INTRA-LABORATORY, CORRESPONDENCE
OAK RIDGE NATIONAL LABORATORY.

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To: M. W. Rosenthal

cc: R. B. Briggs
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Management Advisory Council (MAC) Recommendation
of Biaxial Stress Tests

I initially interpreted the MAC comment to refer to the cracking problem. After our phone conversation, I took a second look and must concede that it may refer to the irradiation embrittlement program. Since I am not completely sure about the two possibilities, my answers to both questions are attached.

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HEM:fc

Attachment
Value of Biaxial Stress Tests for Studying Radiation Embrittlement

H. E. McCoy

The current criterion being used for developing a modified alloy with acceptable resistance to irradiation is that it have a minimum of 3% fracture strain in a creep test after irradiation to a thermal fluence of about $5 \times 10^{20}$ neutrons/cm$^2$ over a period of 1100 hr at 760°C. When the composition is optimized and a heat treatment established that will consistently yield this ductility, then many types of tests must be run on different product forms to determine design properties. However, this stage has not been reached in this program and the screening criterion being used seems appropriate.

Different properties are obtained under biaxial and uniaxial stress conditions. However, the behavior under biaxial stresses can be predicted from uniaxial stress data by use of the effective stress-strain method discussed by Kennedy.$^1$ It is only when the material is highly anisotropic that this analytical treatment is inadequate. The mechanical properties of Hastelloy N do not seem anisotropic. However, the zirconium-base alloys used in PWR's and BWR's are highly anisotropic, and this may have prompted Zinn's comments. The mechanical properties of Hastelloy N tubes and rods were compared in ORNL-TM-1906.$^2$ The analytical treatment seemed adequate.

One strong argument for not running biaxially stressed specimens is that they normally involve thin-walled tubes and the data scatter becomes much worse (Figs. 8, 9, and 10, Ref. 2). The tests also become more complex and more expensive to run.

Thus, there seems no advantage to including biaxial tests in our current alloy development program. When we have completed the screening phase of the program, then tests must be run on numerous product shapes.


Value of Biaxial Stress Tests for Studying the Cracking Problem

H. E. McCoy

We concur with the MAC recommendation that stressed tests be run in various salt environments to further evaluate the extent of the intergranular cracking. There are many cases documented where failures have occurred in stressed parts in environments where failure would not have occurred in the absence of stress. We did not see any evidence of such stress-assisted corrosion in the MSRE, although it is questionable whether we looked at any parts that had been highly stressed. The process leading to the cracking may involve the diffusion of fission products inward along grain boundaries or may be related to the outward diffusion of chromium. As long as these processes are controlled by solid state diffusion, the depths of cracking will likely be acceptable. If straining dislodges the surface grains, then the location of the diffusion source or sink will move inward. Further straining may cause the process to repeat with rather catastrophic results.

There have been several questions raised in the prior paragraph:
1. What is diffusing into or out of the material that causes cracking?
2. What is the mechanism of material transport and what is its rate?
3. How does stress affect the cracking?

The evidence to date indicates that the cracking is due to the inward diffusion of fission products rather than by the selective removal of some element. The production of such cracks by exposure to tellurium vapor lends strong support to this mechanism. The mechanism of material transport seems currently to be one of solid state diffusion, and quantitative measurements are in progress on the rate of tellurium diffusion into Hastelloy N. The main questions related to stress (strain) have to do with propagating grain-boundary cracks so that grains fall out. This is indeed a valid question. In addition, the mechanisms of stress-assisted corrosion that are not diffusion controlled are quite unclear, and I doubt that we have examined any Hastelloy that was exposed to fission products and stressed highly enough to verify that such processes do not occur in salt. (Recall that we have failed three in-pile loops.)

Thus, the MAC is certainly correct in the importance that they attached to stressed tests. However, the importance of biaxial versus uniaxial tests
is not at all clear. The important factor is to stress in tension the metal surface in contact with salt. This is equally well done by uniaxial or bi-axial stresses. For experimental ease, we are actually using pressurized thin-walled tubes that have hoop-to-axial stress ratio of 2:1. The item that they may have meant to emphasize is that the material should be exposed to cyclic stresses where grains would be more easily dislodged. Our current program of stressed experiments at 650°C includes:

1. Stressed tubes exposed to environments of (a) helium, (b) LiF-BeF₂-ZrF₄-UF₄ fuel salt, and (c) fuel salt with 500 ppm FeF₂.

2. Tubes coated with small amounts of tellurium and stressed in the three environments listed above.

3. Strain cycle experiments of a cantilever beam in environments of (a) helium, (b) fuel salt, (c) fuel salt with FeF₂, and (d) fuel salt with tellurium.

Other stressed experiments will be initiated after the results of the above tests have been analyzed.