Review of Fuel Rod Metallography
on Fort St. Vrain
Fuel Element SN 1-2415

NRC Fin No. A-7258
July 31, 1984

Los Alamos National Laboratory

William A. Ranken, Q-13
Robert D. Reiswig, MST-6

Responsible NRC Individual and Division
J. Miller/ORB3

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

DISCLAIMER

ABSTRACT

This report reviews the documentation submitted to the NRC by the Public Service Co. of Colorado, on the metallographic examination of a section of fuel stack 308, as found in cracked fuel element SN 1-2415 removed during the third refueling of the Fort St. Vrain HTGR. Los Alamos essentially concurs with the PSCo conclusions, in that the performance of the fuel during irradiation was acceptable, that no evidence of fuel and graphite element interaction has been found, and that no kernel migration was observed. The report 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 previous fuel studies, and 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.

Review of Fuel Rod Metallography
on Fort St. Vrain
Fuel Element SN 1-2415
Technical Evaluation Report

Introduction

During the Segment 2 reload of the Fort St. Vrain High Temperature Gas-Cooled Reactor, two colinear graphite fuel elements were found cracked axially down the B-face, and radially inward two and three webs deep. This report reviews the metallographic examination performed by GA Technologies on a fuel rod from a stack adjacent to the crack region of the more severely cracked fuel element.

Background

The GA Technologies report entitled "Metallographic Examination of a Fuel Rod from Segment 2 FSV Fuel Element 1-2415" (Ref. 1) describes the metallographic examination of a fuel rod from the stack in fuel hole 308 of Fort St. Vrain fuel element SN 1-2415, which developed a crack during irradiation. Stack 308 was centered in the second row of fuel and coolant channels on the B-face side of the hexagonal graphite element, and was adjacent to the crack (which actually passed through fuel hole 307). The metallographic examination was conducted to see if any evidence of unusual thermal effects could be seen that would help in ascertaining the cause of the crack, and was performed in conjunction with a more general postirradiation examination on the fuel element.

Each graphite fuel element is a hexagonal right prism, with 210 fuel holes and 108 coolant channels drilled parallel to one another in a triangular array with 0.74 inch pitch spacing, resulting in a basic ratio of two fuel holes for each coolant channel. Each fuel hole is drilled from the top surface of the element, to within about 0.3 inches of the bottom. Bonded rods containing coated fuel particles, each about 1/2 inch long, are stacked within the hole, and the hole is capped with a graphite plug.

The fuel is in the form of carbide particles, coated with a highly retentive coating, and bonded into fuel rods with a coal tar pitch binder[2].

The fuel rods contain a homogeneous mixture of fissile particles containing both uranium^{235} (93.15% enriched) and thorium, and fertile particles containing only thorium. As schematically shown in Figure 1, the fuel particles are coated with a four-layer TRISO coating, sequentially consisting of an inner layer of porous pyrolytic carbon called the buffer layer; a high density isotropic pyrocarbon (IPyC layer); a thin layer of SiC, which is highly impervious to metallic fission products; and an outermost layer of strong high density isotropic pyrocarbon (OPyC layer). Important particle parameters are reproduced from the FSAR in Table 1.

Discussion

Our general evaluation of the metallographic examination of this fuel rod, and the coated fission and fertile particles it contained, is that it appears to have been done competently. The main criticism relates to the selection of the examined fuel rod from a stack (308) adjacent to the stack in fuel hole 307, through which the crack in the fuel element passed. Presumably this selection was made because the thermal history of stack 307 might have been distorted by the crack and hence would be less representative than stack 308 of events that precipitated the cracking. Nevertheless, it would have been more informative if the fuel rods from 307 had been measured for dimensional changes and one of them chosen for metallographic examination in addition to the rod actually selected. Additional examination would have helped to rule out fuel nonuniformity effects as a cause for crack formation.

The performance of the fuel was found acceptable in Ref 1. Specific observations and conclusions from the document are summarized as follows:

1. Fuel rod 13 from stack 308 was in good condition although minor cracking in the matrix end caps and some debonding of particles from the rod surface were observed.
2. There was no fuel rod-block interaction as evidenced by the visual examination of the rods, by the small pushout force of the stack, and by the small amount of debris collected from the emptied block.
3. The measured macroporosity for rod 13 was 17.5%, which was within the (14-29%) range of macroporosities observed for fuel rods from capsule F-30.

4. A total of 231 fissile and 184 fertile particles from rod 13 were examined. For the $(Th,U)C_2$ and ThC_2 particles, respectively, the OPyC coating failure was 0.4% and 7.6%, and the SiC coating failure was 0.9% and 3.8%. However, these coating failure rates should be regarded as the upper limits since coating failures can be caused during manufacture and during the grinding and polishing procedure, as well as during irradiation.
5. The chemical behavior of the particles was acceptable. There was no kernel migration observed. However, there was evidence of fission product interaction with the SiC coating. 3.9% of the fissile particles and 3.2% of the fertile particles showed fission product--SiC interaction with a penetration depth of ∿ 5 μm, which was higher than the expected value of < 1 μm. The increased penetration may have been caused by fuel dispersion resulting from chlorine trapped in the buffer layer during the SiC coating and/or by higher operating temperatures than the average calculated for the element.
6. Fuel dispersion, which is attributed to chlorine diffusing through a low density IPyC into the buffer layer during the SiC coating process, and IPyC debonding were observed in some of the TRISO $(Th,U)C_2$ and ThC_2 particles. Fuel dispersion and IPyC debonding did not detrimentally affect the performance of the particles.

In general the conclusions reached in the report are reasonable, but there is a need for caution. Visual examination, the ease with which the rods could be pushed out of the block, and the porosity measurements all confirm normal behavior for fuel stack 308. However, the fuel dispersion results, the amount of fission product interaction with the SiC layers, the inner pyrolytic carbon coating debonding (shrinkage of the pyrocarbon), the observed coating failure rates, and the lack of data on total coating failure (because of hydrolysis of the metallographic specimen mount) all raise questions.

As stated in the report, one interpretation of the depth of fission product interaction (~ 5 μm versus < 1 μm expected) is that the operating temperature was higher than the average calculated for this fuel element. Higher than expected operating temperature could presumably also explain the greater than usual amount of fuel dispersion observed in the sectioned fuel rod. Temperature may also have been a factor in the increased irradiation - induced shrinkage of the inner pyrolytic coatings that led to debonding.

As to questions of whether broken coatings were caused by metallographic sample preparation or by irradiation, it would have been helpful if the GA investigators had cited past experience on sample preparation and used this to make a determination of the most probable cause of the observed cracking.

The lack of total coating failure data is indeed unfortunate. It is not known whether the number of failures was a very small fraction of total particles or a significant added population to that of particles with just one of the three containment layers cracked.

Conclusions

Despite the uncertainties in interpretation of some of the fuel rod metallographic data, there is little evidence that the thermal history was abnormal. The observed departures from the norm, particularly in fuel dispersion and fission product interaction, may indeed have been caused by variations in coated particle fabrication as suggested by GA. If the particles were uniform in their properties, one would expect a temperature effect to show up in all of them instead of just a fraction. On the other hand, the variation of particle properties could mask a temperature effect, because one would not be sure, for instance, how much of the increased fuel dispersion was caused by chlorine and how much by a higher than expected temperature. It appears that fuel rod metallography is not, under the current conditions, a very sensitive determinant of fuel and thermal history. In any case the GA promise to monitor the fuel dispersion and fission product - SiC interaction in future FSV fuel surveillance should be seized upon. If any future work is done on fuel element 1-2415, it should include dimensional checks and metallography on the fuel rods from stack 307.

References

1. "Metallographic Examination of a Fuel Rod from Segment 2 FSV Fuel Element 1-2415", GA Technologies Doc. No. 906968, 1983.

2. Fort St. Vrain Nuclear Generating Station, "Updated Final Safety Analysis Report", Public Service Co. of Colorado.

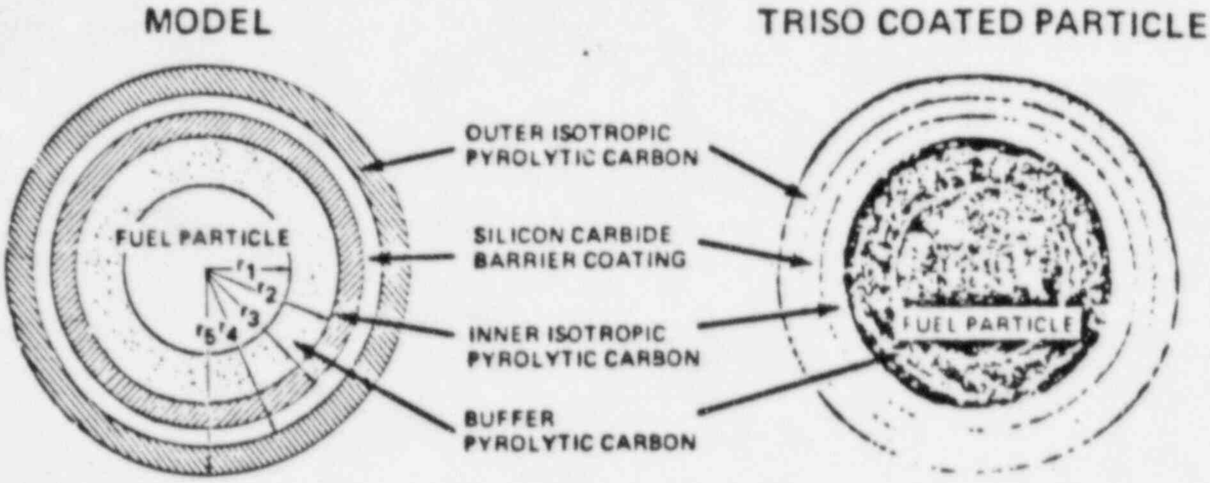

Figure 1. Model of TRISO Coated Fuel Particle

Table 1. Coated Fuel Particle Parameters

Parameter	Fissile		Fertile	
Th:U	3.6:1,4.25:1		All Th	
Kernel composition	$(Th{:}U)C_2$		ThC_2	
	Small	Large	Small	Large
Average fuel kernel diameter, micron	140	225	375	525
Average coating thickness:				
Buffer carbon layer, micron	50	50	50	50
Isotropic carbon layer, micron	20	20	20	20
SiC layer, micron	20	20	20	20
Isotropic carbon layer, micron	30	40	40	50
Average coated fuel diameter, micron	380	485	635	805
inches	(0.015)	(.019)	(.025)	(.032)