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WATER REQUIREMENTS AT 105-K IMMEDIATELY FOLLOWING AN ELECTRICAL OUTAGE

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BY

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PROCESS ENGINEERING UNIT
ENGINEERING DEPARTMENT

JUNE 6, 1952

[REDACTED]

NUCLEONICS DIVISION
RICHLAND, WASHINGTON

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This document consists
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WATER REQUIREMENTS AT 105-K IMMEDIATELY
FOLLOWING AN ELECTRICAL OUTAGE

DESIGN SECTION
PROCESS ENGINEERING UNIT

Prepared by: C. Sege
G.L. Locke

June 6, 1952

This document has been reviewed and
approved by the appropriate members
of Process Engineering and is satis-
factory for use as a design basis for
the 100-K Waterworks

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WATER REQUIREMENTS AT 105-K IMMEDIATELY
FOLLOWING AN ELECTRICAL OUTAGE

PURPOSE

The purpose of this report is to specify the water flow rates and pressures which must be maintained at the process unit immediately following a Bonneville electrical power failure.

RESULTS

The results of this study are shown in Figures 1-a, 1-b, 1-c, and 1-d, in which the required top of riser pressure is shown as a function of time after the power failure. The characteristic of the flywheel which has been designed to follow the shutdown curve of Figure 1-a is shown on Figure 1-a.^{1*} The energy decay curve of this flywheel, with the pumping system operating at lower pressures and flows at the time of the power failure, has been calculated and is shown in Figures 1-b, 1-c, and 1-d. In all cases, the flywheel satisfies the shutdown requirements.

The steady state operating conditions selected for Figures 1-a, 1-b, 1-c, and 1-d at the time the outage occurs are shown as points a, b, c, and d on Figure VI, where the pressure flow characteristics of the system are shown.

BASIS

A. Pile Operation

In order to design a flywheel large enough for realistic, foreseeable increases in power, it has been assumed that power level at each of the operating points on Figure VI is limited only by a 95°C water temperature rise. Adherence to the present boiling disease limitations or a lower corrosion limitation would permit a smaller flywheel.

It has been specified that the maximum outlet water temperature during shutdown shall never exceed the maximum outlet water temperature during operation by more than 5°C. Reference to Figures 1-a - 1-d shows that this condition prevails for less than one second after the power outage.

So that the flywheels store the lowest possible amount of energy, it has been presumed that the minimum number of 190 pumps would be in operation to provide a given pressure and flow.

B. Control System Characteristics

The analysis has been based on the assumption that at least sufficient vertical rods drop to provide a negative reactivity of 485 inhours. The total control value of the 37 vertical rods is 1355 inhours.

The following delays in the start of the rod fall have been taken into account:

1. 0.33 second (20 cycle) delay between time of outage and the actuation of the trip mechanism to permit recovery from voltage fluctuations of the Bonneville system. In the present piles a 60-cycle delay is required to attempt a transfer of load from a dead bus to another bus

* For References, see Page 4.

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which might still be energized. For increased safety at K, the vertical rods will be tripped after the 20 cycle delay - no attempt to transfer load will be made.

2. 0.3 second delay in the start of the rod fall due to an initial sticking of the rubber boot gas seal.²

For conservatism, the drop time for the C type rod has been used. However the free-fall, air-cushioned rod will probably be installed on K-pile. The drop time of this rod is approximately 0.7 seconds less than the 2.7 second value measured for a C rod.^{2,1}

METHODS OF CALCULATION

Rod position as a function of time after start of fall is shown in Figure II.⁶

The inhours of control as a function of rod position are shown in Figure III.³

The ih of control versus time after start of drop, shown in Figure IV were obtained from a cross-plot of Figure II and Figure III.

Relative heating due to delayed fission as a function of inhours of control for a control interval of 0.3 second is shown in Figure V.⁴

Conservative values of relative heating due to delayed fission as a function of time after start of fall were obtained in the following manner:

Figure IV was divided into time increments of 0.3 seconds shown by the dotted lines. The control during the entire 0.3 seconds interval was assumed constant at the initial value. Corresponding values of relative fission heating were obtained from Figure V.

Total power, relative to power during operation, as a function of time after start of fall is shown in Table I. At any time, the total heating is due to delayed fission heat, heat from decay of fission products, and heat from graphite, all of which are shown in Table I.

The required flow rate per maximum performance tube during shutdown for a constant outlet water temperature is obtained from the following relations:

For water temperature rise of 95°C and W $\frac{\text{gpm}}{\text{maximum performance tube}}$ during operation:

Flow rate = Total relative heat x W

For water temperature rise of t °C:

Flow rate = Total relative heat x W x 95/t

Top of riser pressure is shown as a function of flow rate in Figure VI for the two operating phases planned for 105-K. The following data were the basis of calculations for Figure VI:

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No. of tubes: 3220
 No. of effective power tubes: 2330
 No. of effective flow tubes: 2790
 Annulus area: 0.439 in.²
 Active zone length: 28.34 ft.
 Tube length: 47.8"
 Fouling: 40 psi at operating conditions tabulated for Phase I and Phase II on Figure VI.
 Front and rear pigtails and nozzles: Similar to those used on the rear face of 105-C
 One 4" i.d. crossheader per tube row: Arrangement shown on H-1-22323
 Pressure drop across orifice: 67 psi at 35.8 gpm (Phase I)
 34 psi at 50 gpm (Phase II)

The equations used for the extrapolation of the flywheel decay curves from the conditions of Figure 1-a to the conditions of Figures 1-b, 1-c and 1-d are derived in the Appendix.

REFERENCES

(1)	HDC-2118	page 2.310
(2)	HW-21635	page 20 - 27
(3)	duH 7-697	page 26, lower curve
(4)	HW-17718	page 17
(5)	HDC-2118	page 2.311
(6)	HDC-2043	Figure 1 (a), Curve 2
(7)	Test Project 41	Final Report, Run 5

APPENDIX

Derivation of the Flywheel Decay Equations

For Nomenclature, see page 5.

At a given angular velocity the kinetic energy of a flywheel (including all rotational parts of the pump) is given by:

$$E_f = \frac{I \omega^2}{2g}$$

During an incremental time interval, dt, the power given up by a flywheel is:

$$\text{power} = \frac{dE_f}{dt} = \frac{I \omega}{g} \frac{d\omega}{dt} \text{ ---- 1}$$

The power imparted to the water can be estimated by the following relationship:

$$\frac{dE_f}{dt} = \Delta P Q \approx C_2 Q^3 \text{ ---- 1a}$$

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And using the approximation

$$Q \approx C_3 \omega$$

it follows that

$$\frac{dE}{dt} = K\omega^3 - - - - 2$$

With the further idealization that the energy increase of the water equals the energy decrease of the flywheel, 1 and 2 combine to give

$$K\omega^3 = -\frac{I_0 \omega N}{g} \frac{d\omega}{dt}$$

or

$$\frac{d\omega}{\omega^2} = -K \frac{g}{I_0 N} dt$$

which becomes upon integration

$$\frac{1}{\omega} = K \frac{g}{I_0 N} t + C_4$$

Applying the boundary condition

$$(\omega)_{t=0} = \omega_0$$

the above equation becomes

$$\frac{1}{\omega} = \frac{1}{\omega_0} + \frac{K g t}{N I_0}$$

With the approximation

$$\frac{P}{P_0} = \left(\frac{\omega}{\omega_0} \right)^2$$

and the constant, K, evaluated from the steady state operating condition

$$\Delta P_0 Q_0 = K \omega_0^3$$

or

$$K = \frac{\Delta P_0 Q_0}{\omega_0^3}$$

the pressure-time relationship becomes

$$P = P_0 \left[\frac{1}{1 + \frac{\Delta P_0 Q_0 g t}{N I_0 \omega_0^2}} \right]^2$$

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The data required for the evaluation of the constants in the above equations for the flywheel decay curves shown on Figures 1-a, 1-b, 1-c and 1-d are tabulated below: ⁵

	<u>1-a</u>	<u>1-b</u>	<u>1-c</u>	<u>1-d</u>
Total water flow rate-gpm	140,000	126,000	126,000	100,000
Top of riser pressure-psi	585	480	600	385
No. of pumps	6	5	6	4
Pump speed, rpm	2,000	1,875	2,000	1,800

Nomenclature

C_h	-	constant - seconds
E_f	-	energy of flywheel, ft-lb
E_w	-	energy of water, ft-lb
g	-	acceleration of gravity = $32 \frac{\text{ft}}{\text{sec}^2}$
I_0	-	polar moment of inertia of flywheel and pump = 93,500 lb-ft ²
K	-	constant - lb-ft-sec ²
N	-	number of pumps
P	-	pump discharge head $\frac{\text{lb}}{\text{ft}^2}$
Q	-	discharge rate of pump $\frac{\text{ft}^3}{\text{sec}}$
t	-	time after electrical outage - seconds

subscript 0 - refers to $t = 0$

ω	-	angular velocity $\frac{\text{radians}}{\text{sec}}$
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FIG. 1-4

REQUIRED TOP OF RIGID PRESSURE AT
10% AFTER 2% MECHANICAL TONAGE

Outlet Water
Temperature = 50°C

Outlet Water
Temp. = 100°C

OPERATING CONDITIONS

Top of Rigid Pressure 500 mm
Total Water Flow 140,000 gpm
Total Water Temp. 100°C
Outlet Water Temp. 50°C

TOP OF RIGID PRESSURE, PSI

TIME AFTER ELECTRICAL OUTAGE - SECONDS

FIG. 1-b

REQUIRED TOP OF RISER PRESSURE
AT 10% AFTER AN ELECTRICAL OUTAGE

OPERATING CONDITIONS
TOTAL WATER FLOW RATE 126,000 GPM
TOP OF RISER PRESSURE 100 psi
INLET WATER TEMP. 95°C
MAX. OUTLET WATER TEMP. 95°C

Outlet Water Temp. = 95°C

Outlet Water Temp. = 100°C

Physical Decay
5 Pump Sets

Shutdown
Requirement

TOP OF RISER PRESSURE, psi

TIME AFTER ELECTRICAL OUTAGE - SECONDS

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REMOVED TOP OF RISER PRESSURE AT
DOZ-X AFTER AN ELECTRICAL OUTAGE

October 1954

OPERATING CONDITIONS

Total Water Flow = 8000

Top Secret - FROTH 009

Inset top

Max. Outlet Water Temp. - 150°

Outlet Water
Temp. = 100°C

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Fig. 1-4

REQUIRED TOP OF KILN PRESSURE AT
100-X AFTER AN ELECTRICAL OUTAGE

OPERATING CONDITIONS

Total Water Flow 300,000 lbs
Top of Kiln Pressure 300 and
Throat Water Temp. 900°
Max. Outlet Water Temp 950°

Outlet Water Temp. 95°

Outlet Water
Temp. 100°

Wetted Density
1.000

Random Backpressure

100-X AFTER ELECTRICAL OUTAGE - 100000

TOP OF KILN PRESSURE, PSI

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Page 12FIG. II
FALL OF VERTICAL SAFETY RODS

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II

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VERTICAL ROD CONTROL

DISTANCE FROM INITIAL POSITION

POSITION

TOTAL CONTROL IN HOURS

THE UNIVERSITY OF CHICAGO

DISTANCE OF VERTICAL SAFETY ROD FROM INITIAL POSITION(FT)

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FIG II

VERTICAL SAFETY ROD CONTROL
VS
TIME AFTER START OF FALL

ROD IN POSITION

FIG V

RELATIVE FISSION HEATING

V5

INHOURS OF CONTROL

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CONTROL TIME: 0.3 SEC.
REFERENCE: HW17,716 R17

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TABLE I

RELATIVE HEATING VS. TIME AFTER START OF FALL OF VERTICAL RODS

<u>Time After Start of Fall</u>	<u>Delayed Fission Heat</u>	<u>Heat from Decay of Fis- sion Prod.</u>	<u>Heat from Graphite</u>	<u>Total Relative Heat</u>	<u>in of Control</u>
seconds					
0	0.840	0.10	0.06	1.00	0
0.65	0.840	0.10	0.06	1.00	0
1.0	0.840	0.10	0.06	1.00	0
1.5	0.822	.092	0.06	0.97	5
2.0	0.762	.086	0.06	0.85	67
3.0	0.330	.075	0.06	0.47	475
4.0	0.232	.065	0.06	0.36	487
5.0	0.177	.057	0.06	0.29	
10.0	0.137	.055	0.06	0.25	
20.0	0.080	.045	0.06	0.19	
30.0	0.057	.040	0.06	0.16	
40.0	0.045	.036	0.06	0.14	
minutes					
1	.034	.030	.06	.124	
2	.008	.028	.06	.096	
5	.0008	.016	.058	.074	
10	-	.014	.055	.069	
30	-	.010	.047	.057	
hours					
1	-	.009	.036	.045	
2	-	.008	.023	.031	
3	-	.007	.013	.020	

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