Public Service Company of Colorado

July 24, 1979
Fort St. Vrain
Unit No. 1
P-79157

Mr. Themis P. Speis, Chief
Advanced Reactor Branch
Division of Project Management
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Docket #50-267

Subject: Fort St. Vrain Fuel Particle Coating Failure

Gentlemen:

Analysis of Peach Bottom fuel element test data indicates that failure of the outer pyrolytic carbon (OPyC) coating of Fort St. Vrain (FSV) Segment 1-7 fuel particles will occur in greater numbers than originally anticipated. The increase in the OPyC coating failure rate can be attributed to OPyC coating microporosity characteristics in which either a lack of strain accomodation in the fuel particle or matrix/OPyC coating interaction results in coating failure.

The impact of OPyC coating failure upon the performance of fuel particles has been reviewed by PSC and General Atomic Company (GAC) with respect to the performance criteria defined in the FSV FSAR, and has been deemed to be of little consequence. In particular, accident analysis presented in the FSAR remain unchanged. However, as a precautionary action, the microporosity evaluations were submitted to the 10CFR21 Evaluation Committees at both PSC and GAC for determination of reportability to the NRC. The conclusions of both committees were that the fuel particle microporosity question does not constitute a defect or noncompliance which could create a substantial safety hazard at Fort St. Vrain.

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Consequently, PSC is providing the NRC, for information purposes only, copies of both the PSC (Attachment A) and GAC (Attachment B) 10CFR21 Committee evaluations on the above subject. PSC wishes to emphasize that this submittal should not be misconstrued to be a safety hazard report under the provisions of 10CFR21.

If additional information on this subject is desired, please contact this office.

Very truly yours,

Frederic E. Swart

Frederic E. Swart
Nuclear Project Manager

FES/MLP:eg

Attachments

485 002

FORT ST. VRAIN NUCLEAR GENERATING STATION
PUBLIC SERVICE COMPANY OF COLORADO

PART 21 REPORT EVALUATION

Part 21 Report No. P21 - 0009

A. Describe Defect or Failure-to-Comply: Fuel Particle Microporosity

B. Preliminary Evaluation:

Answer each of the following:

	YES	NO
1. Safety related plant structure, system, component, part?	XX	
2. Plant features described in the FSAR?	XX	
3. Plant features addressed in the Tech Specs?	XX	
4. Subject of an applicable NRC regulation?	XX	
5. Situation is not reportable under the criteria of Tech Spec 7.2c, 7.5.2a, or 7.5.2b.	XX	

Note: At least one "yes" box must be checked above for the Defect or Failure-to-Comply to have the potential for creating a Substantial Safety Hazard.

C. Determine if a Substantial Safety Hazard Exists:

NO A situation which could contribute to the release of licensed material.

NO A situation which could contribute to public radioactivity exposure exceeding the calculated exposures of FSAR DBA No. 2 by 25 percent.

NO A situation which could result in failure of a safety related component or device to operate.

NO A deficiency in the design, construction, inspection, testing, or use of a licensed facility or material which could downgrade the margin of safety.

NO A situation that could result in a failure of the physical security system to meet the approved Security Plan.

D. XX The Defect or Failure-to-Comply meets none of the above criteria.

PART 21 REPORT EVALUATION

(Page 2 of 2)

Part 21 Report No. P21- 0009

E. Evaluation Notes and Comments:

The Evaluation Team met on May 21, 1979, to determine if fuel particle microporosity was reportable under Part 21. It was determined that additional information would be required in order to make a decision. The meeting was adjourned until such time that Mr. Fred Swart would be available to discuss this matter with the Evaluation Team. On May 30, 1979, the Evaluation Team met with Mr. Swart and after discussion, concluded that this problem did not meet the criteria for reporting under Part 21. The Evaluation Team, however, recommended to Mr. Swart that the Nuclear Regulatory Commission be made aware of the fuel particl microporosity problem. He concurred and will handle the matter.

F. Evaluation Team and Other Participants:

1. Larry McInroy 2. Milt McBride 3. F. E. Swart
4. J. W. Gahm 5. 6.

G. Conclusion:

The Evaluation Team has concluded (unanimously)(~~by majority vote~~) that the Defect or Failure-to-Comply described on the attached Part 21 Report (~~does~~) (does not) create a substantial safety hazard.

Majority: Larry McInroy 5/30/79 J.W. Gahm L. Milton McBride
Minority: ______

H. Part 21 Report to the NRC No. 50-267/ N/A (if prepared).

J.W. Gahm — Evaluation Team Leader 5/30/79 — Date

I. Remarks:

N/A

DISTRIBUTION

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Resident Engineer
Superintendent, QA Services--Original
Supervisor, Technical Services
Records Storage Building
Part 21 Report Initiator

Vice President, Engineering and Planning
Manager of Production
Manager of Engineering
Nuclear Production Manager
Manager of Purchasing and Stores
Quality Assurance Manager

485 004

FORT ST. VRAIN NUCLEAR GENERATING STATION
PUBLIC SERVICE COMPANY OF COLORADO

PART 21 REPORT

Report No. P21-0009 (For Evaluation Team Use Only)

(Note: See Interdepartmental Work Procedure IWP-5 for instructions on how to complete this form.)

Initiator (print): F.E. Swart

Work Location: Montbello Phone: 571-6687

Basic Component or Activity Involved: Reactor Fuel

Defect or Failure-to-Comply: See attached memo, F.E. Swart to J. Gahm, dated May 15, 1979.

Substantial Safety Hazard Created by Defect or Failure-to-Comply: See above referenced memo.

Frederic E. Swart
Initiator's Signature

5/15/79
Date

Note: Please send this completed Part 21 Report to Supervisor, Technical Services, Fort St. Vrain. A copy shall be given to the initiator's immediate supervisor for information.

005

FORM 850-22-0058

INTER-DEPARTMENT MEMO — PUBLIC SERVICE COMPANY OF COLORADO

DATE May 15, 1979

TO Mr. Jack Gahm, Supervisor — Technical Services (DEPARTMENT OR DIVISION)

FROM Frederic E. Swart — Nuclear Project Manager (DEPARTMENT OR DIVISION)

ATTN. 10CFR21 Report Evaluation Team

SUBJ. Fuel Particle Microporosity

The following represents an evaluation performed by the Nuclear Project Department on the subject of fuel particle "microporosity". The results of the evaluation indicate that the fuel particle microporosity question does not appear to constitute a defect or noncompliance which could create a substantial safety hazard at Fort St. Vrain.

This evaluation is being forwarded to the 10CFR21 Report Evaluation Team for independent assessment and determination of reportability to the NRC.

Outer Pyrolytic Carbon (OP_yC) Microporosity

Background:

GAC analysis of Peach Bottom fuel test element data indicated that failure of the OP_yC coating of the fuel particles in Segments 1-7 at Fort St. Vrain could be expected to occur in larger numbers than originally estimated. This condition is attributed to OP_yC microporosity characteristics that could cause failure either from 1) a lack of strain accommodation in the fuel particle or 2) matrix/OP_yC interaction.

Impact:

Failure of the OP_yC coating on fuel particles could result in greater than expected fuel particle failure with the attendent fission product release which increases the activity of the primary coolant. Attachments 1 and 2 indicate that the expected fissile and fertile particle percentage failures in layer 3 of the Fort St. Vrain core (highest temperature and core burnup layer) at 100% power will increase to approximately 1.7%, causing an overall core fuel particle failure percentage increase to 0.95%.

The effect of the increased failed fuel particle percentage on circulating activity in the primary coolant is shown in Attachment 3 where the circulating activity change is described in terms of Kr-85 release rate/birth rate (R/B) in layer 3 of the core at 100% power. Attachment 3 assumes total hydrolysis of the kernels of the failed fuel particles which represents the worst case. At the end of cycle 4, the primary coolant activity would approach Technical Specification limits.

Under these worst case assumptions, Attachment 4 indicates that plant operation must be restricted to 75% thermal power with the present fuel in order to not exceed Technical Specification limits. At 65% power, primary coolant activity remains well within Technical Specification limits as shown by Attachment 5.

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Safety Analysis:

Attachment 6 is a summary of the effect of fuel OP_yC coating failure on the Design Basis Accident (DBA) #1 doses at the plant Exclusion Area Bounda[illegible] (EAB) and Low Population Zone (LPZ). The dose figures are in agreement with the FSAR with the exception of the LPZ thyroid and bone doses. These discrepancies were questioned in item 3 of PG-0012 and were [illegible]ispositioned by GAC as being the result of refined analytical methods. Using older analytical tools, the LPZ thyroid and bone doses would agree with the FSAR.

Att[illegible]ent 7 delineates the findings of an experimental program at GAC to validate the analytical models used for the fuel failure calculations. It is evident that the fission product release as a function of temperature is independent of the OP_yC coating condition. Under accident conditions where fuel temperatures rise above 2100°C, it can be seen that primary coolant activity will not be dependent upon the OP_yC coating.

Attachment 8 is a comparison of the various DBA #1 fuel failure model results. The "Original FSV Model" assumes total fuel failure at approximately 1720°C and is the basis for the information existing in the FSAR. Minimal difference is shown for the "No OP_yC Failure" and "OP_yC Failure" model results which apparently diminishes the concern of the fuel particle microporosity problem under accident conditions. The solid line represents the Core Heat Up Simulation Test (CHST) results which indicate that all analytical models used to determine fuel particle failure were conservative.

PSC letter PG-0012, Attachment 9, requested information from GAC concerning the effect of fuel particle microporosity on the additional safety analyses performed in the FSV FSAR. Attachment 10 is the GAC reply, GP-0028, which states that all plant accident analyses were based upon "design" activity levels that assume a 5% fuel particle failure. The accident analyses in the FSAR thus remain unchanged.

Technical Specification LCO 4.2.8, Primary Coolant Activity, specifies the limiting conditions of operation with regard to circulating activity, and is based upon the "design" levels used in the FSAR accident analyses. Thus, compliance with LCO 4.2.8 will ensure no reduction in the margin between FSAR calculated accident doses and 10CFR100 limits, regardless of fuel failure due to the microporosity problem.

In conclusion, the microporosity problem does not appear to involve a substantial safety hazard due to the following:

1) No contribution to the release of licensed material has been created as discussed in the above paragraphs. All licensed materi[illegible]l is contained within the PCRV at activities less than the "design" value which would result in an offsite dose significantly below the 10CFR100 permissable value during accident conditions.

2) The calculated exposures of FSAR DBA No. 2 remain unchanged as the DBA is based upon "design" activity in the primary coolant.

3) No safety related component or device would fail as a result of the microporosity problem.

4) No margin of safety reduction has been created as the margin of safety is based upon "design" activity levels in the primary coolant.

5) No physical security considerations.

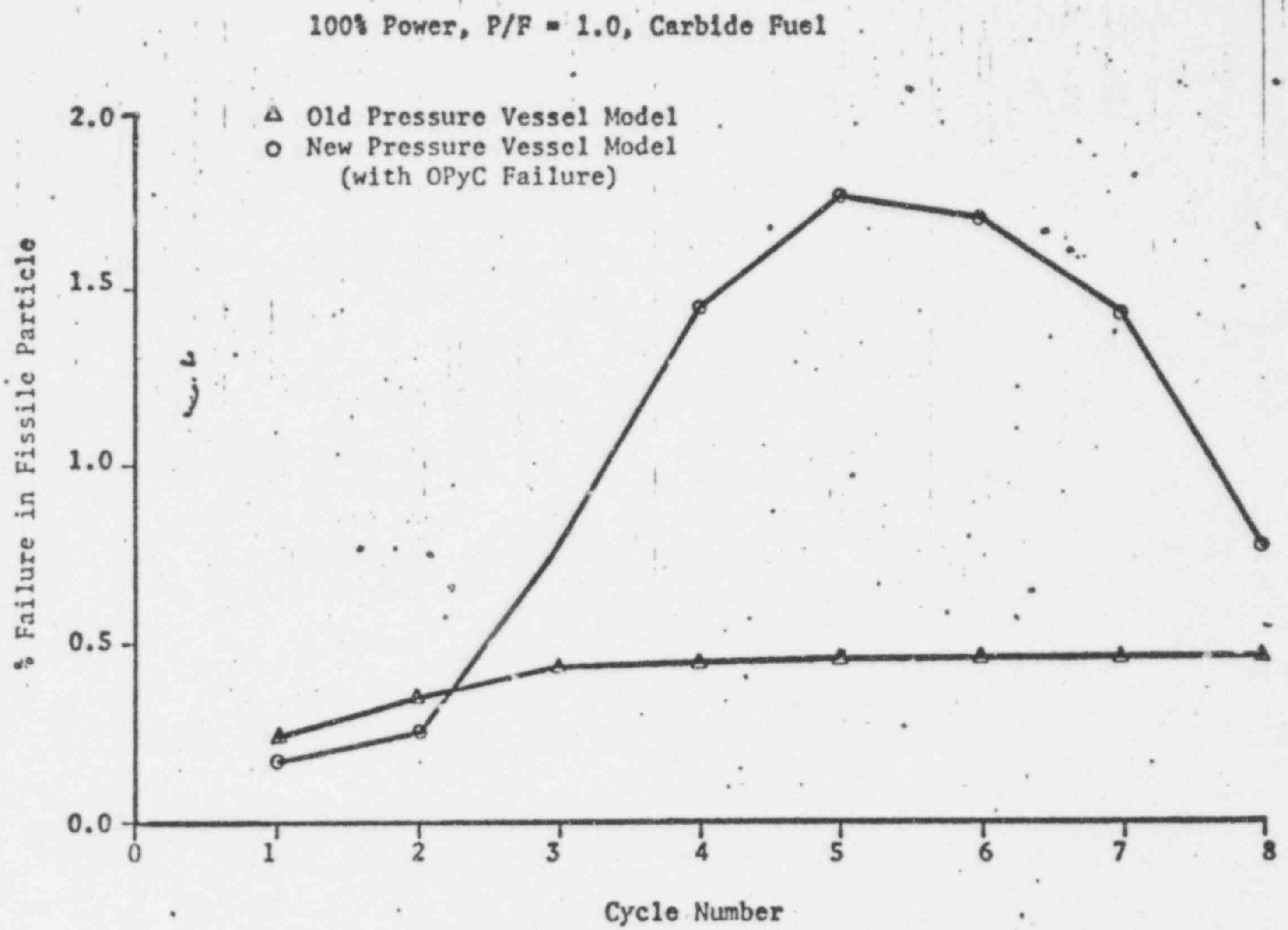
Should your review require additional information, please contact me.

Frederic E. Swart
Frederic E. Swart

FES/MLP:ler

Attachments

cc: J.K. Fuller



FS Layer 3 - Total Failure at End-of-Cycle

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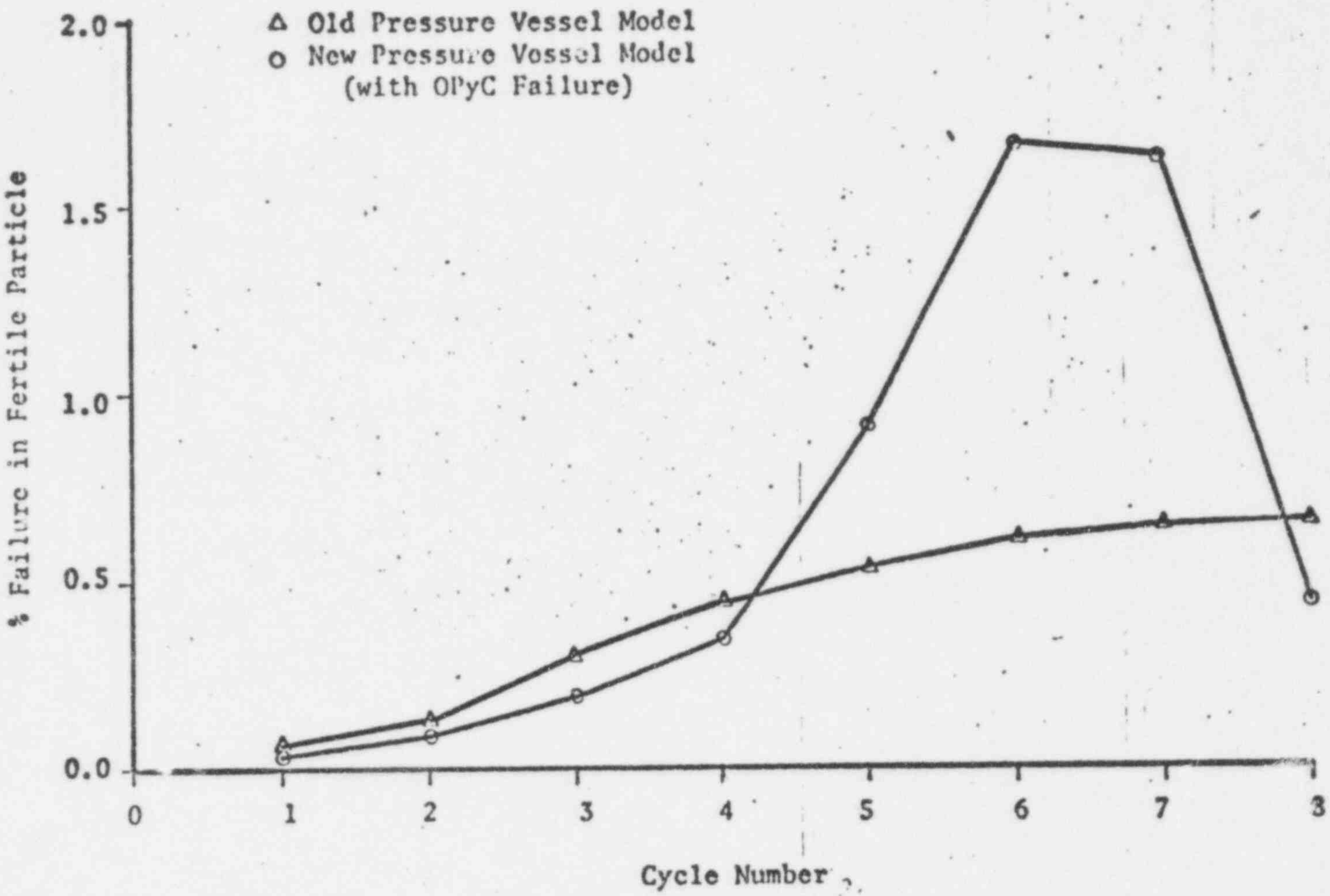
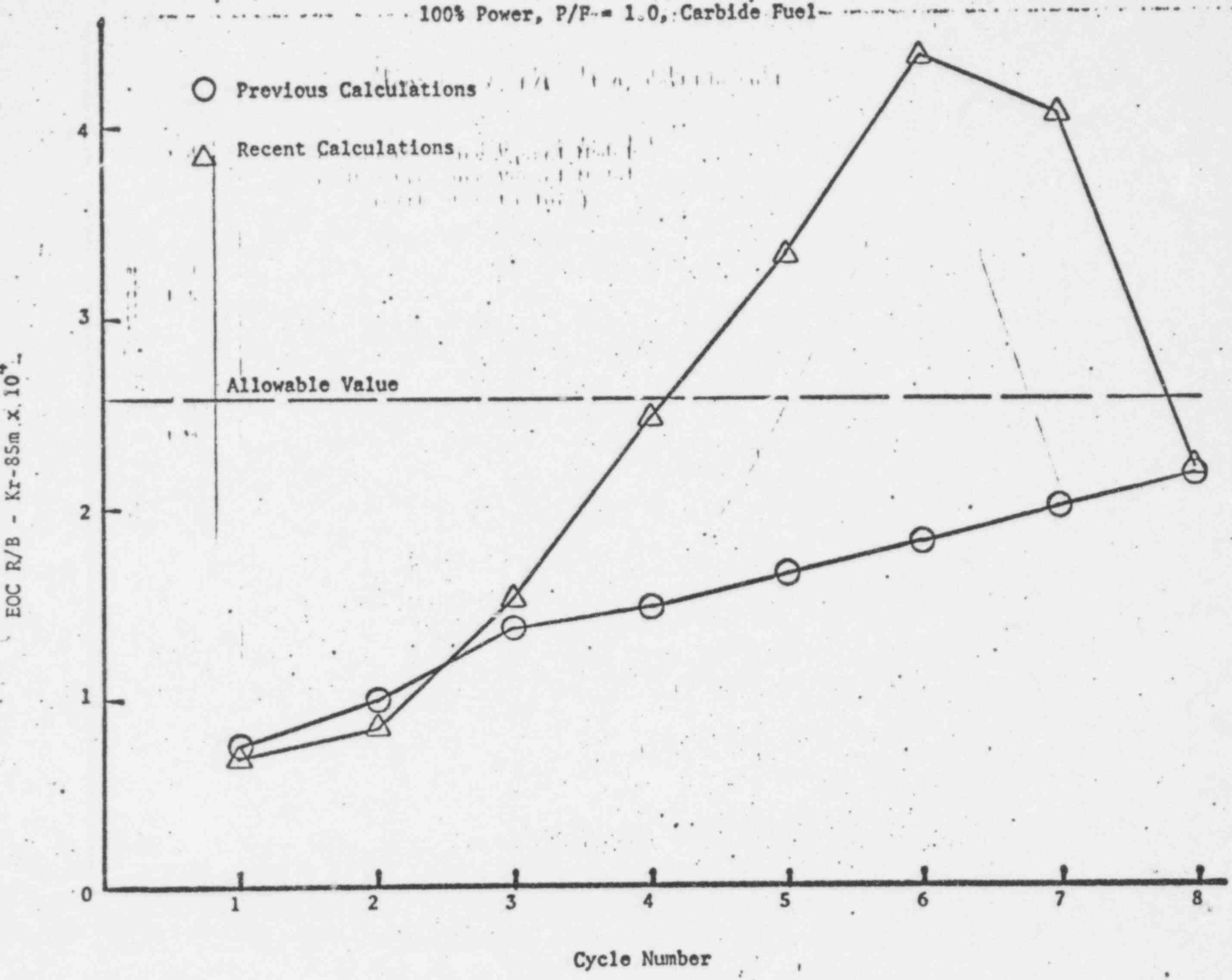
485 010

100% Power, P/F = 1.0, Carbide Fuel

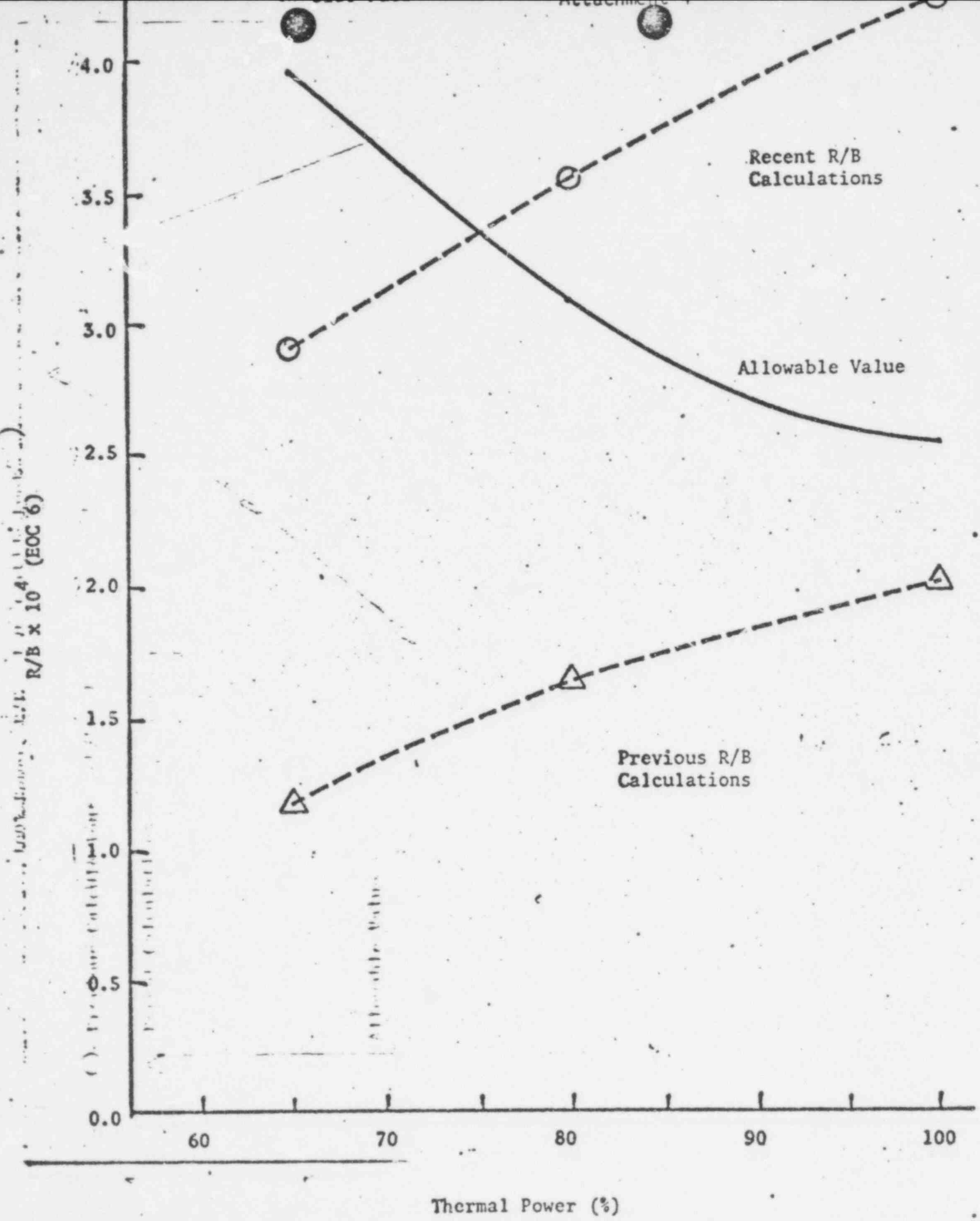


FSV Layer 3 - Total Failure at End-of-Cycle

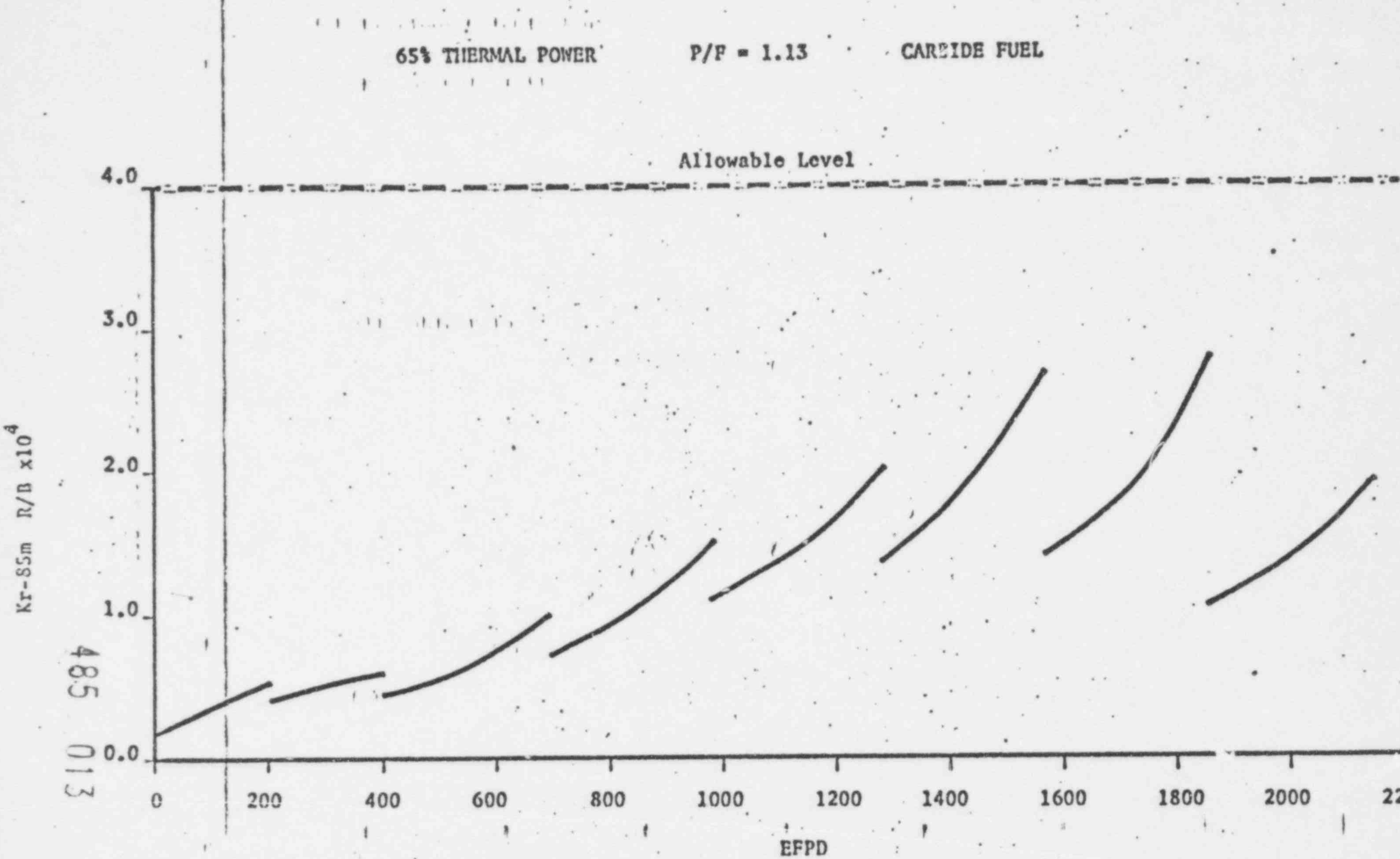
Attachment 2



Attachment 3



R/B x 10^4 (EOC 6)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
60
70
80
90
100
Thermal Power (%)
Recent R/B Calculations
Allowable Value
Previous R/B Calculations



65% THERMAL POWER
P/F = 1.13
CARBIDE FUEL
Allowable Level
4.0
3.0
2.0
1.0
0.0
Kr-85m R/B x10^4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
EFPD

485 013

1/17/79

SUMMARY OF FAILED OPyC COATING EFFECT ON DBA #1

Case	LTA Heat Load At 9 Hrs. (BTU/Hr)	DOSE (Rem): EAB At Two Hours			DOSE (Rem): LPZ At 6 Months		
		Whole Body Gamma	Thyroid	Bone	Whole Body Gamma	Thyroid	Bone
Current Submittal	28,000	(1)	(1)	(1)	3.7-04	4.2-02	1.1-03
Estimated Fuel Failure With Microporosity	14,000	3.5-06	3.8-06	2.0-10	3.7-04	4.2-02	1.1-03
Estimated Fuel Failure Without Microporosity	11,000	2.8-06	3.0-06	2.0-10	3.7-04	4.2-02	1.1-03
10CFR100 Limits		25	300	150	25	300	150

(1) Not reported in FSAR or SER.

485 014

Attachment 6

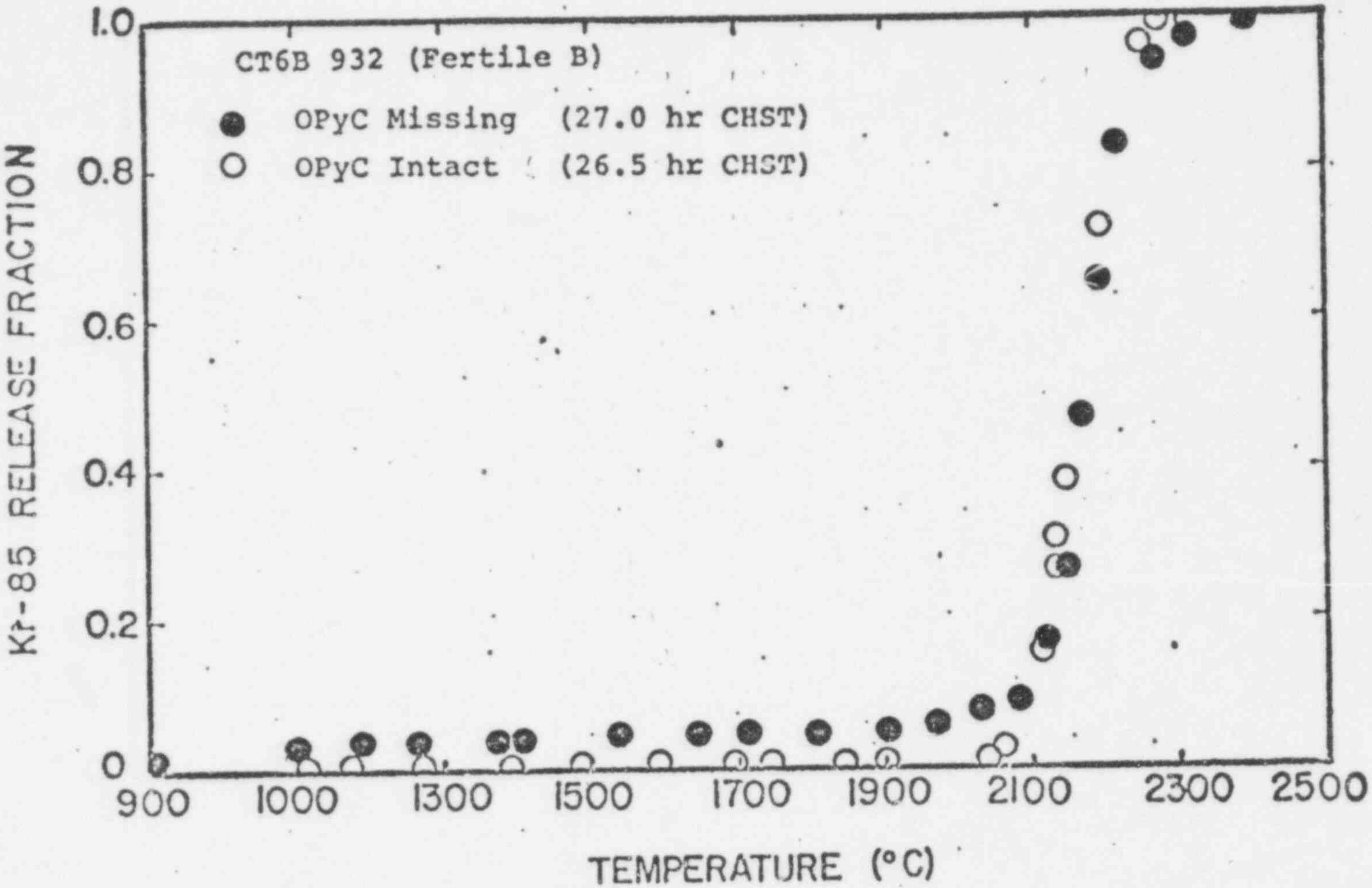


Figure 3. Kr-85 Release Fractions Observed as a Function of Temperature During 30 hour CHST's Conducted on Fertile B FSV Production Fuel With and Without Outer Pyrocarbon Coatings

485 0145

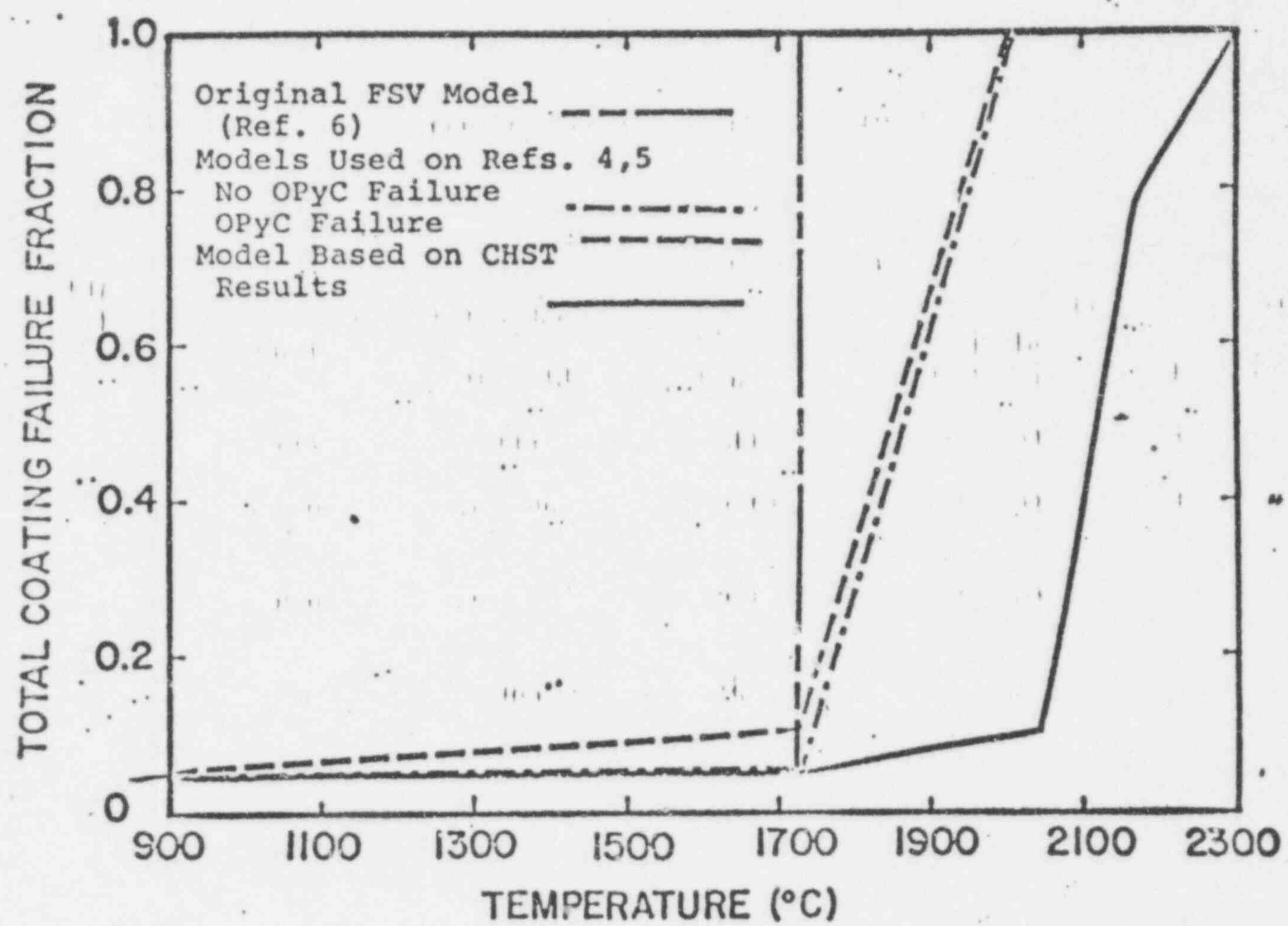


Figure 13. Comparison of Models for FSV Fuel Failure versus Temperature for DBA #1 Conditions with Model Based on CHST Data. The Model Based on CHST Results is Independent of Microporosity Induced OPyC Failure

Attachment 8

485 016

Public Service Company of Colorado
P.O. BOX 840 · DENVER, COLORADO 80201

— F. E. SWART
— M. H. HOLMES
— L. M. McBRIDE
— J. R. REESY
— D. W. WAREMBOURG
— H. L. BREY
— FSV RECORD STORAGE
— W. M. HAWKINS - GA
X FSV-6
— FSV-82
— PSC WORK MANAGER

February 15, 1979
Fort St. Vrain
Unit No. 1
PG-0012

Mr. W. A. Graul, Project Manager
Fort St. Vrain Project
General Atomic Company
P.O. Box 81608
San Diego, California 92138

Subject: Fuel Particle Outer Coating Failure

Reference: PSC/GA Meeting 1-23-79 on "Microporosity" GLP-5820

Dear Mr. Graul:

The January 23, 1979 General Atomic Company (GAC) presentation to Public Service Company (PSC) on the subject of fuel particle coating "microporosity" indicated that failure of the outer pyrolytic carbon (OPyC) coating of Fort St. Vrain (FSV) fuel particles was expected to occur in greater numbers than previously anticipated. GAC's analysis estimated that approximately 1.7% of both the fissile and fertile fuel particles will experience failure after several cycles of exposure in the FSV reactor.

PSC is reviewing the material presented by GAC at the meeting to determine if compliance with the requirements of 10 CFR 50.59 have been achieved and if the event is reportable under 10 CFR Part 21.

In order to conduct this evaluation PSC requires additional information on how GAC took certain FSAR statements and Technical Specification requirements into consideration in assessing the microporosity problem. Specifically, GAC is requested to provide PSC with the following information:

Item 1 - FSAR - Table 3.7-1 Primary Coolant System Activities

Table 3.7-1 of the FSAR contains the "expected" gas-borne activity for each isotope in the primary coolant at a reactor power level of 842 MW(t). The "expected" values are based upon the GAIL (IV) krypton and xenon release curves which represent a fuel particle failure percentage of .8%.

Provide the new "expected" gas-borne activity for each isotope based on the anticipated fuel particle failure percentage of 1.7%.

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Item 2 - FSAR - Tables 1.2-1 and 14.13-1

FSAR Tables 1.2-1 and 14.13-1 summarize the off-site doses resulting from Design Basis Accident (DBA) No. 2 and the Maximum Credible Accident.

Provide the necessary analysis and technical basis to determine the expected off-site doses for DBA No. 2 and the Maximum Credible Accident considering the higher level of "expected" activities obtained from Item 1, above.

Item 3 - GAC "Microporosity" Safety Appendix Handout 1-23-79

The Safety Appendix Handout provided to PSC by GAC contains a table titled "Summary of Failed OPyC Coating - Effect on DBA No. 1." The low population zone (LPZ) dose (Rem) at 6 months is estimated by GAC to be the following:

Whole Body Gamma	Thyroid	Bone
3.7×10^{-4}	4.2×10^{-2}	1.1×10^{-3}

Provide the analysis and technical basis to document the above LPZ doses. It should be noted that the figures developed by GAC for thyroid and bone doses exceed the existing FSAR LPZ figures shown in Tables 1.2-1 and 14.13-1 (3.6×10^{-2} and 1.0×10^{-3}, respectively).

Item 4 - FSAR - Table 14.11-1

Table 14.11-1 of the FSAR shows the dose at the Exclusion Area Boundary (EAB) to be 5.0 rem (thyroid) and 0.075 rem (bone) for the Maximum Hypothetical Accident, DBA No. 2.

Provide an explanation as to why the Table 14.11-1 doses differ from the thyroid and bone doses indicated in FSAR Tables 1.2-1 and 14.13-1 (17.4 rem and 4.8 rem, respectively).

Item 5 - FSAR Figures 14.10-4 and 14.10-5

FSAR Figures 14.10-4 and 14.10-5 indicate fission product activity versus time for DBA No. 1.

Indicate and substantiate any changes that will be required to these graphs as a result of the increased fuel particle failure percentage.

Item 6 - Technical Specification LCO 4.2.8

Technical Specification LCO 4.2.8 requires that the product of primary coolant noble gas beta plus gamma activity multiplied times $\overline{E}$ shall not exceed 2.40 curies-MeV. per lb. (where $\overline{E}$ is the weighted average of the beta and gamma energies per disintegration in MeV).

485 018

Describe the effect of the increased particle failure percentage on the product of item 5 and provide supporting documentation.

Item 7 - Basis for Specification LCO 4.2.8

The table on page 4.2-9 of the Technical Specifications titled "Activity Levels Determined by the Depressurization Accident" lists values for plate out, environmental release and resulting dose.

Provide the analysis indicating if changes to the table will be required as a result of the increased fuel particle failure percentage.

Item 8 - FSAR Question 14.12 (Amendment 18)

Question 14.12 contains the basis for expecting the fuel particle failure percentage to be less than 1%.

Provide any revisions to the response to this question which may be appropriate, including the basis for the revisions.

Item 9 - GA-10600, HTGR Fuel Specifications

Documents 4.1.4.1 and 4.2.4.1 of GA Fuel Specification GA-10600 define the outer isotropic fuel particle coating process for $(Th,U)C_2$ and ThC_2 triso particles, respectively. In each of the documents, microporosity limits are set solely by a visual standard with a specified percentage of the fuel particles allowed to exceed the porosity of the visual standard.

The handout presented to PSC by GAC contains a graph of OPyC microporosity as a function of the OPyC coating failure percent which indicates OPyC coating microporosity values of 20 to 32 ml per kg will result in minimum OPyC failure.

Define the relationship between the fuel specification visual standard and graph of OPyC microporosity. Was the FSV fuel fabricated in accordance with the visual standard requirements? How will GAC modify the fuel specifications to assure that OPyC coating microporosity will fall in the range of 20 to 30 ml per kg for future fuel fabrication?

In view of the responses to the above requests, GAC is requested to submit determinations as to whether the microporosity problem involves a 10 CFR 50.59 unreviewed safety question or a 10 CFR 21 substantial safety hazard. GAC should submit the 50.59 safety evaluation and the 10 CFR 21 evaluation which support GAC's determinations.

Due to the possible implications of the microporosity problem, GAC is requested to respond to the above requests by March 9, 1979.

Very truly yours,

Frederic E. Swart

Frederic E. Swart
Nuclear Project Manager

485 019

FES/MLP:lm

FILE - FSV - 6

GENERAL ATOMIC

GENERAL ATOMIC COMPANY
P.O. BOX 81608
SAN DIEGO, CALIFORNIA 92138
(714) 455-3000

March 19, 1979

GP-0028-P

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Mr. F. E. Swart
Nuclear Projects Manager
Public Service Company of Colorado
12015 E. 56th Avenue
Suite 440
Denver, Colorado 80239

Subject: Fuel Particle Outer Coating Microporosity

Reference: PG-0012

Dear Mr. Swart:

Your letter of February 15, 1979 (PG-0012) requested additional information regarding General Atomic Company's assessment of fuel particle performance in view of our current understanding of the influence of outer coating microporosity. Specifically, nine items of information were requested. In addition, PSC requested that GAC submit its determinations as to whether the microporosity situation involves an unreviewed safety question as defined in 10CFR50.59 or represents a "substantial safety hazard" as defined in 10CFR21.

GAC's response to the nine specific requests for additional information are enclosed.

10CFR50.59 applies to changes to the facility or facility operating procedures as described in the safety analysis report or applies to conduct of tests or experiments in the reactor not described in the safety analysis report. The microporosity situation is not a change to the facility as described in the FSAR. Any reduction in margin between "expected" and "design" activity levels as a result of microporosity does not constitute a reduction in the margin of safety defined as the basis for any of the technical specifications.

Holmes / Padovan to respond

485 020

(Specifically, technical specification LCO 4.2.8, Primary Coolant Activity, defines limiting conditions for operation and is derived directly from FSAR "design" activity levels.) Accordingly, it is GAC's position that the provisions of 10CFR50.59 are not relevant to the microporosity question.

With regard to 10CFR21: General Atomic Company has been conducting a safety evaluation of the microporosity question relative to 10CFR21. As discussed on January 23, this evaluation consists of two phases. Phase 1 was an analytical study based on the available data and was completed in December, 1978. GAC concluded that the microporosity situation does not constitute a "substantial safety hazard" as defined in 10CFR21.

Phase 2 of the evaluation is an experimental program involving core heat up simulation tests. This program was initiated to confirm that the models used in Phase 1 are conservative. The actual testing portion of Phase 2 has been completed and the final report is scheduled for completion by April 30, 1979. The experimental data confirm our initial belief that the analytical models used in the Phase 1 analysis were quite conservative.

Documents issued by GAC's 10CFR21 committee are enclosed. The technical basis for these documents, which is quite voluminous, is available at GAC for your examination.

If you have any further questions regarding this matter, please let me know.

Very truly yours,

William A. Graul

W. A. Graul, Manager
Fort St. Vrain Project

Enclosures

485 021

GAC RESPONSES TO ITEMS IN PG-0012

ITEM 1 - It appears that clarification is required with regard to "expected" and "design" activity levels, the assumptions made in calculating them, and their use in safety evaluations.

The "expected" activity levels shown in FSAR Tables 3.7-1 and 3.7-2 were calculated assuming that fission product release characteristics of the fuel in the Fort St. Vrain core would be the same as those of the fuel irradiated in the GAIL IV experiment. They represented GAC's best estimate, at the time when the FSAR was written, of the equilibrium primary coolant system activity.

Calculations performed during the design of the reactor (as well as our most recent calculations, which include the effects of microporosity) indicated that less than 1% of the coated fuel particles would fail in service. Nevertheless, to provide for the possibility that particle failure modes unforeseen during the design of the plant might exist, a second set of primary circuit activity levels were calculated - the "design" activity levels. The "design" activities were calculated assuming a non-mechanistic average particle failure of 5%. No allowance for hydrolysis of the kernels of failed fuel particles was provided.

All accident analyses in Chapter 14 of the FSAR use "design" activity levels as initial source terms. Continual updating of "expected" activity levels as new data on coated particle performance are obtained is neither practical nor necessary. For the purpose of making a judgement with regard to public health and safety, it is not the "expected" activity which is of interest, but rather the "design" values of the gas-borne activity.

As noted above, no allowance for hydrolysis of the kernels of failed fuel particles was provided in the calculation of "design: activities. The effect of hydrolysis is to increase the release rate of gaseous fission products from failed fuel particles by about a factor of 18.

Therefore, given a certain number of failed coated fuel particles, the resultant gas-borne activity level is about a factor of 18 higher when total hydrolysis of failed fuel occurs than when no hydrolysis occurs. Conversely, for a given gas-borne activity level, the amount of failure required to produce the activity level is about a factor of 18 higher when no hydrolysis occurs than when total hydrolysis occurs.

Technical Specification LCO 4.2.8, Primary Coolant Activity, defines limiting conditions of operation which are directly derived from the "design" gas-borne activity levels in the FSAR. Accordingly, compliance with LCO 4.2.8 assures that the maximum levels of gas-borne activity in the primary coolant are consistent with the assumptions used in FSAR accident analyses. The total amount of fuel particle failure necessary to produce activity levels approaching LCO 4.2.8 levels depends upon the amount

of hydrolysis of failed fuel kernels which takes place. It will be about 5% if no hydrolysis occurs, or it may be less than 5% if hydrolysis takes place. However, as long as the provisions of LCO 4.2.8 are met, there will be no reduction in the large margin between FSAR calculated accident doses and 10CFR100 limits.

The January 23rd presentation on microporosity and its impact on circulating activity during normal operation was based on current projected fuel failure and total hydrolysis of the failed fuel. Since the consequences (LTA heat load, LPZ doses) of Design Basis Accident #1 are most severe for the largest assumed initial fuel failure percentage, the effects of microporosity on the accident analysis were determined assuming 5% of failure and "design" activity levels. Again, compliance with LCO 4.2.8 assures that "design" gas-borne activity levels will not be exceeded.

ITEM 2 - Since all accident analyses in Chapter 14 of the FSAR use "design" activity levels as initial source items (Technical Specification LCO 4.2.8 prohibits plant operation with activity levels in excess of "design"), no changes in the analyses are necessary due to any variation in the "expected" gas-borne activity. Therefore, Tables 1.2-1 and 14.13-1 remain valid as presented in the FSAR.

ITEM 3 - It is correctly noted that the LPZ doses in the handout of 1/23/79 differ from those given in the FSAR. This slight discrepancy arises from minor improvements in the methods for dose calculation which have been developed in the last ten years. The newer methods were used to calculate the doses shown in the handout used in our presentation. Using the older methods, the handout would agree exactly with the FSAR. The point of the table, however, is that failed OPyC coatings have no perceptible effect on the consequences of DBA #1, and that resultant doses are substantially less than 10CFR100 limits.

The analyses which support the doses shown in the table are extensive - on the order of 104 pages of computer output and 103 pages of notes and documentation. These are available at GAC for your inspection should you wish to make arrangements to examine them.

ITEM 4 - An explanation for the different doses can be found in FSAR Section 14.11. The doses in Table 14.11-1 for the Maximum Hypothetical Accident include only the release of the "design" gas-borne activity, while the doses for DBA #2, as presented in Tables 14.11-4, 1.2-1, and 14.13-1, also include a fraction of the removable, plated-out fission products (i.e., lift off).

ITEM 5 - As stated in the response to Items 1 and 2, all accident analyses in Chapter 14 are based on "design" activities, not "expected". Accordingly, no changes are appropriate or necessary for Figures 14.10-4 and 14.10-5 since the "design" activities are unchanged and cannot be exceeded per the provisions of Technical Specification LCO 4.2.8.

ITEM 6 - The value of 2.40 Ci-Mev/lb specified in Technical Specification 4.2.8 is directly derived from the "design" circulating activity levels given in the FSAR. No changes to "design" activities or to LCO 4.2.8 are necessitated by the new information on microporosity.

ITEM 7 - No changes to the table on page 4.2.-9 of the Technical Specifications will be required as a result of the microporosity situation. The equivalent activity levels shown in the referenced table were developed from the "design" activity levels in the FSAR.

ITEM 8 - No revisions to the response to Question 14.12 are required. The 1.7% fuel particle failure percentage referred to in your letter and shown in the view graphs presented on January 23 was calculated only for fuel in active core axial layer 3. The fuel in this layer experiences the highest burnup and temperatures in the core, conditions which tend to aggravate fuel failure. However, the core average fuel failure at the same time point, taking into account axial burnup and temperature distributions, is 0.95%, which is consistent with the response to Question 14.12.

ITEM 9 - PSC appears to have confused "OPyC oriented porosity", which has been specified for some time in GA-10600, with "OPyC microporosity", which was discussed with PSC on January 23rd. Oriented porosity is specified to restrict the distribution of porosity within a pyrocarbon layer and is measured by metallographic visual standards. OPyC microporosity is specified to limit the amount of surface connected porosity and is measured by a high pressure mercury intrusion technique.

Currently all fuel fabricated for Fort St. Vrain is produced in accordance with the oriented porosity visual standards. However, a change to GA-10600 has recently been approved which restricts the amount of microporosity determined by mercury intrusion.

This change defines the following OPyC microporosity requirements:

1) Mean OPyC microporosity on (Th/U) C_2 and ThC_2 fuel particle composits is $\geq$ 13 ml/Kg-OPyC and $\leq$ 32 ml/Kg-OPyC for R-1 type matrix, and is $\geq$ 13 ml/Kg-OPyC and $\leq$ 38 ml/Kg-OPyC for R-2 type matrix.

2) Volume fraction of active coating gases if $\geq$ 0.25 during OPyC coating of (Th/U) C_2 and ThC_2.

These specifications differ in two respects with regard to the 20 to 32 ml/Kg-OPyC limits quoted in your letter. First, the limit of 20 Ml/Kg-OPyC was never proposed and is most probably a misunderstanding with regard to 17 ml/Kg-OPyC, a limit originally considered. However, this limit was subsequently reduced to 13 ml/Kg-OPyC with the addition of the process control on the volume fraction of active coating gases. Secondly, the upper microporosity limit, which was directed at minimizing matrix-OPyC coating interaction, was related to the process conditions associated with different matrix types used in fuel rod fabrication. Microporosity $\leq$ 32 ml/Kg-OPyC is now specified for one matric type (R-1), and $\leq$ 38 ml/Kg-OPyC is specified for the second matrix (R-2), as each matrix requires a different injection pressure.

Attachment B

REC'D JUN 14 1979

Fsv-68

GENERAL ATOMIC

GENERAL ATOMIC COMPANY
P.O. BOX 81608
SAN DIEGO, CALIFORNIA 92138
(714) 455-3000

June 12, 1979
Project 90-330 MW HTGR
Fort St. Vrain Unit 1
GLP-5863

Mr. J. K. Fuller, Vice President
Engineering and Planning
Public Service Company of Colorado
5900 East 39th Avenue
Denver, Colorado 80201

Subject: Microporosity Investigation

References: GLP-5820
GP-0028-P

Dear Mr. Fuller:

As committed to in our meeting with Mr. F. E. Swart on May 9, 1979 in San Diego, General Atomic Company is enclosing the following documents related to our evaluation of outer pyrocarbon coating microporosity.

1. The summary finding of GAC's 10CFR21 Ad Hoc Panel that the microporosity issue is not a reportable defect as defined in 10CFR21.

2. The report on Phase 2 safety studies -- core heatup simulation tests.

If you have any questions regarding the enclosed material, please let us know.

Very truly yours,

William A. Graul

William A. Graul, Manager
Fort St. Vrain Project

Enclosures

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Holmes / Padovan to respond

INTERNAL CORRESPONDENCE
GA 1076

ENCLOSURE #1
TO GLP-5863

FROM T. R. Colandrea

IN REPLY REFER TO 79:116:TRC

TO 10CFR21 Ad Hoc Panel

DATE June 1, 1979

SUBJECT Potential Deviation of FSV Fuel Performance from Technical Requirements

Ref:

1. T. R. Colandrea, "Potential Deviation of FSV Fuel Performance from Technical Requirements," 78:230:TRC, December 14, 1978
2. F. A. Silady/F. S. Dombek, "FSV: Additional DBA #1 Analysis," SAM:307:FD/FS:78, December 14, 1978
3. F. S. Dombek/F. A. Silady, "FSV Summary of OPyC Effect on DBA #1," SAM:309:FD/FS:78, December 19, 1978
4. C. L. Smith/R. E. Foster, "FSV Fuel Performance Under Simulated DBA #1 Conditions," FCB:045:CLS:79, April 30, 1979

The purpose of this memo is to summarize the findings of the 10CFR21 Ad Hoc Panel regarding the subject item. Based upon a review of all available information generated to date on this subject, we conclude that the microporosity issue is not a reportable defect. Furthermore, we feel that the experimental program that was conducted, Reference 4, was sufficiently comprehensive in approach such that the problem was adequately addressed. This closes the subject item and no further action is planned.

Concur: T. R. Colandrea

Concur: H. N. Wellhouser

Concur: J. Lestyk

Concur: G. L. Wessman

Concur: R. B. Holden

cc: ✓D. Alberstein
F. D. Carpenter/J. H. Rusk
R. E. Foster
W. C. Gallaway
J. Ganley
W. V. Goeddel
W. Graul
T. Gulden
C. Fisher
B. Kovacs
D. Kowal
D. Pettycord
G. W. Rankin
C. L. Rickard
F. Silady
W. Simon
C. L. Smith
O. Stansfield
J. Steibel

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INTERNAL CORRESPONDENCE
GA 1016

ENCLOSURE #2
TO GLP-5863

cls RF

FROM C. L. Smith/R. E. Foster

IN REPLY REFER TO FCB:045:CLS:79

TO Members, 10CFR21 Committee

DATE April 30, 1979

SUBJECT FSV Fuel Performance Under Simulated DBA #1 Conditions

Distribution:

T. Colandrea
H. Wellhouser
G. Wessman
J. Lestyk
R. Holden
D. Dean
D. Kowal
D. Alberstein
F. S'lady
J. Ganley
J. Steibel
T. Gulden
W. Simon
W. Graul
C. Fisher
O. Stansfield
B. Kovacs

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RECEIVED
MAY 1 1979
W. A. GRAUL

1.0 SUMMARY AND CONCLUSIONS

The behavior of FSV initial core production fuel was studied under conditions predicted for FSV Design Basis Accident #1 (DBA #1). The purpose of the experimental program was to evaluate models developed to account for effects of microporosity induced OPyC failure on total coating failure during DBA #1. Test samples had been irradiated to average fast neutron exposures and kernel burnups expected upon removal of a 6 yr old fuel segment from the core. Total coating failure fractions were determined from Kr-85 release fractions measured while heating test samples having intact or failed OPyC layers in the temperature range 900 to 2500°C. Observations relative to FSV fuel performance include

1. Only fertile fuel with failed OPyC layers exhibited total coating failure at temperatures less than 1850°C.
2. Fertile A and B performance is virtually identical.
3. Total coating failure fractions remain constant as temperatures are increased from 1100°C to temperatures exceeding 1750°C.
4. Failure fractions for samples with intact or missing OPyC layers did not exceed 0.10 until test temperatures exceeded 2050°C.
5. Performance above 2050°C is independent of the presence or absence of the OPyC layer.

The following conclusions were drawn relative to fuel performance models used for DBA #1 analyses.

1. The basis for pressure vessel failure predictions used to evaluate fuel performance during DBA #1 is conservative.
2. Observed total coating failure fractions are much lower than values predicted for DBA #1 analyses.
3. The margin associated with the heat load on the LTA during the depressurization stage of DBA #1 is not affected by microporosity induced OPyC failure.

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2.0 INTRODUCTION

Analyses of irradiation data collected on FSV and LHTGR fuels suggest that failure of the OPyC layer on TRISO fuels is related to OPyC microporosity (Ref. 1). Recent evaluation of FSV fuel OPyC microporosity data suggests a potential for 5.6% failure of the OPyC layers on fissile fuel and 34% failure of the OPyC layers on fertile fuel in the first seven FSV fuel segments (Ref. 2). The degree of OPyC failure is expected to increase linearly with fast neutron exposure from 0 at beginning of life to the values indicated above at 2.0×10^{25} n/m^2 ($E \geq 29$ fJ_{HTGR}). Outer PyC failure fractions will then remain constant as fast neutron exposures increase. This potential OPyC failure does not translate directly to total coating failure and fission product release; however, it does increase the probability for pressure vessel coating failure and fission product release. In order to evaluate the potential for increased fuel failure, pressure vessel performance models (Ref. 2) were developed for FSV fissile and fertile fuels having intact or failed OPyC layers. The models were based on kernel and coating dimensions and densities measured during FSV segment 7 fuel production. These models can be used to evaluate the impact of OPyC failure on total coating failure and fission product release during normal reactor operation or during the hypothetical accidents that are considered for reactor licensing and siting applications.

Concern was expressed that the increased probability for total coating failure that is associated with OPyC failure could represent a substantial safety hazard as defined by 10CFR21. A committee was consequently convened to evaluate the situation. The key item identified and analyzed for presentation to the committee was the heat load on the low temperature absorber (LTA) following depressurization during FSV DBA #1. The following steps were followed in this analysis.

1. Develop predictions of core average total coating failure fraction vs temperature for DBA #1 conditions that (a) assume no OPyC failure and (b) account for expected levels of OPyC failure (Ref. 3, 4, 5).

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2. Utilize performance models from step 1 to predict fuel failure fractions, fission product release, and the heat load on the LTA as a function of time during DBA #1 (Ref. 4,5).

3. Compare the predicted heat load with projections made using the original FSV FSAR fuel performance models (Ref. 6).

These efforts led to the conclusion that the margin between the LTA heat load estimated in Refs. 5 and 6 is not reduced significantly if one accounts for possible microporosity induced OPyC failure. The 10CFR21 committee agreed with this conclusion but requested that testing of FSV fuel with failed and intact OPyC layers be done under DBA #1 conditions to confirm the fuel performance assumptions. The results of the fuel test program are summarized in this report.

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3.0 TEST PROGRAM PHILOSOPHY

The primary objective of the test program was to show that fuel performance models used in the DBA #1 analysis (Ref. 4) are conserva.ive. This experimental verification would support the conclusion of analyses prerented to the 10CFR21 committee. The models, which are shown on Fig. 1, were developed using assumptions outlined in Ref. 3. The key steps utilized while developing the models included:

(1) calculation of SiC layer stress distributions as a function of irradiation exposure and temperature for fuel with intact and failed OPyC layers using kernel and coating property distributions determined during segment 7 fuel fabrication,

(2) estimate total coating failure fractions for temperatures $\leq 1725^{\circ}C$ assuming the failure fraction equals the probability that calculated SiC stresses are more positive than -2800 psi,

(3) assume that coating failure fractions increase linearly with temperature from the pressure vessel value at $1725^{\circ}C$ to 1.0 at $2000^{\circ}C$,

(4) develop failure models for fissile and fertile fuel that (a) assume no OPyC failure and (b) account for expected populations of fuel with intact and failed OPyC layers,

(5) develop core average failure models for predicted DBA #1 conditions that account for the distribution of irradiation exposure conditions projected for FSV, and

(6) assume (a) an initial failed fuel fraction of 0.05 at $900^{\circ}C$ and (b) that failure fractions increase with temperature during DBA #1 in the fashion suggested at the completion of step 5,

A specific experimental verification of the DBA #1 performance models would require that test samples have (1) expected OPyC failure fractions, (2) segment 7 kernel and coating property distributions, and (3) the distribution of irradiation exposures expected in an equilibrium FSV core. It was not possible to obtain test samples having these characteristics.

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The approach utilized was to test the pressure vessel model by comparing failure predictions for specific samples of initial core production fuel with performance data collected under simulated DBA #1 conditions. The test samples were irradiated in the FSV fuel proof test (Capsule F-30, Ref. 7). Samples were tested with intact and failed* OPyC layers. Failure predictions for temperature $\leq 1725^{\circ}C$ were made from SiC layer stress distributions that were calculated using kernel and coating property distributions and F-30 irradiation conditions for each individual sample. It was assumed that the failure fraction would equal the probability that calculated stresses were more positive than -2800 psi. Total coating failure fractions were assumed to increase linearly with temperature from the pressure vessel value at $1725^{\circ}C$ to 1.0 at $2000^{\circ}C$. Comparison of experimental results with model predictions at this point results in a verification of models provided through the third step of the six step development process outlined above. Since the first three steps represent the basis for the model, verification through step 3 is equivalent to verification of the total model.

*OpyC failure was simulated by removing OPyC layers during a 2-hr anneal in air at $900^{\circ}C$.

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4.0 EXPERIMENTAL

4.1 SAMPLE DESCRIPTION

Samples chosen for this series of tests were from initial core FSV production fuel batches which were irradiated in capsule F-30 (Ref. 7). Fissile A, fertile A, and fertile B samples were tested with and without outer pyrocarbon layers; kernel and coating properties are given in Table 1. A comparison of the test particle properties with those of segment 7 fuel (see Table 2) shows that the kernel and coating properties of the test samples are consistent with those of fuel currently in the FSV reactor. Irradiation conditions experienced by the test samples are given in Table 3; predicted FSV conditions are shown for comparison. Test sample fast neutron exposures exceed maximum values expected after 6 yrs of residence in FSV; kernel burnups are equivalent to average values expected for a segment removed after 6 yrs of residence in FSV.

4.2 TEST METHODS

FSV production fuel was tested using methods (Ref. 8,9) developed on the DOE sponsored core heatup simulation test (CHST) program. Key stages of the test method are itemized in Table 4. Test conditions were chosen to simulate predicted FSV DBA #1 conditions. Total coating failure fractions were determined from Kr-85 release fractions measured (1) after removal of the OPyC layer and (2) continuously as all samples were heated from approx. 1100 to approx. 2500°C. A detailed description of the test method is provided in Appendix A.

4.3 CHST CONDITIONS

Each of the three samples identified in Tables 2 and 4 was tested with intact and missing (failed) OPyC layers. A summary of the CHST conditions for each of the six tests conducted is given in Table 5. The rates at which temperatures were increased with time are representative of maximum heating rates shown for DBA #1 in the FSV FSAR (Ref. 10).

5.0 RESULTS

Krypton 85 release fractions measured during 25-27 hr CHST's of FSV fertile fuel are shown as a function of temperature on Figs. 2 and 3 (Ref. 11-14). Krypton release fractions detected following removal of the OPyC layers from fertile A and B samples at 900°C were, respectively, 0.025 and 0.011. Radiographic examinations following OPyC removal suggested total coating failure fractions of 0.02 for the fertile A fuel and 0.01 for the fertile B fuel. The good agreement between total coating failure and Kr-85 release fractions observed after OPyC removal suggests that the Kr-85 release fraction per failed particle was one at this stage. This is not surprising since the particles were heated in air and any ThC_2 kernels exposed by coating failure would be expected to oxidize and release their total Kr-85 inventory. The inventory of Kr-85 released at this stage was added to Kr-85 inventories released during subsequent CHSTing to obtain the total Kr-85 released as a function of temperature.

All test samples were held at approx. 1100°C for 10 to 20 hrs prior to CHSTing. Krypton 85 release measurements were made within 1 hr of reaching 1100°C and after the 10-20 hr hold period was completed. The only samples showing Kr-85 release at this point were fertile A and B particles with missing OPyC layers. Krypton 85 release was detected from both samples within 1 hr of reaching approx. 1100°C. Although additional Kr-85 release was detected during the 10-20 hr hold, the increases were negligible. The time period over which most of the Kr-85 was released at 1100°C (<1 hr) suggests that the SiC and IPyC layers failed by a pressure vessel mechanism.

Release of Kr-85 would occur in two stages following failure at 1100°C. Krypton 85, that had been released from the kernel to the buffer during irradiation, would be released rapidly following total coating failure (stage 1). Stage 1 release from fertile A and B fuels with missing OPyC layers was observed during the 10-20 hr hold at 1100°C. Krypton 85 remaining

in the kernels of failed particles would then be released slowly via a diffusive mechanism (stage 2). This was also observed during the hold at 1100°C. Recent studies conducted on laser failed TRISO UC_2 fuel have shown that Kr-85 release from carbide kernels would be complete at approx. 1750°C under CHST conditions (Ref. 15). If no additional coating failure occurred in the temperature range 1100-1750°C, the Kr-85 release fraction would increase smoothly with temperature. If additional total coating failure occurred in the temperature range 1100-1750°C, rapid increases in Kr-85 release (stage 1) would be superimposed over the smooth increase associated with stage 2 release. Careful examination of the Kr-85 release data from tests of fertile fuel with missing OPyC layers showed a smooth increase with temperature in the range 1100-1750°C suggesting that no additional failure occurred. The Kr-85 release fraction at 1750°C can therefore be assumed equivalent to the failed fuel fraction at 1100°C.

Results obtained from fertile fuels with intact OPyC layers suggest no Kr-85 release (coating failure) until CHST temperatures approach 2050°C. Because of the high temperatures reached before observing Kr-85 release, it is reasonable to assume, for these fuels, that release fractions are equivalent to total coating failure fractions.

A general examination of results from the four fertile fuel CHST's (Figs. 2 and 3) leads to two additional conclusions. The first is that fertile A and B performance is virtually identical. The second is that fertile fuel performance at temperatures exceeding 2050°C is independent of the presence or absence of the OPyC layer.

Krypton 85 release fractions measured during CHSTing of FSV fissile A fuel are shown as a function of temperature on Fig. 4. No Kr-85 release (coating failure) was detected in samples with or without OPyC's until temperatures exceeded 1850°C. Krypton 85 release fractions observed from fissile fuel with missing OPyC layers were higher than observed from fuel with intact OPyC layers at temperatures $\geq$1850°C. Fuel with missing OPyC layers was tested in a 26.5 hr CHST; fuel with intact OPyC's was tested in a 9.0 hr CHST. Past tests have shown that the release fraction at any given temperature will increase as the length of a CHST increases. This result coupled with the results

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obtained on FSV fertile fuel leads to the potentially conservative assumption that Kr-85 release from fissile fuel at temperatures exceeding 2050°C would be independent of the presence or absence of the OPyC layer.

Given the assumption indicated above, one reaches the final conclusion that Kr-85 release fractions at temperatures exceeding 2050°C are independent of OPyC condition (failed or intact), fuel size (A or B), and fuel type (fissile or fertile).

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6.0 DISCUSSION

6.1 PREDICTED VS OBSERVED FAILURE FRACTIONS

The primary purpose of this test series was to evaluate fuel failure assumptions utilized to predict the heat load on the LTA during FSV DBA #1. To accomplish this, the experimentally measured Kr-85 release fractions must be related to total coating failure fractions. Based on discussions presented in Section 5.0, the following assumptions were made to define failed fuel fractions from the measured Kr-85 release fractions.

Failure mode: all gas release occurred after failure of the IPyC, SiC, and OPyC layers if the OPyC layer was present (i.e., no Kr-85 was released by diffusion or permeation through intact SiC or PyC layers).

OPyC removal stage: Total coating failure that occurred while OPyC layers were removed by heating in air at 900°C resulted in oxidation of exposed kernels and 100% release of stored fission gases. Kr-85 release fractions observed at this stage therefore equal total coating failure fractions.

Temperatures ≥1750°C: Tests conducted on laser-failed TRISO UC_2 fuel under CHST conditions (Ref. 15) suggest 100% release of Kr from carbide kernels at temperatures exceeding 1750°C. Krypton 85 release fractions observed at temperatures exceeding 1750°C are therefore equivalent to failed fuel fractions.

Temperatures in the range 1100-1750°C: Fuel failing at 1100°C would release that fraction of Kr-85 released to the buffer during irradiation. The Kr-85 remaining in the kernel would be released slowly with increasing temperature between 1100 and 1750°C. Since Kr-85 data indicated gradual increases in release between 1100 and 1750°C but no "bursts" of Kr-85, which would be expected following failure of additional fuel, it will be assumed

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that failed fuel fractions at 1100°C are the same as indicated by Kr-85 release fractions at 1750°C.

Measured Kr-85 release fractions and the corresponding failed fuel fractions are shown for each test in Table 6. Total coating failure fractions predicted for each test sample (Ref. 16) are compared with failure fractions determined experimentally on Figs. 5-10. Predicted failure fractions for test samples having intact OPyC layers are, although somewhat conservative, in reasonable agreement with experimental values at temperatures ≤1725°C. Predictions are extremely conservative for temperatures ≥1725°C. Predicted failure fractions for samples having missing OPyC layers are extremely conservative for temperatures ≥900°C.

The predictions shown on Figs. 5-10 were made using the same failure criterion used to develop the core average performance models utilized to evaluate FSV fuel performance during DBA #1 (Refs. 3,4,5). Since the predictions have been shown to be extremely conservative for individual batches of initial core production fuel it is concluded that FSV core average performance predictions are also conservative.

6.2 FSV CORE PERFORMANCE DURING DBA #1

The basis for models used to describe the impact of OPyC microporosity on fuel failure during FSV DBA #1 has been shown to be conservative. The data used to draw this conclusion were developed from CHST's conducted on FSV production fissile and fertile fuels that were irradiated to average conditions expected for a fuel segment removed after 6 yrs residence in FSV. The data collected on this high exposure fuel can be used to develop an empirical model for FSV fuel behavior under DBA #1 conditions. If one assumes that all fuel in FSV will perform like the test fuel and then compares the empirical model with failure assumptions made in Refs. 4 and 5, an evaluation of the assumed core average failure model can be made. The steps used to develop the empirical model are described below.

Fissile Fuel with Failed OPyC Layers: The variation in expected failure fraction with temperature was developed from the test conducted on

fissile A fuel. Ninety percent confidence bounds for the expected failure fractions were defined on the basis of sample size. ...ugh no fissile B fuel was tested, it is assumed that fissile A and B fuel behavior is identical based on fertile A and B fuel test results.

Fertile Fuel with Failed OPyC Layers: Results from both tests conducted on fertile fuel with failed OPyC layers were combined to define expected and 90% confidence bounds for expected failure fractions.

Fissile and Fertile Fuel with Intact OPyC Layers: Fissile fuel with intact OPyC layers was tested in a 9.0 hr CHST. All other data were collected from 24.75-27.0 hr CHST's. This one fissile test suggested failure fractions less than those observed in all other tests. Data collected from both CHST's conducted on fertile fuel with intact OPyC's were combined and assumed to represent expected and 90% confidence bounds for expected failure fractions of fissile and fertile fuel having intact OPyC layers.

Expected values and the range for expected failure fractions for fissile and fertile fuels with missing or intact OPyC layers are given as a function of temperature in Table 7. Values shown for fissile and fertile fuel with intact OPyC layers represent expected behavior of a FSV core that experiences no OPyC failure. The data in Table 7 were combined to determine fissile and fertile total coating failure fractions, that account for expected OPyC failure fractions, using.

$$f_i = (1-F_{OPyC})\, f_1 + F_{OpyC}\, f_2 \qquad (1)$$

where

f_i = total fissile or fertile fuel failure fraction

F_{OPyC} = OPyC failure fraction (0.056 for fissile fuel and 0.34 for fertile fuel , Ref. 2)

f_1 = total coating failure probability for fuel with intact OPyC layers

f_2 = total coating failure probability for fuel with failed OPyC layers

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The fissile and fertile fuel failure fractions were then combined to yield an "average" failed fuel fraction (f_{avg}) using

$$f_{avg} = 0.451\ f_{fis} + 0.549\ f_{fert} \qquad (2)$$

where

f_{fis} = fissile fuel failure fraction

f_{fert} = fertile fuel failure fraction

The values 0.451 and 0.549 are, respectively, the fraction of fissions in fissile and fertile fuel in a 6 yr old FSV fuel segment. Expected and high confidence values for f_{fis}, f_{fert} and f_{avg} are given in Table 8. Comparison of the range of values for f_{avg} (Table 8) with the range of failure values for fuel with no OPyC failures (Table 7) shows, as expected, that total coating failure fractions will be increased slightly because of OPyC failure at normal reactor operating temperatures. Failure models assumed in Refs. 4 and 5 are compared with the high confidence bound empirical models (Tables 7,8) on Figs. 11 and 12. Figure 11 assumes no OPyC failure; Figure 12 assumes expected fissile (0.056) and fertile (0.34) fuel OPyC failure fractions. In each case, the failure fraction based upon experimental observations is less than assumed in DBA #1 analysis.

Although the presence of OPyC failure increases the expected total coating failure fraction during normal reactor operation, the most significant observation is that the increase in failure fraction, as tempe[illegible]es are increased to simulate DBA #1 conditions, is essentially independent of the presence or absence of OPyC failure during normal reactor operation. The fuel performance models used in Refs. 4,5 assumed an initial total coating failure fraction of 0.05 at 900°C to be consistent with the design circulating activity allowed by FSV technical specifications (assumes no hydrolysis). If the empirical models based upon the results of this test program (Tables 7, 8) are adjusted to a failure fraction of 0.05 at 900°C, using the same method used to develop models for Refs. 4 and 5, the resulting failure fractions are 0.05 at 900-1750°C, 0.10 at 2050°C, approx. 0.80 at 2175°C, and 1.0

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at 2300°C independent of the presence or absence of fuel with failed OPyC layers. This model for fuel failure is compared with original FSV fuel performance assumptions made when analyzing DBA #1 (Ref. 6) and assumptions made in Refs. 4 and 5 on Fig. 13. On the basis of this comparison one would not expect the margin between the heat load on the LTA estimated in Ref. 6 and the expected heat load to be reduced by the presence of microporosity induced OPyC failure.

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1. Memo, W. J. Kovacs to Distribution, "Justification of a Proposed OPyC Microporosity and Coating Rate Specification for FSV Fuel (C. N. No. 004512)," WJK:001:FMB:79, Jan. 9, 1979 Rev. 26 Jan. 1979.

2. W. J. Kovacs, "Pressure Vessel Performance Models for FSV TRISO $(Th/U)C_2$ and ThC_2 Fuel", Doc. No. 184-45, Feb. 7, 1979.

3. Memo, C. L. Smith to F. A. Silady, "Fuel Failure Assumptions for FSV Hypothetical Accident Analyses," FCB:090:CLS:78, Dec. 7, 1978.

4. Memo F. A. Silady/F. S. Dombek to D. Alberstein, "FSV Technical Memo: Effect of Failed Outer PyC Coatings on LTA Analyses," SAM:299:FS/FD:78, Dec. 7, 1978.

5. Memo, F. S. Dombeck/F. A. Silady to Distribution, "FSV, Summary of OPyC Effect on DBA #1", SAM:309:FD/FS:78, December 19, 1978.

6. J. K. Fuller, "PCRV Depressurization - Loss of Forced Circulation Accidents", PSC letter to NRC, P-77250, December 22, 1977.

7. C. B. Scott and D. P. Harmon, "Post Irradiation Examination of Capsule F-30," GA-A13208, April 1, 1975.

8. "HTGR Fuels and Core Development Program Quarterly Progress Report For the Period Ending November 30, 1976," GA- A14180, December 27, 1976.

9. "Procedure for Burning Back Outer Pyrocarbons of Irradiated Fuel Particles", Document No. 903878, Issue A, in review.

10. Fort St. Vrain Nuclear Generating Station Final Safety Analysis Report, Docket No. 50-267, Public Service Company of Colorado, Appendix D.

11. GA Notebook #7284.

12. GA Notebook #7828

13. GA Notebook #7945

14. GA Notebook #7946

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15. B. F. Myers and R. E. Morrissey, "The Measurement and Modeling of Post Irradiation Fission Product Release From HTGR Fuel Particles Under Accident Conditions," GA- A15018, December 1978.

16. Memo, W. J. Kovacs to C. L. Smith, "Fuel Failure Predictions for CHST Samples," WJK:048:FMB:78, 29 Dec. 1978.

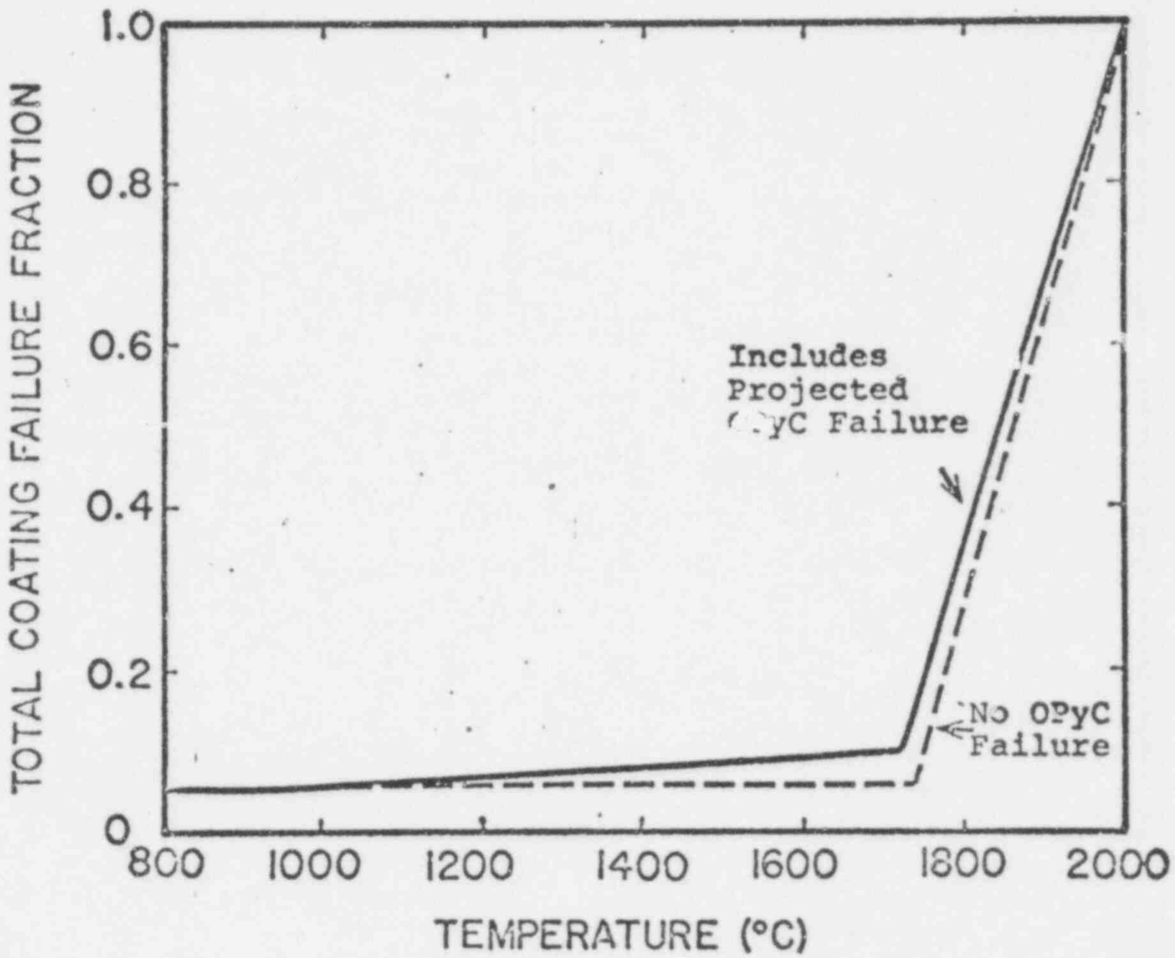

Figure 1. Total Coating Failure Fraction as a Function of Temperature Assumed for Evaluation of the Impact of Microporosity Induced OPyC Failure on the LTA Head Load During FSV DBA #1

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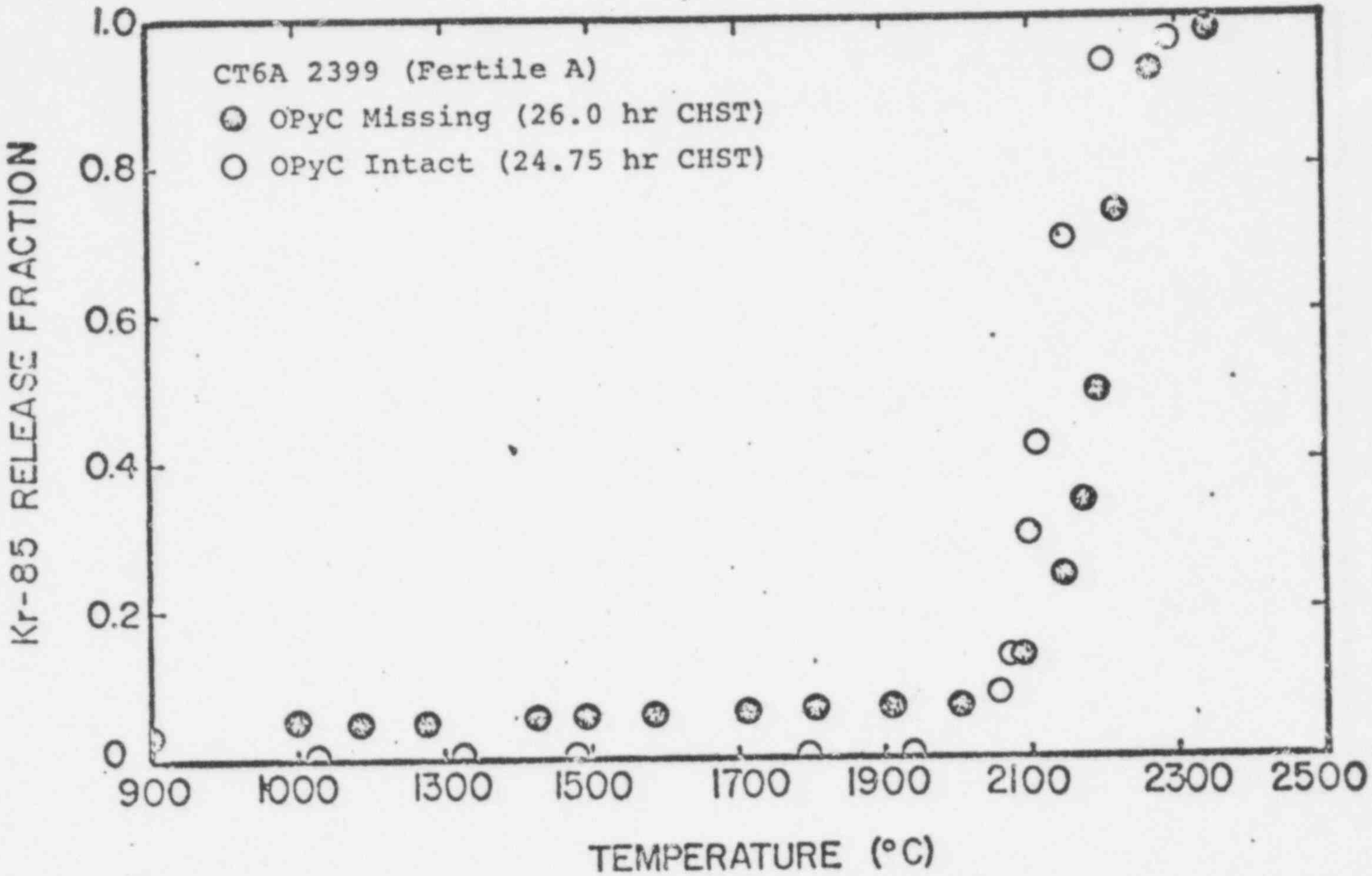

Figure 2. Kr-85 Release Fractions Observed as a Function of Temperature during 30 hour CHST's Conducted on Fertile A FSV Production Fuel With and Without Outer Pyrocarbon Coatings

485 046

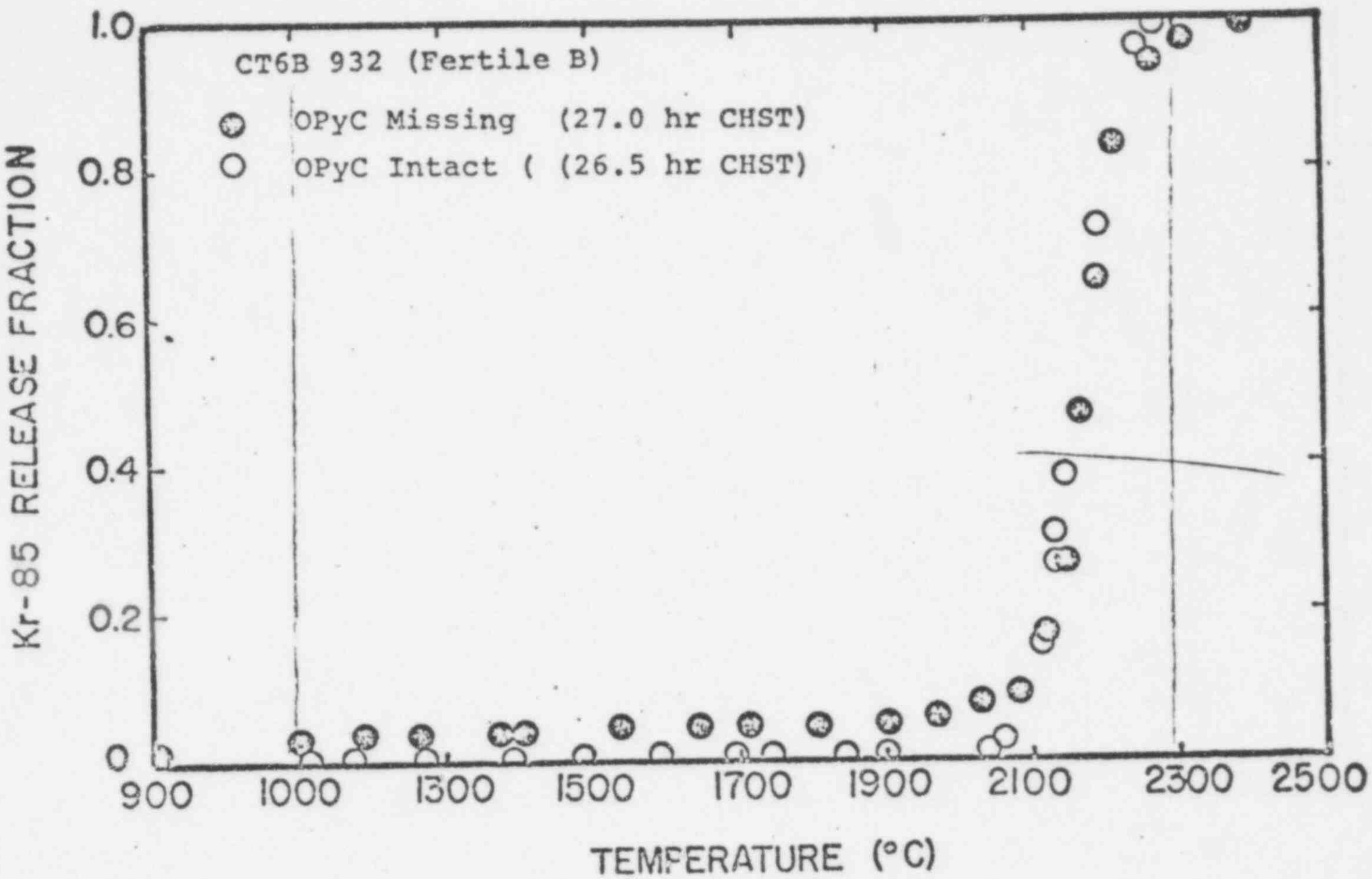

Figure 3. Kr-85 Release Fractions Observed as a Function of Temperature During 30 hour CHST's Conducted on Fertile B FSV Production Fuel With and Without Outer Pyrocarbon Coatings

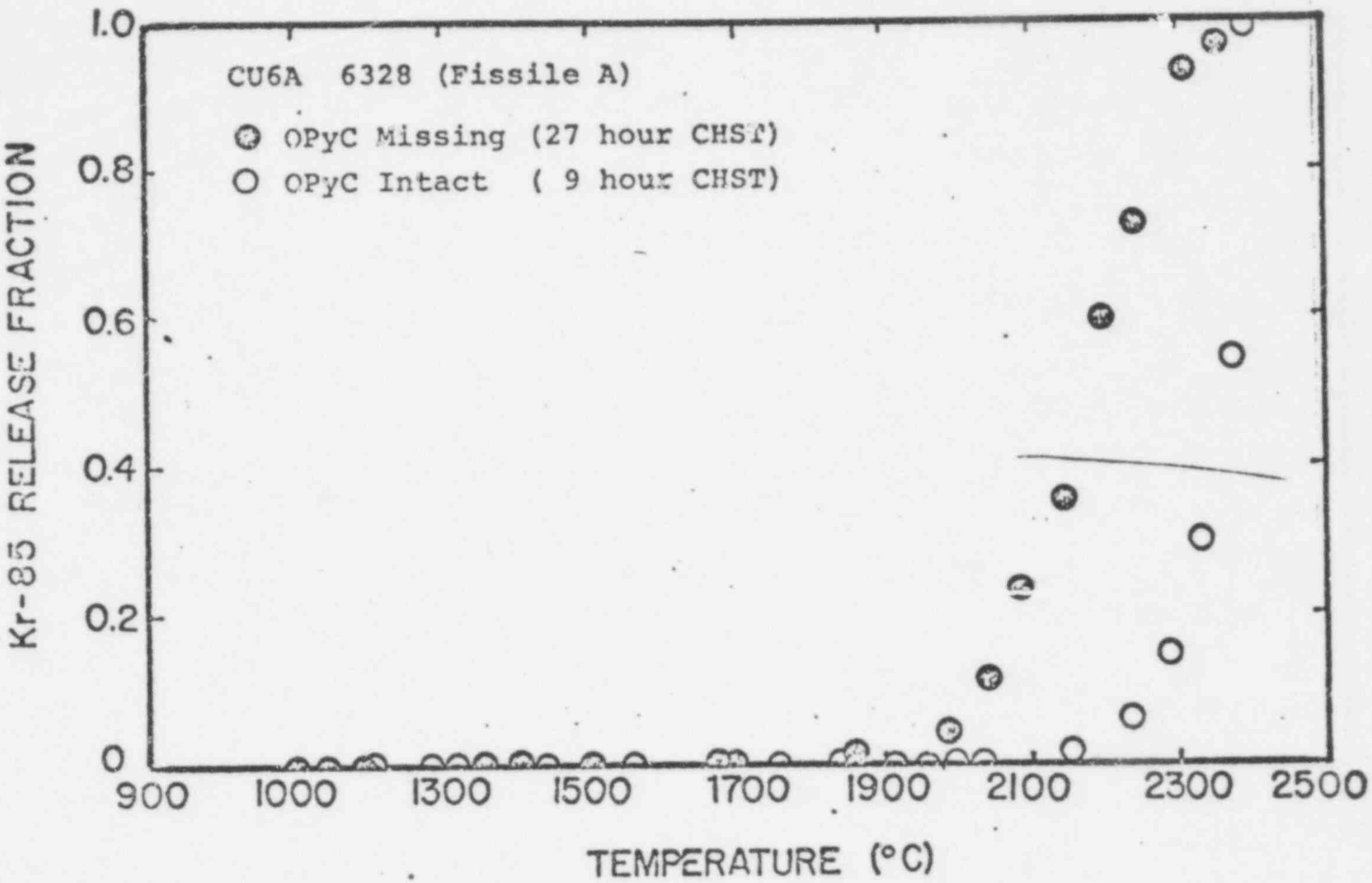

Figure 4. Kr-85 Release Fractions Observed as a Function of Temperature During CHST's Conducted on Fissile A FSV Production Fuel With and Without Outer Pyrocarbon Coatings

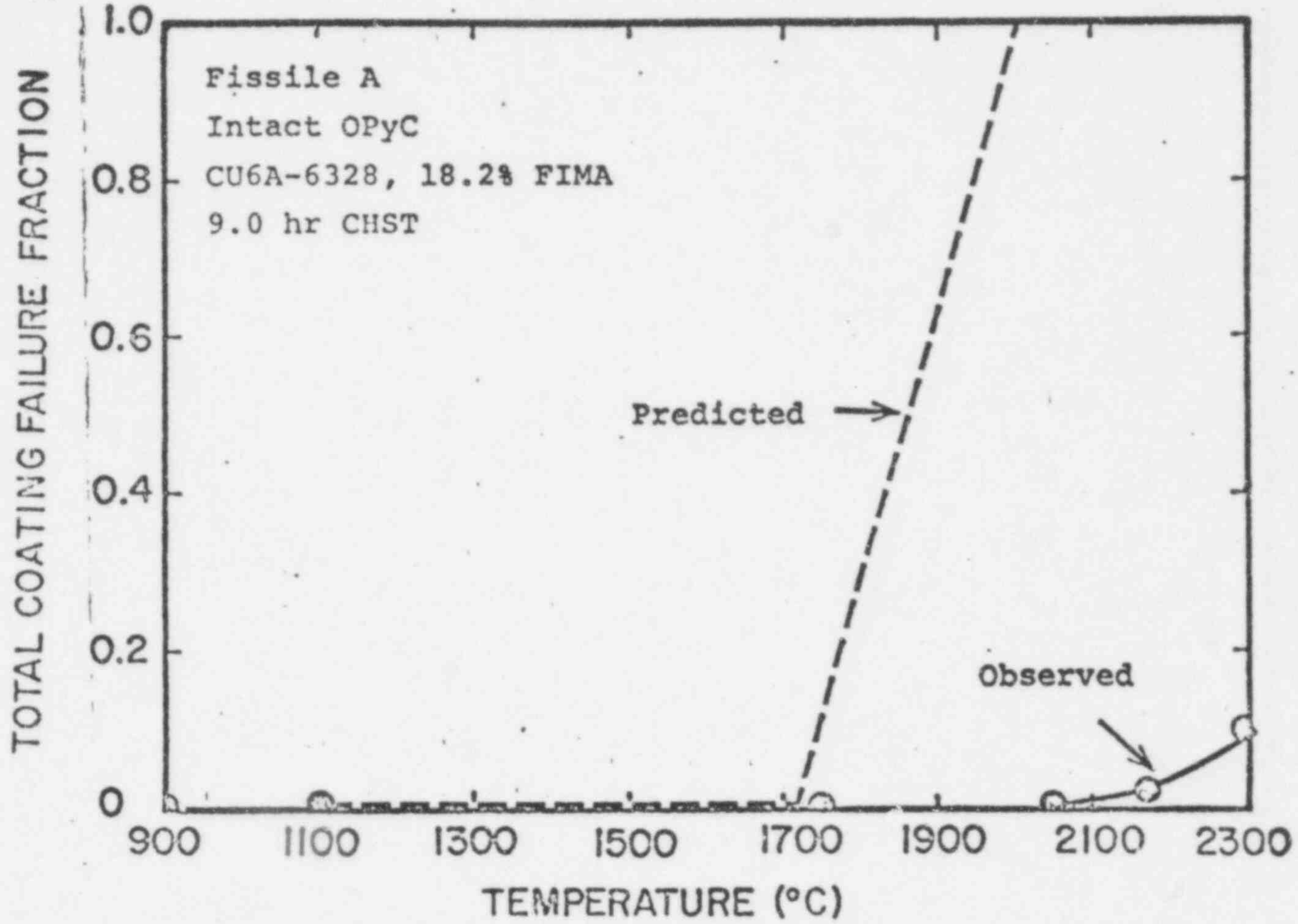

Figure 5. Comparison of Observed and Predicted Total Coating Failure Fractions for FSV Core I Production Fuel Tested Under Hypothetical DBA #1 Conditions

485 049

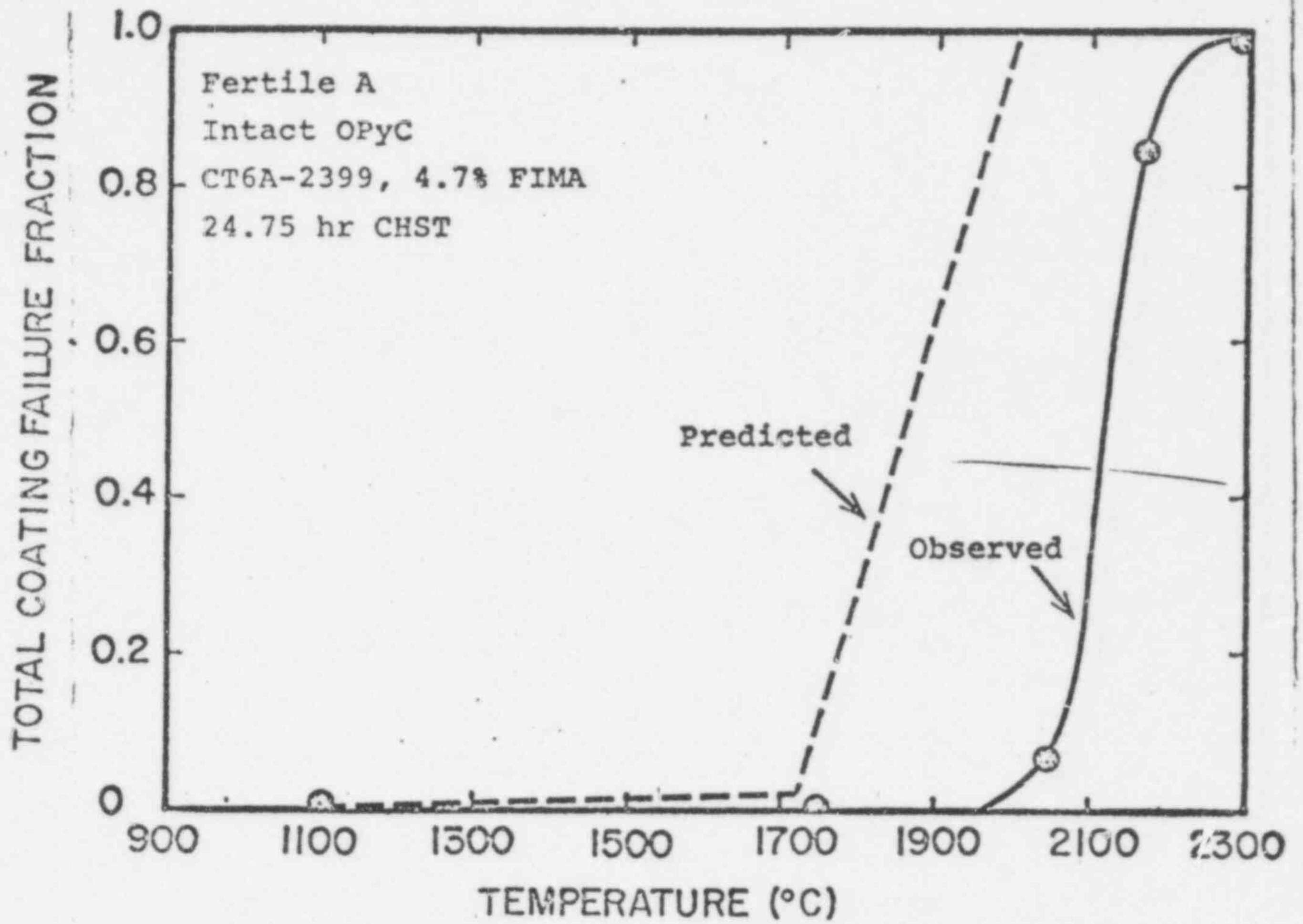

Figure 6. Comparison of Observed and Predicted Total Coating Failure Fractions for FSV Core I Production Fuel Tested Under Hypothetical DBA #1 Conditions

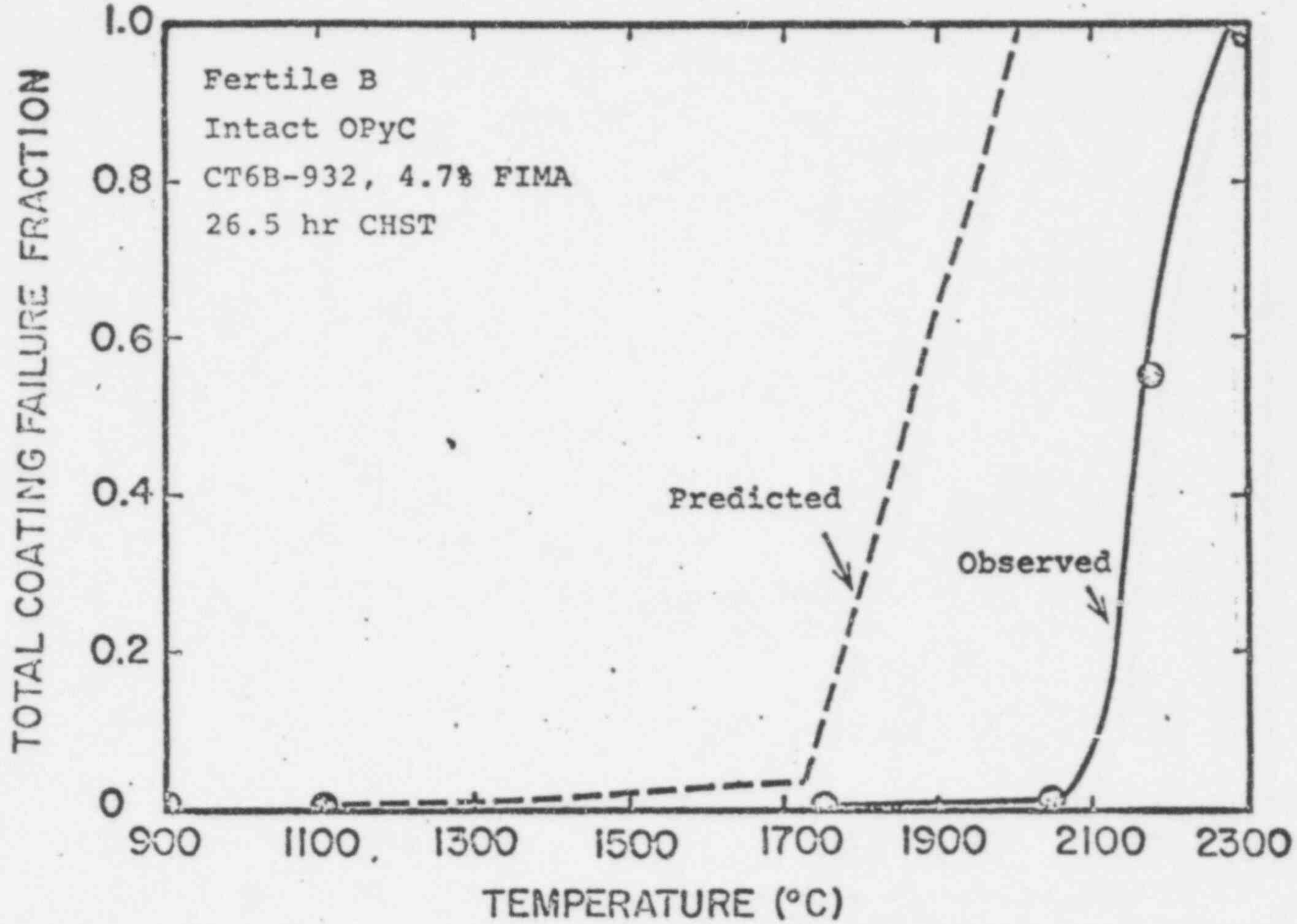

Figure 7. Comparison of Observed and Predicted Total Coating Failure Fractions for FSV Core I Production Fuel Tested under Hypothetical DBA #1 Conditions

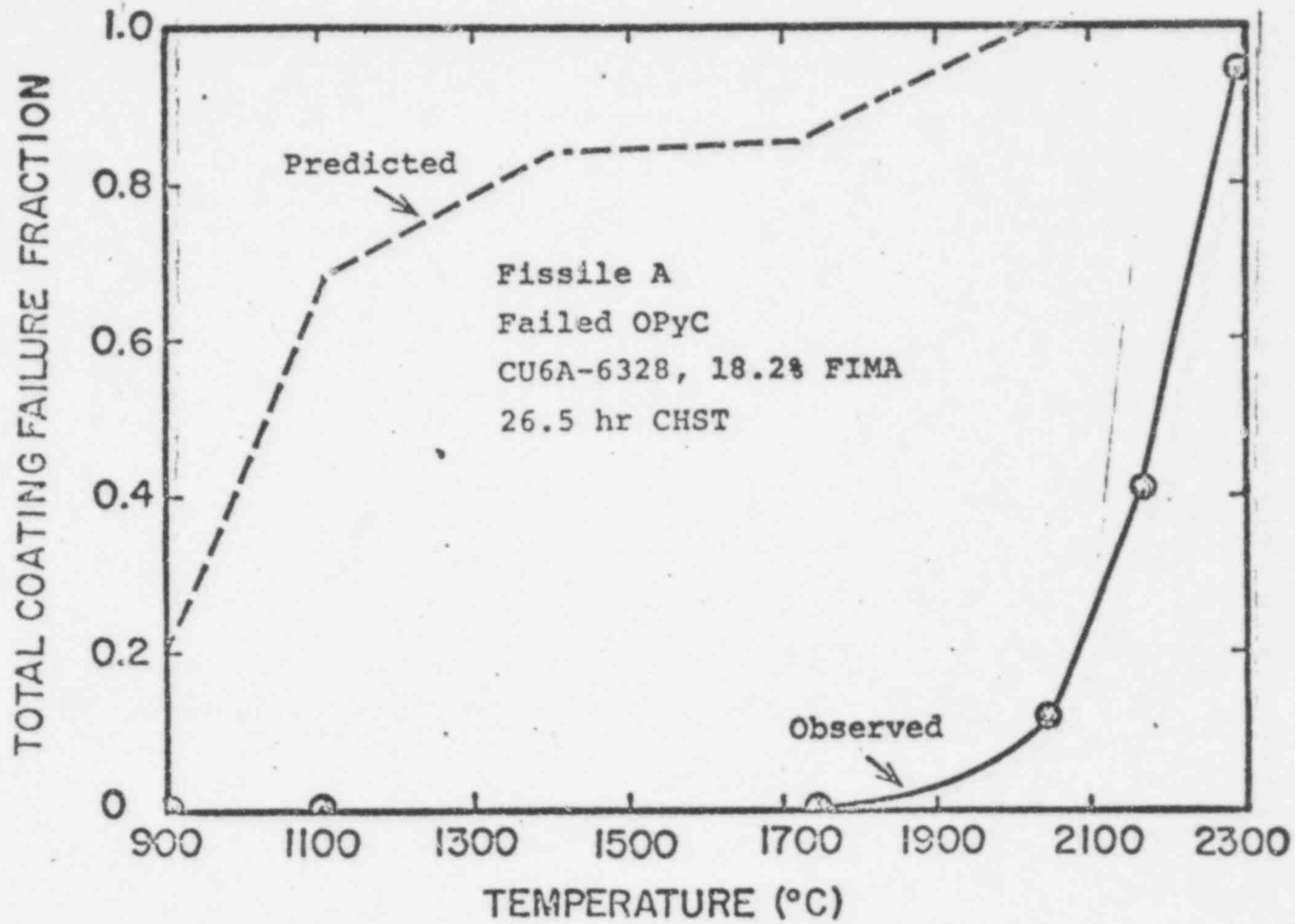

Figure 8. Comparison of Observed and Predicted Total Coating Failure Fractions for FSV Core I Production Fuel Tested Under Hypothetical DBA #1 Conditions

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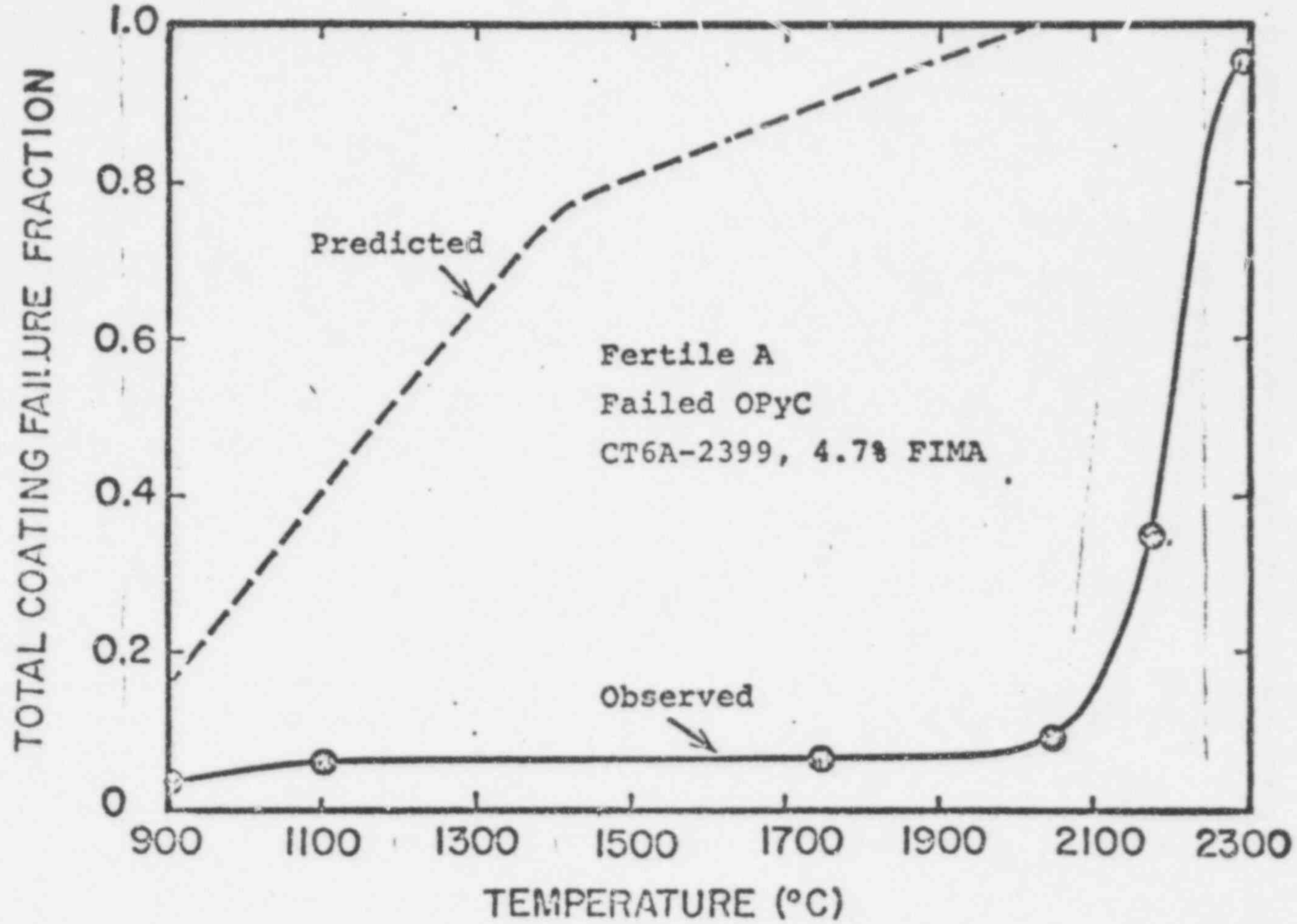

Figure 9. Comparison of Observed and Predicted Total Coating Failure Fractions for FSV Core I Production Fuel Tested Under Hypothetical DBA #1 Conditions

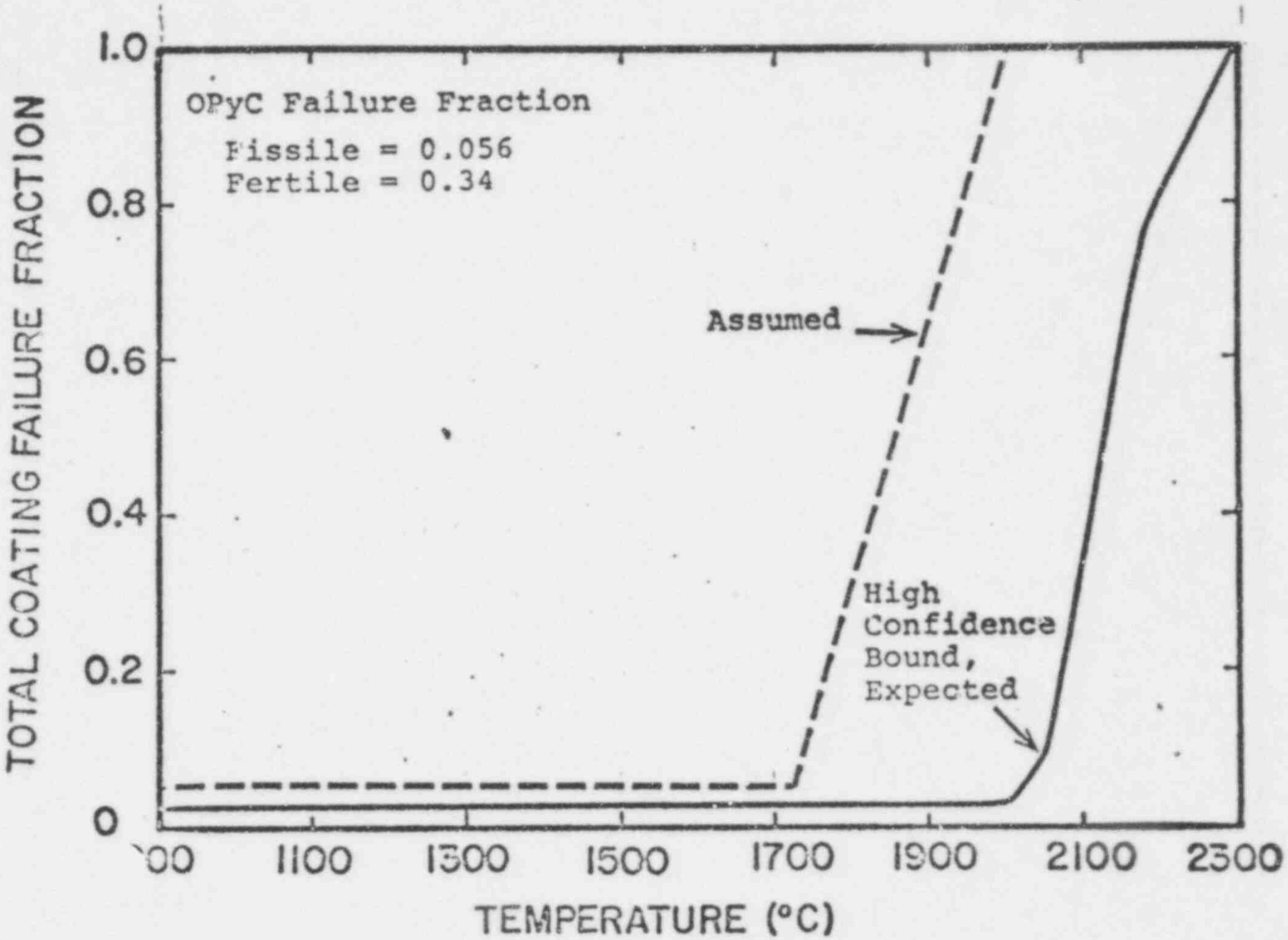

Figure 12. Comparison of Failure Model Used for FSV DBA #1 Analysis Assuming Expected OPyC Failure Fractions with High Confidence Bound Model Based on Experimental Data

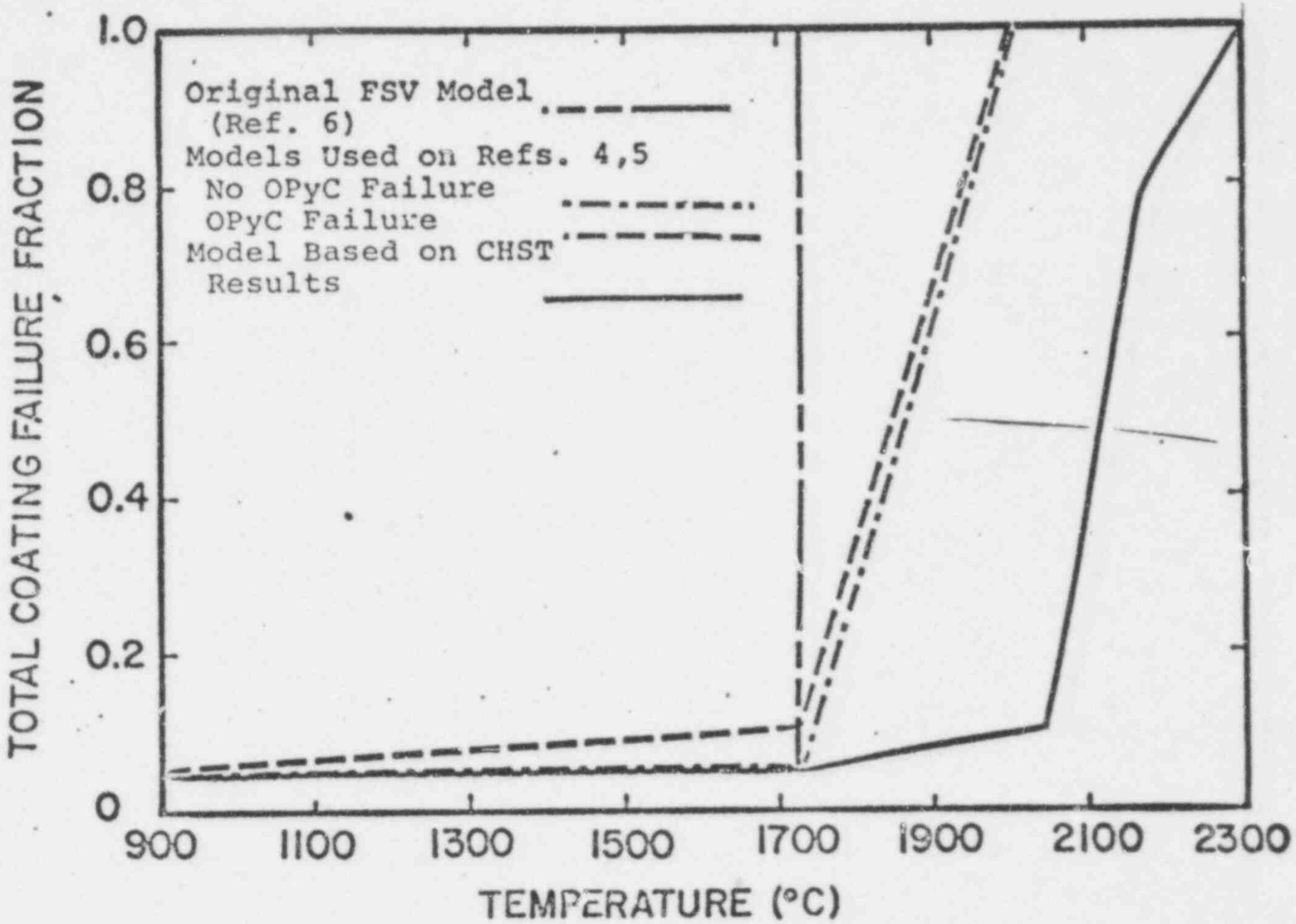

Figure 13. Comparison of Models for FSV Fuel Failure versus Temperature for DBA #1 Conditions with Model Based on CHST Data. The Model Based on CHST Results is Independent of Microporosity Induced OPyC Failure

Table 1. Description of FSV Fuel Samples Used in CHST Studies

Particle Type Data Retrieval No.	Fissile A CU6A 6328	Fertile B CT6B 932	Fertile A CT6A 2399
Particle Parameters[a]			
Kernel			
Density (gm/cm^3)	9.19	8.90	8.89
Diameter (μm)	180(23.1)	437(24.4)	374(35.1)
Buffer			
Density (gm/cm^3)	1.10	1.14	1.19
Thickness (μm)	54(11.5)	49(14.7)	50(14.5)
IPyC			
Density (gm/cm^3)	1.89	1.91	1.89
Thickness (μm)	23(3.0)	35(7.7)	29(3.7)
SiC			
Density (gm/cm^3)	3.21	3.19	3.20
Thickness (μm)	28(2.5)	26(2.7)	27(2.7)
CPyC			
Density (gm/cm^3)	1.84	1.80	1.80
Thickness (μm)	39(4.5)	48(8.4)	41(6.2)

[a] Numbers in parentheses are standard deviations.

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Table 2. Description of FSV Segment VII Reload Fuel

Particle Type	Fissile A	Fissile B	Fertile A	Fertile B
Particle Parameters[a,b]				
Kernel				
Density (gm/cm^3)	8.90(.10)	9.01(.10)	8.83(.05)	8.81(.07)
Diameter (μm)	189.2(25)	251.2(16)	365.1(36)	446.0(36)
Buffer				
Density (gm/cm^3)	1.13(.07)	1.19(.07)	1.11(.06)	1.06(.05)
Thickness (μm)	54.8(10)	51.6(8)	55.5(13)	53.3(12)
IPyC				
Density (gm/cm^3)	1.89(.02)	1.90(.03)	1.89(.03)	1.88(.03)
Thickness (μm)	25.5(4)	24.4(4)	27.1(5)	27.4(5)
SiC				
Density (gm/cm^3)	3.20(.005)	3.21(.008)	3.20(.004)	3.20(.005)
Thickness (μm)	25.1(3.6)	25.0(2.9)	24.7(3.1)	25.0(3.6)
OPyC				
Density (gm/cm^3)	1.86(.01)	1.81(.01)	1.81(.01)	1.83(.01)
Thickness (μm)	60.2(7)	41.1(6)	51.8(8)	46.2(8)

[a] Mean values.

[b] Numbers in parentheses are standard deviations.

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Table 3. Irradiation Conditions of FSV Fuel CHST Samples

Fuel Description	Test Sample Data Retrieval No.	Irradiation Conditions: Fast Neutron Exposure (10^{25} n/m^2)	Kernel Burnup (% FIMA): Fissile	Kernel Burnup (% FIMA): Fertile
Fissile A	CU6A-6328	9.1	18.2	NA[(a)]
Fertile A	CT6A-2399	9.1	NA	4.7
Fertile B	CT6B-932	9.1	NA	4.7
FSV[(b)]				
Core avg[(c)]	NA	2.8	14	1.9
Avg. 6 yr fuel[(d)]	NA	4.9	19	4.5
Maximum[(e)]	NA	8.0	22	7.4

(a) NA = not applicable.
(b) Irradiation exposures expected at equilibrium.
(c) Average over all fuel in the FSV reactor.
(d) Average conditions for a segment removed after 6 yrs residence.
(e) Maximum conditions experienced after 6 yrs residence.

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Table 4. Key Stages of the CHST Method

Stage	Comments
1. Sample characterization	• determine initial fission product content • contact x-radiograph samples
2. Remove OPyC Layer[(a)]	• heat in air to 900°C, hold for 2 hrs • monitor fission product release • contact x-radiograph samples
3. Conduct CHST	• heat approx. 100 particles from 1100 to 2500°C in approx. 8 or approx. 30 hrs • monitor fission product release
4. Post-test Characterization	• determine final metallic fission product content • visual assessment of particle condition • contact x-radiograph samples
5. Data Analysis	• relate Kr-85 release data to total coating failure fraction

(a) Stage 2 was used to prepare samples with "failed" OPyC layers.

Table 5. Test Conditions During FSV Fuel CHST Studies

Particle Type Data Retrieval No.	Fissile A CU6A 6328		Fertile B CT6B 932		Fertile A CT6A 2399	
CHST Condition						
No. of Particles	88	100[a]	101	100	99[a]	101
Temperature Range (°C)	1015-2400	1141-2364	1120-2475	1134-2390	1117-2323	1107-2410
Duration of CHST (HRS)	9.0	26.5	26.5	27.0	24.75	26.0
OPyC Condition	Intact	Missing[b]	Intact	Missing[b]	Intact	Missing[b]

(a) 33 particles removed from test at approximately 2000°C.
(b) Simulates fuel with failed OPyC layers.

485 061

Table 6. **Failure Fractions Suggested by CHST Data Collected on Individual Batches of FSV Core 1 Production Fissile and Fertile Fuel**

Fuel Type	Data Retrieval No.	OPyC Condition	900°C Kr-85 Release Fraction	900°C Failure Fraction[a]	1100-1750°C Kr-85 Release Fraction	1100-1750°C Failure Fraction[a]	2050°C Kr-85 Release Fraction	2050°C Failure Fraction[a]	2175°C Kr-85 Release Fraction	2175°C Failure Fraction[a]	2300°C Kr-85 Release Fraction	2300°C Failure Fraction
Fissile A	CU6A-6328[b]	Intact	<0.001	0	<0.001	0	<0.001	0	0.018	0.02	0.095	0.10
Fertile A	CT6A-2399[c]	Intact	<0.001	0	<0.001	0	0.070	0.07	0.85	0.85	1.0	1.0
Fertile B	CT6B-932[c]	Intact	<0.001	0	<0.003	0	0.005	0.01	0.55	0.55	1.0	1.0
Fissile A	CU6A-6328[c]	Failed[d]	<0.001	0	<0.001	0	0.12	0.12	0.41	0.41	0.95	0.95
Fertile A	CT6A-2399[c]	Failed[d]	<0.025	0.03	0.044-0.058	0.06	0.092	0.09	0.35	0.35	0.95	0.95
Fertile B	CT6B-932[c]	Failed[d]	0.011	0.01	0.032-0.046	0.05	0.076	0.08	0.47	0.47	0.95	0.95

(a) Total coating failure fraction.
(b) 9.0 hr CHST.
(c) 24.75-27.0 hr CHST's.
(d) Removed after irradiation by burning in air at 900°C.

Table 7. Failure Fractions[a] Expected FSV Fissile and Fertile Fuel Irradiated to Average Conditions Predicted for a 6 Yr Old Fuel Segment

Fuel Type	OPyC Condition	Number of Particles Tested	Failure Fraction at 900°C		Failure Fraction at 1100-1750°C		Failure Fraction at 2050°C		Failure Fraction at 2175°C		Failure Fraction at 2300°C	
			Expected	Range at 90% Confidence	Expected	Range at 90% Confidence	Expected	Range at 90% Confidence	Expected	Range at 90% Confidence	Expected	Range at 90% Confidence
Fissile[b]	Failed	100	0	0-0.03	0	0-0.03	0.12	0.06-0.18	0.41	0.30-0.55	0.95	0.80-1.0
Fertile[b]	Failed	201	0.020	0.01-0.05	0.050	0.03-0.09	0.085	0.05-0.13	0.41	0.38-0.55	0.95	0.80-1.0
Fissile & Fertile [b,d,d	Intact	200	0	0-0.02	0	0-0.02	0.040	0.02-0.07	0.70	0.60-0.80	1.0	0.85-1.0

(a) Based on 24.75-27.0 hr CHST's.
(b) Assumes A and B size fuel performance will be the same.
(c) Assumes fissile and fertile fuel with intact OPyC layers will be the same; does not include fissile fuel CHST data since they were obtained in a 9.0 hr CHST.
(d) Empirical failure model for a FSV core assuming no OPyC failure.

Table 8. Empirical Description of Expected FSV Fuel Failure in a 6 Yr Old Segment

Temperature (°C)	Failure Fraction[a]					
	Fissile[b]		Fertile[c]		Combined Fissile/Fertile[d]	
	Expected	Range[e]	Expected	Range[e]	Expected	Range[e]
900	0	0-0.02	0.007	0.003-0.03	0.004	0.002-0.03
1100-1750	0	0-0.02	0.02	0.01-0.04	0.009	0.005-0.03
2050	0.04	0.02-0.08	0.06	0.03-0.09	0.05	0.03-0.08
2175	0.68	0.58-0.79	0.60	0.53-0.72	0.64	0.55-0.75
2300	1.0	0.85-1.0	0.98	0.83-1.0	0.99	0.84-1.0

(a) Normalized to expected OPyC failure fractions.
(b) Assumes 5.6% OPyC failure.
(c) Assumes 34% OPyC failure.
(d) Accounts for fraction of fissions in fissile and fertile fuel.
(e) Assumes that all fuel failure fractions equal 5% or 95% confidence bounds.

APPENDIX A

CHST METHOD

FSV production fuel was tested using standard methods developed on the DOE sponsored accident condition test program, which is bettern known as the core heatup simulation test (CHST) program, (Ref. A1- A3). Unbonded irradiated particles were heated from 1100°C to approximately 2500°C over a period of approx. 8 or 30 hours. Particle performance was monitored by measuring the fraction of Kr-85 and Cs-137 released as a function of time and temperature. Since fission gas release is indicative of total coating failure, particle failure fractions were determined from Kr-85 release fractions. Tests were conducted in a maximum of five stages. These stages are summarized in Table A1, and described below.

Stabe 1 includes collection and characterization of the irradiated fuel samples. Initial gamma counting is used to determine activities and activity ratios of key fission products (Cs-137, Ce-144, Ru-106). The initial gamma-count results are used to predict the Kr-85 inventory using the FISPROD code since Kr-85 is not detectable when gamma-counting intact irradiated fuel particles. Samples are contact X-radiographed to provide a permanent record of particle appearance prior to heating.

During stage 2, samples to be tested with missing(failed) OPyC layers are heated for two hours in air at 900°C in order to remove (burnoff) their OPyC layers (Ref. A3). During the burnback operation, the furnace atmosphere is periodically purged through a liquid nitrogen cold trap and the air replenished to provide an additional oxygen supply; subsequent gamma counting of the cold trap provides a measure of Kr-85 release due to pressure vessel failure resulting from removal of the OpyC coatings. Post-burnback gamma counting and sample radiography is done to characterize the sample prior to the CHST and provide a measure of Cs-137 release that occurred during the burnback operation.

During stage 3, samples are heated out-of-pile in standard, resistance heated graphite tube (King) furnaces. Each test sample is separated into 3 equal groups of particles; each group is then placed into a type H-451 sample holder prior to insertion in the furnace. A schematic of the test furnace/fission product release sampling system is shown in Fig. A1. Four Ta tubes are inserted into each furnace (only one is shown in Fig. A1 for simplicity). One tube extends approximately half way through the furnace, is sealed on one end, and contains a temperature control thermocouple. The other 3 Ta tubes are open ended and extend through the furnace. One sample holder is placed in each of these tubes; a mullite Cs trap is also placed in each tube. Sample temperatures are monitored optically during testing. Samples are heated to approximately 1100°C for 10-20 hours to simulate normal operating conditions prior to a core heatup and then heated from approximately 1100 to 2500°C in approx. 8 or 30 hours. A continuous flow of He (50 cc/min/open ended Ta tube) is maintained during testing. Fission product gases released during heating are swept up by the flowing He and passed through a series of traps to remove tritium and radon. The remaining gases are then passed through two ionization chambers (vibrating reed electrometers); the cold traps are changed at approximately 100-200° intervals and analyzed for Kr-85 by gamma counting. Results from the ionization chambers are normalized to cold trap results to obtain a continuous measure of Kr-85 release as a function of time and temperature.

A mullite tube is placed at 1100°C on the downstream side of each Ta tube to collect cesium released during testing. The mullite tubes are changed at approximately 70°C intervals during testing and gamma counted to monitor Cs release as a function of time and temperature.

An option occasionally chosen is to remove a portion (approx. 1/3) of the test sample at approx. 2000°C. Post-test characterization of the sample provides information needed to define failure mechanisms at elevated temperatures.

Gamma count results obtained during stage 4 are compared with preheating data to provide a measure of the release of additional metallic fission products (i.e. Ce, R, Zr, Eu). Post-heating radiography and metallography are used to illustrate the appearance and phase distributions within particles after heating.

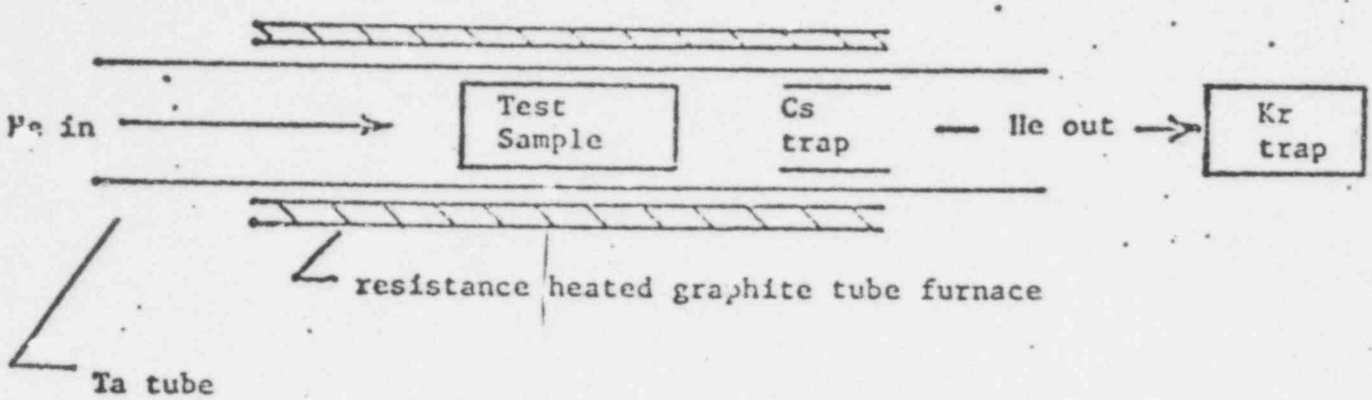
APPENDIX A - REFERENCES

A-1. "HTGR Fuels and Core Development Program Quarterly Progress Report for the Period Ending November 30, 1976," GA-A14180, December 27, 1976.

A-2. "Test Plan for FY-79 Core Heatup Simulation Tests", Document No. 903856, Issue A, December 7, 1978.

A-3. "Procedure for Burning Back Outer Pyrocarbons of Irradiated Fuel Particles", Document No. 903878, Issue A, in review.

(a) test configuration



(b) component description

- test sample - ~100 particles in H-451 graphite crucible
- Cs trap - mullite at ~1100°C
- Kr trap - liquid N_2 cold trap

(c) test conditions

- 1100 to 2500°C
- linear increase in temperature with time
- 8 to 30 hrs per test

Figure A-1. Schematic of Test Configuration used for CHST Studies

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Table A-1. Summary of Steps Involved in FSV CHST Series

Stage	Description
1	Sample Characterization 1. Recover Test Sample 2. Gamma Count Test Sample 3. Radiograph Test Sample 4. Do FISPROD calculationgs to Estimate Inventories of Fission Products Not Detected During Gamma Counting
2	OPyC Burnoff (only those samples to be tested with missing (failed) OPyC's) 1. Load Sample 2. Heat Sample in Air for 2 Hours at 900°C 3. Monitor Fission Product Release 4. Radiograph Test Sample
3	Core Heatup Simulation Test 1. Load Sample into H-451 Holder 2. Load Furnace 3. Heat 4. Monitor Fission Product Release
4	Post-Test Sample Characterization 1. Gamma Count Test Sample 2. Radiograph Test Sample 3. Perform Metallographic Examination
5	Analyze and Summarize Results

485 069

FSV-38-11-R-9

GENERAL ATOMIC

GENERAL ATOMIC COMPANY
P.O. BOX 81608
SAN DIEGO, CALIFORNIA 92138
(714) 455-3000

June 4, 1979
Project 90-330 M HTGR
Fort St. Vrain Unit 1
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FSV 38(11-R-9)

Mr. J. K. Fuller, Vice President
Engineering and Planning
Public Service Company of Colorado
5900 East 39th Avenue
Denver, Colorado 80201

Subject: Report - Fort St. Vrain In-Core Inspection Region 35 and Region 13 Core Support Block

References: 1) T. P. Speis to J. K. Fuller NRC letter dated April 9, 1979

2) FPLG-1772

3) GLP-5858

Dear Mr. Fuller:

Attached for your use and transmittal to the NRC are three (3) copies of the subject report. The report will be published at a later date as a "GA-A" report and additional copies will be supplied. The photograph reproductions will be improved in the "GA-A" report over the generally good quality of those in the attachment.

This completed NRC action items 2 and 4 of Reference 1) and assigned to GAC by Reference 2). NRC action 3 was previously responded to by Reference 3).

If you have any questions, we would be pleased to discuss them with you.

Very truly yours,

William A. Graul

William A. Graul, Manager
Fort St. Vrain Project

Attachment

No response required

485 070