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NUS CORPORATION
ENGINEERING DIVISION

RECORD OF SYSTEM/COMPONENT ANALYSES

(1) FILE NUMBER	(2) NUMBER OF PAGES	(3) NUMBER OF VOLUMES OF COMPUTER OUTPUT
5148-PE-A7	18	—

(4) CLIENT	(5) ACCOUNT NUMBER
Consumers Power Co. - Big Rock Point	5148-HC

(6) ANALYSIS TITLE Spent Fuel Pool Thermal Analysis

(7) AUTHOR
J.W. Phillips

(8) PURPOSE OF ANALYSIS Determine max pool water temperatures, time to boiling, and required makeup under conditions of continued refueling through 1995 and refueling through 1991 followed by a full core offload.

(9) SUMMARY OF ANALYSIS PROCEDURE AND RESULTS For continued refuelings through 1995 the max pool temp. with one heat ex. will be 93°F, with two heat ex's. will be 82°F. Loss of cooling capability will result in boiling in 70. hours and require a makeup rate of 2.8 gpm.
For continued refuelings through 1991 followed by a full core offload will result in max. pool water temp of 101.4°F with two heat ex's running and 131.6°F with only one heat ex. Loss of cooling will result in boiling in the pool in 19.6 hours and require a makeup of 7.8 gpm.

QUALITY ASSURANCE RECORD

(10) DATE COMPLETED
June 14, 1979

(11) VERIFICATION REQUIRED ☒ YES ☐ NO

(12) ANALYSIS REVIEWED AND ACCEPTED B. [signature] 6/25/79
DISCIPLINE MANAGER DATE

(13) ANALYSIS ☐ SUPERSEDED ☐ SUPPLEMENTED BY ______ FILE NUMBER ______ DISCIPLINE MANAGER ______ DATE ______

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APPROVED DATE

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DATE 6-12-79

CLIENT Consumers Power Co FILE NO. 5148-PLF-A7 BY J W Phillips

SUBJECT Spent Fuel Pool Thermal Analysis Checked By [illegible]

1. Client Identification : Consumers Power Co, Big Rock Point
2. Analysis File Number : 5148-PLF-A2
3. Analysis Title : Spent Fuel Pool Thermal Analysis
4. Author Identification : J. W. Phillips

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5. Purpose of Analysis: To determine the maximum pool water temperature, and the time it will take for the pool to reach boiling when there is a loss of offsite power or the loss of one pump or heat exchanger under the following conditions:

a. Continued refuelings through 1995

b. refuelings through 1991 followed by a full core off load 6 month later.

6. General Method of Analysis: Decay heat input as per Technical Position APCSB 9.2

7. Input Information

a. Decay heat generation rates for both cases as per analysis 5148-PE-A6; Big Rock Point Fuel Pool Cooling Analysis

b. Spent fuel pool cooling pumps are not on the emergency buss.

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c. The heat rejection capabilities of the spent fuel pool heat exchangers are:

(1) 1.5×10^6 BTU/hr each at 95°F inlet and 85°F outlet

(2) 3.0×10^6 BTU/hr each at 119°F inlet and 95° outlet

(3) poolwater flow = 1.25×10^5 lb/hr ; service water = 1.25×10^5 lb/hr

8. Major Assumptions

a. The pool temperature is measured at the pool surface and is equal to the heat exchanger inlet temperature

b. There are no heat losses from the pool other through the heat exchanger. (Heat losses due to evaporation and conduction through the walls are ignored)

9. References

Ref 1. Specification for Furnishing and Delivering of Fuel Pit Cooling Heat Exchangers for the Big Rock Point

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Plant of the Consumers Power Company Spec No. 3159 H-10 July 13, 1960.

Ref 2 NUS Drawing 5148 H 2000 Rev E, Pool Arrangement, April 5, 1979.

Ref 3 Bechtel Drawing C-2 Rev 4.

10. Identification of Computer Codes

none.

11 Detailed Calculations

A - Maximum Pool Temperatures

Based on Analysis 5148-PE-A6 the maximum heat load on the cooling system from continued refuelings through 1995 will be 1.37×10^6 BTU/hr. Refuelings through 1991 with a subsequent full core offload will result in a heat load of 3.79×10^6 BTU/hr.

The basic equation used to describe a heat exchanger is $Q = UA\Delta T$ or $Q = \dot{m} C_p \Delta T'$

where

Q = heat transfer rate, BTU/hr

U = heat transfer coefficient, $\frac{BTU}{hr\,°F\,ft^2}$
$\dot{m}$ = mass flow rate for one fluid, lb/hr
A = heat transfer area, ft^2
C_p = specific heat of water, 1 BTU/lb°F
ΔT = log mean temperature difference, °F
$\Delta T'$ = temp. rise or drop of one fluid, °F

The operating parameters for the Big Rock Point fuel pool heat exchanger under the conditions outlined in Section 7c of this calculation are: (Ref 1)

$Q = 1.5 \times 10^6 \frac{BTU}{hr}$

$U = 343 \frac{BTU}{hr\,°F\,ft^2}$

$A = 402\ ft^2$

$\Delta T = LMTD = 13°$
corrected LMTD = 10.9°F

Fluid Temperatures

Pool Water	Inlet	95°
	Outlet	83°
Service Water	Inlet	70°
	Outlet	82°

$Q = 3 \times 10^6 \frac{BTU}{hr}$

$U = 362 \frac{BTU}{hr\,°F\,ft^2}$

$A = 402\ ft^2$

$\Delta T = LMTD = 25°$
corrected LMTD = 20.6°F

Fluid Temperature

Pool Water	Inlet	119°
	Outlet	95°
Service Water	Inlet	70°
	Outlet	94°

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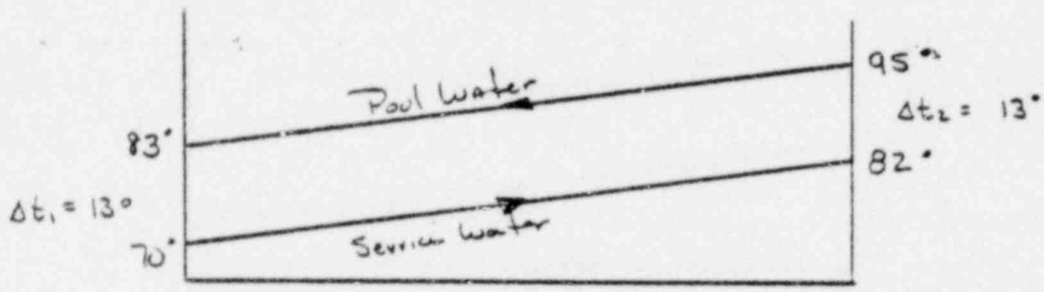
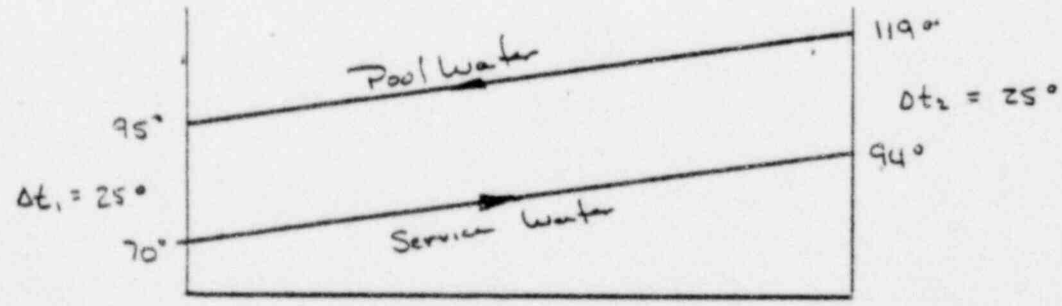
The temperature profiles for these two conditions are shown below:



$$Q = 1.5 \times 10^6 \ \frac{BTU}{hr}$$

$$LMTD = 13°$$

correction factor = .838; $LMTD_c$ = 10.9°



$$Q = 3 \times 10^6 \ \frac{BTU}{hr}$$

$$LMTD = 25°$$

correction factor = .824; $LMTD_c$ = 20.6

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SUBJECT Spent Fuel Pool Thermal Analysis Checked By

These two figures illistrate that an increase in the pool water inlet of Y degrees results in an increase in the service water outlet temp., the pool water outlet temp, and the LMTD (uncorrected) of Y/2 degrees.

Assuming tha the LMTD correction factor is relatively constant over the operating range of the two heat exchangers and that the change in U from 343 to 362 is linear with the change in the total heat transfer rate allows for a straight forward calculation of pool temperatures for a given heat transfer rate.

1. Continued Refuelings through 1995

a Two heat exchanger operation

$Q = 1.37 \times 10^6$ BTU/hr

$Q' = 6.85 \times 10^5$ BTU/hr per heat exchanger

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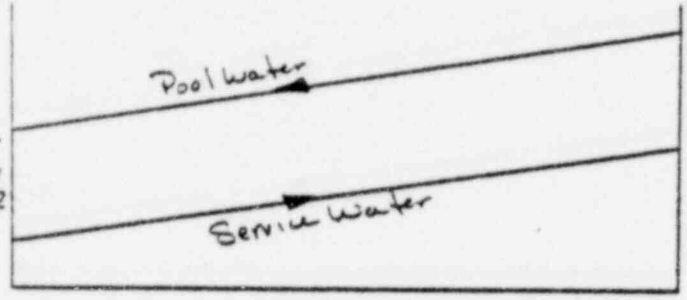

$76.5° = 83 + y/2$

$6.5° = \Delta t_1 = 13 + y/2$

$70° \cdot 70$

$95 + y = 82°$

$\Delta t_2 = 13 + y/2 = 6.5°$

$82 + y/2 = 75.5°$

$U = 343$ BTU/hr °F ft² at 1.5×10^6 BTU/hr

$U = \underline{362}$ BTU/hr °F ft² at $\underline{3.0 \times 10^6}$ BTU/hr

$\Delta U = 19$ BTU/hr °F ft² $\quad \Delta Q = 1.5 \times 10^6$ BTU/hr

$\Rightarrow 12.67 \dfrac{\frac{BTU}{°F\,hr\,ft^2}}{10^6\ BTU/hr}$

Therefore:

$Q = 6.85 \times 10^5 \ \frac{BTU}{hr}$ per h.ex.

$\dot{m} = 1.25 \times 10^5$ lb/hr

$C_p = 1$

$\Delta T' = \dfrac{6.85 \times 10^5}{1 \cdot 1.25 \times 10^5} = 5.5°$

$\therefore$ Service Water Outlet = 75.5°

$75.5 = 82 + y/2 \quad \therefore y = -13$

$\boxed{\text{Pool Water inlet} = 95 - 13° = 82°F}$

Pool Water Outlet = $83 - 6.5 = 76.5°F$

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Check with $Q = U\,A\,LMTD_c$

$$6.85\times10^5 = \left\{343-\left[(6.85\times10^5-1.5\times10^6)\left(\frac{12.67}{10^6}\right)\right]\right\}(402)(6.5)(.83)$$

$$= (343-10.3)(402)(6.5\times.83)$$

$$= 332.7\cdot402\cdot5.4$$

$$= 7.22\times10^5$$

o/c since actual LMTD correction factor will be less than .83 due to low temperatures.

b. One heat exchanger operation

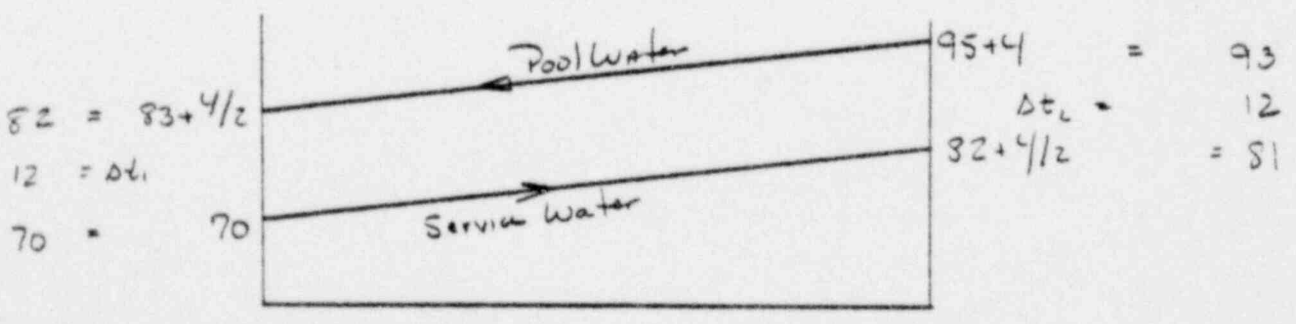
$$Q = 1.37\times10^6 \text{ BTU/hr}$$

$$\dot{m} = 1.25\times10^5 \text{ lb/hr}$$

$$C_p = 1$$

$$\Delta T' = \frac{1.37\times10^6}{1.25\times10^5} = 11^\circ$$

∴ Service Water Outlet = 81°



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DATE 6-12-79

CLIENT Consumers Power Co FILE NO. SWS-PE-A7 BY J.W. Phillips

SUBJECT Spent Fuel Pool Thermal Analysis Checked By [illegible]

$81 = 82 + y/2 \qquad y = -2°$

$\boxed{\text{Pool Water Inlet} = 95 + y = 93°}$

Pool Water Outlet $= 83 + y/2 = 82°$

Check with $q = UA\,LMTDc$

$$1.37\times10^6 = \left\{343 - (1.37\times10^6 - 1.5\times10^6)\left(\frac{12.67}{10^6}\right)\right\} 402 \cdot 12 \cdot .83$$

$$= (343 - 1.6)(402)(9.96)$$

$$= 1.366\times10^6 \ \underline{\text{check}}$$

2. Refuelings through 1991 followed by a full core offload

a Two heat exchanges operating.

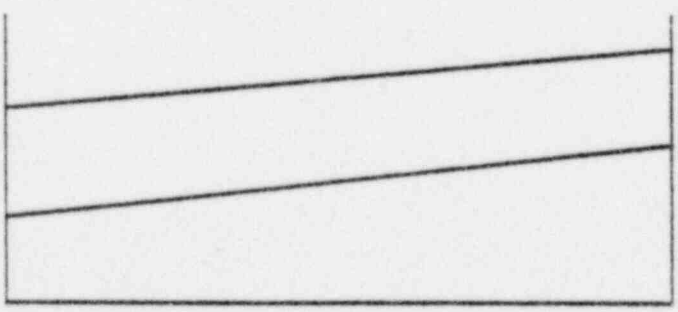
$q = 3.79\times10^6$ BTU/hr

$q' = 1.895\times10^6$ BTU/hr per heat ex.

$86.2 = 83 + y/2$

$16.2 \ \Delta t_1 = 13 + y/2$

$70° = 70$



$95 + y = 101.4$

$\Delta t_2 = 13 + y/2 = 16.2$

$82 + y/2 = 85.2$

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Calc the temp rise of the service water

$Q' = \dot{m} C_p \Delta T'$

$1.895 \times 10^6 = 1.25 \times 10^5 (1)(\Delta T')$

$\Delta T' = 15.2$

∴ The service water outlet = 70 + 15.2 = 85.2°

And $82 + y/2 = 85.2$

so. $y = 6.4°$

$\boxed{\text{The pool water inlet temp is } 95 + 6.4 = 101.4°F}$

The pool water outlet temp is $83 + 6.4/2 = 86.2°F$

Check with $Q = UA \, LMTD_c$

$1.895 \times 10^6 = \{343 + (1.895 \times 10^6 - 1.5 \times 10^6)(\frac{12.67}{10^6})(402)(15.2 \times .83)$

$= (343 + 5.0)(402)(12.6)$

$= 1.76 \times 10^6$ check <10% diff.

b. One heat exchanger operating

$Q = 3.79 \times 10^6$ BTU/hr

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CLIENT Consumers Power Co FILE NO. 5148-DE-A7 BY J.W. Phillips

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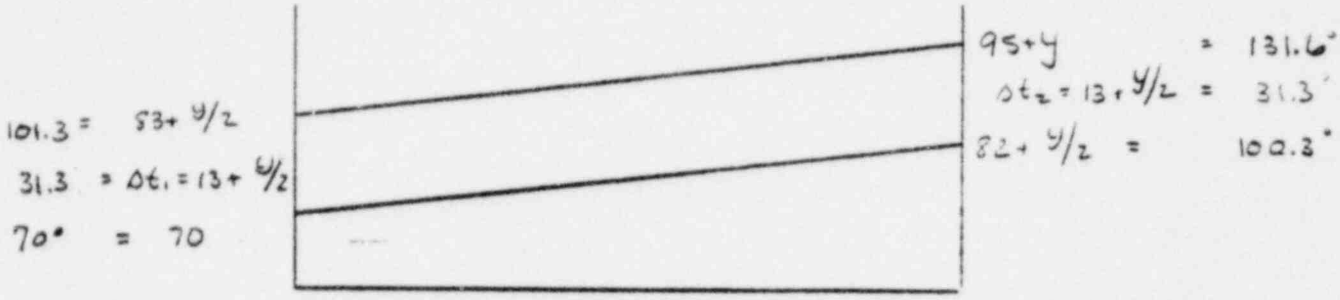

Calc temp rise on service water side

$Q = \dot{m} C_p \Delta T'$

$3.79 \times 10^6 = 1.25 \times 10^5 \cdot \Delta T'$

$\Delta T' = 30.3$

Service water out let $= 70 + 30.3 = 100.3$

And $82 + y/2 = 100.3$

so $y = 36.6$

$\boxed{\text{Pool water inlet temp is } 95 + y = 131.6\ F}$

Pool water outlet temp is $83 + y/2 = 101.3$ F

Check with $Q = U A\ LMTDc$

$3.79 \times 10^6 = \{362 + (3.79 \times 10^6 - 3.0 \times 10^6)(\frac{12.67}{10^6})(402)(30.3 \times .83)$

$= (362 + 10)(402)(25.1)$

$= 3.75 \times 10^6$ check $<1\%$ diff

B. Time to Boiling - Loss of Off Site Power

Since the fuel pool cooling system pumps are not on the emergency buss a loss of offsite power will result in a loss of cooling and subsequent boiling (during a shutdown). The problem then becomes one of determining how long it takes for the pool to boil.

Assumptions used: (1) 15% of the pool volume is taken up with the fuel and the spent fuel racks

(2) The heat input to the pool ($1.37 \times 10^6 \frac{BTU}{hr}$ or $3.79 \cdot 10^6$ BTU/hr) does not decrease appreciably during the time it takes for the average pool temp. to reach 212°F.

(3) The average temperature of the pool water prior to the loss of offsite power is the average between the pool water heat ex. inlet and outlet temps as calculated above with one heat ex. operable.

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CLIENT Consumers Power Co FILE NO. 5148-DIE-A7 BY J.W. Phillips

SUBJECT Spent Fuel Pool Thermal Analysis Checked By [illegible]

Pool Volume :

$V = 25.9' \times 19.9' \times 28'\,4\tfrac{13}{16}"$ (Ref 2 & 3)

(28.4') → top of weir 630'-6"
bottom of pool 602'-1 3/16"

$= 1.46 \times 10^4\ ft^3$

Mass of Water $= 1.46 \times 10^4 \times 62.4 \times .85$

$= 7.76 \times 10^5$ lbm.

1. Continued refuelings through 1995.

Average Pool temp $= \frac{93+82}{2}$ page 9

$= 87.5°$

Heat input to reach 212°

$Q = 7.76 \times 10^5 lb (212 - 87.5)\ °F \times 1 \frac{BTU}{lbm\,°F}$

$= 9.66 \times 10^7$ BTU

Heat Input $= 1.37 \times 10^5$ BTU/hr

Time $= \dfrac{9.66 \times 10^7\ BTU}{1.37 \times 10^5\ \frac{BTU}{hr}} =$ 70. hours

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2. Refuelings through 1991 followed by F.C.O.

Average Pool Temp = $\frac{131.6+101.3}{2}$ = 116.5 °F (Pg 12)

Heat Input to reach 212°

$$Q = 7.76 \times 10^5 \, lb (212-116.5)°F \cdot 1 \frac{BTU}{lb \, °F}$$

$$= 7.41 \times 10^7 \, BTU$$

Heat Input = 3.79×10^6 BTU/hr

$$time = \frac{7.41 \times 10^7 \, BTU}{3.79 \times 10^6 \, BTU/hr} = \underline{19.6 \text{ hours}}.$$

C. Make up requirements to prevent pool level drop from boiling.

1. Continued refuelings through 1995.

Once boiling occurs, water will evaporate at a rate defined by.

$$F = \frac{Q}{h_v}$$ h_v = heat of vaporization of water @ 1 atm and 212°F.
= 970 BTU/lb.

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$$F = \frac{1.37 \times 10^6 \text{ BTU/hr}}{970 \text{ BTU/lb}} = 1412 \text{ lbm/hr}$$

$$= \underline{2.8 \text{ gpm}}$$

2. Refueling through 1991 followed by a F.C.O.

$$F = \frac{Q}{h_v} \qquad Q = 3.79 \times 10^6 \text{ BTU/hr}$$

$$F = \frac{3.79 \times 10^6 \text{ BTU/hr}}{970 \text{ BTU/lb}} \qquad 3907 \text{ lbm/hr}$$

$$= \underline{7.8 \text{ gpm}}.$$

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DATE 6-12-79

CLIENT Consumers Power Co FILE NO. 5148-PIE-A7 BY J.W. Phillips

SUBJECT Spent Fuel Pool Thermal Analysis Checked By [illegible]

12. Summary of Results.

A. Maximum Pool temperatures are calculated to be:

1. For continued refueling through 1995:

a Two heat ex. op. 82°F ✓

b. One heat ex op. 93°F.

2. For refuelings through 1991 followed by a F.C.O.

a. two heat ex. op. 101.4 F ✓

b. one heat ex op. 131.6°F ✓

B. Following a loss of offsite power during a refueling the time it will take for the average pool temp. to reach 212° is:

1. For continued refuelings through 1995

a One heat ex. op. - 70 hours

2. Refuelings through 1991 followed by a F.C.O.

a One heat ex op. - 19.6 hours.

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DATE 6-12-79

CLIENT Consumers Power Co FILE NO. 5115-PE-A7 BY J.W. Phillips
SUBJECT Spent Fuel Pool Thermal Analysis Checked By [illegible]

C. Pool makeup requirements to prevent water level in pool from dropping following a loss of offsite power during a refueling is:

1. For continued refueling, through 1995 - 28 gpm
2. Refuelings through 1991 followed by a F.C.O. - 75 gpm.