GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY . . . . 310 DEGUIGNE DRIVE
SUNNYVALE, CALIFORNIA 94086, Phone (408) 297-3000

NUCLEAR ENERGY DIVISION

BREEDER REACTOR DEVELOPMENT OPERATION

Regulatory File Cy.

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February 1, 1971

Dr. Peter A. Morris, Director
Division of Reactor Licensing
U.S. Atomic Energy Commission
1717 H Street
Washington, D.C. 20545

RE: Docket No. 50-231
License No. DR-15

Dear Dr. Morris:

Discussions with members of your staff have indicated that certain additional information is required to complete their current review of proposed changes to the Technical Specifications. This additional information is provided in the attached document.

Very truly yours,

for Karl Cohen
General Manager

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Att.

Subscribed and sworn to before me this first day of February, 1971.

Margaret J. Shergalis

OFFICIAL SEAL
MARGARET J. SHERGALIS
NOTARY PUBLIC-CALIFORNIA
SANTA CLARA COUNTY
My Commission Expires Nov. 18, 1972

20526 Lynde Court, Saratoga, Calif. 95070

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Southwest Experimental Fast Oxide Reactor

February 1, 1971

Re: License No. DR-15

Docket No. 50-231

GENERAL ELECTRIC COMPANY
310 DeGuigne Drive
Sunnyvale, California 94086

Additional Information Regarding

Sodium Logging of SEFOR Fuel Rods

I. Introduction

General Electric has submitted Proposed Change No. 4, Revisions 1 and 2, to the SEFOR Technical Specifications, as required by Section 3.10.E of the Technical Specifications. Discussions with the DRL staff have indicated that additional information regarding sodium logging of fuel rods would be helpful to them in their review of the proposed changes. This additional information is presented herein.

II. Discussion

A. General

Specification 3.12.B.10 of the SEFOR Techr'cal Specification prohibits the conduct of transient tests, if there is evidence that the core contains defective fuel rods. Specific surveillance activities are required by Sections 4.3 and 3.13 of the Technical Specifications to provide reasonable assurance that Specification 3.12.B.10 is met. Results from recent tests which have confirmed the sensitivity of methods employed at SEFOR to detect defective fuel are discussed in Revision 2 to Proposed Change No. 4. Therefore, the discussions of consequences of transient testing with defective fuel (specifically sodium-logged fuel) presented in this submittal should be viewed in the context of a back up to the detection capability, and required operating philosophy for transient operation.

B. Summary of Additional Analysis

Reference 1 presents a discussion of the analvcical and test results related to transient operation with a sodium-logged fuel rod. The analytical results presented in Reference 1 apply specifically to the condition of sodium being in the fuel-to-clad gap during the Design Transient. Since the Design Transient

is about three times as large as the Maximum Planned Transient[2] allowed by the Technical Specification[3], the additional analysis discussed below have been completed for the Maximum Planned Transient (MPT).

Reference 1 discusses the consequence of sodium in the fuel-to-clad gap during a large transient, and concludes that no clad deformation will occur as a result of high sodium vapor pressure since sodium temperatures remain below the normal boiling point of sodium. This conclusion in Reference 1 had additional margin since the saturation temperature is about 1830°F (corresponding to the local coolant pressure in the core) rather than the normal boiling point of sodium.

Analysis have also been performed that assume that sodium is in the interior of the fuel pellet as well as in the fuel-to-clad gap during a MPT. This analysis is presented in detail as Case I, below. The model analyzed assumes that the fuel and sodium are in thermal equilibrium prior to and during the transient. The pressure inside the fuel rod is assumed to be the local static coolant pressure in the core (38 psia) prior to the MPT. Therefore, the peak temperature of liquid sodium in the defected fuel rod is about 1830°F prior to the MPT. Using the maximum average fuel temperature rise for the MPT[4] and applying the appropriate power peaking factors, the maximum fuel temperature rise is 1040°F. Therefore, if the hot fuel rod were sodium logged, the maximum sodium temperature would be 2870°F. As discussed in Case II, below, the fuel rod cladding hoop stress corresponding to the sodium saturation pressure at 2870°F is only about one third of the at-temperature yield strength of the 316 stainless steel cladding. On this basis, it is concluded that the presence of liquid sodium in the interior of a fuel pellet in the hot rod during a planned transient presents no safety problems, since it would not generate sufficient pressure to distort the cladding of the defective fuel rod.

The model used to generate the results summarized above (Case I) assumes that sufficient gas space is available in the sodium-logged fuel rod to accommodate the volumetric change of the fuel and sodium inside the rod that would occur during the MPT. It is believed that this is a realistic assumption. A failure would have to occur near the upper end of the gas plenum regions of the fuel rod[5] to reduce the gas volume in the fuel rod to a value such that this assumption would not be valid. The probability of a defect occurring at these locations, rather than a location opposite the fuel, is very small because the temperature and stress levels in the fuel rod at these locations are significantly lower than in the fuel regions. However, to demonstrate the inherent capabilities of the design, it was assumed that the gas plenum was also completely filled with liquid sodium (Case II, discussed below). The TGRV model of Reference 2 was used to calculate the time dependent fuel, sodium and cladding temperatures which were used to determine the maximum differential volume mismatch between the fuel, sodium and cladding. The calculated cladding strain to accommodate the volume change is 0.6%. The SEFOR fuel cladding has a minimum ductility of 15%.[2] The calculated strain is therefore well within the capabilities of the cladding. It is also significant to note that this is less than the 1% cladding strain given in Specification 3.3.K to define a defect.

Case I - Sodium in a Fuel Pellet Crack

Results

The maximum hoop stresses resulting from the peak sodium saturation pressure in a crack in a fuel pellet in a hot rod is 8500 psi. The yield strength of 316 stainless steel at the maximum average clad temperature reached during the maximum planned transient of 960°F is 21,200 psi. The ultimate tensile strength at this temperature is 70,000 psi.

Model Description

Assumptions:

1. The fuel rod has a small leak that admits sodium, and the sodium enters the cracks in the fuel pellets.
2. Sufficient sodium vaporizes during the transient to yield an equilibrium vapor pressure in the fuel rod.
3. Sodium temperature rise is equal to the temperature rise of the hottest pellet in a fuel rod.
4. During the transient no sodium leaves the fuel rod through the hole in the clad which admitted the sodium.

The model hypothesizes that a fuel rod contains a small leak which enables sodium to enter the fuel rod, replacing the gas which previously surrounded the fuel pellets. The sodium enters the fuel pellets through small radial cracks or at the pellet interfaces and is vaporized when it reaches a depth in the pellet at which the fuel temperature is greater than the saturation temperature of sodium at the local pressure. Since the fuel rod contains a leak which admitted the sodium, the pressure inside the fuel rod is equal to the static pressure in the sodium outside the fuel rod. This static pressure determines the maximum liquid sodium temperature in a fuel pellet before initiation of a transient. At the lower end of a fuel rod the static pressure is 38 psia, composed of:

Cover gas pressure	20	psig
Atmospheric pressure	14.7	psia
Static sodium head	3.3	psi
	38.0	psia

The saturation temperature at this pressure is 1830°F.[6] The MPT results in a maximum average fuel temperature rise of 568°F.[4] The corresponding temperature increases of the hot pellet in the hot rod (determined by peaking factors) is 1040°F. This leads to a peak sodium temperature of 2870°F. The corresponding sodium vapor pressure is 726 psia.[7] The hoop stress resulting from this internal fuel rod pressure is calculated to be 8500 psi. This compares to a yield strength for 316 stainless steel of 21,200 psi at the average clad temperature reached during the MPT.

Discussion of Results

The average temperature rise of the fuel during the MPT was calculated using a heat capacity relation for UO_2 as discussed in Ref. 8. The heat capacity for mixed oxide fuel is greater than that of UO_2 at temperatures greater than 1400°K (2060°F). Since the fuel adjacent to the liquid sodium in this model is initially at 1830°F and is heated above 2060°F, its actual temperature rise would be less than that used to determine the peak sodium pressures given above. This effect would reduce the peak pressures and hoop stresses below the values given above. Since the results given above were calculated for the temperature rise of the hot pellet in a hot rod, sodium present in a fuel rod at any other radial location in the core would be heated to lower temperatures, which would result in lower calculated pressures.

Case II - Completely Sodium-Logged Fuel Rod

Results

The area expansions associated with expansion of the hot fuel pellet and sodium in the pellet clad gap at the hot pellet location in a hot rod results in a maximum local clad strain of 0.6%. The differential volumetric expansion of the fuel and sodium in the lower segment of the fuel rod relative to the total volume of the fuel rod is 1.1% or .185 in^3. If the entire volumetric expansion is accommodated by radial expansion of the clad, the resultant average clad strain is 0.5%. The ductility of the fuel cladding after the low exposures anticipated for the fuel will be at least 15% uniform elongation.[9] Therefore, the fuel cladding can safely accommodate the strains associated with a sodium-logged hot rod and the maximum planned transient.

Description of Model

Assumptions:

1. The fuel rod has a small leak that admits sodium into the fuel rod, completely replacing the gas which had surrounded the fuel pellets and had occupied the gas plenum.

2. During the transient no sodium leaves the fuel rod through the hole in the clad which admitted the sodium.

3. The sodium and fuel are incompressible.

4. The expansion of fuel column length is determined by the increase in the fuel shoulder temperature (dished pellets).

A maximum clad strain of 0.6% for the hot rod was calculated by considering the area expansions of the fuel pellet and the sodium in the pellet clad gap at the hot pellet location in the rod. Since the total area expansion of the pellet and the sodium was greater than the area of expansion of the clad, the difference is accommodated by straining the clad.

The initial radii of the pellet and the clad at a steady state reactor power of 9 MW with sodium in the pellet clad gap are 0.443 inches and 0.449 inches, respectively. The area expansion of the fuel sodium and clad are each given by:

$$A = A_o (1 + 2\alpha\Delta T)$$

where A = cross sectional area of sodium, pellet or cladding at peak temperatures encountered during the transient.

A_o = initial areas at a steady state reactor power of 9 MW.

α = coefficient of linear expansion of the fuel, sodium, or cladding.

ΔT = temperature rise of fuel, sodium or cladding.

The temperature rise of the hot pellet of the hot rod during the maximum planned transient is 1040°F. The temperature rise of the sodium in the pellet clad gap is 260°F and the clad temperature rise is 180°F. The fuel temperature rise was determined from the average fuel temperature rise and peaking factors. The clad and sodium temperature increases were calculated

by the TGRV model of Ref. 2, using the fuel temperature rise associated with the MPT as input. The fuel expansion data was taken from Reference 10 and the sodium expansion data was taken from Ref. 6.

The total volume mismatch over the lower segment of a fuel rod was calculated by summing the volumetric changes associated with the axial expansion of the fuel pellets, reflector, and insulator, and the volumetric change associated with the radial expansion of the hot pellet. The total axial expansion of the pellets, reflector, and insulator relative to the clad is 0.041 inch, leading to a volume change of 0.025 in^3. The axial expansion of the fuel pellets was determined from the increase in pellet shoulder temperature and the linear expansion data given in Ref. 10. The volumetric change due to the increase in radius of the pellet and sodium expansion in the pellet-clad gap was calculated by multiplying the area mismatch at the hot pellet by the total fuel length, in the lower segment, of 20.6 inches. The mismatched area expansion at the hot pellet was 0.0077 $inch^2$ per inch, leading to a volumetric mismatch over the length of the fuel rod of 0.16 $inch^3$. Therefore, the total volumetric mismatch is 0.185 $inch^3$, which can be compared to a lower segment volume of 17 $inches^3$ and a gas plenum volume of 0.57 $inch^3$.

Discussion of Results

Ref. 5 shows a cross section of a fuel rod. Unless a clad defect occurs at the upper end of the gas plenum in either segment, the fuel rod cannot completely fill with sodium. The trapped gas bubble would allow the volumetric increase mismatch to be accommodated by compressing the gas. This would minimize if not eliminate the clad strains calculated above. It is extremely unlikely that a clad failure would occur at the upper end of the gas plenum since that region of the fuel rod does not reach the temperature and stress levels present in the cladding in other parts of the fuel rod. In addition, the wall thickness near the upper end of each gas plenum is greater than the normal wall thickness, which further reduces the probability of a defect in that region. The volume of the lower segment gas plenum, less the spacer and spring volume, is 0.57 $inch^3$, which can be compared to the volumetric mismatch of 0.185 $inch^3$. Therefore a gas bubble in the lower gas plenum could readily absorb the volume mismatch during the MPT. This analysis is also conservative in assuming that the area mismatch at the hot pellet occurs over the

total length of the fuel region. Pellets at other axial locations in the fuel rod would have a smaller fuel temperature rise, smaller sodium temperature rise in the clad-pellet gap, and consequently, less area mismatch.

The volumetric expansions in the upper fuel segment of the hot rod would be less than those presented for the lower region because the peak axial power occurs in the lower fuel segment. Therefore the temperature increase and volumetric increase of the fuel during the MPT are less in the upper segment. The upper segment gas plenum is larger than that of the lower segment which would provide additional room for sodium expansion if the plenum were gas-filled at the time of the transient.

References

(1) SEFOR FDSAR, Supplement 21, pp 5-8

(2) SEFOR FDSAR, Supplement 10, pp 1-45 through 1-53.

(3) SEFOR Technical Specifications, Paragraphs 3.12.A.3, 3.12.B.1. and 3.12.B.2.

(4) SEFOR FDSAR, Supplement 10, p 1-52

(5) SEFOR FDSAR, Supplement 10, Figure II-3.

(6) G. H. Golden and J. V. Tokar, "Thermophysical Properties of Sodium," ANL 7323, Argonne National Laboratory, 1967.

(7) D. L. Booth, "The Thermodynamic Properties of UO_2 and Sodium," TRG Report 1871 (R/X), United Kingdom Atomic Energy Authority, 1969.

(8) SEFOR FDSAR Supplement 10, p 1-126.

(9) SEFOR FDSAR, Supplement 21, p 2

(10) B. F. Rubin, "Summary of $[U,Pu]O_2$ Properties and Fabrication Methods," GEAP 13582 AEC Research and Development Report, General Electric Co., November, 1970