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HW--36920

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Classification Canceled (Change to DECLASSIFIED)
By Authority of RLO CG-4
CA Bauman 12-4-91
By PM Eck 10-20-92
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May 31, 1955

This Document consists of 13 Pages No. 26 of 26 Copies, Series A

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COPY 1 OF 1, [redacted]

FUTURE POWER LEVELS OF HANFORD PILES

This document has been prepared in response to a recent request* from the Atomic Energy Commission for a brief review of the principal ideas and technical developments which might affect power levels over the next six years. Also requested were approximate data on any pile modifications that might be involved, including rough estimates covering possible cost and completion dates.

The forecasts which follow must be presented with a number of important qualifications. It has been assumed, first of all, that much better slugs will be developed during this period, and at a rate which will keep pace with the increasingly severe service requirements of higher and higher pile power levels.

* Letter D. F. Shaw to W. E. Johnson, March 28, 1955, "Speculations on Future Power Levels of Hanford Piles."

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The entire forecast is dependent upon timely realization of this prime objective of the Pile Technology program. The timing projected for achievement of various increments in pile power has been estimated on the basis of favorable results in a continuing research and development program; it likewise has been assumed that budgetary provision for necessary capital outlays will be a straightforward matter based upon an undiminished demand for further production.

An optimistic approach of this kind appears to be well taken in any speculation as to the possible course of pile power levels over the next few years. While such speculative forecasts cannot be considered as commitments in any sense, it is our plan to revise the figures each year and thus through repeated refining and adjustment of the predicted levels to arrive eventually at figures which should provide a sound approach to the overall planning problem.

SUMMARY:

A brief discussion of plans for increasing the power levels of the Hanford Piles is provided. This document does not attempt to outline an overall plan for the Hanford Atomic Products Operation and no consideration is given here to the basic question of when it may become desirable to build new piles rather than to improve existing units. It will also require further study and development work to resolve the ultimate question of whether it is feasible and economically desirable to convert the piles to recirculation.

Within these limitations, the plans for increasing power levels involve the following improvements to the piles:

1. Project CG-558 for increasing the total water flow rates of the B, D, and DR Piles to 71,000 - 74,000 gpm and a similar project for the F and H Piles.

2. Project CG-600 for increasing the total water flow rate at the C Pile to 94,000 gpm.

3. Development of methods of reducing slug corrosion and to a lesser extent, tube corrosion.

4. Increase of the total flow rate through the K Piles to the maximum capacity of the process pumps - about 165,000 gpm.

5. Solving problems associated with pressurization of the rear face piping to allow maximum tube outlet temperatures of about 160 C at the B, D, DR, F, and H Piles, and of about 145 C at the C, KE, and KW Piles.

6. The replacement of present 2S, 72S clad, aluminum tubes with tubes having higher creep strength.

7. The development and production of slugs which will withstand irradiation at the high power levels to a reasonable discharge exposure.

Assuming that the above improvements can be achieved, the goal power levels (maximum) after completion of the program in 1961 can be summarized. For the following summary table it has been assumed that no major technological restriction to the plans will occur. It should be recognized further that major alterations to existing units require shut down time, and it is possible that the pressure for delivery of product could delay such improvements. Within these limitations the following table gives the goal power levels for 1961.

GOAL POWER LEVELS FOR 1961

Pile	Estimated Maximum Power Levels Summer	Estimated Maximum Power Levels Winter
B	2200	2500
D	2200	2500
DR	2200	2500
F	2200	2500
H	2200	2500
C*	2500	2800
KE*	4600	5100
KW*	4600	5100

* 5000 MW at C and 10,000 MW at each K Pile in 1962 if recirculation is provided.

DISCUSSION:

1. Process changes and approved or definitely planned plant modifications which produce increases in production.

A. Project CG-558

This project is divided into two phases. Briefly, Phase I of this project consists of the following:

1. The installation of poison column charge-discharge equipment, the replacement of horizontal rods and the replacement of all Panellit* gages.

* A Panellit gage indicates the pressure at the venturi throat or orifice just upstream of the inlet of each process tube.

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2. Modifications of the water plants and inlet piping and fittings of the B, D, and DR Piles to produce total flow rates of 71,000 to 74,000 gpm as compared to present flow rates of 48,000 to 53,000 gpm.

3. The preparation of detailed design for the modifications of "2", above, for the F and H Piles.

It is expected that the increased water flow rate will become available at the following times.

B Pile - November 1, 1956.
DR Pile - January 1, 1957
D Pile - March 1, 1957

Within a very few months thereafter power increase percentages equivalent to the percentage of flow rate increase (40 to 45 per cent) should result, provided that slugs sufficiently rupture resistant are available, and that for the slugs which are available, the exposure can be low enough to prevent an excessive rupture rate.

The estimated total project cost for Phase I is $26,984,000 including $184,000 transferred capital property, and not including shutdown time. A total of about ten pile months of shutdown time is required. Nearly 1600 megawatts of additional production capacity should result.

B. Project CG-600 for the C Pile

The flow rate at the C Pile will be increased from 83,000 to about 86,000 gpm by the installation of new front nozzles, fittings and connectors either early or late in 1946. During the Summer or Fall of 1946, the present process pumps will be replaced with new, more efficient pumps, raising the total flow rate to 94,000 gpm.

The estimated total project cost, exclusive of the cost of about three weeks shutdown time, is $1,000,000. About 260 megawatts of additional production capacity will result.

C. Process changes other than major plant modifications

These process changes consist of the expected schedule for raising the limitations to pile process tube and bulk outlet water temperatures, pile graphite temperatures, and of the use of enrichment for increasing power levels, if tube outlet temperature limits are not high enough to make enrichment unnecessary. Briefly, technology must be developed so that changes in process limits can be made as follows:

1. Increase of the bulk outlet temperature limit to 100 C as the result of pile testing.

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2. Increase slug and tube corrosion limits by successive steps of process water pH reduction from the present 7.3 to 7.0, and some value below 7.0. It is hoped that the tube outlet water temperature limits for 800 MWD/T slug exposure can be increased in steps to 135 C by these pH changes. Preliminary testing has shown that considerable increases are probable, and further testing is in progress to determine magnitudes.

3. Effective elimination of graphite temperature limit for the highest power levels as the result of small scale and full pile tests, now in progress.

4. Increase of tube outlet water temperature limits necessary to prevent unstable boiling in the process tubes to 130 - 135 C by minor pressurization of the rear crossheaders, and by development of more information on tube boiling and its effects. To achieve limits higher than 130 - 135 C, modification of rear piping will be required, and will have to be done under auspices of a project. This project will be discussed in a later section.

The foregoing changes in process limits are expected to have the effect of increasing power levels up to that allowed by the 100 C bulk outlet temperature limit by the Summer of 1946. In August and September 1956, when the inlet water temperature is 20 C, resulting power levels for the total flow rates which would exist at that time are shown below. Maximum Winter power levels (5 C inlet) for this limit are also shown.

Pile	Total Flow Rate gpm	Power Levels, MW Summer	Power Levels, MW Winter
B	48,000	1020	1200
D	52,500	1110	1330
DR	51,000	1070	1270
F	46,000	970	1150
H	56,000	1180	1410
C	94,000	1980	2350
KE	165,000	3480	4130
KW	165,000	3480	4130
	Totals	14290	16970

D. <u>Other process improvements necessary to achieve these power levels or to increase production by increasing the time operated efficiency are as follows:</u>

1. Replacement of tube orifices by venturi tubes at H Pile will increase the total flow rate from 52,000 gpm to 56,000 gpm.

2. Resetting the pressure indicating ranges of the K Pile Panellit gages will allow the total flow rate to be increased from 138,000 gpm to 165,000 gpm.

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3. The development of slugs which will not have excessive rupture rates at the expected specific powers will be necessary. Present slugs would probably be suitable for the above power levels at the B, D, DR, F and H Piles though some reduction in exposure may be necessary. At the C and K Piles, particularly the C Pile, the suitability of present slugs is not likely, even for production of low exposure product (200 - 300 MWD/T). New slug types would probably be required. A series of new slug types have recently been tested. In their present state of development, none of these slugs has shown superiority over present solid slugs. However, internally-externally cooled cored slugs have not yet been adequately tested. One modification of the externally cooled cored slug has been developed since initial testing and will be tested shortly.

Metallurgical examination of the experimental slug failures is in progress. From this work and from new developments, it is expected that a superior slug will be developed.

4. Completion of the replacement of the horizontal control rods and their thimbles with new rods sealed at the pile face will be required. This work is a part of Project CG-558 and will probably be completed shortly. If the rods were not replaced, power level would have to be restricted to prevent softening and sagging of the thimbles.

5. New, improved pile temperature instrumentation is needed to assure pile safety. Operating power levels up to that allowed by a 100 C bulk temperature rise could be made without addition to or modification of the instrumentation other than increase of the indicating range of temperature and power level measuring instruments. However, both pile safety and time-operated efficiency would be improved by the installation of temperature devices on 100 to 150 selected process tubes. These devices would automatically indicate approach to unsafe temperatures, allowing better temperature control, particularly on startups after brief shutdowns. The devices would also shut the pile down automatically before unsafe temperatures were attained. The project proposal for this work is being prepared. It is expected that the total project cost will be about $500,000 for the B, C, D, DR, F and H Piles, and that the completion date will be Summer or early Fall of 1946. At the K piles, the only work required to establish a similar system will be the installation of a read-out system for outlet temperatures of selected tubes with warning for approach to unsafe temperatures. This work can probably be done at a cost of about $30,000.

6. Replacement is planned of the present system which monitors principally the beta activity of the process water at each end of each rear crossheader for the purpose of detecting slug ruptures. The replacement system is a scintillation-type gamma ray monitor which will monitor water from the same sources. Earlier and more definite detection of slug ruptures should be possible. This should effect

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an increase in time-operated efficiency because fewer slug ruptures will become lodged in the process tubes. This work is to be done under auspices of the following projects:

Pile	Project Number	Total Estimated Project Cost
B, D, DR, F, H	CG-578	$ 527,000
C	CG-579	135,000
KE, KW	K Construction Project	350,000

For operation at and above 100 C bulk outlet temperatures some difficulty caused by the temperature of the water sample may be experienced. Development work is presently in progress to define and solve this problem. It is expected that modifications necessary for the elimination of this problem can be made under auspices of the respective projects.

7. The use of sufficient enrichment to maintain 1380 effective power tubes* at the B, D, DR, F and H Piles, 1460 effective power tubes at the C Pile, and 2300 effective power tubes at the K Piles would be required to prevent restriction by tube outlet temperature limits to a lower power level than allowed by the 100 C bulk outlet temperature limit. This assumes that the lowest tube outlet temperature limit will be 130 C, as stated in part C-4. If tube outlet temperature limits are lower, the maintenance of a higher number of effective tubes could probably be economically justified.

8. Installation of improved, faster acting vertical safety rods is planned. This is not necessary for the attainment of the quoted power levels, but can be justified on the basis of improved pile safety. New rods would be required for the B, C, D, DR, F and H Piles, a slight modification of the K Pile rods is necessary. Total budgeted cost is $4,650,000.

9. Also justified on the basis of pile safety may be the installation of tube-outlet-temperature-sensitive automatic shutdown devices on every tube, and the provision of new or modified tube flow measuring devices. A total of $7,250,000 has been budgeted of these items and also for possible installation of devices measuring local power level rising periods.

E. Power Levels Produced

The completion of all the items listed in parts A, B, and C are expected to result in maximum power levels identical to those given in part C, with the

* No. of Effective Power Tubes = (Power Level)/(Maximum Tube Power)

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exception of higher levels for the B, D and DR Piles because of completion of Phase I of CG-558. Thus, in March 1957, the following goal power levels (maximum) should be possible.

Pile	Total Flow Rate gpm	Power Levels, MW Summer	Winter
B	74,000	1560	1850
D	74,000	1560	1850
DR	74,000	1560	1850
F	46,000	970	1150
H	56,000	1180	1410
C	94,000	1980	2350
KE	165,000	3480	4130
KW	165,000	3480	4130
	Totals	15770	18720

II. Projected and Proposed Process Changes and Plant Modifications for Further Increases in Production

A. Project for Increasing Flow Rates at the F and H Piles-Phase II of CG-558

This project would be essentially the same as Project CG-558 for the B, D, and DR Piles. Total flow rates of 71,000 - 74,000 would be obtained. The total project cost is estimated to be $11,200,000. The attainment of these flows, assuming project approval in August or September of this year, is late in 1957 or early in 1958. Four months of shutdown time would be required.

B. Charge-Discharge During Operation

Pile testing is in progress on a system which allows charging and discharging of uranium slugs during operation. The system consists of a ball-type valve installed on each inlet and outlet nozzle. A special charging machine permits slugs to be charged one at a time through a water lock. Discharge of a process tube may be accomplished by opening the rear ball valve, thus flushing the slugs from the tube or by other methods. It is planned to take continuous effluent water samples from each vertical column of tubes. These samples would be monitored by a gamma ray monitor of the type described in part I, D, No. 6. This indication plus the indication from the crossheader will show which tube contains a rupturing slug. Since the tube can be determined during operation and discharge can be attempted immediately thereafter, it is expected that a high percentage of slug ruptures can be discharged before they become lodged in the tube.

The following gains should result from the use of this system:

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1. Five to ten per cent production would be gained, depending on the uranium throughput rate, because of the elimination of shutdown time and low-power-level operating time.

2. Shutdown time now required for removal of slug ruptures should be reduced. Consequently, if power is limited by rupture rate economies, higher powers could be achieved.

3. Improvement of operating power distribution should increase production two to four per cent.

First installation of this system is planned by September 1956 for the C Pile as a 100 tube demonstration unit. Full installation at C Pile would be completed about a year later. Indicated cost for the C Pile is about $1,800,000. Application to the K Piles is being studied. A possible completion date at the K Piles is Spring 1959, and estimated cost for the installation at both piles is of the order of $5,500,000.

C. Pressurization

Pressurization of the rear piping to allow higher bulk outlet temperatures is under study. In general, pressurization would be effected by placing a restriction or restrictions in the effluent piping at one of the following locations:

1. At the rear of each tube.

2. At both ends of each crossheader.

3. At the top of each riser or between the risers and the downcomer.

4. In the downcomer.

5. Between the downcomer and the retention basins.

To dispose of the large volume of steam which will be generated, one of the following three methods will be used.

1. Addition of relatively low cost, low pressure "quench" water upstream of the flow restriction.

2. Electrical power recovery.

3. Discharge of steam from a steam separator into the atmosphere.

Of these alternatives, the use of quench water has been more thoroughly investigated, and will continue to receive primary consideration. Study of electrical power recovery will continue but it is not expected that any electrical power recovery system would be put into operation before 1961 or 1962. Discharge to the atmosphere has undesirable radiological and meteorological effects, but has not been definitely eliminated from consideration.

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Preliminary cost estimates of pressurization with quench water and with the restriction at locations 2,3,4 and 5 above, have been made. The least expensive appears to be alternative 2, i.e. restriction at both ends of each crossheader. With this alternative, two new risers would be installed on the rear face to supply water upstream of each restriction. River water would be supplied to these risers through a new pipe line from new pumps. The river pump house would be enlarged to accommodate these pumps, and provision would be made for increased pressure in the junction boxes of the effluent line, provision to pump water from certain process drains into the effluent system would be required. Total estimated cost of this system is of the order of $3,000,000 per reactor. It should be emphasized that this is one alternative that now appears possible. Continued investigation may show that more extensive modification is required, or that other alternatives are more desirable.

With this system installed, the rear face pressure could be raised to the maximum value economically desirable for the existing water plant. This maximum is dependent on the way that tube flow rates and tube boiling outlet temperature limits vary with the pressurization pressure used. Increasing this pressure increases the tube boiling limit. However, as this pressure is increased, the inlet pressure can be increased to maintain tube flow rates only to a fixed point. As the rear face pressure is further increased, a point is soon reached at which a further increase would cause a decrease in allowable power. For tubes having annulus sizes the same as presently used, calculations have shown the following maximum tube outlet temperatures:

Pile	Maximum Tube Outlet Temperature, °C
B,D,DR,F,H	160
C,KE,KW	145

However, tests may show that these temperatures are either high or low. In particular, the value for C, KE and KW has been only roughly calculated. Detailed study and testing will be required.

At the B, D, DR, F and H Piles, more flow and thus more power can be achieved by increasing the annulus size. The optimum annulus size has not been determined but is somewhere between the sizes presently used at B and C Piles. Presumably, this would be done by decreasing slug diameter, although it is possible that a tube material having sufficient strength and corrosion resistance to allow thinner wall construction will be found suitable. To achieve these tube outlet temperatures several other improvements will be necessary in addition to solution of all the design problems associated with pressurization and high outlet temperatures. These are:

1. The maximum tube outlet temperatures of present tubes at the proposed pressures, from considerations of 2S aluminum creep, is believed to be about 140 C. Tubes made of 63S aluminum, which has about twice the creep strength of 2S are being tested. It is expected that tubes of 63S or some other alloy would be installed at the same time as pressurization equipment at the B, D, DR, F and H Piles. This cost is not included

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in the current estimate of $3,000,000. Installation of new tubes at the C and K Piles may not be necessary but if needed, would probably be done only as old tubes required replacement. Zirconium tubes are also under investigation. The cost of zirconium tubes is presently high, but will undoubtedly decrease in the future. The justification for the use of zirconium tubes depends on the process tube outlet water temperatures achievable with tubes of zirconium as compared to aluminum, and on the relative costs, including later replacement requirements, of tubes of the two materials. Because the above information cannot now be predicted with reasonable accuracy, the lowest outlet temperature at which use of zirconium is desirable is not known. However, rough estimations range from 140 to 170°C. Continued development and testing of zirconium tubes is necessary because there is a fair chance that they will prove desirable and also because of the possibilities for recirculation of the cooling water with still higher water temperatures.

2. Increase of slug and tube corrosion limits to 160 C tube outlet temperature will be necessary. The planned schedule of pH reduction is expected to allow tube corrosion limits of 160 C and slug corrosion limits for 600 MWD/T exposures of 140 C by the middle or last of 1957. By the end of 1958, further improvement by increasing can wall thickness or some other change may allow 160 C for slugs exposed to 600 MWD/T.

3. The largest uncertainty in achieving these maximum temperatures is slug quality. By slug quality is meant the resistance of the slugs to ruptures caused by uranium cleavage or failure. An intensive development program to produce slugs which will withstand high specific powers at reasonable exposures is underway.

While there is some possibility that solid cores will operate satisfactorily with the centers in the β phase ($\sim$ 660 C) it appears unlikely that they would operate in the γ phase - a condition which would be imposed by the 110 - 120 KW/ft. specific power and 160 C outlet temperatures contemplated after pressurization of the rear piping. One solution might be a slug with increased surface to volume ratio. The least radical alteration of present geometry is the internally-externally cooled slug already mentioned. The proposed specific powers will impose severe stresses on even this slug. Other solutions may be possible.

Possible completion dates for pressurization are of course quite tentative. It is hoped that modifications could be completed by some time in 1961. Goal Summer and Winter power levels (maximum) are given below:

Pile	Goal Power Levels (Maximum) Summer	Winter
B	2200	2500
D	2200	2500
DR	2200	2500
F	2200	2500
H	2200	2500
C	2500	2800
KE	4600	5100
KW	4600	5100
Totals	22700	25500

Increases above these power levels may be found possible without additional modifications, particularly at the K Piles. Also, it is possible that relatively minor modification of the piles or water plants may allow higher power levels. An example is replacement of the K Pile process pumps with higher capacity pumps. Neither this example nor any other schemes have as yet undergone more than cursory examination, with one exception. The exception is recirculation which is discussed in part E.

D. Other Improvements and Problems

To achieve the power levels projected after pressurization, several other changes may or will be necessary, or would improve the time operated efficiency. A listing follows:

1. A method of reducing the incident neutron flux, or of cooling of the exposed side shields of the old piles, may be necessary. A method of reducing the flux by poisoning the fringe tubes and compensating the reactivity loss with enrichment is to be tested.

2. Revision and extension of the range of instrumentation will be necessary.

3. It may be necessary to provide some means for reducing the discharge to the Columbia River of radioactive materials. Reliable predictions of the magnitude of this problem cannot be made at this time, but considerable extrapolation of available data indicates that some action will probably be necessary.

   Changes in water quality are undergoing preliminary study. Recirculation, discussed in part E, below, would solve the problem. In fact, reduction of radioactive river discharge may become a major justification for the adoption of recirculation.

4. Methods of segmental discharge are under study and might be employed in two or three years. Uranium consumption would be reduced.

5. A method of using poison splines for supplemental reactivity control during operation is being developed. Time-operated efficiency would be improved.

6. Plant modifications to provide auxiliary cooling in case of a disaster caused by bombing or Grand Coulee Dam rupture are being investigated and appear desirable. However, such a system is not essential for the achievement of the predicted power levels unless the following reasoning should apply. It is possible that consideration of the serious effects of a major pile disaster involving loss of cooling water and vaporization of fuel would result in a decision that in-pile inventory of fission products, and thus power level, should be restricted to some value. Provision for reliable auxiliary cooling would considerable reduce the very small probability for disaster that does exist.

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7. New nozzles and new methods of process tube closure are being developed. These would allow replacement of process tubes without nozzle removal, and so would save shutdown time.

E. Recirculation

A study of recirculation was reported in document HW-30907-RD. "Economic Evaluation or Recirculation as a Method of Pile Cooling", (4-7-54). The general conclusion of this report was that recirculation at high outlet temperatures is economically attractive, if a number of assumptions were found true, and that recirculation with high outlet temperatures should be tested and further investigated.

Investigation is in progress and in-pile testing will soon begin. It is expected that by 1958, sufficient technology will have been demonstrated to provide design bases for pile alterations. Project study on these bases through 1959 could lead to firm plans for conversion to recirculation, provided economic desirability exists at that time. Construction might then be possible in 1961. Provisions for pressurization previously completed would probably be largely adaptable to recirculation. The most likely piles for application of recirculation are the K and C Piles. Power levels would be in the range of 5,000 and 10,000 megawatts at the C and at each K Pile, respectively. Reference to Case 5, pages 57 and 58 of document HW-30907, may be made for details on the most probable installation.

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