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Released 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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3. ~~105~~
4. 700 2400
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~~W. J. Agnew~~
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DATE Dec. 14, 1950

SUBJECT Limits of Pile Operating Level

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J. W. B.	1-10-51
R. J. B.	1-22-51
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Richland, Washington
December 14, 1950

LIMITS OF PILE OPERATING LEVEL

INTRODUCTION

This report, compiled by Mr. W. R. Lewis of the Pile Technology Division, is a revision of Document HW-15516 (January 5, 1950) in consideration of new knowledge obtained during the past year. The document discusses the technical factors involved in attaining higher power levels in the various Hanford Piles. The purpose of this presentation is to summarize the present operating limitations and the possibilities of increased production rates.

The limitations discussed are:

- A. Reactivity and flattening
- B. Aluminum thimbles
- C. Graphite temperature considerations
- D. Boiling or vapor binding considerations
- E. Tube and slug jacket corrosion
- F. Effluent water activity
- G. Distortion of the biological shields
- H. Radiation considerations
- I. Pile control system capacity

The current power levels of the Hanford piles and the immediate limiting conditions are:

<u>File</u>	<u>Power</u>	<u>Limiting Condition</u>
B	365	Graphite temperature
D	335	Graphite temperature
DR	430	Available reactivity and boiling consideration
H	470	Graphite temperature in the region of the enriched fuel slugs and boiling considerations
F	315	Graphite temperature

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SUMMARY

Sufficient reactivity is normally available in the Hanford piles so that the nuclear reaction could be maintained at levels of 600 MW or higher. However, the excess reactivity available for flattening determines the uniformity with which the heat generation can be distributed in these piles and therefore has a significant effect on the power levels obtainable. The maximum operable power level is determined largely by the ability to remove heat generated without excessive temperature in the various pile components. The power levels of the B, D, and F Piles are now limited by temperature of the graphite moderator, the DR Pile is limited by the ability to remove heat from the uranium without excessive corrosion or vapor binding, and both these considerations are limiting at H Pile.

The immediate program for the B, D, F, and H Piles is directed towards obtaining information and modifying the piles so that the limiting moderator temperature can be safely increased from the present 380-400°C limit to 500°C or higher. There is a reasonable chance that this can be accomplished within 1 to 1-1/2 years. If so, operating levels of about 450 MW should be feasible at the B, D, and F Piles and 500 MW at the H Pile before the next restriction is reached.

The second limitation, that of removal of heat from the uranium, depends primarily on the process water supply available for the operating piles. Pressure, flow, and water quality available from the present water plant equipment are the factors which determine the limits based on the possibility of vapor binding, corrosion, and film formation in the piles. Currently, it appears that some increases in power level above the 450-500 MW range are possible, but only rough estimates can be made until further information has been obtained.

It is expected that at the DR Pile reactivity gains during the next six months will permit improved flattening with an attending power increase to 500 MW.

A. Reactivity and Flattening

The reactivity, k , is a measure of the multiplication of neutrons within a pile in each succeeding generation. At equilibrium operation at any uniform power level k is unity, if it were slightly more than unity the power would increase exponentially. In order to control the reaction, neutron absorbing materials i.e. poisons, are used in the form of control rods and special loadings in process tubes. The cold clean reactivity of a pile is a term used to denote the k in excess of unity when the pile is shutdown if all control rods, poison columns and xenon were removed. This excess reactivity depends on pile design, characteristics and exposure of the uranium slugs, pile atmosphere composition, purity of graphite and the amount of neutron absorbing materials present. Sufficient cold clean reactivity is available at the B, D, and F Piles when charged with natural uranium under present operating conditions to permit a power level increase well above 600 MW. Shortly after startup of the DR Pile a few temporary restrictions were encountered because of insufficient reactivity at levels of 400 to 430 MW. After about six months of operation no reactivity restrictions are anticipated below 600 MW, primarily because of gains from increasing plutonium inventory in the pile.

The H Pile is now being used for large scale production of tritium in addition to normal plutonium manufacture. The reactivity absorbed in the Li-Al target slugs is supplied largely by the use of U^{235} in order to maintain the desired operating conditions. The term "cold clean reactivity" under these conditions of special loading has little significance as it is only a function of the amount of U^{235} added. If the H Pile were loaded with natural uranium it would have slightly more reactivity than the DR Pile.

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At the present time the power levels of the Hanford Piles are limited because of the possible adverse effects resulting from exceeding a certain maximum heat generation in a local area of a pile rather than the heat generation of a pile as a whole. Therefore, the uniformity of heat distribution is important in determining the total output. A radial flattening is obtained by the use of carefully spaced poison columns of properly adjusted strengths, so that a large number of the process tubes in the central zone of the pile operate at approximately the same output. The extent to which a pile can be flattened in this manner depends on the excess reactivity available for this purpose and the skill with which the poison columns are located.

One convenient measure of flattening is the effective number of tubes of maximum heat generation. If a 2000 tube pile is operated without flattening there are approximately 1000 effective tubes. If the heat generation is limited to 390 KW per tube the total pile output would be 390 MW, which is a condition analogous to the DR Pile shortly after startup and before there had been any reactivity gains from metal exposure. At the B and D Piles reactivity gains from higher metal exposure and graphite temperatures permit 400 to 500 inhours of flattening, resulting in about 1400 effective tubes. It is expected that there will be sufficient reactivity available at the DR Pile in about six months so that the power level can be increased to 500 MW by flattening without increasing the heat generation in any individual tube.

The uniformity of heat distribution which can be obtained is not a direct function of the amount of excess reactivity available. It depends upon a nice balance of the poison pattern. Reactivity changes at each shutdown due to discharge of metal, special irradiations, and other changes in operating conditions change the balance or temperature moment causing a change in number of effective tubes and therefore in power level. Changes of 5% in power level from one operating period to the next are not unusual. Therefore, if the piles are to be operated at their maximum outputs each impending change in reactivity must be carefully evaluated for its effect on the heat distribution.

Power level increases decrease flattening at the rate of about 0.2 to 1.0 ih/MW. Small increases above the present power levels at the B, D, and F Piles will increase the neutrons available for tritium production in poison columns even though the amount of target material is decreased. Under some conditions, such as the DR Pile at present or other piles at extremely high levels, the tritium production may be decreased by power increases. The use of U^{235} to increase reactivity either for increased flattening or for production of special isotopes is feasible under some conditions. The special loading in the H Pile is an illustration.

B. Aluminum Thimbles

Aluminum thimbles are used as a gas seal around the vertical and horizontal rods. In addition, the vertical thimbles are used as containers for the third safety device, which is a water solution of borax.

For purposes of gas seal it is probable that the thimbles can be operated at a temperature of 500°C. Failure of a single thimble would not be serious. Several thimbles have been replaced in the past at a cost of about \$100 plus eight hours shutdown time each. Therefore, if the liquid third safety is not considered, temperatures of the aluminum thimbles probably would not be limiting at power levels below 450 MW at B, D, and F Piles and 600 MW at DR and H Piles.

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Although the present third safety system is not limiting to power, its effectiveness decreases and the risks involved in the system increase with increasing graphite and thimble temperatures because:

1. The injection of the liquid into this long hot tube, the only opening of which is restricted with a solid rod, would produce a geyser effect which might eject most of the liquid from the tube. This could reduce the amount of control exerted by the boron to provide little or no effect.
2. The pressure developed by the steam produced in the thimble might well rupture the thimble and allow the boron containing solution to run into the graphite moderator.

If either event occurred, the final result might well be the permanent destruction of the pile's usefulness, depending of course on the extent of the effects described above.

In order to overcome the objectionable features of the present vertical thimbles and aqueous third safety, it is planned to remove the thimbles, use external gas seals, and provide a boron-steel ball third safety. These improvements which are under study at the present time are expected to take one to one and one-half years to accomplish. Preliminary studies of removal of horizontal thimbles and provision of external gas seals are also in progress.

C. Graphite Temperature Considerations

The power level of the B, D, and F Piles is limited by graphite temperature. This is also true at H Pile because of the use of low density enriched fuel slugs which increases the heat load on the graphite. At the present time graphite temperatures would not limit the power level of the DR Pile below 600 MW, but this condition could be altered by progressive irradiation damage or by use of low density enriched fuel slugs.

An increase in the power levels of the piles, except for DR Pile, involves either or both of the following factors:

- a. An increase in the central graphite temperature.
- b. A partial or total displacement of the carbon dioxide pile gas by helium.

The older piles, B, D, and F, have already sustained large amounts of irradiation damage to the graphite moderator particularly in the cooler fringe zones. Further expansion in these piles may result in rapid deterioration and for this reason, it is not at present considered advisable to use any helium in the pile gas. However, at the H Pile improved design of the graphite structure will accommodate expansion of the tube bearing graphite blocks without distortion of the pile structure as a whole. Therefore, partial replacement of the carbon dioxide by helium may be justified if a higher rate of output can be obtained.

The chemical reaction between the carbon dioxide atmosphere and the graphite moderator is now under investigation. Preliminary data obtained from an experiment on the rate of reaction of carbon dioxide with graphite in the pile at a temperature of about 380°C suggest that burnout, even at this temperature, may be a serious problem. A rate of about 1%/1000 days was determined; this is considerably higher than calculations based on currently available literature data would indicate.

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Because of the complicated nature of the burnout problem, it is not possible to use the pile gas composition as an indication of the degree of severity of burnout. The maximum burnout may occur in a very small, but hot, region in the central zone of the pile. Initiation of burnout to any significant degree in a localized hot region would lower the thermal conductivity in that region; this would raise the temperature and accelerate the burnout, which in turn would lower the conductivity, which would raise the temperature, etc., until the localized burnout reached serious proportions. This could proceed to a very serious degree without unusual changes in the pile gas composition. The total volume of gas product resulting from the burnout might be small compared to the total amount of gas in the circulating system. Present information on reactions between graphite and gases indicates that both previous radiation damage of the graphite and also concurrent irradiation effect large increases in the normal reaction rates. Data are not yet available on the maximum amount of burnout which can be tolerated without serious reduction of the mechanical strength of the graphite.

Investigations are in progress, and detailed studies have been planned, which will allow the determination of optimum operating conditions with regard to power level, graphite temperature, and gas composition. Some information should be available within 6 months which will allow a re-evaluation of the problem, and may indicate that the present decision to hold the graphite temperature below 380°C is conservative. At that time the problem should be re-considered.

The apparent thermal conductivity of the graphite moderator varies from point to point in a pile because of differences in type of graphite, changes in thermal conductivity and dimensional changes. Because of the large number of thermocouples in the graphite of the H Pile it is feasible to operate this pile closer to the limiting temperature than can be done at the B, D, and F Piles. Additional thermocouples are being installed in the B, D, and F Piles at the present time. With information gained from these thermocouples it may be possible to increase the power level of the B, D, and F Piles by 10 to 15% without exceeding the present operating temperature limit.

D. Boiling or Vapor Binding Considerations

It has been the operating policy to restrict the heat generation in any tube so that if boiling should be initiated there would be sufficient header pressure available to sweep the steam out of the tube, thus preventing vapor binding. These limitations, as described in Doc. 7-2562, are dependent largely on the header pressure.

The present boiling limitations, which are based on the calculated header pressure required plus 30%, are approximately:

BOILING OR VAPOR BINDING - PRESENT LIMITS

Header Pressure psi	KW per tube	Temperature Rise °C (0.240" orifice)	Power Level MW	
			1090 Effective Tubes	1300 Effective Tubes
330	329-341	63		428-443
350	347-364	65		451-473
385	390-404	68	425-440	503-523
400	405-426	70		504-552

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There are some variations from the above values depending on film, dummy pattern and inlet water temperature. With the present 330-350 psi header pressure and about 1400 effective tubes the D and B Piles are limited in this respect to about 450 MW.

DR Pile now is operating with about 1090 effective tubes. It is expected that in about six months sufficient reactivity will be available to allow it to be flattened to 1300 to 1400 effective tubes. With the current 385 psi header pressure this should result in a power level above 500 MW. The H Pile at present has 1350 to 1400 effective tubes and a header pressure of 358 psi. This results in boiling limitations at 470 to 500 MW.

E. Tube and Slug Jacket Corrosion

The rate of corrosion of the aluminum is largely determined by temperature, water composition, and alloy constituents. Under normal Hanford conditions the maximum slug surface temperature is 8°C to 10°C above the outlet water temperature assuming no film on the slugs. With maximum film this would be increased an additional 5°C or more. If the slug cans and tube were of the same material the temperature difference would be expected to cause the slugs to corrode at 2 to 3 times the rate of the tube. However, this is not the case; the tubes are clad internally with a 3 to 7 mil layer of 72S aluminum while the slug cans are 2S aluminum. It is expected that the 72S tube wall will corrode preferentially to the cans near the point of contact. There have been no indications that corrosion due to elevated temperatures of either tubes or slug jackets have been of operating significance at outlet water temperatures of 50°C to 70°C.

If power levels were increased to the point at which operating difficulties were encountered from corrosion at elevated temperatures serious losses would result. Penetration of a slug can permits a rapid reaction between the uranium and water resulting in contamination of the effluent water. Similar occurrences in the past due to defective welds have caused operating losses of 5 to 15 days to clean up the resulting radioactive contamination and remove the ruptured piece. Therefore if serious corrosion of slug cans were general throughout the pile a large part of the uranium would have to be discharged in order to permit continued operation. Equally serious difficulties would result from a high rate of corrosion of the process tubes. Single tubes can be replaced in two to five hours each. A large scale tube replacement, which would be necessary from widespread corrosion, would require several months shutdown time and probably some premature discharge of uranium.

The present operating limit is an 80°C outlet water temperature. The inlet water temperature varies from about 5°C in the winter to 20°C in the summer. The B, D, F and H Piles are now limited to a temperature rise of less than 60°C in the central zones therefore the 80°C outlet limit does not cause a significant loss in production at present. At the DR Pile there will be a loss of about 10% during the summer months with the present permitted 68°C temperature rise.

The rate of corrosion of slug cans in the piles is measured by weighing the slugs before and after exposure. Measurements at temperatures above normal operation are obtained by restricting the flow in individual tubes. As additional information is gained from these "in-pile" test and from laboratory measurements it may be possible to revise the present limit upward.

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F. Effluent Water Activity

The cooling water, in its passage through an operating pile, is made radioactive by the action of neutrons on its various chemical components. These components are present either as additives for control of film formation or as naturally occurring elements in the water.

It has been demonstrated that all of the radio-elements in the water are not of equal importance with regard to their possible harmful effects. The long-lived components are the serious offenders as they tend to be accumulated in the marine plants and aquatic life. The short-lived elements are not of serious consequence with the present water composition provided the present retention basins are used followed by the rapid dilution which occurs as the water enters the Columbia River.

There are no indications that the radioactivity discharged into the Columbia River, when expressed as curies of long-lived elements per gram of plutonium produced, is increased by higher power levels unless changes are also made in water treatment. Although this is a somewhat objectionable feature of plant operation, it is not considered a limitation of pile power level up to 600 MW.

G. Distortion of the Biological Shield

There are two types of distortion of the biological shielding:

- a. Permanent expansion caused by distortion of the carbon moderator under the effects of neutron bombardment.
- b. Thermal expansion of the shields and moderator caused by heating of the graphite and the shielding.

Increasing the power level in general decreases (a), because the rate of graphite irradiation damage decreases rapidly with increasing temperatures of exposure, and increases (b).

The effect of the thermal expansion is to cause non-uniform movement between the various components of the biological shield and possibly to rupture the gas seal between these components. The expansion is not a function of operating level alone, but depends also on flattening, outlet water temperature, pile gas composition, and the several independent variables that affect water flow and temperature.

The original pile design specified that the maximum permissible movement between parts of the shield was 0.07 inches. To date, movements up to 0.038 inches have been observed.

While the rupture of a gas seal may not be an absolute limit on operation, it is not good operating practice to proceed without caution into a condition which may result in such a failure. Unfortunately, the complex nature of the expansion is such that a maximum safe operating level cannot be readily established.

For the purpose of this document, it is probably safe to assume that operation of all Piles up to 500 MW is possible so far as shield movement is concerned. Beyond that point, increases in level should be based on observation of shield movement.

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H. Radiation Considerations

Although the Hanford Piles are provided with massive shields for the purpose of stopping radiation leakage, numerous openings had to be left in the shielding for the performance of the various operations necessary for the proper functioning of the pile. Every such opening in the shields is a possible source of radiation leakage into the operating areas surrounding the piles. At the present time, there are beams of radiation as high as 6 mr/hr. emitted from the front face tubes, and the general background on the top of the reactors is 100 mr/hr. A radiation beam emitted from between the far side and top biological shields reads as high as 2 r/hr at the F Pile. Certain other areas surrounding the piles (the inner rod room, the rear face discharge area, and the basket level) are never entered while the piles are operating because the radiation levels are too high.

If we assume that radiation readings around the piles will increase linearly with respect to the power level, the readings at the discharge area doors would rise to about 40 mr/hr at B, D, and F Piles at 500 MW.

All such readings would have to be considered during an increase in operating level. However, such radiation levels, while requiring more stringent controls, would not impose an actual limit on operating level. Likewise, operation of the piles at higher power levels will increase the radioactivity of objects removed from the piles, such as plugs, process tubes, control rods and thimbles. This will require more elaborate precautions in some operations, and will increase required down-time but will not impose any definite limit on pile operating level.

All experiments and measurements performed to date indicate that the shields are substantially unchanged from their original physical condition, and that there is no indication of unexpected reduced shielding efficiency at higher operating levels.

I. Pile Control System Capacity

When considering the adequacy of the pile control system for operation at higher levels, three separate evaluations must be made:

- a. Ability of the system to stop the operation under emergency conditions in a reasonable length of time.
- b. Ability of the system to control the reaction during reactivity peaks induced by transient poison following startup.
- c. Ability of the system to hold the pile inactive under emergency conditions (loss of water, etc.).

Analysis of these considerations has developed the following facts:

- a. It has been demonstrated that the control system of the piles is adequate rapidly to shutdown the piles from any power level in the range currently considered practical; i.e., up to 600 MW.
- b. With the present power levels at the B, D, and F Pile, generally the effect of reactivity transients is such that the present rod control system alone will not provide adequate control during peak reactivity periods. These effects will increase at higher levels at B, D, and

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- F and will also occur at the DR Pile. However, the use of reduced level or poison start-ups makes it possible to overcome this inadequacy. The additional control provided at the H Pile is adequate to overcome this difficulty.
- c. The present system is sufficient to hold the pile inactive under emergency conditions.

In view of the above, it appears that the control system will not limit operating level up to about 600 MW. It is true that reduced level or poison start-ups will reduce operating efficiency, but this cannot be considered a limit to operating level.

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