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J.A. Brown OS-6 TSM 12/1/93
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Metallurgical Laboratory

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FINAL DETERMINATION
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L. M. Redman
JAN 14, 1987

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C. M. Cooper by Leverett

Heavy Water Piles

[redacted] This [redacted] consists of [redacted] pages and [redacted] figures. table
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In accordance with your request a quick survey of the possibilities of heavy water plants has been made by Mr. M. D. Abbott, who reports as follows:

A brief survey has been made of several possible designs for heavy water piles. Two piles were considered in which water would be recirculated over metal. In the first, ordinary water was considered as coolant, in the second, heavy water was the coolant. The third pile considered utilized liquid UF_6 as the reacting form of the metal and was cooled by recirculating through an external cooling system.

Water Cooled Piles

The general features of these piles were considered to be similar to a shell and tube heat exchanger with aluminum tubes. The heavy water moderator would then surround the tubes and the metal consisting of bundles of rods would be inside the tubes. The coolant would flow inside the tubes.

In the pile cooled with ordinary water, the external system could be similar to any of the modifications now contemplated for the water cooled metal-graphite pile. In the pile cooled with heavy water, a recirculating system is essential and it is desirable to keep the volume of heavy water in this external system at a minimum. One possible solution to this problem would be to take the hot heavy water as it emerges from the pile and flash-cool it in a vacuum, the vacuum being maintained by a surface condenser which would condense the heavy water vapor. The combined liquid stream cooled in this manner could then be recirculated to the pile. It is believed that the quantity of water in such a system would be considerably less than in a conventional liquid to liquid exchanger system. A small amount of heat would be generated in the moderator so it too would be cooled in an external exchanger system.

The basic nuclear data used in the calculations for these piles are included in the attached table. The item labeled "base k" was taken as the limiting value of k with no aluminum in the system. Corrections to this value were made in the following manner.

Loss for the aluminum tubes was based on a danger coefficient of 0.5 and a thickness of the aluminum tube equal to 7.5% of the inside tube diameter. This is in agreement with usual minimum standards of the Tubular Exchanger Manufacturers for tubes up to 1 1/4" O. D. Sizes greater than this are outside the range of ordinary exchanger design. Using this approximation for tube thickness it is not necessary to know the optimum size of the unit cell nor the lattice spacing in order to calculate the k loss due to the aluminum tube. The loss in k due to metal coatings was obtained by comparison with current plans for the water cooled graphite pile, in which the coating on a rod

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3.5 cm. diameter would result in a k loss of 0.004. For other size rods, the surface to volume ratio was used as a criterion for making extrapolations.

The attached table gives our best guess, at the present time, of probable limits of practical operation. These limits are not firmly established but are the following.

Maximum Allowable Water Velocity = 20 ft./sec.

Maximum Heat Density = 250,000 - 300,000 Btu/Hr. - Sq. ft.

This table also presents very rough estimates of the quantities of heavy water in the external system as well as in the pile itself. The accuracy of these estimates is considered bery low and may be wrong by a factor of two or more. A firm value for these quantities could only be made from detailed design of the unit which would involve settling the questions mentioned in the next paragraph.

A partial list of the unsolved problems follows:

1. Physics: Dr. Wigner, who supplied the physical constants used in evaluating the water cooled piles has pointed out that their accuracy is quite uncertain.

2. Loading and Unloading: Sufficient time and thought has not been given to this problem; however, it is believed that all the problems encountered in the water cooled met-graphite pile will also exist in this pile, as now contemplated.

3. Leakage: Leakage in the external system involving heavy water would be quite serious and pump gland trouble may be anticipated.

4. Impact Corrosion: This problem is similar to that encountered in the water cooled metal-graphite pile, and the limits it imposes on operations is not now known.

5. Tube Thickness: The minimum thickness for safe operation is not definitely established since it will involve questions as to the necessity for internal supports and vibrational stresses at the tube sheets.

Hex Piles

The hex piles were also visualized as being similar to shell and tube heat exchangers with the hex flowing through the inside of aluminum tubes and the heavy water outside. The hot liquid emerging from the [redacted] would be cooled in ordinary shell and tube exchangers.

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The basic nuclear data as well as a result of the calculations is shown in the last two columns of the attached table. The two columns differ only in the assumed thickness of tube used to retain the hex. Column three assumes a 2 mm wall thickness for an 8 cm diameter tube which for a 250 Psi operating pressure results in a working stress of 5000 Psi. This would not exceed the allowable stress of certain of the aluminum alloys but with such thin walls it is believed that difficulty would be experienced in obtaining durable connections to a tube sheet. Consequently, the data of column four was calculated assuming the tube wall thickness would be 7.5% of the tube inside diameter (the same assumption as was made above for the water cooled piles.)

As in the water cooled piles, a limiting velocity of 20 ft./sec. was assumed and a temperature rise from 194°F (90°C) to 302°F (150°C) taken. It is felt that this represents close to the maximum for operations since if the inlet temperature was reduced appreciably, possibilities of hex freezing in the external system would be encountered. Also at 150°C, the vapor pressure of hex is about 180 Psi and rises rapidly at higher temperatures. Thus a further increase in outlet temperature would result in very high operating pressures. The choosing of 20 ft./sec. as the velocity is purely arbitrary.

The estimate of hex (expressed in terms of tons of U) in the external system is very approximate and could easily be in error by two fold. This uncertainty is due, as in the case of the water cooled piles, to unsolved problems such as physics, leakage, impact corrosion, tube thickness, shielding and the process for extraction of the product from the recirculating hex. Dr. Anderson supplied approximate values of k and the critical size of a pile not containing any aluminum. These values were used in extrapolating to the piles considered here.

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By

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HEAVY WATER PILES
ESTIMATED PRACTICAL LIMITS OF OPERATION

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Metal Form	Bundle of Rods		UF_6 Liquid	
Metal Density	9.45	9.45	2.50	2.50
Coolant	H_2O*	D_2O	UF_6	UF_6
Aluminum Tube Thickness, % of tube I.D.	0.075	0.075	0.025	0.075
Metal Rod Diam. Ins.	0.20	0.15	-	-
Tube Wall Thickness, Ins.	see above		0.0787 (2mm)	0.236 (6mm)
Tube I.D. Ins.	(as req'd by	)	3.15	3.15
Lattice Spacing, Ins.	(Physics	)	8.37	8.37
Volume Ratio of D_2O to U or UF_6	18	41	8	8
Base k	1.100	1.210	1.140	1.140
k loss for Al Tube	.026	.026	.033	.099
k loss for Coatings	.028	.037	-	-
k loss for Heating	.004	.004	-	-
Net k	1.042	1.143	1.107	1.041
Diffusion Area, cm^2	145	194	410	410
Pile Size, Ins. (Height = Diam.)	133	83	140	226
Wt. D_2O in Pile, Tons	29.5	7.9	55	145
Wt. U in Pile, Tons	29.5	5.5	10.8	45
Estm. Wt. D_2O outside Pile, Tons	5	12	10	25
Estm. Wt. U outside Pile, Tons	-	-	175	500
Velocity of Fluid Flow, Ft/sec.	20	20	20	20
Temp. Fluid into Pile, °F	80	80	194 (90°C)	194 (90°C)
Temp. Rise Fluid in Center Tube, °F	100	100	108 (60°C)	108 (60°C)
Temp. Fluid out of Center Tube, °F	180	180	302	302
Approx. Pres. Drop through Pile, PSI	55	50	25	29
Upper Pres. Fluid at Temp. out of Center Tube, PSIA	7.5	7.5	180	180
Pile Power kw	250,000	45,000	490,000	1,270,000
Pumping Power Req'd, % of Power out	0.51	0.47	0.52	0.57
Max. Heat Density in Center of Pile, Btu/hr-sq.ft-°F	250,000	280,000	-	-
Temp. Drop through Metal, °F	210	180	-	-
Temp. Drop through Film, °F	45	49	-	-
kw per Total Tons Metal	8,500	15,000	2,600	2,500
kw per Total Tons D_2O	7,200	2,500	11,000	7,500

* 5% H_2O in pile, based on D_2O

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