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April 30, 1962

C REACTOR OVERBORE FUEL FAILURES

INTRODUCTION

The concept of overboring the graphite channels in an older Hanford reactor and installing oversized tubes charged with oversize fuel elements is being investigated at C reactor. Recently a column of these oversized test fuel elements exhibited three uranium cleavage (split) type failures after experiencing severe reactor flux cycling. This report presents a preliminary description of both the fuel failures and the flux cycling encountered by the reactor.

SUMMARY

On April 16, the fuel charge in overbore tube 3062-C ruptured, and upon examination was found to have three split failures and three "worm tracked" elements (depressions in the aluminum can giving the impression that the uranium beneath is split and the can is approaching failure). These failures occurred approximately 10 days after one period of flux cycling and during a second such cycle at C reactor. During the initial flux cycling, five tubes (none of which were overbore columns) exceeded outlet temperature limits by 2 to 4 degrees C for a short period of time. An increase of outlet temperatures above normal, extending over a period of a few hours, occurred in the 44 tube overbore block. Maximum specific powers of 150 kw/ft are estimated to have occurred for a short

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period of time in the maximum powered overbore tube and 135 kw/ft. in the failure tube. Normal maximum specific powers in the overbore fuel are 120 kw/ft. These fuel failures are believed to be a direct result of the high specific powers and of the exaggerated flux cycling of the high exposure material, although the precise impact of these factors is not definable. It is pointed out that C reactor, fully overbored, will generate about 70 kw/ft average specific powers and maximum specific powers of about 100 kw/ft. Performance of the overbore fuel at the normal maximum test conditions of 120 kw/ft has been good. Failure in the 135 to 150 kw/ft range thus establishes a rough upper limit to overbore fuel operation - a limit substantially above the powers to be expected in the full overbored reactor.

DISCUSSION

A total of 62 overbore tubes are currently installed in C reactor; 44 in a block near the center of the reactor, two in the lower part of the reactor, and the remaining 16 in the reactor fringes. Since the overbore fuel and tubes are larger with less surrounding graphite, the effective lattice is considerably changed from the normal C-lattice. These larger tubes rob neutrons from the surrounding lattices and operate at higher powers than the regular C reactor fuel. To compensate, the central zone tubes are charged with 19 pieces to keep the tube powers consistent with the others in the reactor. The fringe tubes have a normal length charge but do generate some of the maximum tube powers in the reactor. The 44 tube block was designed primarily to give conversion ratio data and fuel testing space. Since the block does rob neutrons, special enrichment around the block is required. The tube powers can be controlled by short charging but specific powers cannot be reduced in this manner. Thus, the specific powers have been higher than would be typical in a fully overbored reactor, this is particularly true of those charges on the two outer rows of the block. The block thus provides considerable test space and the opportunity to operate the test fuel at specific powers higher than those to be expected in a completely overbored reactor. The test results must, of course, be interpreted in light of these accelerated test conditions.

I. Reactor Operating Experience

Following six days of normal operation, a Pammit scram occurred at 12:59 a.m. on April 5, 1962. The cause for this scram was not determined. A hot startup was made at 1:18 a.m. During the next 12 hours of operation, a series of minor heat cycles occurred, none of which were abnormal for operation following a hot startup. Maximum outlet temperatures reached during this period were approximately 120°C as compared with normal maximums in the range of 105-110°C experienced during equilibrium operation. By 12:00 noon, localized above average temperatures appeared in the top-far region of the reactor. Although a series of horizontal rod movements were made to control this region, a cyclic xenon transient developed, causing the localized region of high temperatures to shift back and forth across the top of the reactor.

During this period, temperatures were being monitored by the use of the Flexowriter and the Brown recorder. Flexowriter temperature maps were run almost on a continuous basis and selected tube temperatures were monitored with the Brown recorder. At about 2:00 p.m., it was noticed that tube temperatures were exceeding 120°C as read on the Brown recorder. This instrument has two ranges, 0-150 C and 0-120 C. The 0-150 C range was inoperable at this time preventing immediate verification of the temperature. A partial temperature map run at 2:15 p.m. showed maximum tube temperatures

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in the top-near side of the pile of 128°C for six regular tubes and 127°C for one overbore tube. Compensating rod movement was then made and temperatures immediately reduced to values below 120°C as read on the Brown recorder. A temperature map at 2:45 p.m. indicated temperatures in this region of approximately 120°C. At approximately 2:45 p.m., gamma monitor indication for #29 crossheader reached full scale indicating a rupture had occurred on row 29. A normal shutdown was completed at 3:00 p.m.

Two tubes were discharged as rupture suspects. One, an enriched normal size charge in 2955, sustained two ruptures classified as a "side-other" and a "hot-spot". In the other tube, overbore column 2969, no rupture could be located. An analysis was made of the temperature map run at 2:15 p.m., and a decision made to discharge most of the tubes involved in the heat cycle, including fringe overbore tube 2853.

Examination of the 2:15 p.m. temperature map indicated that five tubes had been in excess of TAI limits by 2-4 C at the time the map was run. TAI limits for the five tubes ranged between 120-126 C. No overbore tube exceeded TAI limits. The maximum overbore tube powers experienced during this heat cycle were approximately 1840 kw for 32-piece fringe charge and 1820 kw for a 19-piece test block charge. Tube powers for these test tubes are approximately 1450 kw during normal operation.

Continued reactor operation with five tube outlet temperatures having exceeded TAI limits was the result of a lapse in procedural control. Process standards specify that the reactor should be immediately scrammed if outlet temperatures on any tube exceeds its respective TAI limit. The fact that five tube outlet temperatures had exceeded TAI limits by 2-4 C was not recognized until detailed examination of the 2:15 p.m. temperature revealed limits for certain of the tubes were 120 to 126 C. TAI limits for most central zone tubes are 128 to 130 C. On this hot startup, the flux peaked to the near side of the normal flattened zone where TAI limits are lower. Hot startup procedures have been abandoned by C Processing to preclude such severe heat cycling. While undesirable, the brief period of operation above TAI limits in this case did not significantly compromise reactor safety. The normal high trip protection afforded by the Panellit system was not affected and in all likelihood if upstream plugging had occurred (coincident with operation above TAI limit) a low Panellit trip would have resulted. If tube powers had increased further such that boiling was initiated, a pressure monitor trip would have prevented jacket melting.

A normal startup was made at 3:44 p.m. on April 7. Normal operation was continued until 9:10 a.m. on April 12, at which time the reactor was shut down due to excessive water collection. After leak repairs were made, the reactor was started back up at 5:45 p.m. on April 14.

At approximately 10:00 a.m. on April 16, it was decided to attempt repair of a leaky rear connector on overbore tube 3366 during the scram recovery time available. As power was being reduced, a Panellit scram occurred (10:50 a.m.). A hot startup attempt was made with first indication at 11:29 a.m. The rate of rise was consistent with process standards, but temperatures in the top region of the pile increased rapidly relative to other regions. The maximum spread between the top and bottom regions of the reactor reached about 40 C with maximum tube outlet temperatures in the top reaching 112 C within 20-25 minutes of startup. At about noon, a Panellit trip on overbore tube 3062-C scrammed the reactor. Activity on #30 cross-header confirmed the presence of a rupture.

II. Discharge of the Rupture

Following normal procedures the failed charge was discharged with a maximum force used of 7000 lbs - a value comparable with that required for discharge of some normal sized failure charges. The rear face hardware involves a Van Stone flange. The pull-out force for the Van Stone flange has been previously determined by laboratory tests and found to be 17,000 pounds. The front-face hardware involves a double-welded Zircaloy-2 collar. The sheer force for this collar was similarly determined and found to be 30,000 pounds. The tensile strength of the tube is 33,000 pounds, and the compressive strength of the tube is greater than 14,000 pounds. The forces of backseating and discharge were thus well below those which would be expected to cause damage to either the tube or hardware. Following removal of the rupture, the tube was given a routine pressure test and found to be sound. The tube was also borescoped, and with the exception of a few minor (and acceptable) scratches, was found in good condition. The tube was then released for re-charging.

It is interesting to note that had the rupture occurred in an aluminum over-bore tube, the removal would have involved discharge of tube and rupture as a unit. Comparative forces for aluminum are, 1) double-welded collar fails in tension at an average value of 7700 pounds; 2) tube tensile strength is about 13,000 pounds; and 3) single-welded collar fails in tension at an average value of 5100 pounds.

III. Flux Effects

At C reactor during equilibrium operation, six control rods are positioned to control the heat in the center and far sides. All six rods go through the near side but do not extend completely to the far side. To compensate for neutron absorption in these rods, enrichment has to be added to the near side. Therefore, when a majority of the rods are out for a hot startup, the flux will peak on the near side until sufficient reactivity is gained to permit rods to be inserted through the near side. Since December, 1961, when the 40-tube overbore test pattern was completed, flux peaking has been more pronounced because 50 columns were charged with enriched metal around the overbore pattern to compensate for the reactivity loss resulting from short overbore charges. In addition, 35 fringe tubes have been charged with enrichment in that same region. This results in 85 more enriched columns on the near side than on the far. It must be realized also that the peaking potential around the overbore block becomes greater as the exposure on the overbore slugs increases because the plutonium buildup in the over-bore slugs exceeds the U-235 burnout in the enrichment columns. On April 16 when the overbore slugs ruptured, the exposure on the material was 84 per cent of goal. Based on experience to date, it is estimated that 25 enriched columns will compensate for the overbore block after the fuel has achieved 84 per cent of goal exposure. Also, experience shows that on a newly charged overbore block only approximately 38 enrichment columns may be required rather than 50. A reduction of supporting enrichment tubes in this region is planned.

The axial flux distribution at C reactor during normal operation is peaked 10 per cent above a cosine curve and skewed slightly to the front of the graphite stack center line. This is the result of normal operation with the center upstream rod #6 out of the reactor. During this and the previous

hot startups, #6 rod was inserted in the stack; thus tending to decrease the flux in the region of the overbore fuel element failures. Weasel data are discussed later. In the absence of instrumentation to give direct information the front-to-rear flux distribution during the heat cycles, it is not possible to state just what power distribution existed. In spite of the presence of #6 rod in the reactor, the failures occurred in general upstream of the midpoint of the columns.

IV. Fuel Performance

Until this past week, one overbore rupture had been experienced. This earlier failure resulted from accelerated corrosion attack between the self-support rails. Some mechanical problems had been encountered with charging the overbore pieces, and it is believed that this failure was a direct result of self-support rail damage received during charging. Although the fuel, process tube, and associated hardware have rather tight clearances, these problems are mechanical and are being eased through hardware design and development and fuel dimensional control. The more recent experience is outlined below.

A. Rupture Column

The 19-piece rupture charge contained rolled ingot uranium fuel cores which had reached an exposure of 670 MWD/T and was operating at a tube power of 1450 kw at the time of failure. The charge contained three split type failures and three elements showing worm tracks which are thought to be incipient split failures. The affected pieces were numbers 10 through 15 with the charge being numbered from the downstream end. Since the charge was centered with regard to the normal reactor charge, the affected elements were all just upstream of the center line. Pieces 12, 14, and 15 were split, and pieces 10, 11, and 13 were incipient splits. The splits were all longitudinal in nature and on pieces 12 and 14 full length segments about 90° to 120° of circumference were completely detached from the fuel element. The detached segments did not extend to the spire but seemed to terminate nearly midway through the uranium radius. In both of these cases the end caps were fairly well intact.

Weasel data from the previous fuel column in the failure tube showed the power to have been peaked upstream. However, weasel data from the failure column indicate that the flux was peaked downstream for the major part of the exposure period. At a tube power of 1450 kw and assuming a cosine flux distribution, the maximum specific slug powers would be about 110 kw/ft. Peaking this value to be consistent with weasel data, a maximum power of 120 kw/ft is noted.

During the flux cycle, the outlet temperature from this tube underwent considerable variation as shown in the following table:

<u>Startup Time</u>	<u>Outlet Temperature</u>
1:18 a.m.	8 C
5:10 a.m.	103 C
9:00 a.m.	62 C
2:15 p.m.	114 C

The maximum tube power reached was 1650 kw which corresponds to a specific power of 135 kw/ft. Tubes 2863 and 2865 encountered a very similar temperature transient to 3062. It is noted that tubes 2863 and 2865 contained

four and three worm tracked fuel elements, respectively. Two of those in 2865 were classified as transverse worm tracks. The significance attached to the rapid change from low to high powers in a few hour period is unknown. It is believed that cycling this high exposure fuel to powers above their normal operation conditions over this few hour period was the cause of failure. This behavior is not inconsistent with solid slug performance of several years ago, when it was concluded that a rapid rise to power was a significant factor in the split type failures.

B. Fuel Conditions During Flux Cycle

The exposures through the block ranged from 500 to 766 MWD/T and tube powers normally range from 1200 to 1450 kw; however, during the cyclic period, a maximum specific tube power of 1820 kw as noted on 3162. Tubes on the edge of the block in 62 column all saw tube powers in excess of 1650 kw during the peak. Tube 3162 and 2962 contained one and two worm tracked elements, respectively. Although the normal conditions in these tubes were rather severe, the consequences of the flux cycling are believed of greater importance. Some of the fuel elements experienced specific powers up to 150 kw/ft. during the flux cycling and extremely high stresses can be calculated for these cores. The maximum temperatures in the fuel elements are also calculated to be rather high compared to normal size fuel. It is impossible to use calculated elastic stresses as anything other than an indicator of severity since it is known that the uranium under irradiation does not respond elastically. However, the calculated stress levels and maximum temperatures give an idea of the conditions the fuel has encountered. The following table shows a few examples:

<u>Slug Type</u>	<u>Tube Power</u> kw	<u>Peak</u> <u>Slug Power</u> kw/ft	<u>Maximum U Temp.</u> °C	<u>Computed</u> <u>Maximum Stress</u> psi
CIV (Overbore)	1400	106	455	110,750
	1650	125	515	126,000
	1820	138	565	136,000
CII-Standard I&E	1650	93	374	79,600
Solid Slug	875	50	550	102,000
	1050	60	628	119,000

C. Fuel Examination

In light of the general high powers and high exposures in the block, it was decided to replace all of the metal in the block with the exception of the eight conversion ratio tubes. These eight tubes are in the center of the block and did not undergo the degree of cycling experienced by the outer surrounding tubes. The value of having timely conversion ratio data and the lower operating severity led to the decision not to replace those charges but to continue them to goal exposure.

Examination of the 35 columns of overbore fuel is complete, about 665 overbore fuel elements have been inspected and the following observations can be made:

1. Ten elements in addition to those six in the failure tube have been found with indications of worm tracking; eight of these had longitudinal

tracks and two were reported as transverse worm tracks.

2. All of these elements come from tubes with exposures in excess of 660 MWD/T.
3. With one exception the worm tracked elements were just upstream of the center line and from tubes in the immediate area of the rupture tube.
4. The self-supports were generally in good condition with less support damage than noted in the past.
5. A number of hot areas were noted.

Of the ten worm tracked elements one is ingot material and nine are dingot material, four of which are from tube 2863, three in 2865, two in 2962, and one in 3162. At the time of shutdown, 2863 was operating at 1500 kw and an average exposure of 708 MWD/T. The worm tracked pieces from tube 2863 are numbers 9, 10, 11, 13, and 15.

Of the 44 tubes in the central block, only four of them were charged with ingot columns. The rupture column was one of these four. Seventeen of the nineteen elements in the charge were large grained material as a result of low impurities in the uranium. The grain sizes were about A-3 on the standard monitoring scale. The impurity levels were below those now specified for normal incoming cores. Two pieces, number six and eleven had fine grains (about A-6) and were rolled from an ingot to which Fe and Si additions were made. Since these overbore pieces were rolled from the same sized ingots, the reduction ratios are lower than obtained for normal sized I&E material; all dingot material was alpha extruded into hollow fuel cores.

D. Fuel Conditions in Overbored Reactor

An examination of the conditions encountered by the fuel which failed indicates that the results are not unexpected. With specific powers roughly double those normally seen today for normal I&E fuel compounded with some flux cycling and several hot startups, extreme demands were placed on the fuel elements, and the majority of them performed adequately. It is pointed out that in a completely overbored reactor with 115,000 gpm expanded water plant capacity, 95 C bulk outlet temperature and 17,000 ECT the maximum reactor power level would be about 2700 mw. Under these conditions, a 32-piece natural charge would generate 1600 kw with a resultant maximum specific power of 95 kw/ft. A full length enriched column would have specific powers about 105 per cent of these or a maximum of 100 kw/ft. The maximum calculated stress for a 100 kw/ft fuel element is 105,500 psi and for 70 kw/ft the calculated stress is 76,500 psi. Since these conditions are well below those being successfully sustained in the normal test environment and further yet below the conditions imposed by flux cycling, the threshold for split failures as revealed by this incident does not appear to offer serious problems for a full overbored reactor.

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