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POSSIBLE CONSEQUENCES OF OPERATION WITH KIVN FUEL ELEMENTS IN K ZIRCALOY PROCESS TUBES

by

Paul A. Carlson

August 6, 1963

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POSSIBLE CONSEQUENCES OF OPERATION WITH KIVN FUEL ELEMENTS IN K ZIRCALOY PROCESS TUBES

INTRODUCTION

The inadvertent charging of nonsupport fuel elements in smooth-bore process tubes could result in local fuel and tube temperatures high enough to cause fuel and tube damage. Therefore, methods to prevent these charging errors are under study as a part of the K Zircaloy-2 tube program. At this point in the development no fool-proof methods have been devised to guarantee protection, and it was requested that an analysis of the outcome of these charging errors be made to provide a basis for determining the need for further work in this area. An experimental basis for this study was available in laboratory work performed by the Thermal Hydraulics Unit, and in the outcome of similar type incidents that have occurred in the reactors: On this basis the maximum outcome of the irradiation of fuel elements without self-supports (KIVN) in K-Reactor smooth-bore process tubes was determined, as described in this report.

SUMMARY AND CONCLUSIONS

From considerations of the results of experimental simulations of non-axial placement of fuel elements in process tubes and in-reactor experience, it is concluded that the ultimate outcome of a charging error which results in operation with one or more unsupported fuel elements in a K Zircaloy-2 process tube would be multiple fuel failure and failure of the process tube. The outcome of the accident is determined by the speed with which the fuel failure is detected and the reactor is shut down. The release of fission products would be expected to be no greater than that which has occurred following severe fuel failure incidents. The highest probability for fission product release occurs during the discharge of failed fuel elements, when a small fraction of the exposed uranium of the fuel element may be oxidized when exposed to air before the element falls into the water-filled discharge chute. The confinement and fog spray facilities were installed to reduce the amount of fission products which might escape from the reactor building after such an event.

DISCUSSION

A. The Problem

The K Reactors contain both ribbed and smooth-bore process tubes, and thus use both fuel elements with supports (KVN and KVE) and fuel elements without supports (KIVN and KIVE). With the use of the two types of fuel elements it is probable that at some time the nonsupported fuel elements may be wrongly charged into the smooth-bore tubes, in which case the fuel elements will rest on the bottom of the tubes, the bottom surface of the fuel elements will not be in direct contact with the coolant flow, and excessive local fuel element temperatures could develop. Because of size limitations it should be impossible to charge the self-supported fuel elements in the ribbed tubes without detection.

The Equipment Development Operation is currently studying the possibilities of providing charging machine interlocks or other devices which would detect these charging errors during the charging operation to prevent the exposure of unsupported fuel in smooth tubes.[1] As stated in Reference [1], no method of guaranteeing that these charging errors will be detected has been devised. It was requested, therefore, that the maximum outcome of these charging errors be determined, to provide some insight into the need for guaranteed protection.

B. Laboratory Data

The Thermal Hydraulics Unit has performed a series of experiments to determine the effect of eccentric placement of fuel elements in process tubes on the burnout heat flux.[2] The experiments were performed in smooth tubes approximating the size of the K ribbed tubes with heater elements of approximately KIVN outside diameter. All coolant flow was directed around the annulus, there being no central passage to simulate I&E hole flow. The coolant flow rate and pressure were established to simulate normal conditions in the annulus at a point in the fuel charge analytically determined to be the most probable burnout position in the reactor (40 gpm, 107 psig, coolant temperature 100 C).

These tests show that the burnout heat flux decreases with increasing eccentricity. With 90 per cent eccentricity, or with the restricted annulus thickness at about 0.010 inches and the open annulus at about 0.090 inches, the burnout heat flux was about 250,000 Btu/hr-ft^2. The K-Reactor fuel element outer surface heat flux is calculated to be 105,000 Btu/hr-ft^2 at the end of the fuel charge and 565,000 Btu/hr-ft^2 at the center of the fuel charge.

Tests have also been run in glass tubes to observe the local boiling process. In these tests, the maximum coolant pressures which could be obtained were 10 to 30 psig, limited by the strength of the glass tube. With a flow rate of 52 gpm and the simulated fuel element resting against the tube, boiling began at a heat flux of 30,000 Btu/hr-ft^2. At 60,000 Btu/hr-ft^2 a dry spot developed between the tube and heater rod. As the heat flux was increased the dry spot became larger. At 240,000 Btu/hr-ft^2 the glass tube failed, terminating the experiment. The heater did not burn-out.

These tests demonstrate that local small tube-to-fuel element spacings result in high fuel element surface temperatures and may result in burnout and melting of the fuel cladding.

C. In-Reactor Experience

It is well-known that eccentric placement of fuel elements in a process tube results in high local coolant temperatures and, thus, high tube surface and fuel cladding corrosion rates. The "hot spot" failure and concurrent tube

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[1] Letter, P. B. McCarthy to R. F. Corlett, "Interlocks for Smooth or Self-Supported Fuel Elements," dated May 3, 1961.

[2] Waters, E. D., and J. M. Batch, Experimental Burnout Conditions for Hanford Production Reactors, HW-71074, September 20, 1961. (SECRET)

failure have been the most severe outcomes of fuel eccentricity. This experience resulted in measures to prevent fuel misalignment, such as the use of bumper fuel elements, and caused the change to X-8001 fuel cladding material to increase the resistance of the cladding to intergranular corrosion.

The H-Loop experience provided some pertinent data on the effects of fuel failure on zirconium tube integrity.[3] The H Loop was an in-reactor experimental loop containing a ribbed, zirconium tube and used for irradiating standard Hanford solid fuel elements at elevated temperatures and pressures. During an irradiation test, warping of the fuel elements caused the annulus area to be reduced sufficiently to result in intergranular corrosion and failure of the fuel cladding of a downstream fuel element. As the uranium and high temperature water reacted, the fuel element swelled and caused a reduction in coolant flow to the remainder of the downstream fuel elements. The fuel element just downstream of the initial failure failed by local burnout of the cladding.

The initial fuel failure swelled to the point when it contacted the zirconium tube wall. Localized heating occurred here, and this heating, coupled with hydrogen being evolved as a result of the uranium-water reaction, resulted in embrittlement of the zirconium tube. This embrittlement resulted in failure of the tube. An examination of the material in the immediate region of the failure disclosed practically no zirconium present, the majority of the material having been converted to zirconium hydroxide.

D. Application to Postulated K Zircaloy Tube Incident

Laboratory data demonstrate that nonaxial placement of fuel elements in a process tube reduces the heat flux at which film boiling or burnout occurs as compared to concentric placement because of the unbalance of heat transfer surface area and fluid flow area. The results show that an eccentricity of about 80 per cent could cause film boiling in current K process tubes. The experimental conditions would lead one to observe that this result is probably conservative for reactor operation because thin-walled test sections with annulus flow only were used in the tests. With annulus and hole flow there could be a significant shift of the radial heat flow pattern as burnout was approached, and greater eccentricity may be required in the reactor to cause burnout at the same heat flux as observed in the laboratory. Also, local film boiling does not necessarily mean that the cladding will reach the melting temperature. However, if the jacket does not melt, temperatures are high enough to cause rapid corrosion and eventual failure of the cladding, as shown by in-reactor experience. With or without local melting of the cladding, the outcome would be the same; failure of the fuel element cladding. With burnout the failure would be immediate, while corrosion may proceed several days before the cladding fails. Groot has shown that the induction time for intergranular corrosion to begin with X-8001 alloy in 470 C superheated steam is greater than 64 hours.[4]

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[3] Lobsinger, R. J., Examination of Fuel Elements and Process Tubes from H Loop following a Rupture Incident, HW-43588. April 15, 1957. (SECRET)

[4] Groot, C., and R. E. Wilson, "Intergranular Corrosion of Aluminum in Superheated Steam", Industrial and Engineering Chemistry, 49: 1251. August 1957.

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Considering the failure will most probably be in the location next to the process tube surface, it is also probable that local hydriding of the Zircaloy-2 process tube could occur. Thus, the ultimate outcome of a charging error which results in operation with one or more unsupported fuel elements in a smooth-bore process tube could be multiple fuel element failure and failure of the process tube.

E. Indications of Charging Errors

Charging of unsupported fuel elements of KIVN geometry in a K smooth-bore Zircaloy-2 process tube will change the hydraulic characteristics of the process tube. If only a few such fuel elements were charged it is probable that the changes would be within normally-observed variations and go unnoticed. If a full charge of unsupported fuel elements were placed in a K Zircaloy-2 process tube the coolant flow rates would increase about 25 per cent and the Panellit pressure would be about 100 psi lower than normal. Also, if the reactor were started up despite this indication, the outlet coolant temperature would be abnormally low due to the higher tube coolant flow rate.

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