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RICHLAND, WASHINGTON

HANFORD ATOMIC PRODUCTS OPERATION

October 26, 1954

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MONTHLY REPORT OF THE DESIGN ANALYSIS GROUP FOR SEPTEMBER 1954

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Design Section
ENGINEERING DEPARTMENT

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October 26, 1954

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MONTHLY REPORT OF THE DESIGN ANALYSIS GROUP
FOR SEPTEMBER 1954

MAJOR DESIGN DEVELOPMENT PROGRESS

Pressurization of the Rear Face for Existing Reactors - W. J. Love, E. R. Rudock

A preliminary study was made concerning the potential power level increases which could be achieved if the rear face pressure of existing reactor plants were raised to permit operation at higher process tube outlet temperatures. This study was made to evaluate work now planned for Project CG-558 to determine if the effluent system design might compromise such a pressurization program. A process water outlet temperature of 130°C was arbitrarily used to evaluate the piping; this temperature would require a 25 psi rear face orifice. Three schemes of modification proposed consist of placing orifices in the end of each rear crossheader, placing orifices in the rear face cross-over line and placing an orifice in the process sewer inlet to the retention basins; the first two schemes would require injection of river water upstream of the orifice. No changes would be made to the reactor front face or pumping system. The present effluent lines for project CG-558 are not designed for the pressurization resulting from the combined process and river water flow of 94,700 gpm in the first two cases or the additional orificing pressure resulting from the third case, and thus would require redesign or future replacement in a pressurization program; also the downcomers would have to be replaced or by-passed if the pressurization of the third case were carried out.

Loss of Steam in Existing Reactors (Document HW-33193) - W. J. Love, G. L. Locke

Document HW-33193 has been issued which contains a recommendation that check valves should be placed in the steam lines entering the 190 Buildings of the B, D, F, DR and H Reactor Plants. This recommendation was based on the desirability of preventing bulk boiling in the reactor effluent piping upon loss of steam to the steam driven process pumps prior to the Project CG-558 modification program.

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Two meetings of the Reactor Design and Development Representatives were held during the month to discuss the necessity of this check valve installation. Two different philosophies of operation developed during the course of the meetings, which were primarily dependent upon whether boiling should or should not be permitted in the effluent during the reactor transitory shutdown period. This information was forwarded to the Design Council in document HW-33306.

In-Pile Boiling in the 105-KER Recirculation Facilities - C. A. Pursel

A study has been completed on the flexibility of the 105-KER recirculation facilities to test the system over a wide range of tube powers and exit steam qualities. Five cases were considered which showed that the system was adequate to handle steam over the entire range of 0 to 100 per cent quality for tube powers in the range of 1200 to 1600 kw/tube at inlet temperatures at 250°F to 350°F, when the pressure at the condensing exchanger is maintained at 1000 psia. There are at present two one inch pipes leading from each recirculating tube and if these were replaced by one two inch pipe increased flexibility could be obtained.

Feasibility Report for Special Study Reactor Plant

Based on the design bases previously established for the 1600 mw dual purpose reactor plant (described in document HW-33070, "An Interim Feasibility Report for an Intermediate Capacity Dual Purpose Reactor Plant", by J. R. Wolcott). Work continued during the month on the preparation of a final feasibility report. This report will discuss the design philosophy leading to the establishment of the basic criteria for the plant, as well as a complete description and cost estimate of the plant.

Shielding Requirements of the Special Study Reactor Plant - C. A. Pursel

The work area for the special study reactor will not be shielded from the activity of the water wall so that access to the work area will be possible only during shutdown. The building walls around the work area will serve as shielding walls from the water wall and reactor activity. This means that the design emphasis for the front and rear shielding will be on neutron shielding rather than gamma shielding. Neutron leakage will be minimized so that activity will not be induced in the piping or the water wall. Further it is not practical to cool the front and rear shields so that these shields will be operated at temperatures somewhat above that of the process water (225°F to 550°F). No information is presently available on the shielding properties of heavy aggregate concrete in this temperature range, but preliminary estimates indicate that a 51 inch shield will provide adequate neutron attenuation. Shield attenuation tests for high-temperature heavy aggregate shields of this geometry will be recommended. The side shield design is similar to the 100-K plant design with a water cooled shield of approximately 51 inches in thickness. The thermal shields are also similar to the 100-K design and will be cast iron, 10 inches in thickness.

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Sulfuric Acid Addition to 100-K - W. L. Pearl and W. D. Bainard

A document, HW-33178⁽¹⁾, is being issued containing a proposed scope of the 100-K sulfuric acid addition facilities. The dosages of sulfuric acid used for design purposes were based on sufficient acid to decrease the pH of the process water to the reactor to 7.0 at the temperature of measurement. A minimum of 4.0 ppm alum were considered as essential for the entire year. A 45-day storage facility based on the maximum feed rate of 10 ppm sulfuric acid was considered adequate because of the nearness and adequacy of supply and the fact that acid addition is not essential to the system operation.

Decreasing process water pH may decrease the process tube and slug jacket corrosion rates and hence lower the frequency of process tube replacement (HW-33035-RD)⁽²⁾. These decreased rates may be realized as monetary savings with operation at the same outlet temperature or as increased production with operation at the same corrosion rates at higher temperatures. It was recommended that some of these large savings be realized by having process water specifications require a given pH at a definite temperature such as 20°C. This required pH should be the lowest that has actually undergone thorough testing when corrected to this 20°C.

(1) Pearl, W. L. and Bainard, W. D., "A Proposed Scope of the 100-K Sulfuric Acid Addition Facilities, HW-33178, September 20, 1954.

(2) Miller, N. R., "An Evaluation of the Use of Sulfuric Acid in the 100 Areas' Water Treatment Process, HW-33035-RD, September 13, 1954.

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OTHER DESIGN DEVELOPMENT INFORMATION

Pressurization of the Rear Face - W. J. Love, E. R. Rudock

A preliminary study was requested concerning the potential power level increase which would exist if the rear face pressure were raised to permit operation at higher process tube outlet temperatures. This study was made to evaluate work now planned for CG-558 to determine if the effluent system design might compromise such a pressurization program.

The following simplifying assumptions were made:

- A. Process tube inlet temperature - 10°C .
- B. Process tube bulk outlet temperature during scram is the rear face saturation temperature.
- C. Flow without rear face pressurization - 73,000 gpm. The reactor characteristic is taken as: pressure drop = Constant (flow)^{1.82}.
- D. Total Dynamic Pressure across pump - 600 psi (it was assumed that the pump head would remain constant for all cases in order to avoid any appreciable increase in front face pressure. The existing impellers would be trimmed to accomplish this.)

The results of this study are shown in Fig. 1. The maximum reactor power gain would occur with a 180 psi orifice in the rear face which will reduce the reactor flow to 60,000 gpm and provide an outlet temperature of 193°C . Aluminum process tube corrosion rates and shielding temperature limits would not permit this point of operation to be achieved.

A process water outlet temperature of 130°C was arbitrarily* used to evaluate the piping. This temperature would require a 25 psi rear face orifice. Three alternate schemes of modification were proposed.

- I. Place orifices at end of each rear crossheader. Two new rear risers would supply river water (23,200 gpm) to crossheaders to cool the process water (71,500 gpm) just before it passed through the orifices.
- II. Place an orifice in the rear face crossover line. The process water would be cooled by injection of river water upstream of the orifice.
- III. Place an orifice at the entrance of the effluent line into the retention basin.

* Scale in aluminum tubes will become pronounced at temperatures above 120°C . Quarterly Report, Second Quarter-FY-54. TPl8-TPl9 - Pipe Technology Sub-Section by R. B. Richards.

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Some of the modifications to the rear face piping necessary to accomplish pressurization are as follows. In all cases, the crossheaders will expand to such an extent that the existing crossheader expansion loops are inadequate. The riser-header nipples would require reinforcing and perhaps the rear risers would have to be replaced. Foundation bracing of rear risers would have to be improved to withstand additional thermal stress and in Case II and III, hydrostatic thrust. In all cases a 105 drainage lift station would be required. The effluent system would have to become a closed system in Cases I and II to provide for static head to remove the combined process-river water flow of 94,700 gpm or in Case III to permit pressurization. The present effluent lines for CG-558 are not designed for pressurization and would require redesign or future replacement. The downcomer would be replaced or bypassed with piping if the pressurization of Case III were carried out.

The questions concerning safety and stability of operation for rear face pressurizing were not examined in this study.

Radiation from Activated Iron in a Recirculating System - C. A. Pursel

In a recirculating system one of the major corrosion products is iron. In each pass through the pile some of this iron is activated. The activity is from Fe^{59} which has a half life of 45 days. If it assumed that the water is recycled until saturation is reached this activity reaches high levels. On the other hand a more likely system is one in which there is a continuous bleed-off such that the contamination from corrosion is held constant.

In the proposed design for the Intermediate Power Level Reactor the activity build-up from iron is negligible.

The pertinent formulas and design data are as follows:

$$\frac{dN^*}{dt} = \phi \sigma \bar{N} \frac{(1 - e^{-a}) (1 - e^{-nb(a+\beta)})}{1 - e^{-b(a+\beta)}} e^{-bt}$$

$$\frac{dN^*}{dt} = \text{dis}/(\text{sec-cc}) \text{ at end of active zone.}$$

$$\phi = \text{thermal neutron flux; } 5 \times 10^{13}$$

$$\sigma = \text{cross section; } 0.8 \text{ barns}$$

$$\bar{N} = \text{susceptible nuclei/cc; } 1.8 \times 10^{13} \text{ at } 0.5 \text{ ppm of oxide at } 500^\circ\text{F}$$

$$a = \text{time in active zone, conservatively, 1 second.}$$

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Effect of Varying Rear Face Pressure on Relative Power of an Existing Reactor

FIG. 1

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β = time out of active zone; 30 seconds

n = average number of cycles for each atom. This number is dependent on the rate of bleed-off.

2×10^6 gals. = total volume of water in-loop

275 gpm = bleed-off

$b = \ln 2/T = 1.78 \times 10^{-7}$

T = half life of element; 45 days for Fe^{59}

t = time after leaving rear face

There are three isotopes of Fe, Fe^{56} , Fe^{57} , and Fe^{58} that by neutron capture can form radioactive Fe^{59} .

Isotopes	% Abundance	(barns)
Fe^{56}	91.6	2.5
Fe^{57}	2.2	2.4
Fe^{58}	0.33	0.8

For the above conditions less than 10^8 Fe^{56} and Fe^{57} atoms/cc are converted to Fe^{58} . This amount is negligible compared to the 10^{13} atoms/cc that are originally present.

Substitution of the design data into the original formulas gives

$$\frac{dN^*}{dt} = 6.35 \times 10^{-2} e^{-bt} \text{ dis/(sec-cc)}.$$

In all pile components except ion exchangers this amount of radiation is negligible. Actually if the bleed-off rate were such that the Fe concentration were 50 ppm the activity would still not be a problem except in large unshielded storage basins. The activity from ion exchangers is discussed in a separate article.

Ion Exchanger Activity from Fe Corrosion - C. A. Pursel

In the Intermediate Power Level Reactor the recirculating water is constantly purified or cleaned up. There is a continuous bleed-off from the primary loop.

This bleed-off is run into a 2,000,000 gallon storage tank. Water is taken from the storage tank, run through an ion exchanger, and returned to the primary loop.

It has been suggested that carbon steel might be substituted for some or all of the stainless steel in the primary loop. One of the problems concerning this substitution is the increase in activity from the ion exchanger.

Calculations show that the activity from the ion exchanger due to corrosion of iron will be negligible.

$$A(\text{Fe}) = \frac{w}{V_E} (1 - e^{-bt}) \left. \frac{dN^*}{dt} \right|_R e^{-\frac{bV_T}{w}}$$

$A(\text{Fe})$ = Average dis/(sec-cc) in exchanger at any time.

w = flow in bleed-off loop, cu. ft/sec

V_E = Volume of water in the ion exchanger, cu. ft.

$\left. \frac{dN^*}{dt} \right|_R$ = dis/(sec-cc) at the rear face.

V_T = Volume of storage tank, cu. ft.

t = Time after regeneration of the ion exchanger, seconds.

Ion exchanger 10 ft. diameter, 10 ft. high (half filled with water).

Fe concentration = 0.5 ppm as oxide.

Average number of cycles in the primary loop before bleed-off = 500

$$b = \frac{\ln 2}{T}$$

T = half life; 3.888×10^6 sec (= 45 days)

For the conditions stated above.

$$A(\text{Fe}) = 5.13 \times 10^2 (1 - e^{-bt}) \text{ dis/}(\text{sec-cc})$$

At the end of one year

$$A(\text{Fe}) = 5.11 \times 10^2 \text{ dis/}(\text{sec-cc}).$$

- The dosage rate from the ion exchanger described above with no shielding would be 7.8 mr/hr from the activated iron.

In case the corrosion concentration were allowed to increase by a factor of 100, the dosage rate at the end of 10 weeks would be 520 mr/hr and require a shield equivalent to 18 inches of ordinary concrete.

Thermal Shock - KER Loop - W. D. Bainard

A request was received for an investigation of the thermal shock to the main pumps for the KER loop which would result when water at room temperature was introduced to the system upon detection of a slug rupture.

The problem when simplified, resulted in the following data; if 120 feet of 2 1/2 inch schedule 80 stainless steel pipe initially at 490°F has 70° water introduced into it at 13.78 lbs/sec how does the outlet water temperature vary with time?

Investigation of the water film heat transfer coefficient showed that it was not limiting, i.e., the water outlet temperature would be essentially equal to the pipe temperature at all times. The problem then reduced to a simultaneous solution of two heat balance equations as follows.

$$\Delta Q_p = W_p C_p \Delta T \text{ and } \dots (1)$$

$$\Delta Q_w = W_w C_w \Delta t \dots (2)$$

where ΔQ_p = heat lost by pipe

ΔQ_w = heat gained by water

W_p = weight of pipe = 919 lbs

W_w = weight of water = 14.78 ϕ
(ϕ = time in seconds)

C_p = heat capacity of pipe = 0.135 Btu/lb/°F

• C_w = heat capacity of water = 1.085 Btu/lb/°F

ΔT = temperature change of pipe = 490 - T °F
(T = pipe wall temperature)

Δt = temperature change of water = t - 70 °F
(t = water outlet temperature)

Since T = t and $\Delta Q_p = \Delta Q_w$

$$t = \frac{4063.6 + 70 \phi}{8.3 + \phi} \quad (\text{equating (1) \& (2) and substituting in values})$$

A plot of this equation will give the water outlet temperature versus time in seconds. This is the temperature of the inlet water to the pump from which the thermal shock is determined.

Shielding of Tube Bundles - W. D. Bainard

A request was received to determine the amount of shielding necessary to reduce the radiation intensity at one foot to less than 6 mr/hr in the following two cases.

Bundle I contained 0.045 gallons per foot of normal 105-K effluent water one minute old while bundle II carried twice this amount.

The radiation intensity was found to be the same in both cases; about 8 mr/hr at one foot neglecting self-absorption. Since self-absorption would reduce the true intensity to about 7 mr/hr at one foot it was recommended that no shielding be used unless it was imperative to reduce the intensity to less than 6 mr/hr. If this is so then 1/4 inch of lead shielding was recommended.

Adjustment of Raw Water pH - W. D. Bainard

The alkalinity of raw Columbia River water is attributable to dissolved carbon dioxide which results in a carbonate-bicarbonate ion buffer equilibrium. When alum is added to this water both aluminum and aluminate ions are introduced. The equilibrium constants concerned are as follows (at 25°C)*:

$$[H_2CO_3] = 2.33 \times 10^6 [H^+] [HCO_3^-]$$

$$[CO_3^{2-}] = 4.7 \times 10^{-11} \frac{[HCO_3^-]}{[H^+]}$$

$$[OH^-] = \frac{10^{-14}}{[H^+]}$$

$$[Al^{+++}] = 1.9 \times 10^9 [H^+]^3$$

$$[H_2AlO_3^-] = \frac{4 \times 10^{-13}}{[H^+]}$$

* In this discussion [a] indicates "the concentration of a in moles per liter."

It may be seen that the concentration of each of these ions in a solution will be dependent upon the pH of the solution. Calculated concentrations of these ions in water of varying pH are presented in Table I. It will be noted that the above constants hold true only for saturated solutions, therefore enough alum must be added to obtain aluminate ion saturation for these values to hold. The carbonic acid concentrations are calculated from an experimental value of 56 ppm as CaCO_3 in raw water of 8.1 pH.

Let x equal the moles per liter of $\text{Al}_2(\text{SO}_4)_3$ added to a sample of the raw water. Then $2x$ will be the number of moles per liter of Al^{+++} added. The aluminum ion will take three forms in the solution, part remaining as free Al^{+++} , part forming H_2AlO_3^- , and part precipitating as $\text{Al}(\text{OH})_3$. Then

$$2x = [\text{Al}(\text{OH})_3] + [\text{Al}^{+++}] + [\text{H}_2\text{AlO}_3^-]$$

The formation of a molecule of $\text{Al}(\text{OH})_3$ requires three molecules of water from which upon combining, three atoms of H^+ are released. The formation of an aluminate ion requires three molecules of water from which four atoms of H^+ are released. Therefore

$$[\text{H}^+ \text{ released}] = 3[\text{Al}(\text{OH})_3] + 4[\text{H}_2\text{AlO}_3^-]$$

Combining the two above equations

$$[\text{H}^+ \text{ released}] = 6x - 3[\text{Al}^{+++}] + [\text{H}_2\text{AlO}_3^-]$$

In the raw water

$$[\text{H}^+] = [\text{OH}^-] + [\text{HCO}_3^-] + 2[\text{CO}_3^{=}]$$

In the treated water

$$[\text{H}^+] + 3[\text{Al}^{+++}] = [\text{OH}^-] + [\text{HCO}_3^-] + 2[\text{CO}_3^{=}] + [\text{H}_2\text{AlO}_3^-]$$

$$[\text{H}^+ \text{ used}] = \Delta[\text{OH}^-] + \Delta[\text{HCO}_3^-] + 2\Delta[\text{CO}_3^{=}]$$

$$[\text{H}^+ \text{ released}] - [\text{H}^+ \text{ used}] = \Delta[\text{H}^+]$$

therefore

$$\Delta[\text{H}^+] = 6x - 3[\text{Al}^{+++}] - [\text{H}_2\text{AlO}_3^-] - \Delta[\text{OH}^-] - \Delta[\text{HCO}_3^-] - 2\Delta[\text{CO}_3^{=}]$$

From this equation and Table I the amount of alum necessary to change the pH of water from 8.1 to any desired value may be found. These values are shown as the x intercepts of Fig. 2.

ppm ALUM vs. ppm SULPHURIC ACID

TO ADJUST pH FROM 8.1

(MO. ALK. RAW WATER = 56 ppm as CaCO_3)

NOTE: POINTS BETWEEN 0 AND 5.4 ppm ALUM (NOT INCLUSIVE)
ARE OF DOUBTFUL ACCURACY SINCE THE EQUILIBRIUM
CONSTANTS USED DO NOT HOLD IN THIS RANGE.

ALL VALUES TRUE ONLY
AT TEMPERATURES NEAR
20 ° C.

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If y is the number of moles per liter of H_2SO_4 added then $2y$ is the number of moles per liter of H^+ released from the acid.

If only acid is added the equation is

$$\Delta[H^+] = 2y - \Delta[OH^-] - \Delta[HCO_3^-] - 2\Delta[CO_3^{2-}]$$

The values of this equation are shown as the Y intercepts of Fig. 2.

If both acid and alum are added the equation becomes

$$\Delta[H^+] = cx + 2y - 0.3[A^{+++}] + [H_2AlO_3^-] - \Delta[OH^-] - \Delta[HCO_3^-] - 2\Delta[CO_3^{2-}]$$

This equation holds true only for values of x greater than 9×10^{-6} moles per liter. For values less than this the aluminate ion is not at saturation and the constants used do not hold. The values of this equation are plotted in Fig. 2.

CONCENTRATION OF IONS IN ALUM TREATED WATER
AT VARIOUS pH's

MOAlk = 56 ppm as CaCO_3 @ pH = 8.1

All concentrations expressed in 10^{-5} moles per liter.

pH	$[\text{H}^+]$	$[\text{HCO}_3^-]$	$[\text{CO}_3^{--}]$	$[\text{OH}^-]$	$[\text{H}_2\text{AlO}_3^-]$
8.1	0.00+	113	0.67	0.13	5.04
8.0	0.00+	112	0.53	0.10	4.00
7.8	0.00+	110	0.33	0.06	2.52
7.6	0.00+	108	0.20	0.04	1.59
7.4	0.00+	104	0.12	0.03	1.01
7.2	0.01	99.5	0.07	0.02	0.63
7.0	0.01	92.7	0.04	0.01	0.40
6.8	0.02	83.0	0.02	0.01	0.25
6.6	0.03	71.9	0.01	0.00+	0.16
6.4	0.04	59.1	0.01	0.00+	0.10
6.2	0.06	56.1	0.00+	0.00+	0.06
6.0	0.10	34.2	0.00+	0.00+	0.04

pH	$\Delta[\text{H}^+]$	$\Delta[\text{OH}^-]$	$\Delta[\text{HCO}_3^-]$	$\Delta[\text{CO}_3^{--}]$	$2\Delta[\text{CO}_3^{--}]$
8.1	0	0	0	0	0
8.0	0.00+	0.03	1	0.14	0.28
7.8	0.00+	0.06	3	0.34	0.68
7.6	0.00+	0.09	5	0.47	0.94
7.4	0.00+	0.10	9	0.55	1.10
7.2	0.01	0.11	13.7	0.60	1.20
7.0	0.01	0.12	20.3	0.63	1.26
6.8	0.02	0.12	30.0	0.65	1.30
6.6	0.03	0.12	41.1	0.66	1.32
6.4	0.04	0.12	53.9	0.66	1.32
6.2	0.06	0.12	66.9	0.67	1.34
6.0	0.10	0.13	78.8	0.67	1.34

TABLE I

Zircaloy Fuel Element Jackets - E. L. Armstrong

On paper, the cost of fabricated Zircaloy jackets has risen from about \$30 per pound to \$75 per pound in the last six months.

For dual purpose operation of the intermediate power graphite reactor, the cost of Zircaloy jacket throw-away has become a major item of expense. At 700 MWD/T exposure, for example, the cost per year is over five million dollars. There exists at least two ways to avoid this expense during dual purpose operation. Stainless steel and possibly certain aluminum alloys may be used. Stainless steel will increase the enrichment requirements and decrease the conversion ratio. The total cost of the increased inventory value, loss in production, and cost of steel jackets, is less than $3\frac{1}{4}$ million dollars. The possible use of aluminum alloys is somewhat uncertain due to corrosion problems in hot water (about 300°C).

In any event it is possible to save in excess of four million dollars by using stainless steel and perhaps by using aluminum.

For single purpose operation (5000 MWD/T), the cost of the Zircaloy throw-away is reduced to about $3\frac{1}{4}$ million dollars. The cost to use stainless steel instead, is about $3\frac{1}{4}$ million dollars. The assumption is made here that the fuel is discarded after irradiation. This assumption is strictly an economic convenience. By making this assumption it does not become necessary to speculate on costs of possible fuel cycles. However, with this consumption, the full difference in the cost of the fuel must be charged. In the dual purpose case, no charge is made here because the saleable uranium after irradiation is also worth more. Document HW-33450 is being issued to cover this problem in more detail.

It should be mentioned that during the dual purpose operation of the reactor, the hole in the fuel element could be made smaller. This means fewer elements are put through the reactor per year. For example, if the hole were .25 inches in diameter and the fuel irradiated to 1000 MWD/T, the Zircaloy cost per year would be \$2.74 million. At 1000 MWD/T and a .5 inch hole, the cost would be \$3.64 million at 600 MWD/T and a .5 inch hole, the cost becomes \$6.0 million.

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