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PROJECT 9536

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Date 7-6-45

Subject Consequences of High Power Levels

To [redacted]

From H. Worthington

Copy No. 7-A

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H.V. 9-47

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JULY 6, 1945

INV. 9-47

TO: FILE

FROM: H. WORTHINGTON

CONSEQUENCES OF HIGHER POWER LEVELS

This memorandum discusses the effects of advancing to higher power levels in the light of the original design basis of the 105 Piles and of their subsequent actual operation. It is concluded here that there is no technical reason against a cautious advance to higher powers. The units can be run at substantially higher levels than their rating of 250 MW, or the additional reactivity that they will gain with the passage of time may be taken entirely in the form of lower peak temperatures and radiation levels. The decision as to what course to follow between these extremes involves such issues as the best use of uranium and the most effective separation of adequate amounts of product of proper quality. A discussion of these issues is outside the scope of this memorandum.

A recent study (S-2722, W. K. Woods to File, 6/23/45) shows that, if the present rise in temperature of the cooling water in the hottest tubes at D (43°C) is kept as the limiting criterion, the power of the D-pile could rise in the way given in column four of the accompanying table. Alternatively, if the design figure of 85°C for the maximum allowable outlet temperature from the hottest tube is used to determine the upper power limit, the output could rise in the way shown in column 5. It is strikingly apparent that the additional gains to be expected from the first method are slight in comparison with those from the second.

Potential Power Output from D-Pile

Date	Temperature, °C River	Temperature, °C Inlet	Power Output, MW, Limited by 43° Rise	Power Output, MW, Limited by 85° outlet
7/1/45	14.4*	11.5*	282	333
8/1/45	18.3	14.1	290	333
9/1/45	18.3	14.1	295	340
10/1/45	17.8	15.7	300	349
11/1/45	11.1	12.1	304	375
12/1/45	6.7	6.7	307	395
1/1/46	1.7	5.0	312	415

* Estimated from previous years for purposes of this study. The actual values on that date were 15.7°C for the river temperature and 13.3°C for the inlet to 105 Bldg.

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Date	Temperature, °C River	Inlet	Power Output, MW, Limited by 43° Rise	65° outlet
2/1/46	4.4	5.0	312	415
3/1/46	5.6	5.6	314	414
4/1/46	7.8	7.8	315	405
5/1/46	10.0	9.5	316	397
6/1/46	11.7	10.4	317	396
[illegible]1/46	14.4	11.9	318	385

(NOTE: Attaining these power levels is contingent upon a quality of flattening as good as the plant has maintained for any considerable number of days in the past).

Increasing the power from the present level of 290 MW to 315 by increasing the flattening without increasing the temperature rise in the hottest tubes represents a relatively small step into the unknown; more of the water will reach the same activity as that from the center of the pile, more of the graphite will reach the same temperature as the hottest and the same stored energy and low thermal conductivity as the most exposed material now in the pile, more slugs will develop the same amount of power as the most active ones at present, and more surfaces will be subjected to the same corrosive conditions as those currently being most severely treated. Only insofar as the ever-increasing flattening increases the leakage of radiation from the core of the pile and thus increases the thermal, radiative and structural burden on the shielding does this case represent anything new. As these conditions are at least as severe in the 65° outlet case, they need not be considered separately.

Before proceeding to a discussion of the effects of permitting the outlet temperature from the hottest tubes to advance to 65°, however, a discussion of the reason why this particular temperature has such especial prominence in the record is in order. In April, 1943 it was learned from the Metallurgical Laboratory that experiments on the corrosion of aluminum had shown that bulk water temperatures of 70°C were "safe". (CT 610) For design purposes it was decided to reduce the nominal allowable bulk water temperatures to 65°C. It then developed that under winter conditions a 1500-tube unflattened pile with the tubes and flows that were already embodied in the design would develop about 250 MW. Later experiments at the Metallurgical Laboratory under conditions of heat flux and water composition more like those anticipated in the pile, together with computations of temperatures in the neighborhood of the ribs failed to shake this temperature for design purposes; the higher aluminum surface temperatures that came out of these computations were offset by favorable results from the experiments, which led to the conclusion that the corrosion rates associated with 20 KW per ft. heat generation and 65°C bulk water temperatures were tolerable.

From this discussion it is evident that the principal reasons for limiting the outlet temperature of the water to 65° were those connected with corrosion of the aluminum of the tubes and jackets underneath films or in the neighborhood of the ribs. The actual corrosion rates encountered so far in the plant on the surfaces of the slugs, underneath far thicker films than were thought likely in the original design work, have been on the order of one tenth as great as were considered tolerable then. In view of the fact that by more frequent purges the hottest slug surfaces can be kept as cool at higher levels as they are under current conditions, and moreover, that the corrosion rates are being closely followed by inspection and weighing, slug corrosion appears unlikely to bar an advance to a 65° outlet temperature.

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The surface of the tube that is subject to the most severe corrosive action is the inside of the outlet end, judging by CMX experience. Fortunately, this is fairly easily inspected in the plant, so that the effect of higher outlet temperatures at this point can be watched. Our information on the surfaces inside the pile is derived from borescope observations (which can not detect uniform corrosion), from experiments at CMX and Site X which show that the YBW lining under our conditions of pH, and water temperature corrodes at the same rate as the slugs, and from the fact that the tube walls run at a lower temperature than the slugs because of the far smaller amount of heat that is transferred through them from the graphite. There is, accordingly, more inference involved than in the case of the slugs.

It is recognized that film formation may be more rapid with the higher outlet water temperatures, so that purging will have to be more frequent or more effective. The problem of decreasing the rate of film formation and increasing the effectiveness of purges is being actively worked on. From what has already been found, it appears likely that other factors have as profound an effect on the rapidity of film formation as temperature.

The higher temperatures associated with higher power levels will also affect the biological shields. Extrapolation of the movements of the shields up to 250 MW shows no cause for alarm in going to 415 MW except possibly in the case of the relative vertical movement between the rear and the side shield at the top of the unit, which may reach the caution point at 330 MW. If this point is reached, it will be necessary to review the engineering considerations on which it is based. The gunbarrels should not bind at 415 MW. The graphite temperatures will of course rise, but they are so low in comparison with the temperatures at which the aluminum thimbles will creep objectionably that we feel no concern on this score. All other steady state temperatures at 100-D at 250 MW were so low that a rise to 415 MW should not bring them near the caution point. Energy stored in the graphite as a result of radiation, however, might temporarily raise the temperature in a way discussed later in this memorandum.

Raising the power is accomplished by raising the amount of radiation, which not only increases the temperatures in the ways just discussed, but also produces specific effects. The cooling water will become more active, but it is unlikely that it will be in any new and unusual way.

Operating Standard 105-1A states that the activity of the outlet water from the retention basin "must not exceed a limit of 0.1r/24 hrs. to a receptor submerged in an effectively infinite body of water". The purpose here is to protect aquatic life in the river against continuous exposure to higher levels of radiation than that represented by 0.1r/24 hrs. It was recognized that the water from the retention basin was diluted by the addition of about 50% additional water from other sources, but no advantage was taken of this fact in the Standard. The Standard is also silent on whether the instantaneous activity must never exceed 0.1r/24 hrs., or whether it represents an average that must not be exceeded, and if so, over what period of time it must be taken. In view of the way that similar limitations are used for exposure of human beings, it appears clear that occasional brief rises above 0.1r/24 hrs. are consistent with the purpose of the Standard. The point is important because there have been short periods at 100-F when the activity of the exit water

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from the retention basin has come close to the limit even at 250 MW, while it was averaging about 80% of the limit. This suggests that it may be necessary to take advantage of both the average activity concept and the known dilution in order to operate at levels of 350 to 400 MW, unless it proves possible to keep the ratio of activity to power at or below the current values continuously. It must be admitted, however, that we have not been able to determine with certainty the causes of the periods of high activity nor by following a planned course of action to bring them to an end. Nevertheless, as a result of investigations now in progress, it may prove possible to keep the activity down, perhaps by careful control of additives for water treatment and by proper methods of purging. No change that is of significance to operation is expected in the chemical composition of the effluent water as a result of radiative decomposition.

The Masonite of the biological shields will decompose about twice as fast as at present because of the combination of higher power and more flattening. No deleterious effects have been seen from this source. An exploratory Production Test has been approved to find out how severe the effects may eventually be.

The Metallurgical Laboratory has pointed out that the effect of radiation on the uranium of the slugs may be destructive; stable xenon is one of the end products of fission, and could migrate to voids in the slugs, build up high pressures there, and cause eventual failure. The uranium itself may undergo destructive changes in the crystal lattice and become brittle or crumbly. There has been no indication of either of these effects, but they will be watched for as metal of higher and higher product content is discharged. A limited number of dropping tests of such heavy but fragile matter as lead shot or lead shot plus resin, canned in aluminum, have helped to allay our fears of the effects of embrittlement.

It should be mentioned in passing that the ratio of higher isotopes to product is increased as the neutron flux is raised, if one assumes a constant rate of metal throughput. W 7/14 The change in neutron flux in going from a 45°C maximum temperature rise to one of 60° will represent an increase of 50% or more in these ratios. This problem has been recognized in the changes in flux already experienced, and a system of sampling of the product is now functioning which should enable the customer to inform us if its quality should change significantly for the worse.

The influence of radiation on the properties of graphite is large. Our results are best interpreted by saying that these changes are functions of the total exposure, modified by the thermal history, rather than functions of radiation level. As the thermal conductivity ratio and the stored energy have both levelled out at the present exposure, no further change is to be expected in these quantities except those associated with the higher temperatures that will be encountered. Extrapolation gives a value of 300°C to which the graphite in the center of the piles may rise if the level is raised to 415 MW. The way in which this temperature is approached may possibly be important; it is quite certain that if the graphite temperature were suddenly raised to this value, it would continue to rise to about 500°C, from which it would gradually fall to about 300°, as mentioned above. We do not know what will happen if the temperature is raised much more slowly. It is possible that the release of stored energy will be so slow that the temperature will never rise above 300°C. On the other hand, several hours' operation with a temperature of 300°C is not an especially alarming prospect. This is because there

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is little stress on the aluminum thimbles that may reach temperatures that are of this order. There is no danger of explosive boiling of cooling water under these conditions; the only reason that the graphite gets so hot is that heat transfer to the water is so slow.

It should be mentioned that these changes in the properties of the graphite are being followed by means of samples exposed in capsules attached to active slugs in the center of the pile and in test holes extending into the center of the graphite lattice. The rate of release of the stored energy and its rate of dissipation into the cooling water are being carefully studied. Changes that might alter the considerations given above are not likely to escape notice.

The gas pouring down the face of the pile from the safety rod wells after a scram will be more active than in the past. The present measures appear adequate to insure safety, and it is possible that improvements in ventilation now being worked on will still further reduce the hazard.

The helium will increase in activity, but it is not expected that a rise to 415 MW will make this troublesome.

All the rods will become about 40% more active than at present. No new problems appear to arise from this fact. Rod effectiveness will not be affected in any way that we will not be faced with eventually at current lower levels as flattening is increased. The present power coefficients at D are, metal, -0.2; graphite + 0.4; overall, + 0.2 ih/MW. Changes in these may occur as the power is raised, but if higher powers are approached cautiously the proper changes in procedure can easily be developed. These changes in procedure, if any, will result from the fact that the metal and graphite periods are so different that the effects show up as separate motions of the control rods, which, accordingly, will undergo more extensive displacements at the time of starting and stopping the units than at present.

It is believed that this review indicates that there is no technical reason against a cautious program of increasing the power of the 100 units to an amount limited by a 65°C outlet temperature for the cooling water of the hottest tubes. It must be pointed out, however, that corrosion may prove to increase so rapidly at higher temperatures that if the limiting concentration of 250 grams of product per ton implicitly used as a basis for this memorandum were to be raised to 800 grams per ton, for example, the best route to the higher concentration might be by way of lower power levels. This is a separate problem that can be solved only after we have had more experience at higher temperatures and powers.

H. WORTHINGTON, CHIEF SUPERVISOR
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