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FILE MODIFICATIONS RESULTING IN INCREASED POWER LEVELS

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PILE MODIFICATIONS RESULTING IN INCREASED POWER LEVELS

PART A - GENERAL PROBLEM

I. INTRODUCTION

The power output of the present piles is being restricted primarily by three important limitations; those due to graphite temperatures, slug and tube corrosion and maximum power per tube or "boiling disease." The purpose of this document is to present means for increasing very appreciably the "boiling disease" limits. In addition, means for alleviating the corrosion limitations will be discussed. Possible solutions to the graphite problem will not be considered here.

II. SUMMARY

Two means for increasing the maximum power per tube or "boiling disease" limits at the piles are presented here. One consists of increasing the header pressure; the other consists of installing larger outlet fittings on the process tubes.

The header pressures may be increased after (a) the installation of new front face risers and crossheaders and (b) the installation of new casings on the secondary process water pumps in the 190 Building.

The outlet fittings which must be changed are the (a) pigtail, (b) Parker fitting between the pigtail and the crossheader, and (c) outlet nozzle. A specific outlet fitting size has not been recommended. Such choice will depend upon several factors such as ease of manufacture and installation.

In the interest of safety, it is proposed that the front face risers be replaced with stronger ones at each pile. In addition, it is proposed that inflowing check valves be installed in each end of each front face crossheader. These alterations are proposed regardless of any other changes.

A proposal is made to utilize the increased water flow available at each pile. In general, the increased flow may be obtained through higher header pressures or altered orifice patterns. The problem of possible slug erosion must be considered before the flow at the H Pile is increased.

Present power level limits and possible power level gains are indicated graphically in Figures A-2, A-3, A-4, A-5, and A-6. The boiling consideration limits indicated are conservative and may at times be low by as much as 70 MW. The graphite temperature limits indicated may also be conservative if increased flattening and graphite annealing are attained. The power level limitations imposed by corrosion considerations may or may not be valid depending upon such factors as the effect of power level on slug corrosion.

It is proposed that modified pumps and rear face outlet fittings be installed at the 100-DR and H Piles at the time the 3X system is modified. The possibility of this co-ordination will depend to a large extent upon the availability of sufficient man power to perform the jobs simultaneously.

It is proposed that modified pumps be installed at the 100-B, D, and F Piles soon after the 3X change. They may be installed without loss of operating time.

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A discussion is given of the desirability of altering the outlet fittings at the 100-B, D, and F Piles. No definite recommendations are made, however. The desirability depends upon the probability that the graphite temperature limitations will be relaxed at those piles.

As a secondary issue in this report, it is proposed that the drive on the primary process water pumps be altered. Such alterations will result in appreciable financial savings.

After the proposed changes are made, the DR and H Piles can possibly be operated at levels up to 650 MW during portions of the year, but only small gains will be made at the D, B, and F Piles. If the graphite temperature limits are later relaxed, the DR and H Piles may be operated at levels up to 700 MW during portions of the year. The B, D, and F Piles might be operated at about 575 MW or about 700 MW if additional water and modified outlet fittings are provided. However, operation of any pile above 550 MW is dependent upon slug corrosion and/or failures, and these phenomena are not fully understood. Operation of the piles above 600 MW will also depend upon other considerations such as pile expansion, and the accuracy of expansion predictions is quite low. A capacity up to 48,000 gpm might be desired at each area if the boiling and graphite limits are altered upward. No consideration is given to possible increased water flow requirements resulting from possible radial enrichment of the piles.

The average estimated cost per pile by Technical personnel to modify the front face piping, the pumps and the outlet fittings is \$900,000 and 15 days downtime. If the modifications can be made when the Ball 3X System is installed, the downtime cost can be reduced to zero.

The capital cost of increasing the water supply at each area to 48,000 gpm is estimated by Technical personnel at \$600,000 per pile area. The H Area already has that flow, however, so the cost there would be zero.

The estimated savings from modifying the primary pump drive is \$600,000 per year per pile area. This savings results from reduced steam consumption.

III. DISCUSSION

A. Methods for Increasing Boiling Consideration Limits

One of the limitations on the power output of the piles is that imposed by the so-called "boiling disease" phenomena. It arises from the consideration that should steam be formed in a process tube, a certain header pressure would be required to sweep the steam from the tube. As the power generated in the tube is increased, the header pressure necessary to remove the steam is likewise increased. If steam should be formed in a tube, and if the header pressure were insufficient to remove the steam, abnormally high temperatures would be reached by the slugs; the possibility exists that the aluminum jacket on many of the slugs might melt. Consequently the power output of all the tubes in the piles must be limited by the available header pressure.

It is obvious from the above that the "boiling disease" limits may be raised by increasing the header pressure.

The limits may be raised by other means, also. If the pressure drop caused by steam flowing through the tube can be decreased, less header pressure will be

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required to sweep the steam from the tube. The header pressure can then be reduced for a given power, or the power can be increased for a given header pressure.

In Part B a means for increasing the header pressure at each pile is discussed. It involves, primarily, (a) alterations to the impellers and casings of the 190 Building process water pumps, and (b) revision of the front pile face piping. The discussion is limited to increasing the header pressures to a maximum of about 500 psig.

Curve A of Figure 1 indicates the degree to which the permissible tube power changes with increased header pressure.

In Part III a means for decreasing the pressure drop due to steam flow through the process tubes is discussed. It involves (a) enlarged pigtails, (b) enlarged Parker Fittings between the pigtails and rear crossheaders, (c) enlarged flow paths through the outlet nozzles, and (d) possible alterations to the tube dummy pattern.

Curve B of Figure A-1 indicates the permissible power per tube versus header pressure for a tube with representative, modified outlet fittings. A comparison of Curves A and B at a constant header pressure indicates the change in permissible tube power resulting from changing the outlet fittings only. The location of Curve B varies appreciably with the size of modified fittings and with the dummy loading pattern.

Both parts give detailed discussions of the problems, alternatives and costs involved in the proposed alternations.

B. Other Pile Power Level Limitations

The pile power level limitations were reviewed by E. P. Lee and W. K. Woods (1)*. That document indicates that levels on the order of 600 MW are probably feasible at each pile except for the graphite temperature, corrosion and "boiling disease" limitations. The document also states that distortion of the biological shield might become excessive at power levels above 500 MW. However, it is difficult to specify an absolute limit, and the latter will have to be determined by actual measurements near the limiting levels.

A large effort is being directed toward obtaining some solution to the graphite temperature limitation. This document will not attempt to discuss the approach to that problem; however, it seems reasonable to assume that the limitation will be relaxed in some fashion in the future. Consequently, it is felt that steps to remove other important limitations should not be delayed.

A limitation has been imposed on the maximum tube outlet water temperature due to slug and tube corrosion. The June 15, 1951 corrosion limit is 80° C. Under the limit the power output of the piles is near the maximum for the present water flows and for summer inlet temperatures. The probability that the corrosion temperature limits will be relaxed in the relatively near future is indefinite at this time. However, more water can probably be supplied to the piles. Table I shows the present flow for each pile and the maximum which can be obtained within the limits of the present water supply systems. The latter figures were obtained by Massey (2).

*Numbers in parenthesis refer to Bibliography.

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TABLE I

Pile	Present Flow *	Maximum Available
	MGD	MGD
100-B	33,000	34,500
100-D	34,000	38,000
100-DR	36,000	39,500
100-F	32,000	34,500
100-H	41,000	48,000

* As of June 15, 1951

The maximum flows indicated in Table I may be increased further by the addition of more filter capacity at each area. The possibility exists that such additional filter capacity for the 100-B Area can be installed in the C Pile water system. The increased water flows would permit the power under corrosion limitations to be raised approximately in direct proportion to the flow increase.

It will not be proposed in this document that additional filter capacity be built at the present time. The reasons are as follows: (a) The construction of additional filters is a straight-forward engineering problem, and they may be built at any time. However, there is a time lag of approximately a year between the time construction is started and the time the filters are placed in operation. (b) The need for additional filters depends primarily upon the degree to which the graphite temperature limitations are relaxed. (c) An extensive program on water quality is underway to determine whether the water filtering standards may be relaxed. It is anticipated that results will be available from this investigation within a year.

Two other considerations related to flow will be introduced in this section although they are not specifically pile power level limitations. The first is a modification of the pile front face piping for purposes of safety. The second is a modification to the drive of the 190 Building process water primary pumps for purposes of increased economy. These considerations are introduced here because they are important secondary issues which resulted from this study.

Investigation has indicated that the weakest parts of the entire process water piping system are probably the inlet risers. In addition, it appears that the failure of a riser could produce far more serious results than the failure of any other part of the system. Such a failure could result in the cooling water flowing up the unruptured riser, across the crossheaders, and out the ruptured riser. The seriousness of this type of failure could be minimized by installing inflow check valves at each end of the crossheaders.

In view of these considerations it is believed that the present risers should be replaced with stronger ones at each area. In addition, it is believed that check valves should be installed in each front face crossheader at each area. A more detailed discussion of this problem is given in Part B.

Other investigations have indicated that appreciable financial savings can be made through modification to the primary pump drive. This change would consist of converting the drive of the primary pumps to a dual electric-steam drive similar in principal to the proposed C Pile design. Under this proposal the steam turbine, the electric motor, and the primary pump would be mounted coaxially. As discussed in Part B, it is believed these changes should be made for purposes of economy.

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In general, the maximum flows indicated in Table I may be obtained in the piles themselves either by increased header pressures or by modified orifice patterns. The cost for changing the orifice pattern is small compared to that of modifying either the pumps or outlet fittings; consequently, that problem will not be discussed further here. The necessary Panellit changes to accompany the increased flows would be approximately identical for both cases. If the increased flows at the B, D, F, and DR Piles were obtained through the use of larger orifices only, the present pump outlet pressures would decrease about 25 psi.

A unique problem would be encountered in obtaining the 48,000 gpm flow at the H Pile, however. The present pump pressure is almost sufficient to push that flow through the pile, but only if there were no pressure drop across the orifices in the central zone. Consequently, the present Panellit system for measuring flow in individual tubes would not function properly. Thus, the increased flow should not be obtained by changes in the orifice pattern only.

A second problem must be considered before the flow at the H Pile is increased to 48,000 gpm. Laboratory data indicate that serious slug erosion problems might occur at flows higher than the present. Although it is believed that this difficulty may be overcome, it will be investigated before higher flows are actually recommended.

C. Probable Power Level Gains Resulting from Proposed Changes

Table II indicates the estimated maximum power level for each of the piles based on graphite temperature limitations. These estimated values are only approximate, as are all the other estimations made in this section.

TABLE II

<u>Pile</u>	<u>*Present Power Level MW</u>	<u>Estimated Maximum Level Based on Graphite Temperatures, MW</u>
100-B	400	550
100-D	400	500
100-DR	525	650
100-F	400	500
100-H	500	550
100-H		**650

*As of June 15, 1951

**After removal of the H-10 loading

It is entirely possible that the estimated graphite temperature limits may be too conservative. As higher graphite temperatures are reached, the graphite tends to anneal and the temperatures decrease. It might not be too unreasonable to predict graphite temperature limits near 750 MW at the H Pile, for example.

The estimated maximum seasonal power level for each of the piles based on corrosion limitations is indicated in Table III. The values were obtained by assuming the following: (a) The flows indicated in Table I. (b) An 80° C. outlet temperature. and (c) An orifice pattern for each pile such that the bulk water outlet temperature is 14° C. below the maximum outlet temperature. These assumed conditions approximate those at the DR Pile, although it is entirely possible that orifice patterns

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can be established which will decrease the 14° C. value and permit higher levels. Inlet temperatures of 3°, 11°, 20°, and 15° were assumed for January, April, July, and October respectively.

TABLE III

Estimated Power Levels Based on Corrosion Limitations

<u>File</u>	<u>Maximum Level Based on Present Flow, MW (See Table I) Inlet Temperature</u>				<u>Maximum Level Based on "Maximum" Water Flow, MW (See Table I) Inlet Temperature</u>			
	3°	11°	20°	15°	3°	11°	20°	15°
100-B	550	480	400	440	570	500	420	460
100-D	560	500	410	460	630	550	460	510
100-DR	600	520	440	480	650	570	480	530
100-F	530	460	390	430	570	500	430	470
100-H	680	590	500	550	800	700	580	650

Power level limitations based on "boiling disease" may be calculated from Figure A-1 if a set, uniform flattening is assumed. Based on 1330 effective tubes, the levels for various header pressures become:

TABLE IV

Power Levels* Based on "Boiling Disease"

<u>Header Pressure, psi</u>	<u>Type of Outlet Fittings</u>	<u>Power Level, MW</u>
385	Present	480
475	Present	600
385	Modified (Figure 1)	665
475	Modified (Figure 1)	850

*These values are based on a film pressure drop of 40 psi.

It should be noted that the values in Table IV hold for all the piles. It is assumed that the header pressure at the B, D, and F Piles can be increased to 385 psi with the present system. It should be noted that conservative boiling consideration limits have been used. Consequently, if there are over 1330 effective tubes or if the film buildup is less than 40 psi, levels greater than those indicated in Table IV may be obtained. For example, the limit for a 385 psig header pressure with present outlet fittings is given as 480 MW, whereas DR Pile has been operated at 550 MW before the limit was reached. Since the boiling consideration limit increases linearly with pressure, the datum is unimportant in as far as predicting power level gains are concerned. Consequently, the limits for higher header pressures and modified pigtailes would be increased correspondingly if a less conservative boiling considerations limit were used. Thus, for the present operating philosophy, the limit for DR Pile would be about 675 MW rather than 600 MW if the header pressure were 475 psi and if the present fittings were used.

From Tables II, III, and IV, composite curves may be drawn to show the power level limitations for each area. That has been done in Figures 2, 3, 4, 5, and 6.

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Figures 3 and 4 indicate that the 100-D Pile has more water than needed at present, and that the 100-DR Pile has an insufficient supply. Therefore, it is proposed that the D water supply be limited to its present value, 34,000 gpm, and that the extra available 4,000 gpm be supplied to the DR Pile. Curve C-3 in Figure 4 indicates power levels for that case. It will be noted that the yearly average power level of the pile would then be about 600 MW.

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Conditions:

- a. 20°C. Water Inlet Temperature
- b. 0.240" Orifice
- c. 40 psi Film
- d. 30% Safety Factor
- e. No Upstream Dummy Slugs
- f. For curve B-a 1" id. spiral pigtail and corresponding changes in the outlet nozzle and header fitting. For Forged slug only in downstream dummy pattern.
- g. Accuracy $\pm 10\%$

FIG. A-1 PERMISSIBLE POWER PER TUBE, VS. HEADER PRESSURE

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G - Present Graph Temp Limit
 ED-1 - Present Boiling Disease Limit
 ED-2 - Boiling Disease Limit with Modified Pumps
 BD-3 = " " " " " " Outlet Fittings
 BD-4 = " " " " " " Pumps & Outlet Fittings
 C-1 = Corrosion Limit with Present Flow
 C-2 = " " " " Increased " (See Table III)

FIG. A-3 POWER LEVEL LIMITS FOR 100-D PILE

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- S-1 = Graphite Temp Limit at Present
 S-2 = " " " after H-10 Material is Removed
 BD-1 = Present Boiling Disease Limit
 BD-2 = Boiling Disease Limit with Modified Pumps
 BD-3 = " " " " " Outlet Fittings
 BD-4 = " " " " " Pumps & Outlet Fittings
 C-1 = Corrosion Limit with Present Flow
 C-2 = " " " Increased " (See Table VII)

FIG. A-6 POWER LEVEL LIMITS FOR 100-H PILE

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PART B - HEADER PRESSURE INCREASE

The calculations in this section were done by W. C. A. Woods.

I. INTRODUCTION

It is possible to increase both boiling consideration limits and corrosion limits by increasing the pressure of the pile inlet risers. At present the maximum pressure is limited by two conditions: (a) A maximum allowable working pressure of 425 psig for the secondary pump casings, and (b) A maximum allowable working pressure of 400 psig for the inlet risers. While it is possible to increase the pile header pressure by revising the process water pumping system, the revised system must be satisfactory with regard to sufficiently strong pipe lines, emergency water supply requirements, and reasonable economics for both installation and operation.

The purpose of this part is to investigate the problems associated with increasing the pile header pressure and to determine the most feasible method of revising the pumping system in order to secure this increased pressure.

II. SUMMARY

It is proposed that in the event graphite temperature is not limiting that the pumping systems of all piles be modified to operate with a pump discharge pressure of 525 psig which corresponds to a header pressure of about 475 psig. Two cases are considered, (a) using the present maximum available flows, and (b) expanding the water systems of each pile to 48,000 gpm.

The proposed revisions consist of replacing the secondary casings with like casings made of stronger material and equipped with larger diameter impellers. It is also demonstrated that by replacing the present steam drives on the primary pumps with dual electric-steam drives, considerable operational savings may be realized. The drive conversion would amount to about \$2,000,000 per year for the plant under the present operating conditions. Extra pumping and filter capacity are considered for each of the proposed operating conditions.

The pile inlet risers appear to be the weakest part of the cooling water system, and it is pointed out that these risers should be replaced. In addition, inflowing check-valves should be installed as a safety feature. The other necessary modifications to the process water system are discussed. Considerations of possible failures show that the proposed system will be satisfactory for the safe operations of the piles.

An estimated cost analysis shows that it will cost about \$3,800,000 and 75 pile days downtime to complete all modifications for the entire plant so that the process water system will operate with a pump discharge pressure of 525 psig and with the present maximum utilisable flows. These changes will result in operational savings of about \$1,700,000 per year for the plant and will allow production limit increases of 770 MW for boiling considerations and 202 MW for the summer corrosion limit for the plant. To expand the flow rate at each area to 48,000 gpm would cost an additional \$3,200,000 with no downtime. With the increased flow the water plants operational costs would still be about \$1,200,000 less than they are at present. Allowable production increases over the present limits would be 770 MW for boiling and 1010 MW for summer corrosion limits for the plant.

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III. PUMPING SYSTEM CHANGES

In increasing the header pressure a balance must be made between the amount of pressure increase and the costs of securing this increase. As will be shown later, it is relatively simple to change the process pumping system to secure a pump discharge pressure of 525 psig. The majority of the high pressure process water system was designed for a maximum allowable working pressure of 600 psig. While it would be possible to go to 600 psig without a complete redesign of the process water lines, in order to secure the pressure increase from 525 to 600 psig, it would be necessary to completely redesign the pumping system. Thus, since a pump discharge pressure of 525 psig will give a boiling consideration limit of about 825 MW, it seems reasonable to accept a design pressure for the secondary pump outlet of 525 psig.

By replacing the secondary casings and by operating the present primary steam driven pumps at 2660 rpm, each unit would operate on a pressure flow characteristic from which the two points given below are taken.

	PRIMARY	SECONDARY	COMBINED
Capacity	3000 gpm	3000 gpm	3000 gpm
Total Head	585 ft	628 ft	525 psig
Speed	2660 rpm	1750 rpm	
Efficiency	77 %	80 %	
BHP	576	594	
Capacity	3500 gpm	3500 gpm	3500 gpm
Total Head	570 ft	585 ft	500 psig
Speed	2660 rpm	1750	
Efficiency	80 %	80.5%	

H. F. Measley of the Power Division has made a survey (4) on the feasibility of the proposed change insofar as the Power Division is concerned and reports that the proposed change will require certain alterations in the filter plant capacities and in the 183 process water pump capacities. The estimated cost of replacing the secondary pumps with the proposed pumps is from \$7,000 to \$10,000 per unit. By using the maximum figure, which should include the necessary minor changes in the filter pumps, a cost for the pump replacement for the number of units now on the plant would be for B, D, and F Areas, \$120,000 each; for DR Area \$140,000; and for H Area \$160,000.

In order to supply the estimated flow of 48,000 gpm at 525 psig it would be necessary to have 16 units operating at each area. For the above flow at 500 psig, it would be necessary to have 14 units operating at each area. Assuming 16 operating units and a cost of \$50,000 per unit, the number of units required and the estimated cost would be for B, D, and F Areas, 6 units at \$300,000 for DR Area, 4 units at \$200,000; and for H Area, 2 units at \$100,000. In order to increase the corrosion limits it is necessary to increase the flow of the process water. The maximum amount of water which can be put through the piles depends upon the pile header pressure and the orifice pattern of the pile. Maximum flow rates for any given header pressure would be obtained if the orifices were completely removed. However, since tube flow rates are now determined by the orifices, it appears that some orifice pattern will always be necessary. If it is assumed that all piles were equipped with orifice patterns similar to that of H Piles, the maximum flow for a pump pressure of 525 psig would be about 48,000 gpm. Assuming that the maximum allowable outlet temperature is 35° C. and that the orifice efficiency is 100 per cent, this flow would give

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power level of 825 MW when the inlet water temperature reaches its maximum value of 20° C. Consequently, the maximum practical limits for the pumping system revision appears to be a pump discharge pressure of 525 psig and a nominal flow rate of 48,000 gpm.

Although this amount of water is presently available only at H Area, it would be well, especially in view of the programs currently in progress on water quality and graphite temperature, to have a pumping system capable of being easily and economically expanded to the above limits.

A. The Method of Replacing the Secondary Pump Casings

One method which has been proposed (5) is to replace the secondary pumps with like pumps made of stronger material and equipped with larger impellers. The present pumping system is composed of dual units operating in parallel. Each area has two units on standby and B, D, and F Areas have 10 units operating, DR has 12 units operating, and H has 14 units operating. Each unit consists of a steam driven primary pump and an electrically driven secondary pump. If the secondary casings are replaced as proposed, the maximum allowable casing pressure for these units would be 550 psig with a maximum head of 628 feet at 3000 gpm. This proposed replacement of casings and impellers is extremely simple since the present electrical motors and pump base plates could be used. Since there are extra units at all areas, the replacement would not cause any loss in production.

Under the proposed system it would be necessary to operate the primary pumps at 2660 rpm which would require 576 BHP for a secondary discharge pressure of 525 psig. Operating the primary turbines at this speed would result in an increase in steam consumption of about 50 per cent per unit. If the incremental cost of \$0.60 per thousand pounds of steam is used, which is about the cost of the coal and chemical required, the cost of the increased steam consumption would amount to about \$1,800,000 per year for the plant for the number of units required to deliver the present maximum available flows; or an increase of about 577,000 lbs/hr of steam costing about \$3,030,000 per year for the plant for the number of units required to deliver 48,000 gpm per area.

It has been proposed that the drive of the primary pumps be converted to a dual electric-steam drive similar in principal to the proposed C Pile design. Under the proposal the steam turbine, the electric motor, and the primary pump would be mounted coaxially. Preliminary investigations indicate that such a change is mechanically feasible and could be accomplished for about \$25,000 per unit. The estimated cost for the number of units now on the plant, would be for B, D, and F Areas, \$300,000; for DR Area, \$350,000; and for H Area, \$400,000. The primary pumps would normally be driven by electric motors, with only a sufficient amount of steam used to keep the turbines heated. This amount would be about 300 lbs/hr/unit. In the event of a power failure, the turbines would pick up the load.

Table I shows the calculated steam and electrical requirements for three cases: Case I shows data for present operation; Case II, for operation at 525 psig pump discharge pressure and the maximum utilisable flow; Case III, for operation at 525 psig pump discharge pressure and 48,000 gpm per area. Table II is a cost analysis of the steam and electric operational costs for each area, assuming an incremental steam cost of \$0.60 per thousand pounds of steam and that the cost of electricity is \$20 per kw-year.

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TABLE I

CALCULATED STEAM AND ELECTRIC REQUIREMENTS FOR 100 PROCESS PUMPS

CASE I - Present Operation

A. Pressure and Flow Requirements

1. Secondary pump discharge pressure, psig
2. Total flow, gpm
3. Number of units required

B. Primary Pumps

1. Turbine Driven

- a. Normal steam rate, lbs/hr
- b. Emergency steam rate, lbs/hr

2. Motor Driven Turbine Standby

a. Normal Operation

1. Electric rate, kw
2. Steam rate, lbs/hr

b. Emergency Operation

1. Electric rate, kw
2. Steam rate, lbs/hr

C. Secondary Pumps

1. Normal electric rate, kw

	B	D	F	DR	H	TOTALS
1. Secondary pump discharge pressure, psig	380	365	371	425	413	
2. Total flow, gpm	33,000	34,000	31,500	36,000	41,800	
3. Number of units required	10	10	10	12	14	
B. Primary Pumps						
1. Turbine Driven						
a. Normal steam rate, lbs/hr	92,000	85,000	79,500	109,000	117,000	483,000
b. Emergency steam rate, lbs/hr	115,000	121,000	112,000	122,000	146,000	616,000
2. Motor Driven Turbine Standby						
a. Normal Operation						
1. Electric rate, kw	2,820	2,610	2,440	3,940	4,220	16,000
2. Steam rate, lbs/hr	3,000	3,000	3,000	3,600	4,200	16,800
b. Emergency Operation						
1. Electric rate, kw	-0-	-0-	-0-	-0-	-0-	-0-
2. Steam rate, lbs/hr	115,000	121,000	112,000	122,000	146,000	616,000
C. Secondary Pumps						
1. Normal electric rate, kw	4,750	4,820	4,610	5,330	6,210	25,720

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TABLE 7 (Continued)

CALCULATED STEAM AND ELECTRIC REQUIREMENTS FOR 150 PROCESS PUMPS

CASE II

A. Pressure and Flow Requirements

1. Secondary pump discharge pressure, psig
2. Total flow, gpm
3. Number of units required

Primary Pumps

1. Turbines Driven

- a. Normal steam rate, lbs/hr
- b. Emergency steam rate, lbs/hr

2. Motor Driven, Turbine Standby

a. Normal Operation

1. Electric rate, kw
2. Steam rate, lbs/hr

b. Emergency Operation

1. Electric rate, kw
2. Steam rate, lbs/hr

Secondary Pumps

1. Normal electric rate, kw

	B	D	F	DR	N	TOTALS
1. Secondary pump discharge pressure, psig	525	525	525	525	525	
2. Total flow, gpm	33,000	36,000	33,000	39,000	48,000	
3. Number of units required	11	12	11	13	16	
1. Turbines Driven						
a. Normal steam rate, lbs/hr	146,000	159,000	146,000	173,000	212,000	836,000
b. Emergency steam rate, lbs/hr	101,000	110,000	101,000	119,000	147,000	578,000
2. Motor Driven, Turbine Standby						
a. Normal Operation						
1. Electric rate, kw	5,250	5,730	5,250	6,200	7,640	30,000
2. Steam rate, lbs/hr	3,300	3,600	3,300	3,900	4,800	18,900
b. Emergency Operation						
1. Electric rate, kw	-0-	-0-	-0-	-0-	-0-	-0-
2. Steam rate, lbs/hr	101,000	110,000	101,000	119,000	147,000	578,000
Secondary Pumps						
1. Normal electric rate, kw	5,410	5,900	5,410	6,400	7,870	30,990

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TABLE I (Continued)
CALCULATED STEAM AND ELECTRIC REQUIREMENTS FOR 190 PROCESS PUMPS

	B	D	F	DR	H	TOTALS
1. Pressure and Flow Requirements						
1. Secondary pump discharge pressure, psig	525	525	525	525	525	
2. Total flow, gpm	48,000	48,000	48,000	48,000	48,000	
3. Number of units required	16	16	16	16	16	
1. Primary Pumps						
1. Turbine Driven						
a. Normal steam rate, lbs/hr	212,000	212,000	212,000	212,000	212,000	1,060,000
b. Emergency steam rate, lbs/hr	147,000	147,000	147,000	147,000	147,000	735,000
2. Motor Driven, Turbine Standby						
a. Normal Operation						
1. Electric rate, kw	7,640	7,640	7,640	7,640	7,640	38,200
2. Steam rate, lbs/hr	4,800	4,800	4,800	4,800	4,800	24,000
b. Emergency Operation						
1. Electric rate, kw	-0-	-0-	-0-	-0-	-0-	-0-
2. Steam rate, lbs/hr	147,000	147,000	147,000	147,000	147,000	735,000
Secondary Pumps						
1. Normal electric rate, kw	7,870	7,870	7,870	7,870	7,870	39,350

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TABLE II

UNOFFICIAL OPERATIONAL COST ANALYSIS FOR 190 PROCESS PUMPS

	B	D	F	IR	E	TOTALS
PAGE I - Normal Operation						
Primary Pumps						
1. Turbine Driven						
a. Normal steam rate, \$/yr	465,000	430,000	401,000	551,000	592,000	2,439,000
2. Motor Driven, Turbine Standby						
a. Electric rate, \$/yr	56,400	52,000	48,800	78,800	84,400	320,600
b. Steam rate, \$/yr	1,500	1,500	1,500	1,800	2,100	8,400
Secondary Pumps						
1. Normal electric rate, \$/yr	95,000	96,400	92,400	106,800	124,200	514,800

PAGE II - Normal Operation

Primary Pumps						
1. Turbine Driven						
a. Steam rate, \$/yr	733,000	802,000	728,000	873,000	1,062,000	4,213,000
2. Motor Driven, Turbine Standby						
a. Electric rate, \$/yr	104,200	114,600	104,200	124,000	153,000	600,000
b. Steam rate, \$/yr	1,700	1,800	1,700	2,000	2,400	9,600
Secondary Pumps						
1. Electric rate, \$/yr	108,200	118,000	108,200	128,000	157,400	619,800

PAGE III - Normal Operation

Primary Pumps						
1. Turbine Driven						
a. Steam rate, \$/yr	1,062,000	1,062,000	1,062,000	1,062,000	1,062,000	5,310,000
2. Motor Driven, Turbine Standby						
a. Electric rate, \$/yr	153,000	152,000	153,000	152,000	153,000	765,000
b. Steam rate, \$/yr	2,400	2,400	2,400	2,400	2,400	12,000
Secondary Pumps						
1. Electric rate, \$/yr	157,400	157,400	157,400	157,400	157,400	787,000

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B. The Method of Converting to C Pile Design

Consideration has been given to the possibility of changing the pumping systems in the old areas to the same system as has been proposed for C Pile. The C Pile design consists of a fluid drive, a single pump, an electric motor, and a steam turbine all mounted coaxially. Normally the turbine floats on the line and only picks up the load in the event of failure of the electric drive. The pressure fluctuations of the pumping system are compensated for by the automatic variation of the fluid coupling. The estimated steam consumption for the C Pile turbines is 2400 lb/hr for normal operation and 64,000 lb/hr for emergency operation.

While this system appears to have certain advantages, the costs involved in redesigning the old areas, estimated at about \$90,000,000, is prohibitive, especially since the advantage of low steam consumption may be obtained by the much less expensive method already outlined.

IV. OTHER REQUIRED CHANGES IN THE COOLING WATER SYSTEM

A. Component Equipment Prior to the 190 Building

Because of the export system, which allows water to be transported between pile areas, the 181 and 182 pumps have capacities greater than are required to supply the area in which they are located. Thus, it is felt that these facilities are either of sufficient capacity or may easily be expanded to supply the maximum desirable flow rate of 48,000 gpm in all areas. It has been estimated (4) that modifications will have to be made in the 183 pumps if the flow rates are increased about 16 per cent. Thus, if the nominal flow rates are increased by 60 per cent in B, D, and F Areas and by 33 per cent in DR Area, it will be necessary to increase the 183 process pumping capacity and possibly the capacity of some of the pile lines before the 190 pumps.

If the present standards and procedures of water treatment are maintained, the filter capacity of all areas, except H Area, will have to be increased. Assuming a cost of \$150,000 per filter, the number of additional filters required for a 105 Building flow of 48,000 gpm would be for B Area, 4 filters at \$600,000; for D Area, 3 filters at \$450,000; for F Area, 4 filters at \$600,000; for DR Area, 5 filters at \$750,000; and for H Area, none would be required. The operation costs for the filter plants will be increased by \$43,000/yr for B and F Areas; \$32,000/yr for D Area; \$53,000/yr for DR Area; and \$10,000/yr for H Area.

Since the pressure limits in the lines prior to the 190 process pumps would not be appreciably changed, no problems in pressure limits should be encountered.

B. Process Water Lines between the 190 and 105 Buildings

It appears that the capacity of the pipe lines between the 190 and 105 Buildings will handle the desired maximum capacity of 48,000 gpm without undue increases in frictional pressure drop especially if the present spare lines are utilized. That is, for B, D, and F Areas the average frictional pressure drop for these lines are about 18 psi for the present flow rates; if ten lines were used for a flow of 48,000 gpm the pressure drop would be about 40 psi and if all twelve lines were used the pressure drop would be about 28 psi.

The lines between the 190 and 105 Buildings have been hydrostatically pressure tested to 900 psig. With the customary safety factor of 50 per cent, this would mean a maximum working pressure of 600 psig. Calculated maximum working pressures

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are in excess of the 600 psig value. Consequently, it appears that no difficulty from a pressure standpoint will be encountered if the pump casing pressure is increased to a maximum of 550 psig.

C. The Front Pile Face Piping

The pile inlet risers and crossheaders have been hydrostatically pressure tested to 600 psig which gives a maximum allowable working pressure of 400 psig. The calculated maximum allowable working pressure is about 500 psig. It appears that the weak part of the piping is the inlet risers, and ironically, it appears that the failure of a riser could produce far more serious results than failure of any other part of the entire cooling water system. That is, such a failure could cause the cooling water to flow up the unruptured riser, across the crossheader, and out the ruptured riser. The only method of isolating such a ruptured riser is by the crossheader hand valves which must be operated from the front elevator.

The possibility of this type failure is now present and the probability of failure will increase with increased pressure. The seriousness of this type failure could be minimized by installing inflowing check valves at each end of the crossheaders. It appears that the installation of the crossheader check valves should be done whether or not the pressures are increased. This would probably mean that the entire front crossheaders would have to be replaced.

It is believed that the inlet risers should be replaced with risers designed and tested for a working pressure of 600 psig. At the same time the crossheaders should be equipped with inflowing check-valves, and the strainers, valves, and other component equipment should be capable of working pressures of 600 psig. It is estimated that the costs of replacing the risers and installing the check-valves is about \$150,000 and 15 days downtime per area.

D. The Effluent Piping System

If the exit pigtails are replaced, the rear crossheaders will have to be replaced. It is believed that the new rear face crossheaders should be able to withstand working pressures of 400 psig.

DR and H Piles have two effluent downcomers each. Since at present they are operating with only one in service, no problems should be encountered with the downcomers if the flow is increased to the maximum desirable rate of 43,000 gpm. B, D, and F Piles have only one downcomer, and difficulties of operation have been encountered with these downcomers with the present flow rates. If the flow rates are increased, the downcomers at these areas will undoubtedly have to be replaced. It is believed that these areas should be equipped with two downcomers and that all downcomers should be designed for a working pressure of 400 psig. The cost of installing two effluent downcomers is estimated at \$100,000 and 15 days downtime.

The sewer lines at all areas except F Area are designed to be partially-full flowing lines. With the increase flow rates some of these lines will probably become pressurized sewers. However, since no undue difficulties have been encountered with the F Area pressurized sewer, it is not anticipated that any difficulty will be encountered at the other areas.

E. Instrumentation

If the header pressure is increased, the instrumentation for pressure and flow measurements will have to be modified. These changes would include changes in

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the line pressure gages, the Panellit pressure gages, and the Bailey Power recorder. The greatest problem would be the modification of the 2004 Panellit gages in each area. However, at present, procurement of new gages is underway and with these gages it is possible to rerange all the Panellit gages on the plant to the proposed pressure range. The estimated cost of reranging the Panellit gages is about \$20,000 and 7 days downtime per area.

V. FAILURE CONSIDERATIONS

A. Line Failures

The seriousness of failures which might cause interruption of the process water flow to the reactor was recognized by the original designers of the piles and several safety features were incorporated in the original pile design. In the case of line failures between the 190 Building and the 105 Building, emergency cooling water from the high-tanks and the export water system is available at the pile face. While it is not the intent of this study to evaluate these safety features, it may be pointed out that increased pressures and flow rates will not decrease the effectiveness of these safety devices.

As has already been pointed out, failure of the inlet risers could be extremely serious. It is felt that crossheader check-valves should be installed irregardless of whether or not the pressure is increased. If the inlet risers are replaced with stronger risers and if the check-valves are installed on the crossheaders, it is believed that even with increased pressures and flow rates the piles will be operating under safer conditions than they are at present.

B. Pumping Failures

Pumping failures in the 190 Building may be of three types; (a) mechanical failures of any unit, (b) failure of the electrical power supply, and (c) failure of the steam supply to the turbines of the primary pumps.

1. Mechanical Failure

It has been the policy to have two pumping units on standby in the 190 Building during normal operation. It has been pointed out (6) that failure of one pump during operation should not create any hazard and that in the event of the failure of two units the pile should be scrazed. It is unlikely that more than two pumps should be out of service at one time. Thus, mechanical failure would not be serious since only a few minutes are required to put a standby pump on the line.

If more than two pumps were out of service at the same time, the pile could adjust its limit of operation to the available water supply and thus avoid a total curtailment of production. Consequently, mechanical failure does not appear to be a serious problem, especially since the seriousness of failure of an individual unit decreases with an increase in the total number of units in operation such as is being proposed.

2. Electrical Power Failure

The pumping system, in addition to satisfactorily supplying cooling water during normal operating conditions, must also supply sufficient header pressure in the event of electrical power failure. The required header pressure after such an electrical power failure for a header pressure of 500 psig has been specified

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(7) and calculations of the header pressure transient after electrical power failure may be made in the manner outlined in (6). Figure A-1 shows the required pressure-time curve and pressure transient curves for various conditions.

If the present steam turbine drive is retained and the header pressure is increased to 500 psig, the primary pumps would have to be operated at 2660 rpm. In the event of electrical power failure, the primary pump would continue to operate at the same speed. Curves A and B show the pressure transient for a primary pump speed of 2660 rpm. Curve A is based on 14 pumps operating against an H orifice pattern. Curve B is based on 10 pumps operating against a F orifice pattern. Both curves show ample excess pressure above that required. Since either increasing the number of pumping units operating or enlarging the orifice pattern increases the value of the pressure transient at any instant, going to the proposed pressures and proposed flows would give a more desirable pressure decay transient than is shown.

If the present primary pump drive is converted to the proposed dual electric-steam drive, the primary pump will still operate at 2660 rpm. In the event of electrical failure, the steam valves on the turbines may be set so that the turbine will pick up the pumping load at any given speed. If the valves were set so that the turbine would maintain the primary pump speed at 2660 rpm, the pressure decay transient would be identical to the case described above. That is, the transient would be represented by Curves A and B. If the turbines did not pick up the pumping load until the pump speed had dropped to 2100 rpm, the pressure transient for the two different conditions described above would be given by Curves C and D. Curve C corresponds to Curve A and Curve D corresponds to Curve B. It will be noted that if the primary pump speed is reduced to 2100 rpm the pressure decay transient is still greater than the pressure required. This shows that a speed reduction at the time of changeover from electrical to steam power would not seriously effect pile operation.

3. Steam Failures

Steam is produced in similar boilers in all areas. The boilers have a rating of 115,000 pounds of steam per hour. The number of boilers and their total capacity are given below.

TABLE III

100 AREAS STEAM CAPACITY

<u>Area</u>	<u>Number of Boilers in Normal Operation</u>	<u>Steam Capacity for Normal Operation lb/hr</u>	<u>Total Number of Boilers</u>	<u>Total Steam Capacity lb/hr</u>
B-C	3	345,000	4	460,000
D-Dr	4	460,000	5	575,000
F	3	345,000	4	460,000
H	3	345,000	4	460,000

It can be seen from an examination of Table III that the maximum steam demand for the worst case, the normal operation of turbine driven primaries for a flow of 48,000 gpm and a pump pressure of 525 psig, is about 212,000 lb/hr/area.

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Thus, the capacities of the steam generating plants are such, that even with the other steam loads on the plant, that the probability of failure is small, especially if there is an extra unit on standby.

VI. ESTIMATED COST ANALYSIS

Table IV gives a compilation of the estimated cost for modifying the process water system and the change in operating costs for this system for two cases. The first is for the case where no additional filter capacity is provided and the second is for the case where the flow capacity for the 105 Building is increased to 48,000 gpm/area.

VII. ANTICIPATED PRODUCTION GAINS FROM INCREASING THE PILE HEADER PRESSURE

By increasing the pile header pressure to 525 psig, the following gains over the present boiling consideration limits may be made:

AREA	B	D	F	DR	H
<u>With Present Pigtails</u>					
Increase in Production Limits, MW	186	186	186	106	106
<u>With Proposed Pigtails</u>					
Increase in Production Limits, MW	432	432	432	352	352

Increasing the flow rates to the two conditions discussed will give the following gains over the present corrosion production limits. These figures are based upon a maximum allowable outlet temperature of 80° C.

AREA	B	D	F	DR	H
<u>With Present Maximum Utilisable Flow</u>					
Increase in Production Limits, MW					
Summer Minimum	0	32	24	48	96
Winter Maximum	0	38	30	60	123
<u>With Flow of 48,000 gpm</u>					
Increase in Production Limits, MW					
Summer Minimum	238	222	262	190	98
Winter Maximum	297	277	327	233	123

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TABLE IV

SUMMARY OF UNOFFICIAL ESTIMATED COSTS TO REVISE WATER SYSTEM

I. Secondary Pump Discharge Pressure of 525 psig and Maximum Utilizable Flow Rates

A. Capital Costs	B	D	F	DR	H	TOTALS
New Units Required	\$ 50,000	\$100,000	\$ 50,000	\$ 50,000	\$100,000	\$ 350,000
Secondary Pump Replacement	120,000	120,000	120,000	140,000	160,000	660,000
Dual-Drive Installation	300,000	300,000	300,000	350,000	400,000	1,650,000
Front Pile Face						
Piping Revisions	150,000	150,000	150,000	150,000	150,000	750,000
Effluent Piping Revisions	100,000	100,000	100,000	-0-	-0-	300,000
Instrumentation	20,000	20,000	20,000	20,000	20,000	100,000
TOTALS	\$740,000	\$790,000	\$740,000	\$710,000	\$830,000	\$3,810,000
Downtime	15 days	15 days	15 days	15 days	15 days	75 days

B. Operational Cost Increase (+) or Decrease (-) from Present Based on Table II.

1. Turbine Drive						
190 Process Pumps	+286,000/yr	+394,000/yr	+353,000/yr	+343,000/yr	+503,000/yr	+1,879,000/yr
Filter Plant Operation	-0-	-0-	-0-	-0-	-0-	-0-
TOTALS	\$286,000/yr	\$394,000/yr	\$353,000/yr	\$343,000/yr	\$503,000/yr	\$1,879,000/yr
2. Motor Drive, Turbine Standby						
190 Process Pumps	-346,000/yr	-291,000/yr	-279,000/yr	-404,000/yr	-404,000/yr	-1,724,000/yr
Filter Plant Operation	-0-	-0-	-0-	-0-	-0-	-0-
TOTALS	-\$346,000/yr	-\$291,000/yr	-\$279,000/yr	-\$404,000/yr	-\$404,000/yr	-\$1,724,000/yr

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TABLE IV (Continued)

SUMMARY OF UNOFFICIAL ESTIMATED COSTS TO REVISE WATER SYSTEM

II. Pump Discharge Pressure of 525 psig and 48,000 gpm per Area

A. Capital Costs	B	D	F	DR	H	TOTALS
Secondary Pump Replacement	\$120,000	\$120,000	\$120,000	\$140,000	\$160,000	\$ 660,000
New Units Required	300,000	300,000	300,000	200,000	100,000	1,200,000
Dual-Drive Installation	300,000	300,000	300,000	350,000	400,000	1,650,000
Filter Plant						
Increased Capacity	600,000	450,000	600,000	750,000	-0-	2,400,000
Front Pile Face						
Piping Revisions	150,000	150,000	150,000	150,000	150,000	750,000
Effluent Piping Revisions	100,000	100,000	100,000	-0-	-0-	300,000
Instrumentation	20,000	20,000	20,000	20,000	20,000	100,000
TOTALS	\$1,590,000	\$1,440,000	\$1,590,000	\$1,610,000	\$ 830,000	\$7,060,000
Downtime	15 days	15 days	15 days	15 days	15 days	75 days
B. Operational Cost Increase (+) or Decrease (-) from Present, Based on Table II						
1. Turbine Drive						
190 Process Pumps	+659,000/yr	+693,000/yr	+726,000/yr	+561,000/yr	+503,000/yr	+3,142,000/yr
Filter Plant Operation	+43,000	+32,000	+43,000	+53,000	+10,000	+181,000
TOTALS	\$682,000/yr	\$725,000/yr	\$769,000/yr	\$614,000/yr	\$513,000/yr	\$3,323,000/yr
2. Motor Drive, Turbine Standby						
190 Process Pumps	-248,000/yr	-214,000/yr	-181,000/yr	-346,000/yr	-404,000/yr	-1,393,000/yr
Filter Plant Operation	+43,000	+32,000	+43,000	+53,000	+10,000	+181,000
TOTALS	-\$205,000/yr	-\$182,000/yr	-\$138,000/yr	-\$293,000/yr	-\$394,000/yr	-\$1,213,000/yr

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PART C - MODIFIED OUTLET FITTINGS

The data for this section were obtained by M. Altman and R. G. Vanderwater.

I. INTRODUCTION

An investigation was made to determine the effect of modifications in tube outlet fittings on "boiling disease" limits. The investigation was based on both experimental data and theoretical calculations. The purpose of this part is to review and record the data obtained.

II. SUMMARY

Figure C-1 indicates graphically the increase in permissible power per tube which would result from the use of modified tube outlet fittings. These fittings are the pigtail, nozzle, and Parker fitting between the pigtail and the rear header.

The cost per pile of making such modifications is estimated at \$75,000 and 15 days downtime. If the changes can be made while the 3X system is being modified, the downtime cost would be reduced to zero. The \$75,000 figure is based on the assumption that the present outlet nozzles can be altered and used. If new nozzles are required, the figure becomes \$175,000.

III. DISCUSSION

A. Pressure Drop Data

An experimental investigation was conducted to determine the maximum pressure drop in a process tube under conditions of steam flow for the following variables: (a) tube power output, (b) tube loading, and (c) outlet fitting dimensions. The outlet fittings referred to are the outlet nozzle, pigtail, and Parker fitting between the pigtail and crossheader. The tube loading changes consisted of variations in the downstream dummy loading. The tests were conducted on the full-scale, tube mock-up in the 189-D Building. In general, the mock-up duplicates a process tube and slugs as far as heat generation and dimensions are concerned. However, a large amount of correlation work was necessary before the experimental data were applicable to actual pile process tubes.

It was found that the experimental data deviated less than 10 per cent from theory. It should be mentioned, however, that it was impossible to obtain all the experimental data desired due to limitations in the equipment. Consequently, the values provided below are based on a combination of both theory and experiment. Steps are being taken to alleviate the equipment limitations.

Figure C-1 summarizes the data resulting from the investigation. It shows plots of permissible tube power versus required header pressure. Each curve represents a different outlet fitting. Curve 2, for example, indicates header pressure versus power for the case in which the outlet fittings consist of the following: (a) a 3/4 inch ID spiral pigtail similar to those on the piles, (b) modified outlet nozzle having a cross-sectional area for flow equal to that of the pigtail, and (c) a Parker fitting between the pigtail and the crossheader whose inside diameter is equal to that of the pigtail. For other size pigtails, the nozzle flow path and the Parker fitting correspond in size to the particular pigtail. In addition, two different tube loading patterns are indicated. One, that indicated "WSD", corresponds to the present, standard loading of (a) no upstream dummy pattern, (b) 64 active slugs, (c) four solid, 8 inch dummy slugs, (d) eleven 8 inch perforated slugs, and

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(e) one 5 inch perforated slug. The other, indicated "NSD", is the same except that the four solid, dummy slugs are replaced by four perforated slugs. In addition, Curve 7 was obtained by assuming that the 5 inch perforated slug was replaced by a small-cross-section, dumbbell shaped slug. The use of the dumbbell slug appreciably reduced the pressure drop in the tube. The 1-1/4 inch "straight" pigtail consisted of an "L" shaped pipe extending from near the end of the outlet nozzle to the crossheader. Curve 8 represents the best possible condition as far as outlet fittings are concerned. It is the case for critical flow at the end of the active zone. Attainment of that condition in the practical case would be quite difficult.

Larger fittings introduce a secondary issue. For a given flow rate, the pressure drop through the outlet pigtail is less for the larger pigtail than for the smaller. Thus, the absolute pressure in the tube is lower and the temperature at which the water vaporizes is likewise lower. The absolute pressure in the tube could be maintained at its original value through the use of orifices in the rear crossheaders. However, the presence of the orifices might necessitate higher header pressures in order to provide a given liquid flow in each tube. In addition, the use of the orifices would not alter the amount of header pressure required to sweep vapor from a tube. Further study must be made of the desirability of installing such orifices. However, if new rear crossheaders are installed, it is recommended that provisions be made in each to permit the installation of orifices.

It should be realized that higher tube power levels will result in more serious damage to the slugs in the event of a prolonged water stoppage. This would be the case, however, whether the increased power levels were the result of larger outlet fittings or higher header pressures.

In the event that larger outlet fittings were installed, the header pressure requirements following an electrical power failure would remain the same as for standard fittings. These requirements are given in HW-21065.

It may be seen from Figure B-1 that the "boiling disease" limitation on the present piles may be raised quite appreciably by modifications to the outlet fittings. For example, the power level of a pile being operated at a 385 psi header pressure with 1330 effective tubes could be increased from 1330 x 360 or 480 MW to 1330 x 510 or 680 MW as far as "boiling disease" is concerned if fittings corresponding to Curve 6 were installed.

It will be noted that Curve 7 permits much more power per tube than does Curve 2. Thus, from a power per tube standpoint, the conditions of Curve 7 offer the optimum modification. However, other considerations are involved. There is a practical limit to the size of spiral pigtails. The use of a "straight" pigtail necessitates the use of some type of bellows to allow for tube movement. It may be undesirable to replace the solid dummy slugs with perforated slugs. And, finally, the cost of modifying the fittings on a pile will be much less if the present outlet nozzles can be used. Thus, the final choice will probably represent a compromise.

The cost of modifying the rear face fittings of a pile has been roughly estimated by R. R. Meyers, Maintenance Division, as 2400 man hours of labor plus 15 days of shutdown time. This represents the work necessary to replace the crossheaders with others having larger Parker fittings, to remove and replace the pigtails and to remove and replace the outlet nozzles. Thus, the labor cost will be in the vicinity of \$12,000. If new pigtails can be purchased for \$15 each, and if the nozzles

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can be modified for \$15 each, the total cost per pile would be about \$75,000 plus 15 days of downtime. If new nozzles were required, the cost per pile would rise by an additional \$100,000. The downtime cost can be reduced to zero if the modifications are made while the 3X system is being changed. Such co-ordination will depend in large part upon (a) the availability of man power, (b) the feasibility of modifying the present outlet nozzles rather than purchasing new ones, and (c) the speed with which new pigtails can be procured.

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PART D -- CONCLUSIONS

I. DISCUSSION

An analysis of the preceding parts leads to the following conclusions:

1. Increasing the pile header pressure is a practical method of increasing the boiling consideration limits.
2. The method presented for replacing the secondary pump casings is a practical and worthwhile method of increasing the allowable working pressure limits of the present system.
3. Modifying and/or replacing the present outlet fittings is also a practical method of increasing the boiling consideration limits.
4. The drives of the primary pumps should be converted to dual electric-steam drives.
5. The front face piping of the piles, including the risers and crossheaders should be redesigned in the manner outlined regardless of whether the pressure is increased or not.
6. Increasing the capacity of the process water system to 48,000 gpm with a pump casing pressure of 525 psig by replacing the secondary casings and converting the primary drives would give substantial increases in production and substantial decreases in operating cost if other factors are not limiting.
7. Modifications to the front and rear faces of the piles may be made at a greatly reduced cost if the work can be done during the 3X changes.
8. The present boiling consideration limit will probably restrict the level of the B Pile before the graphite temperatures do.
9. The present boiling consideration limit will probably restrict the level of the D and F Piles at about the same point as the graphite temperatures.
10. The DR Pile power level is limited by boiling considerations to a level well below that imposed by graphite temperatures. The same condition will be true for the H Pile when the P-10 loading is removed.
11. More water may be obtained at each pile in a relatively straight-forward fashion. Such additional water will not necessarily, however, permit raising the corrosion limitations at this time.

II. RECOMMENDATIONS

In view of the above conclusions, the following recommendations are made:

1. In the interest of safety, the front face risers on all piles should be redesigned for higher working pressures and inflowing check valves should be installed on all front face crossheaders. The changes should be made at the time of the Ball 3X change, if possible, in order to minimize production losses.
2. The secondary pump casings at all areas should be replaced as soon as the front face piping is modified in order to secure maximum production. Immediate production gains would probably be made at the DR and H Piles and possibly at the B Pile. Gains at the D and F Piles will depend in large part upon further relaxation of the graphite limits.
3. Larger outlet fittings should be installed at the DR and H Piles at the time of the 3X change.
4. Consideration should be given to the installation of larger outlet fittings on the B, D, and F Piles. Although immediate production gains appear doubtful, such installation requires about 15 days of downtime, and that time would be saved if the fittings could be installed during the 3X change.

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5. The drives of the primary pumps should be converted to the proposed dual electric-steam drive in all areas as soon as possible in order to reduce the operating costs of the pumping system.
6. Such changes as are needed should be made in the orifice pattern and Parallit gages in order to secure maximum production with the presently available process water.
7. In the event other limits are relaxed, and if the use of 48,000 gpm proves practical at the H Pile, the water facilities at the other piles should be expanded for 525 psig and 48,000 gpm operating conditions.

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