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SUBJECT: Events Preceding the Large Power Excursion
on November 2, 1959

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Summary

During Run 21, while the reactor was being operated at 1400 psig, 260°C and 5 Mw, there were indications of abnormal fuel behavior which were climaxed by an unusual reactivity disturbance in which the power reached 22 Mw.

Before the excursion, a considerable amount of uranium was apparently lost from circulation. At first the loss was, as usual, of low importance, but later deposits apparently built up at a position of high nuclear importance in the core, causing a rise in nuclear average temperature. Some event, perhaps shifting of a loose screen, dislodged several hundred grams of uranium to cause the large excursion.

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May 18, 1960

The following is a description and a discussion of the circumstances surrounding the largest power excursion of Run 21. J. O. Kolb has studied the excursion itself in detail, and his analysis is reported separately.⁽¹⁾

Description

The excursion occurred while the reactor was being operated at 1400 psig in the investigation of the effects of system conditions on fuel instability. Figure 1 shows graphically the reactor behavior before and after the excursion.

On October 30, with the reactor at 1400 psig and about 260°C, the power was raised to 2.8 Mw. After 16 hours at 2.8 Mw, 8 hours at 3.4 Mw and 8 hours at 4.0 Mw, the temperature had decreased about 5°C from the starting point, so the power was lowered to heat loss at 1300 on Oct. 31. As shown on the plot, there was no apparent effect on the nuclear average temperature when the power was lowered. Pumping the blanket dump tanks empty resulted in the recovery of the temperature. Thus the temperature loss while the reactor was at power appeared to be simply the effect of leakage of solution to the blanket dump tanks.

After the temperature had become steady, the power was again raised, this time to 4.5 Mw. As shown by the plot, the NAT rose slightly, then resumed the gradual downward trend characteristic of leakage to the blanket dump tanks. There was little or no significant change in P_c/P_t , the fraction of the power generated in the core. After about 10 hours at 4.5 Mw, the power was raised to 5.0 Mw. The temperature decrease slowed for several hours after the 5-Mw level was reached, but by about 1700 the rate was back up to "normal" and the 5°C loss limit was being approached.

Since past experience had indicated that the loss was probably due to leakage to the blanket dump tanks, the decision was made to pump out the dump tanks. This operation began at 1740 and was completed at 1855 on Sunday evening. Superficially, there was no recovery, but the temperature did seem to level off.

Small pips of 300-400 Kw, had begun to occur while the dump tanks were being emptied, and one pop had occurred. A little over an hour after the dump tank pumping had been completed, two pips in quick succession were accompanied by a rather sharp increase of 2.5°C in the NAT and an increase of 0.015 in P_c/P_t . From that point until the large excursion there were numerous pips and most of them resulted in increased NAT. By the time of the large excursion the NAT was very near its initial value of 261°C, and P_c/P_t had increased from 0.51 to 0.54.

(1) J. O. Kolb, "Analysis of HRT Power Excursion on November 2, 1959", ORNL CF 60-5-78 (May 9, 1960).

During the excursion, or within a few minutes afterwards, the NAT rose about 4°C . It then began to decrease, and lost 6°C in 5 hours before it finally leveled out.

There apparently had been more leakage to the blanket dump tanks, at some time after the pumpout at power, because the temperature increased 2°C when they were again pumped out.

Discussion

The period of operation described above was unusual in a number of respects. Some of the significant points are discussed below.

(1) Was the decrease in NAT before the pumpout at power actually caused by leakage to the blanket dump tanks? If so, why did the NAT not recover more when the tanks were emptied? It has been suggested that there was a recovery of a considerable amount of uranium from the dump tanks, but that this recovery was in large part compensated for by rapid loss of reactivity which began about that time. The core temperature chart certainly indicates that the temperature had begun to decrease more rapidly just before the pumpout began, that there was actually some decrease during the first part of the pumpout and as soon as the pumpout was completed, the temperature began to fall again. All of this is consistent with simultaneous recovery of uranium from the blanket dump tanks and loss of reactivity from some other cause. There is a difficulty with this explanation, however, namely the behavior of P_c/P_t . Experience has generally been that while a rapid loss of reactivity is occurring, P_c/P_t decreases, consistent with loss of uranium from the solution in the core system. Recovery of solution from the blanket dump tanks also tends to decrease P_c/P_t , as the uranium concentration in the blanket increases. During the period in question, from 1740 to 1900, P_c/P_t did not decrease. The situation within the reactor while the dump tanks were being emptied is therefore uncertain, but it appears that there was neither rapid loss of much uranium nor recovery of much uranium from the blanket dump tanks. Most of the decrease in NAT after the power was raised and before the pumpout appears then to have been caused by gradual loss of reactivity, from some cause other than leakage to the dump tanks.

(2) The low NAT following the recovery from the blanket dump tanks indicates that by that time some uranium had gone out of circulation to a portion of low importance. If, as suspected, the loss was slow, there would have been a fairly uniform decrease of concentrations in all parts of the system. In effect, uranium would have been removed from system average importance to a point of lower importance. For this initial importance, the lower limit on the amount deposited, obtained by assuming zero importance for the deposited material, is 240 g of uranium (200 g of U-235).

(3) During the six hours preceding the large excursion, there was some sort of redistribution of uranium which increased the average importance of all the uranium and the NAT to above normal values.

(4) Most of the pips were directly accompanied by increases in both P_c/P_t and NAT. While the NAT increased quickly during many pips, after others the NAT continued to rise for several minutes. The fact that both P_c/P_t and NAT increased indicates that the pips were caused by movement to higher flux and importance of uranium in the fuel system. The gradual increase in NAT after some pips suggests the return to circulation of uranium, as from a disturbed deposit gradually breaking up or dissolving. (A deposit at an importance less than the fuel high-pressure average.)

(5) It may be that the increase in NAT during the six hours before the excursion was simply the result of return to circulation of uranium which had been deposited at low importance. It is certain that at the end of that period there was much deposited uranium and its average importance was apparently above the average for normally-distributed dissolved uranium. Whether or not these deposits grew simultaneously with breakup of very low importance deposits cannot be definitely resolved. It is significant, however, that P_c/P_t continued to rise for over six hours. Uranium going into circulation in the core during a pip would mix out into the blanket and dump tanks, tending to cause P_c/P_t to fluctuate somewhat above normal. That the increase in P_c/P_t continued over a relatively long period implies the net growth of deposits of uranium exposed to neutrons in the fuel system.

(6) During the excursion, or immediately thereafter, a quantity of uranium went into circulation in the core. It then mixed out into the dump tanks and blanket. The initial importance was less than for uranium circulating in the fuel high-pressure system, but higher than the average for the core, blanket and dump tanks. This is inferred from the sharp rise in NAT, which showed that the importance increased in going into circulation, and the subsequent gradual decrease in NAT, consistent with mixing out of the core into the blanket and dump tanks. The quantity of uranium quickly returning to circulation is estimated from the 6°C NAT decrease to be 240 g, assuming that the only effect was mixing out of the fuel high-pressure system. Taking the xenon buildup into account reduces the estimate by about 50-75 g. Tending to raise the estimate is an effect which cannot be measured, but is probably larger than the xenon reduction. This is the gradual return of deposits at lower than system average importance after the power was lowered.

Some Speculations

The situation within the reactor was too complex, and the external indications too few for an explanation to be forthcoming. It is interesting to speculate, however. One possible course of events is as follows:

During the hour or so after the reactor power increases to 4.5 Mw and then to 5, there is a limited deposition of uranium at high importance. A more gradual deposition of uranium at very low importance also occurs. This shows up as an increase or leveling off of NAT followed by a slow decrease.

Pips begin, as portions of fresh deposits begin to break away. (These first pips are from material deposited near fuel high-pressure average importance, since little change in NAT results.)

By 2010, deposits of fissioning uranium, with their associated steam volumes, have become so extensive under one of the loose screens low in the inlet section that the buoyant forces finally succeed in dislodging and lifting it. Some of the uranium on the screen or in the vicinity breaks away, causing pips. Increases in NAT and P_c/P_t result as the uranium moves to higher importance.

The screen comes to rest in a new position, perhaps held by the flow against the one above it. Changes are produced in flow patterns (and cooling) in the screens higher up. Deposits in these more important regions begin to grow. As they grow, local boiling occasionally dislodges some deposited uranium to cause more pips.

Deposits and steam voids finally reach the point where a large screen is lifted. The movement dislodges several hundred grams of uranium which falls along the wall before it is drawn into the central jet and injected into the core, causing the large excursion.

The uranium which was returned to circulation in the core begins to be mixed into the dump tanks and the temperature, which had risen very rapidly, declines. After the power is reduced, all of the deposited uranium begins to return to circulation and the system slowly returns to normal.

The foregoing picture is consistent with the observations, but alternative explanations are certainly not ruled out.

Relations to Other Operating Experiences

Although this was an unusual period of operation, many aspects were similar to experiences at other times.

In the first place, there was the apparent loss of low importance which caused a decrease in NAT. This is the most common manifestation of uranium loss in the HRT. The question of the mechanism is vexing, and the hot spot - boiling and/or second liquid phase hypothesis is not an entirely satisfactory answer because of the very low importance of the deposited uranium. If all the deposit is at one place it must be far down in the 30° cone where velocities are greater and fluxes are lower than they are higher up. (Perhaps second phase forms higher up and trickles down, but it seems unlikely that it would reach far down.) If a part of uranium is deposited in the 90° cone section, the large part must be at practically zero importance. This was definitely indicated by the analysis of Run 16⁽²⁾). What mechanism results

(2) J. R. Engel et al., "Summary of HRT Run 16", ORNL CF 60-4-4, pp. 52-60.

in deposition of uranium outside the active region when the power is raised, and allows it to return when the power is lowered?

The symptoms of continuously increasing NAT and P_c/P_t accompanied by pips had not been seen before Run 21. (In Run 17, many individual pips were accompanied by a sharp increase of several degrees in the NAT, but no steady increase, such as would come from deposition at higher importance was ever seen.) Twice later in Run 21, at 1600 psi, the NAT began to rise perceptibly after an initial rapid loss. Also in Run 21, there were several occasions at lower pressure when the NAT rose significantly shortly after the power was raised and decreased after the power was lowered. In these cases, however, there were usually no pips.

Some General Comments and Unanswered Questions

The rising NAT and P_c/P_t observed at times is most likely caused by deposition of uranium in the core, either on the upper screens or on the core wall. Run 16 analysis indicated that a portion of the power-dependent uranium loss was deposited in a similar high importance region, but that simultaneously a large part of the uranium was deposited at very low importance, so that the net effect was a decrease in NAT. Decreases in NAT and P_c/P_t have been the most common sort of misbehavior when the reactor power was raised at high pressure, and presumably involve deposition of much uranium at very low importance. Operation at lower pressure (below 1400 psi) reduces the total amount of uranium loss, as shown by physical inventories. At times, however, as shown by NAT increases at power, deposition at high importance seems to occur, not balanced by loss to low importance. That this should occur at low pressure rather than at high seems strange. Reducing the pressure may help prevent gross deposition in high-flux hot spots by permitting boiling and limiting the temperatures. But it appears that in fact the lower pressure prevents deposits at low importance (perhaps outside the core) without entirely preventing deposits at high importance. The effect may be related to pressurizer temperature (or pressure) if the low-importance deposits are in the pressurizer connection. But there seems to be no known reason why deposits in this location should be power-dependent.

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