Fort St. Vrain Fuel Elements
NRC Fin No. A-7258

April 30, 1984

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Prepared for the
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

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ABSTRACT

This report reviews the material submitted to the NRC by the Public Service Co. of Colorado, on the evaluation of two cracked Segment 2 graphite fuel elements, and on the examinations of Segment 3 graphite fuel elements removed during the third refueling of the Fort St. Vrain HTGR. The report also provides comments to the NRC as to whether the licensee's technical information is correct and consistent with the information gained by Los Alamos in their review of graphite slabs from Segment 2 cracked fuel element SN 1-2415.

FORWARD

This technical evaluation report is part of the technical assistance program, "Review of Selected Fort St. Vrain Issues", FIN No. A-7258, and is supplied to the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, by Los Alamos National Laboratory.

Technical Evaluation Letter Report
on
Fort St. Vrain Fuel Elements

by

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NRC Fin No. A-7258
April 20, 1984

On April 4, 1984, the Public Service Company of Colorado, the NRC and its technical consultant, Los Alamos National Laboratory, attended a meeting at NRC, Bethesda, Maryland, to discuss the results of

1. the evaluation of two cracked Segment 2 (second refueling) graphite fuel elements and

2. the examinations of Segment 3 graphite fuel elements removed during the third refueling.

The Fort St. Vrain submittal of April 6, 1984, formally provided the evaluation material discussed at this meeting.

The objective of this evaluation is to review the licensee's letter and related material, and to provide comments to the NRC as to whether the licensee's technical information is correct and consistent with the information gained by Los Alamos in their review of graphite slabs from Segment 2 cracked fuel element SN 1-2415.

The Los Alamos review of the licensee's letter and related material is as follows:

1. <u>Probable Cause</u>

Los Alamos agrees with the statement made by the Public Service Co. of Colorado (PSCo) that the likely cause of cracking in the two elements is thermal stress, induced mainly by cold helium by-pass flow on the B-face of the two elements, and perhaps exacerbated by skewed power and/or flux distributions within the region of interest. Los Alamos has recently completed a finite element failure analysis on a model representing a localized area of a typical graphite fuel element, as shown in Fig. 1. The thermal calculation was done using the thermal and mechanical properties for H-327 graphite (Ref. 1), with consideration to irradiation-induced shrinkage

effects. Fuel heating rates, coolant temperatures, and surface heat transfer coefficients were used as specified or derived from the Fort St. Vrain FSAR and relevant documents (Ref. 2 and Ref. 3). A by-pass flow temperature of 760°F was employed in the calculations, as were two surface heat transfer coefficients on the B-face, reflecting uncertainty in gap thickness between adjacent column elements. From the temperature distribution in the model, the thermal stress distribution was calculated. Finally, using a Weibull statistical strength model (with Weibull modulus of 8 from GA-A13955 and a mean tensile H-327 graphite strength of 1200 psi from the Fort St. Vrain FSAR) we determined the failure probability and failure region in the model. That failure probability is shown in the first two lines of Table I for the two surface heat transfer coefficients covered in the study. For the higher heat transfer coefficient there is a significant probability (about 10^{-2}) of failure in the graphite web between the coolant hole and B-face. Figure 2 illustrates the tensile stress distribution and Fig. 3 shows the temperature distribution in the graphite web between the coolant hole and B-face.

Los Alamos also calculated the probability that, once the outer web cracked, the crack would propagate further into the element. This was accomplished by releasing the stress on the crack and repeating the calculation. These results are shown as the second two lines of Table I. When the crack occurs in the web between B-face and coolant hole (Case B), the probability of further propagation is significantly reduced (Case D). For interior generated cracks the reverse appears to be true. Thus, Los Alamos agrees with the PSCo assertion that a thermal stress crack, generated in the web between B-face and coolant hole, would be limited in extent and would not easily propagate through the element.

TABLE I

FAILURE PROBABILITIES AND CRACK INITIATION POINTS

Case	By-Pass Flow Temperature	Surface Heat Transfer Coefficient	Failure Probability	Failure Region
A	760°F	1.0 W/in^2-F	0.9×10^{-4}	interior web
B	760°F	4.5	0.11×10^{-1}	B-face web
C	760°F	1.0	0.15×10^{-3}	interior web
D	760°F	4.5	0.27×10^{-3}	interior web

2. Cracked Fuel Element Integrity

As mentioned, Los Alamos agrees with the PSCo claim that extensive thermal stress cracking within a given fuel element is highly improbable. However, there is insufficient information to conclude that the existence of supposed thermal stress cracks, as found in the two Segment 2 fuel elements, would have no effect on the failure mode of a fuel element under all plausible mechanical loading conditions. The tests performed on unirradiated graphite slabs at General Atomic involved uniform static loadings on the sides, which induced overall compression in the element. The results of these static tests indicated that the existence of web cracking should not alter the overall failure mode of the slab.

Los Alamos feels that these tests do not account for the presence of a strong, thermal stress field in the specimen, nor do they account for the possibility that the crack could reduce the strength of the element under dynamic loading conditions. For example, during a seismic event the Fort St. Vrain core (as currently constrained by the core restraint devices) will transmit dynamic loads primarily through the dowel pins and socket arrangement located on the ends of the fuel elements. This dynamic load transfer will produce a complex stress field in the interior of the element, and could subsequently cause cracks to further propagate, depending on the magnitude of loads being transmitted. Therefore, Los Alamos recommends that the effects of the initial thermal stress field and the dynamic loading through the dowel pin arrangement be factored into the evaluation of overall element structural integrity.

3. Adequacy of the Inspection/Surveillance Program

The surveillance/inspection program proposed by the Public Service Co. includes a minimum scope of:

i) Photographing all six faces of 175 of 250 fuel/reflector elements removed during the Segment 3 reload, using the Fuel Handling Machine 35mm camera.

ii) Evaluating all photographs for indications of significant structural abnormalities prior to returning to power operation.

iii) Using the Fuel Handling Machine Cask Video Monitor, carefully examine the two Segment 3 fuel elements with operational histories believed to be most similar to those of the two Segment 2 cracked fuel elements

iv) Perform a Non-Destructive Post Irradiation Examination, similiar to the PIE performed on Segment 1 and Segment 2 elements, using 50 to 60 Segment 3 Fuel and Reflector elements.

The first item implies that some 175 Segment 3 fuel and reflector elements have been or will be photographed using the Fuel Handling Machine camera. To date, PSCo has photographed a large percentage of the Segment 3 elements, with special attention to elements from Region 18, which are said to have a comparable operational history to the Segment 2 cracked fuel elements. Los Alamos recommends that all six sides of all fuel and reflector elements removed in Segment 3 and future reloads be photographed.

The second item requires an evaluation of the photos with regard to "significant" structural abnormalities, prior to returning to power operation. The available set of Segment 3 photographs leads to two conclusions: (i) The photographs taken with the Fuel Handling Machine 35mm camera are of sufficient quality to identify cracks of the same order or bigger than the cracks found on the vertical sides of the Segment 2 cracked fuel elements, and (ii) of the Segment 3 elements adequately photographed, there is no visual indication of cracking, although there are numerous water marks and scratches on the element surfaces.

The third item in the PSCo surveillance/inspection program uses the Fuel Handling Machine Cask Video Monitor in examining the two Segment 3 fuel elements that are considered most comparable to the Segment 2 cracked fuel elements in operational history. We have concluded that this monitor can produce an image comparable to the image with the 35mm camera, and has a resolution that is sufficient to identify cracking on a given element surface.

We agree with the fourth item in the surveillance program which intends to examine, in terms of extensive Non-Destructive Post Irradiation Examinations, all of the elements in Region 18 plus some precharacterized elements from Regions 3, 13, 22 and 29, and based on the premise that Region 18 elements are "comparable" to Region 8 elements. Los Alamos recommends obtaining justification from PSCo, providing clarification on the comparability of the Region 18 elements to the Region 8 cracked fuel elements, with regard to operational history and resulting temperature and stress fields.

In conclusion, we consider the PSCo Segment 3 inspection/surveillance program to be adequate, assuming all six sides of the 175 elements are eventually photographed and evaluated as to surface abnormalities. However, we also recom-

mend that in future reloads, all six sides of all fuel and reflector elements removed be photographed and evaluated. The current percentage of elements receiving extensive nondestructive post irradiation examination is considered adequate.

4. Summary

(i) Los Alamos concurs with the licensee's arguments concerning the likely cause of the cracking of the Segment 2 fuel elements.

(ii) Los Alamos concurs with the licensee's arguments that thermal and irradiation-induced stress cracking is relatively localized as observed in the Segment 2 cracked elements and that the cracks will be hairline in nature and not likely to affect the integrity of fuel pellet rods.

(iii) Los Alamos considers the PSCo Segment 3 inspection/surveillance program to be adequate to the needs of identifying further cracked elements.

(iv) Los Alamos concurs with the licensee's argument that extensive thermal stress cracking in a given fuel element is unlikely under normal operating conditions, but disagrees with the licensee's justification of element structural integrity based only on static load tests. Los Alamos considers the issue of dynamic loading, as transmitted primarily through the dowel-sockets in a column of elements during a seismic event, to be relevant in evaluating the overall structural integrity of a cracked element. Therefore, Los Alamos recommends further review of the failure mode of a cracked fuel element under dynamic and thermal stress loadings, based on existing GAT documentation, or further analyses by PSCo.

5. References

a. "H-327 Graphite Design Data Manual", GA Technologies, GA-906933, June 1983.

b. Goodman, Jovanovic, Ganley and Covert, "The Thermodynamic and Transport Properties of Helium", General Atomic Project 2102, GA-A13400, October, 1975.

c. "Heat Transfer and Fluid Flow in Nuclear Systems", edited by Henri Fenech, Pergammon Press, 1982.

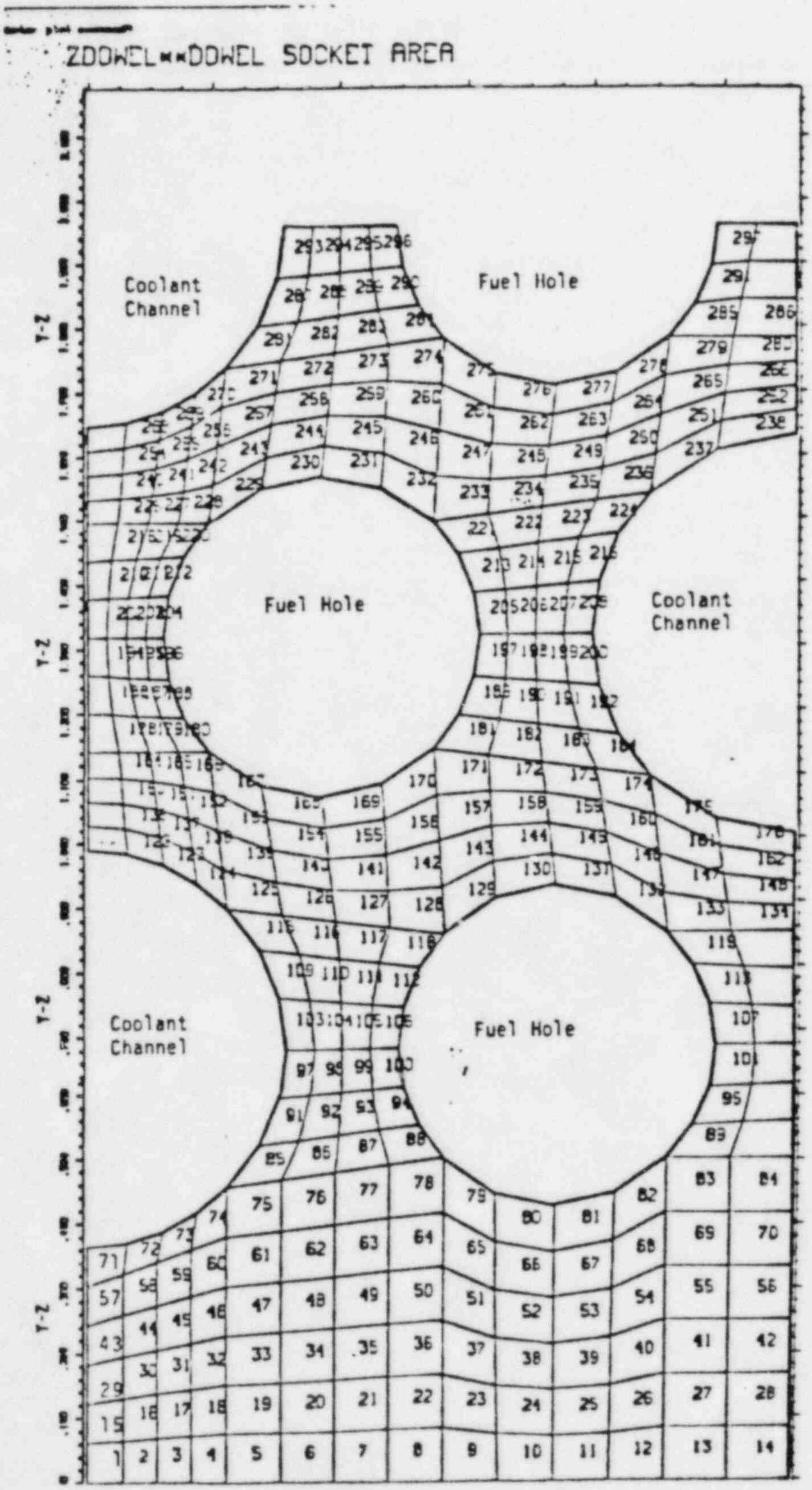

Fig. 1. Finite element model.

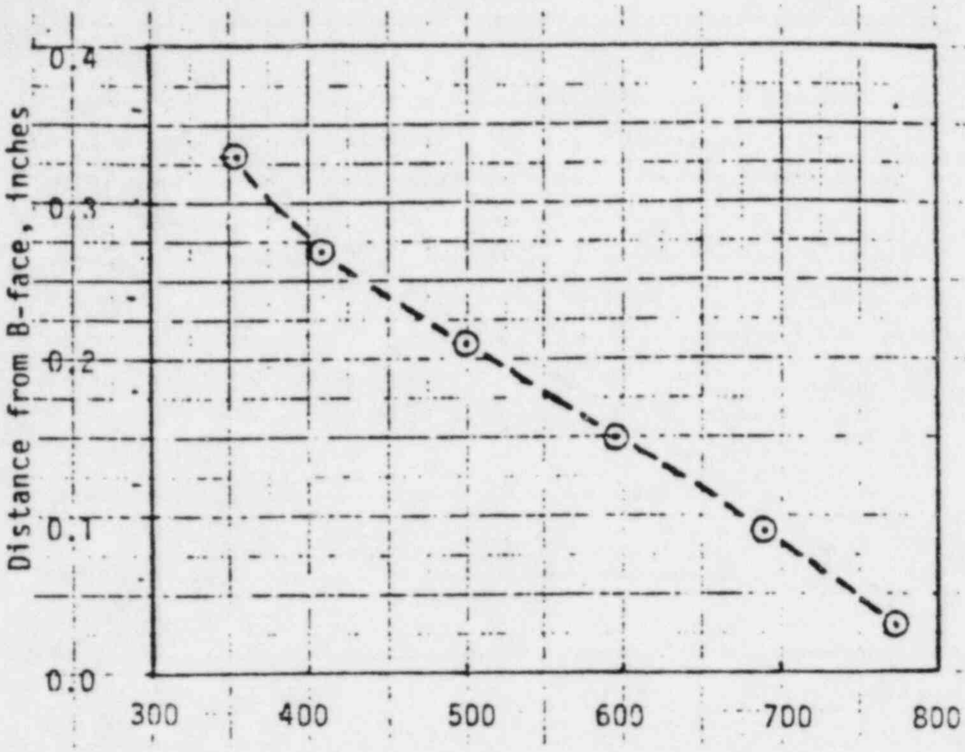

Fig. 2. Graphite web tensile stress, psi.

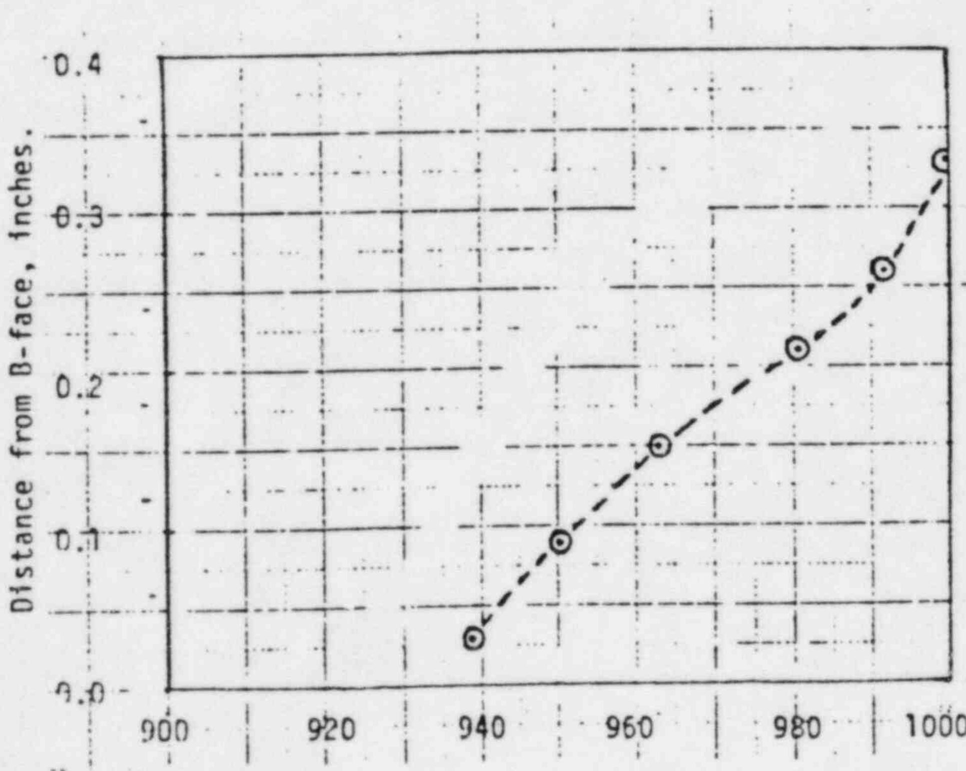

Fig. 3. Graphite web temperature, ^{o}F.