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This document consists
of 6 pages.

TECHNICAL BASIS FOR ESTABLISHING
PROCESS TUBE PRESSURE LIMITS FOR KER LOOPS 2 & 3
AND FOR THE NPR PROTOTYPE FACILITY

by

O. E. Adams

June 26, 1959

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TECHNICAL BASIS FOR ESTABLISHING
PROCESS TUBE PRESSURE LIMITS FOR KER LOOPS 2 & 3
AND FOR THE NPR PROTOTYPE FACILITY

INTRODUCTION

In compliance with a request from Coolant Testing Operation, the Reactor Engineering Operation has made a study to determine the maximum operating pressure limits for the pertinent Zircaloy-2 process tubes. Since these tubes shall be used for testing NPR fuel elements, it is considered desirable that KER Loops 2 and 3 permit operation at temperatures of around 300°C while the NPR prototype facility permit operation at about 316°C in a manner such that there is minimum hazard to the KE-Reactor and to personnel.

This report presents the results of a stress analysis of the process tubes corresponding to their respective operating temperatures.

SUMMARY AND CONCLUSIONS

The maximum operating pressure for the process tubes (I.D. = 2.036 in., wall thickness = 0.170 in.) to be installed in KER Loops 2 and 3 should be 1650 psig at the tube exit temperature of 300°C. This pressure limit calculation was based upon restricting the membrane stress intensity (see page 3) to 54 per cent of the 0.2% offset yield strength corresponding to the pertinent temperature. (1) Using a similar calculation for the process tube (I.D. = 2.70 in., wall thickness = 0.275 in.) to be installed in the NPR prototype facility (2) the maximum operating pressure at a tube exit temperature of 316°C is 1850 psig.

Although the above criterion is based strictly upon pressure stresses, a criterion was also employed that considers thermal stresses. This criterion, which is somewhat analogous to the NPR design criteria, limits the sum of the loop pressure stress plus thermal stress to 90 per cent of the creep rupture strength for five year life. In addition, a fatigue analysis was performed using a criteria recommended for use in the design of Naval reactors. (3)

Since these tubes will be operated at high pressures in essentially an unvented graphite stack, a tube rupture during operation would be catastrophic. It is recommended that the tubes be cold (room temperature) hydrostatically pressure tested to develop membrane stress intensities within a range of 56 to 67 per cent of the average room temperature yield strength of annealed Zircaloy-2. The testing frequency should be in agreement with the Process Standards.

An additional safety feature, such as a high tube pressure scrambling device, is also recommended. It is envisioned that this device would protect against overpressuring the tube during a stuck fuel element rupture, which otherwise, under the present system, would cause the stagnant water in the tube to heat up and eventually to burst the tube.

DISCUSSION

The following non-destructive tests have been performed on the tubes to be installed in Loops 2 and 3

[REDACTED]

1. Eddy current test for wall irregularities
2. Dye penetrant test for defects on the outer surface
3. Wall thickness measurements every square inch
4. Borescope of internal surface
5. Radiograph of all eddy current, dye penetrant, and borescope indications

Similar tests also should be run on the tube to be installed in the NPR Prototype Facility.

Previous pressure limits have been based upon limiting the membrane stress intensity to the most restrictive of the following criteria: 54% of yield strength (0.2% offset), 41% of tensile strength, or 63.5% of 0.9 times the creep rupture strength. Thermal stresses due to a constant temperature differential across the tube wall together with thermal stresses due to variation of temperature around the outer tube circumference have been calculated for the central region of a maximum performance tube using the methods of references (4) and (5) and employing the temperature variation for an uncentered tube expressed in reference (6). Employing a criterion which restricts the sum of the maximum hoop stresses (pressure + thermal stress) to 90% of the creep rupture strength for a five year life, pressures are obtained (Table I) which are not as limiting as the criterion based upon 54% of yield strength.

Pressure limits were also computed by means of a design basis developed for Naval reactors.⁽³⁾ This basis if followed to the letter would have limited the tubes to a pressure resulting in a membrane pressure stress approximately 1/3 the tensile strength (using properties specified in reference (3)) at tube exit temperatures. These pressures were roughly equivalent to pressures computed on the basis of the NPR design criteria (7) which is based upon a creep rupture strength corresponding to twenty year life. Since these tubes are expected to operate at high pressure only through duration of NPR fuel element testing, which is approximately two years, these restrictive pressure limits were relaxed to the values based upon the previously applied criterion. The Naval design basis also stipulates that a fatigue analysis be considered which requires that all total stress differences (page 3) arising during an operating or power excursion cycle (including thermal + pressure stress differences) fall within a safe region on the fatigue diagram (plot of absolute value of alternating stress difference vs absolute value of the mean stress difference). The safe region is that which lies below a line whose intercepts are a maximum alternating stress component (determined for class of loading cycle) and a maximum mean stress equal to the average value of the yield and ultimate strength of the material.

The fatigue analyses corresponding to an estimated operating cycle showed that the previously applied criterion were more restrictive. However, there is no assurance that some phenomena like hydriding may not give rise to fatigue cracks during the operating cycle. Likewise, the fatigue data used in the calculation do not appear to reflect the effect of irradiation on the mechanical properties of Zircaloy-2.

Locs 2 and

NPR Prototype

Tube Center	21,050	28,500	19,100	8,820	--	--	--	--	1900
Tube Exit	18,500	26,500	18,000	8,550	1580	1850	2005	2110	--

$\sigma_r, \sigma_\theta, \sigma_z$ = total radial, hoop, and axial stresses respectively

$$\sigma_{r\Delta T}, \sigma_{\theta\Delta T}, \sigma_{z\Delta T} = \text{radial, hoop, and axial total thermal stresses respectively}$$
$$S_{r\theta} = \sigma_r - \sigma_\theta ; S_{\theta z} = \sigma_\theta - \sigma_z ; S_{zr} = \sigma_z - \sigma_r$$

Membrane stress intensity (thin wall formula)

Hoop Pressure stress at inner surface (thick wall formula)

$$\sigma_{\theta p} = \frac{(b^2/a^2 + 1)}{(b^2/a^2 - 1)} p$$

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LETTERS

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