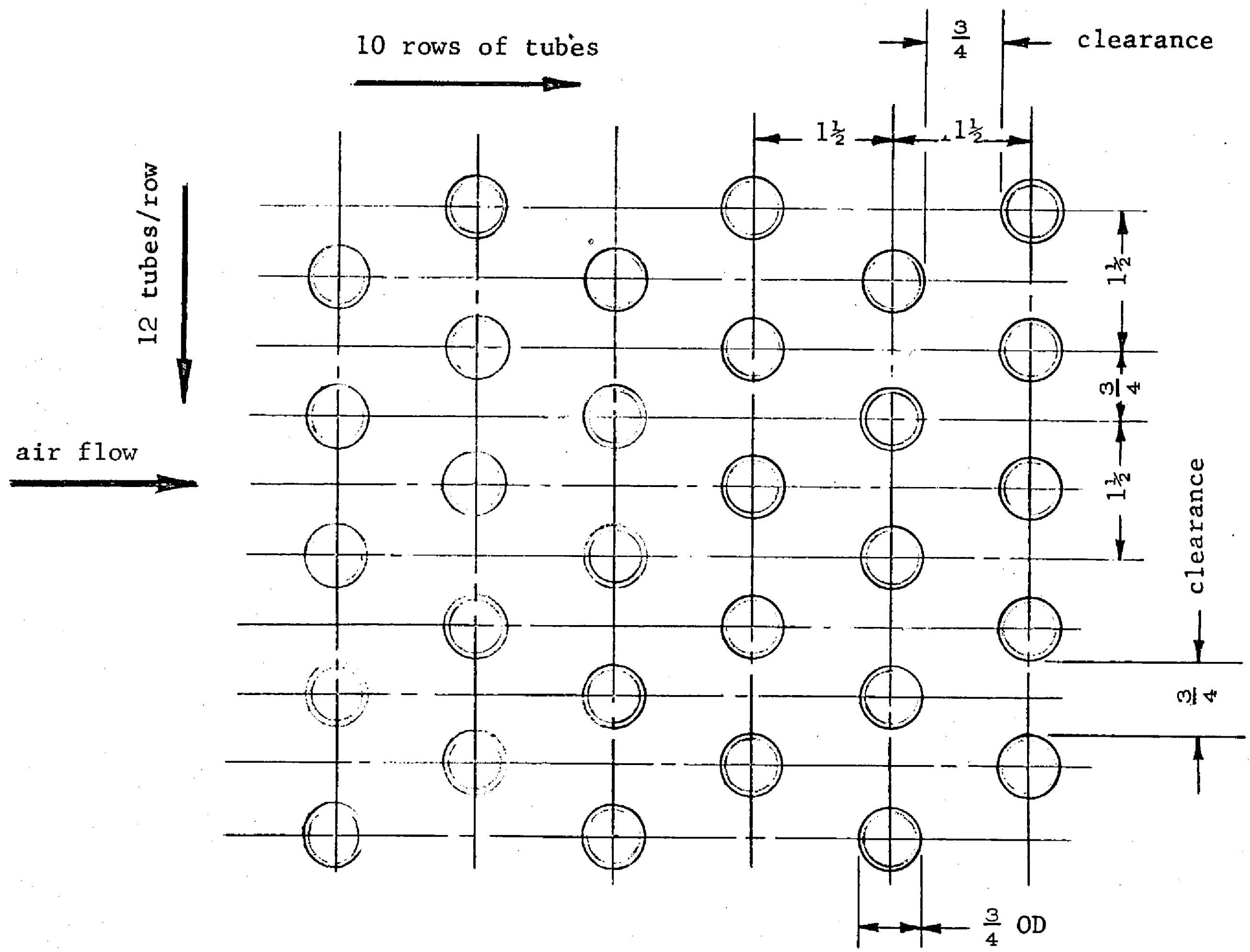

Figure 1. MSRE Radiator Tube Matrix

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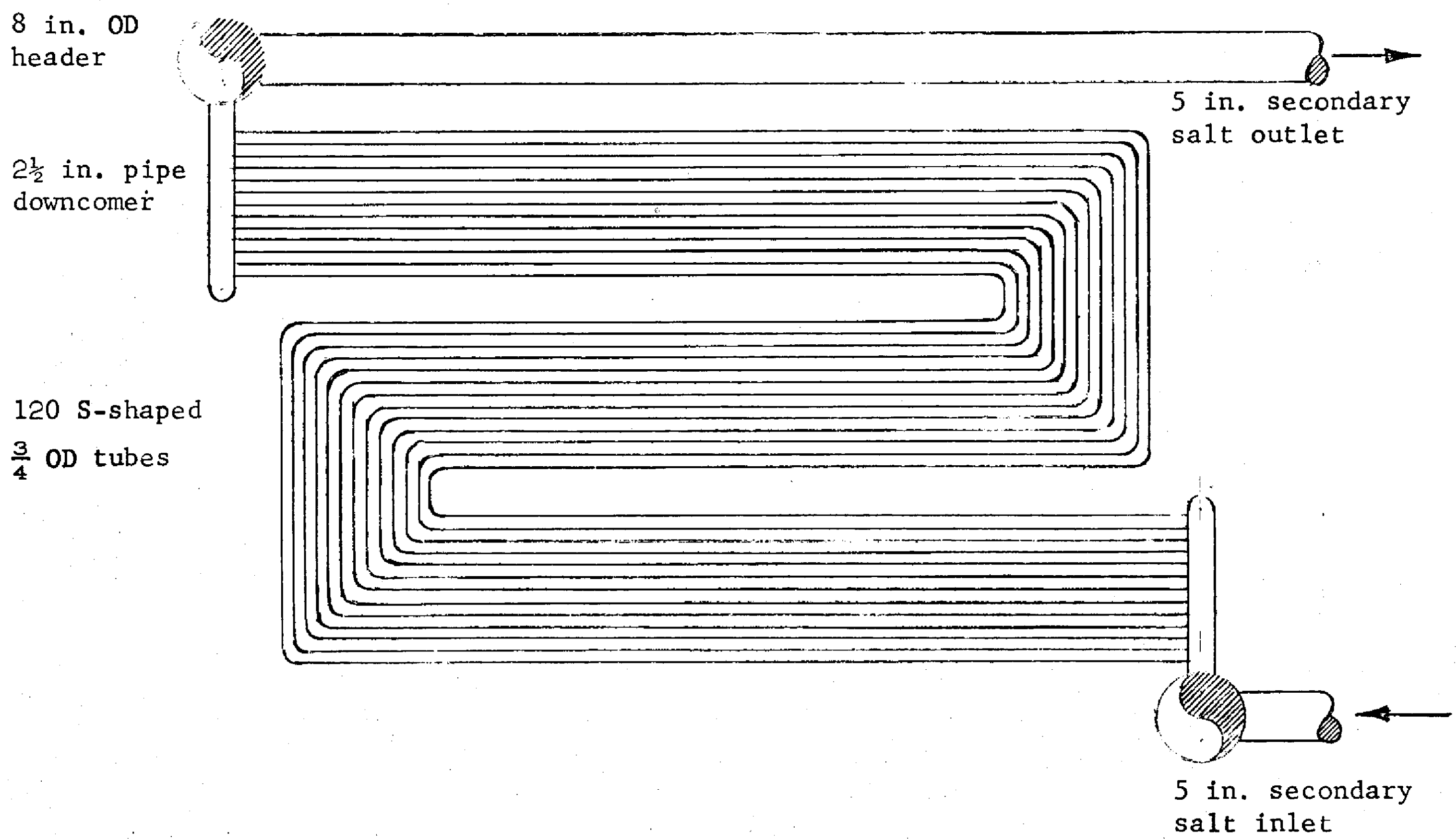

Figure 2. MSRE Radiator Coil Configuration
(Air Flow Out of Paper)

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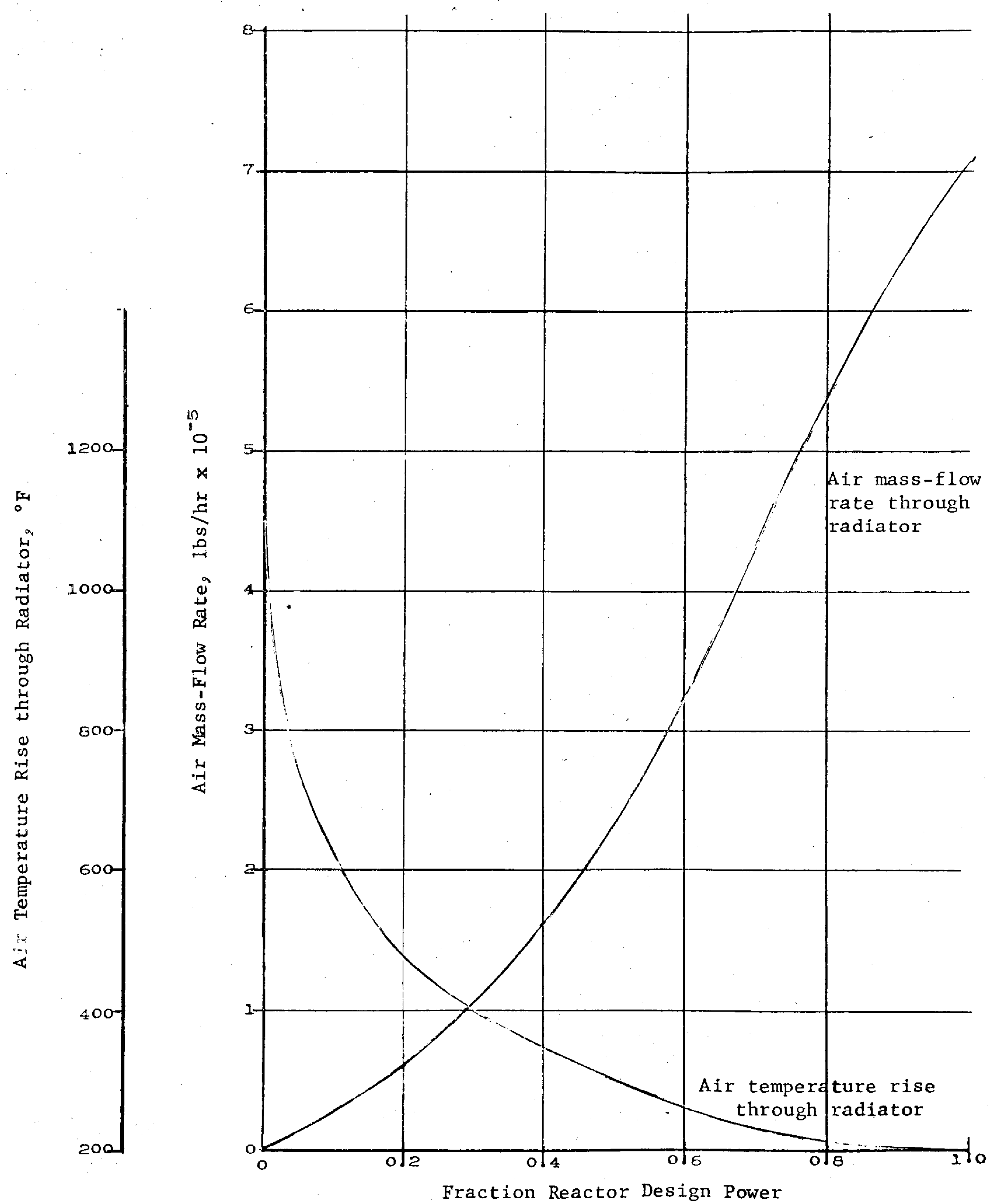

Figure 3. Air Mass-Flow Rate and Air Temperature Rise for MSRE Radiator WCU 11/17/60

Calculations

1. Secondary salt flow required for 10 Mw heat removal:

   a. Secondary salt, 66 mol % LiF, 34 mol % BeF_2

   b. Specific heat, c_p = 0.51 Btu/lb-°F

   c. Density, = 120 lb/ft^3

   d. Salt inlet temperature = 1100°F

   e. Salt outlet temperature = 1025°F

   $q = Wc_p\Delta_t$ Btu/hr ,

   where

   q = rate of heat transfer, Btu/hr

   W = mass flow rate, lb/hr

   c_p = specific heat, Btu/lb-°F, at constant pressure

   Δ_t = temperature difference, °F

   (10,000 Kw)(3415 Btu/Kw-hr) = (W lb/hr)(0.57 Btu/lb°F)(75°F)

   W = 8000,000 lb/hr.

   $$\frac{(800{,}000\ lb/hr)(7.48\ gal/ft^3)}{(60\ min/hr)(120\ lb/ft^3)} = \underline{830\ gpm}$$

2. Amount of air required for 10 Mw heat removal:

   a. Air inlet temperature = 100°F d.b., 76°F w.b.

   b. Air outlet temperature = 300°F

   c. Specific heat of air, $S + 0.24 + 0.45H = 0.24 + 0.45 \times 0.014$

      $S = 0.24 + 0.0063 = 0.2463$ Btu/lb-°F

   d. Humidity of air, H = 0.014 lb water/lb dry air

   e. Volume of air, V_a = 14.45 ft^3/lb dry air

f. Density of dry air, $\frac{1}{V_a}$ = 0.0692 lb dry air/ft^3 dry air

g. Amount of water in air = density of air x humidity

= 0.0692 lb dry air/ft^3 x 0.014 lb water/lb dry air

= 0.001 lb water/ft^3 dry air

h. Density of air = 0.0692 lb dry air/ft^3 dry air + 0.0010 lb water/ft^3 dry air

= 0.0702 lb/ft^3

$$q = WS\Delta_t \text{ Btu/hr,}$$

where

q = rate of heat transfer, Btu/hr

W = mass flow rate, lb/hr

S = humid heat, Btu/lb-°F

Δ_t = temperature difference, °F

$$(10{,}000 \text{ Kw})(3415 \text{ Btu/Kw-hr}) = (W \text{ lb/hr})(0.2463 \text{ Btu/lb-°F})(200°\text{F})$$

$$W = 692{,}000 \text{ lb air/hr}$$

$$\frac{692{,}000 \text{ lb air/hr}}{(60 \text{ min/hr})(0.0702 \text{ lb air/ft}^3)} = \underline{\underline{164{,}000}} \text{ cfm}$$

List of Drawings as of 11-15-60

Drawing Number	Title
E-DD-A40430	General Arrangement of Radiator
E-DD-A40431	Radiator Coil Assembly
D-DD-A40432	Radiator Coil Details, Sheet 1
D-DD-A40433	Radiator Coil Details, Sheet 2
D-DD-A40434	Radiator Coil Details, Sheet 3
D-DD-A40435	Radiator Coil Details, Sheet 4
D-DD-A40436	Radiator Coil Details, Sheet 5
D-DD-A40437	Radiator Coil Supports, Sheet 1
D-DD-A40438	Radiator Coil Supports, Sheet 2
D-DD-A40439	Radiator Coil Supports, Sheet 3
D-DD-B40440	Radiator Door Assembly
D-DD-B40441	Radiator Door Frame Assembly
D-DD-B40442	Radiator Door Frame Details
D-DD-B40443	Radiator Door Frame Details
D-DD-B40444	Radiator Door Reflective Plate
D-DD-B40445	Reflective Plate Hold Down and Gasket Retainer Ring
D-DD-B40446	
D-DD-B40447	
D-DD-B40448	Radiator Door Roller Guide
D-DD-B40449	Radiator Door Roller Guide
D-DD-C40450	Radiator Head Arrangement
D-DD-C40451	Radiator Head Assembly
D-DD-C40452	Radiator Head Sections
D-DD-C40453	Sprocket Shaft Details
D-DD-C40454	Counterweight Details
D-DD-C40467	Magnet and Spring Shock Absorber Details
D-DD-C40468	Drive Motor, Clutch, Brakes and Gear Reducer Assembly
D-DD-C40469	Drive Motor, Clutch, Brake and Gear Reducer Details
E-DD-D40470	Radiator Enclosure Assembly
E-DD-D40471	Radiator Enclosure Elevations
E-DD-D40472	Radiator Enclosure Frame Assembly
D-DD-D40473	Radiator Enclosure Sections and Details
D-DD-D40474	Radiator Enclosure Frame
D-DD-D40475	Radiator Enclosure Sections and Details
D-DD-D40476	Radiator Enclosure Framing Details
D-DD-D40477	Radiator Enclosure Baffle Frame
D-DD-D40478	Radiator Enclosure Baffle Frame
D-DD-D40479	Radiator Enclosure Framing Details
D-DD-D40480	Radiator Enclosure Framing Details
D-DD-D40481	Radiator Enclosure Plating Details
D-DD-D40482	Radiator Enclosure Plating Details
D-DD-D40483	Radiator Enclosure Reflector Plating
D-DD-D40484	Radiator Enclosure Reflector Plating
D-DD-A40485	Tube Support Details
D-DD-A40486	
D-DD-A40487	
D-DD-A40488	
D-DD-A40489	

Distribution

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74. R. W. Swindeman
75. A. Taboada
76. J. R. Tallackson
77. D. B. Trauger
78. W. C. Ulrich
79. D. C. Watkin
80. A. M. Weinberg
81. J. H. Westsik
82. L. V. Wilson
83. C. E. Winters
84. C. H. Wodtke

85-86. RD Library
87-88. Central Research Library
89-90. Document Reference Library
91-93. Laboratory Records
94. ORNL-RC