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Timing Analysis of PWR Fuel Pin Failures

Draft Report for Comment

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Research has been conducted to develop and demonstrate a methodology for calculation of the time interval between receipt of the containment isolation signals and the first fuel pin failure for loss-of-coolant accidents (LOCAs). Demonstration calculations were performed for a Babcock and Wilcox (B&W) design (Oconee) and a Westinghouse (W) four-loop design (Seabrook). Sensitivity studies were performed to assess the impacts of fuel pin burnup, axial peaking factor, break size, emergency core cooling system (ECCS) availability, and main coolant pump trip on these times. The analysis was performed using the following codes: FRAPCON-2, for the calculation of steady-state fuel behavior; SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1, for the calculation of the transient thermal-hydraulic conditions in the reactor system; and FRAP-T6, for the calculation of transient fuel behavior. In addition to the calculation of fuel pin failure timing, this analysis provides a comparison of the predicted results of SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 for large-break LOCA analysis.

Using SCDAP/RELAP5/MOD3 thermal-hydraulic data, the shortest time intervals calculated between initiation of containment isolation and fuel pin failure are 10.4 seconds and 19.1 seconds for the B&W and W plants, respectively. Using data generated by TRAC-PF1/MOD1, the shortest interval for the W reactor is 29.1 seconds. These intervals are for a double-ended, offset-shear, cold leg break, using the technical specification maximum peaking factor and applied to fuel with maximum design burnup.

FIN L1611—LOCA Pin Failure Source Term

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EXECUTIVE SUMMARY

A design basis accident postulated for licensing of nuclear power reactors has been the loss-of-coolant accident (LOCA), in conjunction with an assumed instantaneous release of fission products from the fuel into the containment. Certain equipment performance capabilities, such as rapid closure of containment isolation valves, were required to facilitate compliance with regulations regarding offsite radiological consequences.

The objective of this research was to develop a viable methodology for calculating the timing of the earliest fuel pin cladding failure, relative to the containment isolation signal, for LOCAs. The calculation was expected to show that, with regard to radiological consequences, certain isolation valves may not have to be closed as rapidly as now required.

Methodology

To meet this objective, a calculational methodology was developed using the FRAPCON-2, SCDAP/RELAP5/MOD3, TRAC-PF1/MOD1, and FRAP-T6 computer codes. This four-code approach provided a defensible calculational methodology for performing the analyses, incorporating a fully assessed calculational path, using FRAPCON-2, TRAC-PF1/MOD1, and FRAP-T6, and a parallel path, utilizing FRAPCON-2, SCDAP/RELAP5/MOD3, and FRAP-T6. Demonstration calculations were performed, applying this methodology to two plant designs, a Westinghouse (W) four-loop design analyzed using a Seabrook plant model and a Babcock and Wilcox (B&W) design analyzed using an Oconee plant model. Sensitivity studies were performed to assess the impact on failure timings of break size, emergency core cooling system (ECCS) availability, reactor coolant system (RCS) pump trip, fuel pin burnup, and axial peaking factor.

The calculational methodology that used SCDAP/RELAP5/MOD3 is illustrated in Figure ES-1. In these calculations, FRAPCON-2 was used to calculate the burnup-dependent fuel pin initial conditions for FRAP-T6. FRAP-T6 was used to calculate the initial steady-state fuel pin conditions for SCDAP/RELAP5/MOD3. SCDAP/RELAP5/MOD3 was run to obtain the system thermal-hydraulic boundary conditions, consisting of the fuel pin power distribution and thermodynamic conditions of the coolant channel. Finally, FRAP-T6 was used to calculate the transient fuel pin behavior.

SCDAP/RELAP5/MOD3 was chosen as the primary thermal-hydraulic code for the analysis, since SCDAP/RELAP5/MOD3 provides a considerable cost savings over TRAC-PF1/MOD1 for calculation of system thermal-hydraulic response under LOCA conditions. SCDAP/RELAP5/MOD3 is a relatively fast-running code that can execute from a workstation platform, as opposed to TRAC-PF1/MOD1, which requires a mainframe platform. However, because of the lack of code assessment for SCDAP/RELAP5/MOD3, a supplemental TRAC-PF1/MOD1 calculation, duplicating the case resulting in the shortest time to pin failure for Seabrook, was run to provide an evaluation of its accuracy.

The supplemental calculation utilizes a similar methodology with the exception that SCDAP/RELAP5/MOD3 is replaced by TRAC-PF1/MOD1, as illustrated in Figure ES-2. Initialization of burnup-dependent variables for the TRAC-PF1/MOD1 fuel components is not necessary, since the code does not have a fuel performance model. However, a comparison of initial stored energy calculated by TRAC-PF1/MOD1 to that calculated by FRAP-T6 indicated reasonable agreement.

A significant software development effort was conducted to implement the chosen methodology. This effort included conversion of the FRAPCON-2 and FRAP-T6 codes to portable FORTRAN 77 to allow execution on a 32-bit-based UNIX workstation, and the creation of interface codes to link the thermal-hydraulics codes to FRAP-T6. In addition, advanced graphics capabilities were added to the FRAP-T6

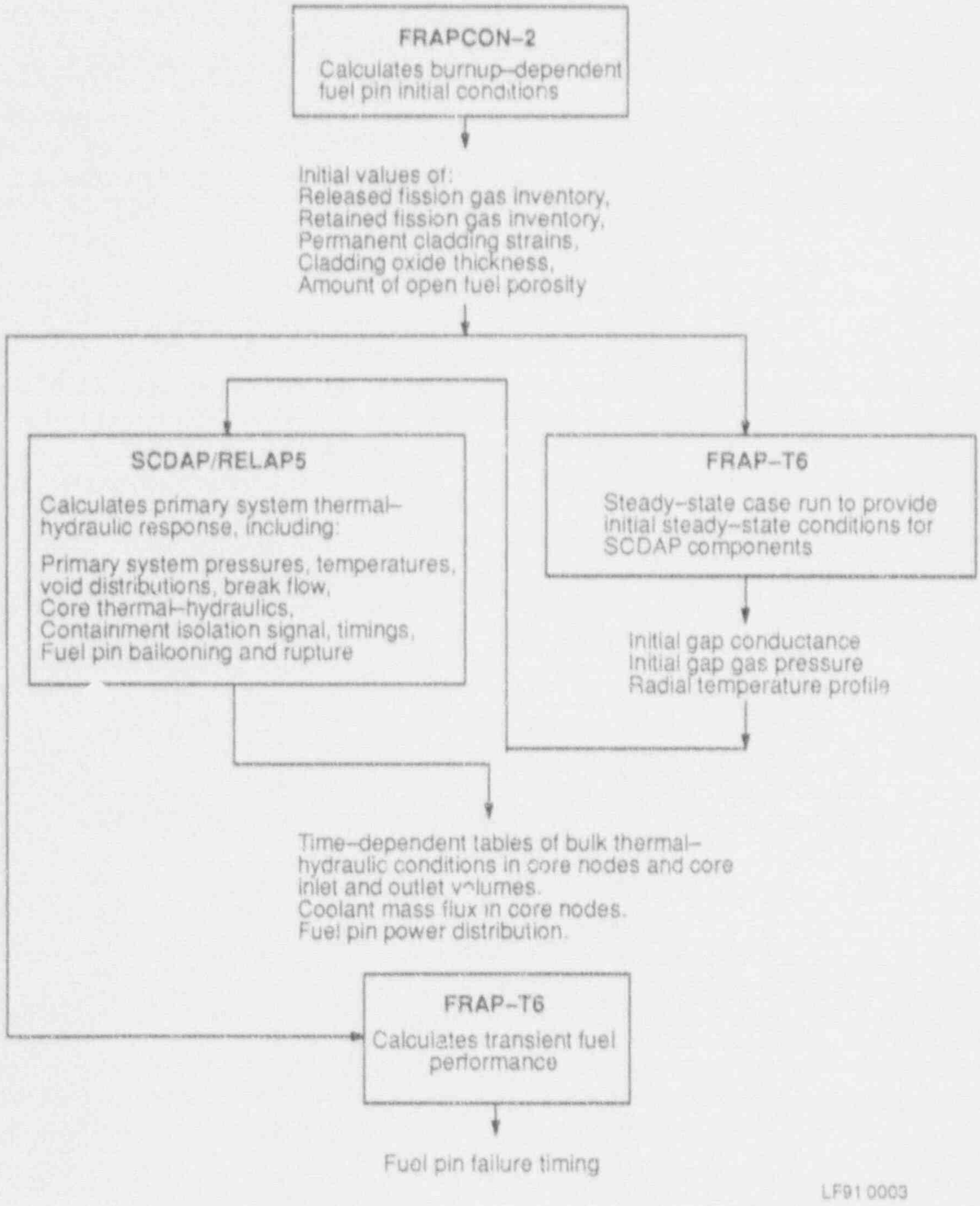

Figure ES-1. Flow chart of methodology using SCDAP/RELAP5/MOD3 thermal-hydraulic data.

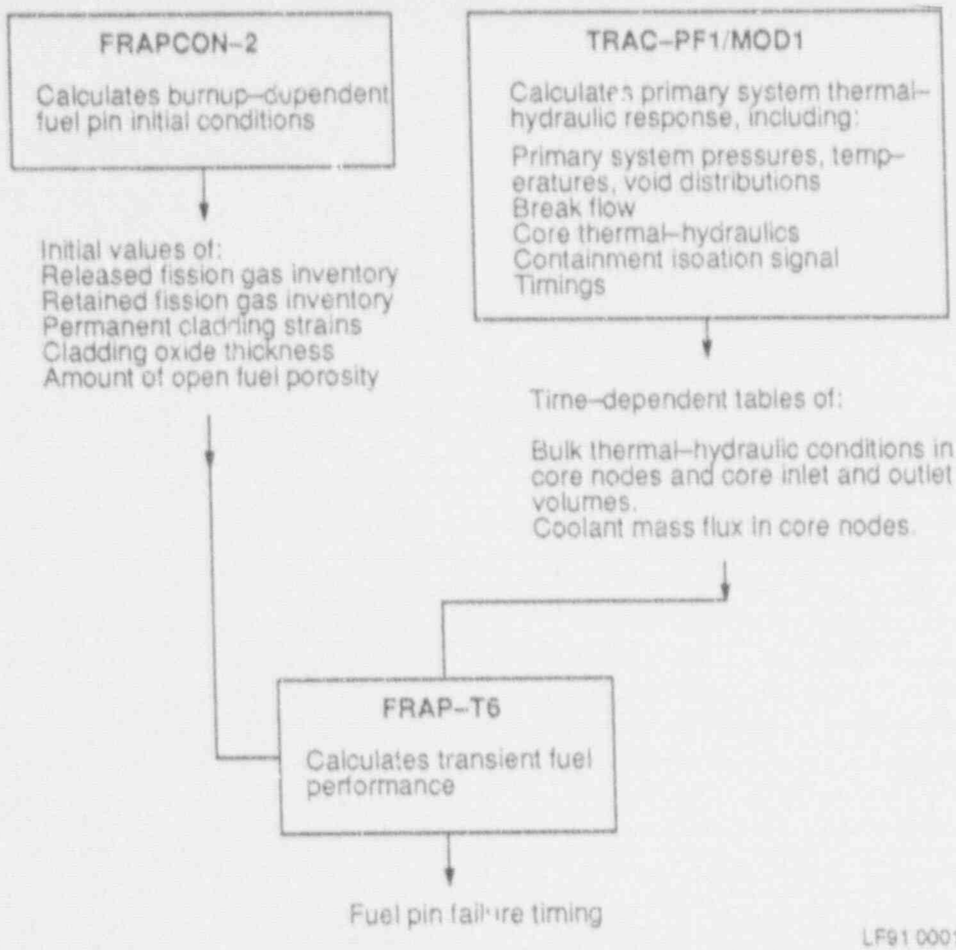

Figure ES-2. Flow chart of methodology using TRAC-PF1/MOD1 thermal-hydraulic data.

code. These capabilities include interfacing to the Nuclear Plant Analyzer (NPA) and the GRAFITI graphics packages. The NPA software is an advanced interactive graphics package that provides an animated display of the fuel rod behavior during program execution. The GRAFITI package provides a presentational graphics capability.

Model Development

Calculations were performed assuming an equilibrium core operating at 102% core thermal power. Similar core nodalization was used for the SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 models, with the exception that the core bypass was lumped into the outer core region in the TRAC-PF1/MOD1 model. This nodalization consisted of a detailed three-channel core model with nine axial nodes, simulating hot channel, central, and outer regions of the core. The hot channel included four fuel assemblies. The total power generated in the hot channel was assumed to be governed by the technical specification enthalpy rise hot channel factor.

Existing RELAP5/MOD2 Seabrook and Oconee reactor models were modified and upgraded to produce the models needed for this analysis. Modifications included the addition of a detailed three-channel, nine-axial-node core model, describing the hot channel and the central and outer core region, with crossflow modeling between channels; point kinetics modeling; SCDAP modeling; a simplified containment model; and a detailed downcomer model.

A simplified containment model, consisting of a single RELAP5 volume with heat conductors representing steel and concrete surfaces, provided a fairly rough estimate of containment response.

A more detailed treatment of containment response would require the use of a containment analysis code. For Seabrook, results indicate that the containment isolation signal from the pressurizer low pressure trip trails the signal received from high containment pressure by only about three seconds. Because of the approximate nature of the containment pressure calculation, the pressurizer low-pressure trip time was used to determine the containment isolation signal time. For Oconee, the containment isolation signal from the RCS low-pressure trip trails the signal received from high containment pressure by only about 0.02–0.28 seconds; and the RCS low-pressure trip time was used to determine the containment isolation signal timing for the large-break cases. The order-of-magnitude difference in containment isolation signal times between the plants is due to the locations of the pressure sensors. For all of the small-break cases, the high containment pressure trip trails the low RCS pressure trip by several seconds, and the low RCS pressure trip time was used to determine containment isolation time.

The Seabrook TRAC-PF1/MOD1 model used for this analysis was also derived from an existing TRAC-PF1/MOD1 model. The modifications for this analysis included renodalization of the core region from five to nine axial nodes, describing the hot channel and the central and outer core region, removal of pumped ECCS, modification of the core power distribution, and replacement of containment pressure and decay heat boundary conditions. Boundary conditions for containment pressure and total core power history were obtained from the corresponding SCDAP/RELAP5/MOD3 calculation.

The FRAPCON-2, FRAP-T6, and SCDAP fuel pin models were developed specifically for this analysis. A single fuel pin design was modeled for each plant type analyzed—the Mk-B9/10 design for the Oconee analysis and the W 17 × 17 standard fuel design for the Seabrook analysis. Reactor-specific fuel data was obtained either from the fuel vendor or the appropriate Final Safety Analysis Report.

The results generated by this analysis are dependent on the specific fuel design parameters, such as initial helium fill inventory, fuel pellet dimensions, cladding dimensions, and plenum volume. Fuel pin failure times can be expected to vary by both fuel design and reactor design.

Sensitivity Studies

Using SCDAP/RELAP5/MOD3, sensitivity studies were performed for each reactor type to identify the break size resulting in the shortest time to pin failure. The following break sizes were analyzed:

- A large-break LOCA, consisting of a double-ended, offset-shear break of a cold leg, with break sizes corresponding to 100, 90, 75, and 50% of the full design basis analysis (DBA) cold leg break area (200% of the cold leg cross-sectional area) without ECCS

- A 6 in. dia., small-break LOCA at the same location used for the large-break case, with and without ECCS.

The large-break case resulting in the shortest time to pin failure (100% DBA for both Oconee and Seabrook) was also run with the following variations:

- With ECCS available

- With RCS pump tripped at time zero, with and without ECCS available.

For each set of large-break transient thermal–hydraulic conditions generated by SCDAP/RELAP5/MOD3, a series of 16 FRAP-T6 cases, using best-estimate models, was run to determine fuel pin failure times for a range of peak burnups and axial power peaking factors up to and including the heat flux hot channel factor. The 16-case FRAP-T6 matrix [illegible] repeated for the worst-case break size (1[illegible]% DBA) using the available licensing audit code options.

For each small-break SCDAP/RELAP5/MOD3 calculation, an initial matrix of four

FRAP-T6 cases was executed, corresponding to the highest peaking factor at four burnups for each reactor type. Since no fuel pin failure was observed prior to 60 seconds in all cases, no additional FRAP-T6 cases were run.

The 16-case FRAP-T6 matrix for the 100% DBA case for Seabrook was also run using thermal-hydraulic boundary condition data provided by TRAC-PF1/MOD1.

Results Generated Using SCDAP/RELAP5/MOD3

The fuel pin failure times for Oconee and Seabrook calculated by FRAP-T6 for the worst-case LOCA are summarized in Tables ES-1 and ES-2. In cases where no fuel pin failure was predicted, the values given in the matrices correspond to the transient time at the end of the calculation, prefixed by a "greater than" symbol (>). The failure nodes are indicated by the numbers in parentheses; nodes are numbered from 1 at the bottom of the core to 9 at the top.

The fuel pin failure times calculated by SCDAP/RELAP5/MOD3 do not, in general, correlate well with those calculated by FRAP-T6. Except for the Oconee 100% DBA LOCA cases, the fuel pin failure times calculated by SCDAP/RELAP5/MOD3 tend to be longer than those calculated by FRAP-T6. This discrepancy increases significantly as the break size is reduced. A fairly good agreement is obtained between the two codes for the 100% DBA Oconee cases, both with and without pumped ECCS. However, fuel pin failure times calculated by SCDAP/RELAP5/MOD3 are about half of those calculated by FRAP-T6 for the two 100% DBA Oconee cases run with main coolant pump trip.

The minimum time to fuel pin failure for Oconee calculated with the FRAP-T6 best-estimate models was 13.0 seconds for the 100% DBA case without RCS pump trip. This minimum pin failure time for Oconee was not affected by availability of pumped ECCS. The minimum time to fuel pin failure calculated by FRAP-T6 for Seabrook was 24.8 seconds for the 100% DBA case without ECCS available. Overall, the results generated by FRAP-T6 are consistent with expected trends. Pin failure times shortened as peaking factors, burnups, and break areas were increased.

The earliest pin failure times calculated for Oconee were significantly shorter than those calculated for Seabrook. The shorter failure times can be directly attributed to the higher linear heat generation rate and the larger fuel pin diameter in Oconee, which results in higher initial stored energy. In addition, the failure times calculated for Oconee were stronger functions of burnup than those reported for Seabrook. The pin failure times calculated for Seabrook were only weak functions of burnup, with only about a total of five seconds or less separating the maximum and minimum pin failure times over the range of burnups.

As anticipated, no fuel pin failures were predicted for the small-break cases during the first 60 seconds of the calculation. The small-break cases without pumped ECCS available were subsequently extended to 6 minutes 33 seconds (at which time code failure occurred) for Oconee and to 10 minutes for Seabrook, with no fuel failures predicted by either SCDAP/RELAP5/MOD3 or FRAP-T6.

Results Generated Using TRAC-PF1/MOD1

The system response calculated using SCDAP/RELAP5/MOD3 agrees fairly well with that of TRAC-PF1/MOD1 for the first 35 seconds, as evidenced by comparisons of RCS pressure, pressurizer pressure, break flow, accumulator flows, hot-leg flows, and cold-leg flows. However, the hot channel thermal-hydraulic conditions calculated by SCDAP/RELAP5/MOD3 produce higher cladding surface temperatures and earlier fuel pin failure times.

The largest deviation between the SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 results

Table ES–1. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for a complete, double-ended, offset-shear LOCA for Oconee.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	22.7 (5)	20.3 (4)	18.0 (4)	13.0 (4)
2.4	> 60.0	25.3 (4)	19.7 (4)	14.1 (4)
2.2	> 60.0	34.8 (4)	23.9 (4)	16.4 (4)
2.0	> 60.0	> 60.0	33.8 (4)	22.5 (4)

Table ES–2. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for a complete, double-ended, offset-shear LOCA for Seabrook.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	29.1 (5)	29.7 (5)	27.7 (5)	24.8 (4)
2.2	34.4 (5)	36.7 (5)	35.8 (5)	32.5 (4)
2.0	44.5 (4)	48.4 (4)	43.6 (4)	43.6 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

occurred after the accumulators emptied and discharged nitrogen into the system. In the SCDAP/RELAP5/MOD3 calculation, the accumulators were isolated as they approached an empty condition, in order to prevent code failure. In the TRAC-PF1/MOD1 calculation, however, as the accumulators emptied, nitrogen gas was discharged into the cold leg and vessel. This surge of noncondensible gas pressurized the upper downcomer, resulting in a surge of fluid into the core region. Core flow surges can be seen as the broken loop accumulator empties at approximately 35 seconds and again as the intact accumulators empty at about 40 seconds. These flow surges are clearly seen in the hot channel mass flow at the midcore level.

The corresponding FRAP-T6 fuel pin failure times generated using TRAC-PF1/MOD1 are summarized in Table ES–3. In cases where no fuel pin failure was predicted, the values given in the matrices correspond to the transient time at the end of the calculation, prefixed by a "greater than" symbol (>). The failure nodes are indicated by the numbers in parentheses; nodes are numbered from 1 at the bottom of the core to 9 at the top.

Cladding surface temperatures calculated by FRAP-T6 using TRAC-PF1/MOD1 data are lower than those calculated using SCDAP/RELAP5/MOD3 data. This deviation becomes even more apparent after about 40 seconds, due to the nitrogen-induced flow surge that results in a quenching of the cladding for the TRAC-PF1/MOD1 calculation. Based on this single TRAC-PF1/MOD1 calculation, the methodology using SCDAP/RELAP5/MOD3 to provide thermal-hydraulic boundary conditions for FRAP-T6 appears to produce conservative results.

Table ES–3. FRAP-T6-calculated fuel pin failure time (s) for the Seabrook 100% DBA case using thermal-hydraulic conditions generated by TRAC-PF1/MOD1.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	> 60.0	41.4 (5)	41.3 (6)	34.9 (6)
2.2	> 60.0	> 60.0	41.4 (5)	41.2 (6)
2.0	> 60.0	> 60.0	> 60.0	> 60.0
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Technical Findings

A detailed methodology for the calculation of fuel pin failure timing under LOCA conditions was developed and applied in two series of demonstration calculations. In each demonstration calculation, the earliest fuel pin failure times were for a complete, double-ended, offset-shear break of a cold-leg, without pumped ECCS and assuming that the main coolant pumps continued operating. These quantitative results are summarized in Table ES–4.

Five major technical findings and recommendations were derived from this analysis, as follows:

1. The demonstration calculations (using conservative assumptions) indicate that no fuel failures will be encountered during the first several seconds of the worst-case design basis LOCA (doubled-ended, offset-shear cold leg break) without pumped ECCS. In addition, these calculations illustrate the potential for providing more realistic times for fission product appearance within containment compared with the instantaneous release assumption of TID-14844.

2. The fuel pin failure times can be expected to exhibit significant variation by fuel and reactor design.

3. Fuel pin failure times calculated by FRAP-T6 using SCDAP/RELAP5/MOD3 thermal-hydraulics are conservative in comparison to those using TRAC-PF1/MOD1 thermal-hydraulics. It is expected that more detailed nodalization schemes would not adversely affect this finding.

4. The time of cladding rupture calculated by the SCDAP ballooning model is different from that calculated by the FRAP-T6 ballooning model; this difference is due to an incomplete modeling of strain rate effects by the SCDAP ballooning model.

5. The uncertainty associated with fuel pin failure timing should be investigated. The relative uncertainty associated with a particular result is crucial to the interpretation of a best-estimate calculation. There are several sources of uncertainty introduced into the calculation of fuel pin failure times. These include variations in fabrication parameters, material property correlations, fuel performance correlations, and thermal-hydraulic boundary conditions. It is recommended that a FRAP-T6 uncertainty analysis be included when implementing the methodology discussed in this report to quantify the uncertainty associated with fuel pin failure times.

Table ES-4. Timing summary for worst-case LOCA runs using highest burnup and peaking factor.

Plant	Thermal-hydraulic model	Containment isolation (s)	Earliest pin failure (s)	Interval (s)
Oconee	SCDAP/RELAP5/MOD3	2.6	13.0	10.4
Seabrook	SCDAP/RELAP5/MOD3	5.7	24.8	19.1
Seabrook	TRAC-PF1/MOD1	5.8	34.9	29.1

FOREWORD

The information in this report will be considered by the U.S. Nuclear Regulatory Commission staff in the formulation of updated accident source terms for light water reactors to replace those given in TID-14844, calculation of distance factors for power and test reactor sites. These source terms are used in the licensing of nuclear power plants to assure adequate protection of the public health and safety.

Any interested party may submit comments on this report for consideration by the staff. To be certain of consideration, comments on this report must be received by the due date published in the Federal Register Notices. Comments received after the due date will be considered to the extent practical. Comments should be sent to the Chief, Regulatory Publications Branch, Division of Freedom of Information and Publications Services, Mail Stop P-223, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Further technical information can be obtained from Mr. Leonard Soffer, Office of Nuclear Regulatory Research, Mail Stop NL/S-324, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Telephone (301) 492-3916.

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ACRONYMS

B&W	Babcock and Wilcox Company
BWR	boiling water reactor
CCFL	counter-current flow
CFR	Code of Federal Regulations
CSAU	code scaling, applicability, and uncertainty evaluation study
CVS	Computer Visual System
CTP	core thermal power
DBA	design basis accident
DEC	Digital Equipment Corporation
ECCS	emergency core cooling system
EOL	end-of-life
F77	Fortran-77
FORTRAN	formula translation
FRACAS	Failure Reporting and Corrective Action System
FRAPCON-2	Fuel Rod Analysis Program-constant power
FRAP-T	Fuel Rod Analysis Program-transient
FSAR	Final Safety Analysis Report
GWd	gigawatt days
INEL	Idaho National Engineering Laboratory
JCL	job control language
LAC	licensing audit code
LHGR	linear new heat generation rate
LOCA	loss-of-coolant accident
LWR	light water reactor
MOD	modification

MTU	metric tons of uranium
NPA	Nuclear Plant Analyzer
NRC	U.S. Nuclear Regulatory Commission
PWR	pressurized water reactor
RCS	reactor coolant system
RELAP	Reactor Excursion and Leak Analyzer Program
SCDAP	severe core damage analysis package
TID	Technical Information Division
TRAC-PF	Transient Reactor Analysis Code for Pressurized Water Reactors
W	Westinghouse Electric Corporation

Timing Analysis of PWR Fuel Pin Failures

1. INTRODUCTION

A design basis accident postulated for licensing of nuclear power reactors has been the loss-of-coolant accident (LOCA), in conjunction with an assumed instantaneous release of fission products from the fuel into the containment. Source term release to the environs is then based on releasing this inventory from the containment at the maximum containment leak rate given in the plant technical specifications. These fundamental assumptions, governing source-term calculations for light-water reactors, are detailed in Technical Information Document (TID) 14844,[1] "Calculation of Distance Factors for Power and Test Reactor Sites," which provides the technical basis supporting U. S. Nuclear Regulatory Commission (NRC) Regulatory Guides 1.3[2] and 1.4.[3] These regulatory guides provide the assumptions to be used for evaluating the potential radiological consequences of a LOCA for boiling water reactors (BWRs) and pressurized water reactors (PWRs), respectively. The radiological consequences used as reference values in the evaluation of reactor sites are set forth in Title 10, Code of Federal Regulations (CFR), Part 100.[4]

The assumption of an instantaneous release of fission products from the fuel to the containment represents a very conservative approach for the assessment of the radiological consequences of postulated severe accidents. Certain equipment performance requirements, such as rapid closure of containment isolation valves, have been required to facilitate compliance with 10 CFR 100 regarding offsite radiological consequences. A more realistic approach for determining the timing of a fission product release to the containment from a postulated severe accident would include (a) calculation of the time required for failure of the fuel cladding containing the fission products, resulting in a fission product release from the fuel pin gap to the reactor coolant; (b) calculation of the release of fission products from molten fuel, and (c) calculation of the time required for fission products released from the fuel to enter the containment.

The research objective is to develop a viable methodology for calculation of the timing between the receipt of the containment isolation signal and the earliest fuel pin cladding failure. Identifying this time is expected to show that, with regard to radiological consequences, certain isolation valves may not have to be closed as rapidly as now required.

In order to meet this objective, a calculational methodology was developed employing the FRAPCON-2,[5] SCDAP/RELAP5/MOD3,[6] and FRAP-T6[7] computer codes. Demonstration calculations were performed, applying this methodology to two plant designs, a Westinghouse (W) four-loop design analyzed using a Seabrook plant model and a Babcock and Wilcox (B&W) design analyzed using an Oconee plant model. These calculations included several sensitivity studies, which assessed the impact of break size, emergency core cooling system (ECCS) availability, and main coolant pump trip on the fuel pin failure and containment isolation signal times.

These calculations represent the first application of SCDAP/RELAP5/MOD3 and were performed using a preliminary version of the code, prior to completion of the code assessment efforts. In order to provide a basis for evaluating the adequacy of SCDAP/RELAP5/MOD3 for large-break LOCA analysis, a single TRAC-PF1/MOD1[8] calculation was also performed for Seabrook, duplicating the worst-case SCDAP/RELAP5/MOD3 calculation, consisting of a complete, double-ended, offset-shear break of a cold-leg, without pumped ECCS, and assuming that the main coolant pumps continued operating.

The calculational methodology developed for this analysis is discussed in Section 2. This methodology required the resurrection of existing codes and development of additional computer programs; these software development efforts are covered in Section 3. The thermal-hydraulic model development efforts are discussed in Section 4. Development of the steady-state and transient fuel performance models is discussed in Section 5. The assumptions used for the sensitivity cases run for this analysis are discussed in Section 6. The results obtained and technical findings derived from this analysis are discussed in Sections 7 and 8, respectively.

All work performed on this project was fully documented in accordance with approved quality assurance procedures. Appendix A provides details of the procedures and a complete documentation list.

2. METHODOLOGY

The methodology developed for the calculation of fuel pin cladding failure timing has undergone substantial changes over the course of this project. A preliminary LOCA pin failure calculation was performed for a W three-loop plant based on the Surry plant model. The SCDAP/RELAP5/MOD2.5[9] code was used in this initial analysis to provide a direct calculation of fuel pin failure timings for a range of large-break LOCAs. This best-estimate code provides a fully integrated approach to severe accident analysis by directly coupling the thermal-hydraulic capabilities of RELAP5 to the fuel performance capabilities of SCDAP. However, this initial work identified several problems with this code; these problems are discussed in Appendix B. The nature of these problems led to the conclusion that SCDAP/RELAP5/MOD2.5 was not entirely suitable for performing the fuel pin failure portion of this analysis. The correction of SCDAP code deficiencies identified during the Surry calculation and consolidation of SCDAP and RELAP5/ MOD3 to create a preliminary version of SCDAP/RELAP5/MOD3 were completed February 1991.

This code was then used as a part of a more complex computational scheme, using the FRAPCON-2, SCDAP/RELAP5/MOD3, TRAC-PF1/MOD1, and FRAP-T6 codes. This four-code approach provided a defensible methodology for performing the calculation, incorporating a fully assessed path (using FRAPCON-2, TRAC-PF1/MOD1, and FRAP-T6) and a parallel, more economical, path (using FRAPCON-2, SCDAP/RELAP5/MOD3, and FRAP-T6).

The FRAPCON-2[5] code was developed to calculate the steady-state response of light water reactor (LWR) fuel rods during long-term burnup. It calculates the temperature, pressure, deformation, and failure histories of a fuel rod as functions of time-dependent fuel rod power and coolant boundary conditions.

The FRAP-T6[7] code was developed for the prediction of the performance of LWR fuel rods during operational transients and hypothetical accidents. It obtains initial fuel rod conditions by reading a file created by the FRAPCON-2 code. The code calculates all of the phenomena influencing the transient performance of fuel rods, with particular emphasis on temperature and deformation of the cladding.

Both FRAPCON-2 and FRAP-T6 were thoroughly assessed over a range of normal burnups;[10-13] however, they were not assessed for analysis of high-burnup fuel (>35 GWd/MTU). However, results obtained for exposures above 35 GWd/MTU are in general agreement with expected trends. In addition, it is not anticipated that high-burnup fuel pins would be operating at power levels that would cause them to fail earlier than [illegible] burnup pins.

The calculational methodology using SCDAP/RELAP5/MOD3 to calculate system thermal–hydraulic conditions is illustrated in Figure 1. In these calculations, FRAPCON-2 was used to calculate the burnup-dependent fuel pin initial conditions for FRAP-T6. FRAP-T6 was used to calculate the initial steady-state fuel pin conditions for SCDAP/RELAP5/MOD3. SCDAP/RELAP5/MOD3 was run to obtain the system thermal-hydraulic boundary conditions, consisting of the fuel pin power distribution and thermodynamic conditions of the coolant channel. Finally, FRAP-T6 was used to calculate transient fuel pin behavior.

Pin failure times were calculated both by SCDAP and by FRAP-T6 to provide a method of evaluating the capabilities of SCDAP/RELAP5/MOD3 for fuel pin behavior analysis under LOCA conditions. The SCDAP modeling of the effect of cladding strain rate on cladding ballooning is not complete; as a result, the model does not correctly calculate the time of cladding rupture. Therefore, the fuel pin failure timings generated by SCDAP are presented only for informational purposes in this report. References to fuel pin failure timings from this report should be based solely on FRAP-T6 results.

SCDAP/RELAP5/MOD3 was chosen as the primary thermal-hydraulics code for this analysis, since it provides a considerable cost savings

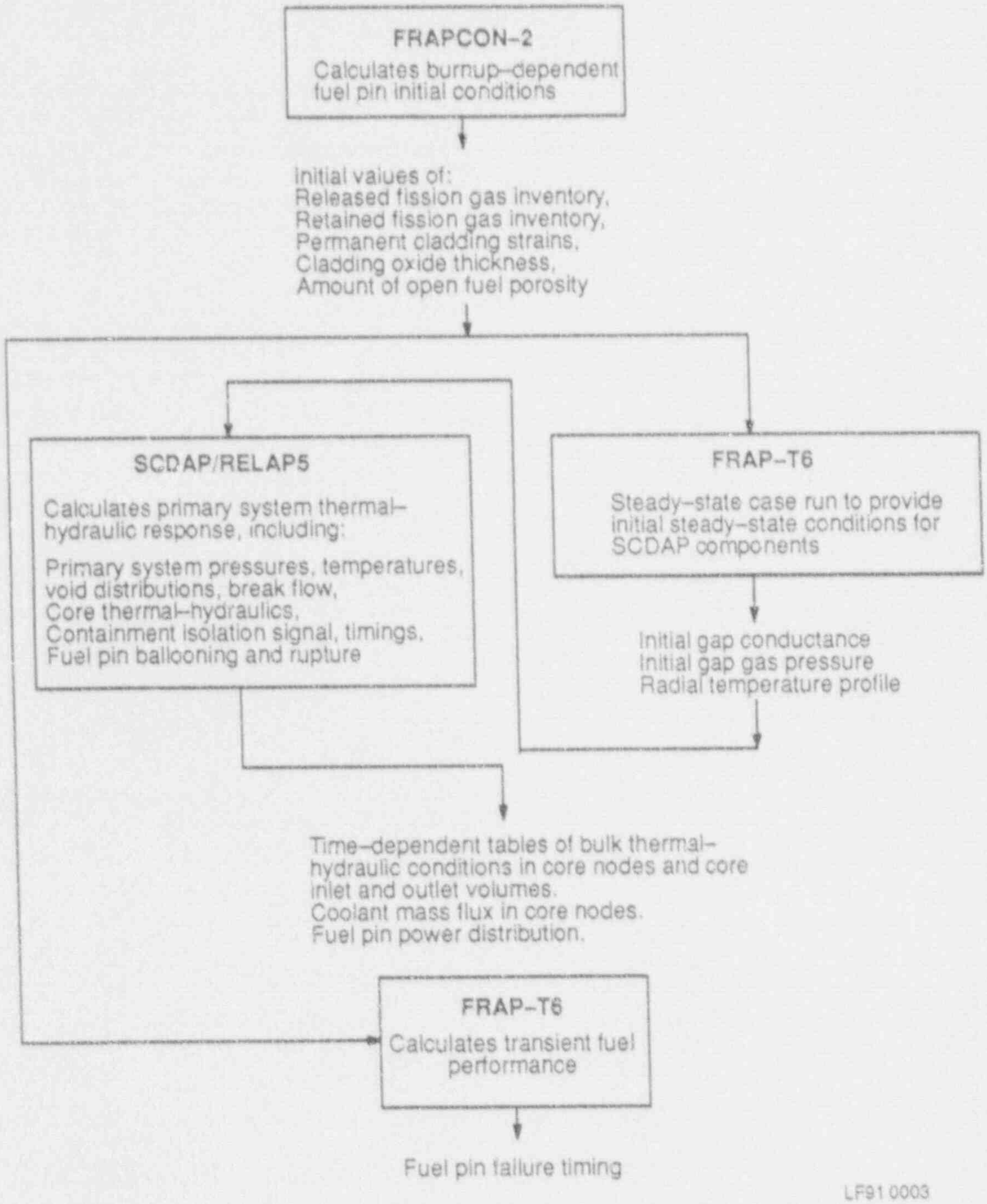

Figure 1. Flow chart of methodology using SCDAP/RELAP5/MOD3 thermal-hydraulic data.

over TRAC-PF1/MOD1 for calculation of system thermal-hydraulic response under LOCA conditions. SCDAP/RELAP5/MOD3 is a relatively fast running code that can be executed from a UNIX workstation platform, as opposed to TRAC-PF1/MOD1, that requires a mainframe platform. This combination of three codes (SCDAP/RELAP5/MOD3, FRAPCON-2, and FRAP-T6), however, is not fully defensible because of the preliminary nature of the SCDAP/RELAP5/MOD3 component and the lack of assessment for large-break LOCA calculations. A parallel calculation was therefore performed, using TRAC-PF1/MOD1 for the thermal-hydraulic calculation instead of SCDAP/RELAP5/MOD3. This calculation, which duplicated the SCDAP/RELAP5/MOD3 case resulting in the shortest time to pin failure for Seabrook, also provided an evaluation of the accuracy of SCDAP/RELAP5/MOD3 for performing large-break LOCA analyses.

The TRAC-PF1/MOD1 code[8] was developed for transient simulation of LWR coolant systems under large-break LOCAs. Version 14.3U5Q.LG was used for this analysis. This version was frozen in 1987 by the NRC for use in the code scaling, applicability, and uncertainty evaluation (CSAU) study.[14] A broad assessment effort has been completed, which has demonstrated that the code is capable of addressing the entire large-break LOCA scenario (blowdown, refill, and reflood). Appendix III of the CSAU report[14] provides an extensive list of assessment reports applicable to the TRAC-PF1/MOD1 code.

The calculation methodology with TRAC-PF1/MOD1 is illustrated in Figure 2. Initialization of burnup-dependent variables for the TRAC-PF1/MOD1 fuel components is not necessary, since the code does not have a fuel performance model. However, a comparison of initial stored energy to that calculated by FRAP-T6 indicated reasonable agreement.

As subsequently discussed, the analysis was run for a representative B&W and W plant, Oconee and Seabrook. Calculations were made for a range of break sizes, with and without ECCS availability and RCS pump trip. For each set of transient thermal-hydraulic conditions generated by either SCDAP/RELAP5/MOD3 or TRAC-PF1/MOD1, a series of FRAP-T6 cases was run to determine fuel pin failure times for a range of fuel pin exposures and axial peaking factors.

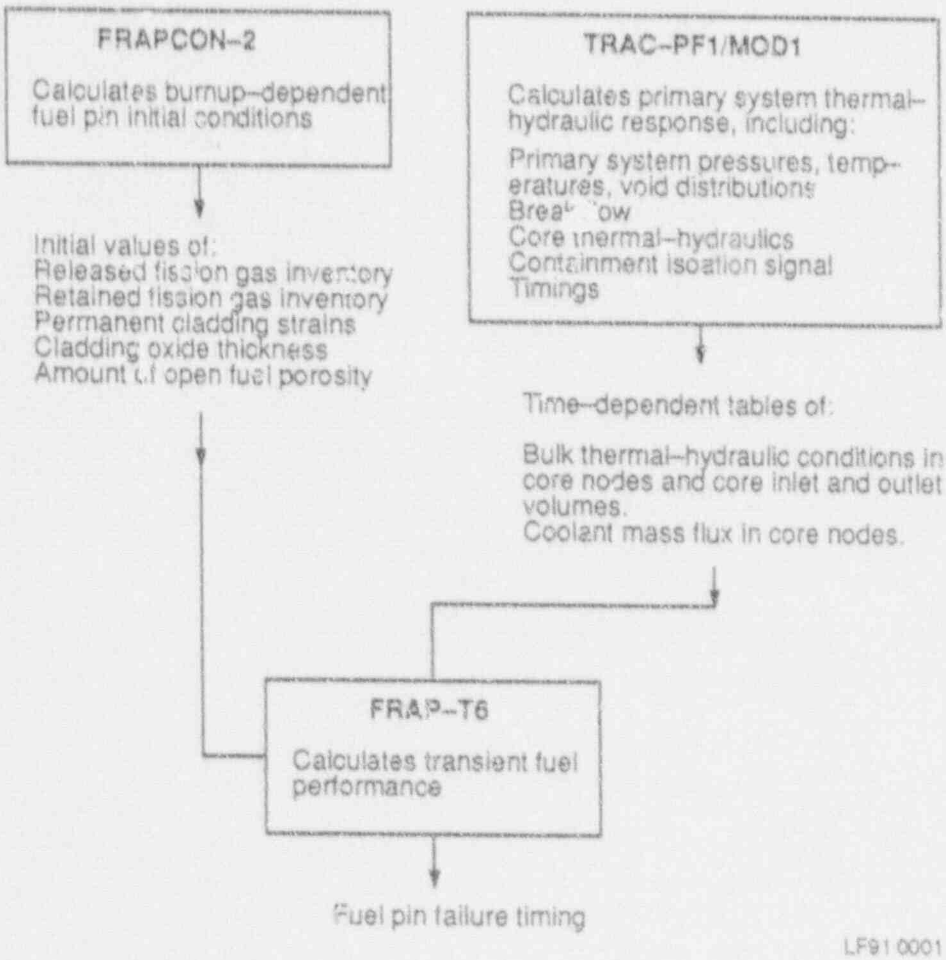

Figure 2. Flow chart of methodology using TRAC-PF1/MOD1 thermal-hydraulic data.

3. SOFTWARE DEVELOPMENT

A significant software development effort was conducted to implement the chosen methodology. This effort included conversion of the FRAPCON-2 and FRAP-T6 codes to FORTRAN 77 (F77), addition of advanced graphics capability to FRAP-T6, and the creation of interface codes to link the thermal-hydraulics codes to FRAP-T6.

FRAPCON-2 and FRAP-T6 were originally written in FORTRAN IV for use on CDC[a] Cyber 175 and 176 computers. At the onset of this project, these codes were no longer functional on the Idaho National Engineering Laboratory (INEL) Cyber computers because of changes in the operating system. As a part of this project, each of these codes was converted to portable F77 coding and ported to a DEC-5000 workstation.

These six conversions involved extensive modifications, that include the following:

1. Removal of the Cyber memory management routines; these routines were designed to allow large programs to execute on the Cyber computers but are not necessary under the UNIX operating system.

2. Replacement of common blocks with include file structures; conflicting common block declarations were resolved.

3. Conversion of source files to double-precision coding to maintain calculational accuracy on a 32-bit computer.

4. Replacement of non-F77 standard and Cyber system calls with standard F77 coding.

5. Replacement of water property calls to achieve compatibility with the current RELAP5/MOD3 environmental library routines.

6. Addition of a standardized job control language type interface to provide flexibility in file handle designations and to provide control over execution of the Nuclear Plant Analyzer (NPA)[15] graphics package described below.

The new code versions were designated FRAPCON-2, Version 01, Mod. 05, and FRAP-T6 V 21(12/90). A number of sample problems were executed to confirm proper code operation. Specific coding modifications and sample problem results are discussed in Appendix C.

Advanced graphics capabilities were also added to the FRAP-T6 code. These capabilities include interfacing to the NPA and the GRAFITI[16] graphics packages. The NPA software is an advanced interactive graphics package that provides an animated display of the fuel rod performance during program execution. The GRAFITI package provides a presentational graphics capability.

A FRAP-T6 input option allows the code to read the transient thermal-hydraulic boundary conditions from a binary data file.[7] An F77 program, [illegible]R5, was written to provide this passive l[illegible] between SCDAP/RELAP5 and FRAP-T6. In addition, another F77 program, TRAC2FRAP, was written to provide a passive link between TRAC-PF1 and FRAP-T6. These interface codes provide an automated method of extracting the hot channel thermal-hydraulic data needed for the FRAP-T6 calculations from the restart plot files generated by SCDAP/RELAP5 and TRAC-PF1. Appendix D provides a description of each of these codes, along with specific input requirements.

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a. Mention of specific products and/or manufacturers in this document implies neither endorsement or preference nor disapproval by the U.S. Government, any of its agencies, or EG&G Idaho, Inc., of the use of a specific product for any purpose.

4. THERMAL-HYDRAULIC MODEL DEVELOPMENT

Three thermal-hydraulic system models were used in this analysis to calculate the hot-channel thermal-hydraulic boundary conditions for FRAP-T6. These include SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 models of the Seabrook plant design and a SCDAP/RELAP5/MOD3 model of the Oconee plant design. Each of these models was adapted from previously existing plant models. This section describes the modifications performed to tailor these existing plant models to calculate LOCA hot channel thermal-hydraulic boundary conditions.

4.1 Oconee SCDAP/RELAP5/MOD3 Model Development

The SCDAP/RELAP5/MOD3 Oconee model used for this analysis was derived from a RELAP5/MOD2 model created for evaluation of operational safety at B&W plants.[12] Several modifications were required to produce the model used for this analysis. These include the addition of a detailed three-channel, nine-axial-node core model, describing the hot channel and the central and outer core regions with crossflow modeling between channels; point kinetics modeling; SCDAP modeling; a simplified containment model; and a split downcomer model. In addition, trip cards and control systems were added to calculate selected variables. These modifications are detailed in Appendix E. The detailed Oconee plant noding diagrams used for the analysis are illustrated in Figures 3 through 6.

The containment isolation setpoints monitored in this analysis were obtained from Oconee

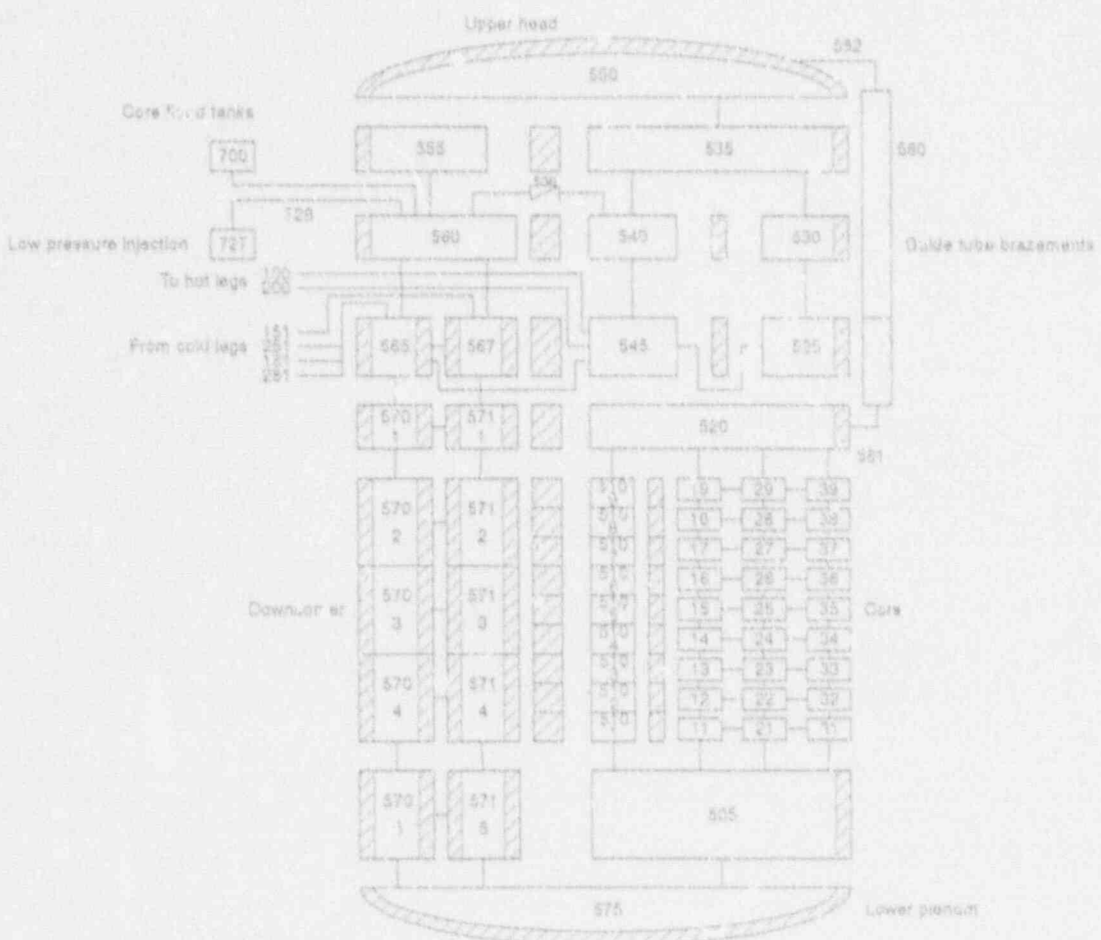

Figure 3. SCDAP/RELAP5/MOD3 nodalization diagram of the Oconee reactor.

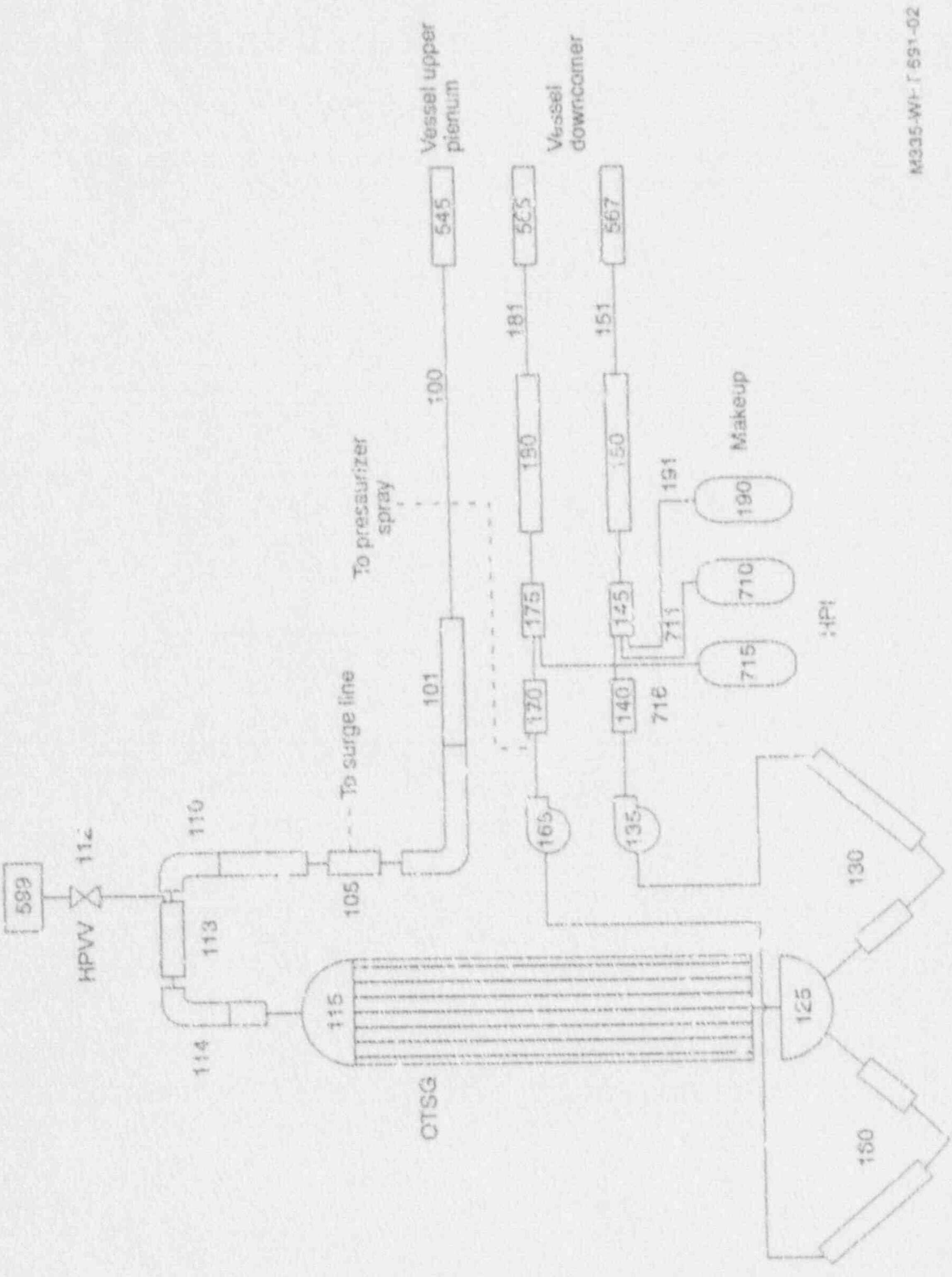

Figure 4. SCDAP/RELAP5/MOD3 nodalization diagram of the Oconee primary loop A.

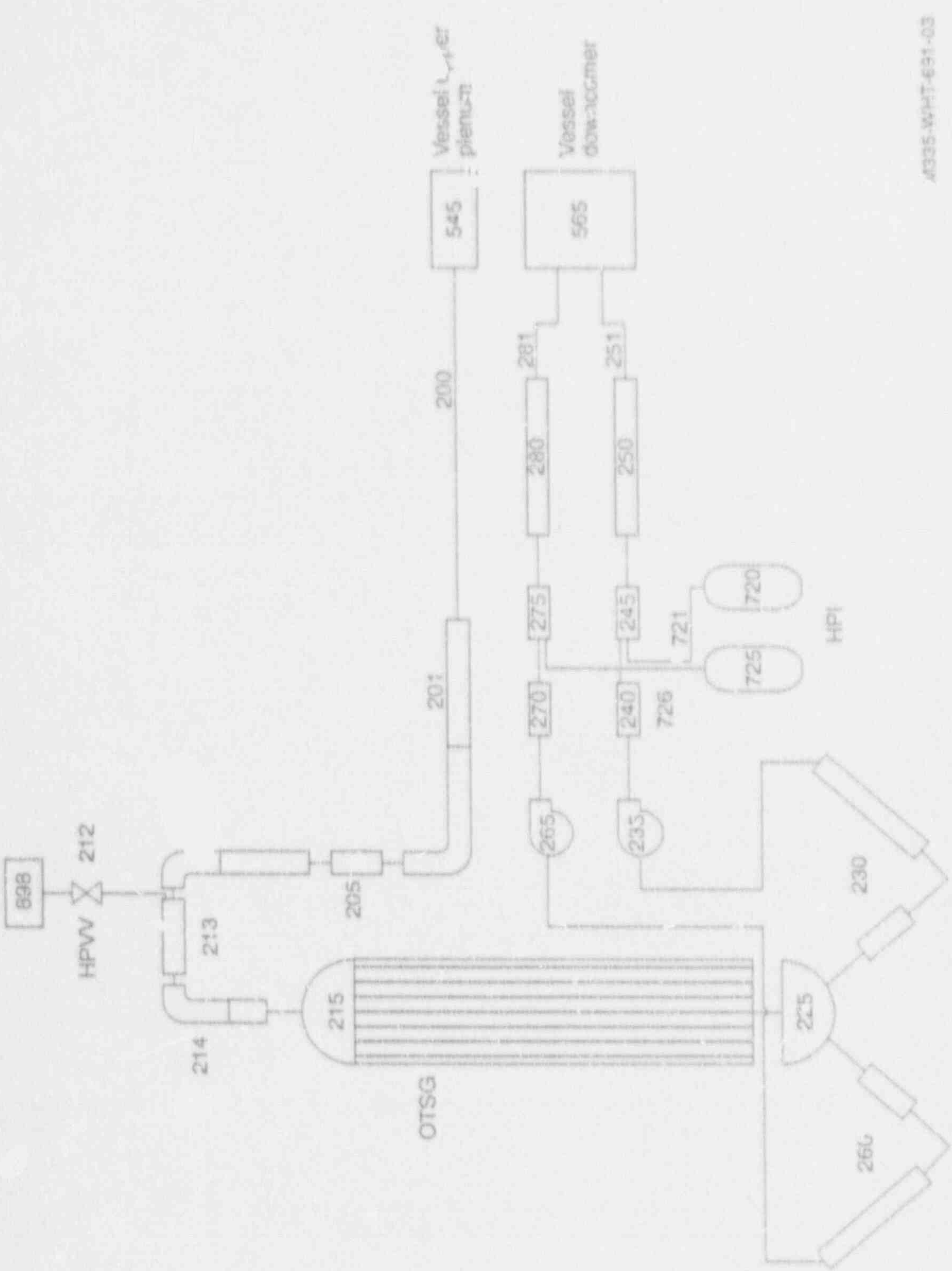

Figure 5. SCDAP/RELAP5/MOD3 nodalization diagram of the Oconee primary loop B.

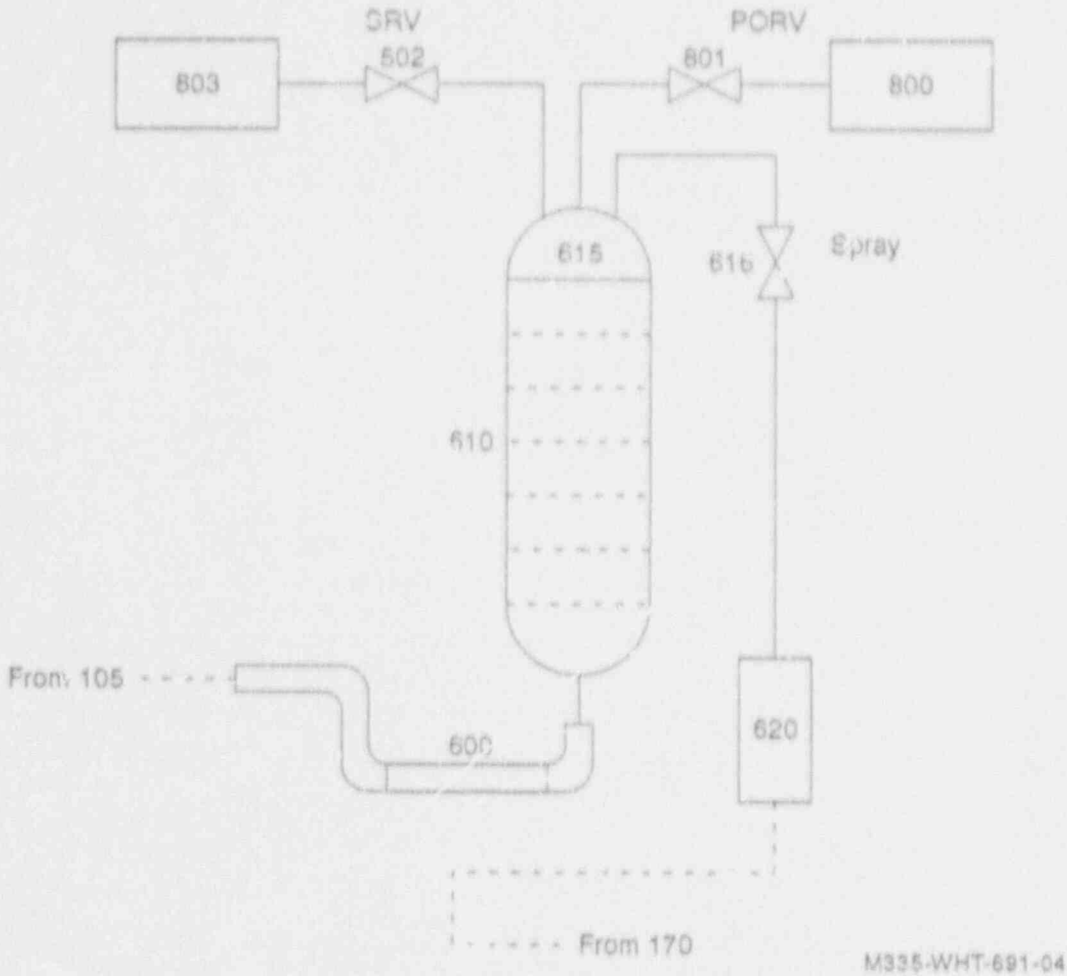

Figure 6. SCDAP/RELAP5/MOD3 nodalization diagram of the Oconee pressurizer.

Technical Specification 3.5.3[18] and are summarized in Table 1. A partial containment isolation, affecting nonessential systems, occurs when the reactor coolant system (RCS) pressure falls below 10.34 MPa (1500 psig). A full containment isolation occurs when a containment pressure of 0.028 MPa (4.0 psig) is reached.

A simplified containment model was used for the analyses, consisting of a single RELAP5 volume, with heat conductors representing steel and concrete structures. This approach provided a fairly rough estimate of containment response. A more detailed treatment of containment response would require the use of a containment analysis code; however, results for all of the large-break LOCA cases analyzed indicated that the containment isolation signal from the RCS low-pressure trip trails the signal received from high containment pressure by only 0.02–0.28 seconds. For the large-break cases, the RCS low-pressure trip time was used because of the approximate nature of the containment pressure calculation. For the small-break cases, the high containment pressure trip trails the low RCS pressure trip by several seconds, and the low RCS pressure trip time was used to determine the time of containment isolation.

A specific reference for Oconee instrument response delay times was not available for this analysis. For the purpose of this calculation, a delay time of 2.0 seconds was assumed, corresponding to the value used for the pressurizer pressure instrumentation in the Seabrook analysis.

The SCDAP/RELAP5/MOD3 calculations were performed assuming 102% core thermal

Table 1. Containment isolation trip setpoin for Oconee.

Trip	Trip setpoint (MPa/psig)	Action
Containment pressure high-1	0.028/4.0	• Safety injection (high and low pressure) • Containment cooling and isolation
Containment pressure high-2	0.034/5.0	• Containment spray
RCS pressure low	12.41/1800.0	• Reactor trip
RCS pressure low-low	10.34/1500.0	• Safety injection (high and low pressure)

power (CTP) and an equilibrium core. A detailed three-channel core model with nine axial nodes was utilized, with two fuel pins placed within the hot channel region. One fuel pin was assumed to be operating with a peak axial exposure of 5 GWd/MTU and the other with a peak axial exposure of 55 GWd/MTU, corresponding to the peak design burnup stated in the Oconee Final Safety Analysis Report[19] (FSAR). The fuel pin with a high exposure exhibits a higher internal pin pressure due to a larger amount of gaseous fission products.

Appendix B provides a detailed description of the calculation of the radial and axial core power distributions. The total power generated in the hot channel is governed by the maximum enthalpy rise hot channel factor allowed by the Oconee technical specifications.[18] The power distribution in the axial direction was defined by a chopped cosine profile peaked at the core midplane. The maximum linear heat generation rate was calculated using the heat flux hot channel factor obtained from the Oconee FSAR. This value was used for both the low and high-burnup fuel pins. This axial profile, in combination with the enthalpy rise hot channel factor, provides a bounding hot pin power distribution. Prompt power and decay heat were modeled using the SCDAP/RELAP5/MOD3 point kinetics model, with kinetics data obtained from the Oconee FSAR.

4.2 Seabrook SCDAP/RELAP5/MOD3 Model Development

The SCDAP/RELAP5/MOD3 Seabrook model used for this analysis was adapted from a RELAP5/MOD2 deck created for analysis of station blackout transients at the Seabrook nuclear power plant.[20] Several changes were required to produce the model used for this analysis. These changes were similar in nature to those made to the Oconee model and included addition of a detailed three-channel, nine-axial-node core model with a hot channel, point kinetics modeling, SCDAP modeling, a simplified containment model, a revised split downcomer model, and control systems to monitor key parameters. In addition, the model was converted to run under SCDAP/RELAP5/MOD3. Appendix E contains a detailed description of these modifications. Figure 7 contains the plant noding diagram used for the analysis and Figure 8 provides a more detailed view of the noding for the reactor core and vessel internals.

A simplified containment model similar to the approach used for the Oconee model, consisting of a single RELAP5 volume, with heat conductors

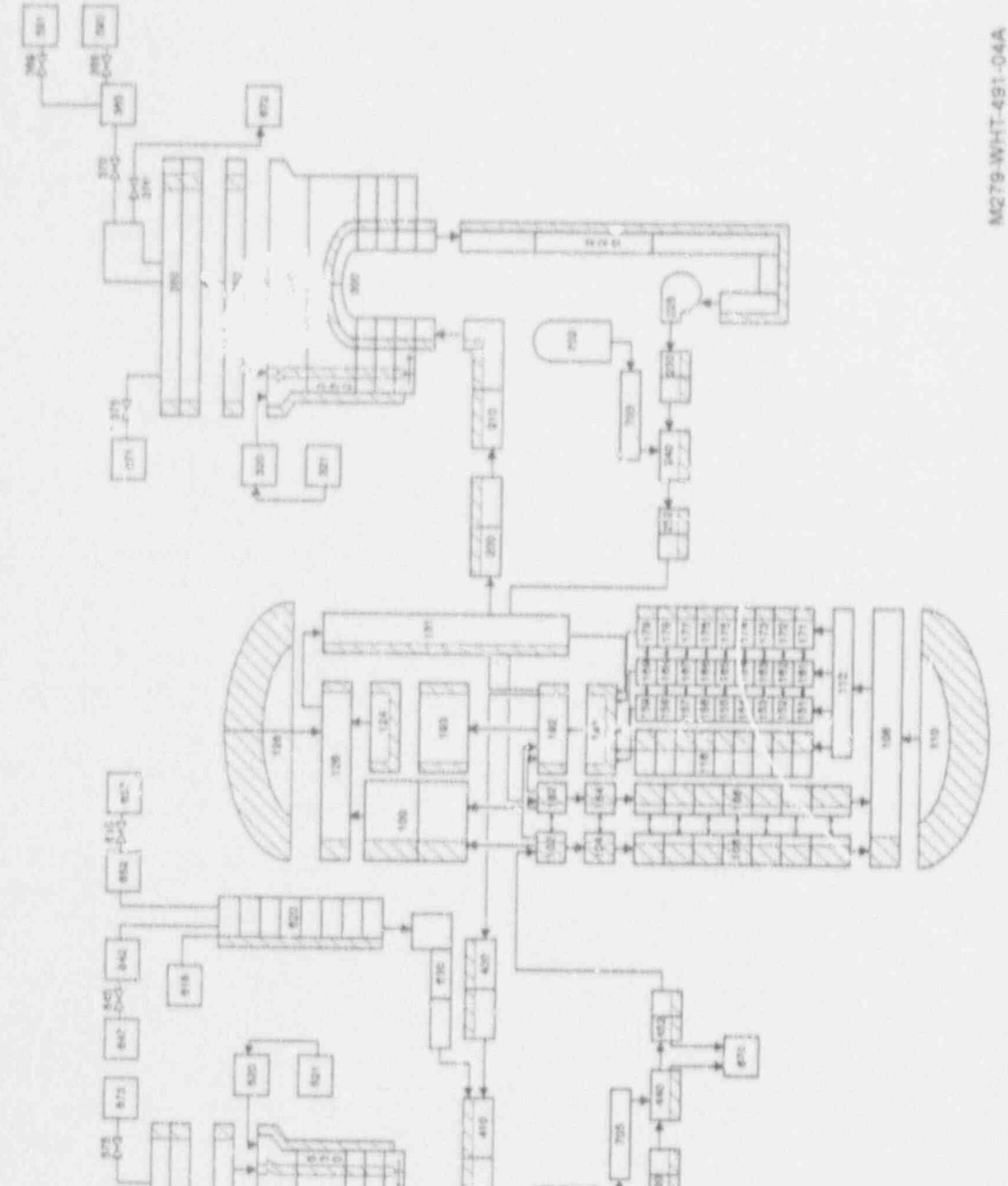

Figure 7. SCDAP/RELAP5/MOD3 nodalization diagram of the Seabrook plant.

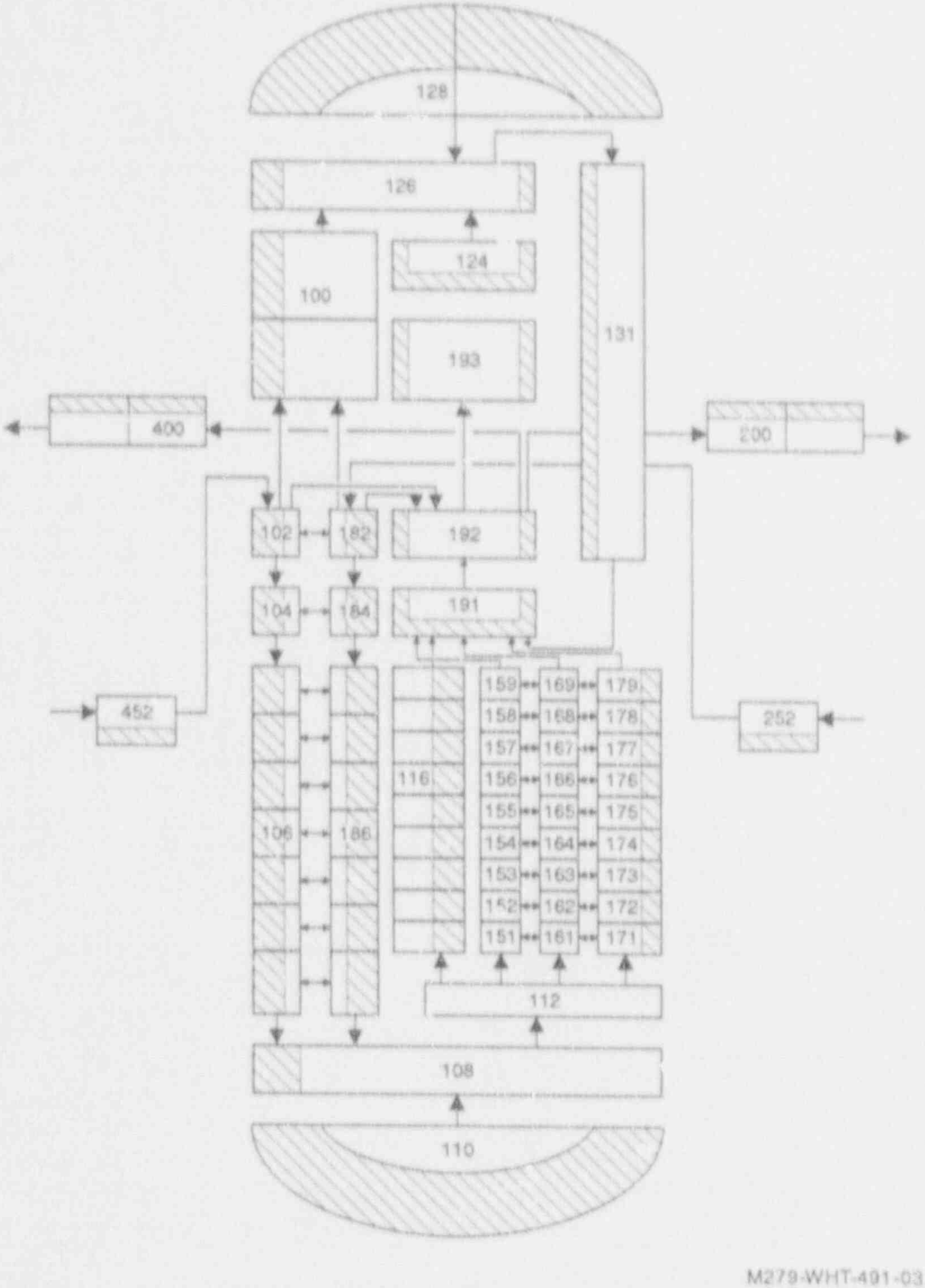

Figure 8. SCDAP/RELAP5/MOD3 nodalization diagram of the Seabrook reactor.

representing steel and concrete surfaces, provided a fairly rough estimate of containment response. A more detailed treatment of containment response would require the use of a containment analysis code; however, results indicate that the containment isolation signal from the pressurizer low pressure trip trails the signal received from high containment pressure (high-1 and high-2) by only about 3.0 seconds in each case. Because of the approximate nature of the containment pressure calculation, the pressurizer low-pressure trip time is used to determine the containment isolation signal timing. The containment isolation setpoints monitored for this analysis were derived from the Seabrook technical specifications and are summarized in Table 2. As previously mentioned, a two-second instrument delay was provided, based on the Seabrook pressurizer pressure instrumentation.

The SCDAP/RELAP5/MOD3 calculation was performed assuming a 102% core thermal power equilibrium core. A detailed three-channel core model with nine axial nodes was used, with two hot fuel pins placed in a center hot channel region. One pin is assumed to be operating with an axial peak exposure of 5 GWd/MTU and the other with an axial peak exposure of 50 GWd/MTU, corresponding to the peak design burnup stated in the Seabrook FSAR.[21] Both hot fuel pins are assumed to be operating at the technical specification power distribution limits. A higher internal pin pressure exists for the high-exposure fuel, because of an increase in fission product gasses.

Appendix G provides a detailed description of the calculation of the radial and axial core power distributions. The total power generated in the hot channel is governed by the technical specification enthalpy rise hot channel factor. The hot pin power distribution was defined by a chopped cosine axial power profile peaked at the core midplane to obtain the technical specification heat flux hot channel factor, with the total pin power based on the enthalpy rise hot channel factor. Prompt power and decay heat were modeled using the SCDAP/RELAP5/MOD3 point kinetics model with end-of-equilibrium-cycle kinetics data based on Seabrook FSAR data.

4.3 Seabrook TRAC-PF1/MOD1 Model Development

The Seabrook model used for this analysis was derived from a TRAC-PF1/MOD1 model used for the CSAU study.[14] Several modifications were required to produce the model used for this analysis. These included renodalization of the core region from five to nine axial nodes, describing the hot channel and the central and outer core region, removal of pumped ECCS, modification of the core power distribution, and replacement of containment pressure and decay heat boundary conditions. These modifications are documented in Appendix H.

Boundary conditions for containment pressure and total core power history were obtained from the corresponding SCDAP/RELAP5/MOD3 calculation. As stated in Section 4.2, because the approximate nature of the containment pressure calculation, the pressurizer low-pressure trip time is used to determine the containment isolation signal timing.

The calculation was performed assuming a 102% CTP equilibrium core. A detailed three-channel core model with nine axial nodes was used, identical to the SCDAP/RELAP5/MOD3 nodalization with the exception that the core bypass flow is lumped into the outer core region. Figures 9 through 11 show the Seabrook TRAC-PF1/MOD1 nodalization diagrams for this model.

The total power generated in the hot channel is governed by the technical specification enthalpy rise hot channel factor. The radial power distribution used in the TRAC-PF1/MOD1 analysis corresponds to that used in the corresponding SCDAP/RELAP5/MOD3 analysis; however, the TRAC-PF1/MOD1 model used one axial power distribution applied to the entire core. This limitation prevented setting the hot channel axial peak to the technical specification heat flux hot channel factor in the TRAC-PF1/MOD1 model. However, this effect is compensated for in the FRAP-T6 model, which applies a range of axial power shapes, including the limiting technical specification profile used in the previous analysis.

Table 2. Containment isolation trip setpoints for Seabrook.

Trip	Trip setpoint (MPa/psig)	Allowable value (MPa/psig)	Action
Containment pressure high-1	0.030/4.3	0.037/5.3	• Safety injection • Containment Phase A isolation
Containment pressure high-2	0.030/4.3	0.037/5.3	• Steam line isolation
Containment pressure high-3	0.124/18.0	0.129/18.7	• Containment Phase B isolation • Containment spray
Pressurizer pressure low	12.93/1875.0	12.69/1840.0	• Safety injection • Containment Phase A isolation

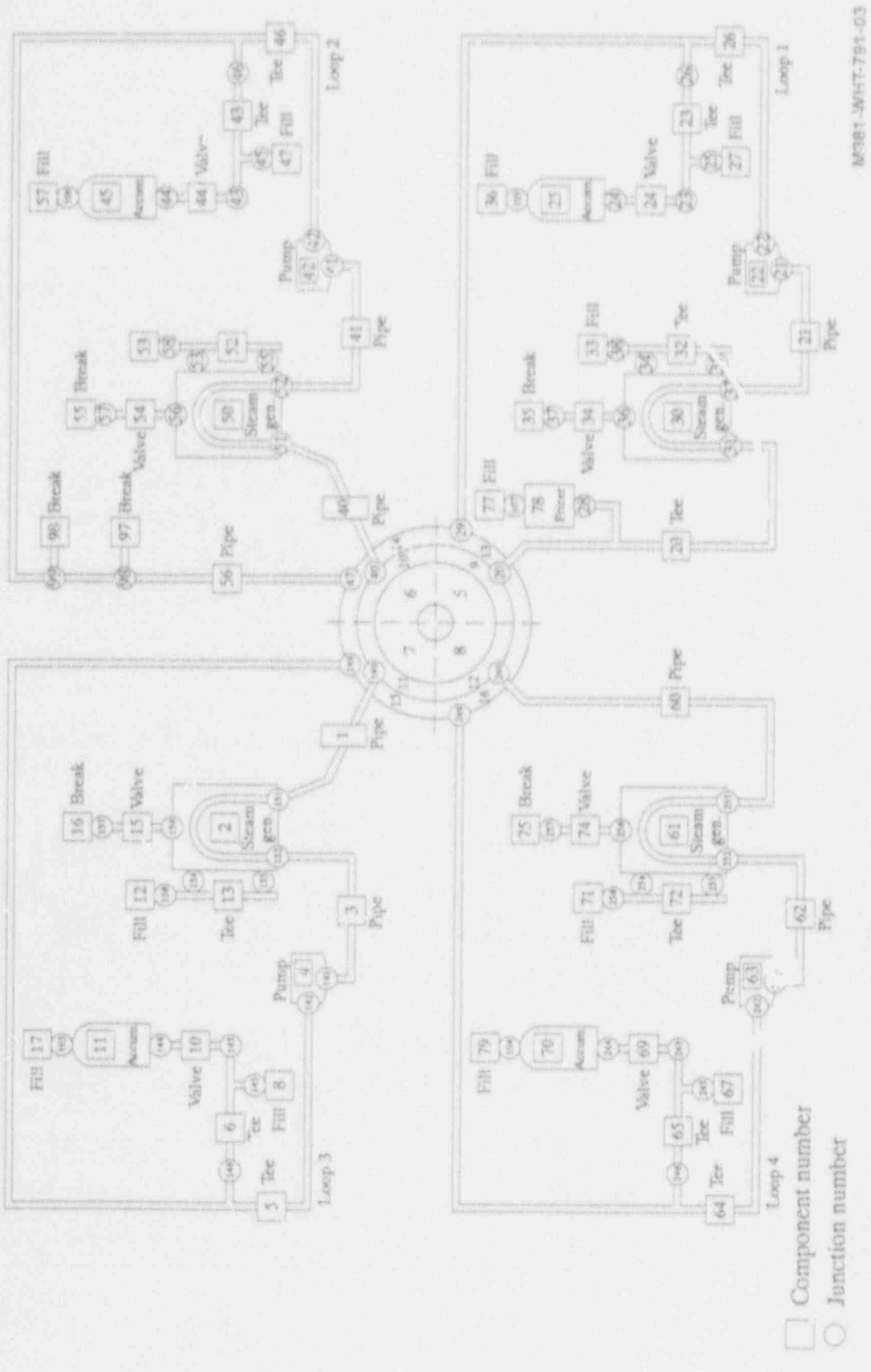

Figure 9. TRAC-PF1/MOD1 nodalization diagram of the Seabrook system model.

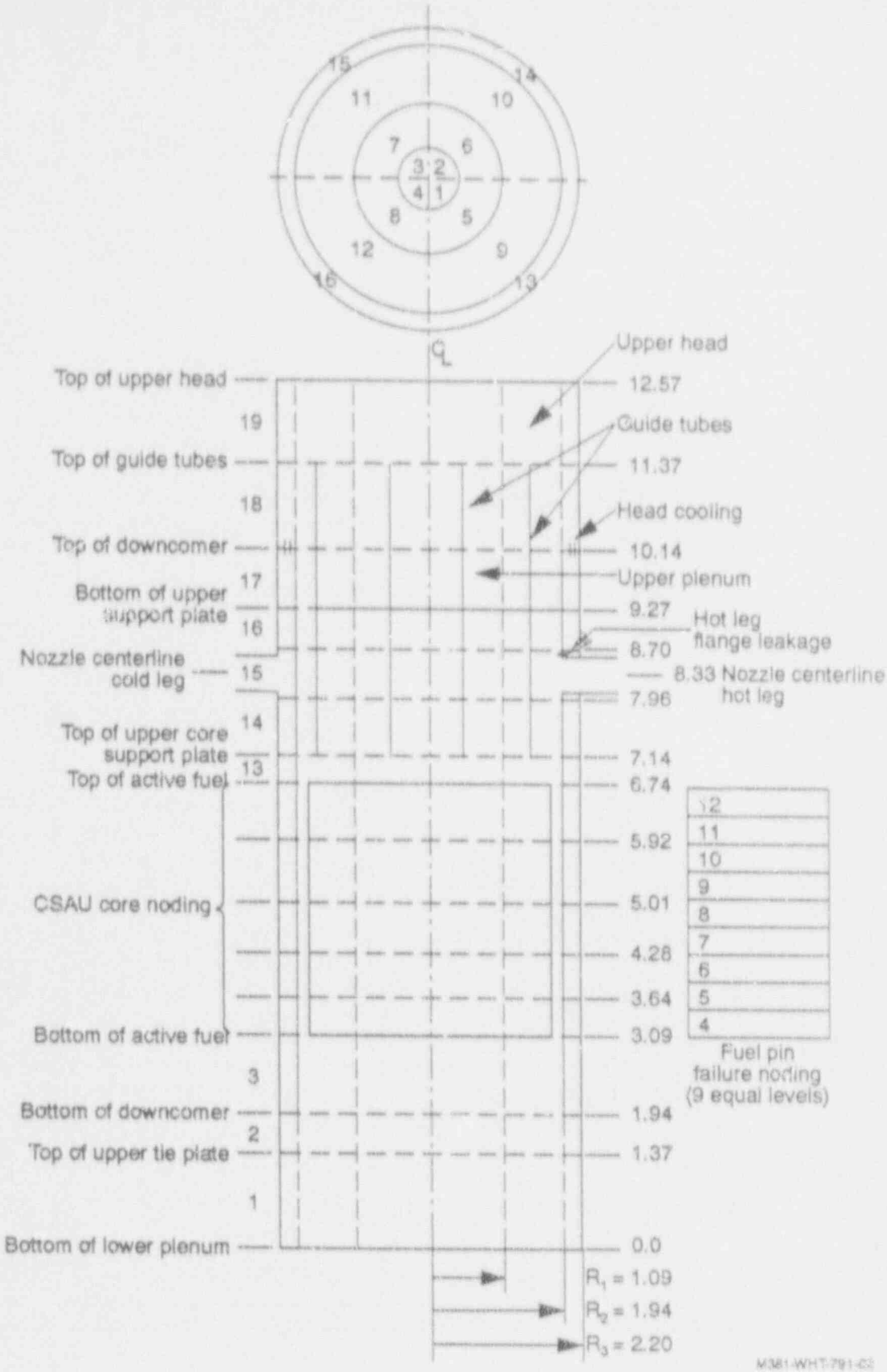

Figure 10. TRAC-PF1/MOD1 vessel axial nodalization for the Seabrook model.

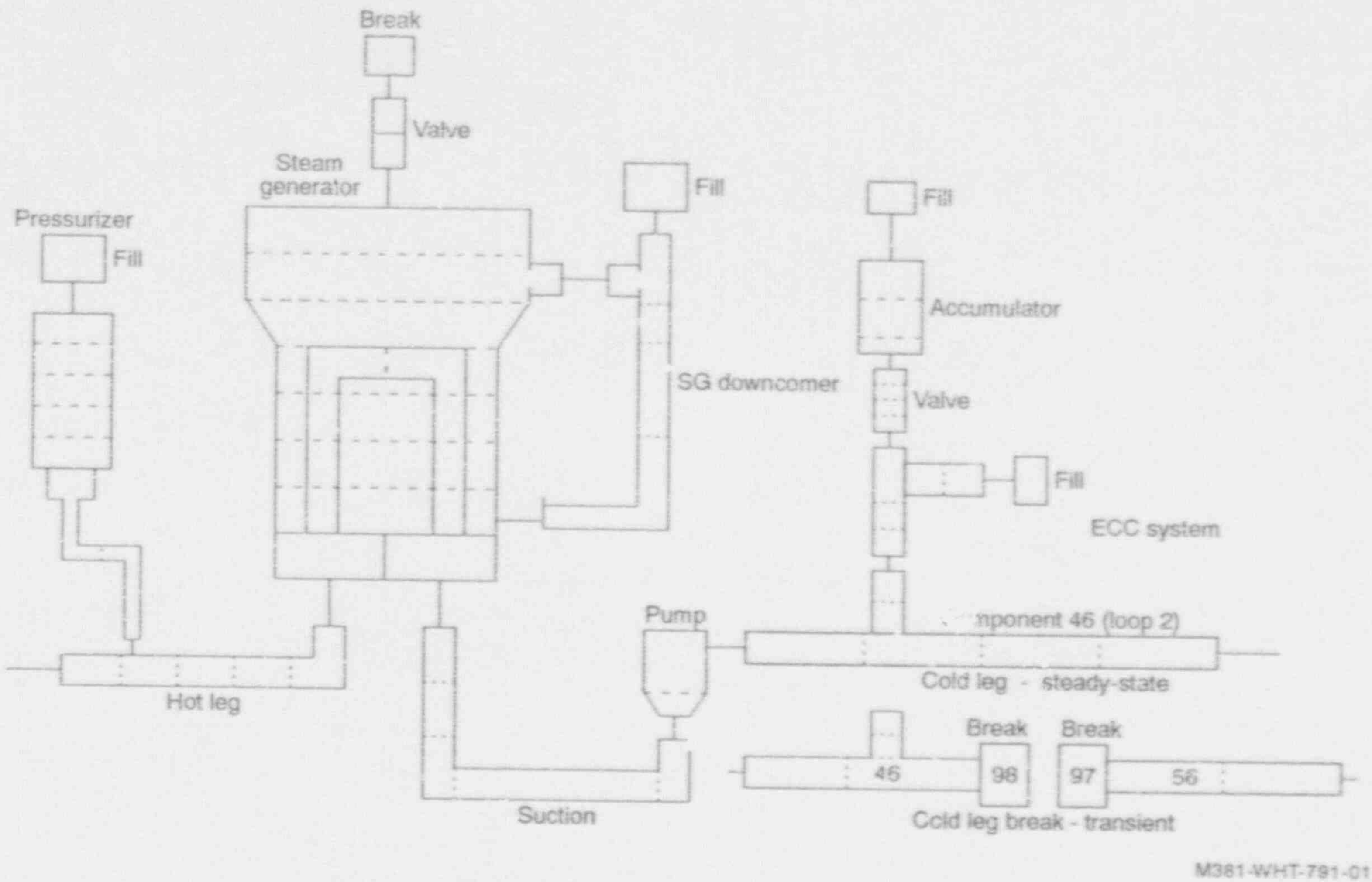

Figure 11. TRAC-PF1/MOD1 loop nodalization for the Seabrook model.

5. FUEL PERFORMANCE MODEL DEVELOPMENT

The FRAPCON-2, FRAP-T6, and SCDAP fuel rod models for both the Oconee and Seabrook reactors were developed specifically for this analysis. As discussed in Section 3, the FRAPCON-2 computer code was used to calculate the exposure-dependent parameters that were used to initialize the FRAP-T6 computer code. FRAP-T6 then calculated the transient response of a single fuel pin to the time-dependent thermal-hydraulic and power-history boundary conditions supplied by either SCDAP/RELAP5/ MOD3 or TRAC-PF1/MOD1. The SCDAP portion of SCDAP/RELAP5/MOD3 also produced a parallel calculation of the transient fuel pin response. However, because of the current lack of code assessment, the SCDAP calculation was used only to evaluate the capability of SCDAP/RELAP5/MOD3 to predict fuel pin behavior under LOCA conditions.

A single fuel pin design was modeled for each plant type analyzed. These fuel designs included the Mk-B9/10 design for the Oconee analysis and the W 17 × 17 standard fuel design for the Seabrook analysis. Specific data for these fuel rod models came from a variety of sources. Reactor-specific fuel data was obtained either from the fuel vendor or the appropriate FSAR.[19-21] The basic design parameters for each fuel type are summarized in Table 3.

5.1 FRAPCON-2 and FRAP-T6 Fuel Performance Model Development

The mechanical and fission gas release models and other code model options were chosen to best suit the analysis requirements based on descriptions and recommendations provided in code assessment documents.[10-13] Details of these model selections follow.

There are two mechanical models available in both FRAPCON-2 and FRAP-T6: FRACAS-I and FRACAS-II. FRACAS-I uses effective fuel conductivity and relocated fuel-cladding gap size for thermal calculations, but does not make use of the relocated fuel surface in the mechanics (deformation) calculations. FRACAS-II also uses effective fuel conductivity and relocated fuel-cladding gap size for thermal calculations, but does use the relocated fuel surface in the

Table 3. Summary of fuel design characteristics.

Characteristic	B&W Mk-B9/10	W 17 × 17 standard
Pin lattice	15 × 15	17 × 17
Fuel pins per assembly	208	264
Fuel pellet OD (m/in.)	9.398E-3/0.370	8.192E-3/0.3225
Cladding ID (m/in.)	9.576E-3/0.377	8.357E-3/0.329
Cladding OD (m/in.)	1.0922E-2/0.430	9.500E-3/0.374
Plenum length (m/in.)	2.1321E-2/8.394	1.6457E-1/6.479
Initial fuel stack height (m/in.)	3.571/140.595	3.6576/144.0
Maximum fuel enrichment (wt% ^{235}U)	3.5	3.1

mechanics calculations. The FRACAS-II mechanical model was chosen for the FRAPCON-2 models; however, the FRACAS-I mechanical model was chosen for the FRAP-T6 model, since FRACAS-I is the only available mechanical model linked to the BALON2 (ballooning) subcode. BALON2 calculates the extent and shape of localized cladding deformation that occurs between the time that the cladding effective strain exceeds the instability strain and the time of cladding rupture.

FASTGRASS, a highly mechanistic gas release model that accounts for bubble formation, migration, coalescence, channeling, and eventual release, was used in both the FRAPCON-2 and FRAP-T6 fuel models. This model is the only gas release model available in FRAP-T6. FASTGRASS is a suitable gas release model for high temperatures and burnups.

Other model options in FRAP-T6 were also chosen to best suit the analysis requirements. The Baker-Just metal-water reaction model was chosen instead of the Cathcart model because it is applicable for temperatures <1240 K. The Dougall-Rohsenow film boiling correlation was chosen because it most closely matches the film boiling correlations used in generating the thermal-hydraulic boundary condition data. The default critical heat flux correlation (W-3) was used; the W-3 correlation is combined with either the Hsu-Beckner, or modified Zuber correlation for certain coolant conditions.

The fuel failure probability threshold in FRAP-T6 was chosen to be 0.5, as recommended in Reference 13. A calculated probability of 0.5 reflects the conditions when rupture is observed in 50% of the rods in an experimental data base. When the computed probability for fuel failure is >0.5, the fuel rod is supposedly failed and internal pressure is set equal to the coolant pressure.

In addition to analyses performed using the best-estimate models described above, one series of FRAP-T6 runs was made for each fuel type for the worst-case accident scenario (100% DBA), using licensing audit code (LAC) model options. The available LAC model options are for cladding axial and diametral thermal expansion; cladding specific heat, elastic modulus, and thermal conductivity; fuel specific heat, elastic modulus, emissivity, Poisson ratio, thermal conductivity, and thermal expansion; cladding plastic hoop strain; cladding surface heat transfer coefficient; gas thermal conductivity; metal-water reaction; fuel deformation; and gap conductance.

In FRAPCON-2 and FRAP-T6, four fuel pins were modeled for each reactor, corresponding to the hot channel hot pin, the hot channel average pin, the middle ring average pin, and the outer ring average pin. The FRAPCON-2 hot channel hot pin models were used to provide steady-state initialization of burnup-dependent variables for FRAP-T6 at specific fuel burnups and varied peaking factors. The FRAP-T6 hot channel hot pin models were used to determine time to pin failure for the various LOCA cases as a function of burnup and peaking factor. All of the FRAPCON-2 and FRAP-T6 fuel rod models were also used to provide initializing data for SCDAP/RELAP5/MOD3 fuel components. Appendices I and J provide a more detailed description of the FRAPCON-2 and FRAP-T6 fuel pin models.

The axial power profiles for FRAPCON-2 and FRAP-T6 were calculated for a range of axial peaking factors using the basic assumptions and methodology described in Appendices F and G. Nine axial nodes were used in FRAPCON-2 and FRAP-T6, as well as each of the thermal-hydraulic system codes. A chopped cosine axial power profile, peaked to the core midplane, was assumed for the analysis. For each hot fuel pin modeled, the total power integrated over the length of the fuel was based on the technical specification enthalpy rise hot channel factor.

As recommended in Reference 5, 14 radial nodes were used in the FRAPCON-2, FRAP-T6, and SCDAP models, with 11 nodes in the fuel pellet and 3 nodes in the cladding region. However, the radial nodalization is not identical among the codes, since the FRAPCON-2 nodalization was based on uniform cross-sectional areas, while the FRAP-T6 and SCDAP nodalizations were based on uniform spacing of nodes through the fuel pellet region. In each case, a normalized radial power profile was assumed, based on a cross-section-weighted distribution peaked from 0.98 at the fuel pellet centerline to 1.02 at the fuel pellet edge to account for self-shielding.

To generate FRAPCON-2 data at the specific burnups required for this analysis, the linear heat generation rate was ramped to the peak power and then held constant. The time array was extended to provide output data beyond the maximum burnup required and then refined to give data at specific axial peak burnup levels (5, 20, 35, and 50 GWd/MTU for Seabrook; 5, 20, 35, and 55 GWd/MTU for Oconee). The data files written for FRAP-T6 at the time steps corresponding to these burnups were then used as input to FRAP-T6. These data files contained initializing values for released and retained fission gas inventory, permanent cladding strains, permanent fuel strains, cladding oxide thickness, and amount of open fuel porosity.

For each steady-state or LOCA case considered, data files generated by either SCDAP/RELAP5/MOD3 or TRAC-PF1/MOD1 were used to provide the thermal-hydraulic boundary conditions for FRAP-T6; i.e., coolant pressure, enthalpy, temperature, and mass flux. Case-specific FRAP-T6 power curves were derived by normalizing SCDAP/RELAP5/MOD3 or TRAC-PF1/MOD1 reactor power data.

5.2 SCDAP Fuel Performance Model Development

A total of eight SCDAP components, representing fuel rods and guide tubes, were modeled in the SCDAP/RELAP5/MOD3 input decks for each plant. The assemblies of the outer and middle core regions were each represented by a guide tube and a fuel rod component model. The hot channel assemblies included a guide tube component model and three fuel rod component models. The hot channel fuel rod models consisted of a low-burnup fuel rod, a high-burnup fuel rod, and an average hot channel fuel rod.

Two different fuel bundle matrices, corresponding to current reactor fuel bundle designs, were modeled by SCDAP fuel components. For Oconee, a 15 × 15 bundle matrix, containing 208 fuel pins and 17 instrument/control rod guide tubes, was modeled in SCDAP. For Seabrook, a 17 × 17 bundle matrix, containing 264 fuel pins and 25 instrument/control rod guide tubes, was modeled. The fuel rod nodalization consisted of nine axial and 14 radial nodes corresponding to that used in the FRAP-T6 models. The modeling assumptions used in the SCDAP modeling were patterned after that of FRAP-T6. Since the results generated by this analysis are dependent on the specific fuel design parameters used, such as initial helium fill inventory, fuel pellet dimensions, cladding dimensions, and plenum volume, departure from these fuel designs may lead to significantly different results.

SCDAP/RELAP5/MOD3 cladding deformation and failure calculations are based on a localized ballooning model, as adapted from the BALON2 model of FRAP-T6. This model is intended for analysis of cladding deformation during rapid blowdown transients, such as LOCAs. The pin failure model does not take into account any constraints imposed by the spacer grids on cladding deformation; however, increased radiative and conductive heat transfer at the spacer grid locations may reduce the likelihood of failure at these locations.

Preliminary comparisons of stored energy calculated by SCDAP and FRAP-T6 during the Seabrook calculation indicated poor agreement. As a result, modifications were made to SCDAP to allow modeling of the thermal resistance across the gap region and adjustment of the initial stored energy to match results generated by FRAP-T6. The initial gap conductances generated by steady-state FRAP-T6 runs are directly input to SCDAP. Figures 12 and 13 illustrate the excellent agreement obtained between the Oconee SCDAP and FRAP-T6 models following implementation of these modifications. In addition, the initial steady-state fuel pin internal pressures for SCDAP were defined to match the steady-state values calculated by FRAP-T6. This definition of internal pin pressure involved an iterative approach, changing the initial helium fill gas inventory input for each SCDAP fuel pin component until the fuel pin pressures closely matched those of FRAP-T6.

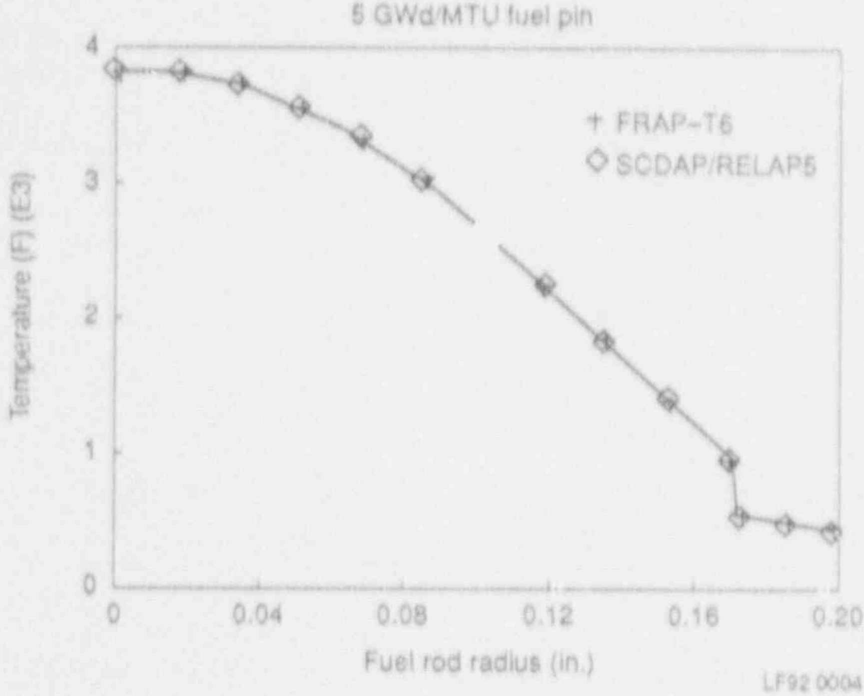

Figure 12. Steady-state radial temperature profile for the Oconee 5-GWD/MTU fuel pin at the core midplane.

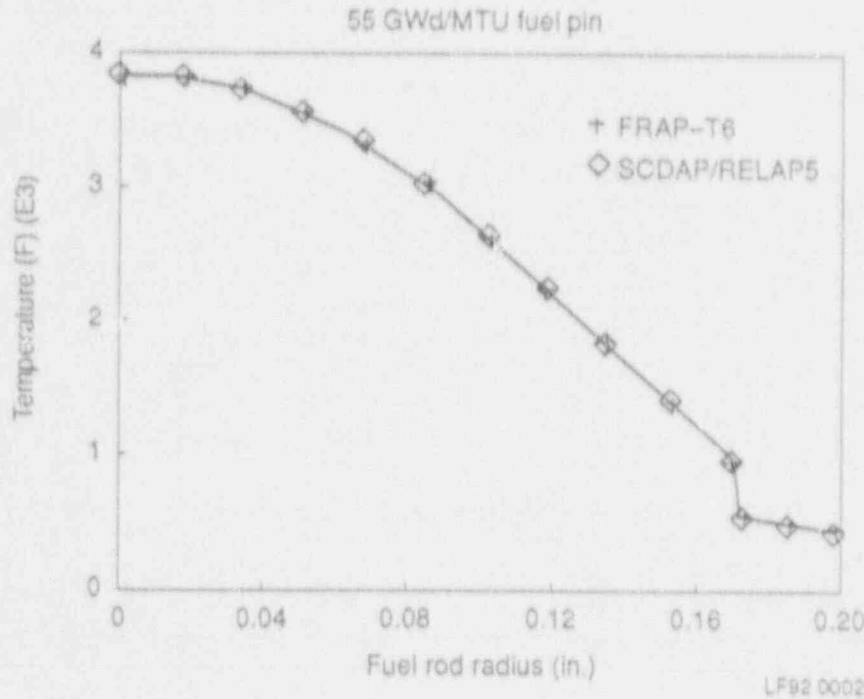

Figure 13. Steady-state radial temperature profile for the Oconee 55-GWD/MTU fuel pin at the core midplane.

6. SENSITIVITY STUDIES

The methodology employing SCDAP/RELAP5/MOD3 was used to determine the sensitivity of fuel pin failure timing to break size, pumped ECCS, and RCS pump trip. An initial sensitivity study was performed for each reactor to identify the break size resulting in the shortest time to pin failure. The large-break spectrum analyzed consisted of double-ended, offset-shear breaks of a cold leg, with break sizes corresponding to 100, 90, 75, and 50% of the full design basis analysis (DBA) cold leg break area (200% of the cold-leg cross-sectional area). The breaks were located in a cold leg close to the reactor vessel. The break modeling consisted of restarting a steady-state calculation with a percentage of the flow area from each side of a cold leg junction redirected into the containment volume. The abrupt area change junction control flag was turned on for each break junction. In addition, a 6 in. dia., small-break LOCA was modeled by a trip valve located between the cold leg and the containment at the same location used for the large-break case.

The large-break spectrum and the small-break case were run without any pumped ECCS available. The accumulators were assumed to be available for all cases. The 100% DBA large-break case was identified as the worst case, i.e., the case resulting in the shortest time to pin failure. The 100% DBA and the small-break cases were repeated with pumped ECCS available to determine its impact on pin failure timing.

The base analysis did not assume a concurrent loss of offsite power. As a result, the RCS pumps are assumed to continue operation throughout the transient. Sensitivity cases were run using the worst-case break size, both with and without pumped ECCS, to determine the impact of tripping the RCS pumps at time zero.

For each large-break SCDAP/RELAP5/MOD3 calculation, a matrix of 16 FRAP-T6 cases was executed. These cases correspond to four axial peak burnups and four peaking factors, using the best-estimate model options of FRAP-T6. For Oconee, the peaking factors chosen were 2.0, 2.2, 2.4, and 2.63; the burnups were 5, 20, 35, and 55 GWd/MTU. For Seabrook, peaking factors were 1.8, 2.0, 2.2, and 2.32; axial peak burnups were 5, 20, 35, and 50 GWd/MTU. A fundamental assumption governing this methodology is that the hot channel thermal-hydraulic conditions generated by SCDAP/RELAP5/MOD3 do not vary significantly for changes in hot pin axial power profile. In each case, the total fuel pin power, integrated over the length of the pin, is governed by the enthalpy rise hot channel factor and is therefore independent of the axial peaking factor applied.

For each small-break SCDAP/RELAP5/MOD3 calculation, a preliminary matrix of four FRAP-T6 cases was executed. These cases correspond to the highest peaking factor at four burnups for each reactor, also using the best-estimate model options of FRAP-T6. Since no fuel pin failure was observed prior to five minutes in all cases, no additional FRAP-T6 cases were run.

FRAP-T6 is a best-estimate code; however, a set of evaluation models, including the NUREG-0630[22] ballooning model, are available as options that can satisfy most criteria specified in 10 CFR 50, Appendix K.[23] The evaluation models include the areas of mechanical deformation and rupture, thermal-hydraulic boundary conditions, initial conditions, and material properties of fuel and cladding. The 16-case FRAP-T6 matrix was repeated for the worst-case break size (100% DBA) using the evaluation model options.

In addition to the cases described above, all of which were run using SCDAP/RELAP5/MOD3 thermal-hydraulic boundary conditions, the 16-case FRAP-T6 matrix for the worst-case break size (100% DBA) for the Seabrook reactor without pumped ECCS and without RCS pump trip was run using thermal-hydraulic boundary conditions provided by TRAC-PF1/MOD1.

7. RESULTS

The results of the timing analysis of PWR fuel pin failures are presented below. Section 7.1 describes the accident scenarios considered and the results obtained using SCDAP/RELAP5/MOD3. Section 7.2 describes the results obtained using TRAC-PF1/MOD1. Section 7.3 provides a discussion of the uncertainty associated with these calculations. Plots of significant variables for each Oconee case are contained in Appendix K, which includes both SCDAP/RELAP5/ MOD3 and FRAP-T6 results. The corresponding plots for the Seabrook analysis are contained in Appendix L, which includes SCDAP/RELAP5/ MOD3, FRAP-T6, and TRAC-PF1/MOD1 results.

7.1 Results Generated Using SCDAP/RELAP5/MOD3

For each plant, seven large-break, double-ended, offset-shear LOCA cases and two 6 in. dia., small-break LOCA cases were run using SCDAP/RELAP5/MOD3. The hot channel thermal-hydraulic conditions generated by these runs were used to provide boundary conditions for FRAP-T6, which was used to calculate fuel pin failure times for a matrix of fuel pin exposures and peaking factors. Details of these calculations are given in the following sections.

7.1.1 SCDAP/RELAP5/MOD3 Calculations. The case parameters and SCDAP/RELAP5/MOD3 timing results for Oconee and Seabrook are summarized in Table 4 for each set of nine cases, respectively. The first four cases for each plant consisted of large-break LOCAs under the base conditions, i.e., without pumped ECCS and main coolant pump trip, and run for a range of break sizes from 200 to 100% of the cold-leg cross-sectional area. Cases 5, 7, and 8 consisted of different combinations of pumped ECCS availability and main coolant pump trip at time zero. Cases 6 and 9 consisted of 6-in.-dia., small-break LOCAs analyzed with and without pumped ECCS, respectively.

Figures 14 through 26 show SCDAP/RELAP5/MOD3 results for the double-ended, offset-shear cold-leg break (Case 1) for Oconee. Table K-1 in Appendix K provides a detailed listing of the SCDAP/RELAP5/MOD3 output identifiers shown in the figures. This case illustrates the general trends observed in each of the large-break LOCA cases.

Table 4. SCDAP/RELAP5/MOD3 results (in seconds) for Oconee and Seabrook.

Case	1	2	3	4	5	6	7	8	9
Break size[a]	100%	90%	75%	50%	100%	6 in.	100%	100%	6 in.
Pumped ECCS	No	No	No	No	No	No	Yes	Yes	Yes
Pump trip	No	No	No	No	Yes	No	No	Yes	No
For Oconee:									
Containment pressure high ≥4 psig[b,c]	0.53	0.55	0.56	0.68	0.52	13.07	0.53	0.53	13.01
Low reactor coolant pressure[b,d] ≤1500 psig	0.59	0.60	0.63	0.96	0.55	8.33	0.59	0.56	8.33

Table 4. (continued).

Low reactor coolant pressure[b],[e] ≤1800 psig	0.05	0.05	0.05	0.05	0.05	0.87	0.05	0.05	0.87
High burnup 55 GWd/MTU pin fails[f]	15.0	15.8	18.3	>60.0	10.3	>393.	14.7	10.3	>60.0
Low burnup 5 GWd/MTU pin fails[f]	22.7	23.5	>60.0	>60.0	22.8	>393.	22.0	22.4	>60.0
For Seabrook:									
Containment pressure hi-1, hi-2[b]	0.77	0.77	0.78	0.94	0.77	17.42	0.77	0.77	17.44
Containment pressure hi-3[b]	5.01	5.18	5.41	5.39	5.10	>60.0	5.02	5.10	>60.0
Pressurizer low-pressure[b]	3.73	3.73	3.73	3.73	3.73	7.13	3.73	3.73	7.13
High burnup, 50 GWd/MTU pin fails[f]	41.70	40.75	>60.0	>60.0	29.65	>600.	38.85	31.45	>60.0
Low burnup, 5 GWd/MTU pin fails[f]	43.40	40.75	>60.0	>60.0	29.95	>600.	39.15	30.60	>60.0

a. For large-break cases, break size is given as a percentage of the design basis, double-ended, offset shear break; i.e., 100% DBA corresponds to a total flow area of 200% of the cold leg cross section. (Cases 6 and 9 are small-break LOCAs with a break diameter of 6 in.)

b. Signal time corresponds to the time at which this parameter exceeds the technical specification allowable value and does not include the instrument response time.

c. At 0.028 MPa (4 psig), the Oconee reactor building isolation is actuated.

d. At 10.34 MPa (1500 psig), the high-pressure injection and reactor building isolation are actuated.

e. At 12.41 MPa (1800 psig), the Oconee reactor is tripped on low RCS pressure.

f. The fuel pin failure times generated by SCDAP are not identical with those generated by FRAP-T6 and should not be referenced. FRAP-T6 results are documented in Appendix J.

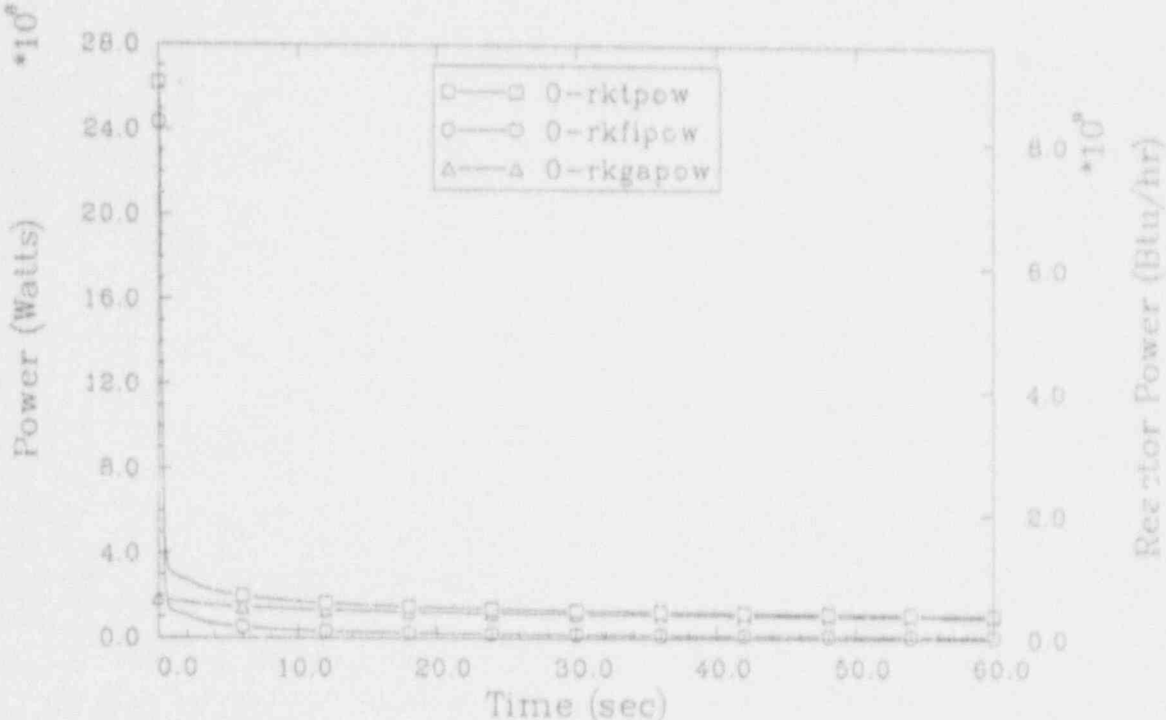

Figure 14. SCDAP/RELAP5/MOD3-calculated core thermal power for the Oconee 100% DBA case.

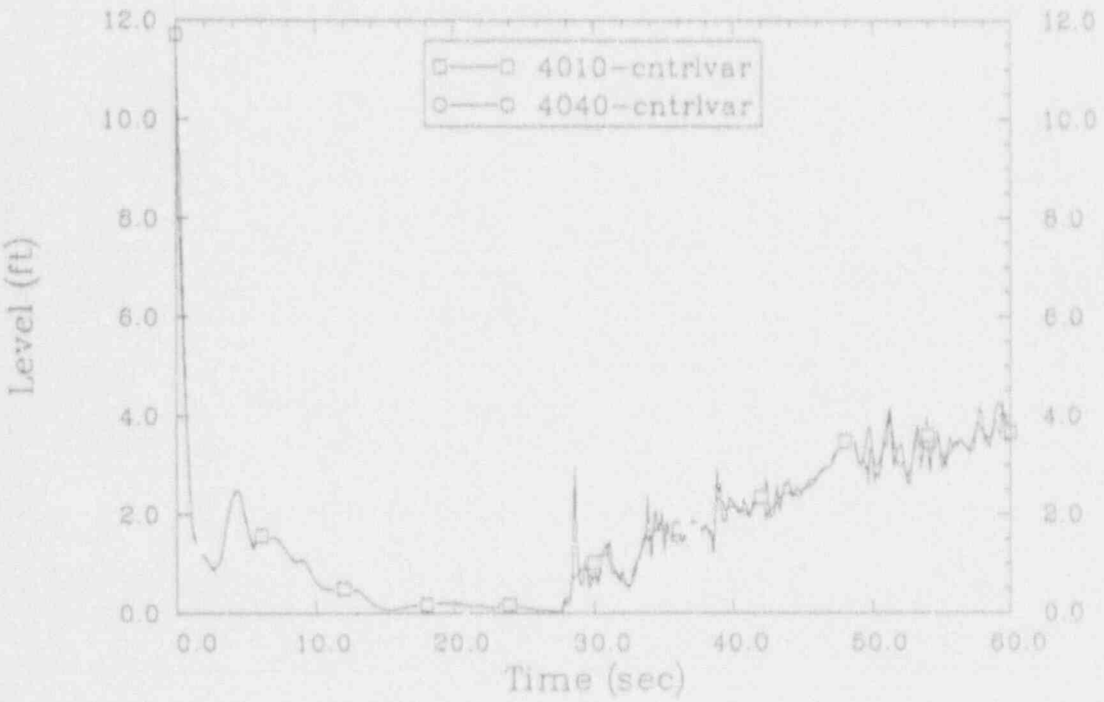

Figure 15. SCDAP/RELAP5/MOD3-calculated collapsed reactor water level for the Oconee 100% DBA case.

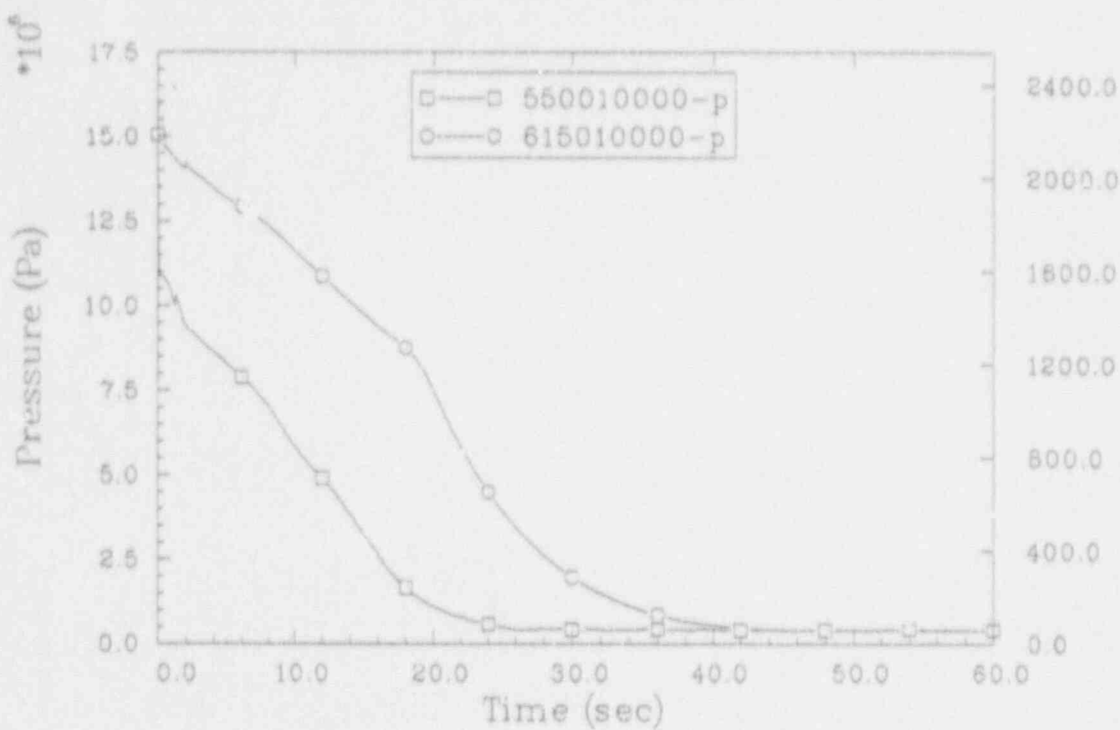

Figure 16. SCDAP/RELAP5/MOD3-calculated reactor upper head and pressurizer pressure for the Oconee 100% DBA case.

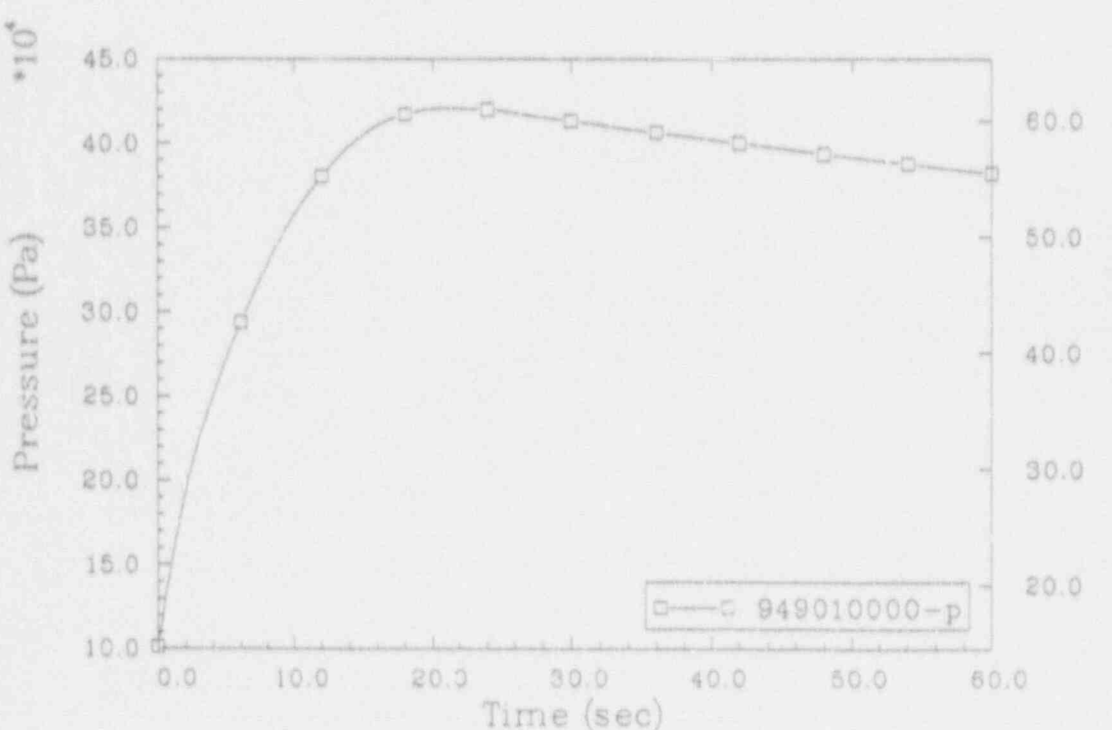

Figure 17. SCDAP/RELAP5/MOD3-calculated containment pressure for the Oconee 100% DBA case.

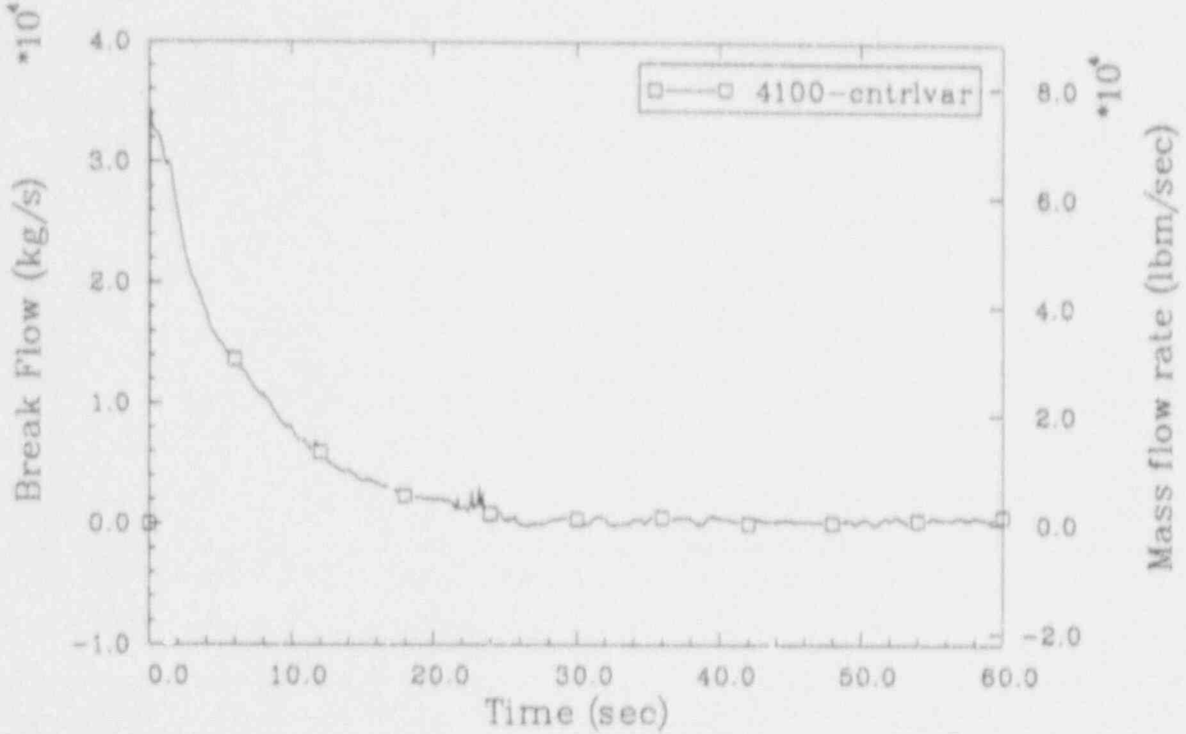

Figure 18. SCDAP/RELAP5/MOD3-calculated total break flow for the Oconee 100% DBA case.

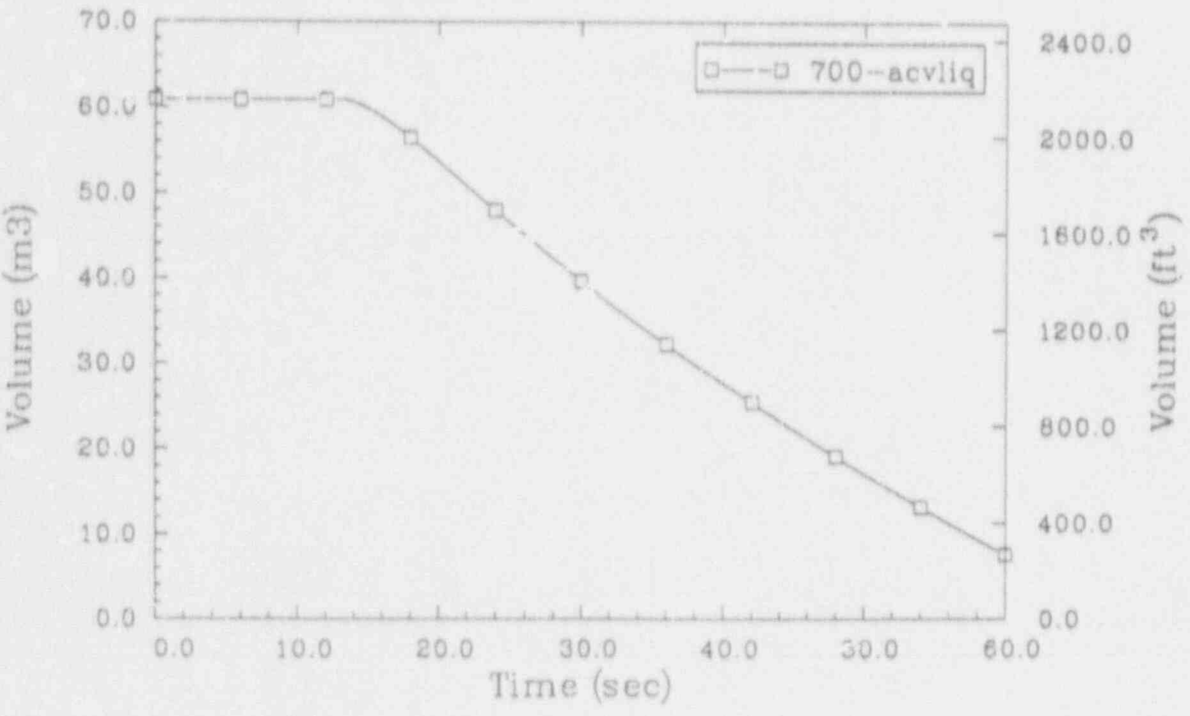

Figure 19. SCDAP/RELAP5/MOD3-calculated accumulator liquid volume for the Oconee 100% DBA case.

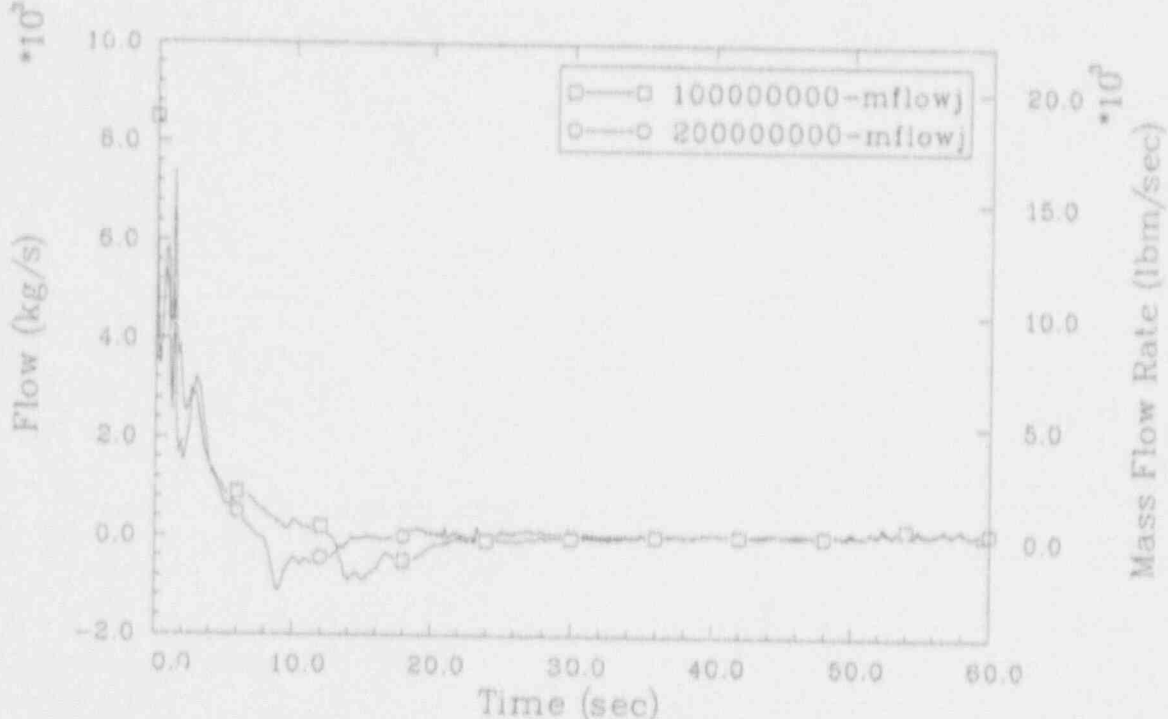

Figure 20. SCDAP/RELAP5/MOD3-calculated hot-leg flow for the Oconee 100% DBA case.

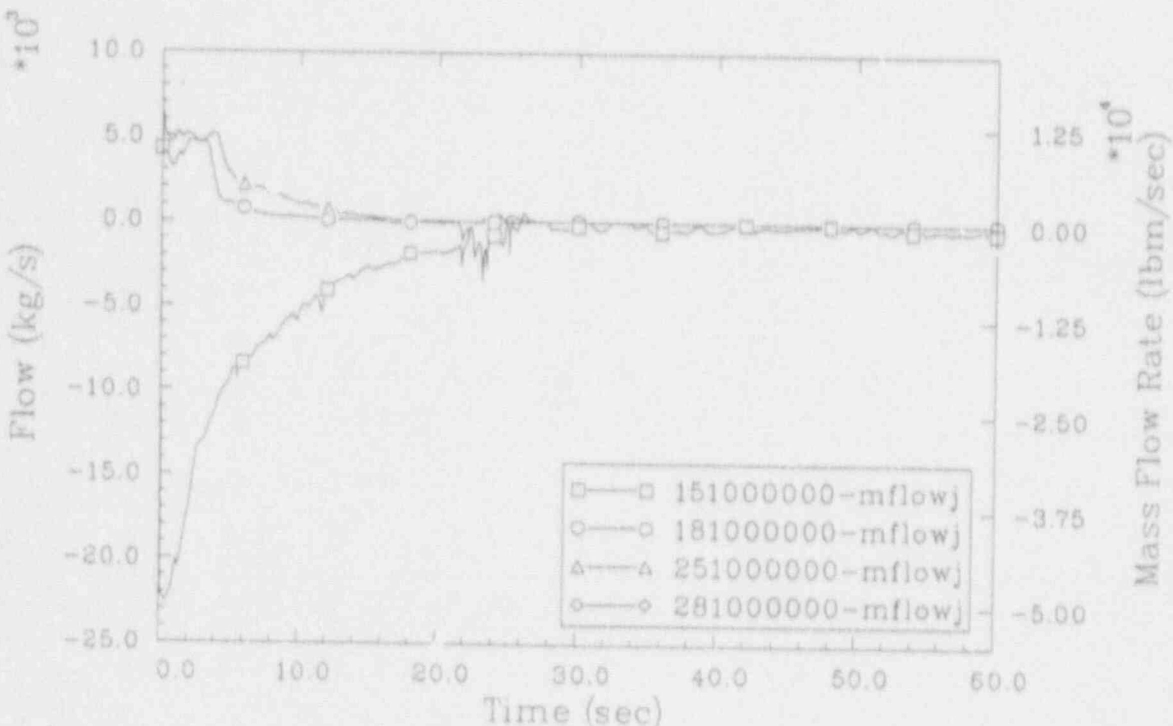

Figure 21. SCDAP/RELAP5/MOD3-calculated cold-leg flow for the Oconee 100% DBA case.

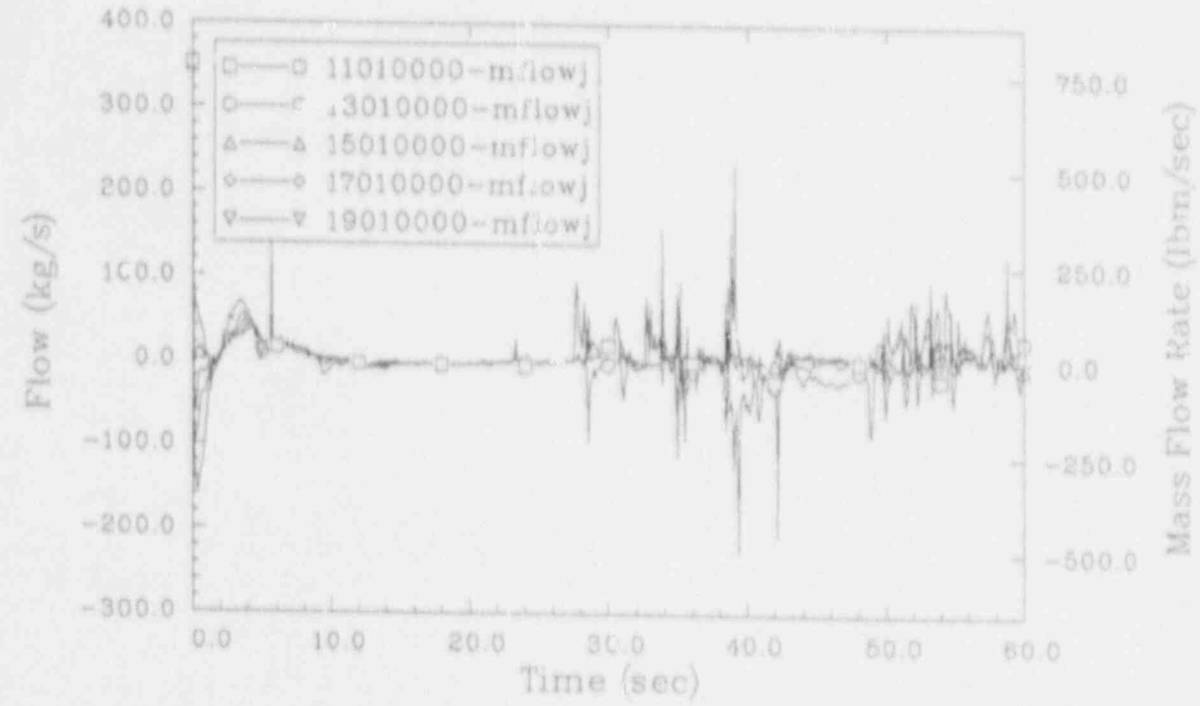

Figure 22. SCDAP/RELAP5/MOD3-calculated hot channel core flow for the Oconee 100% DBA case.

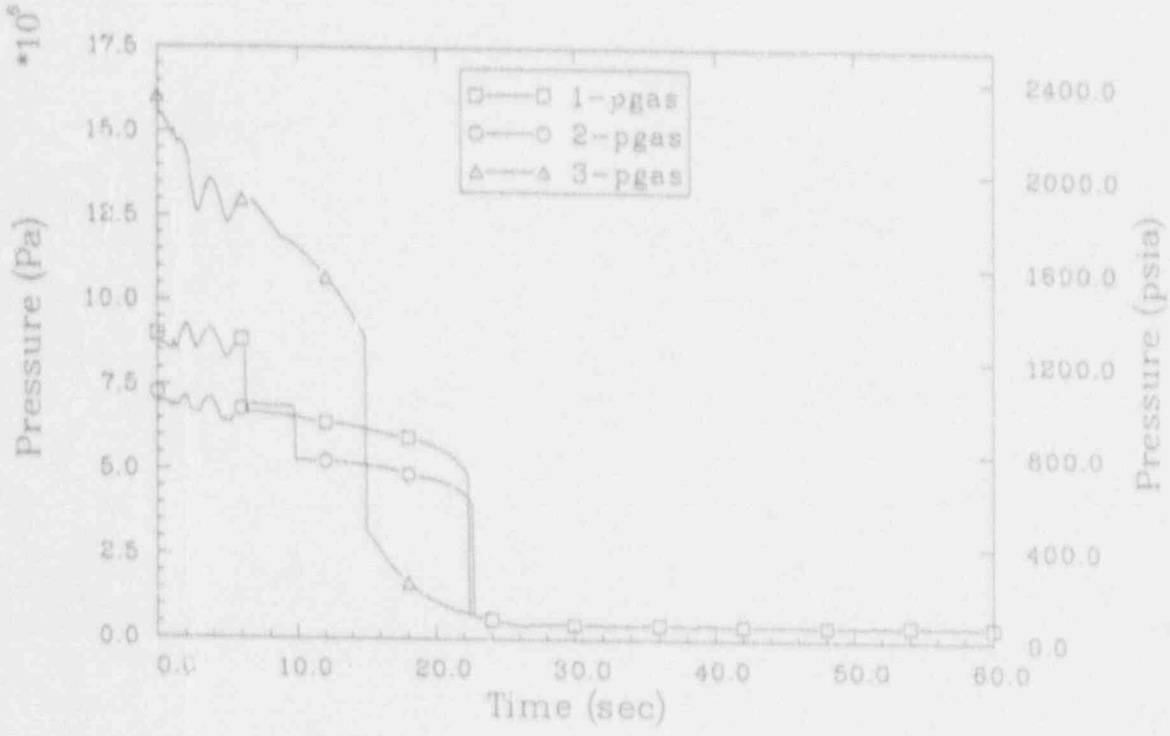

Figure 23. SCDAP/RELAP5/MOD3-calculated internal pin pressure for the Oconee 100% DBA case.

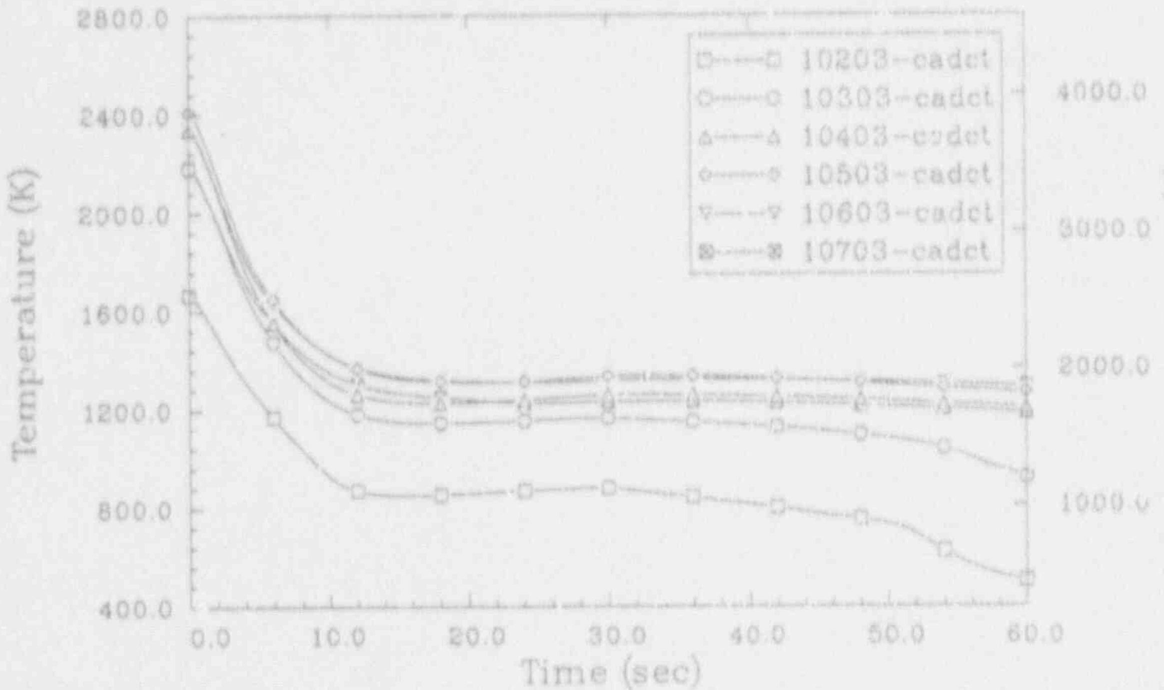

Figure 24. SCDAP/RELAP5/MOD3-calculated fuel centerline temperature for the 55-GWd/MTU fuel pin for the Oconee 100% DBA case.

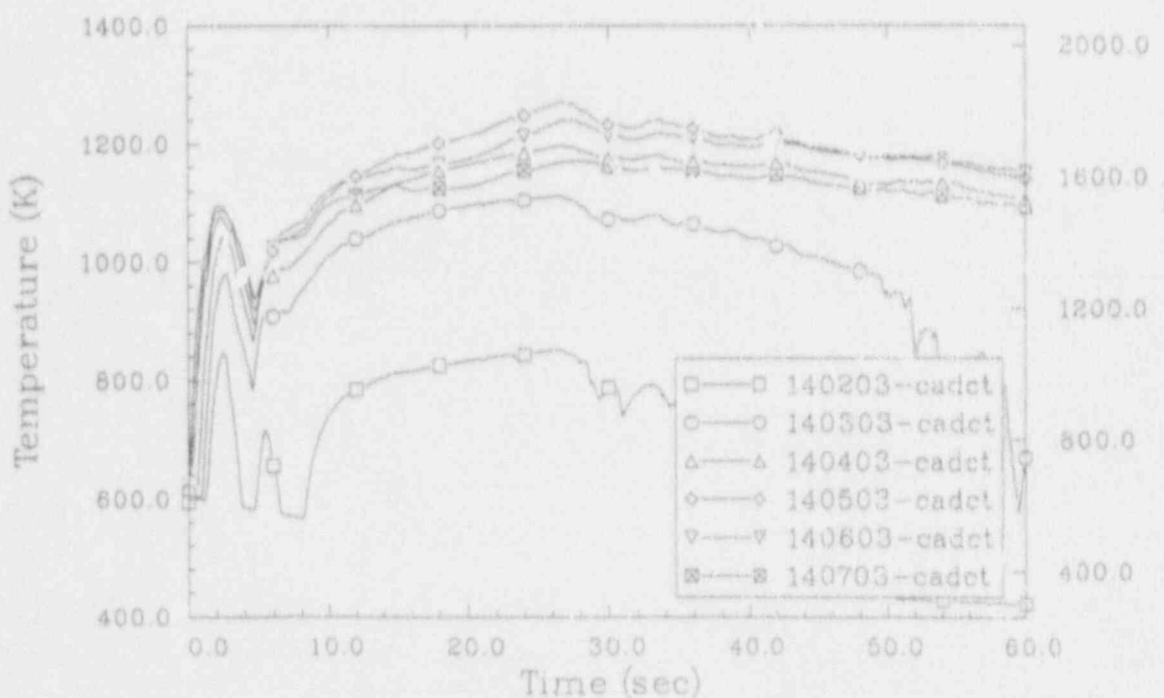

Figure 25. SCDAP/RELAP5/MOD3-calculated cladding surface temperature for the 55-GWd/MTU fuel pin for the Oconee 100% DBA case.

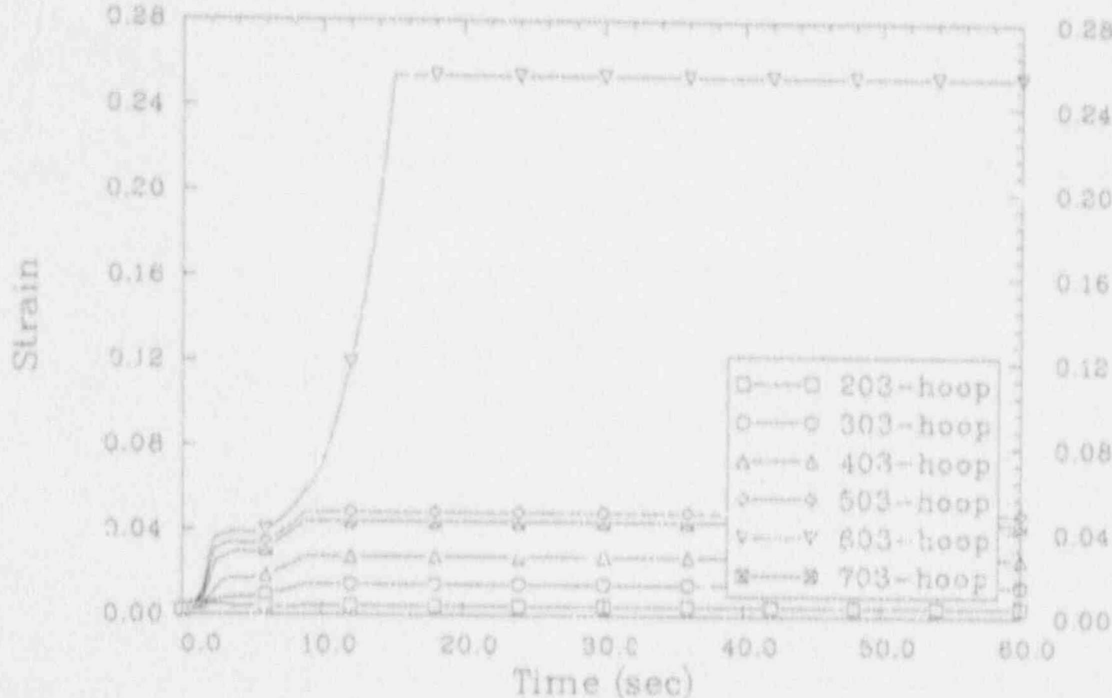

Figure 26. SCDAP/RELAP5/MOD3-calculated cladding hoop strains for the 55-GWd/MTU fuel pin for the Oconee 100% DBA case.

As illustrated in Figure 14, prompt power drops off rapidly in response to moderator density reactivity feedback. Figure 15 illustrates the initial drop in collapsed reactor water level. Starting at about 30 seconds, collapsed reactor water level begins a gradual recovery as flow from the accumulators begins to reach the core. As shown in Figure 16, falling pressurizer pressure lags the drop in system pressure, because of choking in the pressurizer surge line.

The containment pressure setpoint for containment isolation is exceeded at 0.53 seconds; and, as shown in Figure 17, the containment pressure continues to rise to a peak value of about 0.427 MPa (62 psia) at about 20 seconds, followed by a gradual decrease as condensation occurs on the containment heat structures. It should be noted that the calculated containment pressure is somewhat higher than would be expected, because of the simplified nature of the containment model, which does not include containment spray modeling. However, the model does provide a conservatively low calculation of containment pressure for the first few seconds, since it does not account for localized pressurization of containment compartments in the vicinity of the break where pressure sensors would be expected.

The blowdown phase of the LOCA lasts for about 10-20 seconds, as illustrated by Figure 18, the total break flow. The intact loop accumulators begin to inject at about 15 seconds and have not completely drained at the end of the calculation (60 seconds). Hot- and cold-leg flows are shown in Figures 20 and 21, respectively. As expected, a large flow reversal occurs in the broken cold leg. Hot-leg mass flows decrease as the fluid flashes to form a two-phase mixture and reverse for a short duration after about 10 seconds.

The hot channel core flow at several axial levels is shown in Figure 22. Stagnation points are established within the fuel zone at several times during the calculation, most notably during the first two seconds of the LOCA. Stagnation points are formed when the mass flow becomes predominantly downward at the bottom of the core and predominantly upward at the top of the core.

Internal gas pressures calculated by SCDAP/RELAP5/MOD3 are shown in Figure 23. Internal pressures decline as internal temperature falls and internal gas volume increases on account of ballooning. Pin failure is clearly indicated by a sudden drop in internal pressure to the system pressure.

Cladding surface and fuel centerline temperatures calculated by SCDAP/RELAP5/MOD3 for the high-exposure fuel pin are shown in Figures 24 and 25, respectively. The cladding surface temperatures rise rapidly during the first few seconds, as the surface heat flux is reduced because of core voiding. Fuel cladding temperatures peak at around 1100 K (1450°F) during the first couple of seconds, then decline over the next few seconds as the fuel gives up its stored energy and fuel pellet temperatures drop because of the reduced power generation. Eventually, the reduced heat transfer at the cladding surface produces a steady rise in cladding and fuel pellet temperatures. This temperature rise continues until water from the accumulators (and the pumped ECCS, if available) makes its way into the core region.

The zircaloy cladding undergoes a phase change starting at about 1050–1090 K (1900–2000°F) and ending at about 1250 K (2300°F). As a result of this phase change, the material properties of the cladding change rapidly over this temperature range. In each case, pin failures were calculated to occur during this phase transition prior to reaching a temperature of 1250 K (2300°F).

As evidenced by the plots contained in Appendices K and L, SCDAP/RELAP5/MOD3 calculates a spike in accumulator flow as each accumulator approaches empty and is subsequently isolated from the system. Although these flow spikes are not consistent with expected results, they are not considered significant for this analysis, because of the magnitudes and durations involved.

7.1.2 FRAP-T6 Calculations. The FRAP-T6 results for Oconee and Seabrook are summarized in Tables 5 through 24. Each of the cases, with the exception of the 6-in.-dia small-break case without pumped ECCS, was run for a 60-second interval. In cases where no fuel pin failure was predicted, the values given correspond to the transient time at the end of the calculation, prefixed by a "greater than" symbol (>). The failure nodes are indicated by the numbers in parentheses; nodes are numbered from 1 at the bottom of the core to 9 at the top.

Figures 27 through 32 show the FRAP-T6 results for a fuel rod operating with a peaking factor of 2.63 and a peak axial burnup of 55 GWd/MTU, using the SCDAP/RELAP5/MOD3 worst-case Oconee thermal-hydraulics discussed above.

Overall, the results generated by FRAP-T6 are consistent with expected trends; i.e., pin failure times shortened as peaking factors, burnups, and break areas were increased. The minimum time from LOCA initiation to fuel pin failure for Oconee, as calculated with the FRAP-T6 best-estimate models, is 13.0 seconds for the 100% DBA case without RCS pump trip. This time was not affected by the availability of pumped ECCS. The minimum time from LOCA initiation to fuel pin failure calculated by FRAP-T6 for Seabrook is 24.8 seconds for the 100% DBA case without ECCS. The shorter Oconee failure times can be directly attributed to higher linear heat generation rate and larger fuel pin diameter, which results in higher initial stored energy. In addition, the failure times calculated for Oconee are stronger functions of burnup than those reported for Seabrook, which has only about a 5-second difference in failure time for pins with the lowest and highest burnup.

Several parameters affecting fuel pin failure times vary as a function of exposure, including cladding creep, fuel and cladding material properties, internal gas pressure, and gap conductance. The fuel pin failure times calculated for Seabrook generally increase between 5 and 20 GWd/MTU and then decrease to the shortest pin failure time at 50 GWd/MTU. The increase in fuel pin failure time between 5 and 20 GWd/MTU can be attributed to the decrease in stored energy over this range, resulting from cladding creep and increased gap conductance. After 20 GWd/MTU, the fuel pin internal pressure becomes the dominant factor affecting the fuel failure timing.

Table 5. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA without ECCS (Case 1).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	23.7 (5)	20.3 (4)	18.0 (4)	13.0 (4)
2.4	> 60.0	25.3 (4)	19.7 (4)	14.1 (4)
2.2	> 60.0	34.8 (4)	23.9 (4)	16.4 (4)
2.0	> 60.0	> 60.0	3[illegible] (4)	22.5 (4)

Table 6. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 90% DBA without ECCS (Case 2).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	25.0 (5)	22.1 (4)	19.7 (4)	13.6 (4)
2.4	> 60.0	27.7 (4)	22.3 (4)	17.7 (5)
2.2	> 60.0	54.7 (4)	25.8 ([illegible])	22.7 (4)
2.0	> 60.0	> 60.0	34.4 (4)	24.2 (4)

Table 7. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 75% DBA without ECCS (Case 3).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	25.0 (5)	23.5 (4)	21.1 (4)	14.6 (4)
2.4	> 60.0	31.7 (4)	23.5 (4)	15.[illegible]
2.2	> 60.0	51.3 (4)	29.3 (4)	18.0 (4)
2.0	> 60.0	> 60.0	37.5 (4)	25.0 (4)

Table 8. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 50% DBA without ECCS (Case 4).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	33.9 (5)	29.8 (4)	27.2 (4)	20.3 (4)
2.4	> 60.0	53.1 (4)	33.0 (4)	21.6 (4)
2.2	> 60.0	> 60.0	40.8 (5)	29.5 (5)
2.0	> 60.0	> 60.0	57.4 (4)	30.3 (4)

Table 9. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA without ECCS and with pump trip (Case 5).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	37.5 (5)	33.5 (5)	26.2 (4)	22.3 (5)
2.4	> 60.0	49.7 (5)	32.1 (4)	25.5 (4)
2.2	> 60.0	> 60.0	33.8 (4)	27.4 (4)
2.0	> 60.0	> 60.0	> 60.0	32.1 (4)

Table 10. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA with ECCS on (Case 7).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	22.7 (5)	21.1 (4)	18.0 (4)	13.0 (4)
2.4	54.9 (4)	24.9 (4)	20.0 (4)	14.1 (4)
2.2	> 60.0	50.2 (4)	23.6 (4)	18.8 (5)
2.0	> 60.0	> 60.0	28.2 (4)	22.7 (4)

Table 11. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA with pump trip and ECCS on (Case 8).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	24.8 (5)	24.4 (5)	23.5 (5)	20.3 (5)
2.4	> 60.0	25.8 (5)	24.6 (4)	23.6 (5)
2.2	> 60.0	55.4 (5)	25.8 (5)	24.5 (5)
2.0	> 60.0	> 60.0	54.6 (5)	25.3 (5)

Table 12. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 6-in. break without ECCS (Case 6).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 393.0	> 393.0	> 393.0	> 393.0

Table 13. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 6-in. break with ECCS (Case 9).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 60.0	> 60.0	> 60.0	> 60.0

Table 14. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA without ECCS (Case 1).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	29.1 (5)	29.7 (5)	27.7 (5)	24.8 (4)
2.2	34.4 (5)	36.7 (5)	35.8 (5)	32.5 (4)
2.0	44.5 (4)	48.4 (4)	43.6 (4)	43.6 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table 15. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 90% DBA without ECCS (Case 2).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	31.8 (5)	32.6 (5)	30.5 (5)	26.5 (4)
2.2	35.6 (5)	36.2 (5)	35.7 (5)	34.8 (5)
2.0	39.6 (4)	40.1 (4)	39.4 (4)	38.7 (4)
1.8	> 60.0	> 60.0	52.3 (4)	45.7 (4)

Table 16. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 75% DBA without ECCS (Case 3).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	30.6 (5)	31.2 (5)	29.8 (5)	26.9 (4)
2.2	36.2 (5)	38.8 (5)	36.8 (5)	33.5 (4)
2.0	> 60.0	> 60.0	> 60.0	40.5 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table 17. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 50% DBA without ECCS (Case 4).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	44.3 (5)	44.1 (5)	43.0 (5)	42.5 (5)
2.2	45.7 (5)	45.7 (5)	44.7 (5)	43.5 (5)
2.0	> 60.0	> 60.0	58.6 (5)	47.2 (5)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table 18. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA without ECCS and with pump trip (Case 5).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	27.6 (5)	28.0 (5)	25.7 (5)	25.0 (4)
2.2	32.8 (5)	32.2 (5)	32.0 (5)	30.3 (4)
2.0	35.0 (5)	35.5 (5)	35.0 (4)	34.0 (4)
1.8	> 60.0	> 60.0	48.0 (4)	38.2 (4)

Table 19. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA with ECCS on (Case 7).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	30.2 (5)	31.3 (5)	29.2 (5)	24.9 (4)
2.2	34.9 (5)	36.2 (5)	35.5 (5)	33.1 (4)
2.0	42.5 (4)	43.2 (4)	42.7 (4)	39.1 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table 20. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA with pump trip and ECCS on (Case 8).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	28.3 (5)	28.8 (5)	27.7 (5)	25.1 (4)
2.2	31.8 (5)	32.1 (5)	32.0 (5)	30.7 (4)
2.0	35.2 (5)	36.2 (5)	35.5 (5)	34.6 (5)
1.8	> 60.0	> 60.0	42.1 (5)	42.0 (4)

Table 21. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 6-in. break without ECCS (Case 6).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 600.0	> 600.0	> 600.0	> 600.0

Table 22. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 6-in. break with ECCS (Case 9).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 60.0	> 60.0	> 60.0	> 60.0

Table 23. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA without ECCS with licensing audit code models on (Case 1).

[illegible]	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
[illegible]	25.5 (5)	24.5 (5)	21.9 (5)	12.5 (5)
[illegible]	> 60.0	> 60.0	31.9 (5)	23.1 (5)
2.2	> 60.0	> 60.0	> 60.0	33.6 (5)
2.0	> 60.0	> 60.0	> 60.0	> 60.0

Table 24. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA without ECCS with licensing audit code models on (Case 1).

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	39.8 (4)	42.4 (4)	40.2 (4)	37.1 (4)
2.2	> 60.0	> 60.0	> 60.0	> 60.0
2.0	> 60.0	> 60.0	> 60.0	> 60.0
1.8	> 60.0	> 60.0	> 60.0	> 60.0

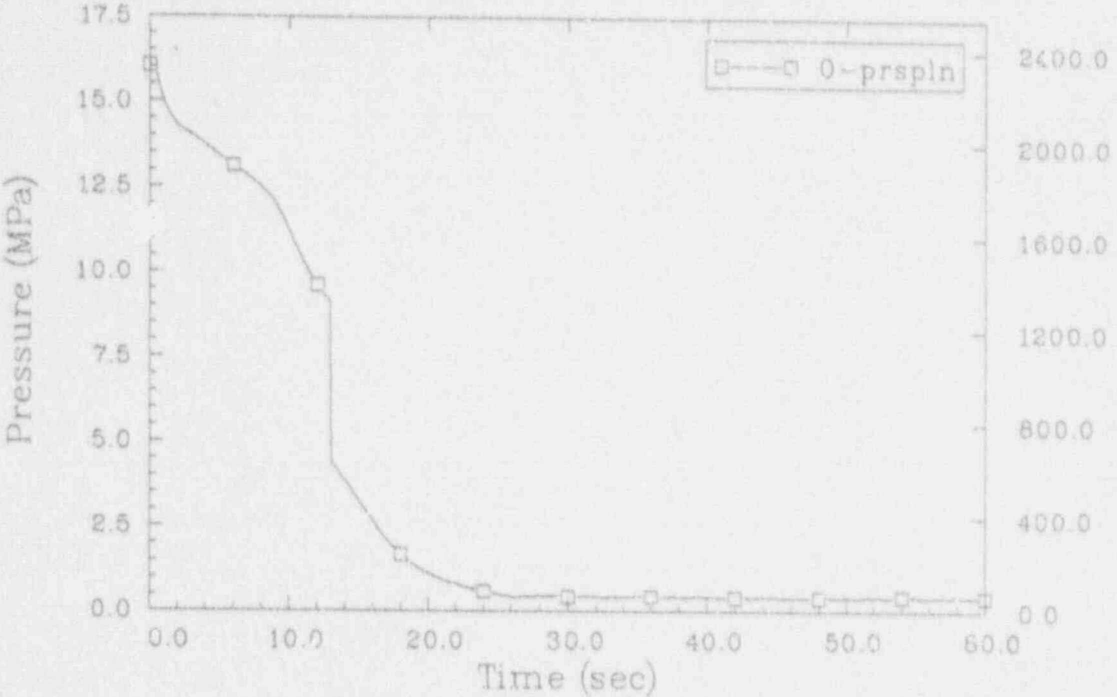

Figure 27. FRAP-T6-calculated internal pin pressure for the 55-GWd/MTU pin, peaking factor of 2.63, Oconee 100% DBA case.

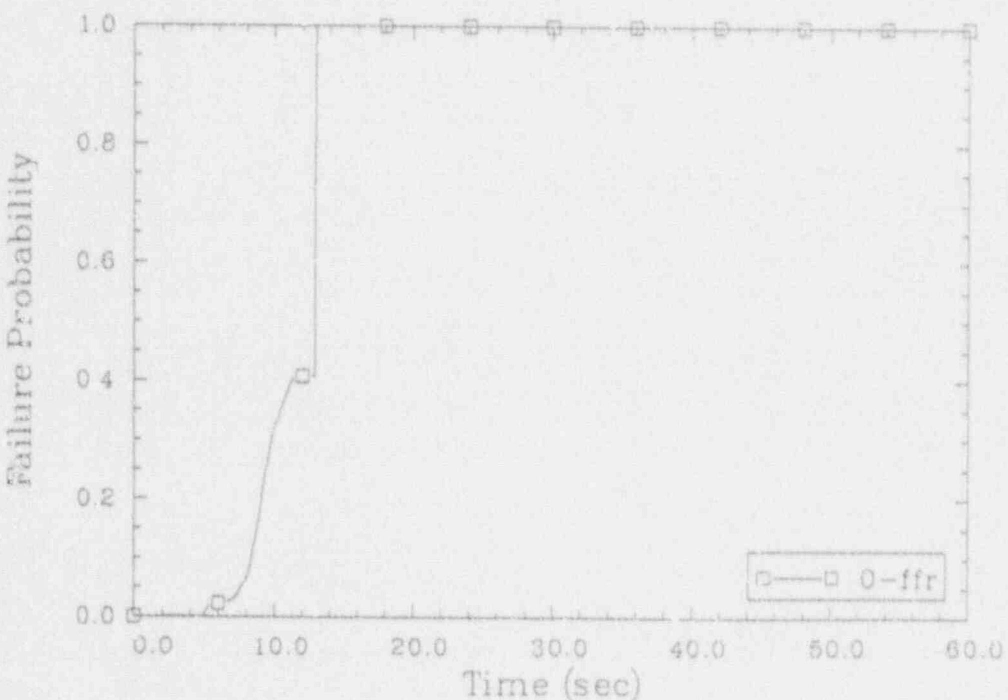

Figure 28. FRAP-T6-calculated failure probability for the 55-GWd/MTU pin, peaking factor of 2.63, Oconee 100% DBA case.

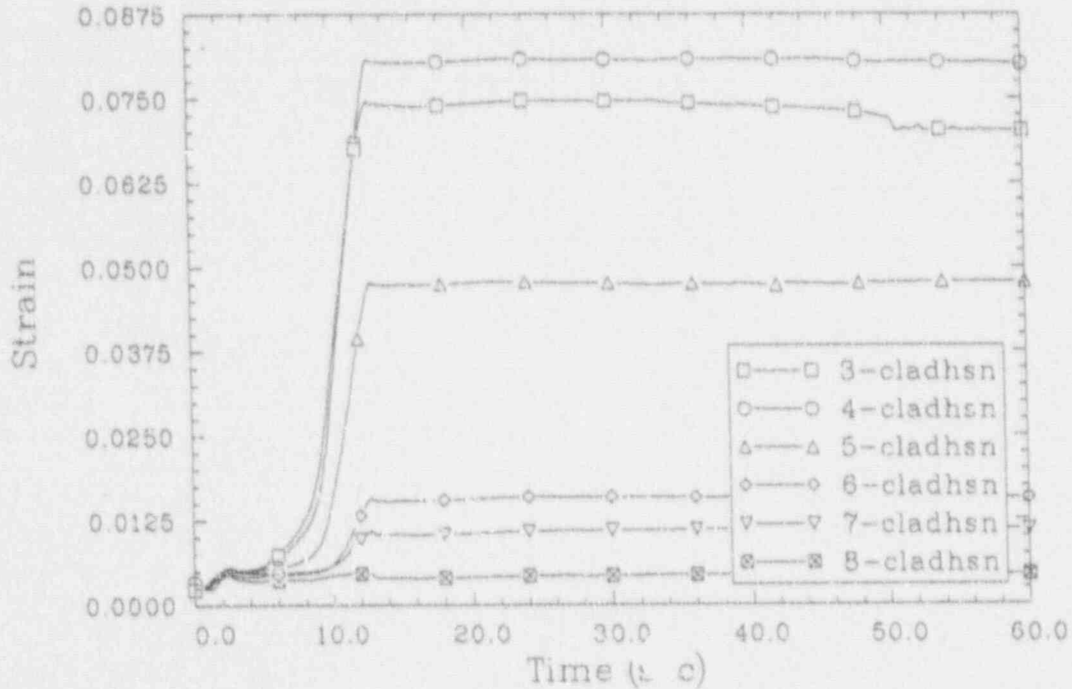

Figure 29. FRAP-T6-calculated cladding hoop strain for the 55-GWd/MTU pin, peaking factor of 2.63, Oconee 100% DBA case.

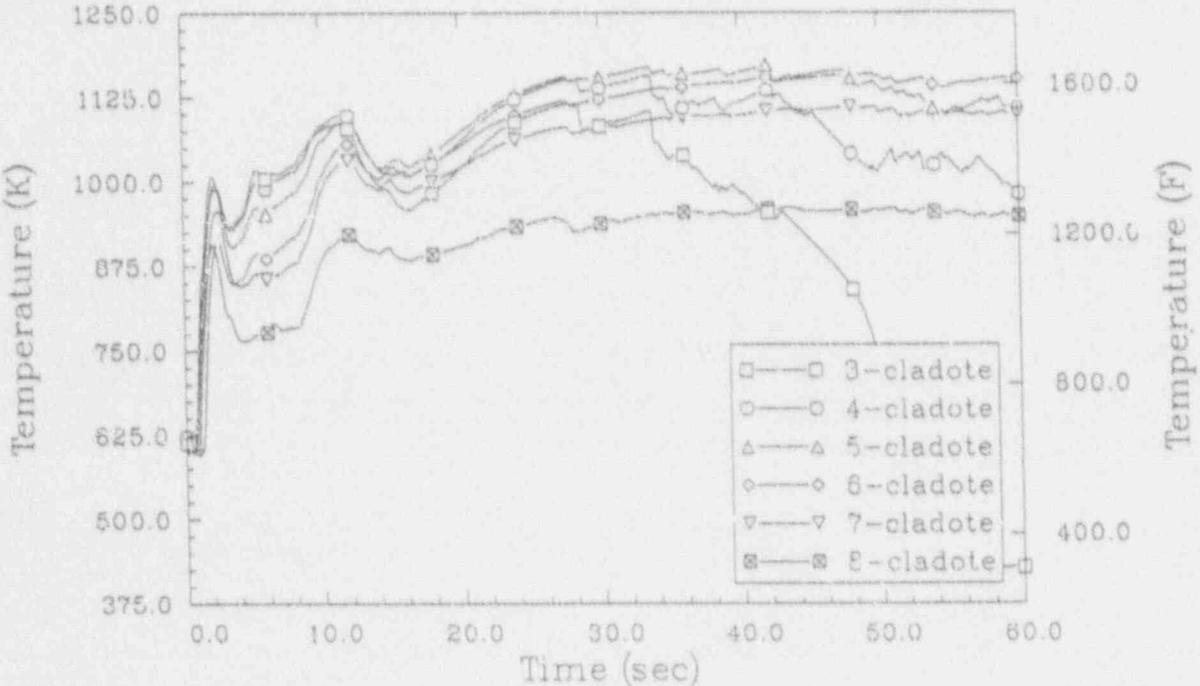

Figure 30. FRAP-T6-calculated cladding surface temperature for the 55-GWd/MTU pin, peaking factor of 2.63, Oconee 100% DBA case.

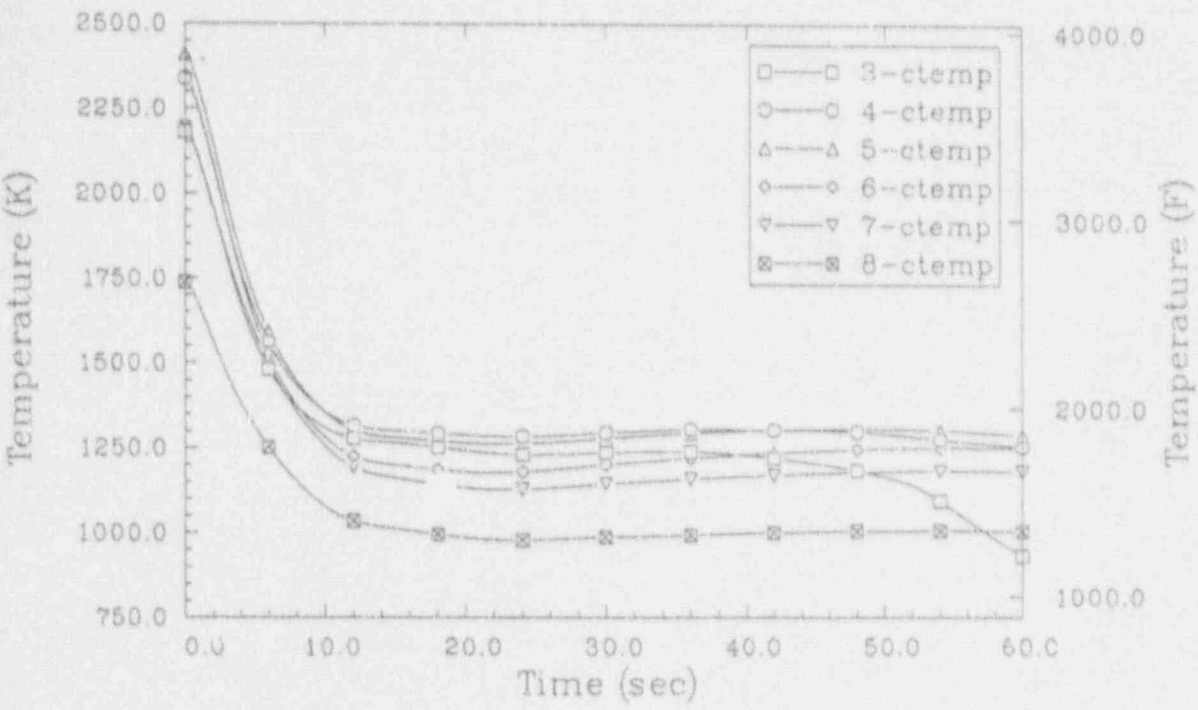

Figure 31. FRAP-T6-calculated fuel centerline temperature for the 55-GWd/MTU pin, peaking factor of 2.63, Oconee 100% DBA case.

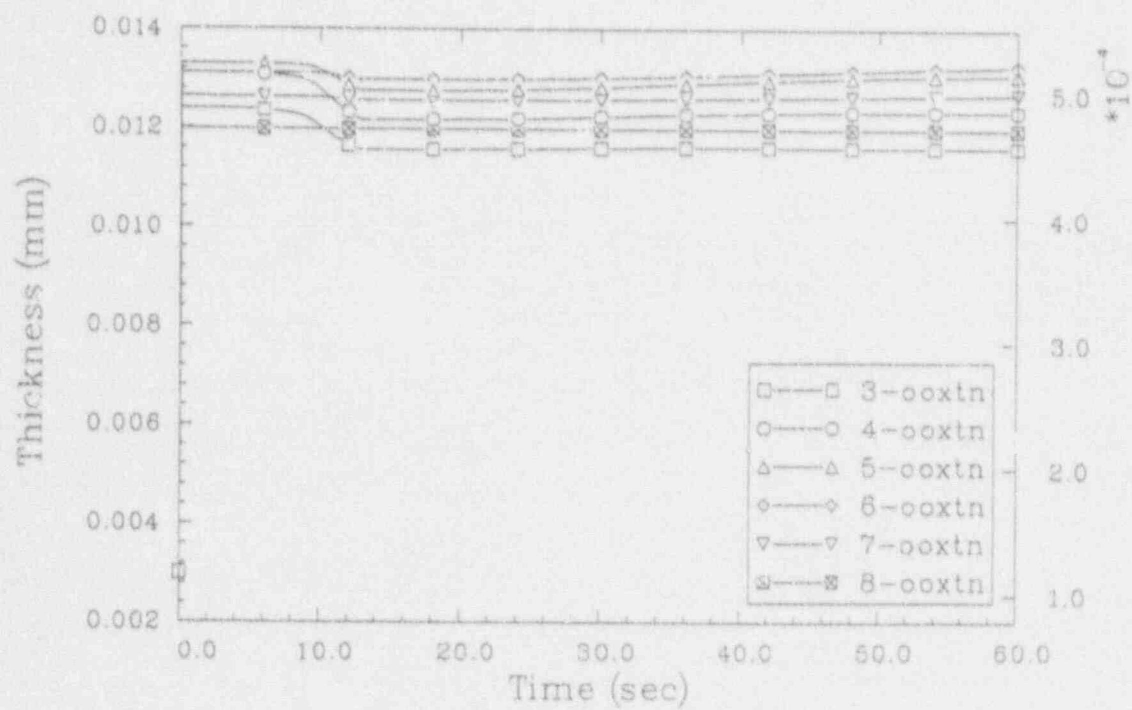

Figure 32. FRAP-T6-calculated oxide thickness for the 55-GWd/MTU pin, peaking factor of 2.63, Oconee 100% DBA case.

The stored energy calculated for Oconee does not vary with exposure to the same extent as observed for Seabrook. Oconee failure times are dominated primarily by the internal pin pressure, resulting in stronger dependence on exposure.

It should be noted that the limitations of point kinetics prevent modeling of the differences in decay heat that would be associated with the differences in fuel pin exposure. For this reason, energy deposition in both the low- and high-exposure pins is identical throughout the transient and produces a conservative estimate of pin failure for the lower-burnup fuel pins.

Tables 23 and 24 summarize the pin failure times generated for the 100% DBA cases for Oconee and Seabrook using the FRAP-T6 evaluation model options. Note that, in all cases except for the highest peaking factor and burnup combination for Oconee, the failure times calculated using the evaluation models are longer than those generated using the best-estimate models (see Tables 5 and 14). In addition, the fuel centerline and cladding surface temperatures calculated using the evaluation models do not correlate well with either SCDAP/RELAP5/MOD3 or the best-estimate results calculated by FRAP-T6.

Since the peak cladding surface temperatures calculated using the evaluation models of FRAP-T6 are at or above those calculated using the best-estimate models, the differences in pin failure times are due to differences between the evaluation and best-estimate rupture models. For cases in which the cladding temperature is monotonically increasing, the evaluation model may predict rupture to occur at nearly the same time as the best-estimate model. But, for cases in which the cladding temperature decreases after ballooning has begun, as was the case for these calculations (see Figure 30), the evaluation model is outside of its intended range of applicability and may calculate results significantly different from the best-estimate model. The evaluation model correlation for rupture temperature is based on constant temperature-ramp rate experiments.[22] This correlation is sensitive to the calculated temperature-ramp rate but may not properly account for rapidly fluctating ramp rates.

As anticipated, no fuel pin failures are predicted for the small-break cases during the first 60 seconds of the calculation. The small-break cases without pumped ECCS were subsequently extended to 6 minutes 33 seconds for Oconee and 10 minutes for Seabrook with no fuel failures predicted by either SCDAP/RELAP5/MOD3 or FRAP-T6.

7.1.3 Comparison of SCDAP/RELAP5/MOD3 and FRAP-T6 Fuel Pin Calculations.

The fuel centerline temperatures calculated by SCDAP/RELAP5/MOD3 and the best-estimate models of FRAP-T6 are in fairly close agreement for both the Oconee and Seabrook plants. The Seabrook results also indicated agreement between SCDAP/RELAP5/MOD3 and FRAP-T6 cladding surface temperatures; however, for Oconee, SCDAP/RELAP5/MOD3 tended to overpredict cladding surface temperatures in comparison to those calculated by FRAP-T6. These differences are attributed to the different heat transfer correlations used in the two codes. The discrepancy between Oconee cladding surface temperatures calculated by the two codes is amplified for the cases that include reactor coolant pump trip.

In general, the pin failure times calculated by SCDAP/RELAP5/MOD3 tend to be significantly longer than those calculated by FRAP-T6. Exceptions are noted for the Oconee 100% DBA cases with and without pumped ECCS, which agree fairly well, and the Oconee 100% DBA cases with RCS pump trip, in which the SCDAP/RELAP5/MOD3 times are several seconds shorter.

Deviations between FRAP-T6 and SCDAP fuel pin failure times can be traced, at least in part, to the difference in the cladding strains calculated by the two codes. In SCDAP, a step change in cladding strain was encountered at each axial node of the low-exposure fuel pins at around 10 seconds for each large-break LOCA case for both the Oconee and Seabrook fuel pins. This step change in cladding strain was also calculated for the Seabrook high-exposure fuel pin. The cladding deformation model does not appear to properly account for strain rate effects. The step change in cladding strain produces a step decrease in internal fuel pin pressure. As illustrated by the SCDAP/

RELAP5/MOD3 plots of internal pin pressure, the step decrease in pressure early in the transient results in a delayed time to fuel pin rupture. SCDAP/RELAP5/MOD3 thus overpredicts the axial extent of cladding deformation, which results in an underprediction of internal pin pressures and an overprediction of the time to fuel pin failure.

In addition, the cladding strain calculated by SCDAP/RELAP5/MOD3 for axial node 6 of the Oconee low-burnup pin during the 50% DBA LOCA case appears to be anomalous. This node experiences a negative step change in hoop strain at about 9.5 seconds, which is not consistent with the calculated behavior of the adjacent nodes. Likewise, both fuel cladding and centerline temperatures for this node appear suspicious, since they do not follow the general trend observed in the adjacent nodes.

7.2 Results Generated Using TRAC-PF1/MOD1

Appendix K contains comparison plots of the transient results generated by SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 for a complete double-ended, offset- shear LOCA calculation (100% DBA) for Seabrook without pumped ECCS and without RCS pump trip. The plots illustrate that the system response calculated by the two codes is in fairly good agreement for the first 35 seconds of the calculation. Excellent agreement was obtained between SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 for the break flow and resulting system depressurization. The SCDAP/RELAP5/MOD3 calculation reached the low containment isolation setpoint at 3.73 seconds, only 0.11 seconds earlier than the TRAC-PF1/MOD1 calculation. The flows from the accumulators, intact hot-legs, and intact cold-legs also compare well. However, the hot channel thermal-hydraulic conditions calculated by SCDAP/RELAP5/MOD3 are more severe throughout the calculation, resulting in higher cladding surface temperatures and early fuel pin failures.

The largest deviation between the two sets of results occurred after about 35 seconds when accumulators emptied and discharged nitrogen into the system. In the SCDAP/RELAP5/MOD3 calculation, the accumulators were isolated as they approached an empty condition, in order to prevent code failure. In the TRAC-PF1/MOD1 calculation, however, as the accumulators emptied, nitrogen gas was discharged into the cold-leg and vessel. This surge of noncondensible gas pressurized the upper downcomer, resulting in a surge of fluid into the core region. A core flow surge can be seen as the broken loop accumulator empties at approximately 35 seconds and again as the intact accumulators empty at about 40 seconds. These core flow surges are clearly seen in the hot channel mass flow at the midcore level. The downcomer void fraction plots indicate similar responses for voiding of the downcomer adjacent to the intact loops; however, the TRAC-PF1/MOD1 calculation indicates a quicker and more prolonged voiding for the downcomer quadrant adjacent to the broken cold-leg.

As with SCDAP/RELAP5/MOD3, the hot channel thermal-hydraulic conditions generated by TRAC-PF1/MOD1 were used to provide boundary conditions for FRAP-T6, which was used to calculate fuel failure times for a matrix of fuel pin exposures and peaking factors. Appendix K contains the plotted results for each of the 16 FRAP-T6 cases run for the supplemental calculation.

Cladding surface temperatures calculated by FRAP-T6 using SCDAP/RELAP5/MOD3 data are higher than those calculated using TRAC-PF1/MOD1 data. This deviation becomes even more apparent after about 40 seconds, because of the nitrogen-induced flow surge that results in a quenching of the cladding for the TRAC-PF1/MOD1 calculation. In the SCDAP/RELAP5/MOD3 case, pin failures were calculated to occur during the zircaloy phase transition temperature range. In the TRAC-PF1/MOD1 case, pin failure occurred during the initial coolant surge, prior to reaching the phase transition temperature.

The previous FRAP-T6 fuel pin failure timings generated using SCDAP/RELAP5/MOD3 thermal-hydraulic data and the timings generated using TRAC-PF1/MOD1 thermal-hydraulic data are summarized in Table 25 for comparison purposes. In cases where no fuel pin failure was predicted, the values given in Table 25 correspond to the transient time at the end of the calculation, prefixed by a "greater than" symbol (>). As before, the failure nodes are indicated by the numbers in parentheses.

SCDAP/RELAP5/MOD3 thermal-hydraulic boundary conditions produced conservative pin failure timings in each case compared to those produced using TRAC-PF1/MOD1. The nitrogen injection from the accumulators resulted in a surge of coolant entering the core starting at about 35 seconds. This coolant surge resulted in a rapid drop in fuel temperatures, preventing fuel failure after 42 seconds.

7.3 Uncertainty

The relative uncertainty associated with a particular result is crucial to the interpretation of a best-estimate calculation. There are several sources of uncertainty introduced into the calculation of fuel pin failure times. These include variations in fabrication parameters, material property correlations, fuel performance correlations, and thermal-hydraulic boundary conditions. An option is available in FRAP-T6[24] that can be used to calculate the uncertainty in fuel behavior responses as a function of known uncertainties in selected input variables and correlations. This approach requires the identification of the major contributors to uncertainty and the selection of appropriate uncertainty factors representative of the relative uncertainty of each contributor. FRAP-T6 uses a response surface methodology to determine the associated time-dependant uncertainty in fuel behavior responses, such as failure probability. FRAP-T6 also determines the fractional contribution to uncertainty from each contributor as a function of time.

It is recommended that a FRAP-T6 uncertainty analysis be included when implementing the methodology discussed in this report, to quantify the uncertainty associated with fuel pin failure times.

Table 25. A comparison of FRAP-T6 fuel pin failure times using SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 thermal-hydraulic data for the 100% DBA case for Seabrook.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
Fuel Pin Failure Times using TRAC-PF1/MOD1 Thermal-Hydraulic Data				
2.32	> 60.0	41.4 (5)	41.3 (6)	34.9 (6)
2.2	> 60.0	> 60.0	41.4 (5)	41.2 (6)
2.0	> 60.0	> 60.0	> 60.0	> 60.0
1.8	> 60.0	> 60.0	> 60.0	> 60.0
Fuel Pin Failure Times using SCDAP/RELAP5/MOD3 Thermal-Hydraulic Data				
2.32	29.1 (5)	29.7 (5)	27.7 (5)	24.8 (4)
2.2	34.4 (5)	36.7 (5)	35.8 (5)	32.5 (4)
2.0	44.5 (4)	48.4 (4)	43.6 (4)	43.6 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

8. TECHNICAL FINDINGS

A detailed methodology for the calculation of fuel pin failure timing (time between the containment isolation signal and fuel pin failure) under LOCA conditions has been developed and applied to two demonstration calculations for the Oconee and Seabrook reactors. The methodology uses SCDAP/RELAP5/MOD3 for thermal-hydraulic calculations and FRAPCON-2 and FRAP-T6 for fuel pin calculations. For Seabrook, the thermal-hydraulic calculations were repeated using TRAC-PF1/MOD1. In each calculation, the earliest fuel pin failure times are for a complete, double-ended, offset-shear break of a cold-leg, without pumped ECCS but with continued operation of the RCS pumps. These quantitative results are summarized in Table 26 for the fuel pin with the highest burnup and peaking factor.

Technical findings are presented below, along with recommendations for further investigation of phenomenological uncertainties in the calculations.

1. *The demonstration calculations (using conservative assumptions) indicate that no fuel failures will be encountered during the first several seconds of the worst-case design basis LOCA (double-ended, offset-shear cold-leg break) without pumped ECCS. In addition, these calculations illustrate the potential for providing more realistic times for fission product appearance within containment compared with the instantaneous release assumption of TID-14844.*[1]

   The minimum fuel pin failure times summarized in Table 26 were obtained for fuel pins with the maximum design burnup, operating at the technical specification limits. This represents a conservative result, since fuel pins with such a high exposure would not be operating at such conditions and fuel pin failure times increase significantly for both lower burnup and lower peaking factor. An improved approach for calculating the source term present inside containment following a LOCA would incorporate a fuel-cycle-specific limiting power distribution, identifying the maximum number of fuel rods with a given exposure operating above a given peaking factor. This approach, taken in conjunction with the methodology used for the demonstration calculations, would allow the calculation of a time-dependent release of fission products from fuel pin failure. It appears likely that this approach would indicate that at least 30 seconds would elapse prior to significant fission product release from the cladding following a design basis large-break LOCA.

2. *The fuel pin failure times can be expected to exhibit significant variation by fuel design and plant type.*

   Fuel design parameters, such as plenum volume, initial fill gas pressure, pellet radius, and cladding thickness, have a direct impact on fuel pin failure timing. Design parameters that result in either higher stored energy or increased gap gas pressure can be expected to result in earlier pin failures. Pin failure timing is also strongly influenced by hot channel thermal-hydraulic conditions. Plant design factors, such as cold leg area, primary system fluid inventory, and accumulator injection point, will affect the hot channel flow patterns established during the blowdown, refill, and reflood portions of the transient.

3. *Fuel pin failure times calculated by FRAP-T6 using SCDAP/RELAP5/MOD3 thermal-hydraulics are conservative in comparison to those using TRAC-PF1/MOD1 thermal-hydraulics.*

   SCDAP/RELAP5/MOD3 has not been assessed for either fuel behavior analysis or large-break LOCA analysis. Furthermore, the analysis used a preliminary version of the code that does not directly correspond to the version that will be used for code assessment purposes. However, the FRAP-T6 results

Table 26. Timing summary for worst-case LOCAs.

Plant	Thermal-hydraulic model	Containment isolation (s)	Earliest pin failure (s)	Interval (s)
Oconee	SCDAP/RELAP5/MOD3	2.6	13.0	10.4
Seabrook	SCDAP/RELAP5/MOD3	5.7	24.8	19.1
Seabrook	TRAC-PF1/MOD1	5.8	34.9	29.1

calculated using SCDAP/RELAP5/MOD3 were conservatively earlier than those calculated using TRAC-PF1/MOD1 for the single Seabrook DBA large-break LOCA case analyzed. The thermal-hydraulic response calculated by SCDAP/RELAP5/MOD3 agreed reasonably well with that of TRAC-PF1/ MOD1 up to the time that the accumulators empty. SCDAP/RELAP5/MOD3 code failures prevented proper modeling of the system response to nitrogen injection following draining of the accumulators.

4. *The time of cladding rupture calculated by the SCDAP ballooning model is different from that calculated by the FRAP-T6 ballooning model; this difference is due to an incomplete modeling of strain rate effects by the SCDAP ballooning model.*

   Code deficiencies have been identified and are being corrected. It is recommended that a portion of the SCDAP/RELAP5/MOD3 calculations be repeated following correction of the code deficiencies and successful completion of the code assessment efforts.

5. *The uncertainty associated with fuel pin failure timing should be investigated.*

   A large degree of uncertainty is associated with these calculations. Variation in fabrication parameters, material property correlations, fuel performance models, and thermal-hydraulic boundary conditions all contribute to the uncertainty in calculated fuel pin failure timing. FRAP-T6 has the capability to calculate the uncertainty in fuel behavior responses as a function of known uncertainties in selected input variables and correlations. It is recommended that, in future calculations, the methodology include FRAP-T6 uncertainty analysis to quantify the uncertainty associated with fuel pin failure timing results.

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22. D. A. Powers and R. O. Meyer, *Cladding Swelling and Rupture Models for LOCA Analysis*, NUREG-0630, April 1980.

23. *Code of Federal Regulations*, 10 CFR 50, Appendix K, "ECCS Evaluation Models," January 1, 1991.

24. S. O. Peck, *Code Development and Analysis Program FRAP Uncertainty Option*, CDAP-TR-78-024, July 1978.

Appendix A

Quality Control

Appendix A

Quality Control

All work performed on the timing analysis of PWR fuel pin failures has been conducted in accordance with an approved quality program plan.[A-1–A-5] All source decks, input files, output files, and associated software have been archived on tape and individually listed. All work performed on this project has been fully documented in individual calculation packages and verified by technically qualified independent checkers. Table A-1 provides a listing of calculation packages. The complete analysis file has been recorded and will be permanently retained.

References

A-1. *E&ST Group Quality Program Plan*, Version 1.0, EG&G QPP-200, March 27, 1991.

A-2. E&ST Group Standard Practice 1.0, "Protection of Proprietary and Sensitive Information," May 29, 1991.

A-3. E&ST Group Standard Practice 2.0, "Facility Input Deck Production," May 29, 1991.

A-4. E&ST Group Standard Practice 3.0, "Performance of Engineering Analyses," May 29, 1991.

A-5. E&ST Group Standard Practice 6.0, "Preparation, Modification, Approval, and Control of E&ST Quality Documents," May 29, 1991.

Table A-1. Calculation packages for timing analysis of PWR fuel pin failures.

Date	Title	Author/Reviewer
11/28/90	Core Power Distribution Calculation for LOCA Pin Failure Timing Source Term Analysis, Revision 1	K. R. Jones/D. A. Brownson
11/29/90	Documentation of FRAPCON-2 Version 1, MOD. 05	K. R. Jones/L. J. Siefken
12/6/90	Documentation of FRAPR5, a Passive Link between SCDAP/RELAP5 and FRAP-T6	K. R. Jones/L. J. Siefken
12/11/90	Documentation of TRAC2FRAP Passive Link between TRAC-PF1 and FRAP-T6	D. M. Snider/L. J. Siefken
12/26/90	Documentation of FORTRAN-77 Workstation Version of FRAP-T6 V 21(12/90)	K. R. Jones/L. J. Siefken
1/2/91	Documentation of LOCA Pin Failure Source Term Analysis FRAPCON2 Input Deck Preparation and Results for Seabrook 17X17 PWR	N. L. Wade/L. J. Siefken
1/11/91	Conversion of the Seabrook Input Deck from RELAP5/MOD2 TO RELAP5/MOD3	J. C. Determan/L. S. Ghan
1/25/91	Documentation of SCDAP/RELAP5 Input Deck Preparation Core and Reactor Vessel Model Modifications for Seabrook 17X17 PWR LOCA Pin Failure Source Term Analysis	N. L. Wade/L. S. Ghan
4/2/91	Documentation of SCDAP/RELAP5 Input Deck Preparation Core and Reactor Vessel Model Modifications for Seabrook 17X17 PWR LOCA Pin Failure Source Term Analysis Addendum 1--Revised Downcomer Model	N. L. Wade/J. C. Determan
4/11/91	Point Kinetics, Containment, and SCDAP Input for Seabrook LOCA Pin Failure Timing Source Term Analysis	K. R. Jones/L. J. Siefken
5/20/91	Seabrook SCDAP/RELAP5/MOD3 Calculations for the LOCA Pin Failure Timing Source Term Analysis	K. R. Jones/L. J. Siefken

Table A-1. (continued)

Date	Title	Author/Reviewer
6/4/91	Documentation of FRAP-T6 Input Deck Preparation and Results for Seabrook 17X17 PWR LOCA Pin Failure Source Term Analysis, Revision 2	N. L. Wade/L. J. Siefken
6/4/91	Documentation of LOCA Pin Failure Source Term Analysis FRAPCON-2 Input Deck Preparation and Results for Oconee 15X15 PWR, Revision 1	N. L. Wade/L. J. Siefken
6/10/91	Core Power Distribution Calculation for LOCA Pin Failure Timing Source Term Analysis, Oconee Nuclear Plant, Revision 1	M. Straka/J. C. Determan
6/11/91	SCDAP/RELAP5/MOD3 Input Preparation for LOCA Pin Failure Timing Source Term Analysis, Oconee Nuclear Plant	M. Straka/K. R. Jones
6/19/91	Oconee SCDAP/RELAP5/MOD3 Calculations for the LOCA Pin Failure Timing Source Term Analysis	M. Straka/L. J. Siefken
6/19/91	Documentation of FRAP-T6 Input Deck Preparation for Oconee 15X15 PWR LOCA Pin Failure Source Term Analysis, Revision 1	N. L. Wade/L. J. Siefken
7/17/91	Documentation of FRAP-T6 Results using TRAC-PF1/MOD1 Thermal-Hydraulic Data for Seabrook 17X17 PWR LOCA Pin Failure Source Term Analysis	N. L. Wade/L. J. Siefken
7/19/91	Documentation of TRAC-PF1/MOD1 Input Deck Preparation and Run Results for Seabrook 17X17 PWR LOCA Pin Failure Source Term Analysis	K. R. Katsma-N. L. Wade/ J. M. Cozzuol

Appendix B

Preliminary LOCA Pin Failure Analysis Results Using the Surry Plant Model

Appendix B

Preliminary LOCA Pin Failure Analysis Results

Using the Surry Plant Model

The purpose of Appendix B is to provide the results of the Loss of Coolant Accident (LOCA) Pin Failure Timing Source Term Analysis obtained for the Westinghouse (W) three-loop reactor design using the SCDAP/RELAP5 Surry plant model. Code version SELAP3B was used for this analysis.

The objective of this analysis was to calculate the timings of the containment isolation signals and the first fuel pin failure for a range of large-break LOCAs. A sensitivity was performed to identify the break size resulting in the shortest time to pin failure. The break spectrum analyzed consists of design basis accident (DBA), double-ended, offset shear breaks of a cold leg with break sizes corresponding to 100, 75, and 50% of the cold leg flow area. In order to maximize the duration until the pressurizer low-low trip is reached, the break was located on the coolant loop that does not contain the pressurizer. Except for the accumulators, no emergency core cooling systems (ECCS) were included in the model.

The analysis was performed assuming a 102% core thermal power (CTP) equilibrium core with a peaking factor of 2.18 applied to two hot fuel pins. This value corresponds to the maximum Technical Specification peaking factor for 100% CTP at the core midplane. A detailed three-channel core model was utilized, with the two hot fuel pins placed in the center region. These pins represent low- (5 MWd/MTU) and high- (31,500 MWd/MTU) exposure fuel pins operating at the maximum peaking factor. This exposure difference produces a higher internal pin pressure for the high-exposure fuel due to an increase in fission product gasses. Prompt power and decay heat were modeled using the SCDAP/RELAP5 point kinetics model, with end-of-equilibrium cycle kinetics data based on the Surry Final Safety Analysis Report (FSAR) LOCA analysis. A 15x15 bundle matrix, containing 20 control pins and one instrument tube corresponding to the current Surry fuel bundle design, was modeled for this analysis. Departure from this fuel design may significantly impact the results of this analysis.

A simplified containment model, consisting of a single RELAP5 volume with heat conductors representing steel and concrete surfaces, provided a fairly rough estimate of containment response. A more detailed treatment of containment response would require the use of a containment analysis code; however, results indicate that the containment isolation signal from pressurizer low-low trip trails the signal received from high containment pressure by only about three seconds in each case. Because of the approximate nature of the containment pressure calculation, the containment isolation signal should be assumed to occur when the pressurizer low-low trip is reached.

Cladding deformation and failure is based on the localized ballooning model of SCDAP/RELAP5, as adapted from the BALON2 model of FRAP-T6. This model is intended for analysis of cladding deformation during rapid blowdown transients such as LOCAs. A basic assumption that governs the implementation of this model is that sausage-type deformation occurs up to a specified transition strain value, at which point one node is selected based on maximum cladding temperature.

The transition to the localized ballooning is assumed to occur after a 5% sausage-type strain is reached. The pin failure model does not take into account any constraints imposed by the spacer grids on cladding deformation; however, the increased radiative and conductive heat transfer at the spacer grid locations may reduce the likelihood of failure at these locations.

The timing results obtained for this analysis are displayed in Table B-1 for each break size. Note that pin failure was calculated to occur earliest for the 75% DBA LOCA case, with a pin failure time of 17.5 seconds. The transient results indicate that the DBA LOCA case provides better core cooling during the early phase of the transient in comparison to the 75% DBA LOCA case.

Table B-1. Timing results (s)

Event	DBA	75% DBA	50% DBA
Start of LOCA	0.0	0.0	0.0
High cont. press	1.37	1.65	2.07
Press. low-low trip	4.98	4.98	5.00
Max. cladding temp. >1050 K	3.17	2.65	3.79
Max. cladding temp. >1090 K	3.87	3.22	6.27
High-burnup pin starts ballooning	4.2	4.7	2.4
Low-burnup pin starts ballooning	4.3	4.7	2.4
Start of localized ballooning	12.0	10.7	16.0
High-burnup pin fails	27.5	17.5	36.6
Low-burnup pin fails	27.5	17.7	36.6

The differences in core cooling, evidenced by the drop in cladding temperatures between 8 and 15 seconds in the DBA LOCA case, is due to differences in the flow patterns established through the core region as the fluid contained in the intact coolant loops flashes to steam and finds its way out of the broken cold leg. Following LOCA initiation, fluid contained in the intact loops may reach the break location by passing through the steam generators, the pumps, or the cold leg inlet annulus, then out through the broken cold leg. Alternately, fluid may pass through the hot leg, into the reactor vessel, through the core region, up the downcomer to the cold leg annulus, and then out through the break. In the DBA case, the core rapidly depressurizes. Reverse core flow is established at about 0.3 seconds as a portion of the fluid contained in the intact hot legs and pressurizer passes through the core, cooling the fuel pins and delaying fuel pin failure. In the

75% DBA case, the reactor vessel takes longer to depressurize. During the period up to about 1.5 seconds, fluid in the upper core nodes travels out the hot leg, while flow in the lower core nodes reverses direction to reach the vessel side of the break, resulting in a flow stagnation in the core.

In addition to improved core cooling in the DBA case, f⸱l ballooning and failure is highly dependent on the pressure gradient across the cladding and the temperature of the clad. The zircaloy cladding undergoes a phase change starting at about 1050-1090 K and ending at about 1250 K. In each case, pin failure occurred during this phase transition prior to reaching 1250 K. As a result of this phase change, the material properties of the cladding are rapidly changing throughout the transient.

In each of the cases, pin rupture occurred in axial node 6 of the 10-node core. (Node 1 represents the bottom of the core.) The results indicate very little dependence on fuel pin exposure; however, it should be noted that the limitations of point kinetics prevent modeling of the relative differences in decay heat that would be associated with the differences in fuel pin exposure. For this reason, energy deposition in both the low- and high-exposure pins is identical throughout the transient and produces a conservative estimate of pin failure for the low-exposure fuel pin.

Figures B-1 through B-3 are plots of significant variables for each break size analyzed; Table B-2 provides a description of plot variables. As illustrated in these plots, prompt power drops off rapidly in response to moderator density reactivity feedback. At two seconds, prompt power is further reduced by control rod SCRAM reactivity. Falling pressurizer pressure lags the drop in system pressure due to choking in the pressurizer surge line. The fuel centerline and cladding temperatures appear to correlate well with the internal fuel pin pressures and hoop strains except for two notable exceptions.

The first noticeable incongruity in the calculated results is the hoop strain calculated in node 6 of the 75% DBA LOCA fuel pins. Review of the results indicates that this node, which is the highest temperature node throughout the transient and is ultimately the failure node, expands very little in comparison to the adjacent nodes until the point of failure. This effect, although non-physical, can be explained by examining the implementation of the localized ballooning model. The ballooning model selects the highest temperature node to apply the localized ballooning model when any of the nodes in that SCDAP component exceeds 5% sausage-type strain. In the 75% DBA LOCA case, the sausage-type strain limit of 5% is exceeded in fuel pin node 4 at 4.7 seconds. At this point, the localized ballooning model is applied to the highest temperature node, fuel pin node 6, prior to significant sausage-type strain occurring in that node. Although this results in the calculated strain of node 6 to be artificially lower than that of adjacent nodes, it should not significantly impact the pin failure time.

The second incongruity involves the SCDAP component internal fuel pin pressure calculation. SCDAP calculates the initial fission product inventory in the fuel and gap regions during its initialization phase. The initial fuel pin pressure for the high-exposure fuel pin is calculated to be only slightly higher (6.97 MPa) than that of the low-exposure fuel pin (6.95 MPa). This

Table B-2. Description of plot variables.

Variable	Description
0-rktpow	Total core thermal power (W)
0-rkfipow	Total core fission power (W)
0-rkgapow	Total core decay heat (W)
150-cntrlvar	Reactor water level (m)
190010000-p	Reactor upper head pressure (Pa)
440010000-p	Pressurizer Dome Pressure (Pa)
449010000-p	Containment Pressure (Pa)
0-bgtfprs	Soluble fission product release rate (kg/s)
0-bgtfprn	Insoluble fission product release rate (kg/s)
10-pgas	Low-burnup fuel pin internal pressure (Pa)
13-pgas	High-burnup fuel pin internal pressure (Pa)
1nn10-cadct	Low-burnup fuel pin centerline temperature for node nn (K)
1nn13-cadct	High-burnup fuel pin centerline temperature for node nn (K)
6nn10-cadct	Low-burnup fuel pin cladding temperature for node nn (K)
6nn13-cadct	High-burnup fuel pin cladding temperature for node nn (K)
nn10-hoop	Low-burnup fuel pin cladding hoop strain (dimensionless)
nn13-hoop	High-burnup fuel pin cladding hoop strain (dimensionless)
702-cntrlvar	Total break flow (kg/s)
520010000-mflowj	Accumulator flow - broken loop (kg/s)
530010000-mflowj	Accumulator flow - intact loop (kg/s)
540010000-mflowj	Accumulator flow - intact loop (kg/s)
200010000-mflowj	Broken loop hot Leg flow (kg/s)
300010000-mflowj	Intact loop hot Leg flow (kg/s)
400010000-mflowj	Intact loop hot Leg flow (kg/s)
111nn0000-mflowj	Center core channel junction nn flow (kg/s)

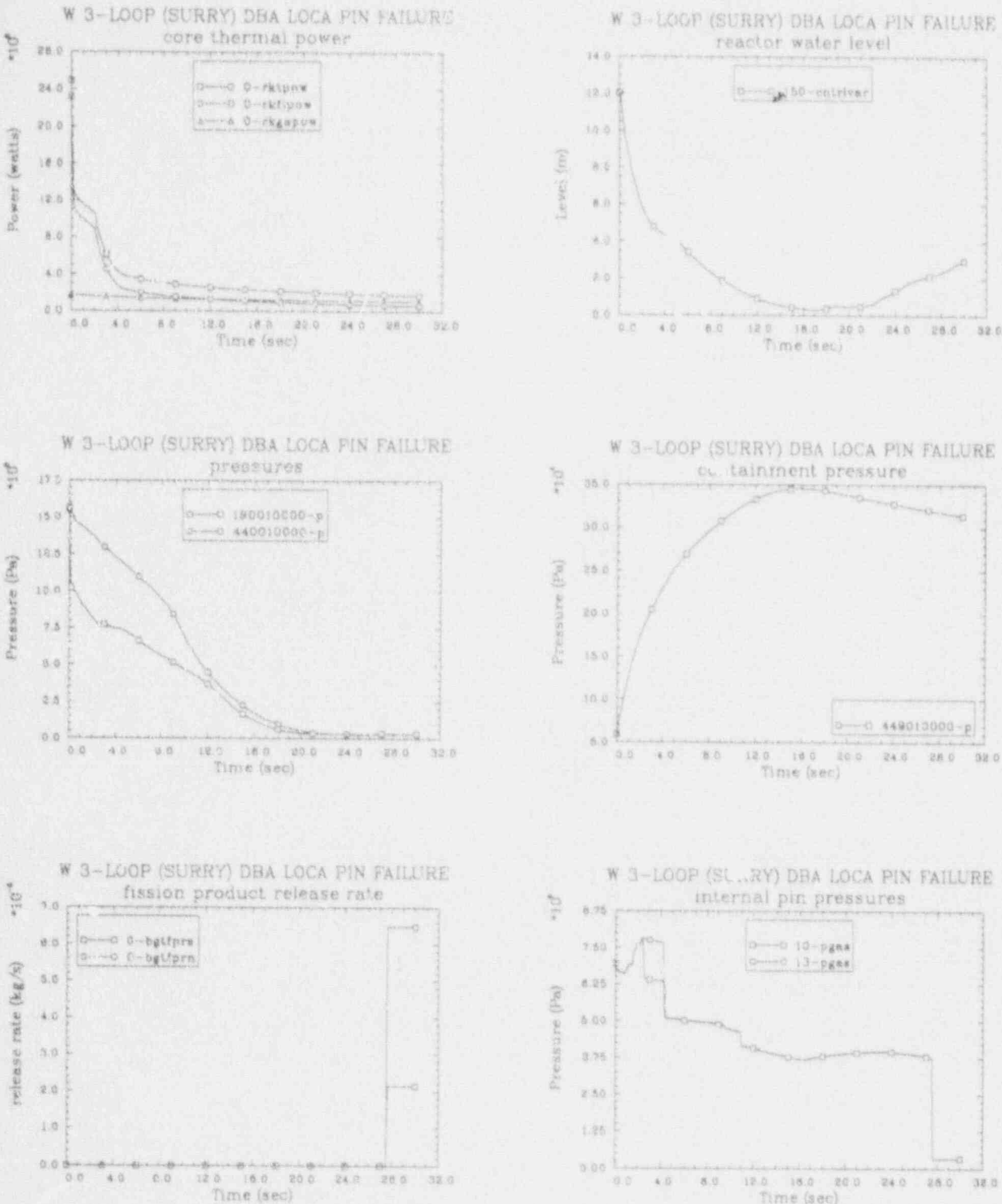


Figure B-1. Plots for the 100% DBA timing analysis of fuel pin failures for Surry using SCDAP/RELAP5/MOD2.5.

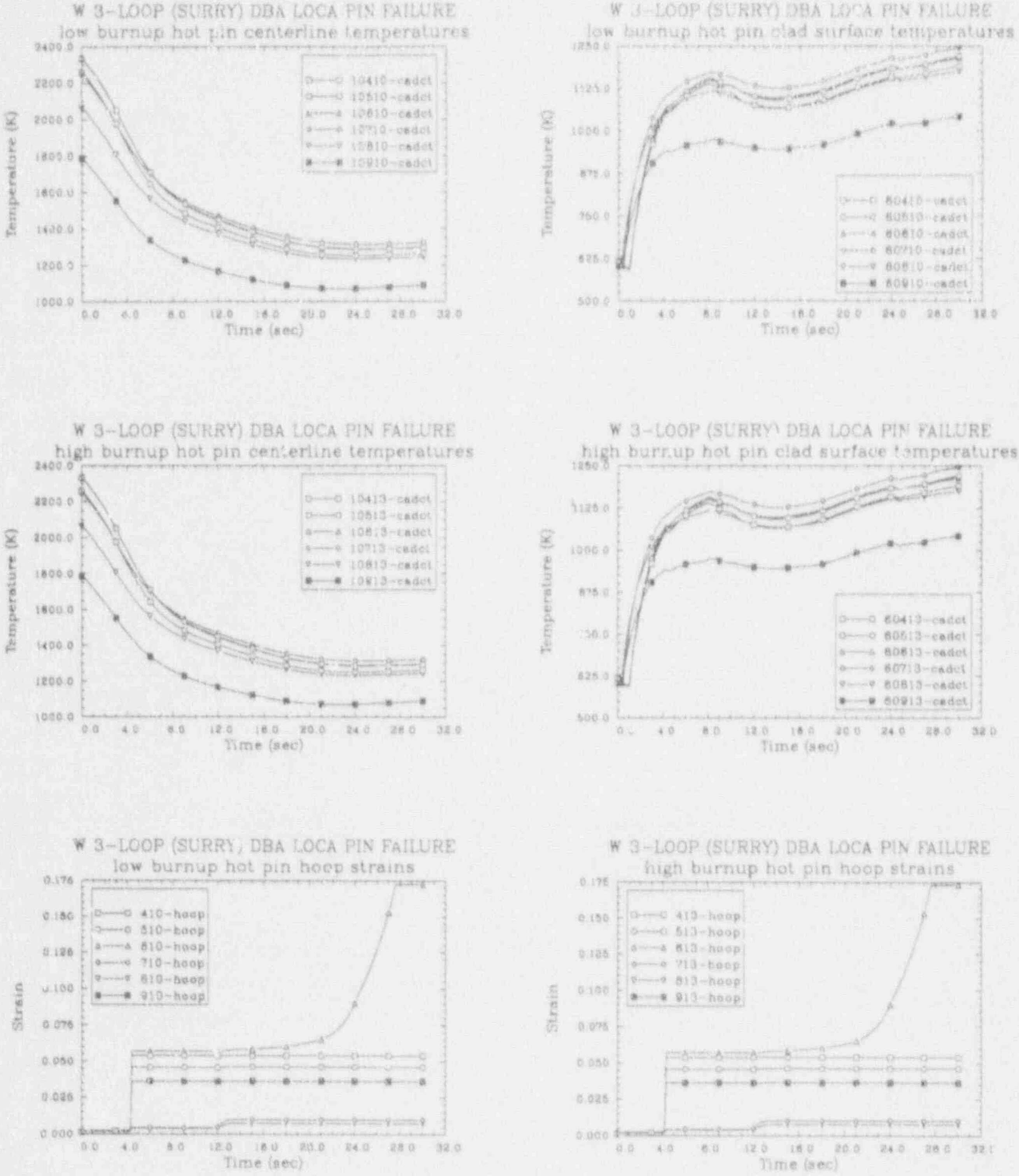
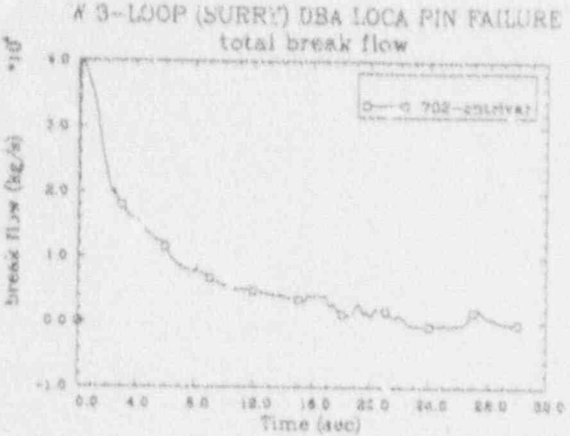
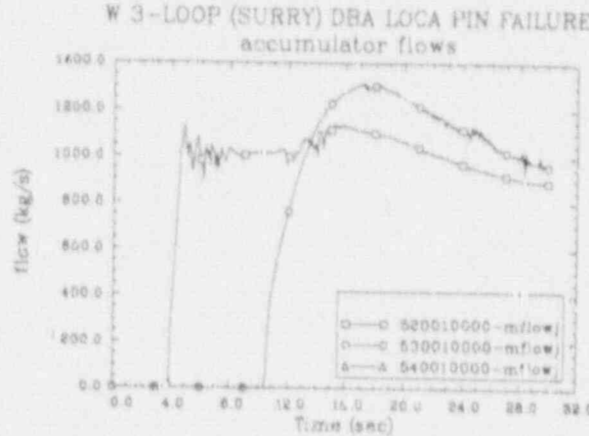
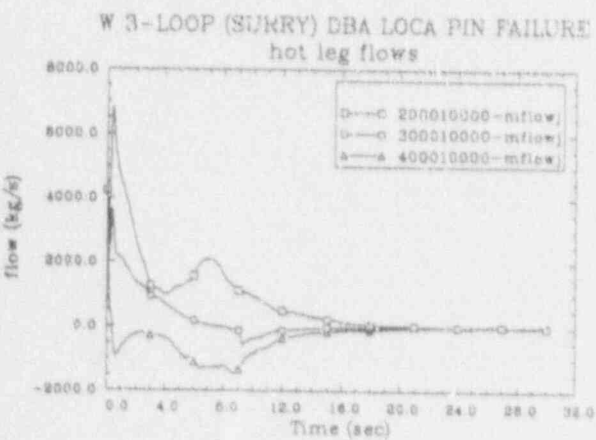


Figure B-1. (continued)







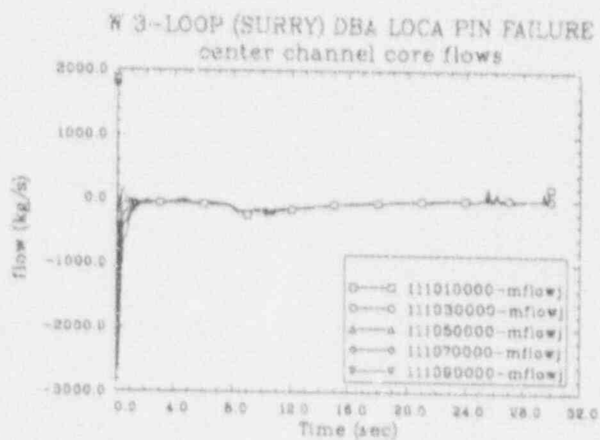


Figure B-1. (continued)

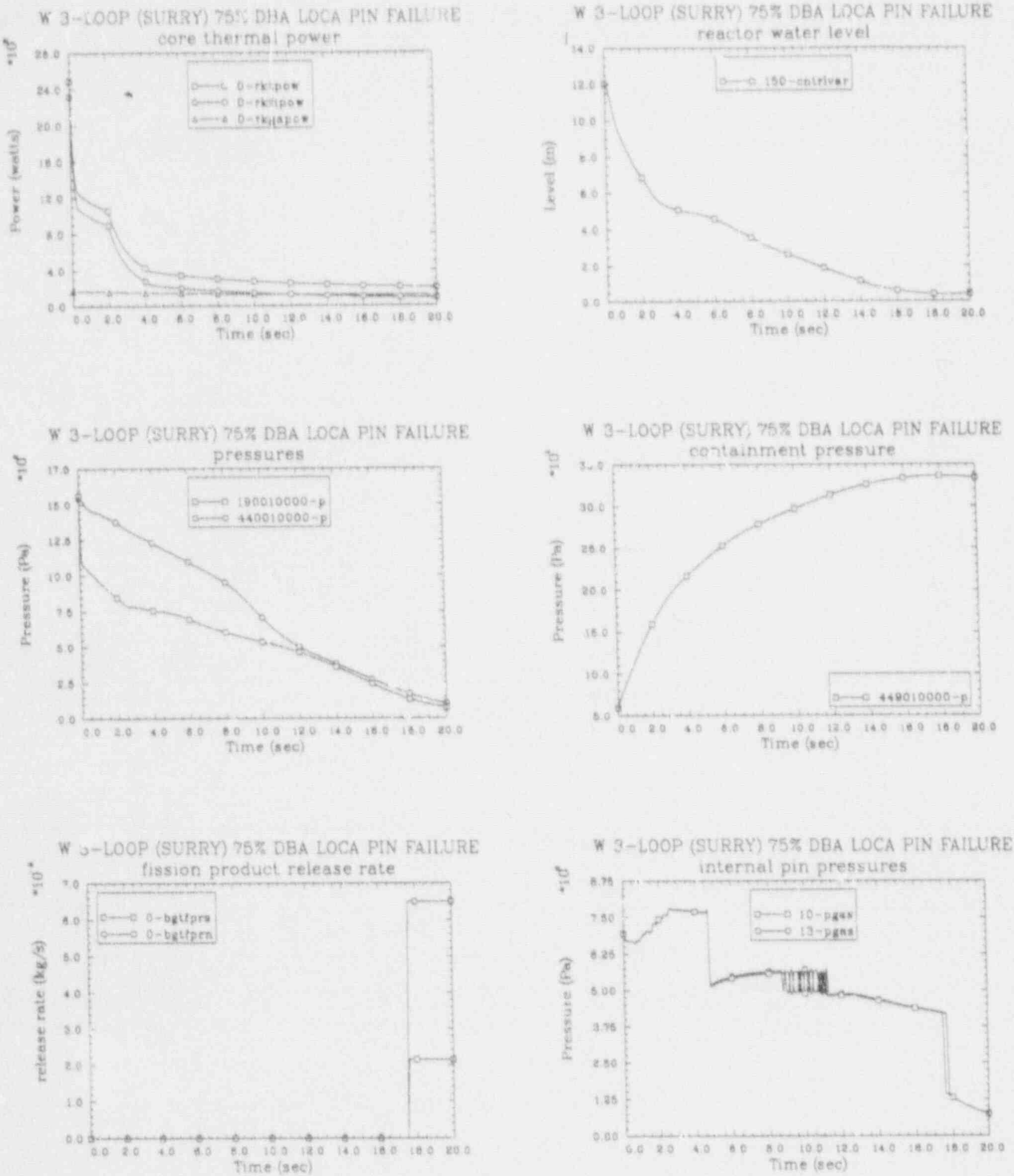


Figure B-2. Plots for the 75% DBA timing analysis of fuel pin failures for Surry using SCDAP/RELAP5/MOD2.5.

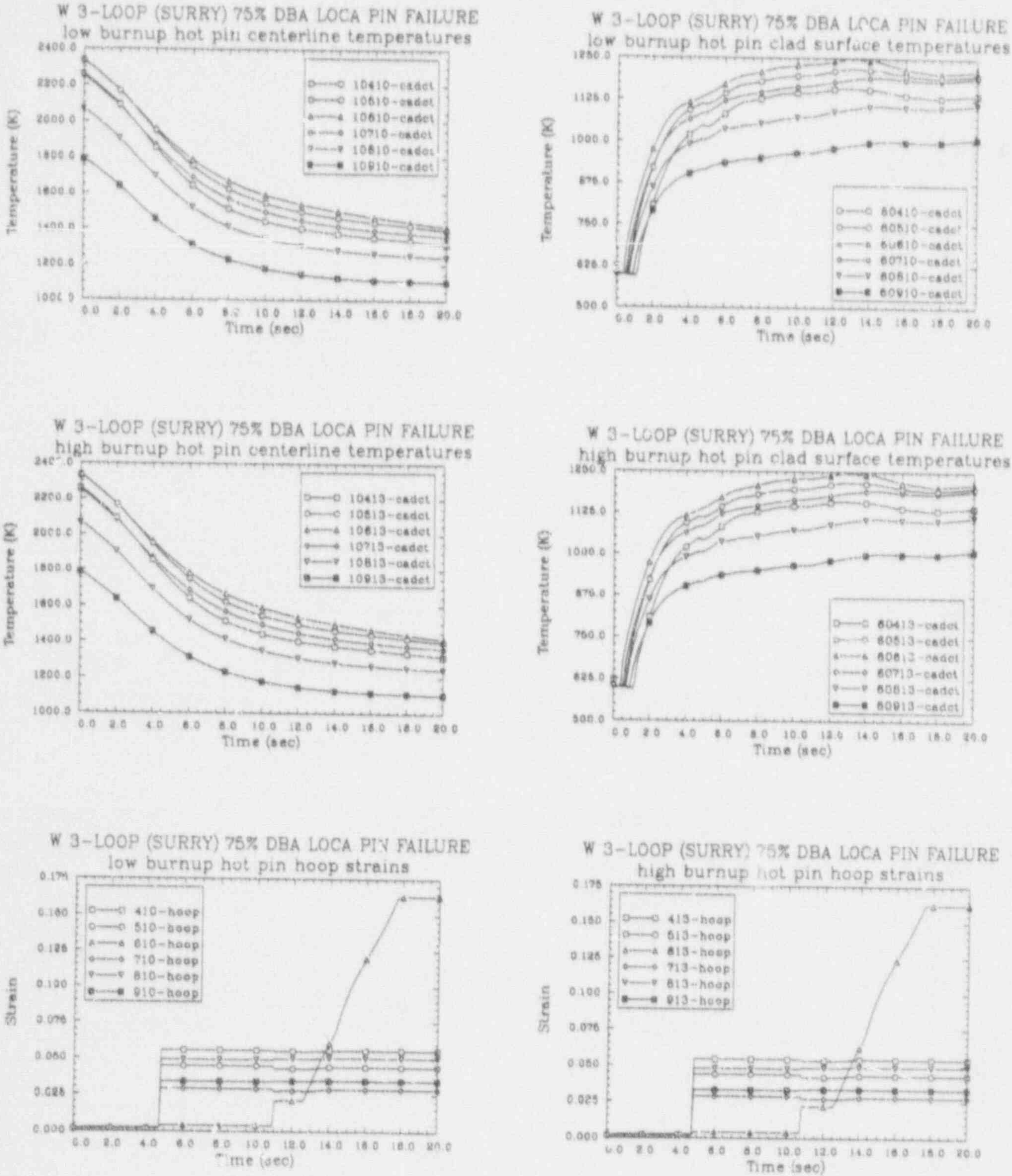


Figure B-2. (continued)

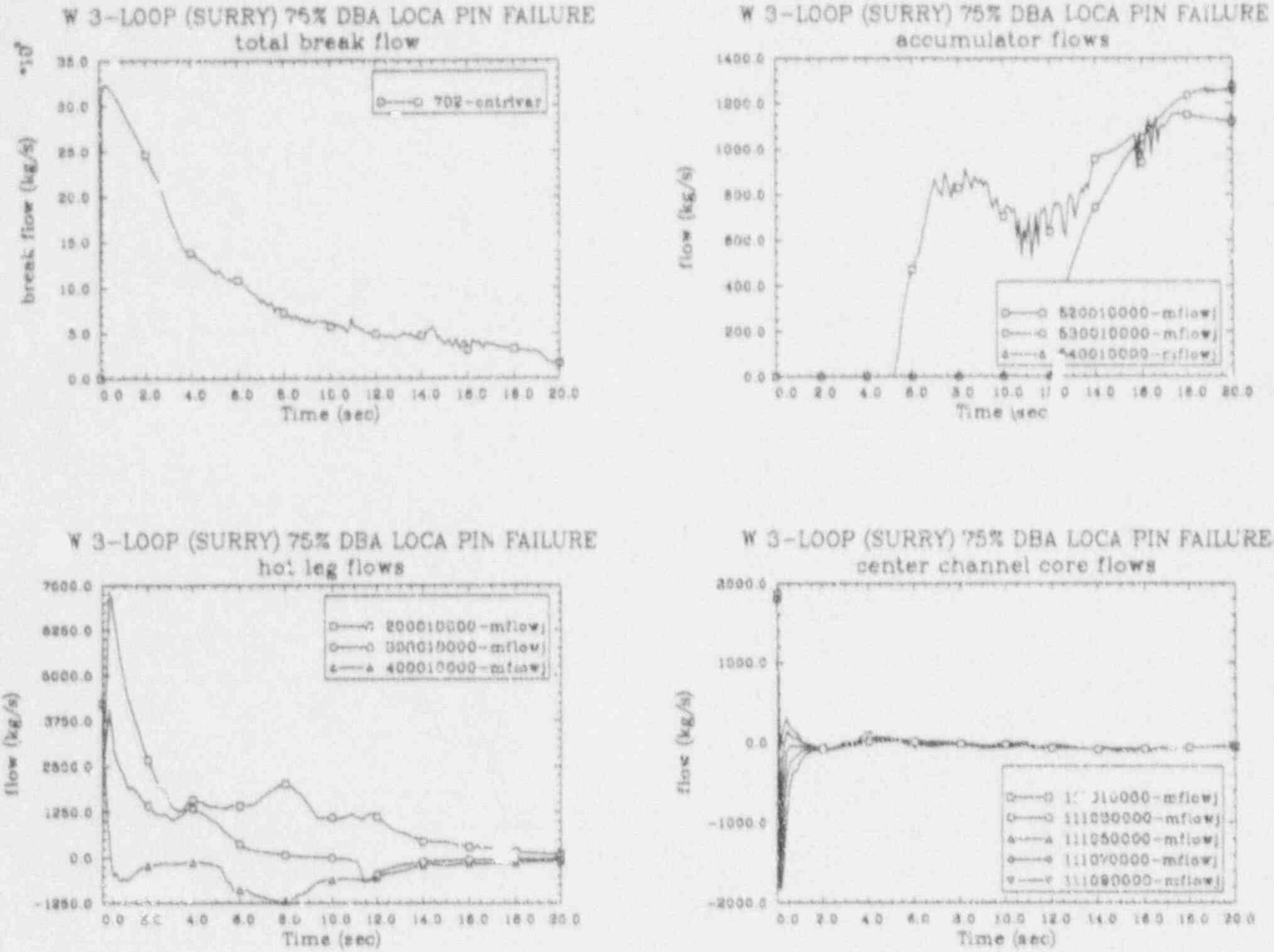


Figure B-2. (continued)

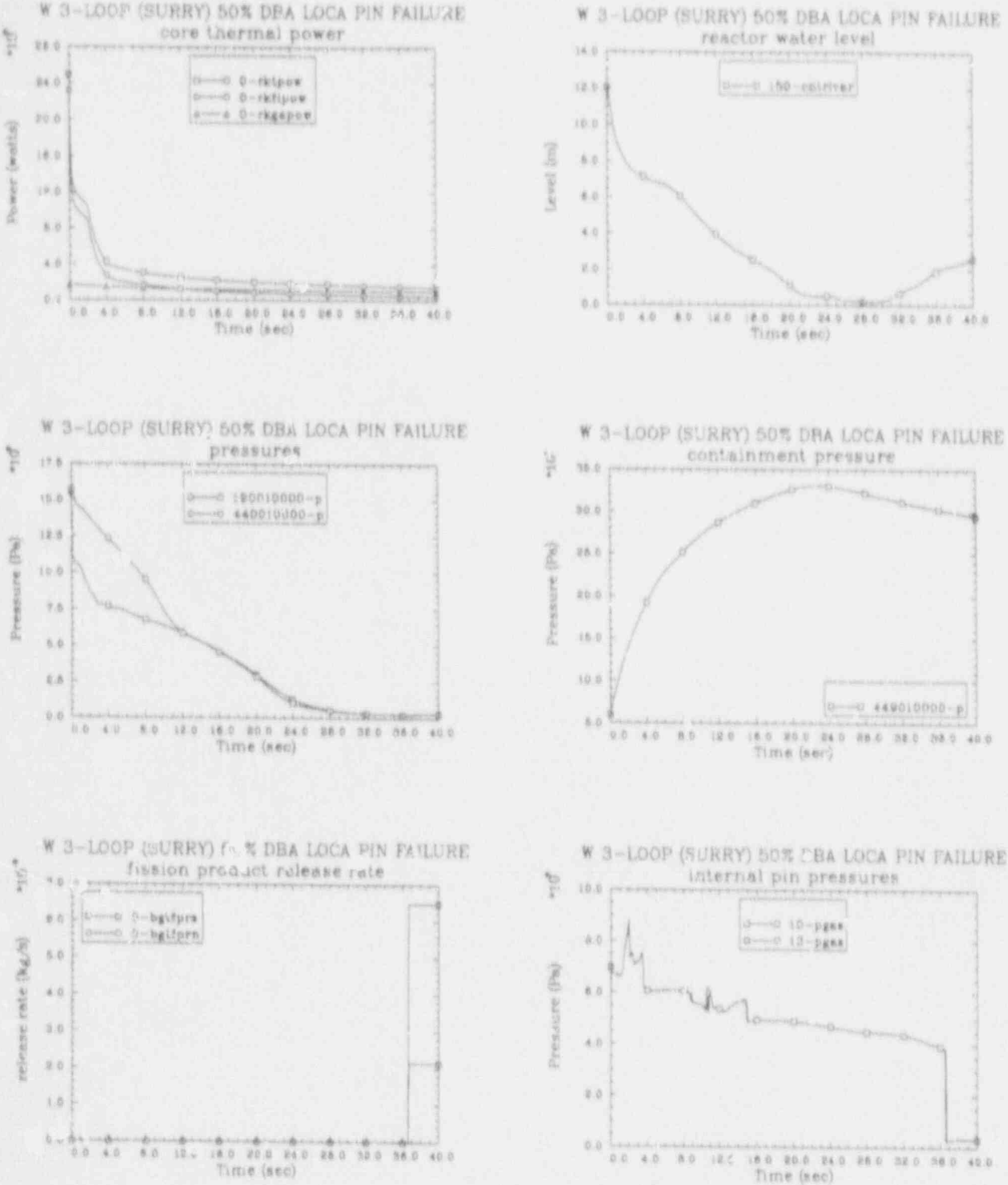


Figure B-3. Plots for the 50% DBA timing analysis of fuel pin failures for Surry using SCDAP/RELAP5/MOD2.5.

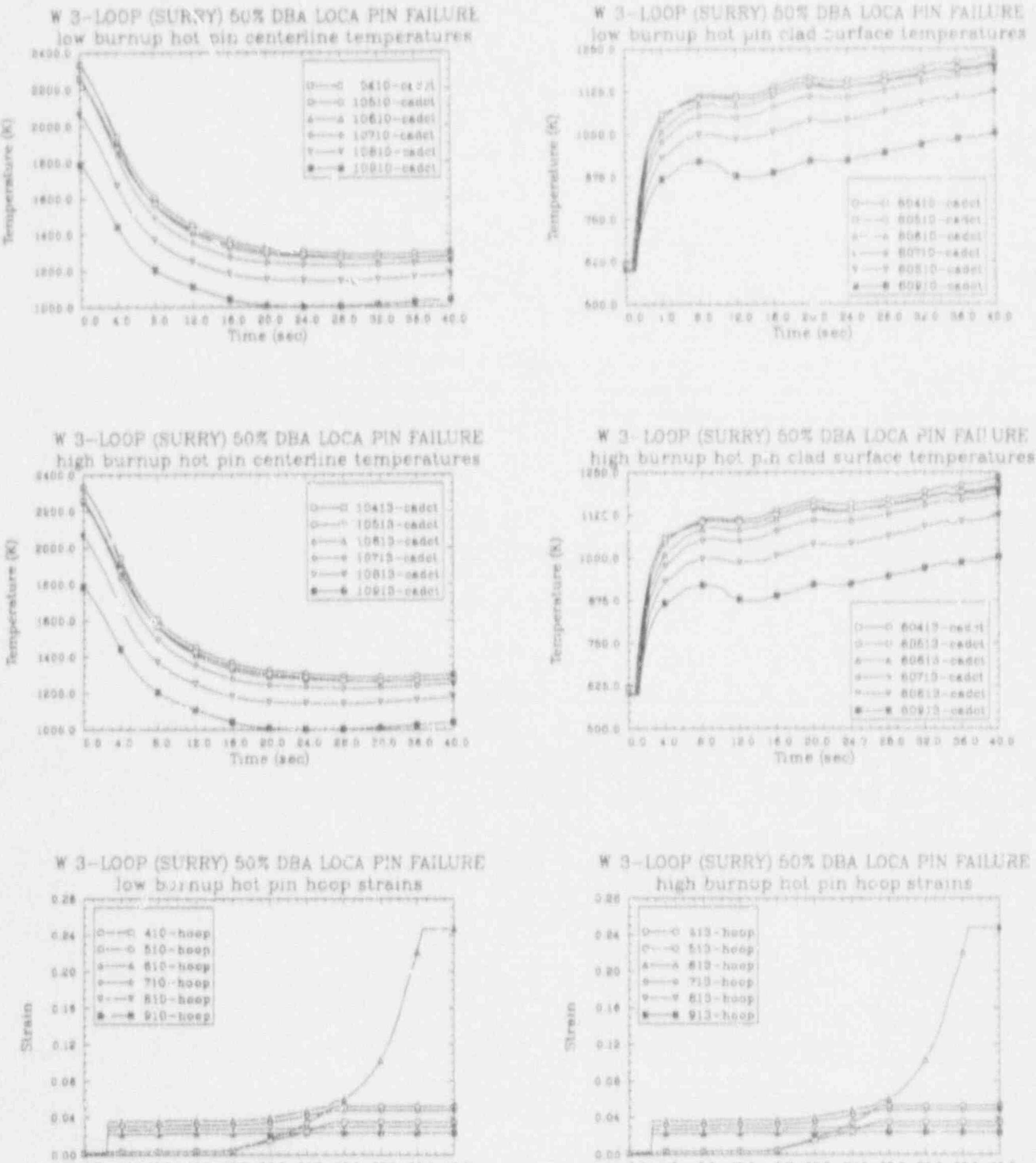


Figure B-3. (continued)

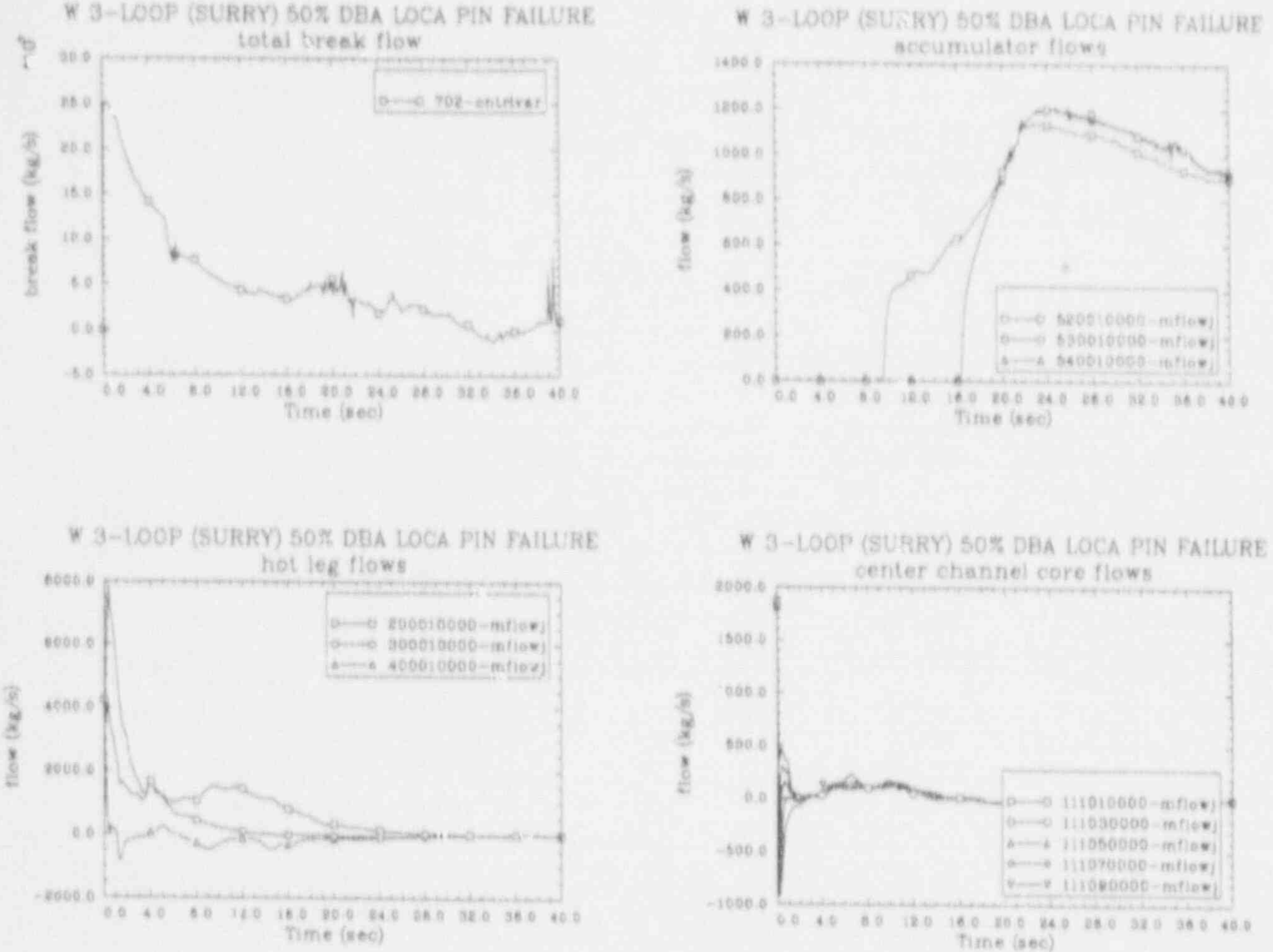


Figure B-3. (continued)

difference appears somewhat lower than expected, considering the difference in exposure between the two fuel pins. The initial total fission product inventories for the two fuel pins do, however, appear to be consistent with their relative levels of exposure. In addition to the problem with the initial internal pin pressure calculation, an internal fuel pin pressure spike occurs in the hot fuel pins in the 50% DBA L^^A analysis. This pressure spike results in early ballooning of the cladding a. 2.4 seconds. This result is currently being investigated, since this pressure rise does not correlate well with the results of the other two cases based on the rates of cladding heatup and the fuel pin temperatures. These inconsistencies indicate that a coding problem may exist in the internal pin pressure calculation of SCDAP/RELAP5.

Several sources of uncertainty enter into this calculation that may significantly impact the results obtained in this analysis. The fundamental assumption governing the point kinetics model is that the power distribution remains constant throughout the transient, changing only in magnitude in response to reactivity feedback mechanisms. This simplification suppresses the effects of the rapidly changing prompt power shape that would be expected for a blowdown transient. A drop in moderator density in the top of the core would cause the code to reduce prompt power by a uniform fraction throughout the core. This could result in lower prompt power at the midplane of the core in the nodes of interest for this calculation. In addition, the ballooning and pin failure models are very sensitive to differences in the heat transfer solution, the fluid conditions of the surrounding thermal-hydraulic nodes, and the changing material properties of the fuel and cladding. A more conservative and probably more realistic measure of fuel pin failure time is the point at which localized ballooning starts, as evidenced by the sudden increase in hoop strain in the failure node. These times are also displayed in Table B-1. Also, it should be noted that intermediate break sizes may exist between the cases analyzed that may result in even shorter times to fuel pin failure than the 75% DBA LOCA case analyzed.

Appendix C

Conversion of FRAPCON-2 and FRAP-T6 to FORTRAN-77

Appendix C

Conversion of FRAPCON-2 and FRAP-T6 to FORTRAN-77

C-1. Introduction

The FRAPCON-2 and FRAP-T6 codes[C-1,C-2] were developed to calculate the steady-state and transient response of light water reactor (LWR) fuel rods. FRAPCON-2 calculates the temperature, pressure, deformation, and failure histories of a fuel rod as functions of time-dependent fuel rod power and coolant boundary conditions. FRAP-T6 calculates all of the phenomena that influence the transient performance of fuel rods, with particular emphasis on temperature, embrittlement, and stress of the cladding. The codes were originally written in FORTRAN IV and programmed for use on CDC Cyber 175 and 176 computers. This Appendix documents the conversion of FRAPCON-2 and FRAP-T6 to portable FORTRAN 77 coding and their preparation for execution on a DEC-5000 workstation. FRAPCON-2, Version 01, Mod. 04 and FRAP-T6 V 20(4/87) were used as a starting point for this conversion. The new code versions have been designated FRAPCON-2, Version 01, Mod. 05 and FRAP-T6 V 21 (12/90).

Section C-2 contains a qualitative description of the coding modifications made to create this version. The results of sample problem execution are discussed in Section C-3, along with comparisons to results generated on the Cyber 176 computer. The original and revised program source files, the UNIX makefile used on the workstation, utility programs used for 32-bit conversion, the program executables, and sample problem runs are archived on a DEC TK50 cartridge tape.

C-2. Code Modifications

Several coding modifications were made to develop the portable FORTRAN 77 (F77) version of the code. For the most part, these modifications are generic in nature, affecting several program units and reflecting elimination of the Cyber-system-dependent memory management routines, differences in allowed programming constructs between FORTRAN IV and FORTRAN 77, changes in the environmental library routines, implementation of advanced graphics capabilities (FRAP-T6 only), and modifications to facilitate conversion to 32-bit coding. The specific coding modifications are too numerous to identify individually on a line-by-line basis, so only a qualitative list of these changes is presented. Modifications applicable to both codes are presented first, followed by those pertinent only to FRAPCON-2 or FRAP-T6.

C-2.1 Generic Code Modifications

The following modifications were made to both FRAPCON-2 and FRAP-T6:

1. All explicit references to single-precision intrinsic functions were replaced with the equivalent generic intrinsic function (i.e., ALOG function calls were replaced with LOG function calls). This modification is necessary to run the program in double precision on 32-bit machines.

2. All of the LEVEL 2 statements were removed. These are Cyber FORTRAN statements for memory management on limited memory systems.

3. The calls to Cyber system routines SYSTEMC, ERRSET, FTBMEM, and STATIC were removed. These system-dependent routines are used to control error recovery and memory management on Cyber computers but are not required in workstation environments.

4. Logic was added to replace the non-F77 standard EOF function calls. These modifications typically involved addition of END qualifiers to READ statements and addition of appropriate transfer logic in placed of the EOF statement.

5. Integer variables that were assigned Hollerith data exceeding four characters in length were replaced by character data types. The corresponding Hollerith fields were changed to literal strings.

8. All double precision D format constants were replaced with E format constants. Floating point constants that were split over two source lines were joined. These modifications corrected errors introduced by an F77 double-precision conversion program, CNV32.

9. The program titles were changed to reflect the new code version, i.e., FRAPCON-2, Version 1, Mod. 05 or FRAP-T6 V 21(12/90).

10. Subroutine IOFILES was added to the program source. The subroutine IOFILES was linked through a call from subroutine DRIVER to establish file handles based on user input from JCL type statements placed before the input file. This allows the user to specify file names including the directory path, file status, file access, file form, and carriage control file attributes for each FORTRAN unit. This subroutine also prints a banner page and file handle summary on the output, which contains the date and start time to uniquely identify the run. A "/*" card terminates the file specification list, and program input follows. The subroutine requires two arguments, which correspond to the primary input and output FORTRAN unit numbers for the program respectively. The input file name containing the file specifications is read from the command line. The format for specification of file handles is as follows:

```
*
FILEnn='/path/filename', STATUS='status' , ACCESS='access',
       FORM='form', CARRIAGE CONTROL='carriage'
*
\*
```

where

nn — is the FORTRAN unit number to be opened. Must be preceded by "FILE" in columns 1 - 4. Possible range of values is 01 - 99.

/path/filename — is the UNIX file path and filename.

status — is the open status of the file. Valid options include: 'NEW', 'OLD', 'UNKNOWN', or 'SCRATCH', corresponding to the FORTRAN77 standard. The default value is 'UNKNOWN'.

access — is the access method for the file. Valid options are 'SEQUENTIAL' and 'DIRECT', with 'SEQUENTIAL' being the default value.

form — indicates the file format and has two possible options: 'FORMATTED' and 'UNFORMATTED.'

carriage — indicates whether the first character from each sequential formatted output record will be used as FORTRAN printer carriage control characters. Possible options are 'FORTRAN' and 'LIST'. The default values are 'LIST' for disk files and 'FORTRAN' for DOS devices.

* — indicates the end of the file processing input. The input file for the ATMOS module (Unit 24) is placed directly after this. card.

NOTE: Comments can be entered by placing a '*' in column 1 and will be echoed to the output file. Only the UNIT number and file name are required input. Columns 73 - 80 are reserved for comments. A line ending in a comma is continued on the following line.

11. Subroutine SECOND, which returns the current CPU time in seconds, was replaced in the program source.

C-2.2 FRAPCON-2 Code Modifications

The following modifications were made only to FRAPCON-2:

1. The calls to AXDRIV, PELET, AXIWRT, and RADIAL were commented out. These calls represent an alternate fuel deformation model. The files containing these routines were not available for conversion and are not necessary for most analyses. Selection of these options will result in an appropriate error message with program abort.

2. Subscripts of unity were added to array variables JPEAK and FLUX. These array variables were accessed in several arithmetic statements without subscripting; F77 requires subscripting of all array elements when used in arithmetic statements.

3. All common blocks containing an unaligned mixture of integers and floating point values were reordered to preserve 8-byte alignment. In addition, common blocks BA, FAST, LACMDL, and LIMITS were replaced with INCLUDE statements and corresponding include files were created.

4. The generic intrinsic function ERF was replaced with the double-precision intrinsic function DERF. The compiler was not automatically substituting the double-precision version of the function when passed a double-precision argument, resulting in erroneous values being returned.

5. The calculations of b(2) and b(3) in subroutine FLUXD were modified to prevent generation of NaN quantities due to 0/0 arithmetic.

6. Program coding to allow restart capability and creation of FRAP-T6 initial conditions files was reactivated. These options had previously been hardwired off.

C-2.3 FRAP-T6 Code Modifications

The following modifications were made only to FRAP-T6:

1. DECODE and ENCODE functions were replaced with F77 portable internal READ and WRITE statements, respectively.

2. Common blocks containing integers that are written to the restart tape were padded with additional dummy integers to preserve total block length. All common blocks containing an unaligned mixture of integers and floating point values were reordered to preserve 8-byte alignment. In addition, the following common blocks were replaced with INCLUDE statements and corresponding include files were created:

bcdcom	bdg02d	bdgr	bdgr2
bdgr4	bdgr5	bloona	bloonb
carcom	collct	coold	cwio
dalcom	defcom	desnbl	dialb
dyna	excb	flecht	frapc
frpsto	gr0235	gr2a3	gr2a4
graph	grassb	grhold	grsptr
gtwolc	htcb	intcom	iocom
ipnt	lacmdl	matfc2	matprc
modcom	numcom	pfcmi2	pfrcs2
phypro	powcom	powrd	presb1
presb2	prntb	prog	qconb
resti1	resti2	resti3	restr1
riptbl	scalr1	scalr2	scalr3
skpidx	thcntl	thyd	

3. All calls to water property routines were modified to allow using the INEL environmental library version 611 created on 2/6/90. This is the same environmental library currently being used for SCDAP/RELAP5.

Modifications consisted of replacing the water property routine calls with corresponding routines from the new library and redimensioning of the prop arrays from 23 to 26.

4. The Nuclear Plant Analyzer (NPA)[C-7] and GRAFITI[C-4] graphics packages were interfaced to FRAP-T6. The NPA provides an interactive graphics capability with customized data displays. This capability allows a vast amount of data to be visually displayed during or after program execution in a form that greatly simplifies interpretation of the computer simulation. The GRAFITI graphics package provides presentational quality graphics capability. These graphics packages were originally developed at the INEL to provide advanced graphics capability for RELAP5. The graphics interface is controlled through subroutines GRAFINI, GRAFOUT, and NPASTOP which have been added to the program source.

5. The following optional inputs may be supplied in the JCL section to control execution of the NPA. See the NPA reference manual[C-5] for a further description of these inputs.

NPAON	Flag to turn on the NPA interface.
NPADBG	Flag to turn on debug output of NPA channels.
NPATRACE	NPA trace option flag.
NPAASY	NPA asyncronous option flag.
NPACOM	NPA communication flag.
NPAPAX='paxfile'	Name of pax file created by CVS for NPA.
NPAMASK='maskname'	Optional name of initial NPA mask.
NPADUH='datafile'	Name of NPA data file. Defaults to paxfile with ".duh" extension.
NPASERV='server'	Name of UNIX server.

C-3. Code Conversion

The modified program routines were split into individual source files with .F and .H extensions, corresponding to F77 source and include files, respectively. A double-precision conversion program, CNV32, also written in F77, was used to convert these .F and .H files to double-precision source files with .f and .h extensions, respectively. CNV32 was originally developed to automate conversion of RELAP5 source files to double precision for 32-bit architectures. It is utilized in the case of FRAPCON-2 and FRAP-T6 to convert all floating point constants to double precision and to provide alignment of integer arrays (containing four-byte elements) equivalenced to double-precision arrays (containing eight-byte elements).

A makefile was written to simplify compiling the program in a UNIX environment. The UNIX **make** utility utilizes the makefile to control conversion of the .F files to double-precision source files with .f extensions using CNV32 and controls the compiling and linking of objects to produce the program executable.

The FRAPCON-2 and FRAP-T6 programs were compiled using version 2.0 of the DEC MIPS F77 compiler on a DECstation 5000 with the following compiler options:

-G 0 -O0 -r8 -static -g -align32 -w1

No error or warning messages were generated during the compilation.

C-4. Code Verification

Sample cases exercising both FRAPCON-2 and FRAP-T6 were executed on the DEC5000 workstation, and the results were compared with those generated by the Cyber, as retrieved from the FRAPCON-2, Version 1, Mod 04 and FRAP-T6 V 20(4/87) transmittal tapes. The title descriptions for these sample problems were:

For FRAPCON-2:

1. CC/EPRI ROD 39 (300 PSIG,2CYCLE)
2. GE/MONT.ROD-BNA-208(MTB099,A1)
3. STANDARD PWR TEST CASE

For FRAP-T6:

1. STANDARD PROBLEM #1[C-2]

Both input and output from these sample problems have been archived.

For FRAP-T6, the results obtained on the workstation are in excellent agreement with the results generated by the Cyber computer. No differences were found between the results generated on each machine. For FRAPCON-2, the results obtained on the workstation are in good agreement with the results generated on the Cyber computer. The slight deviations between these sets of results can be attributed to differences in machine precision and floating point round-off.

It should be noted that although good agreement was achieved between the workstation and Cyber results for FRAPCON-2, in each of the sample cases error messages were printed that indicate convergence problems were encountered in AXRACH. Identical error messages were printed in each code version. This convergence problem was traced to an earlier coding modification, which changed the definition of an input array. The input array, FLUX, originally defined as the fast neutron fluence at each axial node, had been changed to the ratio of the fast neutron fluence to the specific power. This change was not reflected in the sample problem input files, resulting in convergence problems. The sample problems were run to converged solutions after input changes were made to reflect the change in the definition of FLUX.

C-5. References

C-1. G. A. Berna et al., *FRAPCON-2: A Computer Code for the Calculation of Steady State Thermal-Mechanical Behavior of Oxide Fuel Rods*, NUREG/CR-1845, January 1981.

C-2. L. J. Siefken et al., *FRAP-T6: A Computer Code for the Transient Analysis of Oxide Fuel Rods*, NUREG/CR-2148, EGG-2104, May 1981.

C-3. D. M. Snider, K. L. Wagner, and W. Grush, *Nuclear Plant Analyzer (NPA) Reference Manual, Mod-1*, EGG-EAST-9096, April 1990.

C-4. John E. Streit et. al., *GRAFITI Users Manual*, EGG-CATT-9604, March 1991.

Appendix D

Development of the FRAPR5 and TRAC2FRAP Interface Codes

Appendix D

Development of the

FRAPR5 and TRAC2FRAP Interface Codes

Appendix D describes the FRAPR5 and TRAC2FRAP programs. FRAPR5 and TRAC2FRAP were written to provide passive links between FRAP-T6[D-1] and SCDAP/RELAP5/MOD3[D-2] and TRAC-PF1/MOD1,[D-3] respectively. Detailed descriptions of the two programs follow.

D-1. The FRAPR5 Code

An input option of FRAP-T6 [V 21 (12/90)] allows the code to read the transient thermal-hydraulic boundary conditions from a binary data file.[D-1] FRAPR5 is used to create this binary data file from the SCDAP/RELAP5/MOD3 ascii strip file. Section D-1.1 describes FRAPR5, and Section D-1.2 discusses input to FRAPR5 and gives sample inputs.

D-1.1 FRAPR5 Code Description

The thermal-hydraulic boundary condition data required by FRAP-T6 for each time step are defined in Appendix E of Reference D-1 and include:

a. The transient time (s)
b. Coolant pressure (psia), enthalpy (BTU/lbm), and bulk fluid temperature (°F) in the upper and lower plenums.
c. Top and bottom node elevations (ft), coolant pressure (psia), enthalpy (BTU/lbm), bulk fluid temperature (°F), and mass flux (lbm/ft^2-h) for each core node.

Table D-1 lists, by variable name, the SCDAP/RELAP5/MOD1 strip file data required to create the FRAP-T6 data file. Prior to generating the binary FRAP-T6 boundary condition file, the program will scan the SCDAP/RELAP5/MOD3 strip file to confirm that all of the required data are available. If any information is missing, a list of the missing quantities is printed and execution is terminated.

Coolant pressures for each thermal-hydraulic node are read directly from the SCDAP/RELAP5/MOD3 strip file and converted from pascal to psia. Since SCDAP/RELAP5/MOD3 does not directly calculate fluid enthalpy, the following equation is used to generate the coolant enthalpy from SCDAP/RELAP5 quantities:

Table D-1. List of data required from SCDAP/RELAP5/MOD3 strip file.

	Upper and lower plenum	Core nodes
	p	p
	uf,ug	uf,ug
	rhof,rhog	rhof,rhog
	quals	quals
	tempf,tempg	tempf,tempg
		voidf,voidg
		velf,velg

h = [(uf+p/rhof)*(1-quals)+(ug+p/rhog)*quals]/2326.0 (D-1)

where

h	=	fluid enthalpy (BTU/lbm)
p	=	coolant pressure (Pa)
rhof	=	liquid phase density (kg/m^3)
rhog	=	vapor phase density (kg/m^3)
uf	=	liquid phase specific energy (J/kg)
ug	=	vapor phase specific energy (J/kg)
quals	=	static volume quality.

The bulk fluid temperature is based on either the volume liquid temperature or the volume vapor temperature, depending on whether the static volume quality is above or below 0.5. The following equations are used to determine the bulk fluid temperature for each volume:

For quals $\leq$ 0.5:

tblk = (tempf - 273.15) * 1.8 + 32.0 (D-2)

For quals > 0.5:

tblk = (tempg - 273.15) * 1.8 + 32.0 (D-3)

where

tblk	=	bulk fluid temperature (°F)
tempf	=	liquid phase temperature (K)
tempg	=	vapor phase temperature (K)

The coolant mass flux at each core node is calculated by the following equation:

$$G = [(velf*rhof*voidf)+(velg*rhog*voidg)]/0.0013562 \quad (D-4)$$

where

G	=	coolant mass flux (lbm/ft^2-h)
velf	=	liquid phase volume oriented velocity (m/s)
velg	=	vapor phase volume oriented velocity (m/s)
voidf	=	liquid phase void fraction
voidg	=	vapor phase void fraction.

D-1.2 FRAPR5 Input Requirements

FRAPR5 requires a short, fixed-format input file, containing the following information:

Card 1--Output file name (A50). Enter up to 50 characters for the file name to be used for standard output. A directory path may included as part of the name. If the file currently exists, it will be overwritten.

Card 2--FRAP-T6 binary boundary condition file name (A50). Enter up to 50 characters for the file name to be used to store the FRAP-T6 boundary conditions. A directory path may included as part of the name. If the file currently exists, it will be overwritten.

Card 3--SCDAP/RELAP5 stripf file name (A50). Enter up to 50 characters for the file name of the SCDAP/RELAP5 stripf file. A directory path may included as part of the name.

Card 4--Program control and debug options (3I6).

I1 = skip factor. Enter an integer value representing the number of SCDAP/RELAP5 records to skip between writing FRAP-T6 boundary condition records. (Enter -1 to disable skip factor.)

I2 = debug flag for SCDAP/RELAP5 stripf data interpretation. Enter 0 to disable or 1 to enable option.

I3 = debug flag for FRAP-T6 data interpretation. Enter 0 to disable or 1 to enable option.

Card 5: Time controls (3F10.3).

R1 = initial time (s); Enter SCDAP/RELAP5 transient time to begin writing FRAP-T6 records.

R2 = end time (s); Enter SCDAP/RELAP5 transient time to stop writing FRAP-T6 records.

R3 = minimum FRAP-T6 data interval (s); Enter minimum time spacing between FRAP-T6 records. If R3 is less than the SCDAP/RELAP5 time step, then the data interval equals the SCDAP/RELAP5 time step.

Card 6: Plenum data card [2(A9,1x)].

A1 = RELAP5 volume number for lower plenum

A2 = RELAP5 volume number for upper plenum

Card 7,N: Volume data cards (A9,2F10.3). Enter one card for each SCDAP/RELAP5 core volume starting with the bottom core node:

A1 = RELAP5 volume number

R1 = Elevation of bottom of node from bottom of active fuel (ft). If 0.0 is entered for this value on Card 8 or greater, value used will correspond to the elevation of the top of the previous node.

R2 = Elevation of top of node from bottom of active fuel (ft). If 0.0 is entered for this value on Card 8 or greater, value used will correspond to the elevation of the bottom of this node plus the height of the previous node

Card N+1: End terminator (A). Terminate the deck with a card starting with a period in column 1; i.e., A1 = .

Figure D-1 shows a sample input file.

```
/kkju0/kkj/frap/frapr5/frapr5.out
/kkju0/kkj/frap/frapr5/frapr5.dat
/kkju0/kkj/frap/frapr5/stripf
    10     0     1
      0.000  1000.000      0.000
108010000 161010000
111010000     0.000     1.200
111020000     0.000     0.000
111030000     0.000     0.000
111040000     0.000     0.000
111050000     0.000     0.000
111060000     0.000     0.000
111070000     0.000     0.000
111080000     0.000     0.000
111090000     0.000     0.000
111100000     0.000     0.000
.
```

Figure D-1. Sample input file for FRAPR5.

FRAPR5 is written in FORTRAN-77 and was compiled and tested on a DEC-5000 workstation. The program is executed by providing a single command line argument specifying the input file name:

```
> frapr5.x  frapr5.inp
```

where frapr5.x is the name of the executable and frapr5.inp is the name of the frapr5 input file. Figure D-2 gives a listing of the source program. Both the source program and sample problem results are archived on tape.

```
      program  frapr5
      implicit real*8(a-h,o-z)
c
c     Create frap-t6 coolant boundary condition file from
c     relap5 strip file
c
c     Original 09/90: Ken Jones, INEL
c
      parameter (mvar = 1000)
      parameter (mj = 20)
c
      logical    debg1, debg2
      logical    lexist
c
      character*10 num1
      character*9  varn(mvar)
      character*9  varnm(mvar)
      character*40 ttitle1(2),ttitle2(2)
      character*16 thedate,today
      character*9  cvol(mj),nup,nlp
      character*50 stripf,frapout,frapdat
      character*50 iofile,cmdline,filenm
      data iofile /'frapr5.in'/
c
      integer  icvp(mj),icvuf(mj),icvug(mj),icvrhof(mj),icvrhog(mj),
     *         icvxs(mj),icvtf(mj),icvtg(mj),icvvf(mj),icvvg(mj),
     *         icvvelf(mj),icvvelg(mj)
c
      dimension y(mvar)
      dimension zb(mj), zt(mj), pcv(mj), tbcv(mj), gcv(mj), hcv(mj)
c
      debg1 = .false.
      debg2 = .false.
c
c  open input file using command line input or prompt
c
      if(iargc().gt.0) then
        call getarg(1,cmdline)
      else
        cmdline=iofile
      endif
   20 iofile=(cmdline)
      inquire(file=iofile,e
      if(.not. lexist) then
        write(0,1130) iofile
        read(5,1400) cmdline
        if((cmdline) .eq. 'q'  .or.
     *     (cmdline) .eq. 'Q') goto 99999
        goto 20
      endif
```

Figure D-2. Source listing for FRAPR5.

```
      iunit = 1
      filenm=iofile
      open(iunit,file=filenm  ,iostat=msgno,err=40,
     *     status='old',form='formatted')
c
c     read frapr5 input data
c
c  -- card 1 read standard output filename and open file
    1 read (1,'(A)',err=600) frapout
      if(frapout(1:1).eq.'*') goto 1
      iunit = 6
      filenm=frapout
      open(unit=iunit,file=filenm,iostat=msgno,err=40,status='unknown',
     *     form='formatted',carriagecontrol='list')
c
c     write title to output
c
      ipg = 1
      call thedate(today)
      write (6,1110) today, ipg
      write(6,1200) iofile,frapout
c
c  -- card 2 read frap-relap5 data filename and open file
      read (1,'(A)',err=600) frapdat
      iunit = 7
      filenm=frapdat
      open(unit=iunit,file=filenm,iostat=msgno,err=40,status='unknown',
     *     form='unformatted')
      write(6,1201) frapdat
c
c  -- card 3 read relap5 strip filename and open file
      read (1,'(A)',err=600) stripf
      iunit = 5
      filenm=stripf
      open(unit=iunit,file=filenm,iostat=msgno,err=40,status='old',
     *     form='formatted',carriagecontrol='list')
      write(6,1202) stripf
c
c  -- card 4 read skip and debug control
      read (1,2005,end=100) kstep, idbg1, idbg2
      if(kstep .gt. 1) write (6,1106) kstep
      if(idbg1 .gt.0) then
      debg1 = .true.
      write (6,1210)
      else
      write (6,1211)
      endif
      if(idbg2 .gt.0) then
      debg2 = .true.
      write (6,1212)
```

Figure D-2. (continued)

```
      else
     write (6,1213)
      endif
c
c  -- card 5 read time controls
      read (1,2012) tmin, tmax, tdel
      write (6,1115) tmin, tmax
      if (tdel.gt.0.0) write (6,1116) tdel
c
c  -- card 6 read plenum data card
      read (1,2011) nlp, nup
      write (6,1117) nlp, nup
c
c  -- card 7,.... read volume cards
      write (6,1119)
      k = 1
   60 read (1,2018,end=100) cvol(k), zb(k), zt(k)
      if (cvol(k)(1:1) .eq. '.') go to 100
      if (k.gt.1 .and. zb(k).le.0.)  zb(k) = zt(k-1)
      if (k.gt.1 .and. zt(k).EQ.0.0) zt(k) = zb(k)+(zt(1)-zb(1))
      write (6,1120) cvol(k), zb(k), zt(k)
      if (zt(k) .le. zb(k)) then
     write (6,1144)
     go to 200
      endif
      k = k+1
      if (k-1.le.mj) go to 60
      write(6,1175) mj
      goto 200
c
  100 continue
      nz = k-1
c
c     read plot control data
c     read(5,2000) ttitle1(1), ttitle1(2)
      read(5,2000) ttitle2(1), ttitle2(2)
      write(6,1220) ttitle1(1), ttitle1(2)(1:39),
     *              ttitle2(1), ttitle2(2)(1:39)
      read(5,2666) numl, nvar, nzero
      ipg = ipg + 1
      write (6,1110) today, ipg
      write(6,*)' numl, nvar, nzero= ',numl, nvar, nzero
      if (numl .ne. '  plotinf ') then
        print *, '  plotinf card not found, file 1'
        go to 99999
      endif
c
c     read data codes and compare between files
c
c     linvar = number of lines of variables to read (sets of 8).
```

Figure D-2. (continued)

```
c     if nvar is an exact factor of 8 then don't add 1 to linvar.
c
      linvar = nvar/8
      if ((nvar - linvar*8) .gt. 0) linvar = linvar + 1
      write(6,*) ' lines(rows) of plot variables to read= ',linvar
      k = 0
      do i=1,linvar
        read(5,2667) (varn(k+j),j=1,8)
        write(6,2667) (varn(k+j),j=1,8)
        k = k + 8
      enddo
      if(varn(2) .ne. 'time     ') then
        print *, ' stop; time is not the first use, variable'
        print *, ' the first variable is=', varn(2)
        write(6,*) ' stop; time is rot the first user variable'
        write(6,*) ' the first variable is=', varn(2)
        go to 99999
      endif
c
c     read data parameters
c
      k = 0
      do i=1,linvar
         read(5,2663) (varnm(k+j),j=1,8)
         write(6,2663) (varnm(k+j),j=1,8)
         k = k + 8
      enddo
c
c  -- initialize indexes to zero
c     ilpp    = 0
      ilpuf   = 0
      ilpug   = 0
      ilprhof = 0
      ilprhog = 0
      ilpxs   = 0
      ilptf   = 0
      ilptg   = 0
c
      iupp    = 0
      iupuf   = 0
      iupug   = 0
      iuprhof = 0
      iuprhog = 0
      iupxs   = 0
      iuptf   = 0
      iuptg   = 0
c
      do j=1,nz
        icvp(j)    = 0
        icvuf(j)   = 0
```

Figure D-2. (continued)

```
          icvug(j)    = 0
          icvrhof(j) = 0
          icvrhog(j) = 0
          icvxs(j)    = 0
          icvtf(j)    = 0
          icvtg(j)    = 0
          icvvf(j)    = 0
          icvvg(j)    = 0
          icvvelf(j) = 0
          icvvelg(j) = 0
        enddo
c
        do i=1,nvar
c         -- set indexes for lower plenum values -
          if(varn(i).eq.'p          ' .and. varnm(i).eq.nlp) ilpp = i-1
          if(varn(i).eq.'uf         ' .and. varnm(i).eq.nlp) ilpuf = i-1
          if(varn(i).eq.'ug         ' .and. varnm(i).eq.nlp) ilpug = i-1
          if(varn(i).eq.'rhof       ' .and. varnm(i).eq.nlp) ilprhof = i-1
          if(varn(i).eq.'rhog       ' .and. varnm(i).eq.nlp) ilprhog = i-1
          if(varn(i).eq.'quals      ' .and. varnm(i).eq.nlp) ilpxs   = i-1
          if(varn(i).eq.'tempf      ' .and. varnm(i).eq.nlp) ilptf   = i-1
          if(varn(i).eq.'tempg      ' .and. varnm(i).eq.nlp) ilptg   = i-1
c         -- set indexes for upper plenum values -
          if(varn(i).eq.'p          ' .and. varnm(i).eq.nup) iupp = i-1
          if(varn(i).eq.'uf         ' .and. varnm(i).eq.nup) iupuf = i-1
          if(varn(i).eq.'ug         ' .and. varnm(i).eq.nup) iupug = i-1
          if(varn(i).eq.'rhof       ' .and. varnm(i).eq.nup) iuprhof = i-1
          if(varn(i).eq.'rhog       ' .and. varnm(i).eq.nup) iuprhog = i-1
          if(varn(i).eq.'quals      ' .and. varnm(i).eq.nup) iupxs   = i-1
          if(varn(i).eq.'tempf      ' .and. varnm(i).eq.nup) iuptf   = i-1
          if(varn(i).eq.'tempg      ' .and. varnm(i).eq.nup) iuptg   = i-1
c         -- set indexes for core channel values -
         do j = 1,nz
          if(varn(i).eq.'p          '.and.varnm(i).eq.cvol(j))icvp(j)=i-1
          if(varn(i).eq.'uf         '.and.varnm(i).eq.cvol(j))icvuf(j)=i-1
          if(varn(i).eq.'ug         '.and.varnm(i).eq.cvol(j))icvug(j)=i-1
          if(varn(i).eq.'rhof       '.and.varnm(i).eq.cvol(j))icvrhof(j)=i-1
          if(varn(i).eq.'rhog       '.and.varnm(i).eq.cvol(j))icvrhog(j)=i-1
          if(varn(i).eq.'quals      '.and.varnm(i).eq.cvol(j))icvxs(j)=i-1
          if(varn(i).eq.'tempf      '.and.varnm(i).eq.cvol(j))icvtf(j)=i-1
          if(varn(i).eq.'tempg      '.and.varnm(i).eq.cvol(j))icvtg(j)=i-1
          if(varn(i).eq.'voidf      '.and.varnm(i).eq.cvol(j))icvvf(j)=i-1
          if(varn(i).eq.'voidg      '.and.varnm(i).eq.cvol(j))icvvg(j)=i-1
          if(varn(i).eq.'velf       '.and.varnm(i).eq.cvol(j))icvvelf(j)=i-1
          if(varn(i).eq.'velg       '.and.varnm(i).eq.cvol(j))icvvelg(j)=i-1
         enddo
        enddo
c
c       check that all data is available on the strip file
c
```

Figure D-2. (continued)

```
      ikill = 0
c -- lower plenum
      if(ilpp .eq. 0) then
       write(6,1000) nlp
       ikill = 1
      endif
      if(ilpuf .eq. 0) then
       write(6,1001) nlp
       ikill = 1
      endif
      if(ilpug .eq. 0) then
       write(6,1002) nlp
       ikill = 1
      endif
      if(ilprhof .eq. 0) then
       write(6,1003) nlp
       ikill = 1
      endif
      if(ilprhog .eq. 0) then
       write(6,1004) nlp
       ikill = 1
      endif
      if(ilpxs   .eq. 0) then
       write(6,1005) nlp
       ikill = 1
      endif
      if(ilptf   .eq. 0) then
       write(6,1006) nlp
       ikill = 1
      endif
      if(ilptg   .eq. 0) then
       write(6,1007) nlp
       ikill = 1
      endif
c -- upper plenum
      if(iupp .eq. 0) then
       write(6,1000) nup
       ikill = 1
      endif
      if(iupuf .eq. 0) then
       write(6,1001) nup
       ikill = 1
      endif
      if(iupug .eq. 0) then
       write(6,1002) nup
       ikill = 1
      endif
      if(iuprhof .eq. 0) then
       write(6,1003) nup
       ikill = 1
```

Figure D-2. (continued)

```
      endif
      if(iuprhog .eq. 0) then
       write(6,1004) nup
       ikill = 1
      endif
      if(ilpxs   .eq. 0) then
       write(6,1005) nup
       ikill = 1
      endif
      if(ilptf   .eq. 0) then
       write(6,1006) nup
       ikill = 1
      endif
      if(ilptg   .eq. 0) then
       write(6,1007) nup
       ikill = 1
      endif
c -- core nodes
      do i = 1,nz
        if(icvp(i) .eq. 0) then
          write(6,1000) cvol(i)
          ikill = 1
        endif
        if(icvuf(i) .eq. 0) then
          write(6,1001) cvol(i)
          ikill = 1
        endif
        if(icvug(i) .eq. 0) then
          write(6,1002) cvol(i)
          ikill = 1
        endif
        if(icvrhof(i) .eq. 0) then
          write(6,1003) cvol(i)
          ikill = 1
        endif
        if(icvrhog(i) .eq. 0) then
          write(6,1004) cvol(i)
          ikill = 1
        endif
        if(icvxs(i)   .eq. 0) then
          write(6,1005) cvol(i)
          ikill = 1
        endif
        if(icvtf(i)   .eq. 0) then
          write(6,1006) cvol(i)
          ikill = 1
        endif
        if(icvtg(i)   .eq. 0) then
          write(6,1007) cvol(i)
          ikill = 1
```

Figure D-2. (continued)

```
       endif
       if(icvvf(i)   .eq. 0) then
         write(6,1008) cvol(i)
         ikill = 1
       endif
       if(icvvg(i)   .eq. 0) then
         write(6,1009) cvol(i)
         ikill = 1
       endif
       if(icvvelf(i)   .eq. 0) then
         write(6,1010) cvol(i)
         ikill = 1
       endif
       if(icvvelg(i)   .eq. 0) then
         write(6,1011) cvol(i)
         ikill = 1
       endif
      enddo
      if(ikill.eq.1) goto 99999
c
c     redefine linvar for numeric data
c
      linvar = (nvar-1)/5
      write(6,*) 'read= ', linvar
c
c     read data
c
      tlast = 0.0
      jskip = -99
  700 read(5,2680,end=800) numl, (y(i),i=1,4)
      if (numl .eq. '   ') read(5,2680,end=800) numl, (y(i),i=1,4)
      if(debgl) write(6,*) numl, (y(i),i=1,4)
      if (linvar .eq. 0) go to 750
      mm = 5
      nn = 9
      do k=1,linvar
        read(5,2690) (y(i),i=mm,nn)
        if(debgl) write(6,*) (y(i),i=mm,nn)
        mm = mm + 5
        nn = nn + 5
      enddo
  750 continue
c
c     skip data set if not needed
c
      if((tmax.gt.0.0) .and. (y(1).gt.tmax)) then
        write(6,1100) y(1)
        go to 99999
      endif
      if((y(1).lt.tmin)  .or. (y(1).lt.(tlast+tdel))) goto 700
```

Figure D-2. (continued)

```
      jskip = jskip + 1
      if(jskip.gt.0 .and. jskip.lt.kstep) goto 700
      jskip = 0
      tlast = y(1)
c
c     calculate frapt6 quantities, convert to british units
c
      plp = y(ilpp)/6894.757
      hlp = ((y(ilpuf)+y(ilpp)/y(ilprhof))*(1.0-y(ilpxs))+
     *       (y(ilpug)+y(ilpp)/y(ilprhog))*(y(ilpxs)))/2326.0
      if(y(ilpxs).lt. 0.5) then
       tblp = (y(ilptf)-273.15)*1.8+32.0
      else
       tblp = (y(ilptg)-273.15)*1.8+32.0
      endif
      do i = 1,nz
        pcv(i) = y(icvp(i))/6894.757
        hcv(i)=((y(icvuf(i))+y(icvp(i))/y(icvrhof(i)))*(1.0-y(icvxs(i)))
     *      +(y(icvug(i))+y(icvp(i))/y(icvrhog(i)))*(y(icvxs(i))))/2326.0
        if(y(icvxs(i)).lt. 0.5) then
          tbcv(i) = (y(icvtf(i))-273.15)*1.8+32.0
        else
          tbcv(i) = (y(icvtg(i))-273.15)*1.8+32.0
        endif
        gcv(i) = (y(icvvelf(i))*y(icvrhof(i))*y(icvvf(i))+
     *            y(icvvelg(i))*y(icvrhog(i))*y(icvvg(i)))/0.0013562
      enddo
      pup = y(iupp)/6894.757
      hup = ((y(iupuf)+y(iupp)/y(iuprhof))*(1.0-y(iupxs))+
     *       (y(iupug)+y(iupp)/y(iuprhog))*(y(iupxs)))/2326.0
      if(y(iupxs).lt. 0.5) then
        tbup = (y(iuptf)-273.15)*1.8+32.0
      else
        tbup = (y(iuptg)-273.15)*1.8+32.0
      endif
c
c     output data to frapt6 file
c
      write(7) y(1)
      write(7) plp,hlp,tblp
      do i = 1,nz
        write(7) zb(i),zt(i),pcv(i),hcv(i),tbcv(i),gcv(i)
      enddo
      write(7) pup,hup,tbup
c
c     print data to standard output for debug
c
      if(debg2) then
        write(6,1300) y(1)
        write(6,1301) plp,hlp,tblp,y(ilpxs)
```

Figure D-2. (continued)

```
        do i = 1,nz
          write(6,1302) i,zb(i),zt(i),pcv(i),hcv(i),tbcv(i),gcv(i),
     *                  y(icvxs(i))
        enddo
        write(6,1303) pup,hup,tbup,y(iupxs)
c
      endif
c
      go to 700
c
   40 continue
      write(0,1410)kunit,msgno,filenm
      goto 99999
c
  800 continue
      write (6,1150)
      goto 99999
c
  200 continue
      write (6,1140)
      goto 99999
c
  600 continue
      print *, ' Error reading file names from frapr5 input file'
      goto 99999
c
99999 continue
      close(1)
      close(5)
      close(6)
      close(7)
      stop
c
c     format statements
c
 1000 format(' *** error: pressure data not found for volume ',A9)
 1001 format(' *** error: uf       data not found for volume ',A9)
 1002 format(' *** error: ug       data not found for volume ',A9)
 1003 format(' *** error: rhof     data not found for volume ',A9)
 1004 format(' *** error: rhog     data not found for volume ',A9)
 1005 format(' *** error: quals    data not found for volume ',A9)
 1006 format(' *** error: tempf    data not found for volume ',A9)
 1007 format(' *** error: temp6    data not found for volume ',A9)
 1008 format(' *** error: voidf    data not found for volume ',A9)
 1009 format(' *** error: voidg    data not found for volume ',A9)
 1010 format(' *** error: velf     data not found for volume ',A9)
 1011 format(' *** error: velg     data not found for volume ',A9)
 1100 format(' maximum time reached = ',f12.3)
 1106 format (/,' write only 1 frap-t6 record for each ',i3,
     1          ' SCDAP/RELAP5 records')
```

Figure D-2. (continued)

```
1110 format ('1relap to frap - coolant conditions',8x, a16,
    1  5x, 'page', i3)
 1115 format (/,' initial time =',f9.3,' sec.     end time =',f10.3)
 1116 format (/,' minimum frap data interval =', f7.4,' sec.')
 1117 format (/,' relap volume for lower plenum is ', a9, 5x,
    1 'upper plenum is ', a9)
 1119 format(/,' relap vol.    zb(ft)    zt(ft)'/
    *         ' ---------- - ------- ---------')
 1120 format(2x,a9,2F10.3)
 1130 format(/'the input file could not be located.',
    *        /'file: ',a50
    *        /'reenter file specification or "q" to quit.')
 1140 format(/,' run terminated in error')
 1144 format(/,' top is not above bottom')
 1150 format(/,' end of relap5 strip file encountered')
 1175 format(/,' maximum no. of core nodes is ',i4)
 1200 format(/,' frapr5 input file:    ',a50,
    *        /,' frapr5 output file:  ',a50)
 1201 format(  ' relap5 strip file:    ',a50)
 1202 format(  ' frap-t6 binary file: ',a50)
 1210 format(/,' debug edit of stripf data is turned on')
 1211 format(/,' debug edit of stripf data is turned off')
 1212 format(/,' debug edit of frapt-t6 data is turned on')
 1213 format(/,' debug edit of frapt-t6 data is turned off')
 1220 format(/,' relap5 stripf file header:',2(/,1x,a40,a39),/)
 1300 format(/' >>>>>>>>> at time=',F12.3)
 1301 format(' Lower Plenum Data: p=',f8.2,' psia  h=',f8.2,' btu/lbm'
    * ,'  tb=',f8.2,' F  xs=',f5.3,/
    * ,'  node  zb(ft)  zt(ft)  pcv(psia)  hcv(btu/lbm) '
    * ,'tbcv(F) gcv(lbm/ft2-h)  quals')
 1302 format(2x,i4,2F8.3,3F11.3,f11.1,f11.3)
 1303 format(' Upper Plenum Data: p=',f8.2,' psia  h=',f8.2,' btu/lbm'
    * ,'  tb=',f8.2,' F  xs=',f5.3,/)
 1400 format(a)
 1410 format(/' an error was encountered in opening file unit ',i2,/
    *        12x,'error message number = ',i10,' ***'/
    *        2x,'file name: ',a50)
 2000 format (2a40)
 2005 format (3i6)
 2011 format (2(a9,1x))
 2012 format (3f10.3)
 2018 format(a9,2F10.3)
 2663 format(1x,8(a9,1x))
 2666 format(a10,2i10)
 2667 format(2x,8(a9,1x))
 2680 format(1x,a10,4x,4g15.7)
 2690 format(5g15.7)
c
      end
      subroutine thedate(today)
```

Figure D-2. (continued)

```
c
      character*16  today
      character*11  ctime
      character*24  timestr
c
      call fdate(timestr)
      today = timestr(1:10)//', '//timestr(21:24)
      ctime = timestr(12:19)
c
      return
      end
```

Figure D-2. (continued)

D-2. The TRAC2FRAP Code

An input option of FRAP-T6 [V 21 (11/90)] allows the code to read the transient thermal-hydraulic boundary conditions from a binary data file.[D-1] TRAC2FRAP is used to create this binary data file from multiple TRAC-PF1/MOD1 restart files and is composed of two programs. The program xcif reads the TRAC plot file and writes a computer-independent data file that can be moved between brands of computers. The program zcif reads the portable data file and writes a binary FRAP-T6 input boundary condition file. Section D-2.1 describes the xcif and zcif programs, and Section D-2.2 discusses input to xcif and zcif and gives sample inputs. Section D-2.3 describes the subroutine required to calculate the bulk fluid properties needed by FRAP-T6.

D-2.1 TRAC2FRAP Code Description

As noted in Section D-1.1, the thermal-hydraulic boundary condition data required by FRAP-T6 for each time step are defined in Appendix E of Reference D-1 and include:

a. The transient time (s)
b. Coolant pressure (psia), enthalpy (BTU/lbm), and bulk fluid temperature (°F) in the upper and lower plenums.
c. Top and bottom node elevations (ft), coolant pressure (psia), enthalpy (BTU/lbm), bulk fluid temperature (°F), and mass flux (lbm/ft^2-h) for each core node.

Two programs are used to process the required TRAC-PF1/MOD1 data into a form useable in FRAP-T6. The first is xcif, a FORTRAN 77 program that extracts data from the TRAC plot file and writes these data to an intermediate, portable data file. Because the TRAC program executes on the Cray computer, the platform for the xcif program is also the Cray computer. The intermediate data file is written in ascii format. This provides potability between computers.

The second program in TRAC2FRAP is zcif, a FORTRAN 77 program that reads the intermediate data file generated by xcif and writes a binary boundary condition file for FRAP-T6. The current platform for zcif is a Digital Equipment Corp. DEC-5000 workstation used for the FRAP-T6 code runs. The configuration is illustrated in Figure D-3.

The first part (xcif) reads a TRAC plot file and writes an ascii data file. This file is transferred to the workstation. The ascii data file is then read and written (zcif) to a FRAP-T6 binary boundary condition file. All of the TRAC2FRAP files required for both the Cray and workstation programs are archived on tape.

Listed below are the source code, make script, and executable code that reside on the Cray:

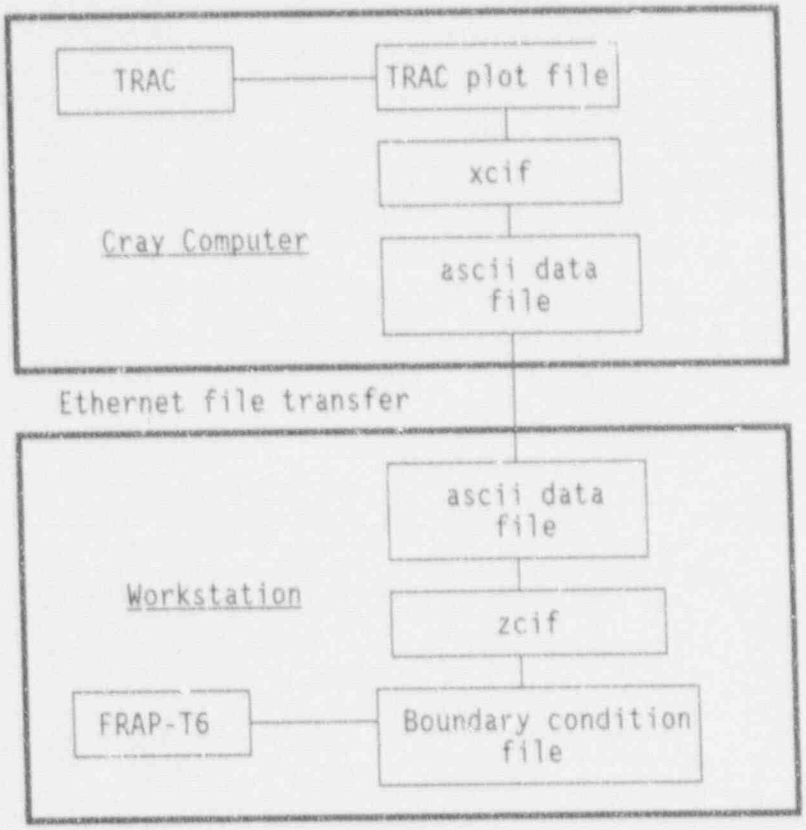


Figure D-3. TRAC2FRAP program configuration.

xcif	Executable code that reads the TRAC graphics file and writes the ascii data file.
xcif.us	Source for the xcif code in update format.
cv0000.f	Source code for the subroutines used to read data in free format.
mkx	The make script used to build the executable code.

To build the executable on the Cray:

mkx

Listed below are the source code, make script, and executable code that reside on the workstation.

zcif	Executable code that reads the ascii data file and writes the binary FRAP-T6 boundary condition file.
zcif.f	Source for the zcif code.
cv0000.f	Source code for the subroutines used to read data in free format.
envrl.a	Environmental library from FRAP-T6.
sth2xt	Steam tables from FRAP-T6.
mkz	Make script used to build zcif.

To build the executable on the DEC workstation:
mkz

D-2.2 Using the TRAC2FR P Programs

The TRAC2FRAP programs are used in the following manner.

D-2.2.1 Make an ascii Data File on the Cray. The xcif program reads directives from standard input and writes messages to standard output. The input TRAC plot file name(s) are specified in the input, and the intermediate ascii data file name is always "pldata". To execute xcif, enter

```
xcif < x_my.inp > x_my.out
```

where "x_my.inp" contains the input directives and "x_my.out" will receive the informative output messages.

The following standard input is required for xcif:

TRAC Plot File Names--The TRAC plot file names are the first entry in the input. On each restart of TRAC, a new file is created. To get data for a complete calculation, which has a number of restarts, each plot file must be defined. Make sure the plot files are in order from first restart to last. The list of TRAC plot file names is terminated with a period (".").

ECHO--The xcif program usually runs without many informative messages. If "ECHO" is in the input stream, input directives are echoed to standard output. <u>The echo command must be after the TRAC plot data file specification</u>.

Data Specification--The xcif program extracts, for each volume, a set of physical parameters required as boundary conditions for FRAP-T6. The data are specified by identifying the TRAC vessel volumes. This is briefly described in Figure D-4 below. For more detailed information, refer to the TRAC user's manual.[D-4]

```
         XXXYYZZ
  | |  └───── Cell number
  | └──────── Level
  └────────── Component
```

Figure D-4. TRAC-PF1/MOD1 vessel volume identifiers.

For component 99, level 7, and cell number 9, the data identifier is:

0990709

TRAC-PF1 Parameters--A selected set of parameters are extracted from the TRAC vessel component. The parameters are as follows:

P	Pressure
VLN-Z	Liquid velocity in the axial direction
VVN-Z	Vapor velocity in the axial direction
ALPHA	Void fraction
RHOL	Density of the liquid
RHOV	Density of the vapor
TL	Temperature of the liquid
TV	Temperature of the vapor
TSAT	Saturation temperature

Sample input for xcif is shown in Figure D-5.

```
TRCGRF1
TRCGRF2
.
ECHO
0990401
0990301
0990401
0990501
0990601
0990701
0990801
0990901
0991001
0991101
0991201
0991301
0991401
```

Figure D-5. Sample input file for the xcif program.

D-2.2.2 Move the ascii Data File to the Workstation. To use the ascii file built by xcif, the file is first moved from the Cray to the workstation. The remote copy (rcp) program is one method of moving the file from the Cray to the workstation. It is assumed that the user is logged-on the Cray and in the directory where the ascii data file resides. To move the file using rcp,

rcp pldata ws-dms:/npax/dms/frap/.

This command moves "pldata" from the current Cray directory to workstation "ws-dms", and places it in directory "/npax/dms/frap/."

D-2.2.3 Make a FRAP-T6 Boundary Condition File on the Workstation. The zcif program reads directives from standard input and writes messages to standard output. The ascii data input file (generated by xcif) and the output FRAP-T6 boundary condition files are specified in the input. To execute zcif, enter

zcif < z_my.inp > z_my.out
where "z_my.inp" contains the input directives and "z_my.out" will receive the output comments.

Input directives to zcif are entered in the following order:

debug flags
ascii data file name
FRAP-T6 boundary condition file name
time control
lower plenum volume number
upper plenum volume number
volume number at bottom of the core and its height
:
:
volume number at top of the core and its height

All input data are entered in free format. Multiple white spaces are ignored. An "*" terminates a line.

Debug Flags--Two numbers are entered specifying the debug level.

1. Debug level 1 gives information on data-name specification. Output is written to standard output.
2. Debug level 2 writes the FRAP output boundary condition data in ascii form. Output is written to standard output.

File Names--The data file name for the ascii file and the file name for the output boundary condition file are specified.

Time Control--The start time, end time, and time interval are used to control the time period and frequency for extracting boundary condition data. A large negative start time, a large positive end time, and a zero time interval will result in all data being extracted.

Variable Names--A predefined set of parameters are written to the boundary condition file for each volume. The only specification is the volume number for each set of variables and the volume height. The volume specification is the same as that used to extract the data from the TRAC plot file (see xcif description). The first two volumes listed are the lower plenum and upper plenum volumes, respectively. No height is given with the plenum volumes. The next series of input are the volume number for each cell and the bottom and top elevation of the cell.

Sample input for zcif is shown in Figure D-6.

```
0 0             * debug level 1 and 2. 0=no debug
pldata          * TRAC ascii data file. (input)
frap.dat        * FRAP binary data file. (output)
-100 10. 0.1    * start, stop and time interval
0990301         * lower plenum
0990401         * upper plenum
0990501 1 2     * core volume 1, bottom height and top height
0990601 3 4     * core volume 2, bottom height and top height
0990701 4 5     * core volume 3, bottom height and top height
0990801 5 6     * core volume 4, bottom height and top height
0990901 6 7     * core volume 5, bottom height and top height
0991001 7 8     * core volume 6, bottom height and top height
0991101 8 9     * core volume 7, bottom height and top height
0991201 9 10    * core volume 8, bottom height and top height
0991301 10 11   * core volume 9, bottom height and top height
0991401 11 12   * core volume 10, bottom height and top height
```

Figure D-6. Sample input file for the zcif program.

Listings of source codes xcif.us, zcif.f, cv0000.f, mkx, and mkz for TRAC2FRAP are given in Figures D-7 through D-10.

D-2.3 Calculation of Bulk Quantities

The FRAP-T6 program uses bulk fluid properties as boundary conditions, which poses two problems when using TRAC as a source or boundary conditions. First, TRAC calculates and outputs the properties for each of the phases, as opposed to bulk values. Second, TRAC does not supply the internal energy or enthalpy on the plot file. Therefore, calculations are made in zcif to obtain the bulk properties and the enthalpy needed by FRAP-T6. The subroutine that calculates the bulk properties and enthalpy is given as Figure D-11.

D-3. References

D-1. L. J. Siefken et al., *FRAP-T6: A Computer Code for the Transient Analysis of Oxide Fuel Rods*, NUREG/CR-2148, EGG-2104, May 1981.

D-2. C. M. Allison et al. (Eds.), *SCDAP/RELAP5/MOD3 Code Manual (Draft)*, Volumes I-III, NUREG/CR-5273, EGG-2555, September 1990.

D-3. D. R. Liles et al., *TRAC-PF1/MOD1: An Advanced Best Estimate Computer Program for PWR Thermal-Hydraulic Analysis*, NUREG/CR-3858, July 1986.

D-4. B. E. Boyack, H. Stumpf, and J. F. Lime, *TRAC User's Guide*, NUREG/CR-4442, November 1985.

```
c source code xcif.us--source code that reads the
c TRAC-PF1/MOD1 graphics file and writes the ascii data file
c
*comdeck system
      common /system/nbyte
      integer nbyte
c nbyte      -Number of bytes per word
*comdeck blankcom
       common  a(mxsize)
       integer  ia(1)
       equivalence  (a(1),ia(1))
*comdeck datblk
       common /datblk/ dbuf(2047),dnbuf,dio,deof,dnext
       real dbuf
       integer dnbuf,dio,deof,dnext
*comdeck cblock
       common  /cblock/ cid(mxvars)
       character*16  cid
c cid         - Input identifiers.
*comdeck control
       common  /control/ ifree,ipkg,lencat,nctx,numtcr,nwtx
       common  /control/ check
       logical  check
c ifree       - Start location for free space in a.
c ipkg        - Length of fixed geometry data stored in 'a'
c               (starts at lfixg).
c lencat      - Length of catalog name (char)
c nctx        - Length of catalog stored in 'a' (starts at lcat).
c numtcr      - Number of title cards.
c nwtx        - Length of data stored in 'a' (starts at ldat).
c               This is initially read in 'cif' and used later
c               in 'wrdata'.
*comdeck iofiles
       common /iofile/ nfnme,nxfnme
       integer nfnme,nxfnme
       common /aofile/ fnme(10)
       character fnme*40
*comdeck iounits
       common  /iounits/ iuntdi,iuntdo
c iuntdi      - TRAC input data file (TRCGRF).
c iuntdo      - Output strip file.
*comdeck paramtrs
       parameter (mxsize=200000)
       parameter (mxvars=500)
*comdeck varnme
      common /varnme/ vessmp,vessnp,vessnn(10)
      common /avrnme/ vessnm(10)

      character vessnm*8
      integer   vessmp,vessnp,vessnn
```

Figure D-7. TRAC2FRAP source code xcif.us.

```
c vessmp     - Max number of parameter names.
c vessnp     - Number of parameters
c vessnm     - Name of vessel parameters to be extracted
c vessnn     - Number char in vessnm(i)
*comdeck ptrs
      common  /ptrs/ lcat,ldat,lfixg,ltitle
c lcat        - Start address of catalog in 'a' (length is nctx).
c ldat        - Start address of data in 'a' (length is nwtx).
c               This address is set when ready to dump the data
c               (see 'wrdata').
c lfixg       - Start address of fixed geometry in 'a' (length is ipkg).
c ltitle      - Start address for the problem title in 'a'
c               (length is numtrc).
*comdeck vinfo
      common /vinfo/ aux(mxvars)
      common /vinfo/ loc(mxvars),lrn(mxvars),nc(mxvars),npv,num(mxvars)

      common /ainfo/ name(mxvars),label(mxvars)
      integer   loc,lrn,nc,npv,num
      real      aux
      character name*8,label*24
c aux         - Auxilary data.
c label       - Label for each variable. Search for and found.
c loc         - Location in plot record. Search for and found.
c               If loc < 0, then one word variable.
c lrn         - Level/rod number.
c name        - Name
c nc            Cell number.
c               If nc < 0, then unpacked data.
c npv         - Number of entries.
c num         - Component number.
c               If num < 0, then fixed geometry variable.
*deck cif
      program  cif
c
c  cif  -  select plot data from trac-pfl graphics data
c            file (trcgrf) and write to card image data
c            file (pldata) for transmission to inel cyber
c            system via tieline.
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  1/86
c  modified:  8/87  j. e. tolli, eg&g idaho
c
c  some routines adapted from lanl grit program
c
*ca paramtrs
c
*ca blankcom
```

Figure D-7. (continued)

```
c
*ca cblock
c
*ca control
c
*ca iounits
*ca iofiles
c
*ca ptrs
c
*ca vinfo
      integer  iaux(mxvars)
      equivalence  (iaux(1),aux(1))
c
      logical  eof,err
c
c initialize parameter names for components
      call dfltnm()
c
c initialize for reading and writing data files variables
      call initdf()
c
c read from input the trac file nanes
      call rdfnme()
c
c get requested plot variables from user input
      call  vessin
c
c open the output strip file
      open (iuntdo,file='pldata')
c
      nxfnme=1
c
c start loop through all TRAC files
   10 continue

c open TRAC plot file and output strip file
      open (iuntdi,file=fnme(nxfnme),form='unformatted')
c
c finished
      err=.false.
c
c set up graphics file i/o control array
      call  bfaloc(iuntdi)
c
c initialize index of first free word in blank common
      ifree = 1
c
c get plot record length
```

Figure D-7. (continued)

```
      call  grfrd (nwtx,1,eof)
      if (eof) then
        write (*,1000)
        call  stop ('cif')
      endif
c
c read and check problem title
      call  rdtitl
c
c get graphics file catalog
      call  gcatlg
c
c get fixed geometry data
      call  gfixgm
c
c get location of each requested plot variable
      call  getloc
c
c stop if check run
      if (check)  call  stop ('checkrun')
c
c write variable names and labels out to pldata
      call  wrvnl
c
c write data out to pldata
      call  wrdata
c
c if another TRAC file, loop
      close(unit=iuntdi)
      nxfnme=nxfnme+1
      if(nxfnme.le.nfnme) go to 10
c
 1000 format ('***** No data on plot file'/
     *          '***** Execution stopped'/)
      end
*deck blkdat
      blockdata  blkdat
c
c
c  blkdat  -  initialize selected common block variables
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  8/87
c
*ca system
*ca paramtrs
*ca control
*ca vinfo
      integer  iaux(mxvars)
```

Figure D-7. (continued)

```
      equivalence  (iaux(1),aux(1))
c
      data lencat /6/
      data check /.false./
      data nbyte /64/
      data iaux /mxvars*-1/
      end
*deck bfaloc
      subroutine bfaloc(iunit)
c
c *** bfaloc - Initialize data i/o
c
c Entry -
c    iunit  :i/o unit number
c
c Exit -
c    none
c
*ca datblk
c
      dnbuf=2047
      deof=0
      dnext=0
      dio=iunit
      return
      end
*deck bfin
      subroutine bfin(x,nwrx,eof)
c
c *** bfin - Reading data from disk
c
c Entry -
c    nwrx  :Number of data to load.
c
c Exit -
c    x      :data
c    eof    :true=eof.
c
*ca datblk
c
      dimension x(*),ibuf(1)
      equivalence (dbuf(1),ibuf(1))
      integer nwrx,ibuf
      logical eof
c
      data ieof/3hEOF/
c
      if(deof.eq.1) then
        write(*,1000)
        call stop('bfin')
```

Figure D-7. (continued)

```
      endif
c
      eof=.false.
c
      nwr=0
   10 if(dnext.lt.1 .or. dnext.gt.dnbuf) then
        read(dio,end=100,err=110) (dbuf(i),i=1,dnbuf)
        dnext=1
      endif
c
      if(nwr.eq.nwrx) return
c
      imt=min0(dnbuf-dnext+1,nwrx-nwr)
c
      if(ibuf(dnext)      .eq.ieof .or.
     1   ibuf(dnext+imt-1).eq.ieof) go to 100
c
      call movlev(dbuf(dnext),x(nwr+1),imt)
      nwr=nwr+imt
      dnext=dnext+imt
      go to 10
c
  100 deof=1
      eof=.true.
      return
c
  110 write(*,1010)
      call stop('bfin')
c
 1000 format(' *** Eof encounterd ... see programmer'/)
 1010 format(' *** Err encounterd ... see programmer'/)
      end
*deck calcvl
       subroutine  calcvl (indx,kpt,dat)
c
c
c  calcvl  -  calculate value of requested variable
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  8/87
c
c  parameters:
c
c  indx = requested variable sequence number (input)
c
c  kpt  = pointer to data in plot record (input)
c
c  dat  = calculated value of variable (output)
c
```

Figure D-7. (continued)

```
c  note:  for rod temperature variables, the cell number, nc, is
c    divided into four 16-bit parcels, numbered 1 to 4 from
c    left to right.  parcel 1 contains the number of radial
c    nodes for the rod (nodes);  parcel 2 contains the maximum
c    number of axial nodes for the fine mesh calculations
c    (nzmax);  parcel 3 contains the pointer to the rod axial
c    height data in the plot record array (lzht);  parcel 4
c    contains the radial node number at which the temperature
c    is to be plotted.
c
c
c
*ca paramtrs
c
*ca blankcom
c
*ca cblock
c
*ca control
c
*ca iounits
c
*ca ptrs
c
*ca vinfo
c
c
      data  nmsk48 /177777b/
c
c
c put identifier sequence number into local variable
c
      idx = indx
c
c get axial node number needed for interpolation, if required
c also get interpolation fraction
c
     if(name(idx)(1:6).eq.'RODTMP' .or.
    +   name(idx)(1:5).eq.'IDRGR') then
        lzht = ifree
        nzmax = shift(nc(idx),32) .and. nmsk48
        if (lzht+nzmax-1.gt.mxsize)  go to 40
        kp = shift (nc(idx),48) .and. nmsk48
        call  unpkit (a(lzht),nzmax,a(ldat+kp-1),npkw)
c
        do 10 i=1,nzmax-1
          h1 = a(lzht+i-1) - a(lzht)
          h2 = a(lzht+i) - a(lzht)
          if (aux(idx).ge.h1 .and. aux(idx).le.h2)  go to 20
   10   continue
```

Figure D-7. (continued)

```
        go to 50
c
   20   ndnum = i
        frac = (aux(idx)-h1) / (h2-h1)
      endif
c
c get number of radial nodes, if required
      if (name(idx)(1:6).eq.'RODTMP')
     *nodes = shift (nc(idx),16) .and. nmsk48
c
c get rod temperature value, if requested
      if (name(idx)(1:6).eq.'RODTMP') then
c
        lrftn = ifree
        nwrd = nodes*(ndnum+1)
        if (lrftn+nwrd-1.gt.mxsize) go to 40
        call  unpkit (a(lrftn),nwrd,a(kpt),npkw)
        nrn = nc(idx) .and. nmsk48
        l1 = nodes*(ndnum-1) + nrn - 1
        l2 = l1 + nodes
        dat   a(lrftn+l1) + frac * ( a(lrftn+l2) - a(lrftn+l1) )
        go to 30
c
      endif
c
c get heat transfer regime, if requested
c
      if (name(idx)(1:5).eq.'IDRGR') then
c
        lihtf = ifree
        if (lihtf+ndnum.gt.mxsize)  go to 40
        call  unpkit (a(lihtf),ndnum+1,a(kpt),npkw)
        if (frac.lt.0.5)  dat = float (ia(lihtf+ndnum-1))
        if (frac.ge.0.5)  dat = float (ia(lihtf+ndnum))
        go to 30
c
      endif
c
c finished
c
   30 return
c
c insufficient core for data processing
c
   40 write (*,1000) cid(idx)
      call  stop ('calcvl')
c
c invalid auxilliary number
c
   50 write (*,1100) aux(idx),cid(idx),a(ldat)
```

Figure D-7. (continued)

```
      call  stop ('calcvl')
c
c
 1000 format ('*****insufficient core for processing of data'/
     *           '*****for variable ',a/
     *           '*****execution stopped'/)
 1100 format ('*****value',1p,e15.8,' for variable ',a/
     *          '*****is not valid at time =',e11.4,' sec'/
     *          '*****execution stopped'/)
c
c
      end
*deck findce
      subroutine  findce (name,num,lrn,nc,icomp,itype,kp,nwrd,llabl,
     *                     found)
c
c  findce  -  find catalog entry
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  8/87
c
c  parameters:
c
c Entry -
c     name  = variable name
c     num   = component number
c     lrn   = level/rod number
c     nc    = cell number
c
c Exit -
c     icomp = sequential component number
c     itype = plot variable type
c     kp    = location of variable in plot record
c     nwrd  = length of variable in words
c     llabl = pointer to variable label
c     found = flag for variable search status
c             true:  catalog entry for variable has been found
c             false: catalog entry for variable has not been found
c
c *** note str is lencat long
      character name*(*),str*8
      logical  found
c
*ca paramtrs
*ca blankcom
*ca control
*ca ptrs
c
c search for catalog entry
```

Figure D-7. (continued)

```
      found = .false.
      do 10 i=1,nctx
        call grfget (icomp,itype,ilrn,ipos,numc,nwrd,kp,nskip,i,
     *       a(lcat))
        if(itype.eq.9) numc = icomp
        if(numc.ne.num .or. ilrn.ne.lrn)  go to 10
        lname = lcat + lencat*(i-1) + 2
        write (str,'(a8)') ia(lname)
        if (str(1:lencat).eq.name(1:lencat)) then
          if (nwrd.lt.nc) return
          found = .true.
          llabl = lname + 1
          return
        endif
   10 continue
      return
      end
*deck gcatlg
       subroutine  gcatlg
c
c   this routine reads catalog from graphics file.
c
c   adapted in part from lanl grit program ready routine.
c
c
*ca paramtrs
c
*ca blankcom
c
*ca control
c
*ca iounits
c
*ca ptrs
c
c
      logical  eof
c
c
      call grfrd(zero,1,eof)
      if (eof)  go to 10
c
      call grfrd(nctx,1,eof)
      if (eof)  go to 10
c
      nw = nctx*lencat
      call grfrd(a(ifree),nw,eof)
      if (eof)  go to 10
      lcat = ifree
      ifree = ifree + nw
```

Figure D-7. (continued)

```
c
      return
c
c premature end of file encountered
c
   10 write (*,1000)
      call  stop ('gcatlg')
c
c
 1000 format ('*****premature eof on plot file'/
     *        '*****execution stopped'/)
c
c
      end
*deck getloc
       subroutine  getloc
c
c  getloc  -  finds and stores location of data for each requested
c  plot variable in plot data dump; also stores labels,
c  and acquires information needed for processing of
c  auxilliary data.
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  1/86
c  modified:  8/87  j. e. tolli, eg&g idaho
c
*ca paramtrs
*ca blankcom
*ca cblock
*ca iounits
*ca vinfo
      integer  iaux(mxvars)
      equivalence  (iaux(1),aux(1))
c
      logical  error,found
c
c find requested variables
      do 20 i=1,npv
        if (iaux(i).eq.-1) then
          n = nc(i)
        else
          n = 1
        endif
        call  findce
     *  (name(i),num(i),lrn(i),n,icomp,itype,kp,nwrd,llabl,found)
        if (.not.found) then
          write (*,1000) cid(i)
          go to 10
        endif
```

Figure D-7. (continued)

```
c
c store location
        loc(i) = kp
c
c if data is unpacked, set nc(i) = -nc(i)
c if fixed geometry variable, set num(i) = -num(i)
c if only one word variable, set loc(i) = -loc(i)
        if (itype.lt.10) then
          if (icomp.eq.0)  nc(i) = -nc(i)
        else
          num(i) = -num(i)
          if (itype.gt.20)  nc(i) = -nc(i)
        endif
        if (nwrd.eq.1)  loc(i) = -loc(i)
c
c store label
        write (iabel(i),'(3a8)') (ia(llabl+ii-1),ii=1,3)
c
c get information for auxilliary data processing, if needed
        if (iaux(i).eq.-1)  go to 20
        call  ginadp (i,error)
        if (error)  go to 10
        go to 20
c
c error in requested plot variable
   10   name(i)(1:) = ' '
c
   20 continue
c
c remove erroneous requested variables from plot variables list
      i=1
   30 continue
        if (i.gt.npv)  go to 50
        if (name(i)(1:1).eq.' ') then
          npv = npv - 1
          do 40 j=i,npv
            cid(j) = cid(j+1)
            name(j)(1:) = name(j+1)(1:)
            num(j) = num(j+1)
            lrn(j) = lrn(j+1)
            nc(j) = nc(j+1)
            aux(j) = aux(j+1)
            loc(j) = loc(j+1)
            label(j)(1:) = label(j+1)(1:)
   40     continue
          go to 30
        endif
        i=i+1
        go to 30
c
```

Figure D-7. (continued)

```
c all done
   50 return
c
 1000 format (' *** Plot variable ',a,' not found'/)
      end
*deck gfixgm
       subroutine  gfixgm
c
c
c  gfixgm  -  read in fixed geometry data
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  1/86
c  modified:  8/87  j. e. tolli, eg&g idaho
c
c
*ca paramtrs
c
*ca blankcom
c
*ca control
c
*ca iounits
c
*ca ptrs
c
c
       logical  eof
c
c
       call  grfrd (ipkg,1,eof)
       if (eof)  go to 10
c
       call  grfrd (a(ifree),ipkg,eof)
       if (eof)  go to 10
       lfixg = ifree
       ifree = ifree + ipkg
c
       return
c
c premature end of file encountered
c
   10  write (*,1000)
       call  stop ('gfixgm')
c
c
 1000  format ('*****premature eof on plot file'/
     *         '*****execution stopped'/)
c
```

Figure D-7. (continued)

```
c
      end
*deck ginadp
      subroutine  ginadp (irv,error)
c
c  ginadp  -  get information needed for auxilliary data processing
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  8/87
c
c  parameters:
c
c  irv   = index of user requested plot variable (input)
c
c  error = error flag (output)
c
c  note:  for rod temperature variables, the cell number, nc, is
c    divided into four 16-bit parcels, numbered 1 to 4 from
c    left to right.  parcel 1 contains the number of radial
c    nodes for the rod (nodes);  parcel 2 contains the maximum
c    number of axial nodes for the fine mesh calculations
c    (nzmax);  parcel 3 contains the pointer to the rod axial
c    height data in the plot record array (lzht);  parcel 4
c    contains the radial node number at which the temperature
c    is to be plotted.
c
      logical  error
c
*ca paramtrs
*ca blankcom
*ca cblock
*ca iounits
*ca ptrs
*ca vinfo
c
      logical  found
      character namev*8
c
c find and store needed information
c
      error = .false.
c
      if(name(irv)(1:6).eq.'RODTMP' .or.
     +   name(irv)(1:5).eq.'IDRGR') then
        namev(1:) = 'ZHT'
        call  findce
     * (namev,num(irv),lrn(irv),1,icomp,itype,kp,nzmax,llabl,found)
        if (.not.found)  go to 10
        nc(irv) = nc(irv) .or. shift(kp,16) .or. shift(nzmax,32)
```

Figure D-7. (continued)

```
      endif
c
      if (name(irv)(1:6).eq.'RODTMP') then
        namev(1:) = 'NDRDS'
        call  findce
     *  (namev,num(irv),0,1,icomp,itype,kp,nwrd,llabl,found)
        if (.not.found) then
          namev(1:) = 'NODES'
          call findce
     *    (namev,num(irv),0,1,icomp,itype,kp,nwrd,llabl,found)
        endif
        if (.not.found)  go to 10
        nodes = ia(lfixg+kp-1)
        nc(irv) = nc(irv) .or. shift (nodes,48)
      endif
c
      go to 20
c
c error
c
   10 write (*,1000) namev,cid(irv)
      error = .true.
c
c finished
   20 return
c
 1000 format (' variable ',a6,' does not exist for ',a/
     *          ' request ignored'/)
      end
*deck grfget
      subroutine grfget(icomp,itype,ilrn,ipos,num,nwrd,kp,nskip,nct,a)
c
c grfget returns entries in graphics catalog block
c
c adapted from lanl grit and trac-pf1 programs
c
c variables:
c
c o -  icomp  -  component sequence number
c o -  itype  -  array selector (1-variable table, 2-array table)
c o -  num    -  component id number
c o -  ilrn   -  level or rod number
c o -  nwrd   -  number of words stored
c i -  nct    -  catalog entry number
c o -  kp     -  pointer in graphics data block
c i -  a      -  catalog array
c
c
*ca control
c
```

Figure D-7. (continued)

```
c
      dimension a(1)
      data msk/177777b/
c
c
      kpt=lencat*(nct-1)
      r=a(kpt+1)
      icomp=and(shift(r,16),msk)
      num=and(shift(r,32),msk)
      itype=and(shift(r,48),msk)
      nwrd=and(r,msk)
      r=a(kpt+2)
      ilrn=and(shift(r,16),msk)
      kp=and(shift(r,32),msk)
      nskip=and(shift(r,48),msk)
      ipos=and(r,msk)
      return
      end
*deck grfrd
      subroutine grfrd(x,nenx,eof)
c
c   this routine loads nenx words from disk into x array;
c   eof = end-of-file indicator
c
c   adapted from lanl grit program
c
c
*ca control
c
*ca iounits
c
c
      dimension x(1)
      logical  eof
c
      call bfin(x,nenx,eof)
c
      return
      end
*deck lc2uc
      subroutine  lc2uc (string,len)
c
c
c  lc2uc   - Convert lower case characters to upper case in a string
c of len characters
c
c  author  : j. e. tolli, eg&g idaho
c  language: fortran 77 (ctss cft)
c  date    : 2/88
c
```

Figure D-7. (continued)

```
c
      character*(*)  string
c
c
      do 10 i=1,len
        icw = ichar(string(i:i))
        if (icw.ge.97 .and. icw.le.122)  string(i:i) = char(icw-32)
   10 continue
c
      return
      end
*deck movlev
      subroutine  movlev (a,b,n)
c
c
c  movlev  -  copy n words from array a to array b
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  1/86
c
      dimension  a(n),b(n)
c
      do 10 i=1,n
        b(i) = a(i)
   10 continue
      return
      end
*deck rdtitl
      subroutine  rdtitl
c
c
c  rdtitl   - read problem title from plot file and obtain
c  user verification
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  1/86
c  modified:  8/87  j. e. tolli, eg&g idaho
c
c
*ca paramtrs
*ca blankcom
*ca control
*ca iounits
*ca ptrs
c
      logical  eof
      character*2  stopgo
c
```

Figure D-7. (continued)

```
c get number of title cards
      call  grfrd (numtcr,1,eof)
      if (eof)  go to 20
c
c read and store title
      nw = 20*numtcr
      call  grfrd (a(ifree),nw,eof)
      if (eof)  go to 20
c
c set title pointer
      ltitle = ifree
      ifree = ifree + nw
c
c display first line of problem title
      write (*,1000) (a(ltitle+i),i=0,19)
      return
c
c premature end of file encountered
c
   20 write (*,1200)
      call  stop ('rdtitl')
c
 1000 format (' First line of problem title is '/20a4//)
 1100 format (a)
 1200 format ('*****premature eof on plot file'/
     *        '*****execution stopped'/)
      end
*deck stop
      subroutine  stop (mssg)
c
c  stop    -  stop program execution
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (cray cft)
c  date    :  9/87
c
c  parameters:
c
c  mssg = message to be displayed at program stop
c
c
       character*(*)  mssg
c
*ca iounits
c
c display message
       write (*,1000) mssg
c
c stop execution
       stop
```

Figure D-7. (continued)

```
c
c1000  format (10x,'stop  ',a)
 1000  format (10x,a)
       end
*deck unpkit
      subroutine unpkit(a,n,b,m)
c
c unpacks trac-pf1 plot data
c
c adapted from trac-pf1 program
c
      dimension a(1),b(1)
c
      data mask1,mask2/17777777777740000000000b,177777b/
c
conjure up amin and scale from first packed word
      amin=and(b(1),mask1)
      m=1
      if(n.le.1) go to 80
      scale=1./shift(b(1),32)
c commence unpacking, scaling and shifting a(1) thru a(n)
      j=0
      do 50 i=1,n
        if(j.gt.0) go to 40
        j=64
        m=m+1
   40   continue
        j=j-16
        itmp=and(shiftr(b(m),j),mask2)
        a(i)=scale*float(itmp)+amin
   50 continue
      return
c
   80 continue
      a(1)=amin
      return
      end
*deck vessin
       subroutine  vessin
c
c *** vessin  -  processes vessel input
c
*ca paramtrs
*ca cblock
*ca contol
*ca iounits
*ca varnme
*ca vinfo
c
      logical  echo,fexist,eor
```

Figure D-7. (continued)

```
      character*80  cbuf
      character*80  cx
      character* 1  break
c
      data  echo /.false./
c
c initialize plot variable counter
      n = 0
c
c get user input ... start loop
   10 read (*,1100,end=110) cbuf
c
c echo input when required
      if (echo) then
        write (*,1100) cbuf
      endif
c
c process user input
      ib=1
   20 call cv02(cbuf,80,ib,cx,lenf,break,eor)
      if(eor) go to 10
c
c if character input convert to upper case
      call  lc2uc (cx,lenf)
c
c check for echo/noecho or check run directive
      if (cx.eq.'ECHO') then
        echo = .true.
        go to 20
      else  if (cx.eq.'NOECHO') then
        echo = .false.
        go to 20
      else if (cx.eq.'CHECK') then
        check = .true.
        go to 20
      endif
c
c update and check number of requests (blocks of vessnp)
      if (n+vessnp.gt.mxvars) then
        write (*,1300) mxvars
        n = mxvars
        go to 110
      endif
c
c get component number, if present
      read (cx,'(i3,i2,i2)') numn,lrnn,ncn
c
c build a set for the vessnp list defined
      do 50 i=1,vessnp
        n=n+1
```

Figure D-7. (continued)

```
          name(n)(1:)=vessnm(i)(1:)
          num(n)=numn
          lrn(n)=lrnn
          nc(n)=ncn
          cid(n)=vessnm(i)(1:vessnn(i))//cx(1:lenf)
          if(echo) then
            write(*,1900) n,cid(n)
          endif
   50 continue
c
      go to 20
c
c end of file on input data
  110 continue
      npv = n
      write (*,1800) npv
      return
c
c
 1000 format (/'enter plot variable requests:')
 1100 format (a)
 1200 format (/' file ',a,' does not exist')
 1300 format (/' over ',i4,' identifiers requested, only first ',
     *         i4,' used')
 1400 format (/' invalid identifier for ',a,' - request ignored')
 1500 format (/' cell no. < 10 for ',a,' - request ignored')
 1600 format (/' invalid variable name for ',a,' - request ignored')
 1700 format (/' invalid aux. field for ',a,' - request ignored')
 1800 format (/i3,' identifiers'/)
 1900 format(' ',i4,' : ',a)
c
c
      end
*deck wrdata
       subroutine  wrdata
c
c
c  wrdata  -  write data for requested plot variables out to pldata
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  1/86
c  modified:  8/87  j. e. tolli, eg&g idaho
c
c
*ca paramtrs
c
*ca blankcom
c
*ca control
```

Figure D-7. (continued)

```
c
*ca iounitr
c
*ca ptrs
c
*ca vinfo
      integer  iaux(mxvars)
      equivalence  (iaux(1),aux(1))
c
c

      dimension  bufr(8)
      logical eof
c
c
c set pointer for graphics data
c
      ldat = ifree
c
      ifree = ifree + nwtx
c
c check for sufficient core storage
c
      if (ifree-1.gt.mxsize)  go to 40
c
c initialize plot data dump counter
c
      npd = 0
c
c read frame of data (start of loop)
   10 call  grfrd (a(ldat),nwtx,eof)
      if (eof)  go to 30

c increment frame counter
      npd = npd + 1
c
c get time value
      kp = ldat
      bufr(1) = a(kp)
c
c initialize the bufr buffer counter
      ndf = 1
c
c obtain rest of data and write to pldata
      do 20 i=1,npv
c
c get pointer to requested variable
c num(i)<0 implies fixed geometry data (num=component num)
         if (num(i).lt.0) then
          idx = lfixg
```

Figure D-7. (continued)

```
        else
          idx = idat
        endif

c pointer to data
        kp = idx + iabs (loc(i)) - 1
c
c iaux(i)=-1 implies no auxilliary data for this variable
c nc(i)<0 implies data is unpacked (cell number)
c loc(i)>0 implies more than one data word stored for variable
c if unpacked, put data in 'a' same location as if packed.
        if (iaux(i).eq.-1) then
          kdx = iabs (nc(i))
          if (ifree+kdx-1.gt.mxsize)  go to 40
          if (nc(i).lt.0) then
            a(ifree+kdx-1) = a(kp+kdx-1)
          else
            nw = kdx
            if (kdx.eq.1 .and. loc(i).gt.0)  nw = 2
            call  unpkit (a(ifree),nw,a(kp),npkw)
          endif
        else
          kdx = 1
          call  calcvl (i,kp,a(ifree))
        endif

c increment the bufr buffer counter
        ndf = ndf + 1

c dump the bufr buffer if full
        if (ndf.gt.8) then
          if (i.eq.8) then
            write (iuntdo,1000) bufr
          else
            write (iuntdo,1100) bufr
          endif
          ndf = 1
        endif

c store data in the bufr buffer
        bufr(ndf) = a(ifree+kdx-1)
c
c end of loop for this data frame
   20  continue
c
c dump the rest of the buffer
      if (i.le.8) then
        write (iuntdo,1000) (bufr(i),i=1,ndf)
      else
        write (iuntdo,1100) (bufr(i),i=1,ndf)
```

Figure D-7. (continued)

```
      endif
c
c end of loop
      go to 10
c
c finished reading plot file
   30 write (*,1200) npd
      return
c
c insufficient core for data
   40 write (*,1300)
      stop 'wrdata'
c
 1000 format (1p,e10.4,0p,7e10.4)
 1100 format (8e10.4)
 1200 format (i5,' data dumps on plot file'/)
 1300 format ('*****insufficient core for plot data'/
     *         '*****execution terminated'/)
      end
*deck wrvnl
      subroutine  wrvnl
c
c
c  wrvnl   -  write plot variable identifiers and labels to pldata
c
c  author  :  j. e. tolli, eg&g idaho
c  language:  fortran 77 (ctss cft)
c  date    :  1/86
c  modified:  8/87  j. e. tolli, eg&g idaho
c
*ca paramtrs
*ca blankcom
*ca cblock
*ca control
*ca iounits
*ca ptrs
*ca vinfo
c
      character cbuf*16,tlabel*24
c
c write number of requested variables, plus 1 for time
      write (iuntdo,1000) npv+1
c
c write name of time variable and label
      write (cbuf,'(a8)') ia(lcat+2)
      write (tlabel,'(3a8)') (ia(lcat+i),i=3,5)
      write (iuntdo,1100) cbuf,tlabel
c
c write identifier and label of each requested variable
      do 10 i=1,npv
```

Figure D-7. (continued)

```
        write (iuntdo,1100) cid(i),label(i)
   10 continue
c
c all done
      return
c
 1000 format (i3)
 1100 format (a,1x,a)
      end
      subroutine initdf()

*ca iofiles
*ca iounits

c initialize iofiles
      nxfnme=1
      nfnme=0
      do 10 i=1,10
        fnme(i)(1:)=' '
   10 continue

c initialize iounits
      iuntdi=12
      iundto=13
      return
      end
      subroutine rdfnme()
c
*ca iofiles
      character str*120,break*1
      integer   ib,nfn
      logical   eor,gexist

      nxfnme=1
      nfnme=0
c
   10 read(*,1000,end=100) str
      if(str(1:1).eq.'.') return
      ib=1
      nfnme=nfnme+1
      call cv02(str,120,ib,fnme(nfnme),nfn,break,eor)
      if(eor .or. nfn .le.0) then
        nfnme=nfnme-1
        go to 10
      endif
      inquire (file=fnme(nfnme),exist=gexist)
      if (.not.gexist) then
        write (*,1020) fnme(nfnme)
        nfnme=nfnme-1
      endif
```

Figure D-7. (continued)

```
      go to 10
c
  100 continue
      write(*,1010)
      call stop('rdfnme')

 1000 format(a)
 1010 format(' *** Premature eof')
 1020 format(' *** TRAC file does not exist:', a)
      end
      subroutine dfltnm()

*ca varnme
      integer i,lenstr

c vessel parameter names
      vessmp=10
      do 10 i=1,vessmp
        vessnm(i)(1:)=' '
   10 continue
      vessnm( 1)(1:)='P'
      vessnm( 2)(1:)='VLN-Z'
      vessnm( 3)(1:)='VVN-Z'
      vessnm( 4)(1:)='ALPHA'
      vessnm( 5)(1:)='RHOV'
      vessnm( 6)(1:)='RHOL'
      vessnm( 7)(1:)='TL'
      vessnm( 8)(1:)='TV'
      vessnm( 9)(1:)='TSAT'
      vessnp=9
      do 20 i=1,vessnp
        vessnn(i)=lenstr(vessnm(i))
   20 continue
c
      return
      end
      integer function lenstr(str)
      character str*(*)
      k=len(str)
      do 10, i=k,1,-1
        if(str(i:i).ne.' ') go to 20
   10 continue
      lenstr=0
      return
c
   20 continue
      lenstr=i
c
      return
      end
```

Figure D-7. (continued)

```
c source code zcif.f--source code that reads the ascii data
c and writes the binary FRAP-T6 boundary condition file
c
      program main
c
c INPUT:
c
c dbg1 dbg2
c trac_file_name
c frap_output_file_name
c start_time stop_time time_interval
c lower_plenum_volume_number
c upper_plenum_volume_number
c core_plenum_volume_number_1  bottom_elev top_elev
c core_plenum_volume_number_2  bottom_elev top_elev
c core_plenum_volume_number_3  bottom_elev top_elev
c core_plenum_volume_number_4  bottom_elev top_elev
c     :
c     :

      INCLUDE 'zcif.h'
      logical err
c
c get requested variables from user input
      call  userin
c
c open the trac input and frap output files
      call openf(err)
      if(err) then
        call clos
        stop '*** Error openf'
      endif
c
c write variable names from data file
      call  rdvnm
c
c process file to FRAP output
      call  dofrap
c
      end
      subroutine  openf (err)
c
c *** openf - Open files
c
      INCLUDE 'zcif.h'
      logical  gexist,err
      integer  ios
c
      err=.false.
c
```

Figure D-8. TRAC2FRAP source code zcif.f.

```
c open TRAC plot file if it exists
      iuntdi=22
      inquire (file=fntrac,exist=gexist)
      if (gexist) then
        open(unit=iuntdi,file=fntrac,form='formatted')
      else
        write(*,1000) fntrac
        err=.true.
      endif
c
c open the FRAP output file
      iuntdo=23
      open(unit=iuntdo,file=fnfrap,form='unformatted')

c set the steam table unit number
      sth2xt=16

c open the steam tables
      inquire (file='sth2xt',exist=gexist)
      if (gexist) then
        open(unit=sth2xt,file='sth2xt',status='old',
     +       form='unformatted',iostat=ios)
      else
        write(*,1020) ios
        err=.true.
        return
      endif

c initialize the steam tables
      nstm=15800
      call sth2xj(stmtbl,sth2xt,nstm)

      if(nstm.lt.0) then
        write(*,1010)
        err=.true.
      endif
c
 1000 format(' *** TRAC ascii file does not exist: ',a)
 1010 format(' *** Error opening steam tables')
 1020 format(' *** Water property table file ios = ',i2)
      return
      end
      subroutine userin()
c
c *** userin - Process user input
c
      INCLUDE 'zcif.h'

      character str*80,break*1
      integer   nstr,ib,istat,nch,k,cvinm
```

Figure D-8. (continued)

```
      logical   eor
      real      cvrnm,dz

c
c characacter buffer length
      nstr=80

c get the debug parameters
      read (*,1000,end=100) str
      ib=1
      dbg1=cvinm(str,nstr,ib,istat)
      dbg2=cvinm(str,nstr,ib,istat)
      write(*,1060) dbg1,dbg2
c
c get input and output data-file names
      read(*,1000,end=100) str
      ib=1
      call cv02(str,nstr,ib,fntrac,nch,break,eor)
      write(*,1010) fntrac
      read(*,1000,end=100) str
      ib=1
      call cv02(str,nstr,ib,fnfrap,nch,break,eor)
      write(*,1020) fnfrap

c get the start, stop and time interval
      read (*,1000,end=100) str
      ib=1
      timnxt=cvrnm(str,nstr,ib,istat)
      timstp=cvrnm(str,nstr,ib,istat)
      timdif=cvrnm(str,nstr,ib,istat)
      write(*,1030) timnxt, timstp, timdif

c read the lower plenum volume number
      read (*,1000,end=100) str
      write (*,1040) str
      ib=1
      call cv02(str,nstr,ib,lpvol,nch,break,eor)

c read the upper plenum volume number
      read (*,1000,end=100) str
      write (*,1040) str
      ib=1
      call cv02(str,nstr,ib,upvol,nch,break,eor)
c
c start loop. read core volume numbers
      k=1
   10 read (*,1000,end=110) str
      write (*,1040) str
c
c process user input
```

Figure D-8. (continued)

```
      ib=1
      call cv02(str,nstr,ib,cvol(k),nch,break,eor)
      if(eor) go to 10
      zb(k)=cvrnm(str,nstr,ib,istat)
      zt(k)=cvrnm(str,nstr,ib,istat)
      if(k.eq.1) then
        dz=zt(k)-zb(k)
      else
        if(zb(k).le.0) zb(k)=zt(k-1)
        if(zt(k).le.0) zt(k)=zb(k-1)+dz
      endif
      if(dbg1.ne.0) then
        write(*,2010) zb(k),zt(k)
      endif
      k=k+1
      go to 10
c
c abnormal end of file on input data
  100 continue
      call clos
      stop '*** Premature eof '

c end of file on input data
  110 continue
      nvol=k-1
      return
c
 1000 format(a)
 1010 format(/' TRAC input file:'a)
 1020 format(/' FRAP output file:'a)
 1030 format(/' Start time    = ',f10.3,
     +       /' End time      = ',f10.3,
     +       /' Time interval = ',f10.6/)
 1040 format(1x,a)
 1060 format(/' Debug 1 = ',i1,'   Debug 2 = ',i1)
 2010 format(' bot=',f10.4,'  top=',f10.4)
      end
      subroutine  rddata(data,ndata,eof)
c
c *** rddata - Read frame of data
c
      INCLUDE 'zcif.h'
      real     data(*)
      integer  ndata,nloop,k,i,j,ndf
      logical  eof

      nloop=dfrnum/8
      k=0

      do 10 i=1,nloop
```

Figure D-8. (continued)

```
          read(iuntdi,1000,end=100) (data(k+j),j=1,8)
          k=k+8
   10 continue

      ndf = mod(dfrnum,8)
      read(iuntdi,1000,end=100) (data(k+i),i=1,ndf)

      ndata=dfrnum
      eof=.false.
      return

  100 continue
      eof=.true.
      return

 1000 format(8f10.0)
      end
      subroutine  rdvnm
c
c *** rdvnm - Read plot variable name
c
      INCLUDE 'zcif.h'
      integer i,nch,ib,nstr
      character str*80,break*1
      logical   eor
c
c characacter buffer length
      nstr=80
c
c read number of requested variables, plus 1 for time
      read(iuntdi,1000) dfrnum
c
c read identifier of each variable
      do 10 i=1,dfrnum
        read(iuntdi,1010,end=100) str
        ib=1
        call cv02(str,nstr,ib,dfrnme(i),nch,break,eor)
   10 continue
      return
c
  100 continue
      call clos
      stop '*** eof reading TRAC names'
c
 1000 format(i3)
 1010 format(a)
      end
      subroutine getloc(name,nname,loc,list,nlist)
c
c *** getloc - Get location of data in data frame
```

Figure D-8. (continued)

```
c
c entry -
c     name  :Array of variable names
c     nname :Length of name and loc
c     list  :List of names for each variable in the data frame
c     nlist .Length of list.
c
c exit -
c     loc   :Location of data (-1 = not found).

      INCLUDE 'zcif.h'
      dimension name(*),list(*)
      character name*(*),list*(*)
      integer   nname,nlist,loc(*),i,j

c initially set to all not found
      do 10, i=1,nname
        loc(i)=-1
   10 continue

c search list
      do 30 i=1,nname
        do 20 j=1,nlist
          if(name(i)(1:).eq.list(j)(1:)) then
            loc(i)=j
            go to 30
          endif
   20   continue
   30 continue
      return
      end
      subroutine dofrap()
c
c *** dofrap - Process the data file
c
      INCLUDE 'zcif.h'
      integer ulocP , ulocTl, ulocTv, ulocDl, ulocDv,
     +        ulocVl, ulocVv, ulocVd, llocP , llocTl,
     +        llocTv, llocDl, llocDv ,llocVl, llocVv,
     +        llocVd,
     +        locP(20)     , locTl(20)     , locTv(20)    ,
     +        locDl(20)    , locDv(20)     , locVl(20)    ,
     +        locVv(20)    , locVd(20)
      dimension namc(8)
      character namc*6,name*16
      integer   ncnam(8),loc(8),nnam,i,j,ndat
      logical   err,eof
      real      dat(10000),tMx,hMx,mMx,cnvH,cnvM,cnvT1,cnvT2,cnvP

      data namc /'P','VLN-Z','VVN-Z','ALPHA','RHOV','RHOL' 'TL','TV' /
```

Figure D-8. (continued)

```
      data ncnam/ 1, 5, 3, 5, 4, 4, 2, 2/

c conversion constants
      data   cnvH,    cnvM,  cnvT1, cnvT2,     cnvP
     +   /4.299e-4, 737.4,  1.8,  -460.,  1.4504e-4/
c
c number of parameters per volume
      nnam=8

c length steam table
      nstm=15800
c
      err=.false.

c data location for lower plenum
      do 10 i=1,nnam
        name=namc(i)(1:ncnam(i))//lpvol(1:)
        call getloc(name,1,loc(i),dfrnme,dfrnum)
        if(dbgl.ne.0) then
          write(*,2010) loc(i),name
        endif
        if(loc(i).lt.0) then
          err=.true.
          write(*,1000) name
        endif
   10 continue
      llocP  = loc(1)
      llocVl = loc(2)
      llocVv = loc(3)
      llocVd = loc(4)
      llocDv = loc(5)
      llocDl = loc(6)
      llocTl = loc(7)
      llocTv = loc(8)

c data location for upper plenum
      do 20 i=1,nnam
        name=namc(i)(1:ncnam(i))//upvol(1:)
        call getloc(name,1,loc(i),dfrnme,dfrnum)
        if(dbgl.ne.0) then
          write(*,2020) loc(i),name
        endif
        if(loc(i).lt.0) then
          err=.true.
          write(*,1000) name
        endif
   20 continue
      ulocP  = loc(1)
      ulocVl = loc(2)
      ulocVv = loc(3)
```

Figure D-8. (continued)

```
      ulocVd = loc(4)
      ulocDv = loc(5)
      ulocDl = loc(6)
      ulocTl = loc(7)
      ulocTv = loc(8)

c data location for core
      do 40 j=1,nvol
        do 30 i=1,nnam
          name(1:)=namc(i)(1:ncnam(i))//cvol(j)(1:)
          call getloc(name,1,loc(i),dfrnme,dfrnum)
          if(dbg1.ne.0) then
            write(*,2030) j,loc(i),name
          endif
          if(loc(i).lt.0) then
            err=.true.
            write(*,1000) name
          endif
   30   continue
        locP(j)  = loc(1)
        locVl(j) = loc(2)
        locVv(j) = loc(3)
        locVd(j) = loc(4)
        locDv(j) = loc(5)
        locDl(j) = loc(6)
        locTl(j) = loc(7)
        locTv(j) = loc(8)
   40 continue

      if(err) then
        call clos
        stop '*** Missing data '
      endif

c loop reading and writing data
   50 continue
      call rddata(dat,ndat,eof)

      if(eof) go to 100
      if(dat(1).gt.timstp) go to 100
      if(dat(1).lt.timnxt) go to 50
      timnxt=dat(1)+timdif

c write time
      write(iuntdo) dat(1)
      if(dbg2.ne.0) then
        write(*,2040) dat(1)
      endif

c write lower plenum data
```

Figure D-8. (continued)

```
      call getprp( dat(llocVd), dat(llocTl), dat(llocTv),
     +             dat(llocDl), dat(llocDv), dat(llocVl),
     +             dat(llocVv), hMx, tMx, mMx)
      dat(llocP)=dat(llocP)*cnvP
      hMx=hMx*cnvH
      tMx=tMx*cnvT1+cnvT2
      write(iuntdo) dat(llocP),hMx,tMx
      if(dbg2.ne.0) then
        write(*,2050) dat(llocP),hMx,tMx
      endif

c write core data
      do 60 j=1,nvol
        call getprp( dat(locVd(j)), dat(locTl(j)), dat(locTv(j)),
     +               dat(locDl(j)), dat(locDv(j)), dat(locVl(j)),
     +               dat(locVv(j)), hMx, tMx, mMx)
        write(iuntdo) zb(j),zt(j),dat(locP(j)),hMx,tMx,mMx
        dat(locP(j))=dat(locP(j))*cnvP
        hMx=hMx*cnvH
        tMx=tMx*cnvT1+cnvT2
        mMx=mMx*cnvM
        if(dbg2.ne.0) then
          write(*,2070) j,zb(j),zt(j),dat(locP(j)),hMx,tMx,mMx
        endif
   60 continue

c write upper plenum data
      call getprp( dat(ulocVd), dat(ulocTl), dat(ulocTv),
     +             dat(ulocDl), dat(ulocDv), dat(ulocVl),
     +             dat(ulocVv), hMx, tMx, mMx)
      dat(ulocP)=dat(ulocP)*cnvP
      hMx=hMx*cnvH
      tMx=tMx*cnvT1+cnvT2
      write(iuntdo) dat(ulocP),hMx,tMx
      if(dbg2.ne.0) then
        write(*,2060) dat(ulocP),hMx,tMx
      endif

c loop back to 50
      go to 50

c eof or time limit reached reached
  100 continue
      write(*,1020)
      return

 1000 format(' *** Variable not located: ',a)
 1020 format(//' Eof or time limit reached')
 2010 format(' Lower plenum. loc=',i4,'  Name= ',a)
 2020 format(' Upper plenum. loc=',i4,'  Name= ',a)
```

Figure D-8. (continued)

```
 2030 format(' Level=',i2,'      loc=',i4,'  Name= ',a)
 2040 format(/' Time = ',f11.5)
 2050 format(' LP:',5(1x,f10.3))
 2060 format(' UP:',5(1x,f10.3))
 2070 format(1x,i2,5(1x,f10.3),1x,1pe10.3)
      end
      subroutine getprp(void,tL,tV,rhoL,rhoV,vL,vV,
     +                  hMx,tMx,mMx)
c
c *** getprp - Get the mixture properties
c
      INCLUDE 'zcif.h'

      real    void,tL,tV,rhoL,rhoV,vL,vV,hMx,tMx,mMx
      real    qual,fac,hL,hV
      integer istate
      logical err

      if(void.gt.0.99) then
        qual=1.0
      else if(void.lt.0.001) then
        qual=0.
      else
        fac=(rhoV/rhoL)*(vV/vL)*(void/(1.0-void))
        qual=fac/(1+fac)
      endif

c istate: 1:liquid 2:2-phase 3:vapor
      if(qual.lt.0.99) then
        prp(1)=tL
        prp(3)=1.0/rhoL
        call sth2x4(stmtbl,prp,istate,err)
        if(err)  then
          call clos
          stop 'water prop err'
        endif
        if(istate.eq.2) then
          hL=prp(15)
        else
          hL=prp(5)
        endif
      else
        hL=0.0
      endif
      if(qual.gt.0.01) then
        prp(1)=tV
        prp(3)=1.0/rhoV
        call sth2x4(stmtbl,prp,istate,err)
        if(err)  then
          call clos
```

Figure D-8. (continued)

```
          stop 'water prop err'
        endif
        if(istate.eq.2) then
          hV=prp(16)
        else
          hV=prp(5)
        endif
      else
        hV=0.0
      endif

      hMx=qual*hV+(1.0-qual)*hL
      tMx=qual*tV+(1.0-qual)*tL
      mMx=vV*void*rhoV+vL*(1-void)*rhoL

      return
      end
      subroutine clos()
c
c *** clos - Close files
c
      INCLUDE 'zcif.h'

      close (unit=sth2xt)
      close (unit=iuntdi)
      close (unit=iuntdo)
      close (*)
      return
      end
```

Figure D-8. (continued)

```
c     Source code cv0000.f--source code for the subroutines used to
c     read data in free format
c
      subroutine cvreal(str,n,ib,rx,stat)
c
c     cvreal - Get the next binary real from a char string.
c
c     Dale M. Snider
c
c     Get the next binary real number from a char string. If the next
c     characters in the string are integer, a real conversion
c     is made. If the next chraracters are character data, then
c     the status flag is set. If an end-of record, then the
c     status flag is set. For either an error or an end-of-
c     record  the real variable is not redefined.
c
c     Entry -
c        str  ... The character string to be parsed.
c        n    ... The length of the character string. If greater
c                 than the dimension length of str, the dimension
c                 length is used.
c        ib   . . The start character location to extract the
c                 number. Reset on exit.
c
c     Exit -
c        rx   ... The real number. If stat > 0, then rx is not
c                 assigned a new value. If the number extracted
c                 from the character string is an integer, a real
c                 conversion is made.
c        ib   ... The location of the next character after the number.
c        stat ... neg = ok.
c                 0   = ok.
c                 1   = end-of-file
c                 2   = error.
c
      character str*(*),break*1,cx*10
      integer   n,ib,stat,type,ix
      real      rx
      logical   eor
c
      call cv01(str,n,ib,rx,ix,cx,type,break,eor)
c
      if(eor) then
        stat=1
        return
      endif
c
      if(type.lt.0) then
        stat=2
        return
```

Figure D-9. TRAC2FRAP source code cv0000.f.

```
      endif
c
      if(type.eq.1) rx=real(ix)
      stat=0
c
      return
      end
      real function cvrnm(str,n,ib,stat)
c
c     cvrnm - Get the next binary real from a char string.
c
c     Dale M. Snider
c
c     Get the next binary real number from a char string. If the next
c     characters in the string is integer, a real conversion
c     is made. If the next chraracters are character data, then
c     the status flag is set. If an end-of-record, then the
c     status flag is set. For either an error or an end-of-
c     record, the real variable is set to 0.0.
c
c     Entry -
c        str  ... The character string to be parsed.
c        n    ... The length of the character string. If greater
c                 than the dimension length of str, the dimension
c                 length is used.
c        ib   ... The start character location to extract the
c                 number. Reset on exit.
c
c     Exit -
c        cvrnm... The real number. If stat > 0, then cvrnm is
c                 assigned 0.0. If the number extracted
c                 from the character string is an integer, a real
c                 conversion is made.
c        ib   ... The location of the next character after the number.
c        stat ... neg = ok.
c                 0   = ok.
c                 1   = end-of-file
c                 2   = error.
c
      character str*(*),break*1,cx*10
      integer   n,ib,stat,type,ix
      real      rx
      logical   eor
c
      call cv01(str,n,ib,rx,ix,cx,type,break,eor)
c
      if(eor) then
        stat=1
        cvrnm=0.0
        return
```

Figure D-9. (continued)

```
      endif
c
      if(type.lt.0) then
        stat=2
        cvrnm=0.(
        return
      endif
c
      if(type.eq.1) then
         cvrnm=real(ix)
      else
         cvrnm=rx
      endif
      stat=0
c
      return
      end
      subroutine cvintg(str.n,ib,ix,stat)
c
c     cvintg - Get the next binary integer from a char string.
c
c     Dale M. Snider
c
c     Get the next binary integer from a char string. If the next
c     characters in the string is real, an integer conversion
c     is made. If the next chraracters are character data, then
c     the status flag is set. If an end-of-record, then the
c     status flag is set. For either an error or an end-of-
c     record, the integer variable is not redefined.
c
c     Entry -
c        str  ... The character string to be parsed.
c        n    ... The length of the character string. If greater
c                 than the dimension lengtn of str, the dimension
c                 length is used.
c        ib   ... The start character location to extract the
c                 number. Reset on exit.
c
c     Exit -
c        ix   ... The integer number. If stat > 0, then ix is not
c                 assigned a new value. If the number extracted
c                 from the character string is a real, an integer
c                 conversion is made. If the real is larger than
c                 the largest integer value, ix is  assigned the
c                 largest value, and stat is assigned 3.
c        ib   ... The location of the next character after the number.
c        stat ... neg = ok.
c                 0   = ok.
c                 1   = end-of-file
c                 2   = error.
```

Figure D-9. (continued)

```
c                 3   = real to integer conversion where the real is
c                       larger than the largest integer.
c
      character str*(*),break*1,cx*10
      integer   n,ib,stat,type
      real      rx,mi,eps
      logical   eor
c
c max integer. machine dependent
      data mi/2.0E9/
c add small amount for integer-to-real round off
      data eps/1.e-7/
c
      call cv01(str,n,ib,rx,ix,cx,type,break,eor)
c
      if(eor) then
        stat=1
        return
      endif
c
      if(type.lt.0) then
        stat=2
        return
      endif
c
      if(type.eq.2) then
         if(rx.lt.mi) then
           ix=int(rx+eps)
           stat=0
         else
           ix=mi
           stat=3
         endif
      else
         stat=0
      endif
c
      return
      end
      integer function cvinm(str,n,ib,stat)
c
c     cvinm - Get the next binary integer from a char string.
c
c     Dale M. Snider
c
c     Get the next binary integer from a char string. If the next
c     characters in the string is real, an integer conversion
c     is made. If the next chraracters are character data, then
c     the status flag is set. If an end-of-record, then the
c     status flag is set. For either an error or an end-of-
```

Figure D-9. (continued)

```
c      record, the integer variable is set to 0.
c
c      Entry -
c         str  ... The character string to be parsed.
c         n    ... The length of the character string. If greater
c                  than the dimension length of str, the dimension
c                  length is used.
c         ib   ... The start character location to extract the
c                  number. Reset on exit.
c
c      Exit -
c         cvinm .. The integer number. If stat > 0, then cvinm is
c                  assigned 0. If the number extracted
c                  from the character string is a real, an integer
c                  conversion is made. If the real is larger than
c                  the largest integer value, cvinm is  assigned the
c                  largest value, and stat is assigned 3.
c         ib   ... The location of the next character after the number.
c         stat ... neg = ok.
c                  0   = ok.
c                  1   = end-of-file
c                  2   = error.
c                  3   = real to integer conversion where the real is
c                        larger than the largest integer.
c
      character str*(*),break*1,cx*10
      integer   n,ib,stat,type
      real      rx,mi,eps
      logical   eor
c
c max integer. machine dependent
      data mi/2.0E9/
c add small amount for integer-to-real round off
      data eps/1.e-7/
c
      call cv01(str,n,ib,rx,ix,cx,type,break,eor)
c
      if(eor) then
        cvinm=0
        stat=1
        return
      endif
c
      if(type.lt.0) then
        cvinm=0
        stat=2
        return
      endif
c
      if(type.eq.2) then
```

Figure D-9. (continued)

```
        if(rx.lt.mi) then
          cvinm=int(rx+eps)
          stat=0
        else
          cvinm=mi
          stat=3
        endif
      else
        cvinm=ix
        stat=0
      endif
c
      return
      end
      subroutine cvchar(str,n,ib,cx,stat)
c
c     cvchar - Get the next character data from a char string.
c
c     Dale M. Snider
c
c     Get the next character data from a char string. If the next
c     characters give a real or integer number, the status
c     flag is set to an error and cx is unchanged.
c     If an end-of-record, then the status flag is set and
c     cx is not changed.
c
c     Entry -
c        str  ... The character string to be parsed.
c        n    ... The length of the character string. If greater
c                 than the dimension length of str, the dimension
c                 length is used.
c        ib   ... The start character location to extract the
c                 characters. Reset on exit.
c
c     Exit -
c        ix   ... The char sub-string. If stat > 0, then cx is not
c                 assigned a new value.
c        ib   ... The location of the next character after the character
c                 sub-string.
c        stat ... neg = ok. The number of characters = abs(stat).
c                 0   = ok.
c                 1   = end-of-file
c                 2   = error (number data).
c
      character str*(*),cx*(*),break*1
      logical   eof
      integer   n,ib,stat,type
      real      rx
c
      call cv01(str,n,ib,rx,ix,cx,type,break,eof)
```

Figure D-9. (continued)

```
c
      if(eof) then
        stat=1
        return
      endif
c
      if(type.lt.0) then
        stat=type
      else
        stat=2
      endif
c
      return
      end
      subroutine cv01(str,n,ib,rx,ix,cx,type,break,eor)
c
c     cv01 - Parse a character string with predefined seperators.
c
c     Dale M. Snider
c
c     Parse a string into integer, real or character data using a
c     defined set of seperators.
c
c     Entry -
c        str  ... Character string.
c        n    ... Length of str. If n is greater than the dimension
c                 length of str, the dimension length is used.
c        ib   ... The start character to begin processing. The first
c                 character is 1. A value less than 1 results in 1.
c                 This must be a variable. It is reset on exit.
c
c     Exit -
c        ib   ... Points at the next character beyond the last
c                 character processed. If the variable is a number
c                 (real or integer), ib is pointing at the next
c                 character which may be a break character. If
c                 the variable is a character string not within
c                 delimeters, ib is pointing at the next character
c                 which may be a break character. If the variable
c                 is a character string within a delimeter, the
c                 last delimeter is eaten. The string  '65abc' gives 65
c                 on the first request and 'abc' on the second request.
c                 The string 'x/i,j/', where '/' is a character
c                 delimeter and ',' is a break character gives 'x'
c                 on the first call and 'i,j' on the second call.
c                 Leading simple break characters are eaten.
c        rx   ... The real number. A real number begins with a plus,
c                 minus, decimal or a number. The number is real if
c                 it contains a decimal point or an exponential.
c        ix   ... The integer number. An integer number begins with a
```

Figure D-9. (continued)

```
c                 plus, minus, decimal or a number. The number is
c                 integer if it does not contain a decimal point or
c                 an exponential.
c        cx   ... The character string. Any data which is not a real
c                 number, or an integer number, or a break character,
c                 or is enclosed within character-break characters
c                 is character data. It is the users responsibility
c                 to insure that cx is long enough to hold the
c                 parsed character data.
c        type ... The type data returned.
c                 type < 0  Character data. Abs(type) is the number
c                           of char.
c                 type = 0  Not used at this time.
c                 type = 1  Integer.
c                 type = 2  Real.
c        break... The break character.
c        eor  ... End of record. No data is loaded.
c
      character str*(*),cx*(*),break*1,brk(8)*1
      integer   n,ib,ix,type,tbrk(8),nbrk,ibrk
      real      rx
      logical   eor
c
      data nbrk/8/
      data  brk/',',' ','=','(',')','''','"','*'/
      data tbrk/ 0 , 0 , 0 , 0 , 0 , 1 , 1 , 2/
c
      call cv00(str,n,ib,rx,ix,cx,type,brk,tbrk,nbrk,ibrk,eor)
      if(ibrk.gt.1) break=brk(ibrk)(1:1)
c
      return
      end
      subroutine cvil(str,n,ix,cx,ic,num)
c
c     cvil - Parse a character string with predefined seperators.
c
c     Dale M. Snider
c
c     Parse a string into integer, real or character data using a
c     defined set of seperators.
c
c     Entry -
c        str  ... Character string.
c        n    ... Length of str. If n is greater than the dimension
c                 length of str, the dimension length is used.
c
c     Exit -
c        ix   ... The real or integer number array.
c                 A real number begins with a plus,
c                 minus, decimal or a number. The number is real if
```

Figure D-9. (continued)

```
c                it contains a decimal point or an exponential.
c                An integer number begins with a
c                plus, minus, decimal or a number. The number is
c                integer if it does not contain a decimal point or
c                an exponential.
c       cx   ... The character string. Any data which is not a real
c                number, or an integer number, or a break character,
c                or is enclosed within character-break characters
c                is character data. It is the users responsibility
c                to insure that cx is long enough to hold the
c                parsed character data.
c       ic   ... The type data returned.
c                type < 0  Character data. Abs(type) is the number
c                          of char.
c                type = 0  Not used at this time.
c                type = 1  Integer.
c                type = 2  Real.
c                type = 3  A break character.
c        num ... The number of parsed variables.
c
      character str*(*),cx(*)*(*),brk(8)*1
      integer   n,ix(*),ic(*),tbrk(8),nbrk
c
      data nbrk/8/
      data  brk/',',' ','=','(',')','''','"','*'/
      data tbrk/ 0 , 0 , 0 , 0 , 0 , 1 , 1 , 2/
c
      call cvx0(str,n,ix,cx,ic,num,brk,tbrk,nbrk)
c
      return
      end
      subroutine cvi2(str,n,ix,cx,ic,num)

c     cvi1 - Parse a character string with predefined seperators.
c
c     Dale M. Snider
c
c     Parse a string into integer, real or character data using a
c     defined set of seperators.
c
c     Entry -
c        str  ... Character string.
c        n    ... Length of str. If n is greater than the dimension
c                 length of str, the dimension length is used.
c
c     Exit -
c        ix   ... The real or integer number array.
c                 A real number begins with a plus,
c                 minus, decimal or a number. The number is real if
c                 it contains a decimal point or an exponential.
```

Figure D-9. (continued)

```
c                 An integer number begins with a
c                 plus, minus, decimal or a number. The number is
c                 integer if it does not contain a decimal point or
c                 an exponential.
c        cx   ... The character string. Any data which is not a real
c                 number, or an integer number, or a break character,
c                 or is enclosed within character-break characters
c                 is character data  It is the users responsibility
c                 to insure that cx is long enough to hold the
c                 parsed character data.
c        ic   ... The type data returned.
c                 type < 0  Character data. Abs(type) is the number
c                           of char.
c                 type = 0  Not used at this time.
c                 type = 1  Integer.
c                 type = 2  Real.
c                 type = 3  A break character.
c         num ... The number of parsed variables.
c
      character str*(*),cx(*)*(*),brk(7)*1
      integer   n,ix(*),ic(*),tbrk(7),nbrk
c
      data nbrk/7/
      data  brk/',',' ','=','(',')','''','"'/
      data tbrk/ 0 , 0 , 0 , 0 , 0 , 1 , 1 /
c
      call cvx0(str,n,ix,cx,ic,num,brk,tbrk,nbrk)
c
      return
      end
      subroutine cv00(str,n,ib,rx,ix,cx,type,brk,tbrk,nbrk,ibrk,eor)
c
c     cv00 - Extract real, integer and character data from char string.
c
c     Dale M. Snider
c
c     This routine extracts integer, real or character data from
c     a character string. The rules for defining the type of data
c     are listed below. This routine is call repeatedly extracting
c     data from the string until an end-of-record is reached.
c
c     Entry -
c        str  ... Character string to be parsed.
c        n    ... Number of characters. If larger than the string
c                 dimension length, the dimension length will be
c                 used.
c        ib   ... The character position to start parsing. The first
c                 character is one. a number less than one results in
c                 one. This character position is updated to the next
c                 character on exit.
```

Figure D-9. (continued)

```
c        brk  ... The array of break characters. Leading simple break
c                 characters are ignored.
c                 The built in rules are:
c                 1  A real number begins with a plus,
c                    minus, decimal or a number. The number is real if
c                    it contains a decimal point or an exponential.
c                    Processing of a number terminates on a non-number
c                    except an e or E followed by a number.
c                 2  An integer number begins with a plus, minus,
c                    decimal or a number. The number is integer if
c                    it does not contain a decimal point or an
c                    exponential. Processing of a number terminates
c                    on a non-number.
c                 3  Any data which is not a real number, or an integer
c                    number, or a break character, or is enclosed
c                    within character-break characters is character
c                    data.
c                 4. The break characters are evaluated before the
c                    built  in rules. Once a number is started the
c                    built-in number rules are followed until the
c                    number is completed.
c        tbrk ... The type of break character.
c                 0 = Break character.
c                 1 = Break. Enclose character type data within the
c                     break character.
c                 2 = End of line character. Terminate the processing.
c                     Returns eor = true when encountered.
c        nbrk ... The number of break characters.
c
c       Exit -
c        ib   ... Points at the next character beyond the last
c                 character processed. If the variable is a number
c                 (real or integer), ib is pointing at the next
c                 character which may be a break character. If
c                 the variable is a character string not within
c                 delimeters, ib is pointing at the next character
c                 which may be a break character. If the variable
c                 is a character string within a delimeter, the
c                 last delimeter is eaten. The string  '65abc' gives 65
c                 on the first request and 'abc' on the second request.
c                 The string 'x/i,j/', where '/' is a character
c                 delimeter and ',' is a break character gives 'x'
c                 on the first call and 'i,j' on the second call.
c                 Leading simple break characters are eaten.
c        rx   ... The real number. A real number begins with a plus,
c                 minus, decimal or a number. The number is real if
c                 it contains a decimal point or an exponential.
c        ix   ... The integer number. An integer number begins with a
c                 plus, minus, decimal or a number. The number is
c                 integer if it does not contain a decimal point or
```

Figure D-9. (continued)

```
c                 an exponential.
c        cx   ... The character string. Any data which is not a real
c                 number, or an integer number, or a break character,
c                 or is enclosed within character-break characters
c                 is character data. It is the users responsibility
c                 to insure that cx is long enough to hold the
c                 . ~sed character data.
c        type ...     type data returned.
c                 type < 0  Character data. Abs(type) is the number
c                           of char.
c                 type = 0  Not used at this time.
c                 type = 1  Integer.
c                 type = 2  Real.
c        ibrk ... The index of the break character used in the last
c                 parse. If a number is terminated by encountering a
c                 non-number or if processing is terminated by reaching
c                 the end of the string (not the string terminator
c                 break character), then ibrk = 0.
c        eor  ... If true, then no more data.
c                 If false, then real, integer or character data
c                 was loaded.
c
      character str*(*),cx*(*),brk(*)*(*),quote*1
      integer   n,ib,ix,type,nbrk,tbrk(*),ibrk
      real      rx
      logical   eor
c
      nm=min(n,LEN(str))
      nc=LEN(cx)
      ib=max(ib,1)
      ibrk=0
c
c check if end-of-line
   10 if(ib.gt.nm) then
        eor=.true.
        return
      else
        eor=.false.
      endif
c
c check if leading break characters.
      do 20 ibrk=1,nbrk
   20 if(str(ib:ib).eq.brk(ibrk)) go to 30
c
c fell through if check. must be number or character
      go to 40
c
c jump here if a leading break character. process the break character
c if a break (=0), eat the char and keep processing
   30 if(tbrk(ibrk).eq.0) then
```

Figure D-9. (continued)

```
          ib=ib+1
          go to 10
        else if (tbrk(ibrk).eq.1) then
          go to 80
        else if (tbrk(ibrk).eq.2) then
          eor=.true.
          return
        endif
c
c check if a number
   40 if((str(ib:ib).ge.'0' .and. str(ib:ib).le.'9') .or.
     +      str(ib:ib).eq.'+' .or.  str(ib:ib).eq.'-'  .or
            str(ib:ib).eq.'.')                          then
          call cvnm(str,nm,ib,rx,ix,type)
          if(ib.gt.nm) then
            ibrk=0
            return
          else
            do 50 ibrk=1,nbrk
            if(str(ib:ib).eq.brk(ibrk)) return
            ibrk=0
            return
          endif
        endif
c
c unidentified. must be a char string. process until a break char
        type=-1
        i=1
        cx=' '
        if(i.gt.nc) return
        cx(i:i)=str(ib:ib)
   60 ib=ib+1
        if(ib.gt.nm) then
          ibrk=0
          return
        endif
        do 70 ibrk=1,nbrk
   70 if(str(ib:ib).eq.brk(ibrk)(1:1)) return
        i=i+1
        if(i.gt.nc) return
        type=type-1
        cx(i:i)=str(ib:ib)
        go to 60
c
c character string within a delimeter. process until next delimeter
   80 quote=str(ib:ib)
        type=0
        i=0
        cx=' '
   90 ib=ib+1
```

Figure D-9. (continued)

```
      if(ib.gt.nm) return
      if(str(ib:ib).eq.quote) then
        ib=ib+1
        return
      endif
      i=i+1
      type=type-1
      if(i.gt.nc) return
      cx(i:i)=str(ib:ib)
      go to 90
c
      end
      subroutine cvnn(str,mb,ib,rx,ix,type)
c
c     cvnn - Process number data from string.
c
c     Dale M. Snider
c
c     Process number data from a character string. The ib character
c     pointer must be pointing at the start of the number.
c
c     Entry -
c       str  ... The character string.
c       mb   ... Maximum characters to process. Must not exceed
c                the str dimension length.
c       ib   ... The start character of the number.
c
c     Exit -
c        rx   ... The real number. A real number begins with a plus,
c                 minus, decimal or a number. The number is real if
c                 it contains a decimal point or an exponential.
c        ix   ... The integer number. An integer number begins with a
c                 plus, minus, decimal or a number. The number is
c                 integer if it does not contain a decimal point or
c                 an exponential.
c        type ... 1 = integer.
c                 2 = real.
c
      character str*(*),ch*1
      integer   ib,ix,type,zero.npwr,mpwr,nstep,epwr,signe,signi,
     +          pow,mf,me
      real      rx,mn
c
      data zero/48/
c
c machine dependent
c mf - max fractional part. assumes integer is same length
c me - max exponential
c mn - max real number
c
```

Figure D-9. (continued)

```
      data mf,me,mn/8388607,36,1.0e37/
c
      ch=str(ib:ib)
      type=1
      rx=0.0
      ix=0
      npwr=0
      mpwr=0
      nstep=1
      epwr=0
      signe=1
      signi=1
c
c process the plus or minus sign
      if(ch.ne.'-' .and. ch.ne.'+') go to 90
      if(ch.eq.'-') signi=-1
c
c loop
   80 ib=ib+1
      if(ib.gt.mb) go to 120
      ch=str(ib:ib)
c
c a number
   90 if(str(ib:ib).ge.'0' .and. str(ib:ib).le.'9') then
        if(ix.le.mf) then
          ix=ix*10+ICHAR(ch)-zero
          npwr=npwr-1
          mpwr=mpwr+nstep
        endif
        go to 80
      endif
c
c a decimal point
      if(ch.eq.'.') then
        nstep=0
        type=2
        go to 80
      endif
c
c an e or E, process exponent
      if(ch.eq.'e' .or. ch.eq.'E') then
        type=2
        ib=ib+1
        if(ib.gt.mb) go to 120
        ch=str(ib:ib)
c
        if(ch.ne.'-' .and. ch.ne.'+') go to 110
        if(ch.eq.'-') signe=-1
c
c loop
```

Figure D-9. (continued)

```
  100   ib=ib+1
        if(ib.gt.mb) go to 120
        ch=str(ib:ib)
c
c exponent number
  110   if(ch.lt.'0' .or. ch.gt.'9') go to 120
        if(epwr.le.mf) epwr=epwr*10+ICHAR(ch)-zero
        go to 100
      endif
c
c complete the number
  120 ix=ix*signi
      if(type.eq.2) then
        pow=npwr+mpwr+(signe*epwr)
        if(pow.lt.me) then
          rx=real(ix*(10.0**pow))
        else
          rx=mn
        endif
      endif

      return
      end
      subroutine cvx0(str,n,ix,cx,ic,num,brk,ityp,nbrk)
c
c     cvx0 - Extract real, integer and character data from char string.
c
c     Dale M. Snider
c
c     This routine extracts integer, real or character data from
c     a character string. The rules for defining the type of data
c     are listed below. This routine is call repeatedly extracting
c     data from the string until an end-of-record is reached.
c
c     Entry -
c        str  ... Character string to be parsed.
c        n    ... Number of characters. If larger than the string
c                 dimension length, the dimension length will be
c                 used.
c        brk  ... The array of break characters. Leading simple break
c                 characters are ignored.
c                 The built in rules are:
c                 1  A real number begins with a plus,
c                    minus, decimal or a number. The number is real if
c                    it contains a decimal point or an exponential.
c                    Processing of a number terminates on a non-number
c                    except an e or E followed by a number.
c                 2  An integer number begins with a plus, minus,
c                    decimal or a number. The number is integer if
c                    it does not contain a decimal point or an
```

Figure D-9. (continued)

```
c                   exponential. Processing of a number terminates
c                   on a non-number.
c                3  Any data which is not a real number, or an integer
c                   number, or a break character, or is enclosed
c                   within character-break characters is character
c                   data.
c                4. The break characters are evaluated before the
c                   built  in rules. Once a number is started the
c                   built-in number rules are followed until the
c                   number is completed.
c        ityp ... The type of break character.
c                 0 = Break character.
c                 1 = Break and store the break character.
c                 2 = Break. Enclose character type data within the
c                     break character.
c                 3 = End of line character. Terminate the processing.
c                 4 = Break and store and enclose alphanumeric.
c        nbrk ... The number of break characters.
c
c      Exit -
c        ix   ... The real or integer number array. A real number begins
c                 with a plus minus, decimal or a number. The number is
c                 real if it contains a decimal point or an exponential.
c                 An integer number begins with a plus, minus
c                 decimal or a number. The number is integer if it
c                 does not contain a decimal point or an exponential.
c                 If both real and integer data are to be used, the
c                 calling program needs to have ix equivalenced to
c                 a real array. If character data is loaded, then
c                 ix is unchanged.
c        cx   ... The character string array. Data which is not a real
c                 number, or an integer number, or a break character,
c                 or is enclosed within character-break characters
c                 is character data. It is the users responsibility
c                 to insure that cx is long enough to hold the
c                 parsed character data.
c        ic   ... The type data returned array.
c                 type < 0  Character data. Abs(type) is the number
c                           of char.
c                 type = 0  Not used at this time.
c                 type = 1  Integer.
c                 type = 2  Real.
c                 type = 3  Break-and store character.
c        num  ... The number of parsed elements.
c                 num=0 indicates end-of-file. No elements loaded.
c
      character str*(*),cx(*)*(*),brk(*)*1,key*1
      integer   n,nm,ix(*),ic(*),ityp(*),itype,nbrk
      logical   quote
c
```

Figure D-9. (continued)

```
      nm=min(n,len(str))
      ib=0
      num=0
      ibrk=0
      ix(1)=0
      cx(1)=' '
c
c check if end-of-line
   10 ib=ib+1
   20 if(ib.gt.nm) return
c
c process break characters
      do 30 ibrk=1,nbrk
   30 if(str(ib:ib).eq.brk(ibrk)(1:1)) go to 40
c
c fell through if check. must be number or character
      go to 60
c
c jump here if a break character. process the break character
   40 if(ityp(ibrk).eq.0) then
         go to 10
c
c break-and-store. store the break character ic=3
      else if(ityp(ibrk).eq.1) then
         num=num+1
         cx(num)=' '
         cx(num)(1:1)=str(ib:ib)
         ic(num)=3
         ix(num)=0
         go to 10
c
c enclose alphanumeric between seperator
c enclose alphanumeric between seperator and store seperator
      else if(ityp(ibrk).eq.2 .or. ityp(ibrk).eq.4) then
         itype=ityp(ibrk)
         if(ityp(ibrk).eq.4) then
            num=num+1
            cx(num)(1:)=' '
            cx(num)(1:1)=str(ib:ib)
            ic(num)=3
         endif
         quote=.true
         key(1:1)=str(ib:ib)
         num=num+1
         ic(num)=0
         cx(num)(1:)=' '
         ix(num)=0
         idx=0
         go to 130
c
```

Figure D-9. (continued)

```
c terminate line character
      else if(ityp(ibrk).eq.3) then
         return
      endif
c
c  check if a number
   60 if((str(ib:ib).ge.'0' .and. str(ib:ib).le.'9') .or
     +    str(ib:ib).eq.'+' .or.  str(ib:ib).eq.'-'  .or.
     +    str(ib:ib).eq.'.')                         then
        num=num+1
        call cvnn(str,nm,ib,ix(num),ix(num),ic(num))
        go to 20
      endif
c
c not a number or unidentified. alpha string terminated with a break char
      quote=.false.
      num=num+1
      idx=1
      ic(num)=-1
      cx(num)=' '
      cx(num)(idx:idx)=str(ib:ib)
      ix(num)=0
c
c process string of characters
  130 ib=ib+1
      if(ib.gt.nm) go to 20
      if(quote) then
         if(str(ib:ib).eq.key(1:1)) then
           if(itype.eq.4) then
              num=num+1
              ic(num)=3
              cx(num)(1:)=' '
              cx(num)(1:1)=str(ib:ib)
           endif
           go to 10
         endif
      else
         do 80 ibrk=1,nbrk
   80    if(str(ib:ib).eq.brk(ibrk)(1:1)) go to 20
      endif
      idx=idx+1
      ic(num)=ic(num)-1
      cx(num)(idx:idx)=str(ib:ib)
      go to 130
c
      end
      subroutine cvch(str,n,ib,cx,nch,brk,tbrk,nbrk,ibrk,eor)
c
c     cvch - Extract character data from char string.
c
```

Figure D-9. (continued)

```
c     Dale M. Snider
c
c     This routine extracts character data from
c     a character string. The rules for defining the type of data
c     are listed below. This routine is call repeatedly extracting
c     data from the string until an end-of-record is reached.
c
c     Entry -
c        str  ... Character string to be parsed.
c        n    ... Number of characters. If larger than the string
c                 dimension length, the dimension length will be
c                 used.
c        ib   ... The character position to start parsing. The first
c                 character is one. a number less than one results in
c                 one. This character position is updated to the next
c                 character on exit.
c        brk  ... The array of break characters. Leading simple break
c                 characters are ignored.
c        tbrk ... The type of break character.
c                 0 = Break character.
c                 1 = Break. Enclose character type data within the
c                     break character.
c                 2 = End of line character. Terminate the processing.
c                     Returns eor = true when encountered.
c        nbrk ... The number of break characters.
c
c      Exit -
c        ib   ... Points at the next character beyond the last
c                 character processed. If
c                 the variable is a character string not within
c                 delimeters, ib is pointing at the next character
c                 which may be a break character. If the variable
c                 is a character string within a delimeter, the
c                 last delimeter is eaten.
c                 The string 'x/i,j/', where '/' is a character
c                 delimeter and ',' is a break character gives 'x'
c                 on the first call and 'i,j' on the second call.
c                 Leading simple break characters are eaten.
c        cx   ... The character string. Any data which is
c                 not a break character,
c                 or is enclosed within character-break characters
c                 is character data. It is the users responsibility
c                 to insure that cx is long enough to hold the
c                 parsed character data.
c        nch  ... The number of characters parsed.
c        ibrk ... The index of the break character used in the last
c                 parse. If a number is terminated by encountering a
c                 non-number or if processing is terminated by reaching
c                 the end of the string (not the string terminator
c                 break character), then ibrk = 0.
```

Figure D-9. (continued)

```
c          eor  ... If true, then no more data.
c                   If false, then real, integer or character data
c                   was loaded.
c
      character str*(*),cx*(*),brk(*)*(*),quote*1
      integer   n,ib,nch,nbrk,tbrk(*),ibrk
      logical   eor
c
      nm=min(n,LEN(str))
      nc=LEN(cx)
      ib=max(ib,1)
      ibrk=0
      nch=0
c
c check if end-of-line
   10 if(ib.gt.nm) then
        eor=.true.
        return
      else
        eor=.false.
      endif
c
c check if leading break characters.
      do 20 ibrk=1,nbrk
   20 if(str(ib:ib).eq.brk(ibrk)) go to 30
c
c fell through if check. must be character
      go to 40
c
c jump here if a leading break character. process the break character
c if a break (=0), eat the char and keep processing
   30 if(tbrk(ibrk).eq.0) then
        ib=ib+1
        go to 10
      else if (tbrk(ibrk).eq.1) then
        go to 80
      else if (tbrk(ibrk).eq.2) then
        eor=.true.
        return
      endif
c
   40 continue
      nch=1
      i=1
      cx=' '
      if(i.gt.nc) return
      cx(i:i)=str(ib:ib)
   60 ib=ib+1
      if(ib.gt.nm) then
        ibrk=0
```

Figure D-9. (continued)

```
          return
        endif
        do 70 ibrk=1,nbrk
   70   if(str(ib:ib).eq.brk(ibrk)(1:1)) return
        i=i+1
        if(i.gt.nc) return
        nch=nch+1
        cx(i:i)=str(ib:ib)
        go to 60
c
c character string within a delimeter. process until next delimeter
   80 quote=str(ib:ib)
        nch=0
        i=0
        cx=' '
   90 ib=ib+1
        if(ib.gt.nm) return
        if(str(ib:ib).eq.quote) then
          ib=ib+1
          return
        endif
        i=i+1
        nch=nch+1
        if(i.gt.nc) return
        cx(i:i)=str(ib:ib)
        go to 90
c
        end
        subroutine cv02(str,n,ib,cx,ncn,break,eor)
c
c       cv01 - Parse a character string with predefined seperators.
c
c       Dale M. Snider
c
c       Parse a string into character data using a defined set
c       of seperators.
c
c       Entry -
c          str   ... Character string.
c          n     ... Length of str. If n is greater than the dimension
c                    length of str, the dimension lengtn is used.
c          ib    ... The start character to begin processing. The first
c                    character is 1. A value less than 1 results in 1.
c                    This must be a variable. ib is reset on exit.
c
c       Exit -
c          ib    ... Points at the next character beyond the last
c                    character processed. If the variable is a number
c                    (real or integer), ib is pointing at the next
c                    character which may be a break character. If
```

Figure D-9. (continued)

```
c                 the variable is a character string not within
c                 delimeters, ib is pointing at the next character
c                 which may be a break character. If the variable
c                 is a character string within a delimeter, the
c                 last delimeter is eaten.
c                 The string 'x, ,j/', where '/' is a character
c                 delimeter and ',' is a break character gives 'x'
c                 on the first call and 'i,j' on the second call.
c                 Leading simple break characters are eaten.
c        cx   ... The character string. Any data which is not
c                 a break character,
c                 or is enclosed within character-break characters
c                 is character data. It is the users responsibility
c                 to insure that cx is long enough to hold the
c                 parsed character data.
c        nch  ... The number of characters parsed.
c        break... The break character.
c        eor  ... End of record. No data is loaded.
c
      character str*(*),cx*(*),break*1,brk(8)*1
      integer   n,ib,nch,tbrk(8),nbrk,ibrk
      logical   eor
c
      data nbrk/8/
      data  brk/',',' ','=','(',')','''','"','*'/
      data tbrk/ 0 , 0 , 0 , 0 , 0 , 1 , 1 , 2/
c
      call cvch(str,n,ib,cx,nch,brk,tbrk,nbrk,ibrk,eor)
      if(ibrk.gt.1) break=brk(ibrk)(1:1)
c
      return
      end
```

Figure D-9. (continued)

```
c  The make script used to build xcif
c

#!/bin/csh
cft77 cv0000.f
update -i xcif.us -c xcif
# cf77 -m 4 -o xcif cv0000.f xcif.f  >& err
cf77 -m 4 -o xcif cv0000.o xcif.f  >& err
more err

c  The make script used to build zcif

#!/bin/csh
# f77 -o zcif -g -trapuv cv0000.f zcif.f envrl.a -lm
f77 -o zcif -g -trapuv cv0000.o zcif.f envrl.a -lm
```

Figure D-10. TRAC2FRAP source code mkx and mkz.

```
      subroutine getprp(void,tL,tV,rhoL,rhoV,vL,vV,
     +                  hMx,tMx,mMx)
c
c *** getprp - Get the mixture properties
c
c     The bulk values of the mixture are calculated.  The
c     property of the mixture is based on the quality. The
c     quality is a non-equilibrium quality based on the
c     ratio of the mass fow rate of the gas  to the total
c     mass flow rate.  This quality is calculated in this
c     routine.  The sth2x4 routine returns equilibrium water
c     properties given the two independent properties,
c     temperature and specific volume.  sth2x4 is called
c     once for the liquid phase and once for the vapor
c     phace.  From the non-equilibrium quality and the
c     properties of the two phases the mixture properties
c     are calculated.  For property "p", with vapor (V) and
c     liquid (L) properties, the bulk property is:
c     p = qual * pV + (1 - qual) * pL.
c
c     Entry -
c        void    :Void fraction.
c        tL      :Temperature of the liquid.
c        tV      :Temperature of the vapor.
c        rhoL    :Density of the liquid.
c        rhoV    :Density of the vapor.
c        vL      :Velocity of the liquid.
c        vV      :Velocity of the vapor.
c
c     Exit -
c        hMx     :Enthalpy of the mixture.
c        tMx     :Temperature of the mixture.
c        mVx     :Mass flux of the mixture.
c
      INCLUDE 'zcif.h'

      real    void,tL,tV,rhoL,rhoV,vL,vV,hMx,tMx,mMx
      real    qual,fac,hL,hV
      integer istate
      logical err

c If void is > 0.99, the qual=1. If void < 0.001, qual =0.0
c Otherwise, qual = Mvap / (Mvap + Mliq) where
c   Mvap = Mass fow rate of vapor.
c   Mliq = Mass fow rate of liquid..

      if(void.gt.0.99) then
        qual=1.0
      else if(void.lt.0.001) then
```

Figure D-11. The zcif subroutine that calculates bulk fluid properties.

```
          qual=0.
        else
          fac=(rhoV/rhoL)*(vV/vL)*(void/(1.0-void))
          qual=fac/(1+fac)
        endif
c sth2x4: lookup of water prop using temp & specific vol
c istate: 1:liquid 2:2-phase 3:vapor
c If the qual < 0.99, get the liquid enthalpy
c  f istate = 2, use sat h. If istate # 2, use single phase h
        if(qual.lt.0.99) then
          prp(1)=tL
          prp(3)=1.0/rhoL
          call sth2x4(stmtbl,prp,istate,err)
          if(err)  then
            call clos
            stop 'water prop err'
          endif
          if(istate.eq.2) then
            hL=prp(15)
          else
            hL=prp(5)
          endif
        else
          hL=0.0
        endif

c If the qual > 0.01, get the vapor enthalpy
c If istate = 2, use sat h. If istate # 2, use single phase h
        if(qual.gt.0.01) then
          prp(1)=tV
          prp(3)=1.0/rhoV
          call sth2x4(stmtbl,prp,istate,err)
          if(err)  then
            call clos
            stop 'water prop err'
          endif
          if(istate.eq.2) then
            hV=prp(16)
          else
            hV=prp(5)
          endif
        else
          hV=0.0
        endif
c calculate the mixture properties
        hMx=qual*hV+(1.0-qual)*hL
        tMx=qual*tV+(1.0-qual)*tL
        mMx=vV*void*rhoV+vL*(1-void)*rhoL
        return
        end
```

Figure D-11. (continued)

Appendix E

SCDAP/RELAP5/MOD3 Input Deck Preparation and Results

Appendix E

SCDAP/RELAP5/MOD3 Input Deck Preparation and Results

E-1. Code Description

The SCDAP/RELAP5 computer code is a light water reactor (LWR) transient analysis code designed to provide the overall reactor coolant system (RCS) thermal-hydraulic response, core damage progression, and fission product release and transport during severe accidents. SCDAP/RELAP5/MOD3[E-1] is a combination of RELAP5/MOD3,[E-2] SCDAP,[E-3] and TRAP-MELT[E-4] models. The RELAP5/MOD3 models calculate the overall RCS thermal-hydraulics, control system interactions, reactor kinetics, and the transport of noncondensible gases, fission products, and aerosols. The SCDAP models calculate the damage progression in the core structures and the formation, heat-up, and melting of debris. The TRAP-MELT models calculate the deposition of fission products upon aerosols or structural surfaces; the formation, growth, or deposition of aerosols; and the evaporization of species from surfaces. These models are fully coupled at each time step. Their functional interaction is described in Figure E-1.

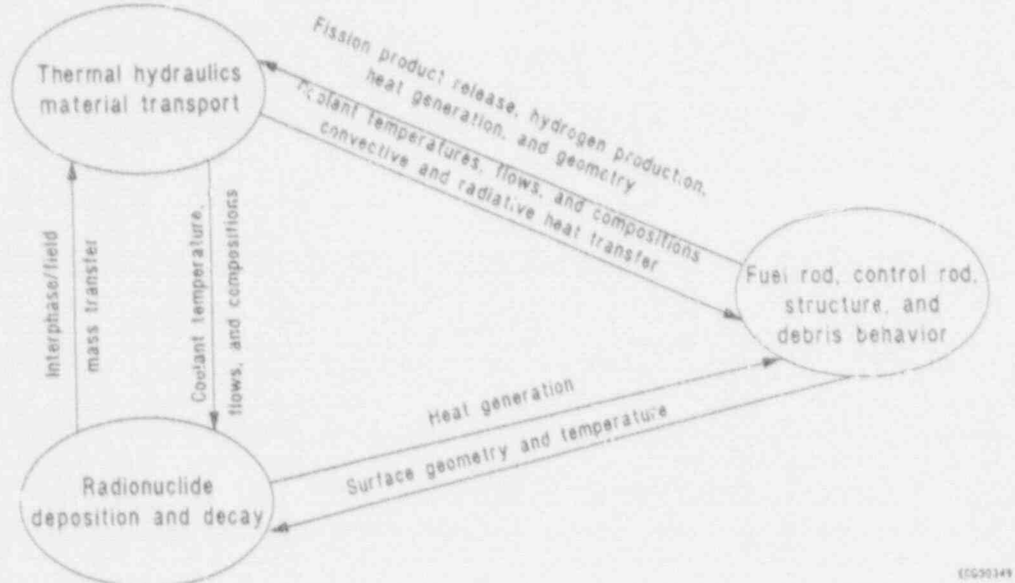


Figure E-1. SCDAP/RELAP5 reactor coolant system interactions.

The MOD3 version of SCDAP/RELAP5 was developed to provide a code version suitable for the analysis of all transients and postulated accidents in pressurized water reactor (PWR) systems, including both large- and small-break loss-of-coolant accidents (LOCAs) as well as the full range of operational transients. It also is a relatively fast-running code that can execute from a workstation platform. SCDAP/RELAP5/MOD3 was thus a suitable selection for modeling accident scenarios for the timing analysis of PWR fuel pin failures. The assessment of SCDAP/RELAP5/MOD3 is in progress.

E-2. METHODOLOGY

Figure E-2 shows the role of SCDAP/RELAP5/MOD3 in the overall methodology for the timing analysis of PWR fuel pin failures. SCDAP/RELAP5/MOD3 was used to calculate primary system thermal-hydraulic response and provide thermal-hydraulic boundary conditions for the FRAP-T6 calculations. A SCDAP/RELAP5/MOD3 transient calculation was made for each of the following accident scenarios for both the Seabrook and Oconee reactors:

- A double-ended, offset shear break of a cold leg, with break sizes corresponding to 100, 90, 75, and 50% of the full design basis accident (DBA), without emergency core cooling systems (ECCS) and without reactor coolant system (RCS) pump trip

- The 100% DBA, or worst, case with RCS pumps tripped, both with and without ECCS

- The 100% DBA case with ECC but without RCS pumps tripped

- A 6-in.-dia small-break case, both with and without ECCS.

Transient calculations were preceded by a null transient (steady-state) calculation to stabilize system parameters.

E-3. INPUT DECK DEVELOPMENT AND EXECUTION FOR SEABROOK

The basic SCDAP/RELAP5 reactor model used in this analysis (referred to hereafter as the base deck) was an existing SCDAP/RELAP5/MOD2.5 input deck for the Seabrook reactor, a Westinghouse four-loop plant with a 17x17 fuel pin configuration, as modified for a station blackout transient study.[E-5] Calculations supporting both the original Seabrook deck and subsequent modifications are archived. Nodalization diagrams for the revised deck are presented as Figures E-3 and E-4.

The following changes were made to the Seabrook base deck to accommodate the specific requirements of this analysis:

- The three-channel RELAP5 core and core bypass models were modified from six to nine axial nodes.

- The number of fuel assemblies in each of the three channels in the core model was modified as follows: hot channel--4; middle ring--77; outer ring--112.

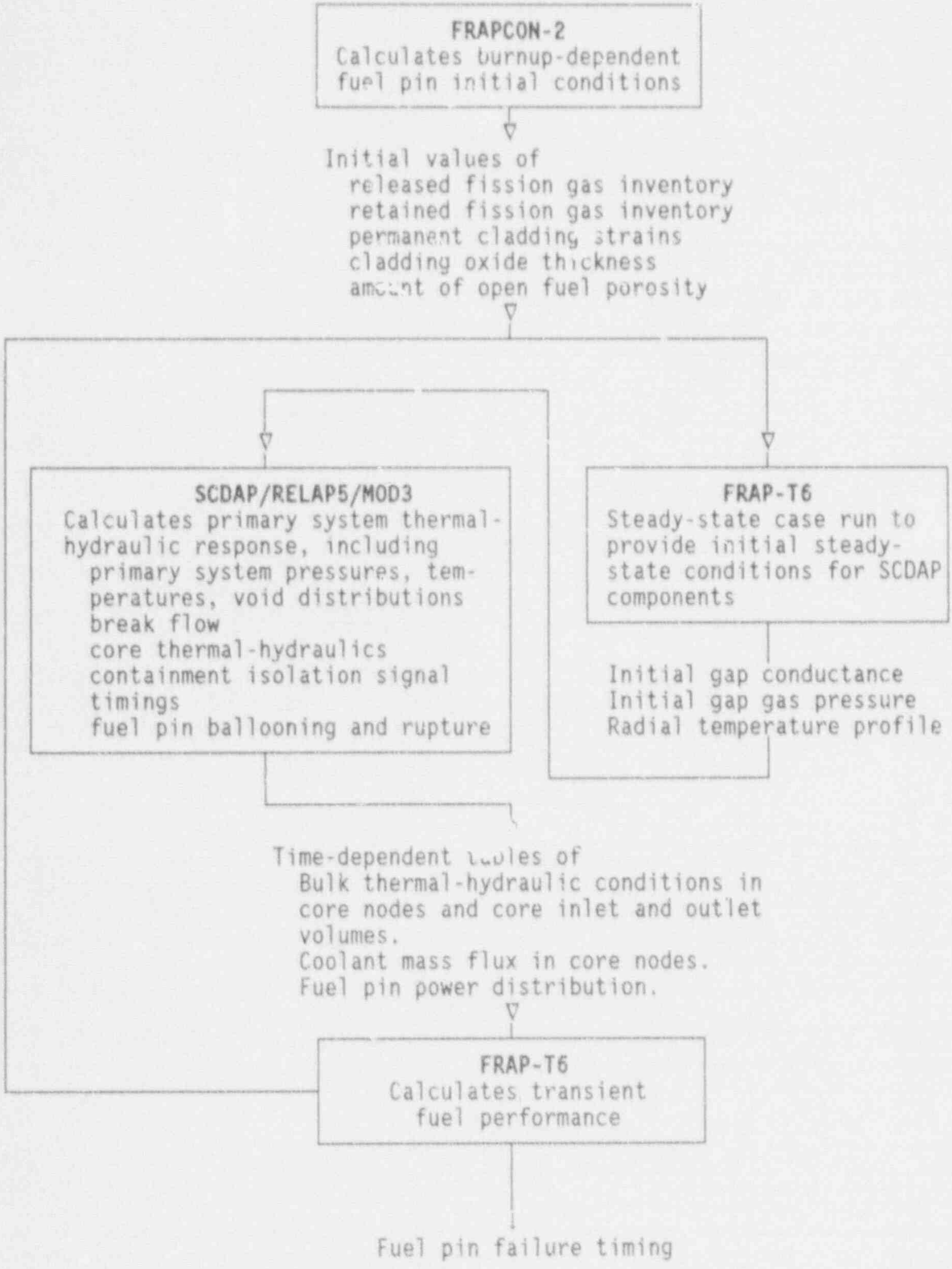


Figure E-2. Flow chart of methodology using SCDAP/RELAP5/MOD3 thermal-hydraulic data.

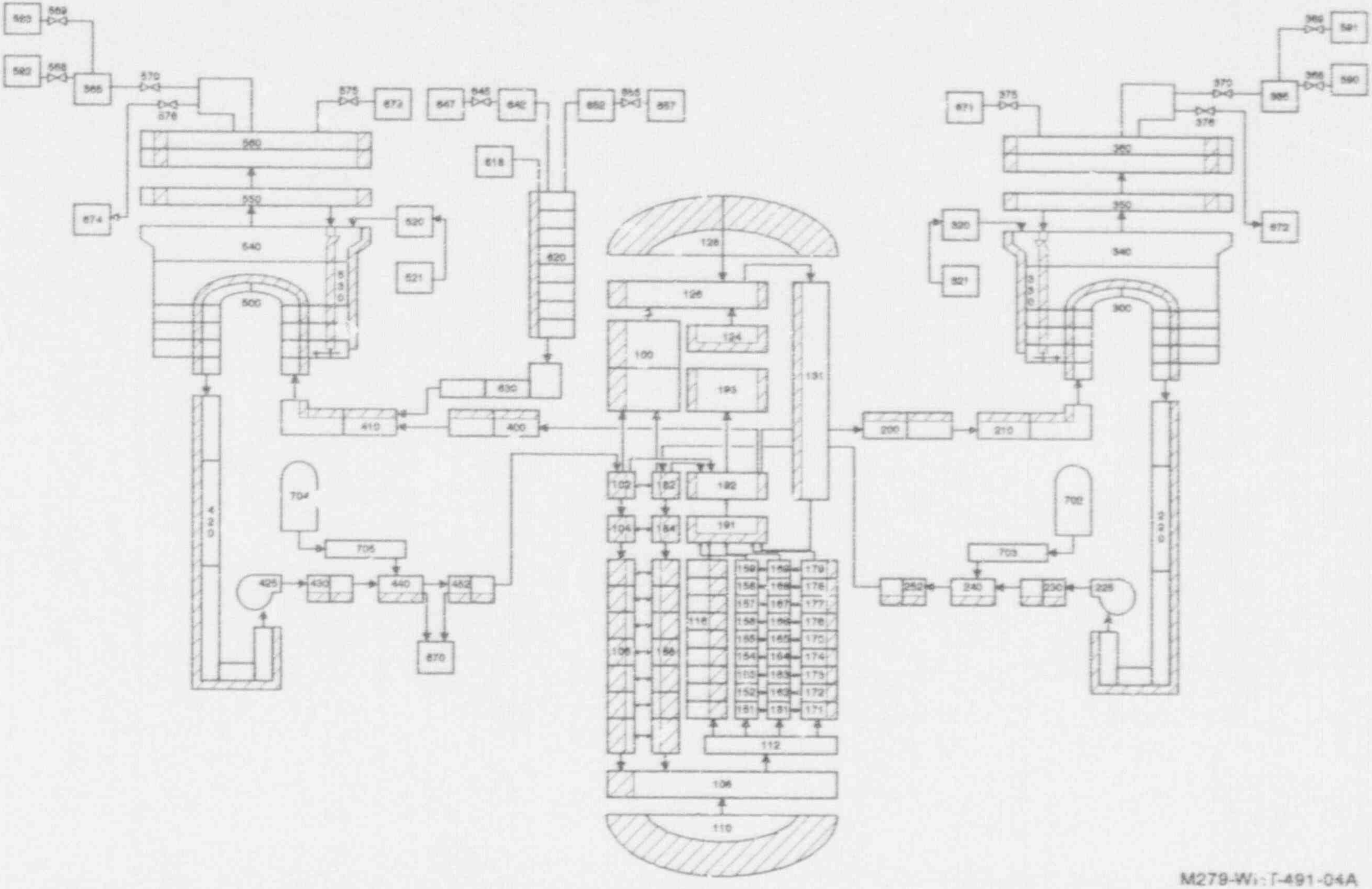


Figure E-3. SCDAP/RELAP5/MOD3 nodalization diagram of the Seabrook reactor model.

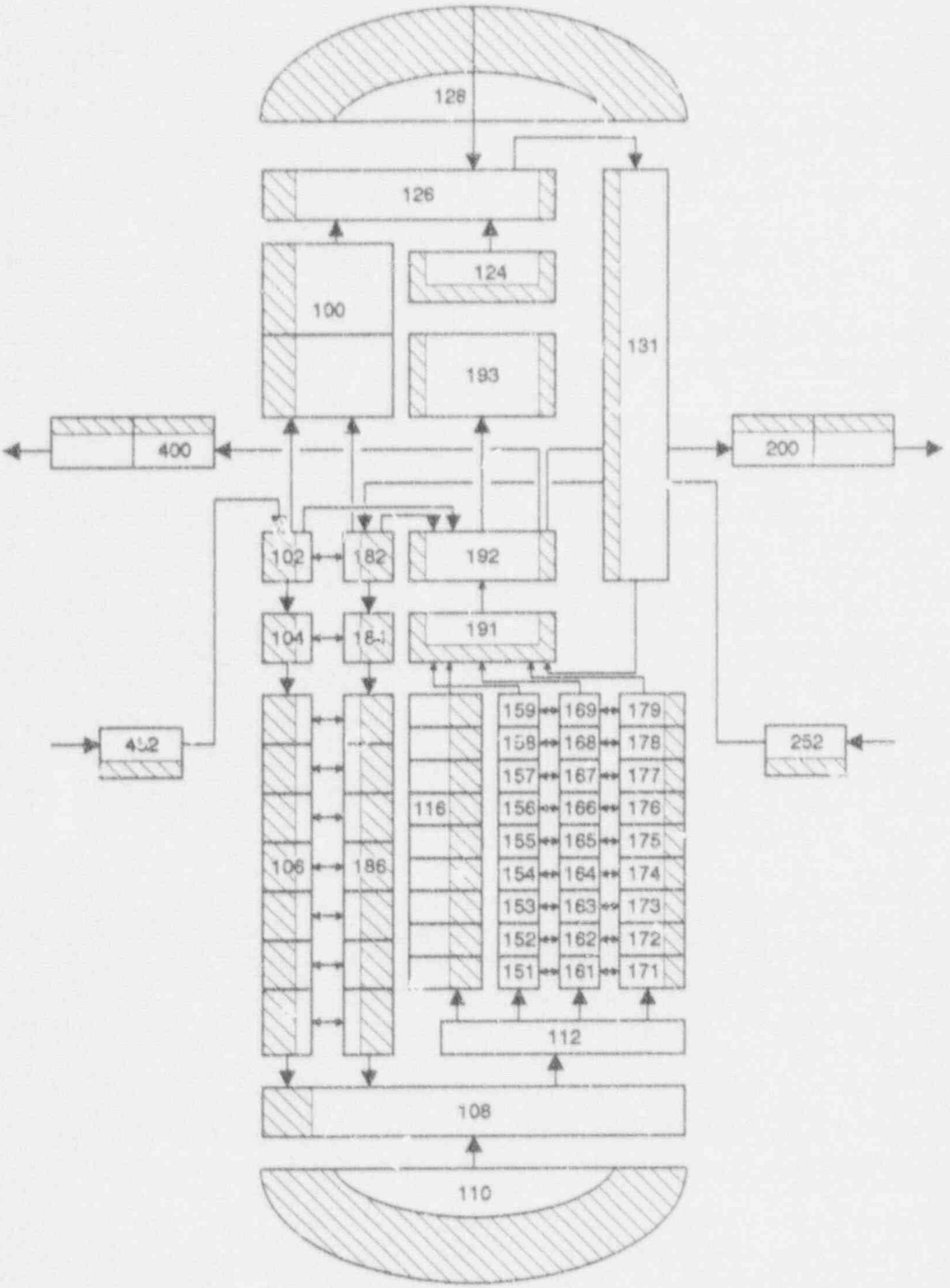


Figure E-4. SCDAP/RELAP5/MOD3 nodalization diagram of the Seabrook reactor vessel.

- The RELAP5 upper plenum and guide tube models were modified from three- to single-channel models.

- The RELAP5 downcomer model and vessel inlet annulus fluid volumes below the cold leg centerline were split into two channels connected by crossflow junctions.

- All heat structures associated with the above models were modified as required.

- A previously developed accumulator model was added, and ECCS models were added for those cases requiring ECCS initiation.

- The RELAP5 portion of the deck was upgraded to run on SCDAP/RELAP5/MOD3.

- RELAP5/MOD3 reactor point kinetics input and a control system for scram reactivity insertion were added.

- A RELAP5/MOD3 containment model and containment isolation trips were added.

- A method for calculating collapsed reactor water level was added.

- A SCDAP input deck was created to represent the Seabrook core model.

These changes are discussed in more detail in the following subsections.

E-3.1 Reactor Vessel Component Modifications

The Seabrook core model in the base deck contained three channels and six axial nodes. To accommodate the axial power profile requirements for the timing analysis of PWR fuel pin failures, the core and core bypass models were modified to contain nine axial nodes. The three-channel upper plenum and guide tube assembly models were also combined into single channels. The number of fuel assemblies in each of the three channels was also modified in order to model the hot pin more accurately. The inner, middle, and outer channels of the base deck contained 37, 92, and 64 fuel assemblies, respectively; the modified core model inner, middle, and outer channels contain 4, 77, and 112 fuel assemblies, respectively.

During a LOCA, the borated water from the emergency cooling accumulators floods the core through two flooding nozzles attached to the reactor vessel. In order to simulate the process of core flooding more realistically, the downcomer model and vessel inlet annulus fluid volumes below the cold leg centerline were split into two channels connected by crossflow junctions. The revised downcomer flow modeling splits Components 102, 104, and 106 into two channels, one for each loop. Components 102, 104, and 106 represent flow from the broken loop, set at 25% of total flow. Components 182, 184, and 186 represent flow from the intact loop, set at 75% of total flow. For consistency, Components 102 and 182 were converted from branch to annulus components. Branch junctions were replaced with single junctions, and single junctions representing both crossflow and vertical junctions were added as required by the three-channel model.

Heat structures connected to restructured reactor vessel components were also modified as required. Specific reactor vessel component modifications are listed in Table E-1.

E-3.2 Addition of Accumulator and ECCS Models

Accumulator and ECCS models were developed for the original Seabrook deck and had been removed from the base deck. These models were taken from the calculation packages for the original Seabrook deck and added to the input decks for the timing analysis of fuel pin failures, where appropriate.

E-3.3 Deck Conversion from RELAP5/MOD2 to RELAP5/MOD3

Upon release of RELAP5/MOD3, the code developers issued a list of changes necessary to convert RELAP5/MOD2 input decks to RELAP5/MOD3 input decks. All the changes listed in Table E-2 are required so that the RELAP5/MOD3 input deck will run similarly to the RELAP5/MOD2 deck. While the code may run without making any changes, the results will not be accurate. Changes required to convert the Seabrook base deck to run on SCDAP/RELAP5/MOD3 are described below.

E-3.3.1 Volume Vertical Angle. The volume vertical angle is used in RELAP5/MOD3 to calculate interphase friction and must be entered in the RELAP5/MOD3 input deck if two-phase flow is important. No changes were necessary, since the Seabrook base deck already had the volume vertical angles entered.

E-3.3.2 Junction Hydraulic Diameter. Junction hydraulic diameter and counter-current flow (CCFL) data cards were added for all junctions found in the base deck and modified reactor vessel models. Depending on the component, these cards require either four or five data words: junction hydraulic diameter, flooding correlation, gas intercept, slope, and junction number (optional). Junction hydraulic diameters were calculated based on available plant-specific data, and these calculations have been documented (see Appendix A). The CCFL model was not turned on; however, input for the flooding correlation form, the gas intercept, and the slope is still required. These values were arbitrarily set to 1.0 for all junctions.

E-3.3.3 Horizontal Stratification Flags. In RELAP5/MOD2, the flag for horizontal stratification off was v = 3; in RELAP5/MOD3, the same flag is v = 0. No changes were necessary, since there were no components in the base deck with v = 3.

Table E-1. Data revisions to RELAP5/MOD3 section of the Seabrook input deck.

Model or component no.[a]	Description of data	Description of revision
Core model		The 3-channel core model was changed from 6 to 9 branch components per channel. The fuel assembly distribution per channel was changed as follows: hot channel, 37 to 4 assemblies; middle ring, 92 to 77; outer ring, 112 to 64. Specific component changes required by this model change are given below.
C151 to C159, center channel; C161 to C169, middle ring; C171 to C179, outer ring	Volume flow area	These values were recalculated because they are based on the number of fuel assemblies per channel.
	Volume length	The volume length was adjusted linearly. NOTE: the difference between the active fuel length and the total fuel rod length was added to the ninth (highest) volume.
	Volume elevation change	Same as above.
	Volume control flags	The rod bundle interphase friction model was turned on.
	Volume initial conditions	The values for pressure and liquid and vapor specific internal energy were interpolated over 9 volumes.[b]
	Crossflow junction flow area	Due to the change in volume height and number of fuel assemblies, this value was recalculated.
	Vertical junction forward and reverse flow loss coefficients	These values were redistributed over the height of the volumes.
	Vertical junction initial liquid and vapor velocity	These values were interpolated over 9 volumes.[b]

Table E-1. (continued)

Model or component no.[a]	Description of data	Description of revision
Upper plenum model		The nine branch volumes of the upper plenum model were combined into three single channels. Specific component changes required by this model change are given below.
C191, C192, and C193, upper plenum	Number of junctions	The number of junctions for C191 changed from three to five.
	Volume volume	The single-channel volume volume is the sum of the three 3-channel volumes.
	Hydraulic diameter	The hydraulic diameters were recalculated from plant-specific data.
	Junction connection codes	Because of the change in number of junctions, the TO and FROM connection codes changed.
	Junction area	The single-channel junction area is the sum of the three 3-channel junction areas.
	Junction mass flows	Because of the restructuring of the core channels, junction mass flows were recalculated.
Core bypass model		The core bypass pipe model was changed from six to nine nodes. Specific component changes required by this change are given below.
C116, core bypass fluid volume	Number of pipe volumes	The number of volumes was changed from six to nine.
	Volume length	The volume lengths were adjusted linearly. NOTE: the difference between the active fuel length and the total fuel rod length was added to the ninth (highest) volume.
	Volume volume	The core bypass volume volumes were recalculated to match the revised core volume lengths.

Table E-1. (continued)

Model or component no.[a]	Description of data	Description of revision
	Volume elevation change	The core bypass elevation changes were adjusted to match the core volume lengths.
	Volume initial conditions	The values for pressure and liquid and vapor specific internal energy were interpolated over nine volumes.[b]
	Vertical junction flow energy loss coefficients	These values were redistributed over the height of the volumes.
	Vertical junction initial liquid and vapor velocity	These values were interpolated over nine volumes.
Guide tube assembly model		The guide tube assembly model was changed from three branch components to one. Specific component changes required by this model change are given below.
C131, guide tube assemblies	Volume volume	The single-channel volume volume is the sum of the three 3-channel volumes.
C126, upper head fluid volume	Number of junctions	The three junctions to the 3-channel guide tube assembly were combined into one, reducing the number of junctions from six to four.
	Junction area	The single-channel junction area is the sum of the three 3-channel junction areas.
Downcomer and vessel inlet annulus fluid models		The downcomer and associated fluid models were split into two channels and linked with crossflow junctions. C102, C104, and C106 and associated vertical junctions represent the broken loop, with flow set at 25% of total flow. C182, C184, and C186 and associated junctions represent the intact loop, with flow set at 75% of total flow. Specific component changes are given below.

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

1

IMAGE EVALUATION
TEST TARGET (MT-3)

150mm

6"

Table E-1. (continued)

Model or component no.[a]	Description of data	Description of revision
C102-C182; C104-C184; C106-C186; vessel inlet fluid volumes below the cold leg centerline and downcomer	Volume volume	C102 was converted to an annulus and split; C104 and C106 were split. C182, C184, and C186 duplicate C102, C104, and C106 except for the volume volume, which was split according to the channel split factor.
C103-C183; C105-C185; vertical junctions between the inlet annulus upper and lower volumes and the lower volume and downcomer	Junction area	C103 replaces a branch junction formerly connected to C102; both C103 and C105 were split. C183 and C185 duplicate C103 and C105 except for the junction area, which was split according to the channel split factor.
C253-C453, vertical junctions between cold legs and vessel inlet fluid volumes		These junctions replace branch junctions formerly affixed to C102. The only change was to junction TO and FROM connection codes.
C194-C195, vertical junctions between the vessel inlet fluid volumes and upper plenum	Junction area	C194 replaces a branch junction formerly connected to C102. C195 duplicates C194 except for TO and FROM codes and the junction area, which was split according to the channel split factor.
C101-C181, vertical junctions between vessel inlet fluid volumes above and below the cold leg centerline	Junction area	C101 replaces a branch junction formerly connected between C102 and C100. C181 duplicates C101 except for TO and FROM codes and the junction area, which was split according to the channel split factor.
C187, C188, and C189; crossflow junctions	Junction area, hydraulic diameter, flow velocity, loss coefficients	Crossflow junctions were added between C102 and C182, C104 and C184, and C106 and C186 (multiple junction). Crossflow junction areas and hydraulic diameters were calculated based on specific reactor data. Flow velocities and loss coefficients were set to zero.

Table E-1. (continued)

Model or component no.[a]	Description of data	Description of revision
108, lower plenum fluid volume	Junction area, number of branch junctions	A branch junction duplicating the branch junction between C108 and C106 was added between C108 and C186. The number of branch junctions was changed from three to four. Junction area for the two branch junctions was split according to the channel split factor.
Heat structures attached to the core, core bypass, upper plenum, guide tube assembly, and downcomer models		All heat structures connected to restructured reactor vessel components were modified as required. Heat structures required by the addition of reactor vessel components were added. Specific changes and additions are given below.
HS116, core baffle assembly	Cylindrical height, volume numbers, number of axial heat structures	HS116 is connected to C116, the core bypass model, and C171 through C179, the core outer ring. Volume numbers, the number of axial heat structures, and cylindrical heights were revised to match the revised core nodalization.
HS1181, upper core plate and fuel assembly top nozzles	Rectangular surface area	HS1181 is connected to C191, . lowest volume of the upper plenum and is a combination of three heat structures. The rectangular surface area is the sum of the three surface areas.
HS1211, upper core support columns; HS1221, guide tube lower assembly; HS123, support plate; HS1241, guide tube upper assembly walls	Surface area factor	HS1121 is connected to upper plenum components 191, 192, and 193. HS1221 is connected to C331, the guide tube assembly, and C191, C192, and C193, the upper plenum. HS123 is connected to C193, upper plenum, and C124, lower upper head. C1241 is attached to C131, guide tube assembly, and C124 and C126, upper head components. All involve combining data from three heat structures into one. The surface area factors are the sums of the three surface areas.

Table E-1. (continued)

Model or component no.[a]	Description of data	Description of revision
HS1001-1002, vessel wall in inlet annulus region	Surface area	HS1001 connects to inlet annulus components C100, C102, and C104 (broken loop); HS1002 is connected to inlet annulus components C100, C182, and C184 (intact loop). HS1001 was split; HS1002 duplicates HS1001 except for surface areas, which were split according to the channel split factors.
HS1021-1022, core barrel wall in inlet annulus region; HS1061-1062, vessel wall in the downcomer region	Cylinder height	HS1021 connects components C100, C102, C104, and C106 (broken loop fluid volumes and downcomer) with components C112 (lower head), C116 (core bypass), and C191, C192, and C193 (upper plenum). HS1022 connects components C100, C182, C184, and C186 (intact loop fluid volumes and downcomer). HS1061 and HS1062 are connected to C106 and C186, the 2-channel downcomer. HS1021 and HS1061 were split; HS1022 and HS 1062 duplicate HS1021 and HS1061 except for cylinder heights, which were split according to the channel split factors.
HS1071-1072, neutron panel assemblies in downcomer	Surface area	HS1071 and HS1072 are connected to C106 and C186, the 2-channel downcomer. HS1071 was split; HS1072 duplicates HS1071 except for surface area, which was split according to the channel split factors.

a. C = component; HS = heat structure.

b. These values are estimates; actual values are calculated during the null transient.

Table E-2. Changes for converting RELAP5/MOD2 input decks to RELAP5/MOD3.

Component	Volume vertical angle	Junction hydraulic diameter	Horizontal stratification flag
Single volume	CCC0101-CCC0109 W5	---	---
Time-dependent volume	CCC0101-CCC0109 W5	---	---
Single junction	---	CCC0110 W1	CCC0101-CCC0109 W6
Time-dependent junction	---	---	---
Pipe	CCC0601-CCC0699 W1	CCC1401-CCC1499 W1	CCC1101-CCC1199 W1
Branch	CCC0101-CCC0109 W5	CCCN110 W1	CCCN101 W6
Valve	---	CCC0110 W1	CCC0101-CCC0109 W6
Pump	CCC0101-CCC0107 W5	CCC0110 W1; CCC0111 W1	CCC0108 W5: CCC0109 W5
Multiple junction	---	CCC2NNM W1	CCC0NNM W6
Accumulator	CCC0101-CCC0199 W5	---	CCC1101 W5

Miscellaneous Changes:

Time step control	If tt=2 in the RELAP5/MOD2 deck, set tt=3 in the RELAP5/MOD3 deck to run with the same time step control.
Heat structures	All of the variables on Cards 801-899 and 901-999 have changed.
Data card for noncondensibles	If an accumulator component is present in the model, the word "nitrogen" must appear on card 000110.

E-3.3.4 Time Step Control. The time step control card was changed as required to run the RELAP5/MOD3 input deck with the same time step control as RELAP5/MOD2.

E-3.3.5 Heat Structures. All the variables on Cards 800-899 and 900-999, additional right and left boundary cards, have changed. The input data required for RELAP5/MOD2 were critical heat flux and heat transfer correlation flag, hydraulic diameter, heated equivalent diameter (optional), channel length, and heat structure number. The input data required for RELAP5/MOD3 are heated equivalent diameter, heated length forward and reverse, grid spacer length forward and reverse, grid loss coefficient forward and reverse, local boiling factor, and heat structure number.

Since the Seabrook base deck contained both hydraulic and heated equivalent diameters, the heated equivalent diameter was used where available. If the heated equivalent diameter was defaulted to the hydraulic diameter (heated equivalent diameter = 0.0), the hydraulic diameter was used. For the revised reactor vessel models, heated equivalent diameters were calculated in some cases. For existing heat structures, the heat structure number was taken from the base deck. For added heat structures, the appropriate number was entered. Default values were used for all other input variables.

E-3.3.6 Data Card for Noncondensibles. The required input was present in the Seabrook base deck.

E-3.4 Addition of Reactor Point Kinetics

The reactor point kinetics option chosen assumes that feedback due to moderator density, moderator temperature, and fuel temperature is separable. Tables defining reactivity as a function of moderator density and volume weighting factors were calculated and input.

The sum of fission power and fission product and actinide decay power was defined as 102% of the maximum rated power for Seabrook, as given in Table 4.4-1 of the Seabrook FSAR.[E-6] The delayed neutron fraction over prompt neutron lifetime was based on end-of-life values for Seabrook found in Table 4.3-2 of the Seabrook FSAR.[E-6] ANS 79-1 standard fission product data were used, with a fission product yield factor of 1.02 to account for the higher-energy fission products resulting from ^{238}U fissions. The ^{239}U yield factor was taken from ANS Branch Technical Position APCSB 9-2.[E-7] The energy release per fission was defined as the RELAP5/MOD3 default value.

The table defining reactivity as a function of moderator density was calculated using data from Figure 15 0-3 of the Seabrook FSAR,[E-6] which provides the minimum moderator density coefficients used for safety analysis as a function of reactor coolant system pressure. For the purposes of this analysis, the coefficient at 40°F above nominal HFP T_{AVG} was selected from this figure. This value, -0.053 drho/(g/cc), corresponds to -8.5E-4 drho/(lb/ft^3). In order to simplify steady-state initialization, the moderator density coefficient of reactivity was assumed to be zero for moderator densities below 40.0 lb/ft^3. A delayed neutron fraction of 0.75% was used to convert reactivity into dollars.

The volume weighting factors used for density reactivity feedback were calculated by applying a power-squared weighting to the power distributions documented in Appendix G, Tables G-7 and G-9, for the middle and outer core regions. Contributions from the hot channel are assumed to be negligible. The total power in each node is obtained by multiplying the single rod nodal power by the number of fuel pins in that node. The normalized distribution is obtained by dividing the square of the total node power by the sum of the squares of the total node power for each node. Table E-3 summarizes the calculation of this distribution.

Table E-3. Calculation of density reactivity weighting factc , for Seabrook.

Center core region				Outer core region			
Single rod (kW)	Total power (kW)	Power squared (kW^2)	Norm. dist.	Single rod (kW)	Total power (kW)	Power squared (kW^2)	Norm. dist.
5.59	1.14E+05	1.29E+10	0.02048	5.05	1.49E+05	2.23E+10	0.03543
7.16	1.46E+05	2.12E+10	0.03370	6.48	1.92E+05	3.67E+10	0.05831
8.36	1.70E+05	2.89E+10	0.04586	7.56	2.24E+05	5.00E+10	0.07936
9.10	1.85E+05	3.42E+10	0.05437	8.23	2.43E+05	5.92E+10	0.09409
9.35	1.90E+05	3.61E+10	0.05743	8.46	2.50E+05	6.26E+10	0.09937
9.10	1.85E+05	3.42E+10	0.05437	8.23	2.43E+05	5.92E+10	0.09409
8.36	1.70E+05	2.89E+10	0.04586	7.56	2.24E+05	5.00E+10	0.07936
7.16	1.46E+05	2.12E+10	0.03370	6.48	1.92E+05	3.67E+10	0.05831
5.59	1.14E+05	1.29E+10	0.02048	5.05	1.49E+05	2.23E+10	0.03543

E-3.5 Addition of Control System for Scram Reactivity

Control rod reactivity does not play a significant part in LOCA analyses. Power reduction is achieved primarily through moderator density reactivity feedback. The control system described in Figure E-5 was used in this model to provide scram reactivity to prevent criticality following reflood. The control system inserted $4.0 of reactivity over a 2-s interval, starting 2 s after LOCA initiation. Trip 411 was manually set to activate at the time of LOCA initiation.

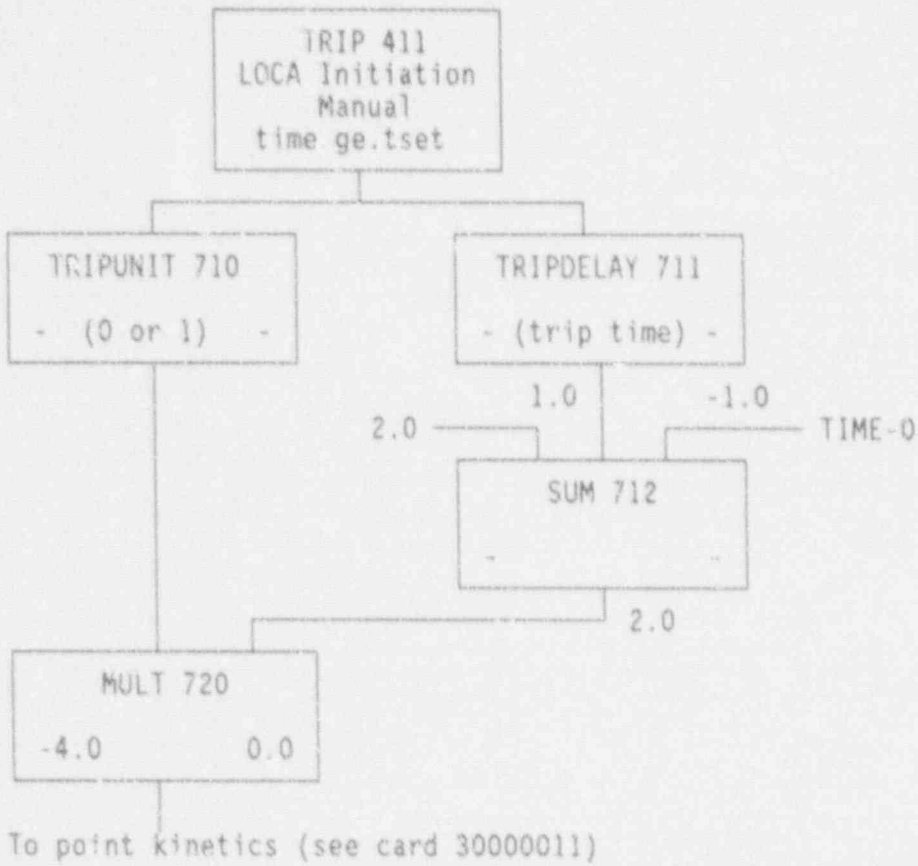


Figure E-5. SCDAP/RELAP5/MOD3 control system for scram reactivity for Seabrook.

E-3.6 Addition of Containment Model

The containment modeling consists of a single thermal-hydraulic volume containing the eleven passive heat structures identified in Table 6.2-3 of the Seabrook FSAR:[E-6] concrete cylinder; containment dome; miscellaneous concrete; refueling canal floor; refueling canal walls; conduit; ducts and trays; structural steel; polar crane, equipment hatch, and personnel hatch; equipment steel; and containment sump and floor. The material properties of these heat structures are based on data from Table 6.2-4 of the Seabrook FSAR.[E-6]

E-3.7 Addition of Containment High-Pressure Trip Signals

Containment isolation trip setpoints were taken from Table 3.3-4 of the Seabrook Technical Specifications and are summarized in Table E-4. The following trips were used to indicate when the allowable values are exceeded:

Table E-4. Containment isolation trip setpoints for Seabrook.

Trip	Trip setpoint (psig)	Allowable value (psig)	Action
Containment pressure hi-1	4.3	5.3	• Safety injection • Containment Phase A isolation
Containment pressure hi-2	4.3	5.3	• Steam line isolation
Containment pressure hi-3	18.0	18.7	• Containment Phase B isolation • Containment spray
Pressurizer - low	1875.0	1840.0	• Safety injection • Containment Phase A isolation

Trip 401--Containment pressure hi-1 trip set > 20 psia
Trip 402--Containment pressure hi-3 trip set > 33.4 psia
Trip 403--Pressurizer low pressure trip set > 1854.7 psia.

E-3.8 Calculation of Collapsed Reactor Water Level

Collapsed reactor water levels were calculated for each core channel by summing the products of node height (1.3333 ft) and liquid fraction (voidf) for each axial node. The average reactor water level was determined by weighted average of the three core channel values based on the number of assemblies in each channel.

E-3.9 Addition of SCDAP Core Components

The SCDAP modeling of the Seabrook core was based on specifications found in the Seabrook FSAR.[E-8] Eight fuel rod component models were used, as listed below:

Component 1--1054 average hot channel fuel pins
Component 2--1 low burnup hot channel fuel pin
Component 3--1 high exposure hot channel fuel pin
Component 4--100 hot channel guide tubes
Component 5--20328 central core region fuel pins
Component 6--1925 central core region guide tubes
Component 7--29568 outer core region fuel pins
Component 8--2800 outer core region guide tubes.

Specific fuel pin data were obtained from proprietary data sheets provided by the fuel vendor. Axial power profiles for the fuel pin components were calculated as described in Appendix G. Radial power profiles were taken from a previous calculation for TRAC-PF1.

Preliminary comparisons of stored energy calculated by SCDAP indicated poor agreement to FRAP-T6 results. As a result, SCDAP input was modified to allow modeling of the thermal resistance across the gap region and to allow adjustment of the initial stored energy to match results generated by FRAP-T6. The initial gap conductances were generated by steady state FRAP-T6 runs. The helium inventory for each fuel pin component was also adjusted in order to match the initial steady-state fuel pin internal pressures calculated by FRAP-T6.

E-3.10 Modifications for Specific Runs

The large-break LOCA cases assumed a double-ended shear break of the cold leg between Components 452 and 450. To accomplish this, both loop- and vessel-side cold leg break junctions were added. Junction areas were adjusted for the various break sizes. For the small-break LOCA cases, the size of the vessel-side cold leg break junction was decreased and a small-break LOCA trip valve was added between Components 440 and 670, the containment volume.

In addition to the above modeling modifications, other changes were required to initiate the specific requirements of each case run and continue code execution to the required time. The null transient required a pressurizer time-dependent volume for steady-state pressure control; this was deleted prior to performing transient analyses. Time step size was modified as required for continued code execution. Trip card setpoints were modified as required to model each accident scenario. To avoid code failure when the accumulators emptied into the system, trips were added to isolate the accumulators at a liquid volume of <0.1 m^3/accumulator.

E-3.11 Execution

The Seabrook base deck was modified as noted above and executed on a Digital Equipment Corporation DEC5000 workstation using SCDAP/RELAP5/MOD3 code version Cycle 7B. Nine cases were run; Table E-5 lists the description and input and output files for each case. All source, input, and output files have been archived on tape for permanent retention.

E-4. Input Deck Development and Execution for Oconee

The basic SCDAP/RELAP5 reactor model used in this analysis (referred to hereafter as the base deck) was an existing RELAP5/MOD2 input deck for the Oconee reactor, a Babcock & Wilcox (B&W) four-loop plant with a 15x15 fuel pin configuration. The Oconee base deck had been prepared for an evaluation of

Table E-5. SCDAP/RELAP5/MOD3 input and output files for the Seabrook timing analysis of fuel pin failures.

Case	File Name	Description
Null transient	null/reset0.out.Z	Compressed output
	null/reset0.r	Restart input to reset time to zero
	null/rstplt	Restart plot file reset to time zero
	null/rstplt.Z	Restart plot file at end of null transient
	null/runit*	Script for running null transient
	null/seanulla.i	Seabrook model base deck
	null/seanulla.out.Z	Compressed output
	null/seanullb.out.Z	Compressed output
	null/seanullb.r	Restart input
100% DBA	100dbafin/rstplt.Z	Restart plot file
	100dbafin/run100*	UNIX script to run case
	100dbafin/sea100dba.out	SCDAP/RELAP5 output
	100dbafin/sea100dba.r	Restart input
	100dbafin/sea100dba.thdat	FRAP-T6 binary link
	100dbafin/sea100dba.thin	Input file for FRAPR5
	100dbafin/sea100dba.thout.Z	Compressed output
	100dbafin/strip.i	Input file to strip data
	100dbafin/strip.out.Z	Compressed output
90% DBA	90dbafin/rstplt.Z	Restart plot file
	90dbafin/run90*	UNIX script to run case
	90dbafin/sea90dba.out	SCDAP/RELAP5 output
	90dbafin/sea90dba.r	Restart input
	90dbafin/sea90dba.thdat	FRAP-T6 binary link
	90dbafin/sea90dba.thin	Input file for FRAPR5
	90dbafin/sea90dba.thout.Z	Compressed output
	90dbafin/strip.i	Input file to strip data
	90dbafin/strip.out.Z	Compressed output
75% DBA	75dbafin/rstplt.Z	Restart plot file
	75dbafin/run75*	UNIX script to run case
	75dbafin/sea75dba.out	SCDAP/RELAP5 output
	75dbafin/sea75dba.r	Restart input
	75dbafin/sea75dba.thdat	FRAP-T6 binary link
	75dbafin/sea75dba.thin	Input file for FRAPR5
	75dbafin/sea75dba.thout.Z	Compressed output
	75dbafin/strip.i	Input file to strip data
	75dbafin/strip.out.Z	Compressed output

Table E-5. (continued)

Case	File Name	Description
50% DBA	50dbafin/rstplt.Z	Restart plot file
	50dbafin/run50*	UNIX script to run case
	50dbafin/sea50dba.out	SCDAP/RELAP5 output
	50dbafin/sea50dba.r	Restart input
	50dbafin/sea50dba.thdat	FRAP-T6 binary link
	50dbafin/sea50dba.thin	Input file for FRAPR5
	50dbafin/sea50dba.thout.Z	Compressed output
	50dbafin/strip.i	Input file to strip data
	50dbafin/strip.out.Z	Compressed output
100% DBA with pump trip at time zero	pt100dbafin/rstplt.Z	Restart plot file
	pt100dbafin/runpt100*	UNIX script to run case
	pt100dbafin/seapt100dba.out	SCDAP/RELAP5 output
	pt100dbafin/seapt100dba.r	Restart input
	pt100dbafin/seapt100dba.thdat	FRAP-T6 binary link
	pt100dbafin/seapt100dba.thin	Input file for FRAPR5
	pt100dbafin/seapt100dba.thout.Z	Compressed output
	pt100dbafin/strip.i	Input file to strip data
	pt100dbafin/strip.out.Z	Compressed output
100% DBA with ECCS	e100dbafin/rstplt.Z	Restart plot file
	e100dbafin/rune100*	UNIX script to run case
	e100dbafin/sea100edba.out	SCDAP/RELAP5 output
	e100dbafin/sea100edba.r	Restart input
	e100dbafin/sea100edba.thdat	FRAP-T6 binary link
	e100dbafin/sea100edba.thin	Input file for FRAPR5
	e100dbafin/sea100edba.thout.Z	Compressed output
	e100dbafin/stripe.i	Input file to strip data
	e100dbafin/strip.out.Z	Compressed output
100% DBA with pump trip at time zero and ECCS	pte100dbafin/rstplt.Z	Restart plot file
	pte100dbafin/runpte100*	UNIX script to run case
	pte100dbafin/sea100pte.out	SCDAP/RELAP5 output
	pte100dbafin/sea100pte.r	Restart input
	pte100dbafin/sea100pte.thdat	FRAP-T6 binary link
	pte100dbafin/sea100pte.thin	Input file for FRAPR5
	pte100dbafin/sea100pte.thout.Z	Compressed output
	pte100dbafin/stripe.i	Input file to strip data
	pte100dbafin/strip.out.Z	Compressed output

Table E-5. (continued)

Case	File Name	Description
6-in. small-break LOCA	6infin/rstplt.Z	Restart plot file
	6infin/run6*	UNIX script to run case
	6infin/sea6in.out	SCDAP/RELAP5 output
	6infin/sea6in.r	Restart input
	6infin/sea6in.thdat	FRAP-T6 binary link
	6infin/sea6in.thin	Input file for FRAPR5
	6infin/sea6in.thout.Z	Compressed output
	6infin/6instrip.i	Input file to strip data
	6infin/strip.out.Z	Compressed output
6-in. small-break LOCA with ECCS	e6infin/rstplt.Z	Restart plot file
	e6infin/run6e*	UNIX script to run case
	e6infin/sea6ine.out	SCDAP/RELAP5 output
	e6infin/sea6ine.r	Restart input
	e6infin/sea6ine.thdat	FRAP-T6 binary link
	e6infin/sea6ine.thin	Input file for FRAPR5
	e6infin/sea6ine.thout.Z	Compressed output
	e6infin/6instripe.i	Input file to strip data
	e6infin/strip.out.Z	Compressed output

operational safety at B&W plants[E-8] and was subsequently modified to run on RELAP5/MOD3. Calculations supporting both the original Oconee deck and subsequent modifications are archived. Nodalization diagrams for both the base deck and revised deck are presented as Figures E-6, E-7, E-8, and E-9.

The following changes were made to the Oconee base deck to accommodate the specific requirements of this analysis:

- The one-channel RELAP5 core model was split into a three-channel model.
- The core and core bypass models were modified from three to nine axial nodes.
- The number of fuel assemblies in each of the three channels in the core model was determined to be: hot channel--4; middle ring--92; outer ring--81.
- The RELAP5 downcomer model and vessel inlet annulus fluid volumes below the cold leg centerline were split into two channels connected by crossflow junctions.
- All heat structures associated with the above models were modified as required.

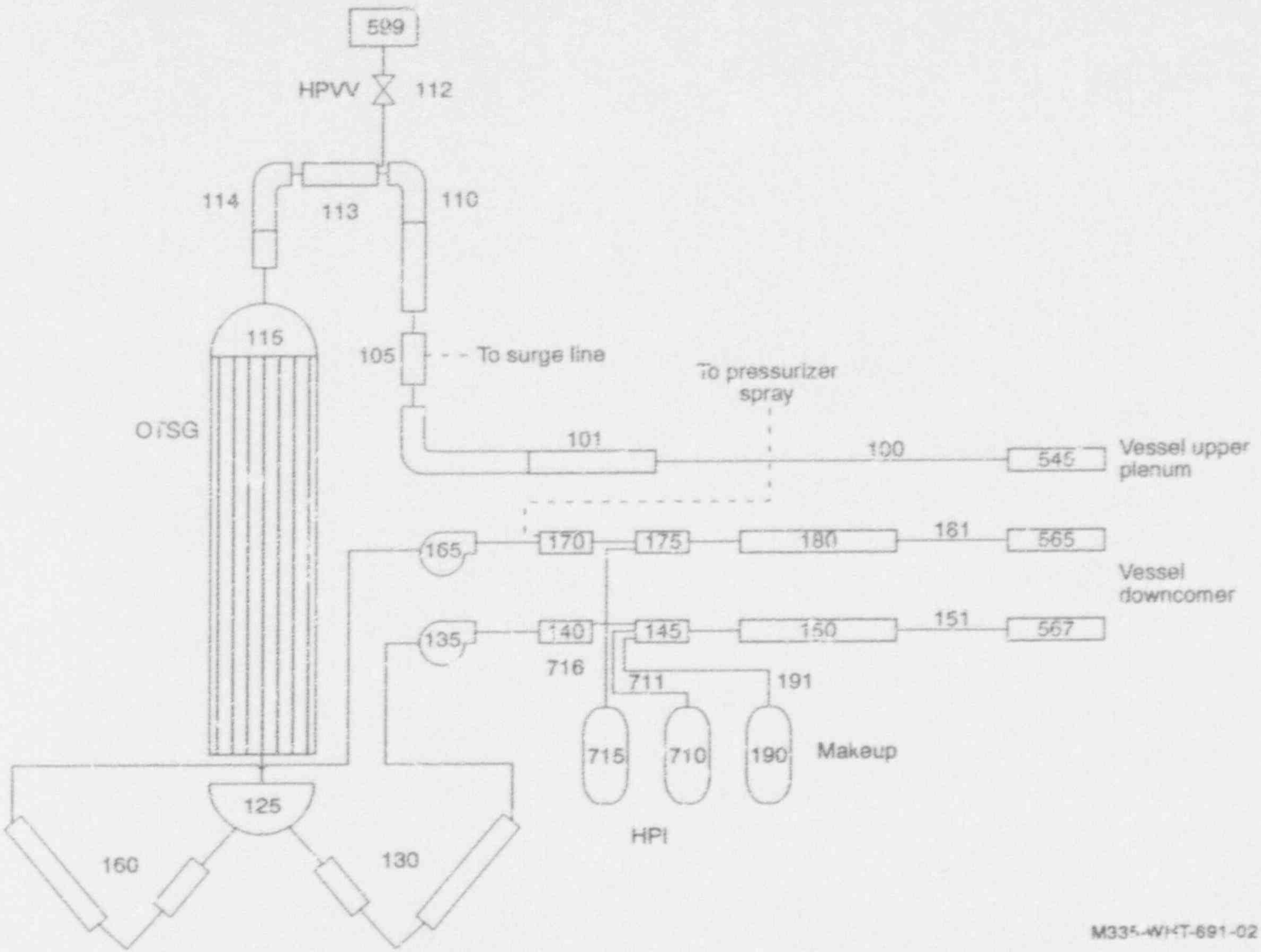


Figure E-6. SCDAP/RELAP5/MOD3 nodalization diagram of Loop A of the Oconee reactor model.

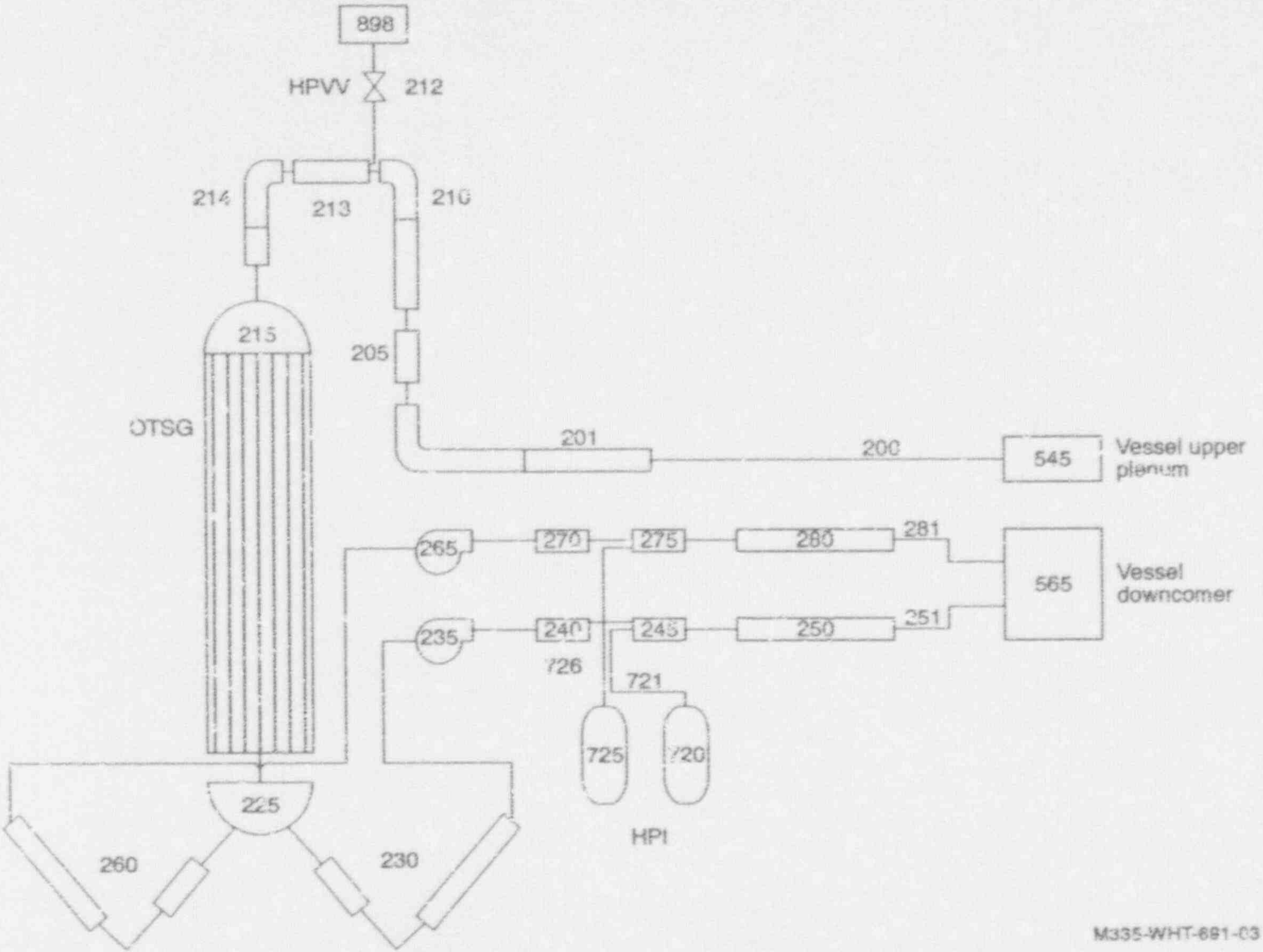


Figure E-7. SCDAP/RELAP5/MOD3 nodalization diagram of Loop B of the Oconee reactor model.

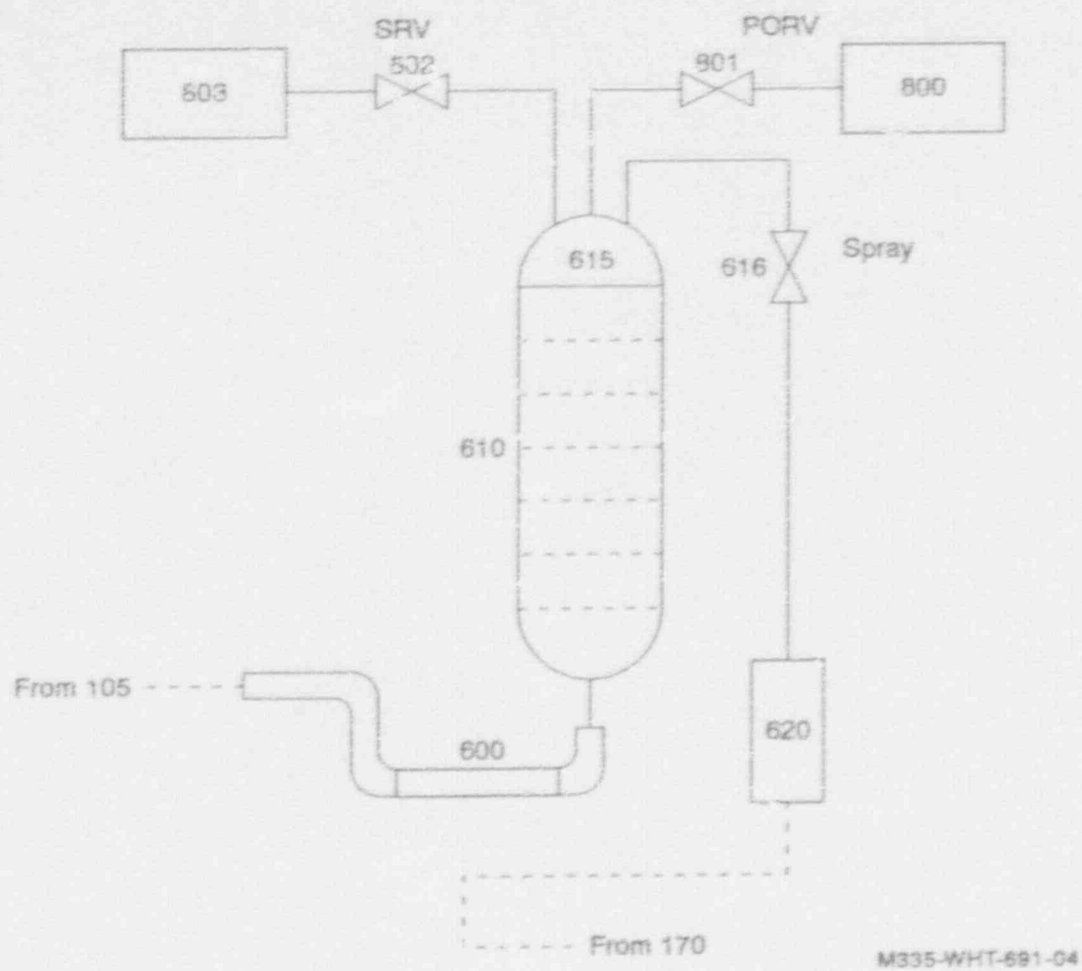


Figure E-8. SCDAP/RELAP5/MOD3 nodalization diagram of the Oconee pressurizer model.

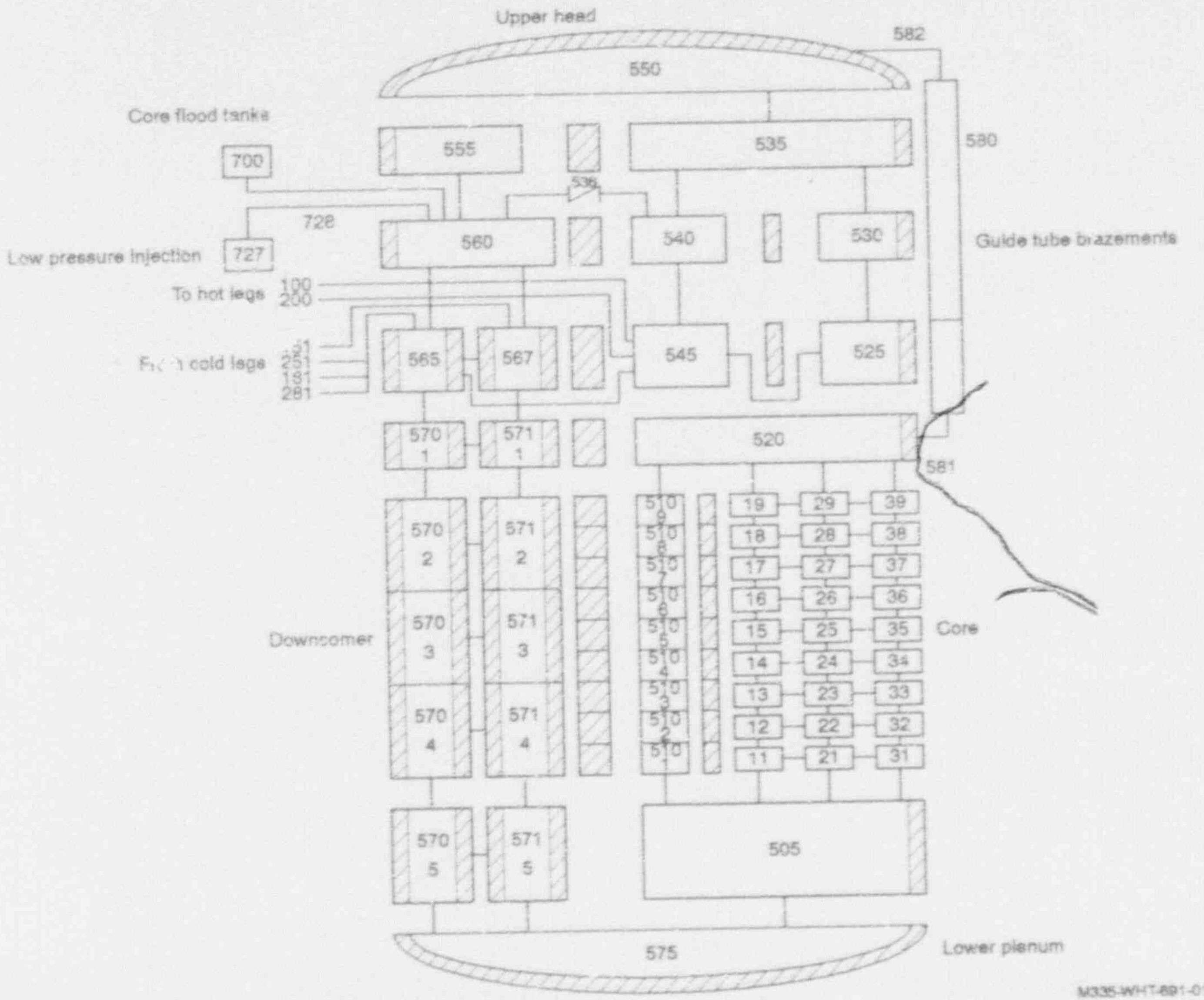


Figure E-9. SCDAP/RELAP5/MOD3 nodalization diagram of the Oconee reactor vessel.

RELAP5/MOD3 reactor point kinetics input and a control system for scram reactivity insertion were added.

- A RELAP5/MOD3 containment model and containment isolation trips were added.
- A SCDAP input deck was created to represent the Oconee core model.

These changes are discussed in more detail in the following subsections.

E-4.1 Reactor Vessel Component Modifications

The Oconee core model in the base deck contained one channel with three axial nodes. To accommodate the axial power profile requirements for the timing analysis of PWR fuel pin failures, the core model was changed to three channels, each with nine axial nodes. The core bypass model was also modified to contain nine axial nodes. The total number of fuel assemblies was divided among the three channels so as to model the hot pin accurately. The modified core model inner, middle, and outer channels contain 4, 92, and 81 fuel assemblies, respectively.

During a LOCA, the borated water from the emergency cooling accumulators floods the core through two flooding nozzles attached to the reactor vessel. In order to simulate the process of core flooding more realistically, the downcomer model and vessel inlet annulus fluid volumes below the cold leg centerline were split into two channels connected by crossflow junctions. The revised downcomer flow modeling splits annulus Component 565 and 570 into two channels, one for each loop. Components 565 and 570 represent flow from the broken loop, set at 25% of total flow. Components 567 and 571 represent flow from the intact loop, set at 75% of total flow. Single junctions representing both crossflow and vertical junctions were added as required by the 2-channel model.

Heat structures connected to restructured reactor vessel components were also modified as required. Specific reactor vessel component modifications are similar to those listed in Table E-1 for Seabrook.

E-4.2 Addition of Reactor Point Kinetics

The reactor point kinetics option chosen assumes that feedback due to moderator density, moderator temperature, and fuel temperature is separable. Tables defining reactivity as a function of moderator density and volume weighting factors were calculated and input.

The sum of fission power and fission product and actinide decay power was defined as 102% of the maximum rated power for Oconee, as given in Table 14-6 of the Oconee FSAR.[E-9] The delayed neutron fraction over prompt neutron lifetime was based on beginning-of-life values for Oconee found in Table 14-6 of the Oconee FSAR.[E-9] ANS 79-1 standard fission product data were used, with a fission product yield factor of 1.02 to account for the higher-energy fission products resulting from ^{238}U fissions. The ^{239}U yield factor was taken from ANS Branch Technical Position APCSB 9-2.[E-7] The energy release per fission was defined as the RELAP5/MOD3 default value.

The table defining reactivity as a function of moderator density was calculated using data from Figure 4.3-4 and 4.3-1 from the Oconee FSAR,[E-9] which provide the void reactivity coefficient Δk/k/void as a function of percent of core void and typical boron concentration versus core life, respectively. Reactivity corresponding to a certain void was determined by using the boron concentration at the beginning of core life with data from Figure 4.3-4. Moderator coolant density is based on the coolant density of 44.75 lb/ft^3 at the core average temperature of 580°F and pressure of 2200 psia; these values were taken from Table 4.2-1 of the Oconee FSAR.[E-9] In order to simplify steady-state initialization, the moderator density coefficient of reactivity was assumed to be zero for moderator densities below 40.0 lb/ft^3. An effective β fraction of 0.0071, taken from Table 14-6 of the Oconee FSAR,[E-9] was used to convert reactivity into dollars.

The volume weighting factors used for density reactivity feedback were calculated by applying a power-squared weighting to the power distributions documented in Appendix F, Tables F-7 and F-9, for the middle and outer core regions. Contributions from the hot channel are assumed to be negligible. The total power in each node is obtained by multiplying the single rod nodal power by the number of fuel pins in that node. The normalized distribution is obtained by dividing the square of the total node power by the sum of the squares of the total node power for each node. (See Table E-3 for the summary of a similar calculation for Seabrook.)

E-4.3 Addition of Control System for Scram Reactivity

Control rod reactivity does not play a significant part in LOCA analyses. Power reduction is achieved primarily through moderator density reactivity feedback. A control system identical to the one shown in Figure E-4 for Seabrook was used in the Oconee model to provide scram reactivity to prevent criticality following reflood. The control system inserted $4 of reactivity over a two-second interval, starting two seconds after LOCA initiation and was manually set to activate at the time of LOCA initiation.

E-4.4 Addition of Containment Model

The containment modeling consists of a single thermal-hydraulic volume containing the five passive heat structures identified in Table 14-10 of the Oconee FSAR:[E-9] reactor building (walls and dome); refueling canal; miscellaneous concrete; miscellaneous steel; and reactor building (floor). The material properties of these heat structures are based on data from Table 14-13 of the Oconee FSAR.[E-9]

E-4.5 Addition of Containment High-Pressure Trip Signals

Containment isolation trip setpoints were taken from Section 3.5.3 and Table 2.3-1 of the Oconee Technical Specifications and are summarized in Table E-6. The following trips were used to indicate when the allowable values are exceeded:

Trip 701--Containment pressure hi-1 trip set >18.7 psia
Trip 702--Containment pressure hi-3 trip set >44.7 psia
Trip 703--Coolant system pressure low trip set <1814.7 psia.

Table E-6. Containment isolation trip setpoints for Oconee.

Trip	Trip setpoint (psig)	Action
Containment pressure hi-1	4.0	• Safety injection (high and low pressure) • Containment cooling and isolation
Containment pressure hi-2	5.0	• Containment spray
RCS pressure low	1500.0	• Safety injection (high and low pressure)
RCS pressure low	1800.0	• Reactor trip

E-4.6 Addition of SCDAP Core Components

The SCDAP modeling of the Oconee core was based on specifications found in the Oconee FSAR.[E-9] Eight fuel rod component models were used:

Component 1--830 average hot channel fuel pins
Component 2--1 low burnup hot channel fuel pin
Component 3--1 high exposure hot channel fuel pin
Component 4--68 hot channel guide tubes
Component 5--19136 central core region fuel pins
Component 6--1377 central core region guide tubes
Component 7--16848 outer core region fuel pins
Component 8--1564 outer core region guide tubes.

Specific fuel pin data were obtained from nonproprietary data sheets provided by the fuel vendor. Axial power profiles for the fuel pin components were calculated as described in Appendix F. Radial power profiles were calculated by assuming a linear distribution skewed -2% at the centerline and +2% at the fuel rod surface. The amount of skew at each respective mesh point, f_r, was correlated to the relative cross-section area inside a circle with the radius equal to the radius of this mesh point, such that

$$f_r = 0.98 + (1.02 - 0.98) * \text{relative area} \quad \text{(E-1)}$$

where the relative area is calculated as a ratio of the nodal area, A_N, and the total pellet cross-sectional area, A_T. Then

$$A_N/A_T = \pi r_i^2/\pi R^2 = (r_i R)^2 \quad \text{(E-2)}$$

where

r_i = radius of the mesh point i
R = radius of the fuel pellet.

The initial gap conductances were generated by steady-state FRAP-T6 runs. The helium inventory for each fuel pin component was also adjusted in order to match the initial steady-state fuel pin internal pressures calculated by FRAP-T6.

E-4.7 Modifications for Specific Runs

The large-break LOCA cases assumed a double-ended shear break of the cold leg between Components 145 and 150. To accomplish this, both loop- and vessel-side cold leg break junctions were added. Junction areas were adjusted for the various break sizes. For the small-break LOCA cases, the size of the vessel-side cold leg break junction was decreased and a small-break LOCA trip valve was added between Components 150 and 949, the containment volume.

In addition to the above modeling modifications, other changes were required to initiate the specific requirements of each case run and continue code execution to the required time. The null transient required a pressurizer time-dependent volume for steady-state pressure control; this was deleted prior to performing transient analyses. Time step size was modified as required for continued code execution. Trip card setpoints were modified as required to model each accident scenario. To avoid code failure when the accumulators emptied into the system, trips were added to isolate the accumulators at a liquid volume of <0.1 m^3 per accumulator.

E-4.8 Execution

The Oconee base deck was modified as noted above and executed on a DEC-5000 workstation using SCDAP/RELAP5/MOD3 code version Cycle 7B. Nine cases were run; Table E-7 lists the description and input and output files for each

Table E-7. SCDAP/RELAP5/MOD3 input and output files for the Oconee timing analysis of PWR fuel pin failures.

Case	File name	Description
Null transient	null/reset0.out.Z	Compressed output
	null/reset0.r	Restart input to reset time to zero
	null/rstplt.Z	Restart plot file reset to timo zero
	null/rstplt.1.Z	Intermediate restart plot file
	null/rstplt.2.Z	Restart plot file at end of null transient
	null/runit*	Script for running null transient
	null/oconulla.i	Oconee model base deck
	null/oconulla.out.Z	Compressed output
	null/oconullb.out.Z	Compressed output
	null/oconullb.r	Restart input
100% DBA	100dba/rstplt.Z	Restart plot file
	100dba/run100*	Unix script to run case
	100dba/oco100dba.out.Z	SCDAP/RELAP5 output
	100dba/oco100dba.r	Restart input
	100dba/oco100dba.thdat	FRAP-T6 binary link
	100dba/oco100dba.thin	Input file for FRAPR5
	100dba/oco100dba.thout.Z	Compressed output
	100dba/strip.i	Input file to strip data
	100dba/strip.out	Output from strip run
90% DBA	90dba/rstplt.Z	Restart plot file
	90dba/run90*	UNIX script to run case
	90dba/oco90dba.out.Z	SCDAP/RELAP5 output
	90dba/oco90dba.r	Restart input
	90dba/oco90dba.thdat	FRAP-T6 binary link
	90dba/oco90dba.thin	Input file for FRAPR5
	90dba/oco90dba.thout.Z	Compressed output
	90dba/strip.i	Input file to strip data
	90dba/strip.out	Output from strip run
75% DBA	75dba/rstplt.Z	Restart plot file
	75dba/run75*	UNIX script to run case
	75dba/oco75dba.out.Z	SCDAP/RELAP5 output
	75dba/oco75dba.r	Restart input
	75dba/oco75dba.thdat	FRAP-T6 binary link
	75dba/oco75dba.thin	Input file for FRAPR5
	75dba/oco75dba.thout.Z	Compressed output
	75dba/strip.i	Input file to strip data
	75dba/strip.out	Output from strip run

Table E-7. (continued)

Case	File name	Description
50% DBA	50dba/rstplt.Z	Restart plot file
	50dba/run50*	UNIX script to run case
	50dba/oco50dba.out.Z	SCDAP/RELAP5 output
	50dba/oco50dba.r	Restart input
	50dba/oco50dba.thdat	FRAP-T6 binary link
	50dba/oco50dba.thin	Input file for FRAPR
	50dba/oco50dba.thout.Z	Compressed output
	50dba/strip.i	Input file to strip data
	50dba/strip.out	Output from strip run
100% DBA with pump trip at time zero	pt100dba/rstplt.Z	Restart plot file
	pt100dba/runpt100*	UNIX script to run case
	pt100dba/ocopt100dba.out.Z	SCDAP/RELAP5 output
	pt100dba/ocopt100dba.r	Restart input
	pt100dba/ocopt100dba.thdat	FRAP-T6 binary link
	pt100dba/ocopt100dba.thin	Input file for FRAPR5
	pt100dba/ocopt100dba.thout.Z	Compressed output
	pt100dba/strip.i	Input file to strip data
	pt100dba/strip.out	Output from strip run
100% DBA with ECCS	e100dba/rstplt.Z	Restart plot file
	e100dba/rune100*	UNIX script to run case
	e100dba/ocoe100dba.out.Z	SCDAP/RELAP5 output
	e100dba/ocoe100dba.r	Restart input
	e100dba/ocoe100dba.thdat	FRAP-T6 binary link
	e100dba/ocoe100dba.thin	Input file for FRAPR5
	e100dba/ocoe100dba.thout.Z	Compressed output
	e100dba/stripe.i	Input file to strip data
	e100dba/strip.out	Output from strip run
100% DBA with pump trip at time zero and ECCS	ept100dba/rstplt.Z	Restart plot file
	ept100dba/runept100*	UNIX script to run case
	ept100dba/ocoept100.out.Z	SCDAP/RELAP5 output
	ept100dba/ocoept100.r	Restart input
	ept100dba/ocoept100.thdat	FRAP-T6 binary link
	ept100dba/ocoept100.thin	Input file for FRAPR5
	ept100dba/ocoept100.thout.Z	Compressed output
	ept100dba/stripe.i	Input file to strip data
	ept100dba/strip.out.Z	Output from strip run

Table E-7. (continued)

Case	File name	Description
6-in. small-break LOCA	sb/rstplt.Z	Restart plot file
	sb/runsb*	UNIX script to run case
	sb/ocosb.out.Z	SCDAP/RELAP5 output
	sb/ocosb.r	Restart input
	sb/ocosb.thdat	FRAP-T6 binary link
	sb/ocosb.thin	Input file for FRAPR5
	sb/ocosb.thout.Z	Compressed output
	sb/strip.i	Input file to strip data
	sb/strip.out	Output from strip run
6-in. small-break LOCA with ECCS	esb/rstplt.Z	Restart plot file
	esb/runesb*	UNIX script to run case
	esb/ocoesb.out.Z	SCDAP/RELAP5 output
	esb/ocoesb.r	Restart input
	esb/ocoesb.thdat	FRAP-T6 binary link
	esb/ocoesb.thin	Input file for FRAPR5
	esb/ocoesb.thout.Z	Compressed output
	esb/stripe.i	Input file to strip data
	esb/strip.out	Output from strip run

case. All source, input, and output files have been archived on tape for permanent retention.

E-5. RESULTS

The timing results for the nine SCDAP/RELAP5/MOD3 runs for the Seabrook and Oconee reactors are summarized in Table E-8. Plots summarizing the results are found in Appendices K and L.

The minimum time to fuel pin failure calculated by SCDAP is 29.65 seconds for Seabrook and 10.3 seconds for Oconee for the 100% DBA case with RCS pump trip. No fuel pin failure is predicted for the small-break cases.

In several cases, SCDAP overpredicts the time to fuel pin failure in comparison to the FRAP-T6 results. The deviation between FRAP-T6 and SCDAP fuel pin failure times can be traced to a difference in the cladding strains calculated by the two codes. In SCDAP, a step change in cladding strain is encountered at each axial node in the first few seconds of each large-break LOCA case. The cladding deformation model does not appear to be properly taking strain rate effects into account. The step change in cladding strain produces a step decrease in internal fuel pin pressure, as shown in the plots of internal pin pressure (see Appendices K and L). The step decrease in pressure, early in the transient, results in a delayed time to pin failure. Because SCDAP/RELAP5/MOD3 overpredicts the axial extent of cladding

Table E-8. SCDAP/RELAP5/MOD3 results for Seabrook and Oconee

Case	1	2	3	4	5	6	7	8	9
Break size[a]	100%	90%	75%	50%	100%	6in.	100%	100%	6in.
Pumped ECCS	no	no	no	no	no	no	yes	yes	yes
Pump trip	no	no	no	no	yes	no	no	yes	no
For Seabrook:									
Containment pressure hi-1, hi-2[b]	0.77	0.77	0.78	0.94	0.77	17.42	0.77	0.77	17.44
Containment pressure hi-3[b]	5.01	5.18	5.41	6.39	5.10	>60.0	5.02	5.10	>60.0
Pressurizer low pressure[b]	3.73	3.73	3.73	3.73	3.73	7.13	3.73	3.73	7.13
High burnup, 50 GWd/MTU pin fails[c]	41.70	40.75	>60.0	>60.0	29.65	>600.	38.85	31.45	>60.0
Low burnup, 5 GWd/MTU pin fails[c]	43.40	40.75	>60.0	>60.0	29.95	>600.	39.15	30.60	>60.0
For Oconee:									
Containment pressure high ≥4 psig[b,f]	0.53	0.55	0.56	0.68	0.53	13.07	0.53	0.53	13.01
Low reactor coolant pressure[b,d] ≤1500 psig	0.59	0.60	0.63	0.96	0.55	8.33	0.59	0.56	8.33
Low reactor coolant pressure[b,e] ≤1800 psig	0.05	0.05	0.05	0.05	0.05	0.87	0.05	0.05	0.87
High burnup 55 GWd/MTU pin fails[c]	15.0	15.8	18.3	>60.0	10.3	>393.	14.7	10.3	>60.0
Low burnup 5 GWd/MTU pin fails[c]	22.7	23.5	>60.0	>60.0	22.8	>393.	22.0	22.4	>60.0

Table E-8. (continued)

Case	1	2	3	4	5	6	7	8	9

a. For large-break cases, break size is given as a percentage of the design basis, double-ended, offset shear break; i.e., 100% DBA corresponds to a total flow area of 200% of the cold leg cross section. (Cases 6 and 9 are small-break LOCAs with a break diameter of 6 in.)

b. Signal time corresponds to the time at which this parameter exceeds the technical specification allowable value and does not include the instrument response time.

c. The fuel pin failure times generated by SCDAP are not identical with those generated by FRAP-T6 and should not be referenced. FRAP-T6 results are documented in Appendix J.

d. At 1500 psig, the high-pressure injection and reactor building isolation are actuated.

e. At 1800 psig, the Oconee reactor is tripped on low RCS pressure.

f. At 4 psig, the Oconee reactor building isolation is actuated.

deformation, which results in an underprediction of internal pin pressures, the time to a pin failure is overpredicted.

As evidenced by the plotted results (see Appendices K and L), SCDAP/RELAP5/MOD3 calculates a spike in accumulator flow as each accumulator approaches empty and is subsequently isolated from the system. Although these flow spikes are not consistent with expected results, they are not considered significant for this analysis due to the magnitudes and durations involved.

The hot channel thermal-hydraulic conditions generated in these runs provide input to FRAP-T6, which is used to calculate fuel failure times for a matrix of fuel pin exposures and peaking factors. The FRAP-T6 results are documented in Appendix J.

E-6. References

E-1. C. M. Allison et al. (Eds.), *SCDAP/RELAP5/MOD3 Code Manual*, Revision 1, Volumes I-IV, (DRAFT), NUREG/CR-5273, EGG-2555, September 1990.

E-2. C. M. Allison et al. (Eds.), *RELAP5/MOD3 Code Manual*, Volumes I-IV, (DRAFT), NUREG/CR-5595, EGG-2596, June 1990.

E-3. C. M. Allison and G. H. Beers, "Comparisons of the SCDAP Computer Code with Bundle Data under Severe Accident Conditions," *Seventh International SMIRT Conference, Chicago, IL, August 22-26, 1983.*

E-4. H. Jordan and M. R. Kuhlman, *TRAP-MELT2 User's Manual*, NUREG/CR-4205, BMI-2124, May 1985.

E-5. P. D. Bayless and R. Chambers, *Analysis of A Station Blackout Transient at the Seabrook Nuclear Power Plant*, EGG-NTP-6700, September 1984.

E-6. *Updated Final Safety Analysis Report, Seabrook Station*, May 26, 1989.

E-7. ANS Branch Technical Position APCSB 9-2, "Residual Decay Energy for Light Water Reactors for Long-Term Cooling," November 24, 1975.

E-8. P. D. Wheatley et al., *Evaluation of Operational Safety at Babcock and Wilcox Plants Volume 2 - Thermal-Hydraulic Results*, NUREG/CR-4966, November 1987.

E-9. Duke Power Co., *Final Safety Analysis Report, Oconee Nuclear Station Units 1, 2, and 3*, March 18, 1972.

Appendix F

Core Power Distribution Calculation for Oconee

Appendix F

Core Power Distribution Calculation for Oconee

F-1. Introduction

Appendix F documents the fuel pin power distribution in a Babcock and Wilcox (B&W) 2x4 loop reactor (Oconee Plant) used for the timing analysis of pressurized water reactor (PWR) fuel pin failures. The purpose of the analysis is to determine the minimum time to fuel pin failure for a range of large-break loss-of-coolant accident (LOCA) break sizes. The analysis assumed an equilibrium core operating at 102% of rated power with some fuel pins of high and low burnup operating at the maximum Technical Specification axial and radial peaking factors. The analysis was performed using a series of three codes to calculate initial steady-state fuel pin conditions, the system thermal-hydraulic conditions, and transient fuel pin conditions. The codes used include FRAPCON-2,[F-1] SCDAP/RELAP5/MOD3,[F-2] and FRAP-T6.[F-3]

The time to fuel pin failure is highly dependent on the core power distribution assumed for the analysis. The power distribution directly impacts the amount of stored energy calculated in the fuel and the internal fuel pin pressure, two factors that greatly influence the time to fuel pin failure.

The purpose of this calculation is to determine the core power distribution supplied as input to FRAPCON-2, SCDAP/RELAP5/MOD3, and FRAP-T6.

F-2 Calculation of Core Power Distribution

The axial and radial core power distributions for each of the core fuel components modeled in SCDAP/RELAP5/MOD3 are calculated in this section. The core representation used in this analysis consists of five fuel components, each modeled with nine axial nodes of uniform height along the active core region. These fuel components represent a low-burnup hot fuel pin located in the hot channel, a high-burnup hot fuel pin likewise located in the hot channel, remaining fuel pins of the hot channel, all fuel pins of the central core region, and all fuel pins of the outer core region.

F-2.1 Hot Channel Hot Fuel Pins

From Table 4.2-1 of the Oconee Final Safety Analysis Report (FSAR):[F-4]

Reactor core thermal power (CTP) (MWt)	2568
Percent of heat generated in the fuel (f)	97.3%
Number of fuel assemblies	177

Number of fuel pins per assembly 208

The fuel stack height is given as 140.595 in.[a] The average linear heat generation rate (LHGR) for the Oconee 15x15 fuel assembly design can then be calculated as follows:

Average LHGR = CTP(kW) * f/(height of active core in ft * # of fuel pins)
Height of active core = 140.595 in. * 1 ft/12 in. = 11.716 ft
Average LHGR = 2.568E6 kW * 0.973/(11.716 ft * 177 * 208 pins)
Avg. LHGR = 5.793 kW/ft

The heat flux hot channel factor, F_q, is defined as:

$$F_q = \frac{\text{Maximum heat flux in the core}}{\text{Average heat flux in the core}}$$

Reference F-4 gives a value of 2.63 for F_q. Applying this value, the maximum LHGR at 102% CTP for the peak power pin can be calculated:

Maximum LHGR = 2.63 * 1.02 * 5.793 kW/ft
Maximum LHGR = 15.540 kW/ft

The total power generated in the hot fuel pin is determined by the enthalpy rise hot channel factor, F_{dh}^{N}. This factor is defined as the ratio of the total integrated power in the hot fuel pin divided by the total integrated power in the average fuel pin:

$$F_{dh}^{N} = \frac{\text{Hot pin power}}{\text{Average pin power}}$$

The Oconee Technical Specification 2.1 Safety Limits[F-5] is based on a value of 1.714 for this factor. The total power in the hot fuel pin, P_{TOT}, at 102% CTP can then be found from:

P_{TOT} = F_{dh}^{N} * Average LHGR * 1.02 * active fuel height
P_{TOT} = 1.714 * 5.793 kW/ft * 1.02 * 11.716 ft
P_{TOT} = 118.657 kW.

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a. Letter, J. N. Ridgely, U.S. Nuclear Regulatory Commission, to R. J. Dallman, EG&G Idaho, Inc., February 12, 1991, and attachment.

This analysis assumes a chopped, symmetric cosine axial power profile for the hot fuel pin governed by the following equation:

$$P(z) = \text{Maximum LHGR} * \cos(\pi * z/(H+T)) \quad \text{(F-1)}$$

where

- z = distance from the core midplane (ft)
- H = active core height (ft)
- T = shape factor (ft)

and the power input into the central node (at the core midplane) is equal to the product of the maximum LHGR and the node height.

The nodal pin power can be found by integrating Equation (F-1) over the length of the node. This results in

$$P_N = \text{Maximum LHGR} * (H+T)/\pi * (\sin(\pi * z_2/(H+T)) - \sin(\pi * z_1/(H+T))) \quad \text{(F-2)}$$

where

- z_1 = distance (ft) from the core midplane to the bottom of the node
- z_2 = distance (ft) from the core midplane to the top of the node

The shape factor T can be found by applying Equation (F-2) to a part of the fuel pin, for example, to the upper four nodes. Then Equation (F-2) becomes

$$\pi * (P_{TOT} - P_c)/(2 * \text{Max.LHGR} * (H+T)) = \sin(\pi * z_2/(H+T)) - \sin(\pi * z_1/(H+T)) \quad \text{(F-3)}$$

where

π	=	3.1416
Maximum LHGR	=	15.540 kW/ft
P_{TOT}	=	118.657 kW
P_c	=	power in the midplane node = 15.540*1.3018 = 20.23 kW
H	=	11.716 ft
z_2	=	top of the highest node = H/2 = 11.716/2 = 5.858 ft
z_1	=	bottom of the lowest node = 1.3018/2 = 0.6509 ft

and can be iteratively solved for T. After a few iterations T = 0.2749 ft is found. Hence Equation (F-1) becomes

$$P(z) = \text{Maximum LHGR} * \cos(\pi * z/(11.9909)) \quad \text{(F-4)}$$

FRAPCON-2 requires the normalized axial power, QF(T), at each node boundary location, X. The FRAPCON input may be normalized to either peak or average values. The FRAPCON-2 values normalized to the maximum LHGR are given in Table F-1, along with the corresponding LHGR at each location. FRAPCON-2 also requires that the ratio of peak to average power, FA, be supplied when the peak normalized axial power distribution is supplied; this value is also provided in Table F-1.

Table F-1. FRAPCON-2 axial power profile for the Oconee hot fuel pin.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.0360	0.5594
1.3018	0.3682	5.7218
2.6036	0.6580	10.2253
3.9054	0.8720	13.5509
5.2072	1.0000	15.5400
6.5090	1.0000	15.5400
7.8108	0.8720	13.5509
9.1126	0.6580	10.2253
10.4144	0.3682	5.7218
11.7160	0.0360	0.5594

FA = 1.534394

SCDAP/RELAP5/MOD3 requires an axial power profile array consisting of values for the ratio of the node power to the average node power for each axial node. The node power P_N (in kW) in each axial node (except the core midplane node) is calculated using Equation (F-2). The power in the core midplane node is then the difference between the total power P_{TOT} and power in the remaining nodes. (Note, for the hot pin considered here the power in the midplane node is maximum LHGR * 1.3018 = 15.54 * 1.3018 = 20.23 kW.) Table F-2 contains the SCDAP/RELAP5/MOD3 axial power profile, along with the total power generated in each node and the nodal LHGR for the hot fuel pin operating at the Technical Specification limit. FRAP-T6 uses the same axial power profile as SCDAP/RELAP5/MOD3.

$$\text{Average nodal power} = P_{TOT}/9 = 118.657/9 = 13.18411 \text{ kW}$$

$$\text{Power Profile} = \frac{\text{nodal power}}{\text{avg nodal power}} = \frac{\text{nodal power}}{13.18411}$$

Table F-2. SCDAP/RELAP5/MOD3 axial power profile for the Oconee hot fuel pin.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6509	4.1287	3.172	0.31316
2	1.9527	10.4818	8.052	0.79503
3	3.2544	15.6274	12.004	1.18532
4	4.5562	18.9724	14.574	1.43903
5	5.8580	20.2300	15.540	1.53442
6	7.1598	18.9724	14.574	1.43903
7	8.4616	15.6274	12.004	1.18532
8	9.7634	10.4818	3.052	0.79503
9	11.0652	4.1287	3.172	0.31316
Total		118.6510		

F-2.2 Hot Channel Average Fuel Pins

The SCDAP/RELAP5/MOD3 hot channel model consists of 832 pins representing four fuel assemblies. Two of the pins represent a high- and low-burnup fuel pin, respectively; their power distribution was determined in Section F-2.1. The power distribution of the remaining 830 fuel pins in the hot channel will significantly influence the thermal-hydraulic conditions of the two hot fuel pins being analyzed. For the purpose of this analysis, it is assumed that the remaining rods of the hot channel are operating at the Technical Specification enthalpy rise hot channel factor, but with a flatter axial power profile. This axial power profile is based on a chopped, symmetric cosine distribution with 5% less axial peaking than used in Section F-2.1.

The linear power at any location along the fuel pin can then be found from

$$P(z) = 0.95 * \text{Maximum LHGR} * \cos(\pi*z/(11.716+T)) \quad \text{(F-5)}$$

where

z = distance from the core midplane (ft)
T = shape factor (ft)
Max. LHGR = 15.540 kW/ft (see Section F-2.1)

and the total pin power can be found by integrating this expression over the length H of the fuel pin:

$$P_{TOT} = 2*0.95*\text{Max.LHGR7}*((11.716+T)/\pi)*(\sin(\pi*H/2*(11.716+T))) \quad \text{(F-6)}$$

The shape factor, T, may be determined by setting this expression equal to the total pin power of 118.657 kW for a fuel pin operation at the Technical Specification enthalpy rise hot channel factor (see Section F-2.1):

$T = 1.008.$

The equation for the power at any axial location then becomes:

$$P(z) = 14.763 * \cos(\pi * z/12.724) \qquad (F\text{-}7)$$

The total power in any node can be found by integrating this expression over the length of the node, as was shown above. Tables F-3 and F-4 contain the corresponding FRAPCON-2 and SCDAP/RELAP5/MOD3 data for the average fuel pin of the hot channel.

F-2.3 Radial Power Distribution

The SCDAP/RELAP5/MOD3 core model consists of three fueled channels with the fuel assemblies distributed as follows:

Channel	Number of Assemblies
Hot Channel	4
Central Region	81
Outer Region	92

Oconee FSAR Figure 3-34[F-6] provides a typical normalized radial fuel assembly power distribution for an end-of-life (EOL) equilibrium core. This information is used to approximate the radial power distribution in this analysis. The power distribution for a 1/8 core is:[F-6]

0.780	0.830	0.830	0.836	1.043	0.986	0.995	1.008
	0.937	0.738	0.794	1.054	1.005	1.311	0.976
		0.704	1.097	1.182	1.025	1.082	0.781
			1.202	1.148	1.091	1.034	
				1.043	1.218	0.798	
					0.911		

[illegible] power profile for the Oconee average hot channel

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.1241	1.832
1.3018	0.4312	6.365
2.6036	0.6942	10.248
3.9054	0.8860	13.080
5.2072	0.9871	14.573
6.5090	0.9871	14.573
7.8108	0.8860	13.080
9.1126	0.6942	10.248
10.4144	0.4312	6.366
11.7160	0.1241	1.832

FA = 1.461822

Table F-4. SCDAP/RELAP5/MOD3 axial power profile for the Oconee average hot channel fuel pins.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6509	5.3829	4.135	0.40829
2	1.9527	10.9084	8.379	0.82739
3	3.2544	15.3153	11.765	1.16165
4	4.5562	18.1559	13.947	1.37710
5	5.8580	19.1320	14.697	1.45114
6	7.1598	18.1559	13.947	1.37710
7	8.4616	15.3153	11.765	1.16165
8	9.7634	10.9084	8.379	0.82739
9	11.0652	5.3829	4.135	0.40829
Total		118.6570		

Increasing the highest power assembly power to 1.714 to correspond to the limiting hot channel enthalpy rise factor (see Section F-2.1 of this report) and renormalizing the data produces the following distribution:

"Outer" region; "Hot" channel (boxed value 1.714); "Central" region

0.773	0.822	0.831	0.928	1.033	0.977	0.986	0.998
	0.928	0.731	0.786	1.044	0.995	1.714	0.967
		0.697	1.187	1.171	1.015	1.072	0.774
			1.191	1.137	1.081	1.024	
				1.033	1.205	0.790	
					0.902		

The core may be divided into central, outer, and hot channel regions, as shown above. The nodalization used in SCDAP/RELAP5/MOD3 actually models the four hot channel assemblies as being face-adjacent to one another. This conservative assumption is not expected to significantly affect the results, since the intent is to achieve hot channel conditions that would be expected in the close vicinity of the analyzed hot fuel pins. The radial peaking factor for the central region can be found as the average of assembly-specific factors within this region, taking into account that some assemblies lie on the segment borderline. The radial peaking factor for the outer region has been calculated as a ratio of power in this region to the average power generated by 92 assemblies. The respective radial power peaking factors are summarized in Table F-5. They can be used to calculate the total fission power produced in the fuel (see below) at 102% power level, the total power generated including gamma heating, and the fraction of total core thermal power to be assigned to a specific component (see Table F-5).

Table F-5. SCDAP/RELAP/MOD3 radial power distribution input summary for Oconee.

Component	Radial peaking factor	No. of pins	Power generation within fuel (kW)	Pin power (kW)	Power including gamma heat (kW)	Power Fraction
Hot pins	1.7140	2	2.37314E+02	118.657	2.4390E+02	9.3116481E-5
Hot channel	1.7140	830	9.84353E+04	118.657	1.0122E+05	3.8643912E-2
Central region	0.9614	16848	1.12130E+06	66.554	1.1524E+06	4.3996487E-1
Outer region	1.0029	19136	1.32856E+06	69.427	1.3654E+06	5.2128431E-1
		36816	2.54858E+06		2.6193E+06	0.9999862

Fission power in hot pins (2 fuel pins) =

$2*P_{TOT}$ = 2*118.657 kW = 2.37314E+2 kW
(P_{TOT} = 118.657 kW, see Sec. 2.1)

Fission power in hot channel (remaining 830 fuel pins) =

$830*P_{TOT}$ = 830*118.657 kW = 9.848531E+4 kW

Fission power in central region (81 fuel bundles) =

radial peaking factor*81*1.02*f*CTP/177 =
0.9614*81*1.02*0.973*2568 MW /177 = 1.12130E+6 kW

Fission power in outer region (92 fuel bundles) =

radial peaking factor*92*1.02*f*CTP/177 =
1.0029*92*1.02*0.973*2568 MW /177 = 1.32856E+6 kW

F-2.4 Central and Outer Region

The data from Table F-5 can be used to determine the axial power distribution in both the central and outer core regions, assuming a symmetric, chopped cosine power shape. The ratio of the maximum power at the core midplane, PMAX, to the minimum power at the fuel zone boundary, PMIN, is assumed to be two. The following expression can then be written for the power at the core boundary:

PMIN = PMAX * cos(π*(H/2)/(H+T)) (F-8)

where H is the height of the active fuel zone = 11.716 ft (Section F-2.1). Solving for T:

0.5 = cos(π*(5.858)/(11.716+T))
T = H/2 = 5.858 ft.

The linear power at any location along the fuel pin can then be found from:

P(z) = PMAX * cos(π*z/17.574) (F-9)

where

PMAX = peak axial power in kW/ft at the core midplane
z = distance from the core midplane in feet

and the total pin power can be found by integrating this expression over the length of the fuel pin:

$$P_{TOT} = 2 * PMAX * (17.574/\pi) * (\sin(\pi*5.858/17.574))$$
$$= 9.689054 * PMAX \quad . \quad . \quad . \quad kW$$

PMAX may be determined by setting this expression equal to the total pin power given in Table F-5. For the central core region,

$$PMAX = P_{TOT}/9.689054 = 66.554/9.689054 = 6.869 \text{ kW/ft.}$$

For the outer core region,

$$PMAX = P_{TOT}/9.689054 = 69.427/9.689054 = 7.165 \text{ kW/ft.}$$

The equation for the power at any axial location then becomes:

$P(z) = 6.869*\cos(\pi*z/17.574)$ kW/ft ... for the central core region
$P(z) = 7.165*\cos(\pi*z/17.574)$ kW/ft ... for the outer core region

The total power in any node can be found by integrating these expressions over the length of the node, as was shown above for the hot fuel pins. Tables F-6 and F-7 summarize the FRAPCON-2 and SCDAP/RELAP5/MOD3 data for the central region fuel pins, while Tables F-8 and F-9 summarize these data for the outer region fuel pins.

Table F-6. FRAPCON-2 axial power profile for the Oconee central core region fuel pins.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.5000	3.434
1.3018	0.6862	4.713
2.6036	0.8355	5.739
3.9054	0.9397	6.455
5.2072	0.9932	6.822
6.5090	0.9932	6.822
7.8108	0.9397	6.455
9.1126	0.8355	5.739
10.4144	0.6862	4.713
11.7160	0.5000	3.434

FA = 1.209202

Table F-7. SCDAP/RELAP5/MOD3 axial power profile for the Oconee central core region fuel pins.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6509	5.3278	4.0926	0.72047
2	1.9527	6.8346	5.2501	0.92423
3	3.2544	7.9723	6.1241	1.07808
4	4.5562	8.6814	6.6688	1.17397
5	5.8580	8.9218	6.8534	1.20648
6	7.1598	8.6814	6.6688	1.17397
7	8.4616	7.9723	6.1241	1.07808
8	9.7634	6.8346	5.2501	0.92423
9	11.0652	5.3278	4.0926	0.72047
Total		66.5540		

Table F-8. FRAPCON-2 axial power profile for the Oconee outer region fuel pins.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.5000	3.582
1.3018	0.6862	4.917
2.6036	0.8355	5.986
3.9054	0.9397	6.733
5.2072	0.9932	7.116
6.5090	0.9932	7.116
7.8108	0.9397	6.733
9.1126	0.8355	5.986
10.4144	0.6862	4.917
11.7160	0.5000	3.582

FA = 1.209114

Table F-9. SCDAP/RELAP5/MOD3 axial power profile for the Oconee outer core region fuel pins.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6509	5.5578	4.2693	0.72047
2	1.9527	7.1296	5.4767	0.92423
3	3.2544	8.3164	6.3884	1.07808
4	4.5562	9.0561	6.9566	1.17397
5	5.8580	9.3072	7.1495	1.20652
6	7.1598	9.0561	6.9566	1.17397
7	8.4616	8.3164	6.3884	1.07808
8	9.7634	7.1296	5.4767	0.92423
9	11.0652	5.5578	4.2693	0.72047
Total		69.4270		

F-2.5 Hot Fuel Pin Case Using Varied Peaking Factors

The hot fuel pin case was also run using varied peaking factors, peak-to-average ratios, and axial power profiles, as calculated according to the technique set forth in Section F-2.1. The FRAPCON-2 values normalized to the peak are given in Tables F-10, F-11, and F-12 for peaking factors of 2.4, 2.2, and 2.0, along with the corresponding LHGR at each location. The ratio of peak to average power, FA, is also provided in the tables. FRAP-T6 requires an axial power profile array containing values for the ratio of the total node power to the average node power for each axial node. The FRAP-T6 values are given in Tables F-13, F-14, and F-15 for peaking factors of 2.4, 2.2, and 2.0, along with the total power generated in each node and the nodal LHGR at each location.

Table F-10. FRAPCON-2 axial power profile for the Oconee hot fuel pin with 2.4 peaking factor.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.1954	2.77
1.3018	0.4812	6.82
2.6036	0.7225	10.25
3.9054	0.8969	12.72
5.2072	1.0000	14.18
6.5090	1.0000	14.18
7.8108	0.8969	12.72
9.1126	0.7225	10.25
10.4144	0.4812	6.82
11.7160	0.1954	2.77

FA = 1.534422

Table F-11. FRAPCON-2 axial power profile for the Oconee hot fuel pin with 2.2 peaking factor.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.3679	4.78
1.3018	0.5989	7.78
2.6036	0.7879	10.24
3.9054	0.9218	11.98
5.2072	1.0000	13.00
6.5090	1.0000	13.00
7.8108	0.9218	11.98
9.1126	0.7879	10.24
10.4144	0.5989	7.78
11.7160	0.3679	4.78

FA = 1.283547

Table F-12. FRAPCON-2 axial power profile for the Oconee hot fuel pin with 2.0 peaking factor.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.5832	6.89
1.3018	0.7402	8.75
2.6036	0.8645	10.22
3.9054	0.9505	11.23
5.2072	1.0000	11.82
6.5090	1.0000	11.82
7.8108	0.9505	11.23
9.1126	0.8645	10.22
10.4144	0.7402	8.75
11.7160	0.5832	6.89
	FA = 1.166861	

Table F-13. FRAP-T6 axial power profile for the Oconee hot fuel pin with 2.4 peaking factor.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6509	6.29	4.84	0.47746
2	1.9527	11.20	8.60	0.84939
3	3.2544	15.06	11.57	1.14273
4	4.5562	17.54	13.47	1.33034
5	5.8580	18.46	14.18	1.40031
6	7.1598	17.54	13.47	1.33034
7	8.4616	15.06	11.57	1.14273
8	9.7634	11.20	8.60	0.84939
9	11.0652	6.29	4.84	0.47746
Total		118.6499		

Table F-14. FRAP-T6 axial power profile for the Oconee hot fuel pin with 2.2 peaking factor.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6509	8.23	6.32	0.62414
2	1.9527	11.80	9.07	0.89529
3	3.2544	14.55	11.18	1.10378
4	4.5562	16.28	12.51	1.23501
5	5.8580	16.92	13.00	1.28356
6	7.1598	16.28	12.51	1.23501
7	8.4616	14.55	11.18	1.10378
8	9.7634	11.80	9.07	0.89529
9	11.0652	8.23	6.32	0.62414
Total		118.6528		

Table F-15. FRAP-T6 axial power profile for the Oconee hot fuel pin with 2.0 peaking factor.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6509	10.22	7.85	0.77502
2	1.9527	12.39	9.52	0.93971
3	3.2544	14.01	10.76	1.06285
4	4.5562	15.02	11.53	1.13898
5	5.8580	15.38	11.82	1.16689
6	7.1598	15.02	11.53	1.13898
7	8.4616	14.01	10.76	1.06285
8	9.7634	12.39	9.52	0.93971
9	11.0652	10.22	7.85	0.77502
Total		118.6512		

F-3. References

F-1. G. A. Berna et al., *FRAPCON-2: A Computer Code for the Calculation of Steady State Thermal-Mechanical Behavior of Oxide Fuel Rods*, NUREG/CR-1845, January 1981.

F-2. C. M. Allison et al. (Eds.), *SCDAP/RELAP5/MOD3 Code Manual, Volumes I-III*, (Draft), NUREG/CR-5273, EGG-2555, Revision 1, September 1990.

F-3. L. J. Siefken et al., *FRAP-T6: A Computer Code for the Transient Analysis of Oxide Fuel Rods*, NUREG/CR-2148, EGG-2104, May 1981.

F-4. *Final Safety Analysis Report for the Oconee Reactor*, Table 4.2-1.

F-5. Technical Specifications for the Oconee Reactor, Technical Specification 2.1, Safety Limits, Reactor Core.

F-6. *Final Safety Analysis Report for the Oconee Reactor*, Figure 3-34.

Appendix G

Core Power Distribution Calculation for Seabrook

Appendix G

Core Power Distribution Calculation for Seabrook

G-1. Introduction

Appendix G documents the fuel pin power distribution in a Westinghouse (W) 4-loop reactor (Seabrook plant) used for the timing analysis of pressurized water reactor fuel pin failures. The purpose of the analysis is to determine the minimum time to fuel pin failure for a range of large-break loss-of-coolant accident (LOCA) break sizes. The analysis assumed an equilibrium core operating at 102% of rated power with some fuel pins of high and low burnup operating at the maximum Technical Specification axial and radial peaking factors. The analysis was performed using a series of four codes to calculate initial steady-state fuel pin conditions, the system thermal-hydraulic conditions, and transient fuel pin conditions. The codes used were FRAPCON-2,[G-1] SCDAP/RELAP5/MOD3,[G-2] TRAC-PF1/MOD1,[G-3] and FRAP-T6.[G-4]

The time to fuel pin failure is highly dependent on the core power distribution assumed for the analysis. The power distribution directly impacts the amount of stored energy calculated in the fuel and the internal fuel pin pressure, two factors which greatly influence the time to fuel pin failure.

The purpose of this calculation is to determine the core power distribution supplied as input to FRAPCON-2, SCDAP/RELAP5/MOD3, TRAC-PF1/MOD1, and FRAP-T6.

F.2 Calculation of Core Power Distribution

The axial and radial core power distributions for each of the core fuel components modeled in SCDAP/RELAP5/MOD3 are calculated in this section. The core representation used in this analysis consists of five fuel components, each modeled with nine axial nodes of uniform height along the active core region. These fuel components represent a low-burnup hot fuel pin located in the hot channel, a high-burnup hot fuel pin likewise located in the hot channel, remaining fuel pins of the hot channel, all fuel pins of the central core region, and all fuel pins of the outer core region.

G-2.1 Hot Channel Hot Fuel Pins

From Table 4.1-1 of the Seabrook Final Safety Analysis Report (FSAR):[G-5]

Reactor core thermal power (CTP) (MWt)	3411
Percent of heat generated in the fuel (f)	97.4%
Number of fuel assemblies	193

Number of fuel pins per assembly	264
Fuel stack height (ft)	12

Without taking into account fuel densification effects, the average linear heat generation rate (LHGR) for the Seabrook 17x17 fuel assembly design can then be calculated as follows:

Average LHGR = CTP(kW) * f/(height of active core in ft * # of fuel pins)
Average LHGR = 3.411E6 kW * 0.974/(12 ft * 50952 pins)
Avg. LHGR = 5.434 kW/ft

The heat flux hot channel factor, F_q, is defined as:

$$F_q = \frac{\text{Maximum heat flux in the core}}{\text{Average heat flux in the core}}$$

Seabrook Technical Specification 3/4.2.2[G-6] provides a value of 2.32 for F_q. Applying this value, the maximum LHGR at 102% CTP for the peak power pin can be calculated:

Maximum LHGR = 2.32 * 1.02 * 5.434 kW/ft
Maximum LHGR = 12.858 kW/ft

The total power generated in the hot fuel pin is determined by the enthalpy rise hot channel factor, F_{dh}^{N}. This factor is defined as the ratio of the total integrated power in the hot fuel pin divided by the total integrated power in the average fuel pin:

$$F_{dh}^{N} = \frac{\text{Hot pin power}}{\text{Average pin power}}$$

Seabrook Technical Specification 3.2.3[G-6] provides a value of 1.49 for this factor at 100% CTP. The total power in the hot fuel pin, P_{TOT}, at 102% CTP can then be found from:

P_{TOT} = F_{dh}^{N} * Average LHGR * 1.02 * active fuel height
P_{TOT} = 1.49 * 5.434 kW/ft * 1.02 * 12 ft
P_{TOT} = 99.098 kW.

This analysis assumes a chopped, symmetric cosine axial power profile for the hot fuel pin governed by the following equation:

$$P(z) = PMAX * \cos(\pi*z/(H+T)) \quad (G-1)$$

where

PMAX = peak axial power at the core midplane = 12.858 kW/ft
z = distance from the core midplane (ft)
H = active core height (ft)
T = shape factor (ft).

If the power for the length of the core midplane node is fixed at PMAX, the total pin power can be found by integrating the axial power over the remaining nodes and adding it to the power generated in the core midplane node.

$$P_N = PMAX * (H/9 + 2(H+T)/\pi * (\sin(\pi*z_2/(H+T)) - \sin(\pi*z_1/(H+T)))) \quad (G-2)$$

where

H/9 = height of one node (ft)
z_1 = height of the top of the core midplane node measured from the core midplane (0.5 * H/9) (ft)
z_2 = height of the top of the core measured from the core midplane (H/2) (ft)

The shape factor, T, can be found by setting the P_{TOT} to 99.098 from above and iterating to find T. This results in a value of 0.096466 for T. The instantaneous LHGR at any location along the fuel pin outside of the core midplane node can then be found from

$$P(z) = 12.868 \text{ kW/ft} * \cos(\pi*z/12.096466) \quad (G-3)$$

and the total power generated in any node, N, except for the core midplane node, can be found by solving the integral of this equation over the length of the node:

$$P_N = 12.868 \text{ kW/ft} * (12.096466)\pi * \sin(\pi*z_2/(12.096466) - \sin(\pi*z_1/(12.096466))) \quad (G-4)$$

where

z_1 = distance from the core midplane to the bottom of the node (ft)
z_2 = distance from the core midplane to the top of the node (ft).

FRAPCON-2 requires the normalized axial power, QF(T), at each node boundary location, X. The FRAPCON input may be normalized to either peak or average values. The FRAPCON-2 values normalized to the maximum LHGR are given in Table G-1, along with the corresponding LHGR at each location. FRAPCON-2 also requires that the ratio of peak to average power, FA, be supplied when the peak normalized axial power distribution is supplied; this value is also provided in Table G-1.

Table G-1. FRAPCON-2 axial power profile for the Seabrook hot fuel pin.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.0125	0.16
1.3333	0.3512	4.52
2.6667	0.6481	8.33
4.0000	0.8681	11.16
5.3333	1.0000	12.86
6.6667	1.0000	12.86
8.0000	0.8681	11.16
9.3333	0.6481	8.33
10.6667	0.3512	4.52
12.0000	0.0125	0.16
	FA = 1.557046	

SCDAP/RELAP5/MOD3 requires an axial power profile array consisting of values for the ratio of the node power to the average node power for each axial node. The node power P_N (in kW) in each axial node (except the core midplane node) is calculated using Equation (G-2). The power in the core midplane node is then the difference between the total power P_{TOT} and power in the remaining nodes. Table G-2 contains the SCDAP/RELAP5/MOD3 axial power profile, along with the total power generated in each node and the nodal LHGR for the hot fuel pin operating at the Technical Specification limit. FRAP-T6 uses the same axial power profile as SCDAP/RELAP5/MOD3.

G-2.2 Hot Channel Average Fuel Pins

The SCDAP/RELAP5/MOD3 hot channel model consists of 1056 pins representing four fuel assemblies. Two of the pins represent a high- and low-burnup fuel pin, respectively; their power distribution was determined in Section G-2.1. The power distribution of the remaining 1054 fuel pins in the hot channel will significantly influence the thermal-hydraulic conditions of the two hot fuel pins being analyzed. For the purpose of this analysis, it is assumed that the remaining rods of the hot channel are operating at the Technical Specification enthalpy rise hot channel factor, but with a flatter axial power profile. This power profile is based on a chopped, symmetric cosine distribution with 5% less axial peaking than used in Section G-2.1.

Table G-2. SCDAP/RELAP5/MOD3 axial power profile for the Seabrook hot fuel pin.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6667	3.15	2.36	0.28600
2	2.0000	8.65	6.49	0.78582
3	3.3333	13.13	9.85	1.19234
4	4.6667	16.05	12.03	1.45732
5	6.0000	17.14	12.86	1.55705
6	7.3333	16.05	12.03	1.45732
7	8.6667	13.13	9.85	1.19234
8	10.0000	8.65	6.49	0.78582
9	11.3333	3.15	2.36	0.28600
Total		99.098		

The linear power at any location along the fuel pin can then be found from

$$P(z) = 0.95 * \text{Maximum LHGR} * \cos(\pi * z/(12+T)) \qquad \text{(G-5)}$$

where

z = distance from the core midplane (ft)
T = shape factor (ft)
Max. LHGR = 12.86 kW/ft (see Section G-2.1)

and the total pin power can be found by integrating this expression over the length H of the fuel pin:

$$P_{TOT} = 2*0.95*\text{Max.LHGR}*((12+T)/\pi)*(\sin(\pi*H/2*(12+T))) \qquad \text{(G-6)}$$

The shape factor, T, may be determined by setting this expression equal to the total pin power of 99.098 kW for a fuel pin operation at the Technical Specification enthalpy rise hot channel factor (see Section G-2.1);

T = 0.805593.

The equation for the power at any axial location then becomes:

$$P(z) = 12.215 * \cos(\pi * z/12.805593)) \qquad \text{(G-7)}$$

The total power in any node can be found by integrating this expression over the length of the node, as was shown above. Tables G-3 and G-4 contain the corresponding FRAPCON-2 and SCDAP/RELAP5/MOD3 data for the average fuel pin of the hot channel.

Table G-3. FRAPCON-2 axial power profile for the Seabrook average hot channel fuel pins.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.0987	1.21
1.3333	0.4132	5.05
2.6667	0.6839	8.35
4.0000	0.8820	10.77
5.3333	0.9867	12.05
6.6667	0.9867	12.05
8.0000	0.8820	10.77
9.3333	0.6839	8.35
10.6667	0.0987	5.05
12.0000	0.1241	1.21
	FA = 1.479194	

Table G-4. SCDAP/RELAP5/MOD3 axial power profile for the Seabrook average hot channel fuel pins.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6667	4.21	3.15	0.38195
2	2.0000	9.01	6.76	0.81866
3	3.3333	12.87	9.65	1.16856
4	4.6667	15.35	11.51	1.39453
5	6.0000	16.21	12.16	1.47261
6	7.3333	15.35	11.52	1.39453
7	8.6667	12.87	9.65	1.16856
8	10.0000	9.01	6.76	0.81866
9	11.3333	4.21	3.15	0.38195
Total		99.098		

G-2.3 Radial Power Distribution

The SCDAP/RELAP5/MOD3 core model consists of three fueled channels with the fuel assemblies distributed as follows:

Channel	Number of Assemblies
Hot Channel	4
Central Region	77
Outer Region	112

Seabrook FSAR Figure 4.3-10[G-7] provides a typical normalized radial fuel assembly power distribution near end-of-life (EOL) for an unrodded, HFP equilibrium xenon core. This information is used to approximate the radial power distribution in this analysis. The power distribution for a 1/4 core is:[G-7]

0.97	1.10	0.97	1.11	0.99	1.15	0.96	0.86
1.10	0.97	1.10	0.98	1.13	1.00	1.14	0.86
0.97	1.10	0.97	1.12	1.00	1.15	0.94	0.81
1.11	0.98	1.12	1.01	1.16	1.01	1.09	0.65
0.99	1.13	1.00	1.16	1.19	1.09	0.93	
1.15	1.00	1.15	1.01	1.09	1.11	0.67	
0.96	1.14	0.94	1.09	0.93	0.67		
0.86	0.86	0.81	0.65				

Increasing the highest power assembly power to 1.49 to correspond to the limiting hot channel enthalpy rise factor (see Section G-2.1) and renormalizing the data produces the following distribution:

	C1							
C1-	0.963	1.092	0.963	1.102	0.983	1.142	0.953	0.854
	1.092	0.963	1.092	0.973	1.122	0.993	1.132	0.854
			Central Region					
	0.963	1.092	0.963	1.112	0.993	1.142	0.933	0.804
							Outer Region	
	1.102	0.973	1.112	1.003	1.152	1.003	1.082	0.645
	0.983	1.122	0.993	1.152	1.490	1.082	0.923	
	1.142	0.993	1.142	1.003	1.082	1.102	0.665	
	0.953	1.132	0.933	1.082	0.923	0.665		
	0.854	0.854	0.804	0.645				

The core may be divided into central, outer, and hot channel regions, as shown above. The nodalization used in SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 actually models the four hot channel assemblies as being face-adjacent to one another. In addition, SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 nodalization further assumes that the hot channel only communicates directly with the central core region. These conservative assumptions are not expected to significantly affect the results, since the intent is to achieve hot channel conditions that would be expected in the close vicinity of the analyzed hot fuel pins. The radial peaking factor for the central region can be found as the average of assembly-specific factors within this region, taking into account that some assemblies lie on the segment borderline. The respective radial power peaking factors are summarized in Table G-5. They can be used to calculate the total fission power produced in the fuel (see below) at 102% power level, the total power generated including gamma heating, and the fraction of total core thermal power to be assigned to a specific component (see Table G-5).

Table G-5. SCDAP/RELAP/MOD3 radial power distribution input summary for Seabrook.

Component	Radial peaking factor	No. of pins	Power generation within fuel (kW)	ALHGR (kW/ft)	Power including gamma heat (kW)	Power fraction
Hot pins	1.4900	2	1.982E+02	8.26	2.0349E+02	5.8486000E-5
Hot channel	1.4900	1054	1.044E+04	8.26	1.0724E+05	3.0822348E-2
Central region	1.04907	20328	1.418E+06	5.81	1.4562E+06	4.1854056E-1
Outer region	0.94876	29568	1.866E+06	5.26	1.9156E+06	5.5057861E-1
		50952	3.389E+06		3.479E+06	1.0

G-2.4 Central and Outer Region

The data from Table G-5 can be used to determine the axial power distribution in both the central and outer core regions, assuming a symmetric, chopped cosine power shape. The ratio of the maximum power at the core midplane, PMAX, to the minimum power at the fuel zone boundary, PMIN, is assumed to be two. The following expression can then be written for the power at the core boundary:

$$PMIN = PMAX * \cos(\pi*(H/2)/(H+T)) \qquad (G\text{-}8)$$

where H is the height of the active fuel zone = 12 ft (Section G-2.1). Solving for T:

$$0.5 = \cos(\pi*(6)/(12+T))$$
$$T = H/2 = 6 \text{ ft.}$$

The linear power at any location along the fuel pin can then be found from:

$$P(z) = PMAX * \cos(\pi*z/18) \qquad (G\text{-}9)$$

where

PMAX	=	peak axial power in kW/ft at the core midplane
z	=	distance from the core midplane (ft)

and the total pin power can be found by integrating this expression over the length of the fuel pin:

$$P_{TOT} = 2 * PMAX * (18/\pi) * (\sin(\pi*6/18))$$
$$= 9.92392 * PMAX \ . \ . \ . \ . \ \text{kW}$$

PMAX may be determined by setting this expression equal to the total pin power given in Table G-5. For the central core region,

PMAX = 7.031 kW/ft.

For the outer core region,

PMAX = 6.358 kW/ft.

The equation for the power at any axial location then becomes:

$P(z) = 7.031*\cos(\pi*z/18)$ kW/ft ... for the central core region
$P(z) = 6.358*\cos(\pi*z/18)$ kW/ft ... for the outer core region

The total power in any node can be found by integrating these expressions over the length of the noo ıs was shown above for the hot fuel pins. Tables G-6 and G-7 summarize the FRA CON-2 and SCDAP/RELAP5/MOD3 data for the central region fuel pins, while Tables G-8 and G-9 summarize these data for the outer region fuel pins.

Table G-6. FRAPCON-2 axial power profile for the Seabrook central core region fuel pins.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.5000	3.52
1.3333	0.6862	4.82
2.6667	0.8355	5.87
4.0000	0.9397	6.61
5.3333	0.9932	6.98
6.6667	0.9932	6.98
8.0000	0.9397	6.61
9.3333	0.8355	5.87
10.6667	0.6862	4.82
12.0000	0.5000	3.51

FA = 1.209199

Table G-7. SCDAP/RELAP5/MOD3 axial power profile for the Seabrook central core region fuel pins.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial Profile
1	0.6667	5.59	4.19	0.72046
2	2.0000	7.16	5.37	0.92421
3	3.3333	8.36	6.27	1.07814
4	4.6667	9.10	6.83	1.17395
5	6.0000	9.35	7.01	1.20647
6	7.3333	9.10	6.83	1.17395
7	8.6667	8.36	6.27	1.07814
8	10.0000	7.16	5.37	0.92421
9	11.3333	5.59	4.19	0.72046
Total		69.772		

Table G-8. FRAPCON-2 axial power profile for the Seabrook outer region fuel pins.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.5000	3.18
1.3333	0.6862	4.36
2.6667	0.8355	5.31
4.0000	0.9397	5.98
5.3333	0.9932	6.32
6.6667	0.9932	6.32
8.0000	0.9397	5.98
9.3333	0.8355	5.31
10.6667	0.6862	4.36
12.0000	0.5000	3.18

FA = 1.209114

Table G-9. SCDAP/RELAP5/MOD3 axial power profile for the Seabrook outer core region fuel pins.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6667	5.05	3.79	0.72046
2	2.0000	6.48	4.86	0.92421
3	3.3333	7.56	5.67	1.07814
4	4.6667	8.23	6.17	1.17395
5	6.0000	8.46	6.34	1.20647
6	7.3333	8.23	6.17	1.17395
7	8.6667	7.56	5.67	1.07814
8	10.0000	6.48	4.86	0.92421
9	11.3333	5.05	3.79	0.72046
Total		63.101		

G-2.5 Hot Fuel Pin Case Using Varied Peaking Factors

The hot fuel pin case was also run using varied peaking factors, peak-to-average ratios, and axial power profiles, as calculated according to the technique set forth in Section G-2.1. The FRAPCON-2 values normalized to the peak are given in Tables G-10, G-11, and G-12 for peaking factors of 2.2, 2.0, and 1.8, along with the corresponding LHGR at each location. The ratio of peak to average power, FA, is also provided in the tables. FRAP-T6 requires an axial power profile array containing values for the ratio of the total node power to the average node power for each axial node. The FRAP-T6 values are given in Tables G-13, G-14, and G-15 for peaking factors of 2.2, 2.0, and 180, along with the total power generated in each node and the nodal LHGR at each location.

Table G-10. FRAPCON-2 axial power profile for the Seabrook hot fuel pin with 2.2 peaking factor.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.1005	1.23
1.3333	0.4145	5.05
2.6667	0.6846	8.35
4.0000	0.8823	10.76
5.3333	1.0000	12.19
6.6667	1.0000	12.19
8.0000	0.8823	10.76
9.3333	0.6846	8.35
10.6667	0.4145	5.05
12.0000	0.1005	1.23

FA = 1.476509

Table G-11. FRAPCON-2 axial power profile for the Seabrook hot fuel pin with 2.0 peaking factor.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.2766	3.07
1.3333	0.5371	5.95
2.6667	0.7538	8.36
4.0000	0.9089	10.07
5.3333	1.0000	11.08
6.6667	1.0000	11.08
8.0000	0.9089	10.07
9.3333	0.7538	8.36
10.6667	0.5371	5.95
12.0000	0.2766	3.07

FA = 1.342282

Table G-12. FRAPCON-2 axial power profile for the Seabrook hot fuel pin with 1.8 peaking factor.

X (ft)	QF(T)	LHGR (kW/ft)
0.0000	0.5015	5.00
1.3333	0.6872	6.86
2.6667	0.8360	8.34
4.0000	0.9399	9.38
5.3333	1.0000	9.98
6.6667	1.0000	9.98
8.0000	0.9399	9.38
9.3333	0.8360	8.34
10.6667	0.6872	6.86
12.0000	0.5015	5.00
	FA = 1.208053	

Table G-13. FRAP-T6 axial power profile for the Seabrook hot fuel pin with 2.2 peaking factor.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6667	4.22	3.17	0.3836
2	2.0000	9.01	6.76	0.8187
3	3.3333	12.85	9.64	1.1672
4	4.6667	15.33	11.50	1.3922
5	6.0000	16.26	12.19	1.4765
6	7.3333	15.33	11.50	1.3922
7	8.6667	12.85	9.64	1.1672
8	10.0000	9.01	6.76	0.8187
9	11.3333	4.22	3.17	0.3836
Total		99.0982		

Table G-14. FRAP-T6 axial power profile for the Seabrook hot fuel pin with 2.0 peaking factor.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6667	6.05	4.54	0.5499
2	2.0000	9.61	7.20	0.8724
3	3.3333	12.37	9.28	1.1236
4	4.6667	14.13	10.60	1.2830
5	6.0000	14.78	11.08	1.3423
6	7.3333	14.13	10.60	1.2830
7	8.6667	12.37	9.28	1.1236
8	10.0000	9.61	7.20	0.8724
9	11.3333	6.05	4.54	0.5499
Total		99.0982		

Table G-15. FRAP-T6 axial power profile for the Seabrook hot fuel pin with 1.8 peaking factor.

Node	Center (ft)	Power (kW)	LHGR (kW/ft)	Axial profile
1	0.6667	7.94	5.96	0.7212
2	2.0000	10.18	7.63	0.9242
3	3.3333	11.86	8.90	1.0775
4	4.6667	12.92	9.69	1.1730
5	6.0000	13.30	9.98	1.2081
6	7.3333	12.92	9.69	1.1730
7	8.6667	11.86	8.90	1.0775
8	10.0000	10.18	7.63	0.9242
9	11.3333	7.94	5.96	0.7212
Total		99.0982		

G-3. References

G-1. G. A. Berna et al., *FRAPCON-2: A Computer Code for the Calculation of Steady State Thermal-Mechanical Behavior of Oxide Fuel Rods*, NUREG/CR-1845, January 1981.

G-2. C. M. Allison et al. (Eds.), *RELAP5/MOD3 Code Manual, Volumes I-IV*, (Draft), NUREG/CR-5535, EGG-2596, June 1990.

G-3. D. R. Liles et al., *TRAC-PF1/MOD1: An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Thermal-Hydraulic Analysis*, NUREG/CR-3858, LA-10157-MS, July 1986.

G-4. L. J. Siefken et al., *FRAP-T6: A Computer Code for the Transient Analysis of Oxide Fuel Rods*, NUREG/CR-2148, EGG-2104, May 1981.

G-5. *Final Safety Analysis Report for the Seabrook Reactor*, Table 4.1-1.

G-6. Technical Specifications for the Seabrook Reactor, Technical Specification 3/4.2.2 and 3.2.3.

G-7. *Final Safety Analysis Report for the Seabrook Reactor*, Figure 4.3-10.

Appendix H

TRAC-PF1/MOD1 Input Deck Preparation and Results

Appendix H

TRAC-PF1/MOD1 Input Deck Preparation and Results

H-1. Code Description

TRAC-PF1/MOD1[H-1] performs best-estimate analyses of loss-of-coolant accidents (LOCAs) and other transients in pressurized water reactors (PWRs). The code also models a wide range of thermal-hydraulic experiments in reduced-scale facilities. Models used include reflood, multidimensional two-phase flow, nonequilibrium thermodynamics, generalized heat transfer, and reactor kinetics. Automatic steady-state and dump/restart capabilities also are provided.

The TRAC-PF1/MOD1 code version used in the timing analysis of PWR fuel pin failures (Version 14.3) was the same version used in the code scaling, applicability, and uncertainty evaluation (CSAU) study.[H-2] As such, its capability for modeling a large-break LOCA has been established. Further, TRAC-PF1/MOD1 models and results have been extensively assessed; and the results of this assessment have been documented. Appendix F of Reference H-2 provides an extensive list of assessment reports applicable to the TRAC-PF1/MOD1 code. Because of its maturity and exhaustive assessment, TRAC-PF1/MOD1 was selected to perform a calculation for comparison of results with SCDAP/RELAP5/MOD3 results.

H-2. Methodology

Figure H-1 shows the role of TRAC-PF1/MOD1 analysis in the overall methodology for the timing analysis of PWR fuel pin failures. To provide a basis for evaluating the adequacy of SCDAP/RELAP5/MOD3 for large-break LOCA analysis, a single TRAC-PF1/MOD1 calculation was made. This calculation provided primary system thermal-hydraulic boundary conditions for the 100% design basis accident (DBA), or worst-case scenario, for the Seabrook reactor. This scenario consists of a complete, double-ended, offset shear break of a cold leg, without pumped emergency core cooling and main coolant pump trip.

The results from the TRAC-PF1/MOD1 calculation were used in two ways. First, thermal-hydraulic conditions of interest to this analysis were directly compared with results calculated by SCDAP/RELAP5/MOD3. Second, the FRAP-T6 fuel pin failure time matrix for the Seabrook 100% DBA case was regenerated, using TRAC-PF1/MOD1 thermal-hydraulic boundary conditions as input. Fuel pin failure times were then compared to those calculated previously using SCDAP/RELAP5/MOD3 thermal-hydraulic boundary condition data. (These results are reported in Appendix J.)

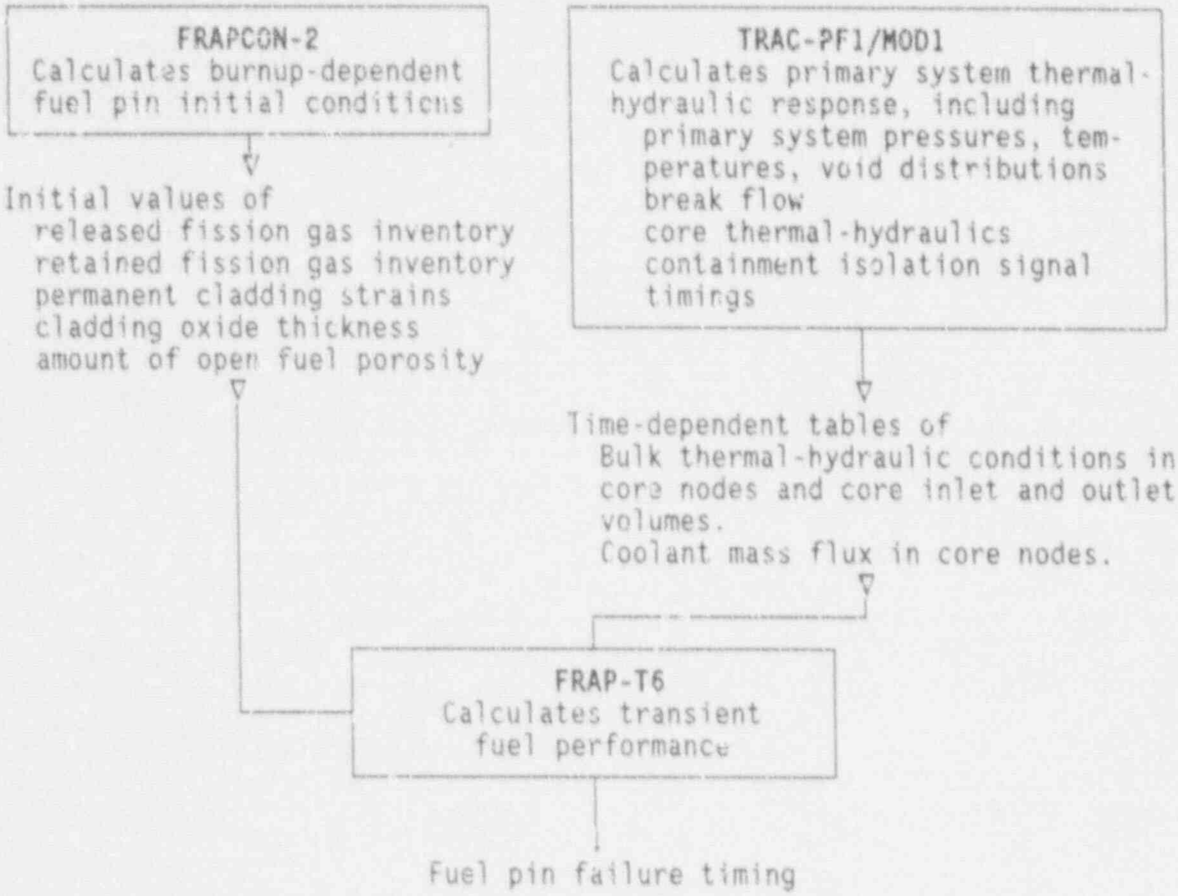

Figure H-1. Flow chart of methodology using TRAC-PF1/MOD1 thermal-hydraulic data.

H-3. Model Development

The basic TRAC-PF1/MOD1 reactor model used in this analysis (referred to hereafter as the base deck) was an existing input deck for a generic Westinghouse four-loop RESAR-3S plant with a 17x17 fuel pin configuration.[H-2] This deck was modified to replicate the modeling and initial conditions of the Seabrook SCDAP/RELAP5/MOD3 deck (see Appendix E).

Since the base deck was developed as a best-estimate model representing an operating plant midlife of a second cycle, plant conditions differed from the conservative assumptions used for the timing analysis for PWR fuel pin failures. Thus, some of the plant model operating and boundary conditions had to be modified. Also, the TRAC code used for the calculations is the "uncertainty" version, which had some updates that allowed for varying certain parameters. These had to be reset to nominal code values. In addition, the axial nodalization in the core region had to be modified to correspond to that used with the FRAP-T6 and SCDAP/RELAP5/MOD3 models. Nodalization diagrams for the revised TRAC-PF1/MOD1 model are presented in Figures H-2 and H-3.

This appendix presents a general description of revisions made to the TRAC-PF1/MOD1 base deck to perform the supplemental calculation for the timing analysis of PWR fuel pin failures. Details of modifications and supporting calculations are found in calculation packages supporting this analysis (see Appendix A). Section H-3.1 describes revisions to steady-state base deck input data; Section H-3.2 describes revisions required for transient analysis.

H-3.1 Steady-State Input Data (Plant Model)

The steady-state deck fully describes the basic plant model. All four loops and the pressure vessel are modeled. Changes made to the CSAU base deck for the timing analysis of PWR fuel pin failure are given in Table H-1.

H-3.2 Transient Input Data

The system plant model was set up in the steady-state model (see Figures H-2 and H-3). To run a large-break transient, the cold leg TEE component (46) was removed and replaced by TEE component 46 and PIPE component 56, plus break components 97 and 98, as shown in Figure H-4. The initial conditions for these components were taken from the steady-state results for component 46. The back pressure (containment pressure) data were taken from the SCDAP/RELAP5 calculation.

During a large-break LOCA, the plant model fails in the steam generator secondary at approximately 25 - 26 seconds into the transient. This failure occurred during all the CSAU transients, as well as during transients for the timing analysis of PWR fuel pin failures. The problem occurs in the recirculation junction of the secondary modeling, as shown in Figure H-2. Very small flow rates oscillate at this junction, causing a convergence failure.

To correct the problem, the flow areas of the secondary tube of the TEE components were set to 0.0 and the problem was restarted. This change was used in both the CSAU and timing analysis of PWR fuel pin failures calculations. Since the feedwater is off and the steam line valve is closed, the secondary is isolated; therefore, this modification has no effect on the large-break LOCA transient.

H-3.3 Execution

The TRAC-PF1/MOD1 base deck was modified as noted above and executed on the Cray Supercomputer using TRAC-PF1/MOD1 code version 14.3U5Q.LG. Table H-2 lists the description, input file, and output file for each case. All source, input, and output files have been archived on tape for permanent retention.

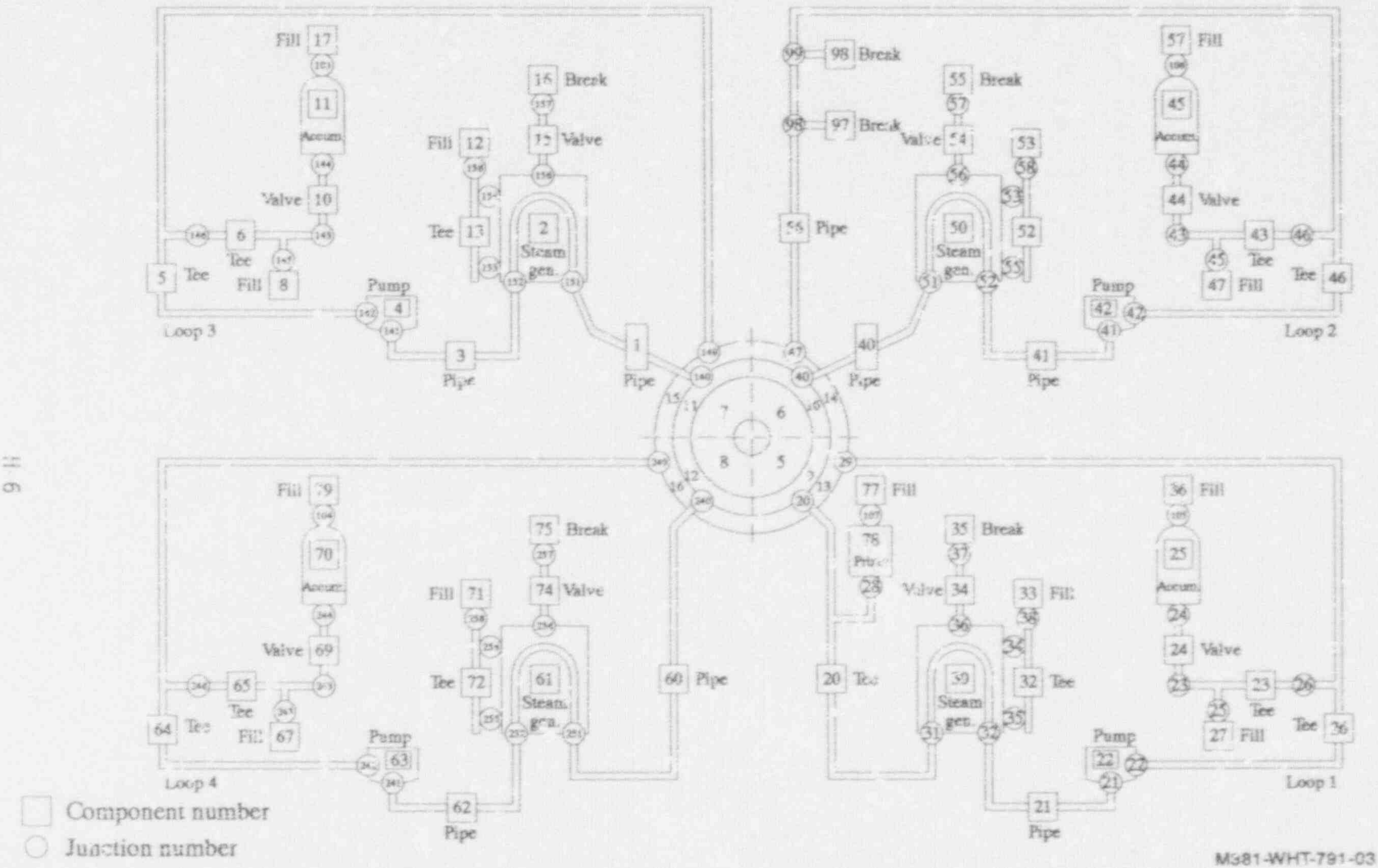

Figure H-2. Nodalization diagram of TRAC-PF1/MOD1 model for Seabrook.

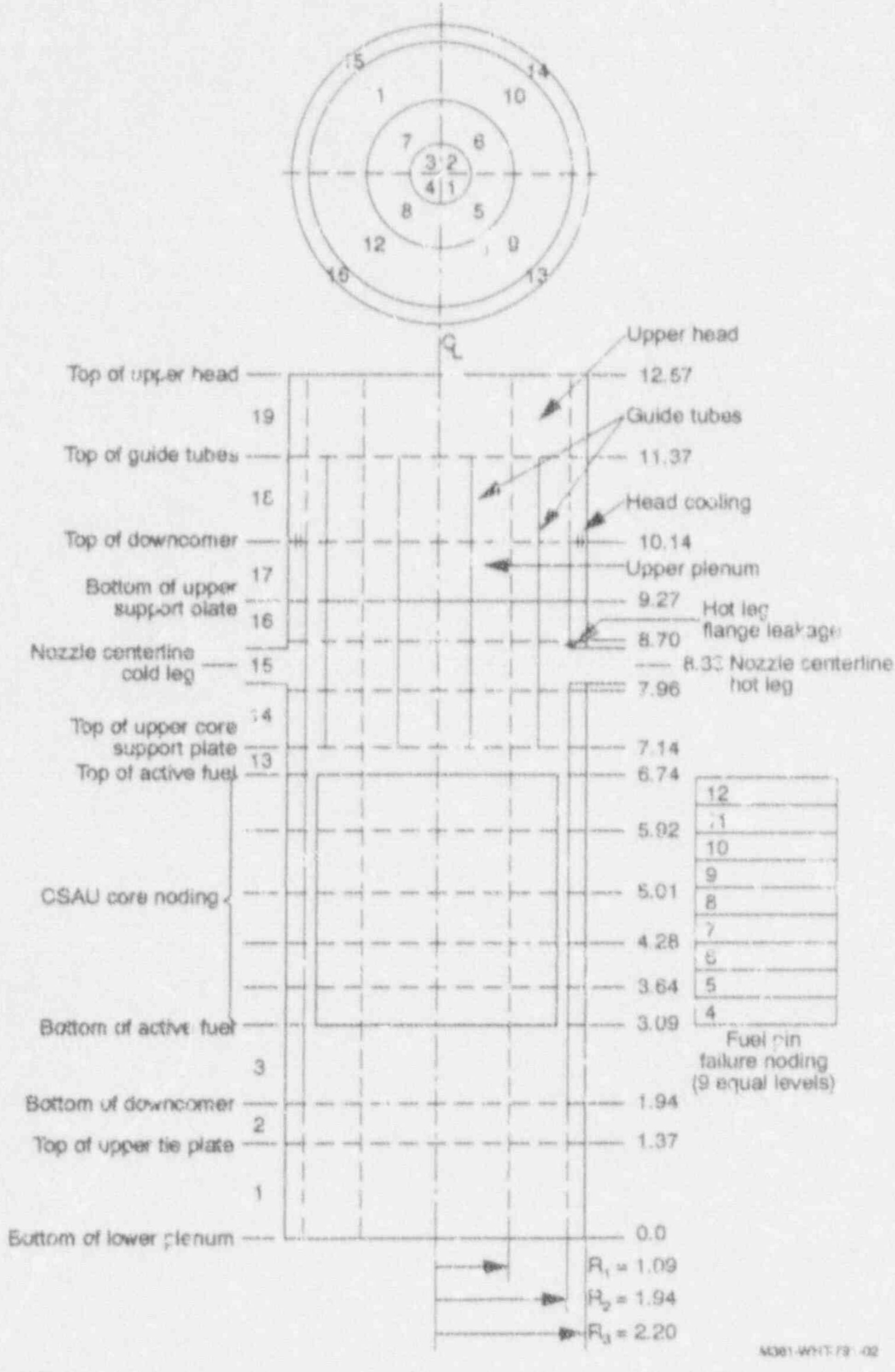

Figure H-3. Nodalization diagram of TRAC-PF1/MOD1 vessel axial noding for Seabrook.

Table H-1. Steady-state input data revisions to TRAC-PF1/MOD1 input deck.

Description of data	Description of modification
User Information:	
Main data card 1	Number of title cards changed from seven to six; number of fuel rods changed from 46 to 16.
NAMELIST modifications	Added cells in core region: changed critical flow multipliers from CSAU values to default values.
Uncertainty multipliers	All of the uncertainty multipliers were changed from CSAU values to default values (1.0).
Safety injection trip	The fill curves for the emergency core cooling (ECC) injection were set to trip "on" with pressure. Since the timing analysis of PWR fuel pin failures allows no pumped ECC, the pressure trip point was reset so that the ECC would not come on. [NOTE: This resetting of the pressure trip setpoint did not work. So the fill curves (mass flow versus pressure) were set to 0.0.]
VESSEL component changes:	
Controls	Increase axial levels due to core region renodalization from five to nine cells. Change number of rods from CSAU value to fuel pin failure value. Change maximum allowable rate of change of programmed reactivity (w/s). Change initial power to 102% (3.411E9 x 1.02 = 3.479E9 W).
Geometry--cell locations	Because of the core region renodalization from five to nine cells, the axial elevations of the cells were recalculated. The core region was divided into nine nodes of equal size
Vent valve location data	Because of the core region renodalization from five to nine cells, the vent valve cell number connections had to be changed.
Guide tube location data	Because of the core region renodalization from five to nine cells, the guide tube cell number connections had to be changed.

Table H-1. (continued)

Description of Data	Description of Modification
Hot and cold leg location data	Because of the core region renodalization from five to nine cells, the hot and cold leg cell number connections had to be changed.
Radial power density at the node positions	The radial power density at the node positions (nodes 1-5 for fuel pellets and nodes 6-8 for cladding) was revised to correspond to the radial profile used in the SCDAP/RELAP5/MOD3 calculations (see Appendix E).
Radial peaking factors for the core	The radial peaking factors for the core were defined as calculated in Appendix G.
Cell numbers for supplemental rods	The CSAU deck had 34 supplemental rods in cell 1. The fuel pin failure analysis has four supplemental rods, located in the center ring, cells 1-4.
Power peaking factors for the supplemental rods	The power peaking factors for the supplemental rods were defined as calculated in Appendix G.
Axial power profile	The axial power profile was defined as calculated in Appendix G.
Reactor power versus time curve	The reactor power versus time curve was defined as the power/time curve generated by the SCDAP/RELAP5/MOD3 calculations for the 100% DBA LOCA case without ECCS.
Mole fraction of gap gas constituents	The CSAU model contained helium, argon, krypton, xenon, and air. The model for the timing analysis of PWR fuel pin failures contains helium, krypton, and xenon. Specified values were defined from the steady-state FRAP-T6 calculation.
Dummy variables	The following variables must be input even though they are not used in the calculation: moles of gap gas per fuel rod; gap gas pressure; fuel rod plenum volume; pellet stack length; total cladding length. Specified values were obtained from the FRAP-T6 input deck.
Heat slab areas	Because of the core region renodalization from five to nine cells, the heat slab areas had to be redistributed.

Table H-1. (continued)

Description of Data	Description of Modification
Heat slab node positions	The average thickness for heat slabs that are now partly divided between two axial levels had to be calculated (to conserve mass).
Additive loss coefficients	Because of the core region renodalization from five to nine cells, the axial (Z) additive loss coefficient terms had to be adjusted linearly by length ratios. (The r and θ values required no adjustment.)
Cell fluid volume fractions	No changes to these data were required for the timing analysis of PWR fuel pin failures. However, the CSAU input value for ring 3 of level 4 appeared to be anomalous and was changed to the value for all other core levels.
Cell edge average area fractions	This change was made after a steady-state run with the modified deck was evaluated. The mass flows in the core region (rings 1, 2, 3) were slightly different than SCDAP/RELAP5/MOD3 mass flows. Thus, the cell edge average area fractions were adjusted slightly by the ratio of mass flows.
VESSEL data initialization	Because of the renodalization of the core region, initial estimates of cell pressure and temperature and slab temperature had to be prorated over nine cells instead of five. [NOTE: These data are initial estimates only; the values are computed during the steady-state calculation.]
VESSEL fuel rod cards	For variables BURN and RFTN, there must be as many sets of fuel rod cards as there are fuel rods modeled in the deck. Since the CSAU deck has 46 rods and the revised deck only 16 rods, 30 sets of fuel rod cards were removed from the deck.
System component changes:	
Steam generator secondary outlet area	The input flow area for all steam line valves and the steam generator outlet was increased by 2% to accommodate increased steam flow. This change was made for all four steam generators.

Table H-1. (continued)

Description of Data	Description of Modification
Feedwater and steam flow	Since the power for the fuel pin failure study is set at 102% of full power, the feedwater and steam flows were raised 2% to remove the excess power.
Loop flow	The steady-state loop flows exceeded those of the SCDAP/RELAP5 model. Thus, the pump speed (OMEGA) was reduced by the flow ratio to adjust the loop flows.
Pumped ECC injection	There is no pumped ECC in the timing analysis of PWR fuel pin failures; thus, the trip for the ECC model was changed so that the fill curve would not be activated. This did not keep the ECC at zero flow, so the flow versus pressure curve was modified to have zero flow at all pressures.

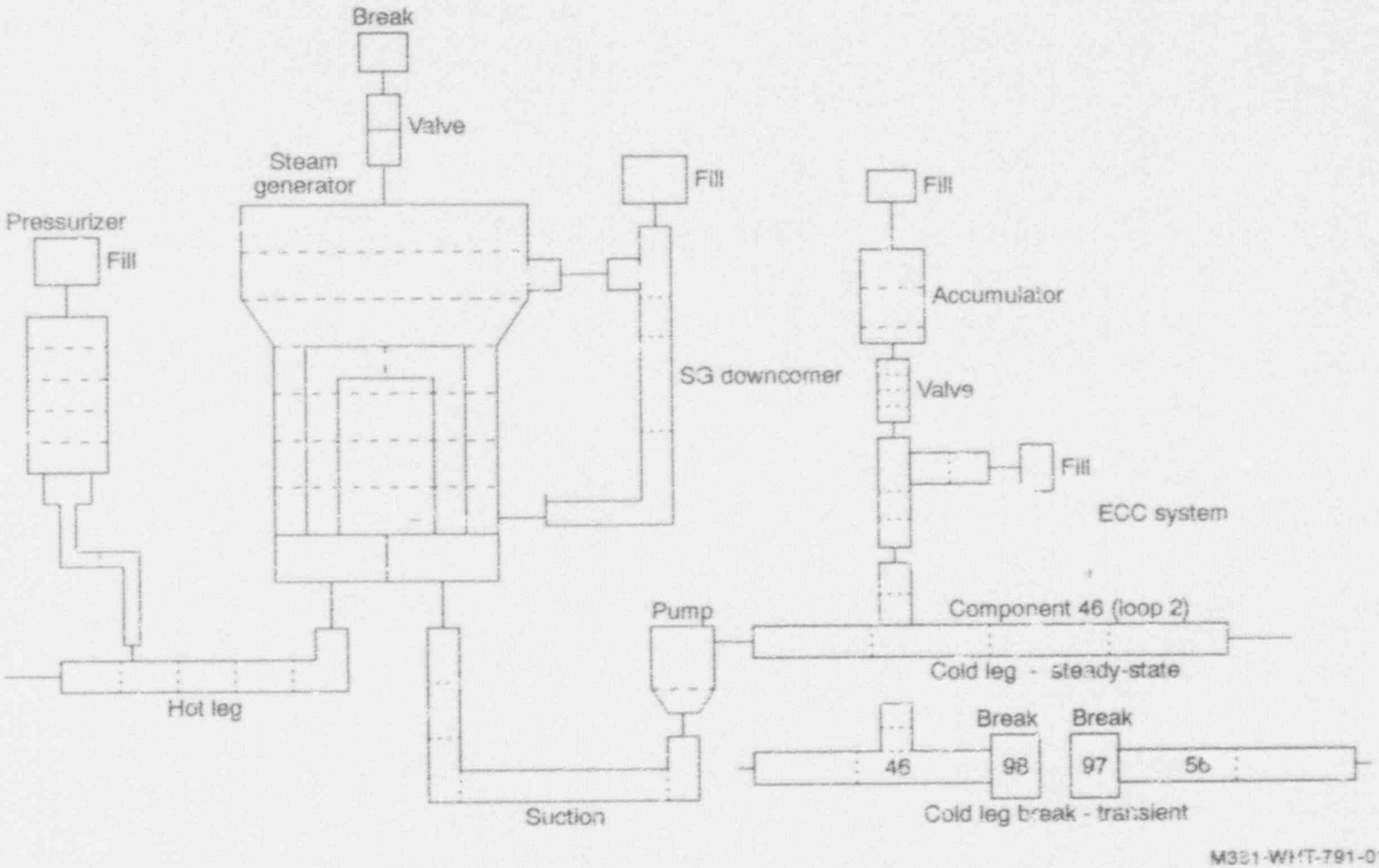

Figure H-4. Loop noding and simulated break for TRAC-PF1/MOD1 for Seabrook.

Table H-2. TRAC-PF1/MOD1 input and output matrix for Seabrook.

Case	TRAC input files	TRAC output files
Steady-state input deck to initialize the system	ssdchc.fpf	TRCOUT.ss TRCGRF.ss TRCDMP.ss
Transient restart from steady state (0 - 24 seconds)	trdkhc.fpf.1	TRCOUT.tr.1 TRCGRF.tr.1 TRCDMP.tr.1
Transient restart at 24.0 seconds (24 - 60 seconds)	trdkhc.fpf.2	TRCOUT.tr.2 TRCGRF.tr.2 TRCDMP.tr.2

H-4. RESULTS

Two TRAC-PF1/MOD1 calculations were performed. From the steady-state input deck, a transient was run to obtain the plant steady-state conditions. From the steady-state restart file, a blowdown transient was initiated by replacing the cold leg TEE component in loop 2 with a TEE and PIPE component and two break components. As explained above, the transient was run for 60 seconds with one restart.

H-4.1 Steady-State Results

The results of the SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 steady-state calculations for Seabrook are compared in Table H-3 for a selected set of parameters.

H-4.2 Transient Results

The transient results are presented graphically in Appendix L. The plots show that good comparison was obtained between SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 for the break flow and resulting system depressurization (plots 6 and 3). The accumulator flows (plot 7) also compare well. However, for the SCDAP/RELAP5/MOD3 calculation, the accumulators had to be isolated when empty of ECC water, thereby shutting off any nitrogen flow into the primary system. The TRAC-PF1/MOD1 calculation discharged nitrogen gas to the cold loop and vessel. This surge of noncondensible gas pressurized the upper downcomer, resulting in a surge of fluid into the core region, as shown in plot 2. This is also seen in plot 12 (downcomer void fraction), where the downcomer is full of liquid until the accumulators emptied.

Table H-3. A comparison of SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 steady-state results for the Seabrook reactor model.

Parameter	SCDAP/RELAP5/MOD3	TRAC-PF1/MOD1	Difference
System data:			
Hot leg temperature (K)	599.6	603.2	3.6 K
Cold leg temperature (K)	565.8	569.8	4.0 K
Delta T (K)	33.8	33.4	0.4 K
Average temperature (K)	582.7	586.5	3.8 K
Intact loop flow (kg/s)	13305.0	13212.0	-0.70%
Broken loop flow (kg/s)	4434.8	4404.0	-0.69%
Reactor dome pressure (MPa)	15.64	15.69	0.32%
Pressurizer dome pressure (MPa)	15.55	15.53	-0.13%
Core Data:			
Core inlet temperature (K)	566.9	569.7	2.8 K
Hot channel top node temperature (K)	615.5	618.2	2.7 K
Middle channel top node temperature (K)	602.6	606.4	3.8 K
Outer channel top node temperature (K)	599.4	601.4	2.0 K
Core average outlet temperature (K)	599.7	603.2	3.5 K
Hot channel flow (kg/s)	346.2	339.2	-2.03%
Middle channel flow (kg/s)	6752.7	6620.6	-1.96%
Outer channel flow (kg/s)	9858.5	10657.1	-
Bypass flow (kg/s)	531.6	N/A	2.57%
Secondary:			
Intact loop flow rate (kg/s)	1451.7	1444.5	-0.50%
Broken loop flow rate (kg/s)	483.57	481.5	-0.43%
Feedwater temperature (K)	499.7	497.7	-2.0 K
Dome pressure (MPa)	6.44	6.39	6.99%
Steam temperature (K)	553.5	558.0	4.5 K

The hot channel mass flow rate at level 8 (midcore) is shown in plot 11. The mass flow rates and temperature at each level in the hot channel are fed into the FRAP-T6 code to compute cladding ballooning and rupture.

H-5. REFERENCES

H-1. D. R. Liles et al., *TRAC-PF1/MOD1: An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Thermal-Hydraulic Analysis*, NUREG/CR-3858, LA-10157-MS, July 1986.

H-2. Technical Program Group, *Quantifying Reactor Safety Margins: Application of Code Scaling, Applicability, and Uncertainty Evaluation Methodology to a Large-Break, Loss-of-Coolant Accident*, EGG-2552, NUREG/CR-5249, December 1989.

Appendix I

FRAPCON-2 Input Deck Preparation and Results

Appendix I

FRAPCON-2 Input Deck Preparation and Results

Code Description

FRAPCON-2[I-1] is a computer code for calculating the steady-state thermal and mechanical behavior of a single light water reactor (LWR) fuel rod. FRAPCON-2 calculates LWR fuel rod behavior when power and boundary condition changes are sufficiently slow so that a series of steady-state analyses (no time derivatives) can be used to model rod behavior. Such situations would include long periods at constant power and slow power ramps typical of normal power reactor operations. The code calculates the variation with time and burnup of all significant fuel rod variables, including fuel and cladding temperatures, cladding hoop strain, cladding oxidation, fuel irradiation swelling, fuel densification, fission gas release, and rod internal gas pressure. In addition, FRAPCON-2 is designed to generate initial conditions for fuel rod analysis using FRAP-T6,[I-2] a companion computer code that calculates LWR fuel rod performance during reactor transients and loss-of-coolant accidents (LOCAs).

FRAPCON-2 was developed for the U. S. Nuclear Energy Commission (NRC) to perform both best-estimate calculations and audit calculations for licensing proceedings. As such, its models and results have been extensively assessed; and the results of this assessment have been documented.[I-3,I-4] Even though code assessment does not address fuel pin burnups > 35,000 MWd/MTU, FRAPCON-2 was chosen as the best code available to provide steady-state fuel pin data for the timing analysis of pressurized water reactor (PWR) fuel pin failures.

Methodology

Figure I-1 shows the role of FRAPCON-2 analysis in the overall methodology for the timing analysis of PWR fuel pin failures. FRAPCON-2 was used to calculate fuel pin initial conditions at specific burnups; these data were then input into FRAP-T6 for transient analysis. FRAPCON-2 calculations were made for the hot channel hot pin with each of four peaking factors considered for the Seabrook and Oconee reactors. FRAPCON-2 data were also calculated for the hot channel average fuel pin, middle core region fuel pin, and outer core region fuel pin; these data were used to initialize SCDAP fuel components so that SCDAP and FRAP-T6 fuel temperatures and failure times could be compared.

Model Development

A single fuel pin design was modeled for each plant type analyzed. These fuel designs included the Mk-B9/10 design for the Oconee analysis and the

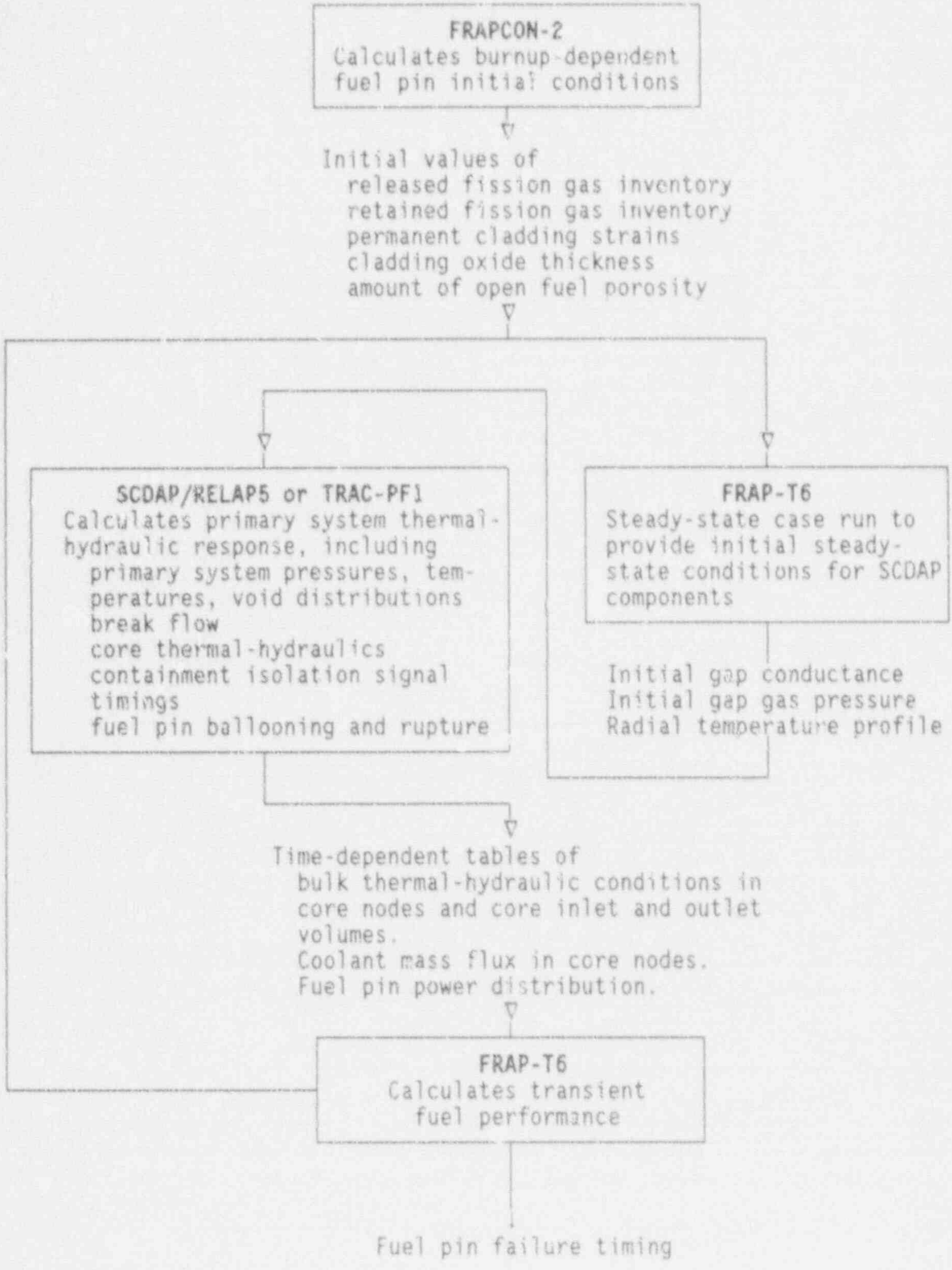

Figure I-1. Flow chart of methodology using FRAPCON-2.

W 17x17 standard fuel design for the Seabrook analysis. Specific data for these fuel rod models came from a variety of sources. Reactor-specific fuel data were obtained either from the fuel vendor or the appropriate FSAR.[I-5,I-6] For the Oconee model only, an adjustment was made to the upper plenum length to account for differences between the Oconee upper and lower plenums. The basic design parameters for each fuel type are summarized in Table I-1.

Table I-1. Summary of fuel design characteristics for fuel types modeled in FRAPCON-2.

Characteristic	B&W Mk-B9/10	W 17x17 standard
Pin lattice	15x15	17x17
Fuel pins per assembly	208	264
Fuel pellet OD (in.)	0.370	0.3225
Cladding ID (in.)	0.377	0.329
Cladding OD (in.)	0.430	0.374
Plenum length (in.)	8.394	6.479
Initial fuel stack height (in.)	140.595	144.0
Initial fill gas pressure (psig)	340.0	365.0
Fuel enrichment (wt. % ^{235}U)	3.5	3.1

The mechanical and fission gas release models and other code model options were chosen to best suit the analysis requirements based on descriptions and recommendations provided in code assessment documents.[I-1,3,4] Of the three mechanical models available in FRAPCON-2 (FRACAS-I, FRACAS-II, and PELET-RADIAL), FRACAS-II was chosen for the FRAPCON-2 models as the most appropriate fuel rod deformation model, when coupled with the FASTGRASS gas release model.[I-3]. FASTGRASS is a highly mechanistic gas release model that accounts for bubble formation, migration, coalescence, channeling, and eventual release and is the most suitable gas release model for high temperatures and burnups.

In FRAPCON-2, four fuel pins were modeled for each reactor, corresponding to the hot channel hot pin, the hot channel average pin, the middle ring average pin, and the outer ring average pin. The FRAPCON-2 hot channel hot pin models were used to provide steady-state initialization of burnup-dependent variables for FRAP-T6 at specific fuel burnups and varied peaking factors. All of the FRAPCON-2 fuel rod models were also used to provide initializing data for SCDAP/RELAP5/MOD3 fuel components.

The axial power profiles for FRAPCON-2 were calculated for a range of axial peaking factors using the basic assumptions and methodology described in Appendices F and G. Nine axial nodes were used in FRAPCON-2 and FRAP-T6, as well as each of the thermal-hydraulic system codes. A chopped cosine axial power profile, peaked to the core midplane, was assumed for the analysis. For each hot fuel pin modeled, the total power integrated over the length of the fuel was based on the technical specification enthalpy rise hot channel factor.

As recommended in Reference I-1, 11 radial nodes were used in the FRAPCON-2 models, with eight nodes in the fuel pellet and three nodes in the gap. The FRAPCON-2 nodalization was based on uniform area cross-sectional regions, and the radial power profile was code-calculated.

To generate FRAPCON-2 data at the specific burnups required for this analysis, the linear heat generation rate was ramped to the peak power and then held constant. The time array was extended to provide output data beyond the maximum burnup required and then refined to give data at specific burnup levels (5, 20, 35, and 50 GWd/MTU for Seabrook; 5, 20, 35, and 55 GWd/MTU for Oconee). The data files written for FRAP-T6 at the time step corresponding to these burnups were then used as input to FRAP-T6. These data files contained initializing values for released and retained fission gas inventory, permanent cladding strains, permanent fuel strains, cladding oxide thickness, and amount of open fuel porosity.

Calculation packages supporting the Oconee and Seabrook fuel deformation models are listed in Appendix A.

Input Deck Preparation and Execution

Listings of the required and optional FRAPCON-2 input variables used in this analysis are given in Tables I-2 and I-3. The specific values given are those used for the Oconee hot channel hot pin model. A complete description of FRAPCON-2 input variables is given in Appendix A of Reference I-1.

FRAPCON-2 input decks for seven different cases for each reactor type were prepared and executed for this analysis. Table I-4 lists the description, input file, and output files for each case. A representative input file and output summary are shown in Figures I-2 and I-3. The input decks were executed using FRAPCON-2, Version 1, MOD. 05, a version converted to portable FORTRAN 77 and modified for use on a DEC 5000 workstation (see Appendix C). All input and output files have been archived on tape for permanent retention.

Results

The FRAPCON-2 results most significant to the timing analysis of PWR fuel pin failures are summarized in Table I-5.

Table I-2. FRAPCON-2 required input variables.

Variable	Description
No name	Uncertainty analysis option card; default = 0
No name	Identifier or title card
$FRPCN	Namelist identifier
IAXSYM=0	Flag controlling the AXISYM local strain model (not used in this analysis)
IM=82	Number of power-time steps. This number must match the number of entries in the power and time arrays (QMPY and TIME).
MECHAN=3	Flag controlling the choice of mechanical model. FRACAS-II was chosen for this analysis.
NA=9	Number of axial nodes (nine used in this analysis).
NR=11	Number of radial nodes in fuel (fixed at 11).
NGASR=-2	Flag controlling the choice of gas release model. FASTGRASS was chosen for this analysis.
$FRPCON	Namelist identifier.
COMP=0.0	Plutonium oxide content of fuel.
CPL=10.314	Plenum length (in.).[a]
DCI=0.377	Fuel cladding inside diameter (in.)
DCO=0.430	Fuel cladding outside diameter (in.)
DE=0.5431	Equivalent heated diameter (in.)
DEN=95.00	Fuel density as percent of theoretical (10.97 g/cm^3).
DISHSD=.0435	Dish shoulder width (pellet radius minus dish radius) (in.)
DP=0.370	Fuel pellet diameter (in.)
DSPG=0.360	Spring outside diameter (in.)
DSPGW=0.062	Spring wire diameter (in.)
ENRCH=3.5	Fuel enrichment (wt%)

Table I-2. (continued)

Variable	Description
FA=1.534422	Axial power profile peak-to-average ratio.
FGPAV=340.0	Initial fill gas pressure (psia).
FLUX= 9*9.0365e11	Ratio of fast neutron flux to specific power (N/M^2-s per W/g fuel); input one value for each axial node.
GO=2.67e6	Mass flow rate (lb/h-ft^2); may be input as an array.
HDISH=0.010	Depth of fuel pellet end dish (in.).
HPLT=0.455	Fuel pellet height (in.).
ICM=4	Index for cladding material. Index = 4 for cold-worked, stress-relieved zircaloy-4.
IDXGAS=1	Index for initial fill gas composition. Index = 1 for helium.
IMSWCH=0	Flag for use of evaluation models with FRACAS-1. Flag = 0; evaluation models not available for use.
IPLANT=-2	Switch to specify the radial power profile. Radial power profile calculated by RADAR subroutine; flag = -2 for PWR, uranium enriched, ≤10%.
IQ=0	Flag for axial power shape. Flag = 0 (user input) for peak pin cases; flag = 1 (code calculated) for average pin cases.
IVARDM=0	Flag for inputting variable axial or radial dimensions. Uniform axial and radial dimensions were used. Flag = 0 (no variation).
JDLPR=1	Flag for output control. Flag = 1 (peak power axial node only per time step).
JN=10	Number of entries in QF and X arrays (JN = N+1, where N = number of axial nodes).
JST=1	Array controlling choice of axial power shape for each time step (IQ=0). Only one axial power shape was used.
NOPT=0	Flag for varying amount of output. Flag = 0 for full output; flag = 3 for summary output.

Table I-2. (continued)

Variable	Description
NSP=0	Flag for inputting time-dependent pressure, temperature, and mass flow (P2, TW, and GO). Constant pressure, temperature, and mass flow values were used. Flag = 0.
NUNITS=1	Flag for input unit type. English units were used. Flag = 1.
P2=2200.	System pressure (psia). May be input as an array.
QF=0.0360, 0.3682, 0.6580, 0.8720, 1.0000, 0.8720, 0.6580, 0.3682, 0.0360	Axial power profile array (input if IQ = 0). Axial power profiles input for all peak pin cases.
QMPY=1.5540, 3.1080, 4.6620, 6.2160, 7.7770, 9.3240, 10.8780, 12.4320, 13.9860, 73*15.540	Linear heat generation rate (LHGR) array versus time (kW/ft). LHGR ramped to peak power in ten time steps using 1/10th increments and then held constant. Number of array entries must match IM and number of array entries in TIME.
RC=0.0	Radius of pellet bore (in.).
ROUGHC= 3.0e-5	Arithmetic mean roughness of cladding (in.).
ROUGHF= 7.0e-5	Arithmetic mean roughness of fuel (in.).
TIME=0.1... 673.684	Time array corresponding to LHGR array (days); first value must be greater than zero. For this analysis, TIME was arbitrarily chosen to be: 0.1-step increments to one day; one-day increments to five days; one five-day increment; 10-day increments to just above maximum burnup. The time steps were then refined to give data at burnups of 5, 20, 35, and 50 (55) GWd/MTU.
TOTL=11.716	Fuel stack height (ft).

Table I-2. (continued)

Variable	Description
TW=555.8	Inlet water temperature (°F); may be input as an array.
VS=54	Total number of spring turns.
X=0.0, 1.3018, 2.6036, 3.9054, 5.2072, 6.5090, 7.8108, 9.1126, 10.4144, 11.7160	Array of axial elevations corresponding to axial power profile array (QF) entries (f), ranging in ascending order from 0.0 to TOTL. [If QF(i) are not input, X(i) are not input.] X(i) = (TOTL/NA) + X(i-1).

a. FRAPCON-2 uses either British or SI units; British units were used in this analysis.

Table I-3. FRAPCON-2 optional input variables.

Variable	Description
AMFAIR, AMFARG, AMFFG, AMFHE, AMFH2, AMFH2O, AMFKRY, AMFN2, AMFXE	These variables are the absolute mole fractions of various gases and are only input when the IDXGAS user input flag if turned on; default value used.
BUIN	Initial fuel burnup (MWd/MTU); default value used.
CATEXF	Texture factor; default value used.
CLDWKS=0.2	Fraction of cold work of cladding. Actual value used for Seabrook; default value used for Oconee.
CP, CR	Anisotropy coefficients; not used with FRACAS-II mechanical model.
CRDT	Initial crud thickness; default value used.
CRDTR	Initial crud building rate; not used.
CTMAX	Maximum cladding temperature attained by the fuel rod axial array; default value used.
DENG=0.75	Difference between pellet immersion density and geometric density. Actual value used for Seabrook; default value used for Oconee.
FOTMTL	Fuel oxygen-to-metal ratio; default value used.
GRNSIZ=5.	Initial fuel grain size (μm). Actual value used for Seabrook; default value used for Oconee.
ICOR	Index for crud model; not used.
ITREST	Time-power step to begin a restart; not used.
LINKT=6	Flag indicating version of FRAPT for data file; flag = 6.
NFROD	Number of fuel rods being analyzed; default value used.
NOFAIL	Flag for cladding failure model in FRACAS-I; not used.
NPCYCL	Number of previous power cycles; default value used.

Table I-3. (continued)

Variable	Description
NPLTAB	Flag for parameter on plot abcissa; default value used. No plotting was done.
NREAD	Restart read flag; not used.
NRESTR	Restart write flag; not used.
NTAPE=1	Flag to store data for use in FRAP-T6. Flag = 1 (data stored at each time step).
NUCFC	User-specified collapse failure criterion; not used.
QEND	Normalized heat flux from top; default value used.
PPMH2O	Fuel initial water content; default value used.
PPMN2	Fuel initial nitrogen content; default value used.
RAPOW	Radial power profile array; not used.
RSNTR	Absolute change in fuel density because of thermal resintering; default value used.
SGAPF	Fission gas atoms produced per 100 fissions; default value used.
SLIM	Limit on fuel volume swelling; default value used.
TSINT=2912.0	Fuel sintering temperature. Actual value used for Seabrook; default value used for Oconee.
UBFS	User-specified balloon failure strain; not used.
UMELT	Cladding failure melting temperature flag; default value used.
UOFD	Cladding oxide failure depth criterion; default value used.
CREPHR	Creep time step limit; default value used.

Table I-4. FRAPCON2 input and output files for the timing analysis of PWR fuel pin failures.

Case description	Input file	Output files
Seabrook files:		
Hot fuel pin case with peaking factor of 2.32	seapeak	seapeak.ol frap-t.pkl
Average hot channel fuel pin case	seaahc	seaahc.ol frap-t.ahcl
Middle core region fuel pin case	seamid	seamid.ol frap-t.midl
Outer core region fuel pin case	seaotr	seaotr.ol frap-t.otrl
Hot fuel pin case with peaking factor of 2.2	seapf22	seapf22.ol frap-t.pf22
Hot fuel pin case with peaking factor of 2.0	seapf20	seapf20.ol frap-t.pf20
Hot fuel pin case with peaking factor of 1.8	seapf18	seapf18/.ol frap-t.pf18
Oconee files:		
Hot fuel pin case with peaking factor of 2.63	ocopf263.i	ocopf27.o ocopf27.dat
Average hot channel fuel pin case	ocoahc.i	ocoahc.o ocoahc.dat
Middle core region fuel pin case	ocomid.i	ocomid.o ocomid.dat
Outer core region fuel pin case	ocooutr.i	ocootr.o ocootr.dat
Hot fuel pin case with peaking factor of 2.4	ocopf24.i	ocopf24.o ocopf24.dat
Hot fuel pin case with peaking factor of 2.2	ocopf22.i	ocopf22.o ocopf22.dat
Hot fuel pin case with peaking factor of 2.0	ocopf20.i	ocopf20.o ocopf20.dat

```
*************************************************************************
* frapcon2, steady-state fuel rod analysis code, version 1, mod. 05    *
*-----------------------------------------------------------------------*
*                                                                       *
*  CASE DESCRIPTION: OCONEE 15X15 ANALYSIS CASES                        *
*                                                                       *
*  UNIT    FILE DESCRIPTION                                             *
*  ----    ------------------------------------------------             *
*   --     Output:                                                      *
*    6       STANDARD PRINTER OUTPUT                                    *
*                                                                       *
*   --     Scratch:                                                     *
*    5       SCRATCH INPUT FILE FROM ECHO1                              *
*                                                                       *
* Input: FRAPCON2 INPUT FILE (UNIT 55)                                  *
*                                                                       *
*************************************************************************
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
       CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE01='ocopf263.p',    STATUS='UNKNOWN', FORM='UNFORMATTED'
FILE22='ocopf263.dat',    STATUS='UNKNOWN', FORM='UNFORMATTED'
FILE06='ocopf263.o',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/************************************************************************
    0              ! uncertainty option turned off
oconee 15x15 hot pin with 2.67 pf
 $frpcon
  iaxsym=0,        ! AXISYM option not used
  im=82,           ! Number of power-time steps
  mechan=3,        ! FRACAS-II mechanical model
  na=9,            ! Number of axial regions
  nr=11,           ! Number of radial nodes in fuel
  ngasr=-2,        ! FAST/GRASS gas release model
 $end
 $frpcon
  comp=0.0,        ! PuO content of fuel
  cpl=10.?4,       ! Plenum length (in.)
  dci=0.377,       ! Cladding ID (in.)
  dco=0.430,       ! Cladding OD (in.)
  de=0.5431,       ! Equivalent heated diameter (in.)
  den=95.00,       ! % theoretical fuel density (10.97g/cc)
  dishsd=.0435,    ! Pellet dish shoulder width (in.)
  dp=0.370,        ! Diameter of pellet (in.)
  dspg=0.360,      ! Spring OD (in.)
  dspgw=0.062,     ! Diameter of spring wire (in.)
  enrch=3.5,       ! Fuel enrichment (weight %)
  fa=1.534422,     ! Axial power profile peak-to-average ratio
  fgpav=340.0,     ! Initial fill gas pressure (psia)
  flux=9*9.0365e11, ! Fast neutron flux/specific power (n*gU/m^2*s*W)
  go=2.67E6,       ! Mass flow rate (lb/h*ft^2)
  hdish=0.010,     ! Depth of pellet end dish (in.)
  hplt=0.455,      ! Height of pellet (in.)
  icm=4,           ! Cladding material index (Zr-4)
  idxgas=1,        ! Initial fill gas composition index (He)
  imswch=0,        ! ZM switch (Use only with MECHAN=2)
  iplant=-2,       ! Radial power profile switch (RADAR)
  iq=0,            ! Axial power shape index (user-specified)
  ivardm=0,        ! Axial dependent dimensions index (no variation)
  jdlpr=1,         ! Output control (1=peak node only, 0=all nodes)
  jn=10,           ! Number of entries in each QF vs. X table
  jst=1,           ! Array of axial power shapes for each step
  nopt=0,          ! Output option (0=full output, 3=summary page)
  nsp=0,           ! Time-dependent parameters switch (constant)
  nunits=1,        ! Input unit type (British)
```

Figure I-2. FRAPCON 2 input deck for the hot channel hot pin for Oconee.

```
  p2=2200.,          ! System pressure (psia)
  rc=0.0,            ! Radius of pellet bore (in.)
  roughc=3.0e-5,     ! Cladding roughness (in.)
  roughf=7.0e-5,     ! Fuel surface roughness (in.)
  totl=11.716,       ! Fuel stack height (in.)
  tw=555.8,          ! Core inlet temperature (F)
  vs=54,             ! Total number of spring turns
*
* optional frpcon inputs
*
  cldwks=0.2,        ! Fraction of cladding cold work
  deng=0.75,         ! Fuel immersion %TD minus geometric %TD
  grnsiz=5.,         ! Fuel grain size
  linkt=6,           ! FRAP-T version
  ntape=1,           ! Write FRAP-T data file
  tsint=2912.0,      ! Fuel sintering temperature (F)
*
* axial power profile array QF vs. X(ft)
  qf(1)=0.0360,0.3682,0.6580,0.8720,1.0000,1.0000,
  qf(7)=0.8720,0.6580,0.3682,0.0360,
  x(1)=0.0,1.3018,2.6036,3.9054,5.2072,6.5090,7.8108,9.1126,
  x(9)=10.4144,11.7160,
*
* Table of peak LHGR QMPY(kw/ft) vs. time(days)

  qmpy(01)=1.5540,3.1080,4.6620,6.2160,7.7770,9.3240,10.8780,
  qmpy(8)=12.4320,13.9860,73*15.540,
  time(01)=    0.1,      0.2,      0.3,      0.4,      0.5,
  time(06)=    0.6,      0.7,      0.8,      0.9,      1.0,
  time(11)=    2.0,      3.0,      4.0,      5.0,     10.0,
  time(16)=   20.0,     30.0,     40.0,     50.0,     60.0,
  time(21)= 61.6524     80.0,     90.0,    100.0,    110.0,
  time(26)= 120.0,     130.0,    140.0,    150.0,    160.0,
  time(31)= 170.0,     180.0,    190.0,    200.0,    210.0,
  time(36)= 220.0,     230.0,    240.0, 245.2632,  260.0,
  time(41)= 270.0,     280.0,    290.0,    300.0,    310.0,
  time(46)= 320.0,     330.0,    340.0,    350.0,    360.0,
  time(51)= 370.0,     380.0,    390.0,    400.0,    410.0,
  time(56)= 420.0,  428.8739,    440.0,    450.0,    460.0,
  time(61)= 470.0,     480.0,    490.0,    500.0,    510.0,
  time(66)= 520.0,     530.0,    540.0,    550.0,    560.0,
  time(71)= 570.0,     580.0,    590.0,    600.0,    610.0,
  time(76)= 620.0,     630.0,    640.0,    650.0,    660.0,
  time(81)= 670.0,   673.684,
 $end
```

Figure I-2. (continued)

*********** peak power axial node output ***********

	time hours	burnup mwd/tu	power kw/ft	clad temp (f) od.	clad temp (f) avg	clad temp (f) id.	gap mils	gap (f)	fuel temp (f) od.	fuel temp (f) avg	fuel temp (f) cent	cont. psi	clad stress hoop	clad stress axial	strain pct	fuel od inch	gap conduct	fgas psi	zro2 mil	h2 ppm
1	2.	0.	1.55	576.	582.	588.	2.97	618.	648.	744.	843.	0.	-12498.	-7094.	0.0927	0.37144	906.	729.	0.00	10.3
2	5.	2.	3.11	596.	608.	620.	2.54	671.	722.	928.	1148.	0.	-12162.	-6959.	0.1041	0.37192	1057.	771.	0.00	10.4
3	7.	5.	4.66	613.	630.	648.	2.10	713.	778.	1103.	1462.	0.	-11872.	-6827.	0.1143	0.37241	1251.	813.	0.00	10.5
4	10.	8	6.22	625.	648.	671.	1.66	743.	815.	1265.	1775.	0.	-11568.	-6698.	0.1229	0.37290	1509.	853.	0.00	10.6
5	12.	12.	7.78	637.	666.	695.	1.21	767.	839.	1417.	2089.	0.	-11263.	-6567.	0.1315	0.37340	1881.	894.	0.01	10.8
6	14.	17.	9.33	649.	683.	719.	0.77	784.	850.	1557.	2393.	0.	-10964.	-6439.	0.1400	[illegible]	2446.	934.	0.01	10.9
7	17.	23.	10.88	654.	693.	733.	0.53	797.	862.	1698.	2651.	0.	-10716.	-6336.	0.1452	[illegible]	2942.	967.	0.01	11.0
8	19.	29.	12.44	654.	699.	744.	0.17	797.	856.	1813.	2920.	0.	-10469.	-6233.	0.1495	[illegible]	4086.	1000.	0.01	11.1
9	22.	37.	13.99	654.	705.	756.	0.00	791.	837.	1942.	3728.	1179.	-1941.	1519.	0.2101	[illegible]	6806.	1031.	0.01	11.2
10	24.	45.	15.54	654.	711.	767.	0.00	798.	829.	2075.	3523.	3291.	12184.	16821.	0.3001	[illegible]	8718.	1057.	0.02	11.2
11	48.	127.	15.54	655.	711.	767.	0.00	807.	846.	2081.	3522.	1104.	-2369.	3732.	0.1991	0.37495	6812.	1043.	0.02	11.7
12	72.	208.	15.54	655.	711.	767.	0.04	823.	879.	2117.	3564.	0.	-10217.	-6140.	0.1554	0.37470	4832.	1030.	0.02	12.0
13	96.	290.	15.54	655.	711.	767.	0.23	835.	903.	2143.	3588.	0.	-10293.	-6176.	0.1547	0.37493	3978.	1020.	0.03	12.3
14	120.	372.	15.54	655.	711.	767.	0.36	846.	924.	2171.	3622.	0.	-10364.	-6210.	0.1540	0.37434	3459.	1010.	0.03	12.5
15	240.	780.	15.54	655.	711.	768.	0.75	872.	976.	2233.	3688.	0.	-10547.	-6295.	0.1521	0.37389	2594.	985.	0.04	13.2
16	480.	1597.	15.54	655.	712.	768.	0.94	885.	1002.	2259.	3711.	0.	-10667.	-6350.	0.1507	0.37367	2315.	971.	0.05	14.1
17	720.	2414.	15.54	656.	712.	768.	0.95	889.	1011.	2267.	3718.	0.	-10635.	-6333.	0.1506	0.37366	2230.	975.	0.05	14.7
18	960.	3231.	15.54	656.	712.	768.	0.94	892.	1016.	2273.	3724.	0.	-10569.	-6301.	0.1508	0.37367	2183.	984.	0.06	15.2
19	1200.	4048.	15.54	656.	712.	769.	0.92	896.	1024.	2281.	3730.	0.	-10484.	-6260.	0.1513	0.37369	2121.	996.	0.06	15.7
20	1440.	4865.	15.54	656.	712.	769.	0.98	905.	1040.	2297.	3745.	0.	-10384.	-6212.	0.1519	0.37363	1990.	1009.	0.07	16.1
21	1480.	5000.	15.54	656.	712.	769.	0.96	908.	1047.	2305.	3753.	0.	-10279.	-6162.	0.1527	0.37365	1940.	1011.	0.07	16.3
22	1920.	6499.	15.54	656.	713.	769.	0.15	843.	916.	2117.	3517.	0.	-10277.	-6165.	0.1523	0.37467	3663.	1040.	0.08	16.9
23	2160.	7316.	15.54	657.	713.	769.	0.00	823.	877.	2067.	3457.	459.	-6723.	-4841.	0.1842	0.37497	4999.	1059.	0.08	17.2
24	2400.	8133.	15.54	657.	713.	769.	0.00	821.	872.	2066.	3456.	955.	-3212.	-2036.	0.2099	0.37567	5250.	1072.	0.08	17.5
25	2640.	8950.	15.54	657.	713.	769.	0.00	819.	869.	2066.	3457.	1406.	-9.	514.	0.2334	0.37517	5427.	1086.	0.09	17.9
26	2880.	9767.	15.54	657.	713.	770.	0.00	818.	867.	2067.	3459.	1800.	2220.	2417.	0.2494	0.37526	5562.	1100.	0.10	18.5
27	3120.	10584.	15.54	657.	714.	770.	0.00	818.	867.	2068.	3459.	1972.	2949.	3065.	0.2545	0.37532	5561.	1112.	0.10	19.2
28	3360.	11401.	15.54	658.	714.	770.	0.00	820.	870.	2069.	3460.	1926.	2912.	2821.	0.2552	0.37537	5416.	1126.	0.11	19.8
29	3600.	12217.	15.54	658.	714.	770.	0.00	821.	872.	2071.	3460.	1902.	2945.	2631.	0.2564	0.37541	5286.	1141.	0.12	20.4
30	3840.	13034.	15.54	658.	714.	770.	0.00	823.	875.	2072.	3461.	1886.	3009.	2465.	0.2578	0.37545	5162.	1156.	0.12	21.1
31	4080.	13851.	15.54	658.	714.	771.	0.00	824.	878.	2074.	3461.	1875.	3091.	2315.	0.2593	0.37549	5043.	1171.	0.13	21.7
32	4320.	14668.	15.54	658.	715.	771.	0.00	826.	880.	2075.	3462.	1866.	3177.	2169.	0.2609	0.37553	4930.	1186.	0.14	22.3
33	4560.	15485.	15.54	659.	715.	771.	0.00	827.	883.	2077.	3462.	1859.	3272.	2030.	0.2625	0.37557	4822.	1202.	0.14	23.0
34	4800.	16302.	15.54	659.	715.	771.	0.00	828.	886.	2078.	3462.	1853.	3373.	1898.	0.2641	0.37560	4719.	1218.	0.15	23.6
35	5040.	17119.	15.54	659.	715.	771.	0.00	830.	888.	2079.	3462.	1848.	3479.	1769.	0.2658	0.37564	4621.	1234.	0.16	24.2
36	5280.	17936.	15.54	659.	716.	772.	0.00	831.	891.	2080.	3463.	1845.	3593.	1649.	0.2676	0.375[illegible]8	4526.	1250.	0.16	24.9
37	5520.	18753.	15.54	660.	716.	772.	0.00	833.	894.	2081.	3463.	1843.	3711.	1532.	0.2694	0.37571	4435.	1267.	0.17	25.5
38	5760.	19570.	15.54	660.	716.	772.	0.00	834.	896.	2083.	3463.	1842.	3837.	1424.	0.2712	0.37575	4347.	1284.	0.18	26.2
39	5886.	20000.	15.54	660.	716.	772.	0.00	836.	899.	2084.	3464.	1806.	4025.	1468.	0.2731	0.37577	4242.	1294.	0.18	26.5
40	6240.	21204.	15.54	660.	716.	773.	0.00	836.	899.	2083.	3461.	1870.	3892.	1030.	0.2735	0.37581	4270.	1316.	0.19	27.5
41	6480.	22021.	15.54	661.	717.	773.	0.00	839.	905.	2087.	3465.	1854.	4333.	1223.	0.2775	0.37585	4074.	1337.	0.20	28.2
42	6720.	22838.	15.54	661.	717.	773.	0.00	840.	907.	2088.	3465.	1843.	4382.	1041.	0.2788	0.37588	4020.	1354.	0.21	28.9
43	6960.	23655.	15.54	661.	717.	773.	0.00	842.	910.	2089.	3465.	1845.	4530.	954.	0.2808	0.37591	3949.	1372.	0.21	29.[illegible]
44	7200.	24472.	15.54	661.	717.	774.	0.00	843.	913.	2090.	3465.	1849.	4689.	878.	0.2828	0.37595	3878.	1391.	0.22	30.2
45	7440.	25289.	15.54	662.	718.	774.	0.00	845.	915.	2091.	3466.	1853.	4852.	808.	0.2849	0.37596	3809.	1413.	0.23	30.9
46	7680.	26106.	15.54	662.	718.	774.	0.00	846.	918.	2093.	3466.	1855.	5016.	748.	0.2870	0.37601	3740.	143[illegible].	0.24	31.6
47	7920.	26923.	15.54	662.	718.	774.	0.00	848.	921.	2094.	3467.	1844.	5114.	691.	0.2883	0.37604	3669.	1450.	0.24	32.3
48	8160.	27740.	15.54	662.	718.	775.	0.00	849.	924.	2096.	3468.	1839.	5240.	653.	0.2899	0.37607	3603.	1469.	0.25	33.0
49	8400.	28557.	15.54	663.	719.	775.	0.00	851.	927.	2098.	3470.	1838.	5385.	628.	0.2916	0.37610	3540.	1490.	0.26	33.7
50	8640.	29373.	15.54	663.	719.	775.	0.00	852.	930.	2100.	3471.	1839.	5543.	513.	0.2934	0.37613	3479.	1510.	0.27	34.4
51	8880.	30190.	15.54	663.	719.	775.	0.00	854.	933.	2101.	3472.	1841.	5711.	605.	0.2953	0.37616	3421.	1532.	0.27	35.1

Figure I-3. FRAPCON-2 output deck summary sheet for the hot channel hot pin for Oconee.

52 9120.	31007.	15.54	663.	719.	776.	0.00	856.	936.2103.3473.	1845.	5896.	614.	0.2973	0.37619	3363.	1553.	0.28	35.8
53 9360.	31824.	15.54	664.	720.	776.	0.00	857.	938.2105.3475.	1850.	6060.	603.	0.2992	0.37622	3310.	1572.	0.29	36.5
54 9600.	32641.	15.54	664.	720.	776.	0.00	859.	941.2107.3476.	1852.	6238.	602.	0.3011	0.37624	3258.	1594.	0.30	37.2
55 9840.	33458.	15.54	664.	720.	776.	0.00	860.	944.2109.3477.	1856.	6423.	610.	0.3032	0.37627	3207	1616.	0.30	37.9
5610080.	34275.	15.54	664.	720.	777.	0.00	862.	947.2111.3479.	1861.	6615.	624.	0.3052	0.37630	3158.	1638.	0.31	38.6
5710293.	35000.	15.54	665.	721.	777.	0.00	863.	950.2113.3480.	1859.	6819.	664.	0.3073	0.37633	3108	1659.	0.32	39.3
5810560.	35909.	15.54	665.	721.	777.	0.00	865.	952.2114.3481.	1876.	6949.	603.	0.3090	0.37636	3076.	1683.	0.33	40.1
5910800.	36726.	15.54	665.	723.	777.	0.00	867.	956.2117.3483	1877.	7251.	720.	0.3118	0.37639	3013.	1712.	0.34	40.8
6011040.	37543.	15.54	665.	721.	778.	0.00	868.	959.2119.3485.	1881.	7456.	746.	0.3140	0.37642	2969	1737.	0.34	41.6
6111280.	38360.	15.54	666.	722.	778.	0.00	870.	962.2121.3487.	1889	7659.	770.	0.3162	0.37645	2927.	1757.	0.35	42.3
6211520.	39177.	15.54	665.	722.	778.	0.00	871.	964.2122.3488.	1891.	7834.	765.	0.3181	0.37648	2891.	1780.	0.36	43.1
6311760.	39994.	15.54	666.	722.	778.	0.00	873.	967.2124.3489.	1897.	8034.	784.	0.3203	0.37651	2854.	1803.	0.37	43.8
6412000.	40811.	15.54	667.	723.	779.	0.00	874.	970.2126.3491.	1903.	8257.	824.	0.3226	0.37654	2815.	1828.	0.38	44.6
6512240.	41628.	15.54	667.	723.	779.	0.00	876.	973.2128.3493.	1899.	8429.	871.	0.3243	0.37656	2775.	1853.	0.38	45.4
6612480.	42445.	15.54	667.	723.	779.	0.00	877.	976.2131.3495.	1896.	8610.	931.	0.3261	0.37659	2735.	1879.	0.39	46.1
6712720.	43262.	15.54	667.	723.	779.	0.00	879.	979.2133.3497.	1896.	8807.	1001.	0.3280	0.37662	2698.	1905.	0.40	46.9
6812960.	44079.	15.54	668.	724.	780.	0.00	881.	982.2136.3499.	1899.	9017.	1082.	0.3300	0.37654	2662.	1933.	0.41	47.7
6913200.	44896.	15.54	668.	724.	780.	0.00	882.	985.2138.3501.	1903.	9260.	1192.	0.3322	0.37667	2625.	1960.	0.42	48.5
7013440.	45712.	15.54	668.	724.	780.	0.00	884.	988.2141.3503.	1908.	9484.	1265.	0.3343	0.37669	2593.	1988.	0.42	49.3
7113680.	46529.	15.54	668.	724.	780.	0.00	885.	990.2143.3506.	1915.	9714.	1382.	0.3365	0.37672	2561.	2013.	0.43	50.1
7213920.	47346.	15.54	669.	725.	781.	0.00	887.	993.2146.3509.	1921.	9959.	1527.	0.3396	0.37675	2531.	2043.	0.44	50.9
7314160.	48163.	15.54	669.	725.	781.	0.00	889.	996.2150.3514.	1936.	10282.	1791.	0.3411	0.37677	2497.	2073.	0.45	51.7
7414400.	48980.	15.54	669.	725.	781.	0.00	890.	999.2154.3518.	1945.	10548.	2000.	0.3432	0.37680	2470.	2102.	0.46	52.5
7514640.	49797.	15.54	670.	726.	782.	0.00	892.1002.2158.3523.		1943.	10753.	2226.	0.3446	0.37682	2439.	2137.	0.47	53.3
7614880.	50614.	15.54	670.	726.	782.	0.00	894.1006.2163.3528.		1925.	10881.	2486.	0.3450	0.37684	2403.	2162.	0.48	54.1
7715120.	51431.	15.54	670.	726.	782.	0.00	896.1009.2168.3534		1912.	11053.	2775.	0.3458	0.37685	2367.	2193.	0.48	55.0
7815360.	52248.	15.54	671.	726.	782.	0.00	897.1013.2173.3539.		1900.	11196.	3026.	0.3464	0.37686	2336.	2224.	0.49	55.8
7915600.	53065.	15.54	671.	727.	783.	0.00	899.1016.2178.3544.		1893.	11406.	3333.	0.3476	0.37688	2302.	2256.	0.50	56.6
8015840.	53882.	15.54	671.	727.	783.	0.00	901.1019.2182.3549.		1885.	11570.	3588.	0.3484	0.37689	2274.	2285.	0.51	57.5
8116080.	54699.	15.54	671.	727.	783.	0.00	903.1022.2186.3554.		1889.	11757.	3861.	0.3494	0.37690	2247.	2316.	0.52	58.3
8216168.	55000.	15.54	672.	727.	783.	0.00	905.1026.2191.3559.		1875.	12085.	4205.	0.3516	0.37692	2217.	2332.	0.52	58.6

1
+

```
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
x                    **** frapcon2 ****                      x
x         steady-state fuel rod analysis code                x
x     ver. 1   mod. 05   mat pro mod 11   rev 1              x
x  run date = 03-Jun-91  options 85300000 page  175          x
x  oconee 15x15 hot pin with 2.67 pf                         x
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
```

end of life strain range (percent) =   0.0027

fission gas cumulative fraction release = 0.245430

zro2 weight gain . (gm/m**2) =   19.79

Figure I-3. (continued)

Table I-5. Peak node fuel centerline temperature and gas gap pressure calculated by FRAPCON-2 for the timing analysis of PWR fuel pin failures.

Case description	Peak node fuel centerline temperature (°F)	Fission gas gap pressure (psi)
Seabrook analysis:		
Hot fuel pin case with peaking factor of 2.32		
5 GWd/MTU burnup	3311	1151
20 GWd/MTU burnup	2913	1324
35 GWd/MTU burnup	2896	1494
50 GWd/MTU burnup	2901	1736
Average hot channel fuel pin case		
5 GWd/MTU burnup	3182	1155
20 GWd/MTU burnup	2787	1315
35 GWd/MTU burnup	2734	1472
50 GWd/MTU burnup	2742	1690
Middle core region fuel pin case		
5 GWd/MTU burnup	2136	1024
20 GWd/MTU burnup	1994	1103
35 GWd/MTU burnup	1885	1226
50 GWd/MTU burnup	1800	1392
Outer core region fuel pin case		
5 GWd/MTU burnup	1980	997
20 GWd/MTU burnup	1856	1072
35 GWd/MTU burnup	1758	1189
50 GWd/MTU burnup	1675	1343
Hot fuel pin case with peaking factor of 2.2		
5 GWd/MTU burnup	3187	1152
20 GWd/MTU burnup	2790	1306
35 GWd/MTU burnup	2737	1459
50 GWd/MTU burnup	2744	1671

Table I-5. (continued)

Case description	Peak node fuel centerline temperature (°F)	Fission gas gap pressure (psi)
Hot fuel pin case with peaking factor of 2.0		
5 GWd/MTU burnup	2968	1149
20 GWd/MTU burnup	2613	1281
35 GWd/MTU burnup	2499	1428
50 GWd/MTU burnup	2519	1621
Hot fuel pin case with peaking factor of 1.8		
5 GWd/MTU burnup	2758	1147
20 GWd/MTU burnup	2457	1271
35 GWd/MTU burnup	2346	1433
50 GWd/MTU burnup	2307	1655
Oconee analysis:		
Hot fuel pin case with peaking factor of 2.63		
5 GWd/MTU burnup	3753	1011
20 GWd/MTU burnup	3464	1294
35 GWd/MTU burnup	3480	1659
45 GWd/MTU burnup	3559	2332
Average hot channel fuel pin case		
5 GWd/MTU burnup	3629	1010
20 GWd/MTU burnup	3325	1280
35 GWd/MTU burnup	3338	1543
50 GWd/MTU burnup	3375	2119
Middle core region fuel pin case		
5 GWd/MTU burnup	2134	835
20 GWd/MTU burnup	1993	885
35 GWd/MTU burnup	1894	982
50 GWd/MTU burnup	1810	1124

Table I-5. (continued)

Case description	Peak node fuel centerline temperature (°F)	Fission gas gap pressure (psi)
Hot fuel pin case with peaking factor of 2.63		
5 GWd/MTU burnup	3753	1011
20 GWd/MTU burnup	3464	1294
35 GWd/MTU burnup	3480	1659
55 GWd/MTU burnup	3559	2332
Outer core region fuel pin case		
5 GWd/MTU burnup	2203	843
20 GWd/MTU burnup	2056	895
35 GWd/MTU burnup	1955	1001
50 GWd/MTU burnup	1870	1155
Hot fuel pin case with peaking factor of 2.4		
5 GWd/MTU burnup	3131	1004
20 GWd/MTU burnup	3215	1262
35 GWd/MTU burnup	3222	1609
55 GWd/MTU burnup	3283	2242
Hot fuel pin case with peaking factor of 2.2		
5 GWd/MTU burnup	3[illegible]45	997
20 GWd/MTU burnup	2942	1242
35 GWd/MTU burnup	2972	1548
55 GWd/MTU burnup	3043	2150
Hot fuel pin case with peaking factor of 2.0		
5 GWd/MTU burnup	3135	988
20 GWd/MTU burnup	2780	1215
35 GWd/MTU burnup	2712	1515
55 GWd/MTU burnup	2795	2091

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I-5. *Final Safety Analysis Report, Seabrook Station*, Public Service Company of New Hampshire, Seabrook, New Hampshire, Amendment 56, November 1985.

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Appendix J

FRAP-T6 Input Deck Preparation and Results

Appendix J
FRAP-T6 Input Deck Preparation and Results

Code Description

FRAP-T6[J-1] is a computer code for calculating the transient performance of a single light water reactor (LWR) fuel rod during reactor transients and hypothetical accidents such as loss-of-coolant and reactivity-initiated accidents. FRAP-T6 calculates the temperature and deformation histories of LWR fuel rods as functions of time-dependent fuel rod power and coolant boundary conditions. The phenomena modeled by FRAP-T6 include heat conduction, heat transfer from cladding to coolant, elastic-plastic fuel and cladding deformation, cladding oxidation, fission gas release, and fuel rod pressure.

FRAP-T6 was developed for the U.S. Nuclear Energy Commission (NRC) to perform both best-estimate calculations and audit calculations for licensing proceedings. As such, its models and results have been extensively assessed; and the results of this assessment have been documented.[J-2,3] FRAP-T6 was chosen as the best code available to provide transient fuel pin data for the timing analysis of pressurized water reactor (PWR) fuel pin failures.

Methodology

Figure J-1 shows the role of FRAP-T6 analysis in the overall methodology for the timing analysis of PWR fuel pin failures. FRAP-T6 was used to calculate transient fuel pin performance using fuel pin initial conditions at specific burnups generated by FRAPCON-2 and case-specific thermal-hydraulic boundary conditions generated by SCDAP/RELAP5/MOD3.[a] Steady-state FRAP-T6 data were also calculated for the hot channel hot pin at burnups of 5 and 50 (or 55) GWd/MTU, the hot channel average fuel pin, a middle core region fuel pin, and components so that SCDAP and FRAP-T6 fuel temperatures and failure times could be compared.

The transient analysis consisted of calculations of fuel pin response for ten distinct loss-of-coolant accident (LOCA) scenarios. For the large-break LOCA analysis, a double-ended, offset, shear break of a cold leg was analyzed, using best-estimate models, for break sizes of 100, 90, 75, and 50% of the full design basis accident (DBA) break area with no emergency core cooling (ECC). The case with the shortest time to pin failure (100% DBA) was chosen as the base case and analyzed, using best-estimate models, under the following conditions: (a) reactor coolant system (RCS) pumps tripped at time zero

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a. One set of FRAP-T6 calculations was made for the Seabrook 100% design basis accident case using thermal-hydraulic boundary conditions generated by TRAC-PF1/MOD1.

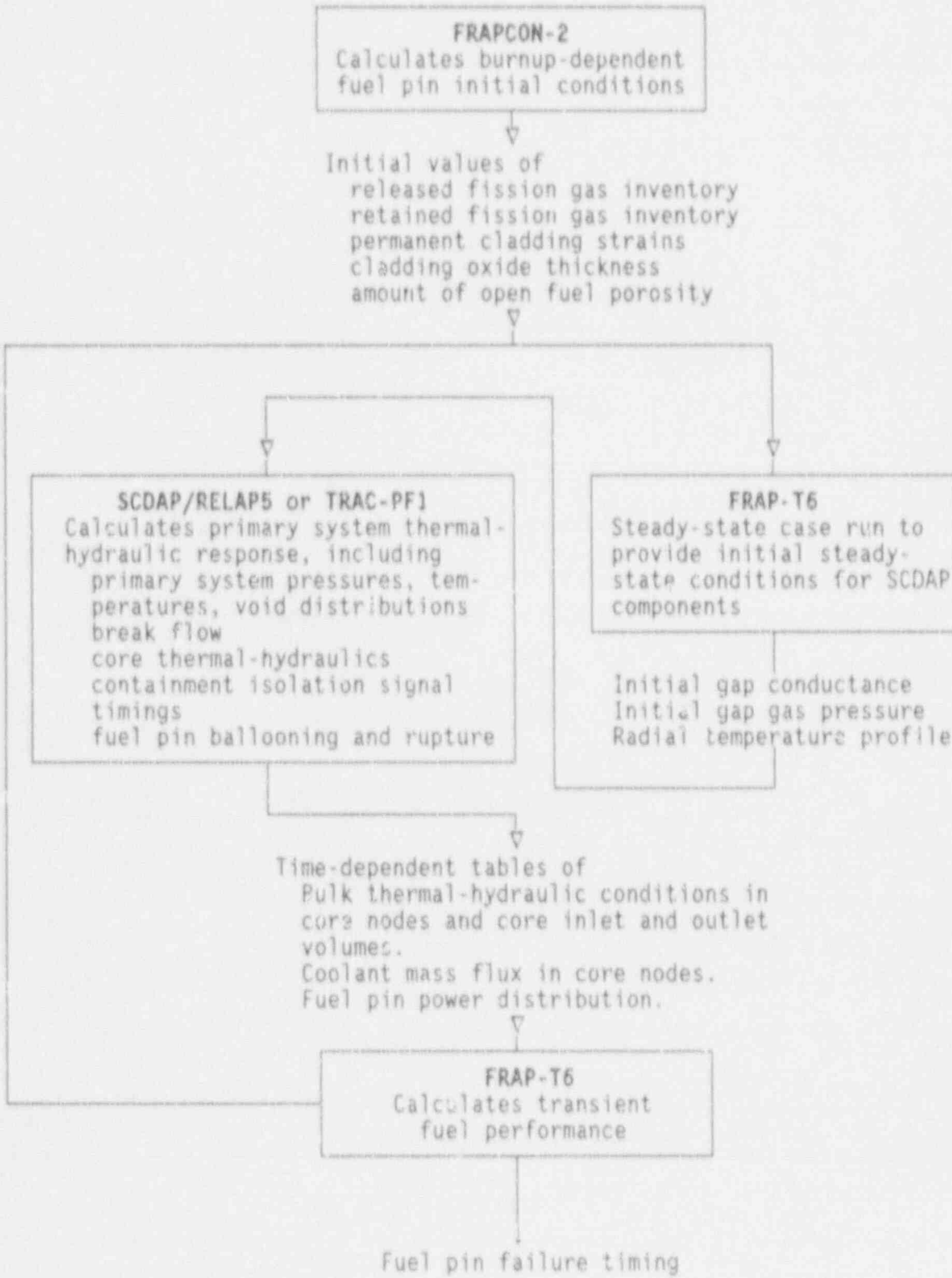

Figure J-1. Flow chart of methodology using FRAP-T6.

without ECC; (b) RCS pumps tripped at time zero with ECC; and (c) RCS pumps running with ECC. The base case was also run with the licensing audit code models turned on. For the small-break LOCA analysis, a 6-in.-dia cold leg break was analyzed both with and without ECC.

Sixteen FRAP-T6 cases were executed for each of the eight large-break an outer core region fuel pin; these data were used to initialize SCDAP fuel LOCA accident scenarios considered, using four different burnups and peaking factors. For Seabrook, the burnups were 5, 20, 35, and 50 GWd/MTU; and the peaking factors were 2.32, 2.2, 2.0, and 1.8. For Oconee, the burnups were 5, 20, 35 and 55 GWd/MTU; and the peaking factors were 2.63, 2.4, 2.2, and 2.0. Each case was run to 60 s.

The cases with the highest peaking factor for the small-break LOCA scenario without ECC were run beyond 290 s without pin failure. Based on this result, runs at lower peaking factors were not made for either small-break scenario.

Model Development

A single fuel pin design was modeled for each plant type analyzed. These fuel designs included the Mk-B9/10 design for the Oconee analysis and the W 17x17 standard fuel design for the Seabrook analysis. Specific data for these fuel rod models came from a variety of sources. Reactor-specific fuel data were obtained either from the fuel vendor or the appropriate FSAR.[J-4,J-5] The basic design parameters for each fuel type are summarized in Table J-1.

Table J-1. Summary of fuel design characteristics for fuel types modeled for FRAP-T6.

Characteristic	B&W Mk-B9/10	W 17x17 standard
Pin lattice	15x15	17x17
Fuel pins per assembly	208	264
Fuel pellet OD (in.)	0.370	0.3225
Cladding ID (in.)	0.377	0.329
Cladding OD (in.)	0.430	0.374
Plenum length (in.)	8.394	6.479
Initial fuel stack height (in.)	140.595	144.0
Initial fill gas pressure (psig)	340.0	365.0
Fuel enrichment (wt% ^{235}U)	3.5	3.1

The mechanical and fission gas release models and other code model options were chosen to best suit the analysis requirements based on descriptions and recommendations provided in code assessment documents.[J-1,2,3] Details of these model selections follow.

There are two mechanical models available in FRAP-T6: FRACAS-I and FRACAS-II. FRACAS-I uses effective fuel conductivity and relocated fuel-cladding gap size for thermal calculations, but does not make use of the relocated fuel surface in the mechanics calculations. FRACAS-II also uses effective fuel conductivity and relocated fuel cladding gap size for thermal calculations, but does use the relocated fuel surface in the mechanics calculations. For the FRAP-T6 model, the FRACAS-I mechanical model was chosen, since FRACAS-I is the only available mechanical model linked to the BALON2 subcode. BALON2 calculates the extent and shape of localized cladding deformation that occurs between the time that the cladding effective strain exceeds the instability strain and the time of cladding rupture.

FASTGRASS, a highly mechanistic gas release model that accounts for bubble formation, migration, coalescence, channeling, and eventual release, was used in the FRAP-T6 fuel models. FASTGRASS is the most suitable gas release model for high temperatures and burnups.

Other code model options in FRAP-T6 were also chosen to best suit the analysis requirements. The Baker-Just metal-water reaction model was chosen because it calculates metal-water reactions for temperatures < 1000 K. The Dougall-Rohsenow film boiling correlations was chosen because it most closely matches the film boiling correlation used in SCDAP. The default critical heat flux correlation (W-3) was used; W-3 is a combination of the Hsu-Beckner and modified Zuber correlations.

The fuel failure probability threshold in FRAP-T6 was chosen to be 0.5, as recommended in Reference J-3. A calculated probability of 0.5 reflects the conditions when 50% of the rods in an experimental data base rupture and 50% do not. When the computed probability for fuel failure is greater than 0.5, the fuel rod is assumed to be failed and the internal pressure is set equal to the coolant pressure.

In addition to analyses performed using the best-estimate models described above, one series of FRAP-T6 runs was made for each fuel type for the worst-case accident scenario (100% DBA), using licensing audit code (LAC) model options. The available LAC model options are for cladding axial and diametral thermal expansion; cladding specific heat, elastic modulus, and thermal conductivity; fuel specific heat, elastic modulus, emissivity, Poison ratio, thermal conductivity, and thermal expansion; cladding plastic hoop strain; cladding surface heat transfer coefficient; gas thermal conductivity; metal-water reaction; fuel deformation; and gap conductance.

In FRAP-T6, four fuel pins were modeled for each reactor, corresponding to the hot channel hot pin, the hot channel average pin, the middle ring average pin, and the outer ring average pin. The FRAP-T6 hot channel hot pin models were used to determine time to pin failure for the various LOCA cases considered at specified burnups and varied peaking factors. All of the FRAP-T6 fuel rod models were also used to provide initializing data for SCDAP/RELAP5/MOD3 fuel components.

The axial power profiles for FRAP-T6 were calculated for a range of axial peaking factors using the basic assumptions and methodology described in Appendices F and G. Nine axial nodes were used in FRAP-T6, as well as each of the thermal-hydraulic system codes. A chopped cosine axial power profile, peaked to the core midplane, was assumed for the analysis. For each hot fuel pin modeled, the total power integrated over the length of the fuel was based on the technical specification enthalpy rise hot channel factor.

As recommended in Reference J-1, 14 radial nodes were used in the FRAPCON-2, FRAP-T6, and SCDAP models, with eight nodes in the fuel pellet, three nodes in the gap, and three nodes in the cladding region. However, the radial nodalization is not identical among the codes, since the FRAPCON-2 nodalization was based on uniform area cross-sectional regions, while the FRAP-T6 and SCDAP nodalizations were based on uniform radii through the fuel pellet region. In each case, a normalized radial power profile based on a cross-section-weighted distribution peaked from 0.98 at the fuel pellet centerline to 1.02 at the fuel pellet edge was assumed.

For each peaking factor and burnup analyzed, FRAPCON-2 data files were used to provide initializing values for released and retained fission gas inventory, permanent cladding strains, permanent fuel strains, cladding oxide thickness, and amount of open fuel porosity. For each steady-state or LOCA case considered, data files generated by either SCDAP/RELAP5/MOD3 or TRAC-PF1-MOD1 were used to provide the thermal-hydraulic boundary conditions for FRAP-T6; i.e., coolant pressure, enthalpy, temperature, and mass flux. Case-specific FRAP-T6 power curves were derived by normalizing SCDAP/RELAP5/MOD3 or TRAC-PF1/MOD1 reactor power data.

Input Deck Preparation and Execution

Listings of the FRAP-T6 input variables used in this analysis are given in Tables J-2 through J-8. Specific data are for the Oconee reactor, 100% DBA case, with peaking factor of 2.63 and burnup of 55 GWd/MTU. A complete description of all FRAP-T6 input is given in Appendix A of Reference J-1.

Sixteen FRAP-T6 input decks were created for each large-break LOCA scenario and four were created for each small-break LOCA, making a total of 136 input decks for each reactor type analyzed. Table J-9 lists the description, input file, and output files for each case. A representative input file and selected output are shown in Figures J-2 and J-3. The input decks were executed using FRAP-T6 V 21 (12/90), a version converted to portable FORTRAN 77 and modified for use on a DEC 5000 workstation (see Appendix C). All input and output files have been archived on tape for permanent retention.

In preliminary calculations, the FRAP-T6 code failed before reaching the desired end time (60 seconds). This problem was eliminated by decreasing the time step and extending the range of the fuel thermal properties table.

Table J-2. FRAP-T6 initial variables.

Option	Suboption	Field variable	Description
		NCARDS=1	Calculation type flag. For new calculations, NCARDS = 1.
		IUNCRT=0	Uncertainty analysis flag. No uncertainty analysis was performed.
		TSTART=0.0	Start time of calculations.
		TEND=60.0	End time of calculations. TEND = 60.0 seconds for all analyses except small-break LOCA without ECC.
		IRCOVR=1[a]	Flag for debugging. Not used for this analysis.
		PRTFRA=0[a]	FRACAS-II data printout flag. Not used for this analysis.
TITLE			Identifier or title card.

a. These field variables are not discussed in Reference J-1.

Table J-3. FRAP-T6 input/output data block.

Option	Suboption	Field variable	Description
INPUT			Option specifying the units and whether or not a FRAPCON-2 data file is to be read.
	SI UNITS		Suboption specifying SI input units. Required because RELAP5/MOD3 input data are in SI units.
	FRAPCON INPUT		Suboption calling for FRAPCON-2 data input file.
		TREST= 5.8206e+7	Field variable providing time of FRAPCON-2 initialization. A time value is printed at the end of each FRAPCON-2 time step. TREST is the time value for the time step when the desired burnup level is reached.
OUTPUT			Option specifying type and extent of output.
	SI UNITS		Suboption specifying SI output units.
	PRINT INTERVAL		Suboption specifying time interval between printouts.
		DTPOA(n)=.1	Field variable defining the time interval between printouts at problem time DTPOA(n+1). This was arbitrarily chosen to be 0.1.
	POWER RAMP		Suboption specifying a printout of the fuel rod state at each step of the first power ramp.
	PLOT FILE OUTPUT		Suboption specifying generation of a plot file.
		DTPLT=.1	Field variable specifying the time interval between plot file points. This was arbitrarily chosen to be 0.1.

Table J-4. FRAP-T6 design of fuel rod data block.

Option	Suboption	Field variable	Description
FUEL ROD			Option specifying overall fuel rod data.
		RL=3.57	Height of active fuel (m).
		PROD= 1.0922e-2	Fuel rod outer diameter (m).
		TMCOLD=294.4	Fuel rod cold state temperature (K).
PELLET			Option specifying fuel rod pellet data.
		RSHD= 3.594e-3	Cold state radius of pellet shoulder (m).
		DISHD= 2.54e-4	Cold state depth of pellet dish (m).
		PELH= 1.16e-2	Cold state pellet height (m).
		DISHVO= 1.0325e-8	Cold state pellet dish volume (m^3).
		PELOD= 9.3980e-3	As-fabricated pellet diameter (m).
		ROUGHF=1.78	Arithmetic mean pellet roughness (μm).
		FDEN=.950	Pellet fraction of theoretical density.
		BUP= 3.0969e+6	Average fuel burnup (MWs/kg) = 86.4 x burnup (MWd/MTU) for the average power cases. For the peak-power cases, this value was divided by the peaking factor to get average burnup values.
		FRPO2=0.0	Fraction of fuel weight that is PuO_2.

Table J-4. (continued)

Option	Suboption	Field variable	Description
		FOTMTL=2.	Ratio of fuel oxygen atoms to uranium and plutonium atoms. Default value used.
		TSNTRK=1873.	Fuel sintering temperature (K).
		FGRAIN-5.[a]	Fuel grain size (μm).
CLADDING			Option specifying cladding data.
		GAP=8.890e-5	Radial distance between the outer surface of the fuel pellet and the inner surface of the cladding (m).
		COLDW=.1	Reduction of cross-sectional area due to the cold-working process. Default value used.
		ROUGHC=0.762	Arithmetic mean roughness of the cladding inner surface (μm).
		CFLUXA= 2.7e+13	Average fast neutron flux (W-s/kgU).
		TFLUX= 5.821e+7	Time span of cladding exposure to fast neutron flux (s). This value is the same as TREST.
		CLDWDC=0.04[a]	Cold work factor for ductility.
UPPER PLENUM			Option specifying the upper plenum data.
		NCS=54	Number of coils in the plenum spring.
		SPL=0.224	Uncompressed height of the plenum spring (m).
		SCD=0.914e-2	Uncompressed spring coil outer diameter (m).
		SWD=1.57e-3	Spring wire diameter (m).

Table J-4. (continued)

Option	Suboption	Field variable	Description
		VPLEN= 1.5355e-5	Plenum volume, including volume of the spring (m^3).
LOWER PLENUM			Option specifying the lower plenum data. Used for Oconee, since upper and lower plenums are not the same.
		NCOLPB=12	Number of coils in the plenum spring.
		SPLBP=0.053	Uncompressed height of the plenum spring (m).
		COLDSP= 0.914e-2	Uncompressed spring coil outer diameter (m).
		SWDSP= 1.91e-3	Spring wire diameter (m).
		VOLBP= 3.5122e-6	Plenum volume, including volume of the spring (m^3).
GAS COMPOSITION			Option specifying the amount and mixture of gases in the fuel rods; mole fractions must sum to 1.0. Default values were used.
		GFRAC(1)=1.0	Fraction of helium.
		GFRAC(2)=0.0	Fraction of argon.
		GFRAC(3)=0.0	Fraction of krypton.
		GFRAC(4)=0.0	Fraction of xenon.
		GFRAC(5)=0.0	Fraction of hydrogen.
		GFRAC(6)=0.0	Fraction of air.
		GFRAC(7)=0.0	Fraction of water vapor.
		GSMS	Amount of gas in rod; left blank when TGASO > 0.0.

Table J-4. (continued)

Option	Suboption	Field variable	Description
		GAPPRO= 2.34e+6	As-fabricated fill gas pressure (Pa).
		TGASO=294.4	As-fabricated fill gas temperature (K).

a. These field variables are not discussed in Reference J-1.

Table J-5. FRAP-T6 solution control data block.

Option	Suboption	Field variable	Description
PROPERTY TABLES			Option specifying the temperature range and number of temperature entries in the thermal property tables.
	FUEL		Suboption specifying the range and number of entries in the fuel thermal property tables.
		NKF=100	Number of temperature entries; recommended value = 100.
		TOF=270.	Minimum temperature in table defined as 270 K.
		TMAXK=2600.	Maximum temperature in table initially defined as 2500 K. This value was raised for some runs to avoid code failure.
	CLADDING		Suboption specifying the range and number of entries in the cladding thermal property tables.
		NKC=50	Number of temperature entries; recommended value = 50.
		TOC=270.	Minimum temperature in tables defined as 270 K.
		TMAXC=2200.	Maximum temperature in table defined as 2200 K.
TIME CONTROL			Option specifying the time step and the time span for modeling steady-state heat conduction.
	.ME STEP		Suboption specifying time step size.
		DTMAXA(n) =0.025	The time step size at time DTMAXA(n+1). If the time step size is constant, DTMAXA(1) is the constant value. A time step of 0.025 was chosen to avoid early code failure.

Table J-5. (continued)

Option	Suboption	Field variable	Description
CONVERGENCE CRITERIA			Option specifying the type of solution and convergence criteria.
	IMPLICIT		Suboption specifying an implicit solution.
		PRSAAC=.001	Maximum fractional change in internal fuel rod pressure between two successive iterations for convergence; Reference J-1.
		TMPACC=.001	Maximum fractional change in temperature at any radial node between two successive iterations for convergence; Reference J-1.
	TEMPERATURE CALCULATION		Suboption specifying accuracy of the temperature solution by controlling the iterations on fuel thermal properties.
		MAXIT=100	Maximum number of iterations in the steady-state temperature solution; Reference J-1.
		NOITER=100	Maximum number of iterations in the transient temperature solution; Reference J-1.
		EPS=1.0	Maximum temperature change between iterations on thermal properties before convergence is declared; Reference J-1.
NODALIZATION			Option specifying the number of axial and radial nodes.
	AXIAL NODES		Suboption specifying the number and position of axial nodes. Since the axial node position is constant, only NAXN is required.
		NAXN=9	Number of evenly spaced axial nodes.

Table J-5. (continued)

Option	Suboption	Field variable	Description
FUEL RADIAL NODES			Suboption specifying the number and position of the radial nodes in the fuel. Since the radial node position is constant, only NFMESH is required.
		NFMESH=11	Number of evenly spaced radial nodes.
	CLAD RADIAL NODES		Suboption specifying the number and position of the radial nodes in the cladding. Since the radial node position is constant, only NCMESH is required.
		NCMESH=3	Number of evenly spaced radial nodes = 3.

Table J-6. FRAP-T6 model selection data block.

Option	Suboption	Field variable	Description
FAILURE			Option specifying the fuel rod failure probability threshold.
	GENERAL		Suboption specifying the fuel rod failure probability threshold.
		PFAIL=0.5	Field variable defining the fuel rod failure threshold. If the computed fuel rod failure probability is >PFAIL, the fuel rod is assumed to be failed and the internal pressure is set equal to the coolant pressure. Recommended in Reference J-3.
INTERNAL GAS PRESSURE			Option specifying any suboption related to internal gas pressure.
	PLENUM TEMP		Suboption to calculate the temperature of the gas in the fuel rod plenum with a heat balance model. Recommended in Reference J-1.
	GRASS		Suboption specifying the modeling of fission gas production and release with the FASTGRASS subcode. This model was chosen because of the high fuel temperatures and burnups being analyzed.
METAL-WATER REACTION			Option specifying the metal-water reaction model (cladding oxidation).
	BAKER-JUST		Suboption specifying the modeling of metal-water reaction with the Baker-Just model. This model was chosen because it calculates metal-water reactions for temperatures <1000 K.
LAC[a]			Option specifying that the licensing audit code models be used.

Table J-6. (continued)

Option	Suboption	Field Variable	Description
	ALL[a]		Suboption specifying all of the licensing audit code models available (see Table A-18, Reference J-1). This is the only LAC suboption available in the code version used for the analysis.

a. This option and suboption were turned on only for the 100% DBA cases without pump trip and ECC.

Table J-7. FRAP-T6 power specification data block.

Option	Field variable	Description
POWER HISTORY		Suboption specifying the fuel rod power history.
	PTHA(n)=33.23, 0.00, 31.56,0.10,21.00,0.20 12.22,0.30,5.49,0.50, 3.88,1.00,3.66,1.50, 3.48,2.00,3.07,3.00, 2.82,4.00,2.65,5.00, 2.20,10.00,1.98,15.00 1.65,30.00,1.45,50.00	Defines the average linear power at time PTHA(n+1). One set of values are input for each power/time point of interest. For steady-state cases, the average linear power was input. For transient cases, the normalized SCDAP/RELAP5/MOD3 power curve was input.
AXIAL POWER PROFILE		Option specifying the fuel rod axial power profile.
	PAXP(n)=0.3132,0.1984 0.7951,0.4336, 1.1854,0.9919, 1.4391,1.3887, 1.5345,1.7855, 1.4391,2.1823, 1.1854,2.5791, 0.7951,2.9759, 0.3132,3.3727	Defines the axial power profile at elevation PAXP(n+1). One set of values is input at the midpoint of each axial node. See Appendices F and G for calculation method.
RADIAL POWER PROFILE		Option specifying the fuel rod radial power profile.
	PRAD(n)=0.9800,0.00 0.9808,4.7202e-4, 0.9816,9.3980e-4, 0.9836,1.4100e-3, 0.9864,1.8800e-3, 0.9900,2.3490e-3, 0.9944,2.8194e-3, 0.9996,3.2893e-3, 1.0056,3.3759e-3, 1.0124,4.2991e-2, 1.0200,4.69950e-3	Defines the radial power profile (normalized) at radius PRAD(n+1). One set of values is input for each radial node, beginning at 0.0 and ending at the fuel pellet radius.

Table J-8. FRAP-T6 boundary condition data block.

Option	Suboption	Field variable	Description
COOLANT CONDITION			Option specifying the coolant pressure, mass flux, and enthalpy.
	GEOMETRY		Suboption specifying the geometry of the coolant channel surrounding the fuel rod.
		DHE=1.380e-2	Equivalent heated diameter of the flow channel (4 x flow area/heated perimeter) (m).
		DHY=1.335e-2	Hydraulic diameter of the flow channel (4 x flow area/wetted perimeter) (m).
		ACHN= 1.145e-4	Flow cross-sectional area (m^2).
	TAPE INPUT		Suboption specifying that the coolant conditions are to be input on tape. Coolant conditions were input by SCDAP/RELAP5/MOD3 or TRAC-PF1/MOD1 data file.
		NVOL=9	Number of coolant volumes surrounding the fuel rod.
	CHF CORRELATION		Suboption specifying the CHF correlation to be used.
		JCHF=W-3	Defines the CHF model chosen. Recommended in Reference J-1.
	FILM BOILING CORRELATION		Suboption specifying the film boiling heat transfer correlation to be used.
		JFB=dougall-rohsenow	Defines the film boiling model chosen. The Dougall-Rohsenow model was chosen, because it best matches the film boiling correlation used in SCDAP/RELAP5/MOD3.

Table J-9. FRAP-T6 input and output files for the timing analysis of PWR fuel pin failures.

Case	FRAPCON-2/ SCDAP/RELAP5 data files	FRAP-T6 input files	FRAP-T6 output files
For Seabrook:			
Steady-state:			
Hot pin, 5 GWd/MTU	frap-t.pkl	seapf23.i50s	seapf23.o50s
Hot pin, 50 GWd/MTU	frap-t.ahcl	seapf23.i5s	seapf23.o5s
Avg. pin, hot chan.	frap-t.midl	seaahc.i20s	seaahc.o20s
Avg. pin, mid. ring	frap-t.otrl	seamid.i20s	seamid.o20s
Avg. pin, outer ring	frapr5ss.dat	seaotr.i20s	seaotr.o20s
100% dba hot pin	frap-t.pkl	seapfN.i5b[b]	seapfN.o5b[b]
pf=2.32; 2.2; 2.0;	frap-t.pf22	seapfN.i20b	seapfN.o20b
1.8	frap-t.pf20	seapfN.i35b	seapfN.o35b
	frap-t.pf18	seapfN.i50b	seapfN.o50b
	sea100dba.thdat		
90% dba hot pin	frap-t.pkl	seapfN.i5d[b]	seapfN.o5d[b]
pf=2.32; 2.2; 2.0;	frap-t.pf22	seapfN.i20d	seapfN.o20d
1.8	frap-t.pf20	seapfN.i35d	seapfN.o35d
	frap-t.pf18	seapfN.i50d	seapfN.o50d
	sea90dba.thdat		
75% dba hot pin	frap-t.pkl	seapfN.i5a[b]	seapfN.o5a[b]
pf=2.32; 2.2; 2.0;	frap-t.pf22	seapfN.i20a	seapfN.o20a
1.8	frap-t.pf20	seapfN.i35a	seapfN.o35a
	frap-t.pf18	seapfN.i50a	seapfN.o50a
	sea75dba.thdat		
50% dba hot pin	frap-t.pkl	seapfN.i5c[b]	seapfN.o5c[b]
pf=2.32; 2.2; 2.0;	frap-t.pf22	seapfN.i20c	seapfN.o20c
1.8	frap-t.pf20	seapfN.i35c	seapfN.o35c
	frap-t.pf18	seapfN.i50c	seapfN.o50c
	sea50dba.thdat		
100% dba hot pin	frap-t.pkl	seapfN.i5bp[b]	seapfN.o5bp[b]
pump tripped at t=0	frap-t.pf22	seapfN.i20bp	seapfN.o20bp
pf=2.32; 2.2; 2.0;	frap-t.pf20	seapfN.i35bp	seapfN.o35bp
1.8	frap-t.pf18	seapfN.i50bp	seapfN.o50bp
	seapt100dba.thdat		
100% dba hot pin	frap-t.pkl	seapfN.i5be[b]	seapfN.o5be[b]
eccs turned on	frap-t.pf22	seapfN.i20be	seapfN.o20be
pf=2.32; 2.2; 2.0;	frap-t.pf20	seapfN.i35be	seapfN.o35be
1.8	frap-t.pf18	seapfN.i50be	seapfN.o50be
	seapt100edba.thdat		

Table J-9. (continued)

Case	FRAPCON-2/ SCDAP/RELAP5 data files	FRAP-T6 input files	FRAP-T6 output files
For Seabrook (continued):			
100% dba hot pin pump tripped at t=0 and eccs turned on pf=2.32; 2.2; 2.0; 1.8	frap-t.pkl frap-t.pf22 frap-t.pf20 frap-t.pf18 sea100ptedba.thdat	seapfN.i5bb[b] seapfN.i20bb seapfN.i35bb seapfN.i50bb	seapfN.o5bb[b] seapfN.o20bb seapfN.o35bb seapfN.o50bb
100% dba hot pin licensing audit code models turned on pf=2.32; 2.2; 2.0; 1.8	frap-t.pkl frap-t.pf22 frap-t.pf20 frap-t.pf18 sea100dba.thdat	seapfN.i5bm[b] seapfN.i20bm seapfN.i35bm seapfN.i50bm	seapfN.o5bm[b] seapfN.o20bm seapfN.o35bm seapfN.o50bm
6-in. break hot pin pf=2.3	frap-t.pkl sea6in.thdat	seapf23.i5e seapf23.i20e seapf23.i35e seapf23.i50e	seapf23.o5e seapf23.o20e seapf23.o35e seapf23.o50e
6-in. break hot pin with ECC turned on pf=2.3	frap-t.pkl sea6ine.thdat	seapf23.i5ee seapf23.i20ee seapf23.i35ee seapf23.i50ee	seapf23.o5ee seapf23.o20ee seapf23.o35ee seapf23.o50ee
100% dba hot pin TRAC-PF1/MOD1 T/H data pf=2.32; 2.2; 2.0; 1.8	frap-t.pkl frap-t.pf22 frap-t.pf20 frap-t.pf18 frap.dat	seapfN.i5bt[b] seapfN.i20bt seapfN.i35bt seapfN.i50bt	seapfN.o5bt[b] seapfN.o20bt seapfN.o35bt seapfN.o50bt
For Oconee:			
Steady-state:			
Hot pin, 5 GWd/MTU Hot pin, 55 GWd/MTU Avg. pin, hot chan. Avg. pin, mid. ring Avg. pin, outer ring	ocopf263.dat ocoahc.dat ocomid.dat ocootr.dat oconullhot.thdat oconullcen.thdat oconullout.thdat	ocopf263.i55s ocopf263.i5s ocoahc.i20s ocomid.i20s ocootr.i20s	ocopf263.o55s ocopf263.o5s ocoahc.o20s ocomid.o20s ocootr.o20s

Table J-9. (continued)

Case	FRAPCON-2/ SCDAP/RELAP5 data files	FRAP-T6 input files	FRAP-T6 output files
For Oconee (continued):			
100% dba hot pin pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat oco100dba.thdat	ocopfN.i5b[b] ocopfN.i20b ocopfN.i35b ocopfN.i55b	ocopfN.o5b[b] ocopfN.o20b ocopfN.o35b ocopfN.o55b
90% dba hot pin pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat oco90dba.thdat	ocopfN.i5d[b] ocopfN.i20d ocopfN.i35d ocopfN.i55d	ocopfN.o5d[b] ocopfN.o20d ocopfN.o35d ocopfN.o55d
75% dba hot pin pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat oco75dba.thdat	ocopfN.i5a[b] ocopfN.i20a ocopfN.i35a ocopfN.i55a	ocopfN.o5a[b] ocopfN.o20a ocopfN.o35a ocopfN.o55a
55% dba hot pin pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat oco55dba.thdat	ocopfN.i5c[b] ocopfN.i20c ocopfN.i35c ocopfN.i55c	ocopfN.o5c[b] ocopfN.o20c ocopfN.o35c ocopfN.o55c
100% dba hot pin pump tripped at t=0 pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat ocopt100dba.thdat	ocopfN.i5bp[b] ocopfN.i20bp ocopfN.i35bp ocopfN.i55bp	ocopfN.o5bp[b] ocopfN.o20bp ocopfN.o35bp ocopfN.o55bp
100% dba hot pin eccs turned on pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat ocoe100dba.thdat	ocopfN.i5be[b] ocopfN.i20be ocopfN.i35be ocopfN.i55be	ocopfN.o5be[b] ocopfN.o20be ocopfN.o35be ocopfN.o55be
100% dba hot pin pump tripped at t=0 and eccs turned on pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat ocoept100dba.thdat	ocopfN.i5bb[b] ocopfN.i20bb ocopfN.i35bb ocopfN.i55bb	ocopfN.o5bb[b] ocopfN.o20bb ocopfN.o35bb ocopfN.o55bb

Table J-9. (continued)

Case	FRAPCON-2/ SCDAP/RELAP5 data files	FRAP-T6 input files	FRAP-T6 output files
For Oconee (continued):			
100% dba hot pin licensing audit code models turned on pf=2.63; 2.4; 2.2; 2.0	ocopf263.dat ocopf24.dat ocopf22.dat ocopf20.dat oco100dba.thdat	ocopfN.i5bm[b] ocopfN.i20bm ocopfN.i35bm ocopfN.i55bm	ocopfN.o5bm[b] ocopfN.o20bm ocopfN.o35bm ocopfN.o55bm
6-in. break hot pin pf=2.63	ocopf263.dat ocosb.thdat	ocopf23.i5e ocopf23.i20e ocopf23.i35e ocopf23.i55e	ocopf23.o5e ocopf23.o20e ocopf23.o35e ocopf23.o55e
6-in. break hot pin with ECC turned on pf=2.63	ocopf263.dat ocoesb.thdat	ocopf23.i5ee ocopf23.i20ee ocopf23.i35ee ocopf23.i55ee	ocopf23.o5ee ocopf23.o20ee ocopf23.o35ee ocopf23.o55ee

a. Graphics output files were also generated, using .g instead of .o as a designator.

b. N = peaking factor designator = 2.32, 2.2, 2.0, and 1.8 for Seabrook; 2.63, 2.4, 2.2, and 2.0 for Oconee.

```
**************************************************************************
* FRAP-T6 input deck for analysis of fuel rods in Oconee reactor        *
*-----------------------------------------------------------------------*
*                                                                        *
*  CASE DESCRIPTION: OCONEE 15X15 TEST CASE                              *
*                                                                        *
*  UNIT    FILE DESCRIPTION                                              *
*  ----    ---------------------------------------------                 *
*   --     Input:                                                        *
*   15       Water properties data                                       *
*                                                                        *
*   --     Output:                                                       *
*    6       STANDARD PRINTER OUTPUT                                     *
*   66       STRIPF FILE FOR GRAFITI                                     *
*                                                                        *
*   --     Scratch:                                                      *
*    5       SCRATCH INPUT FILE FROM ECHO1                               *
*                                                                        *
* Input: FRAP-T6 INPUT FILE (UNIT 55)                                   *
*                                                                        *
**************************************************************************
* NPA FLAGS
*NPAON
NPADBG
NPANOSYNC
NPAPAX='frapt6'
NPADUH='frapt6.dub'
NPASERV='unix:0.0'
*
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
FILE15='/kkju0/kkj/bin/sth2xt',  STATUS='old',
         FORM='UNFORMATTED'
FILE04='/kkjul/mln/loca/100dba/oco100dba.thdat', STATUS='old',
        FORM='UNFORMATTED'
FILE31='/kkju2/nad/frapcon2/oconee/ocopf263.dat',  STATUS='old',
        FORM='UNFORMATTED'
*
* GOESOUTS:
FILE06='ocopf263.c55b',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ocopf263.g55b',   STATUS='unknown', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*************************************************************************
    1    0    0.0          60.    1    0
 Oconee hot pin, 100%DBA, cold leg break, 55 GWD/TU, 2.63 pf
/iodata block
input
                             si units
                          frapcon link          5.8206e+7
output
                          si units
                          print interval                .1
                          power ramp
                          plots                         .1
end block
/design of fuel rod data block
fuel rod data                 3.57 1.0922e-2    294.4
pellet data             3.594e-3   2.54e-4   1.16e-2 1.0325e-8 9.3980e-5       1.78
                        .950     3.0969e+6    0.0        2.        1873.          5.
cladding data           8.890e-5        .1     0.762   2.7e+13  5.821e+7   0.04
upper plenum data             54     0.224  0.914e-2   1.57e-3 1.5355e-5
lower plenum data             12     0.053  0.914e-2   1.91e-3 3.5122e-6
gas composition          1.000        0.00      0.00      0.00      0.00       0.00
                         0.0                 2.34e+6     294.4
end block
```

Figure J-2. FRAP-T6 input deck for Oconee hot channel hot pin, 2.63 peaking factor, 55 GWD/MTU burnup.

```
/solution control data block
property tables
                     fuel conductivity          100       270.      2600.
                     cladding conductivit        50       270.      2200.
end
time control
                     time step                0.025
convergence control
                     implicit                  .001      .001
                     temperature computat       100       100        1.0
end
nodalization
                     axial nodalization           9
                     fuel radial nodaliza        11
                     cladding radial noda         3
end
end block
/model selection data block
failure model
                       general              0.5
end
internal gas pressure
                     plenum temp.
                     grass
end
metal water reaction
                     baker-just
end block
/power specification data block
power history input      33.23       0.00      31.56       0.10      21.00       0.20
                         12.22       0.30       5.49       0.50       3.98       1.00
                          3.66       1.50       3.48       2.00       3.07       3.00
                          2.82       4.00       2.65       5.00       2.20      10.00
                          1.98      15.00       1.65      30.00       1.45      50.00
axial power profile     0.3132     0.1984     0.7951     0.4336     1.1854     0.9919
                        1.4391     1.3887     1.5345     1.7855     1.4391     2.1823
                        1.1854     2.5791     0.7951     2.9759     0.3132     3.3727
radial power profile    0.9800       0.00     0.9808  4.7020e-4     0.9816  9.3980e-4
                        0.9836  1.4100e-3     0.9864  1.8800e-3     0.9900  2.3490e-3
                        0.9944  2.8194e-3     0.9996  3.2893e-3     1.0056  3.3759e-3
                        1.0124  4.2991e-3     1.0200  4.6990e-3
end block
/boundary condition data block
coolant condition
                       geometry             1.380e-2  1.335e-2  1.145e-4
                       tape input                  9
                       chf correlation        w-3
                       film boiling corr.     dougall-rohsenow
end block
/end
```

Figure J-2. (continued)

*** coolant conditions at time = 0.131000E+02 sec ***

	lower plenum enthalpy (j/kg)	upper plenum enthalpy (j/kg)
	2.407E+06	2.140E+06

0channel no.	elev (m)	enthalpy (j/kg)	pressure (n/m**2)	mass flux (kg/sec.m**2)	temperature (k)	sp.volume (m**3/kg)	quality
1	0.198	2.072E+06	4.354E+06	-7.276E+01	528.6	2.650E-02	0.5594
1	0.595	1.740E+06	4.354E+06	-8.068E+01	528.6	1.775E-02	0.3721
1	0.992	1.714E+06	4.354E+06	-7.926E+01	528.6	1.707E-02	0.3567
1	1.388	1.698E+06	4.354E+06	-7.962E+01	528.6	1.666E-02	0.3475
1	1.785	1.682E+06	4.354E+06	-8.429E+01	528.6	1.628E-02	0.3380
1	2.182	1.685E+06	4.354E+06	-8.482E+01	528.6	1.632E-02	0.3397
1	2.578	1.729E+06	4.354E+06	-8.027E+01	528.6	1.747E-02	0.3656
1	2.975	1.803E+06	4.354E+06	-6.467E+01	528.6	1.942E-02	0.4097
1	3.372	1.937E+06	4.354E+06	-5.231E+01	528.6	2.293E-02	0.4889

1frap-t6 v 21(12/90) fuel rod analysis program eg&g idaho inel

Oconee hot pin, 100%DBA, cold leg break, 55 GWd/TU, 2.63 pf

fuel rod # 1 conditions at time =0.131000E+02 sec (0.363889E-02 hours)

time step=0.250000E-01 sec number of temperature-deformation-pressure loop iterations = 2

number of deformation-pressure loop iterations = 1 accumulated cpu time = 12921.41 sec

0average fuel rod power (kw/m)	2.064E+00
volume averaged fuel temperature (k)	1069.0
energy generated by metal-water reaction(kw)	1.9889E-03
fuel stack axial extension (mm)	2.904E+01
cladding axial extension (mm)	1.037E+01
plenum gas temperature (k)	582.4
bottom plenum gas temperature (k)	570.3
plenum gas pressure (n/m**2)	0.4334E+07
gas flow rate from plenum (gm-moles/sec)	0.0000E+00
fraction of molten fuel in fuel rod	0.0000
fraction of fuel rods failed	0.1000E+01

*** probability for various modes of failure ***

failure mode	probability
cladding melting	0.000000
cladding eutectic melting	0.000000
cladding oxidation	0.000000
cladding ballooning	0.000000
cladding collapse	0.000000
cladding overstress	0.407182
stress corrsion cracking	0.000000
cladding fatigue	0.000000

total free gas volume(mm) **3	0.403943E+05
plenum volume fraction	0.284557
crack volume fraction	0.001843
gap volume fraction	0.561136
open porosity volume fraction	0.000926
dish volume fraction	0.077836
bottom plenum fraction	0.066912
central void volume fraction	0.000000
fuel surface roughness volume fraction	0.004694
cladding surface roughness volume fraction	0.002097

0*** cladding ballooning has occurred. ***

maximum circumferential strain (%)	6.31
elevation of ballooning (m)	1.388

Figure J-3. Selected FRAP-T6 output for Oconee hot channel hot pin, 2.63 peaking factor, 55 GWd/MTU burnup.

```
0
0**** failure predicted  1.388  (m) from bottom of rod ****
1frap-t6  v 21(12/90)     fuel rod analysis program eg&g idaho inel
   Oconee hot pin, 100%DBA, cold leg break, 55 GWD/TU, 2.63 pf

 time(sec)=0.131000E+02
 axial node number                                  1             2             3             4             5             6
 elevation (m)                                   0.198         0.595         0.992         1.388         1.785         2.182
 local fuel rod power (kw/m)                     6.460E-01     1.874E+00     2.446E+00     2.969E+00     3.166E+00     2.970E+00
 radially ave. fuel enthalpy      (jou/kg)       0.1152E+06    0.2456E+06    0.2778E+06    0.2875E+06    0.2796E+06    0.2548E+06
 energy in fuel per unit length(kw-s)            0.8318E+02    0.1774E+03    0.2006E+03    0.2076E+03    0.2019E+03    0.1840E+03
 energy in cladding per unit length(kw-s)        0.1508E+02    0.3224E+02    0.3461E+02    0.3598E+02    0.3583E+02    0.3442E+02
 energy input after steady-state(kw-s/m)         0.1346E+02    0.3905E+02    0.5098E+02    0.6189E+02    0.6599E+02    0.6189E+02
 energy output after steadystate(kw-s/m)         0.6667E+02    0.9132E+02    0.1110E+03    0.1215E+03    0.1379E+03    0.1477E+03
 coolant bulk temperature(k)                     528.6         528.6         528.6         528.6         528.6         528.6
 coolant quality                                 0.569E+00     0.372E+00     0.357E+00     0.347E+00     0.338E+00     0.340E+00
 coolant mass flux,kg/sec-m2                    -7.275E+01    -8.067E+01    -7.924E+01    -7.968E+01    -8.428E+01    -8.481E+01
 surface heat flux (watt/m**2)                   4.346E+04     1.417E+05     1.497E+05     1.557E+05     1.584E+05     1.512E+05
 critical heat flux (watt/m**2)                  3.155E-01     1.781E+04     2.885E+04     3.591E+04     4.355E+04     4.213E+04
 critical heat flux / surface heat flux          7.258E-06     1.257E-01     1.928E-01     2.309E-01     2.749E-01     2.786E-01
 surface heat transfer coef. (watt/m**2d0.k)     3.998E+02     3.152E+02     3.011E+02     2.966E+02     3.040E+02     3.067E+02
 heat transfer mode                              9             9             9             9             9             9
 gap heat transfer coef. (watt/m**2d0.k)         1.034E+03     1.144E+03     6.169E+02     6.132E+02     8.159E+02     1.425E+03
 thermal radial gas gap      (mm)                9.846E-02     1.531E-01     4.338E-01     4.651E-01     2.871E-01     1.171E-01
 structural radial gas gap    (mm)               9.846E-02     1.531E-01     4.338E-01     4.651E-01     2.871E-01     1.171E-01
 gap pressure (n/m**2)                           4.354E+06     4.354E+06     4.354E+06     4.354E+06     4.354E+06     4.354E+06
 coolant pressure(n/m**2)                        4.354E+06     4.354E+06     4.354E+06     4.354E+06     4.354E+06     4.354E+06
 displacement of fuel outer surface (mm)         1.463E-03     3.963E-02     5.566E-02     5.861E-02     5.732E-02     5.287E-02
 displacement of clad outer surface (mm)         1.259E-02     9.648E-02     3.632E-01     3.910E-01     2.316E-01     7.737E-02
 cladding hoop strain (midplane)                 2.304E-03     1.949E-02     7.423E-02     8.057E-02     4.753E-02     1.546E-02
 cladding permanent hoop strain                 -7.267E-06     1.488E-02     6.930E-02     7.546E-02     4.244E-02     1.056E-02
 cladding permanent axial strain                 0.000E+00     4.161E-05     1.743E-04     1.875E-04     1.124E-04     2.986E-05
 interface pressure, struct. gap(n/m**2)         0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00
 cladding hoop stress      (n/m**2)             -4.354E+06    -4.354E+06    -4.354E+06    -4.354E+06    -4.354E+06    -4.354E+06
 cladding axial stress     (n/m**2)             -4.354E+06    -4.354E+06    -4.354E+06    -4.354E+06    -4.354E+06    -4.354E+06
 effective cladding stress (n/m**2)              0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00
 cladding yield stress(n/m**2)                   0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00
 cladding effective plastic strain               0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00
 cladding instability strain                     0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00
 oxide thickness,clad outer surface(mm)          4.255E-03     7.231E-03     1.156E-02     1.216E-02     1.275E-02     1.297E-02
 oxygen stabilized alpha thickness(mm)           0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00     0.000E+00
 oxide depth, clad inner surface(mm)             3.000E-03     3.000E-03     3.000E-03     3.000E-03     3.000E-03     3.000E-03
 metal-water reaction energy (kw/m)              0.000E+00     0.000E+00     8.996E-04     1.527E-03     1.365E-03     7.388E-04
 flow area reduction                             0.0000        0.0006        0.0009        0.0525        0.0525        0.0009
 flow area reduction uncertainty                 0.0000        0.0000        0.0006        0.0035        0.0075        0.0006
0                        temperatures by radial mesh points
                    no.  mesh radius   temperatures
                           (mm)           (k)
                     1   0.000E+00      728.8        1168.4        1269.9        1306.0        1288.5        1209.9
                     2   4.699E-01      728.4        1167.6        1269.0        1304.9        1287.3        1208.6
                     3   9.398E-01      727.0        1165.3        1266.2        1301.5        1283.2        1204.8
                     4   1.410E+00      724.7        1161.3        1261.8        1296.1        1276.9        1198.7
                     5   1.880E+00      721.6        1155.9        1255.0        1288.9        1265.4        1190.6
                     6   2.349E+00      717.9        1149.0        1248.4        1280.1        1258.3        1180.9
                     7   2.819E+00      713.6        1140.7        1239.8        1270.1        1246.8        1169.9
                     8   3.289E+00      708.8        1130.8        1230.1        1259.2        1234.4        1157.8
                     9   3.759E+00      703.8        1119.2        1219.3        1247.3        1221.2        1144.6
                    10   4.229E+00      698.5        1105.6        1207.0        1234.5        1206.9        1130.1
                    11** 4.699E+00      693.0        1089.6        1192.0        1220.1        1191.1        1113.5
                    12   4.788E+00      639.2         982.3        1029.4        1056.7        1053.8        1025.8
                    13   5.124E+00      638.2         980.3        1027.6        1055.0        1052.0        1023.8
                    14   5.461E+00      637.3         978.1        1025.5        1052.8        1049.8        1021.6
1frap-t6  v 21(12/90)     fuel rod analysis program eg&g idaho inel
   Oconee hot pin, 100%DBA, cold leg break, 55 GWD/TU, 2.63 pf
```

Figure J-3. (continued)

time(sec)=0.131090E+02

	7	8	9
axial node number	7	8	9
elevation (m)	2.578	2.975	3.372
local fuel rod power (kw/m)	2.447E+00	1.643E+00	6.[illegible]39E-01
radially ave. fuel enthalpy (jou/kg)	0.2445E+06	0.2015E+06	0.1376E+06
energy in fuel per unit length(kw-s)	0.1765E+0[illegible]	0.1455E+03	0.9937E+02
energy in cladding per unit length(kw-s)	0.3340E+02	0.28[illegible]E+02	0.1957E+02
energy input after steady-state(kw-s/m)	0.5100E+02	0.34[illegible]+02	0.1352E+02
energy output after steadystate(kw-s/m)	0.1387E+03	0.1[illegible]+03	0.5682E+02
coolant bulk temperature(k)	528.6	528.[illegible]	528.6
coolant quality	0.366E+00	0.410E+00	0.489E+00
coolant mass flux,kg/sec-m2	-8.026E+01	-6.465E+01	-5.230E+01
surface heat flux (watt/m**2)	1.465E+05	1.058E+05	5.422E+04
critical heat flux (watt/m**2)	2.23[illegible]E+04	3.155E-01	3.[illegible]5E-0[illegible]
critical heat flux / surface heat flux	1.526E-01	2.982E-06	5.818E-06
surface heat transfer coef. (watt/m**2d0.k)	3.0[illegible]8E+02	2.837E+02	2.735E+02
heat transfer mode	9	9	6
gap heat transfer coef. (watt/m**2d0.k)	1.628E+03	1.759E+03	1.140E+03
thermal radial gas gap (mm)	9.292E-02	7.649E-02	9.946E-02
structural radial gas gap (mm)	9.292E-02	7.649E-02	9.946E-02
gap pressure (n/m**2)	4.354E+06	4.354E+06	4.354E+06
coolant pressure(n/m**2)	4.354E+06	4.354E+06	4.354E+06
displacement of fuel outer surface (mm)	4.991E-02	3.[illegible]81E-02	[illegible].293E-03
displacement of clad outer surface (mm)	5.332E-02	2.218E-02	[illegible].583E-02
cladding hoop strain (midplane)	1.047E-02	4.056E-03	2.856E-03
cladding permanent hoop strain	5.700E-03	-3.476E-05	-1.6[illegible]3E-05
cladding permanent axial strain	1.638E-05	1.647E-08	0.000E+00
interface pressure, struct. gap(n/m**2)	0.000E+00	0.000E+00	0.000E+00
cladding hoop stress (n/m**2)	-4.354E+06	-4.354E+06	-4.354E+06
cladding axial stress (n/m**2)	-4.354E+05	-4.352E+06	-4.354E+06
effective cladding stress (n/m**2)	0.000E+00	0.000E+00	0.000E+00
cladding yield stress(n/m**2)	0.000E+00	0.000E+00	0.000E+00
cladding effective plastic strain	0.000E+00	0.000E+00	0.000E+00
cladding instability strain	0.000E+00	0.000E+00	0.00[illegible]E+00
oxide thickness,clad outer surface(mm)	1.256E-02	1.197E-02	1.114E-02
oxygen stabilized alpha thickness(mm)	0.000E+00	0.000E+00	0.000E+00
oxide depth, clad inner surface(mm)	3.000E-03	3.000E-03	3.000E-03
metal-water reaction energy (kw,m)	4.836E-04	0.000E+00	0.000E+00
flow area reduction	0.0000	0.0000	0.0000
flow area reduction uncertainty	0.0000	0.0000	0.0000

0

temperatures by radial mesh points

no.	mesh radius (mm)	temperatures (k)		
1	0.000E+00	1175.8	1022.4	796.5
2	4.699E-01	1174.6	1021.7	796.2
3	9.398E-01	1170.9	1019.4	795.4
4	1.410E+00	1165.0	1015.8	794.0
5	1.880E+00	1157.2	1010.9	792.1
6	2.349E+00	1147.8	1004.9	789.7
7	2.819E+00	1137.1	997.9	786.9
8	3.289E+00	1125.4	990.1	783.6
9	3.759E+00	1112.5	981.2	779.9
10	4.229E+00	1098.3	971.2	775.6
11**	4.699E+00	1082.1	959.7	770.8
12	4.788E+00	1005.5	904.8	728.7
13	5.124E+00	1003.4	903.2	727.8
14	5.461E+00	1001.3	901.4	726.8

Figure J-3. (continued)

Results

Tables J-10 through J-29 present matrices showing the fuel pin failure times and locations calculated by FRAP-T6 using SCDAP/RELAP5/MOD3 thermal-hydraulic data for all accident scenarios considered. (The numbers in parentheses are the nodes in which failure occurred.) Table J-30 provides a comparison of fuel pin failure times and locations calculated by FRAP-T6 using SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 thermal-hydraulic data for the Seabrook 100% DBA case. Appendices K and L contain plots of internal pin pressure, failure probability, cladding hoop strain, cladding surface temperature, fuel centerline temperature, and oxide thickness for all cases run for the Seabrook and Oconee reactors, respectively.

Table J-10. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	22.7 (5)	20.3 (4)	18.0 (4)	13.0 (4)
2.4	> 60.0	25.3 (4)	19.7 (4)	14.1 (4)
2.2	> 60.0	34.8 (4)	23.9 (4)	16.4 (4)
2.0	> 60.0	>60.0	33.8 (4)	22.5 (4)

Table J-11. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 90% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	25.0 (5)	22.1 (4)	19.7 (4)	13.6 (4)
2.4	> 60.0	27.7 (4)	22.3 (4)	17.7 (5)
2.2	> 60.0	54.7 (4)	25.8 (4)	22.7 (4)
2.0	> 60.0	> 60.0	34.4 (4)	24.2 (4)

Table J-12. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 75% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	25.0 (5)	23.5 (4)	21.1 (4)	14.6 (4)
2.4	> 60.0	31.7 (4)	23.5 (4)	15.6 (4)
2.2	> 60.0	51.3 (4)	29.3 (4)	18.0 (4)
2.0	> 60.0	>60.0	37.5 (4)	25.0 (4)

Table J-13. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 50% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	33.9 (5)	29.8 (4)	27.2 (4)	20.3 (4)
2.4	> 60.0	53.1 (4)	33.0 (4)	21.6 (4)
2.2	> 60.0	> 60.0	40.8 (5)	29.5 (5)
2.0	> 60.0	> 60.0	57.4 (4)	30.3 (4)

Table J-14. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA without ECCS and with pump trip.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	37.5 (5)	33.5 (5)	26.2 (4)	22.3 (5)
2.4	> 60.0	49.7 (5)	32.1 (4)	25.5 (4)
2.2	> 60.0	> 60.0	33.8 (4)	27.4 (4)
2.0	> 60.0	> 60.0	> 60.0	32.1 (4)

Table J-15. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA with ECCS on.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	22.7 (5)	21.1 (4)	18.0 (4)	13.0 (4)
2.4	54.9 (4)	24.9 (4)	20.0 (4)	14.1 (4)
2.2	> 60.0	50.2 (4)	23.6 (4)	18.8 (5)
2.0	> 60.0	> 60.0	28.2 (4)	22.7 (4)

Table J-16. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA with pump trip and ECCS on.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	24.8 (5)	24.4 (5)	23.5 (5)	20.3 (5)
2.4	> 60.0	25.9 (5)	24.6 (4)	23.6 (5)
2.2	> 60.0	55.4 (5)	25.8 (5)	24.5 (5)
2.0	> 60.0	> 60.0	54.6 (5)	25.3 (5)

Table J-17. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 100% DBA without ECCS with licensing audit code models on.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	25.5 (5)	24.5 (5)	21.9 (5)	12.5 (5)
2.4	> 60.0	> 60.0	31.9 (5)	23.1 (5)
2.2	> 60.0	> 60.0	> 60.0	33.6 (5)
2.0	> 60.0	> 60.0	> 60.0	> 60.0

Table J-18. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 6-in. break without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 393.0	> 393.0	> 393.0	> 393.0

Table J-19. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Oconee 6-in. break with ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 60.0	> 60.0	> 60.0	> 60.0

Table J-20. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	29.1 (5)	29.7 (5)	27.7 (5)	24.8 (4)
2.2	34.4 (5)	36.7 (5)	35.8 (5)	32.5 (4)
2.0	44.5 (4)	48.4 (4)	43.6 (4)	43.6 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table J-21. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 90% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	31.8 (5)	32.6 (5)	30.5 (5)	26.5 (4)
2.2	35.6 (5)	36.2 (5)	35.7 (5)	34.8 (5)
2.0	39.6 (4)	40.1 (4)	39.4 (4)	38.7 (4)
1.8	> 60.0	> 60.0	52.3 (4)	45.7 (4)

Table J-22. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 75% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	30.6 (5)	31.2 (5)	29.8 (5)	26.9 (4)
2.2	36.2 (5)	38.8 (5)	36.8 (5)	33.5 (4)
2.0	> 60.0	> 60.0	> 60.0	40.5 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table J-23. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 50% DBA without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	44.3 (5)	44.1 (5)	43.0 (5)	42.5 (5)
2.2	45.7 (5)	45.7 (5)	44.7 (5)	43.5 (5)
2.0	> 60.0	> 60.0	58.6 (5)	47.2 (5)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table J-24. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA without ECCS and with pump trip.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	27.6 (5)	28.0 (5)	26.7 (5)	25.0 (4)
2.2	32.8 (5)	32.2 (5)	32.0 (5)	30.3 (4)
2.0	35.0 (5)	35.5 (5)	35.0 (4)	34.0 (4)
1.8	> 60.0	> 60.0	48.0 (4)	38.2 (4)

Table J-25. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA with ECCS on.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	30.2 (5)	31.3 (5)	29.2 (5)	24.9 (4)
2.2	34.9 (5)	36.2 (5)	35.5 (5)	33.1 (4)
2.0	42.5 (4)	43.2 (4)	42.7 (4)	39.1 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table J-26. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA with pump trip and ECCS on.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	28.3 (5)	28.8 (5)	27.7 (5)	25.1 (4)
2.2	31.8 (5)	32.1 (5)	32.0 (5)	30.7 (4)
2.0	35.2 (5)	36.2 (5)	35.5 (5)	34.6 (5)
1.8	> 60.0	> 60.0	42.1 (5)	42.0 (4)

Table J-27. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 100% DBA without ECCS with licensing audit code models on.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
2.32	39.8 (4)	42.4 (4)	40.2 (4)	37.1 (4)
2.2	> 60.0	> 60.0	> 60.0	> 60.0
2.0	> 60.0	> 60.0	> 60.0	> 60.0
1.8	> 60.0	> 60.0	> 60.0	> 60.0

Table J-28. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 6-in. break without ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 600.0	> 600.0	> 600.0	> 600.0

Table J-29. FRAP-T6-calculated hot fuel pin failure time (s) and location as a function of burnup and peaking factor for the Seabrook 6-in. break with ECCS.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	55 GWd/MTU
2.63	> 60.0	> 60.0	> 60.0	> 60.0

Table J-30. A comparison of FRAP-T6 fuel pin failure times using SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 thermal-hydraulic data for the 100% DBA case for Seabrook.

Peaking factor	Burnup			
	5 GWd/MTU	20 GWd/MTU	35 GWd/MTU	50 GWd/MTU
Fuel Pin Failure Times using TRAC-PF1/MOD1 Thermal-Hydraulic Data				
2.32	> 60.0	41.4 (5)	41.3 (6)	34.9 (6)
2.2	> 60.0	> 60.0	41.4 (5)	41.2 (6)
2.0	> 60.0	> 60.0	> 60.0	> 60.0
1.8	> 60.0	> 60.0	> 60.0	> 60.0
Fuel Pin Failure Times using SCDAP/RELAP5/MOD3 Thermal-Hydraulic Data				
2.32	29.1 (5)	29.7 (5)	27.7 (5)	24.8 (4)
2.2	34.4 (5)	36.7 (5)	35.8 (5)	32.5 (4)
2.0	44.5 (4)	48.4 (4)	43.6 (4)	43.6 (4)
1.8	> 60.0	> 60.0	> 60.0	> 60.0

References

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J-4. *Final Safety Analysis Report, Seabrook Station*, Public Service Company of New Hampshire, Seabrook, New Hampshire, Amendment 56, November 1985.

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Appendix K

Plots for the Timing Analysis of PWR Fuel Pin Failures for Oconee

Appendix K

Plots for the Timing Analysis of PWR Fuel Pin Failures for Oconee

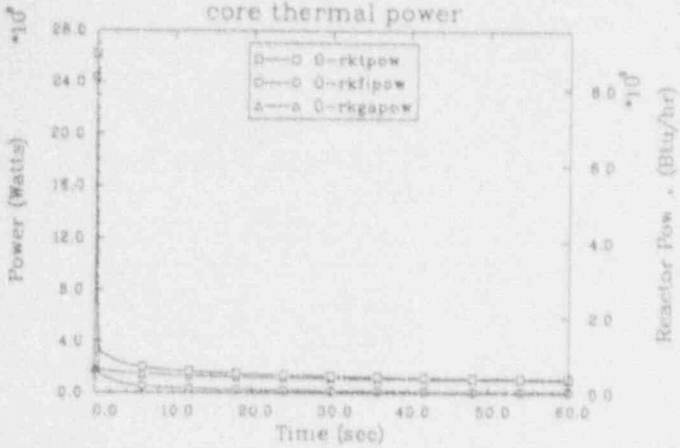
Appendix K contains the plotted results for the timing anlaysis of PWR fuel pin failures for the Oconee reactor. Section K-1.1 contains the SCDAP/RELAP5/MOD3 plots of total core power, collapsed reactor water level, reactor upper head and pressurizer dome pressures, containment pressure, fission product release, internal pin pressures, fuel centerline temperatures, cladding surface temperatures, hoop strains, total break flow, accumulator flow, accumulator liquid volume, hot leg flows, cold leg flows, hot channel core flow, downcomer void fractions, mass error, time step size, and cpu time for the nine accident scenarios. Section K-1.2 contains the FRAP-T6 plots of failure probability, internal pin pressure, cladding hoop strain, cladding surface temperature, fuel centerline temperature, and oxide thickness for the nine accident scenarios. Tables K-1 and K-2 provide a listing of the plot variables.

K-1.1 SCDAP/RELAP5/MOD3 Plotted Results for Oconee

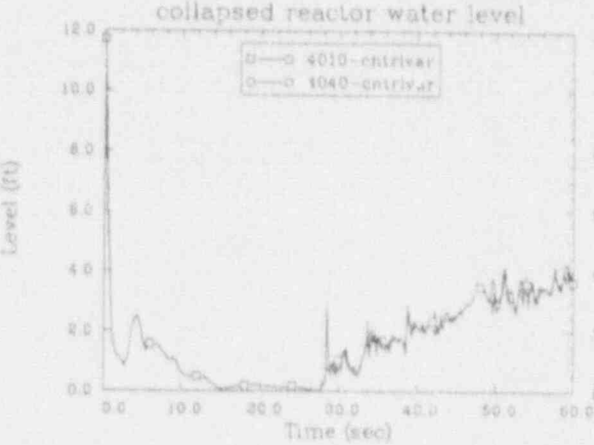
Table K-1. Description of SCDAP/RELAP5/MOD3 plot variables for Oconee.

Variable	Description
0-rktpow	Total core thermal power (W)
0-rkfipow	Total core fission power (W)
0-rkgapow	Total core decay heat (W)
4010-cntrlvar	Hot channel collapsed reactor water level for Oconee (m)
4040-cntrlvar	Core-average collapsed reactor water level for Oconee (m)
550010000-p	Reactor upper head pressure for Oconee (Pa)
615010000-p	Pressurizer dome pressure for Oconee (Pa)
[illegible]49010000-p	Containment pressure for Oconee (Pa)
0-bgtfprs	Soluble fission product release rate (kg/s)
0-bgtfprn	Insoluble fission product release rate (kg/s)
1-pgas	Average-burnup fuel pin internal pressure (Pa)
2-pgas	Low-burnup fuel pin internal pressure (Pa)
3-pgas	High-burnup fuel pin internal pressure (Pa)
1nn02-cadct	Low-burnup fuel pin centerline temperature for node nn (K)
1nn03-cadct	High-burnup fuel pin centerline temperature for node nn (K)
14nn02-cadct	Low-burnup fuel pin cladding temperature for node nn (K)
14nn03-cadct	High-burnup fuel pin cladding temperature for node nn (K)
n02-hoop	Low-burnup fuel pin cladding hoop strain for node n (dimensionless)
n03-hoop	High-burnup fuel pin cladding hoop strain for node n (dimensionless)
410-cntrlvar	Total break flow (kg/s)
702000000-mflowj	Total accumulator flow for Oconee (kg/s)
700-acvliq	Total accumulator liquid volume for Oconee (m^3)
100000000-mflowj	Hot leg flow for the Oconee broken loop (kg/s)
200000000-mflowj	Hot leg flow for the Oconee intact loop (kg/s)
151000000-mflowj	Cold leg flow for the Oconee broken loop (kg/s)
181000000-mflowj	Cold leg flow for the Oconee intact loop (kg/s)
251000000-mflowj	Cold leg flow for the Oconee intact loop (kg/s)
281000000-mflowj	Cold leg flow for the Oconee intact loop (kg/s)
1n010000-mflowj	Hot channel flows for n = 1, 3, 5, 7, and 9 for Oconee (kg/s)

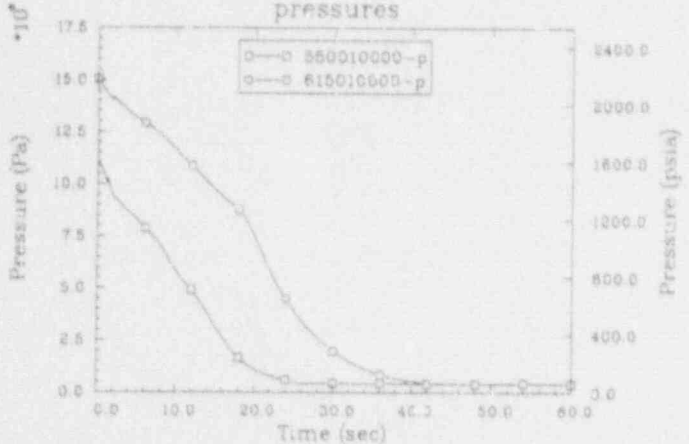
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
core thermal power



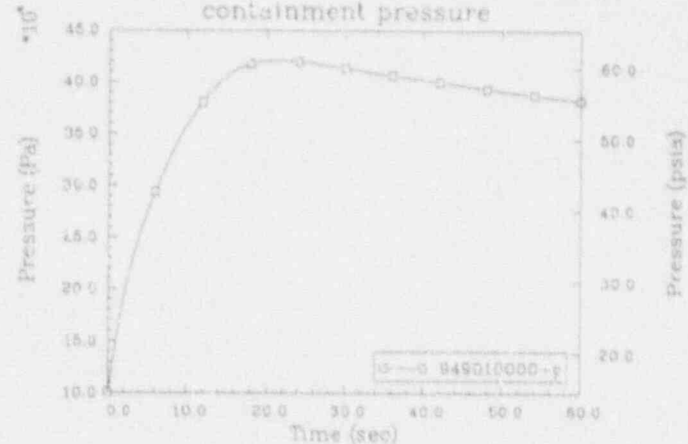
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
collapsed reactor water level



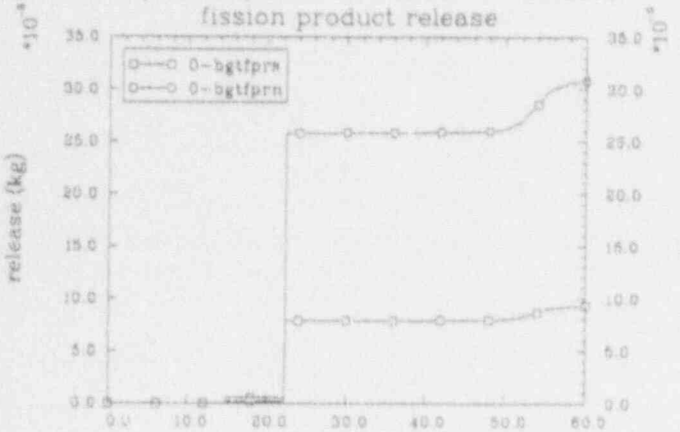
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
pressures



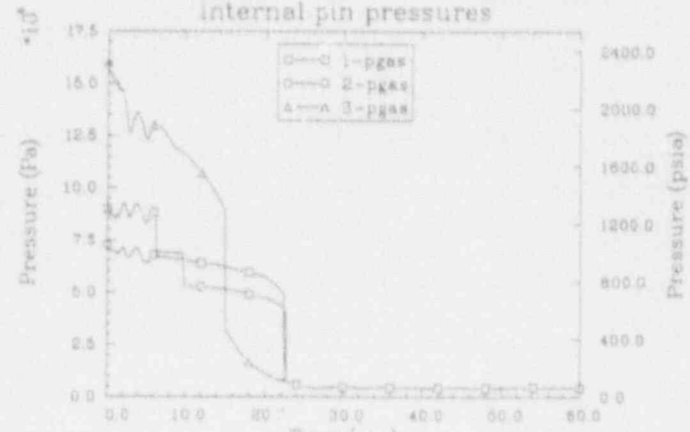
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
containment pressure

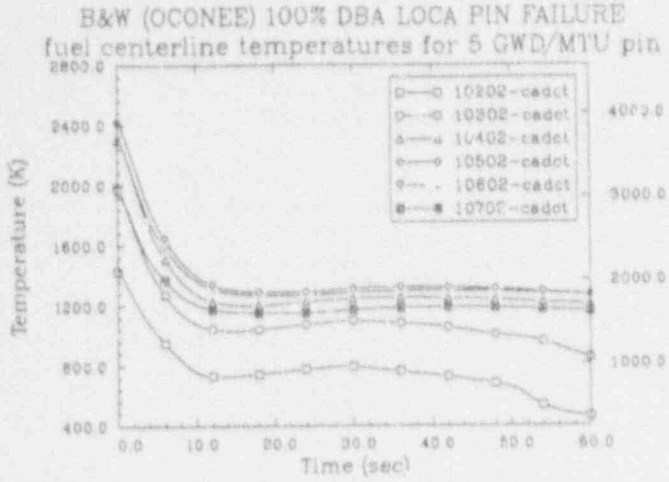


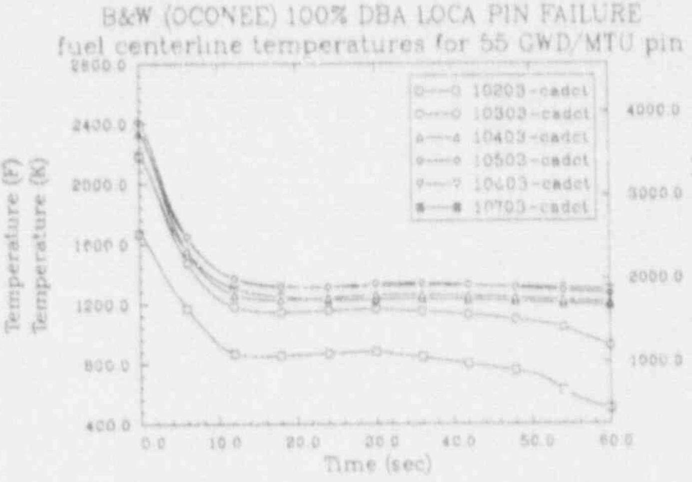
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fission product release

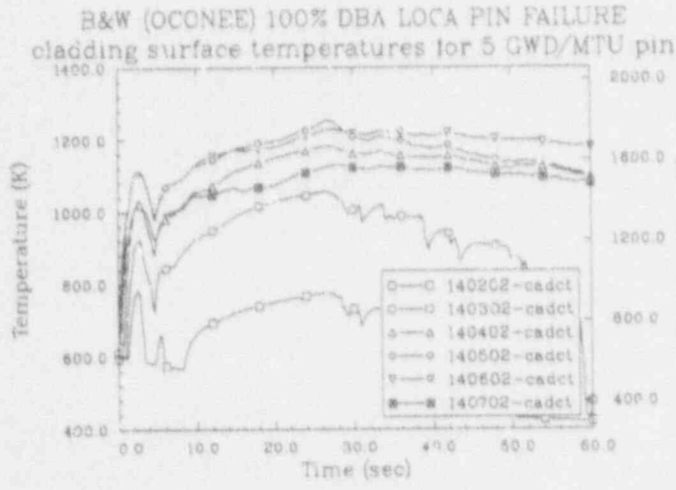


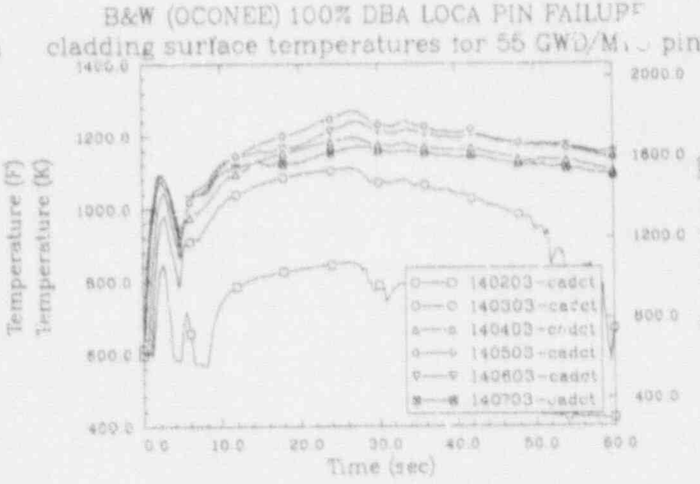
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
internal pin pressures

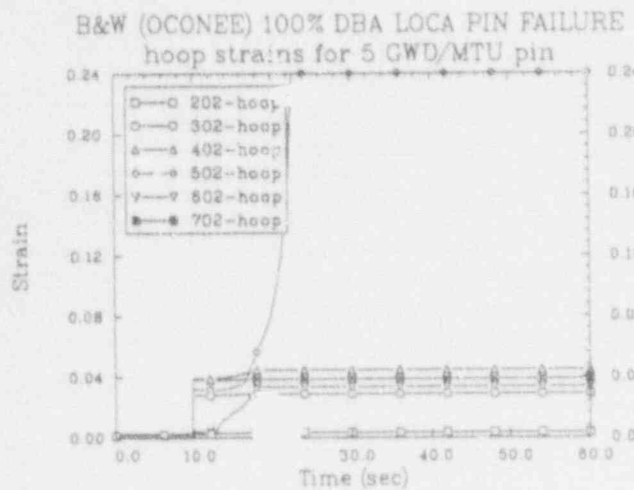


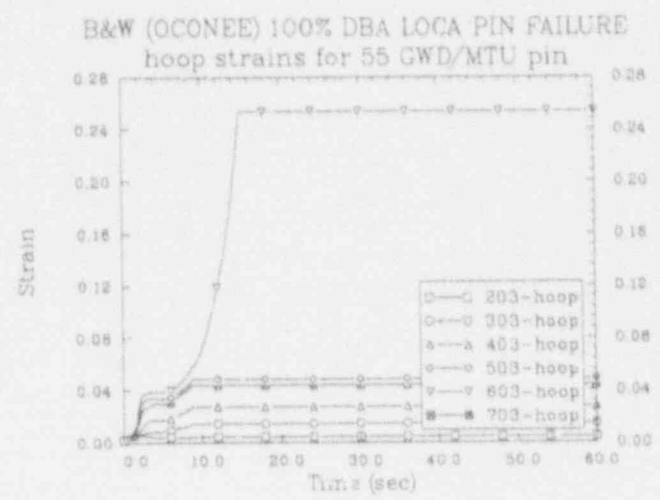

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin
10202-cadct
10302-cadct
10402-cadct
10502-cadct
10602-cadct
10702-cadct
Temperature (K)
Temperature (F)
Time (sec)

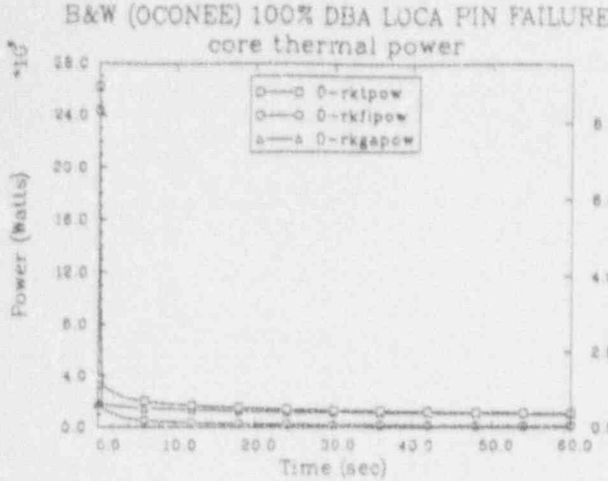

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 55 GWD/MTU pin
10203-cadct
10303-cadct
10403-cadct
10503-cadct
10703-cadct
Temperature (K)
Temperature (F)
Time (sec)

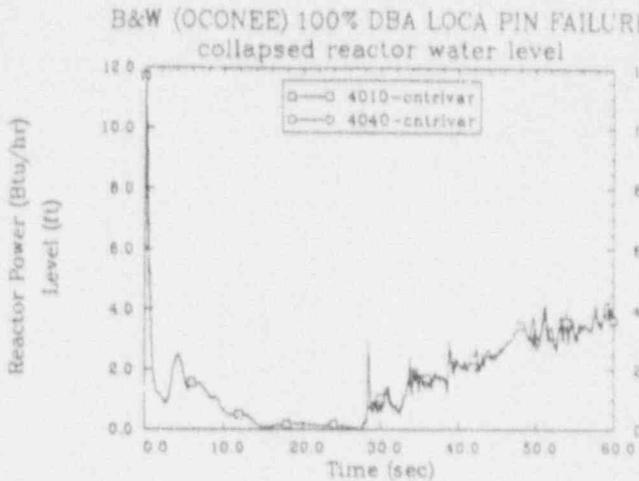

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin
140202-cadct
140302-cadct
140402-cadct
140502-cadct
140602-cadct
140702-cadct
Temperature (K)
Temperature (F)
Time (sec)

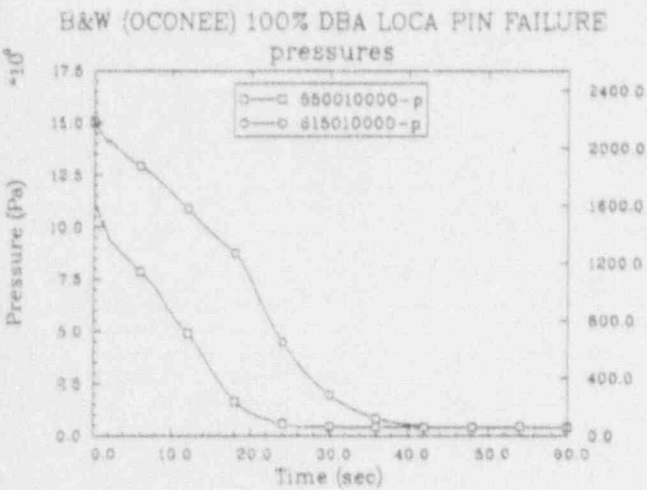

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
140203-cadct
140503-cadct
140603-cadct
Temperature (K)
Temperature (F)
Time (sec)

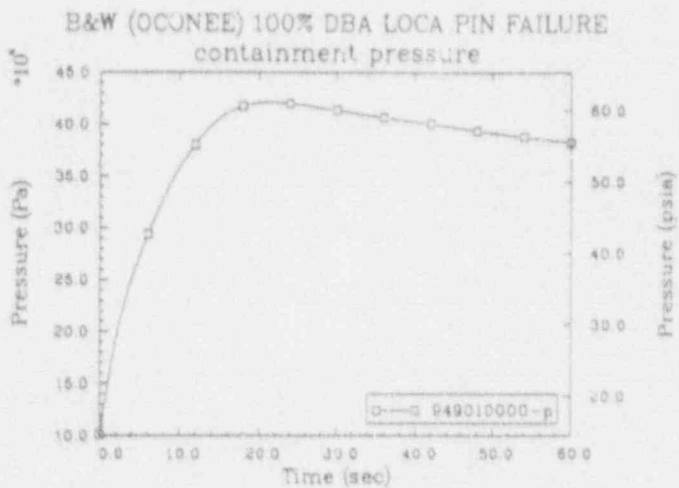

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin
302-hoop
402-hoop
502-hoop
602-hoop
702-hoop
Strain
Time (sec)

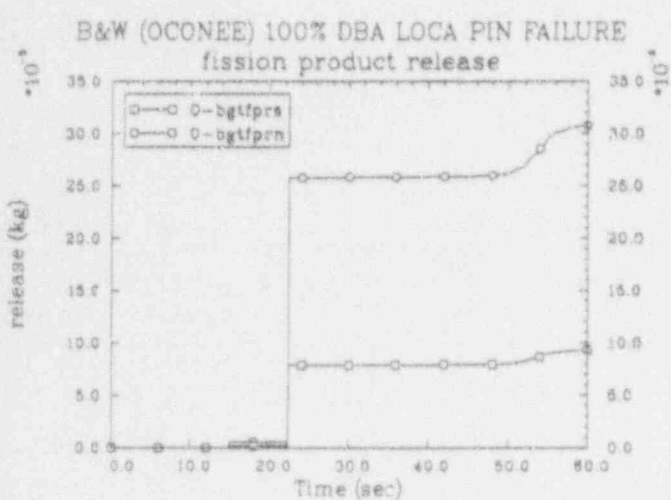

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hoop strains for 55 GWD/MTU pin
203-hoop
303-hoop
403-hoop
503-hoop
603-hoop
703-hoop
Strain

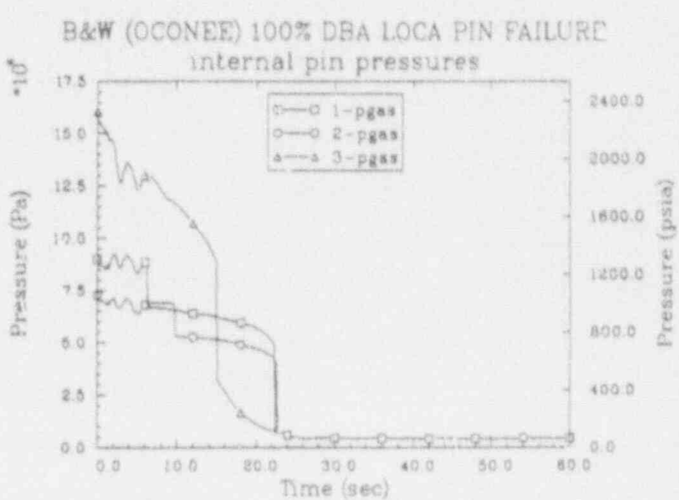

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


B&W (OCONEE) 100% DBA LOCA PIN FAILURE
collapsed reactor water level
4010-cntrlvar
4040-cntrlvar
Level (ft)
Time (sec)

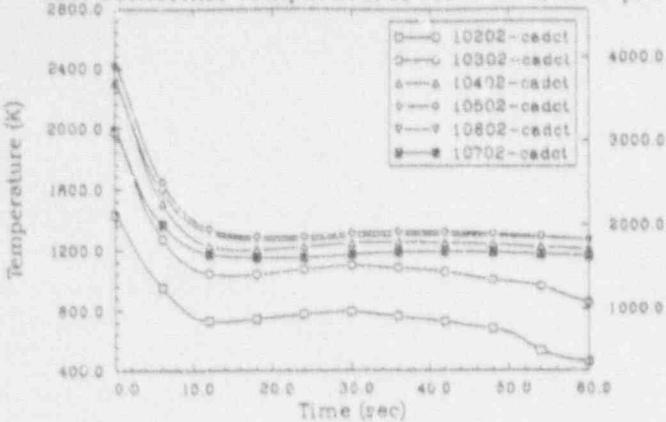

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
pressures
550010000-p
615010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)


B&W (OCONEE) 100% DBA LOCA PIN FAILURE
containment pressure
949010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)

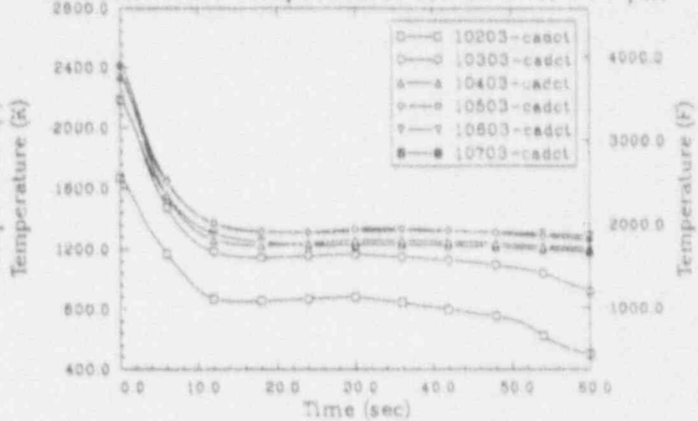

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fission product release
0-bgtfprs
0-bgtfprn
release (kg)
Time (sec)


B&W (OCONEE) 100% DBA LOCA PIN FAILURE
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

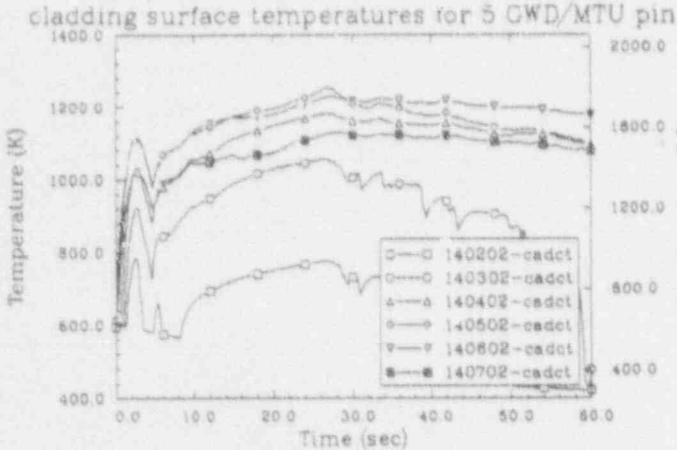
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



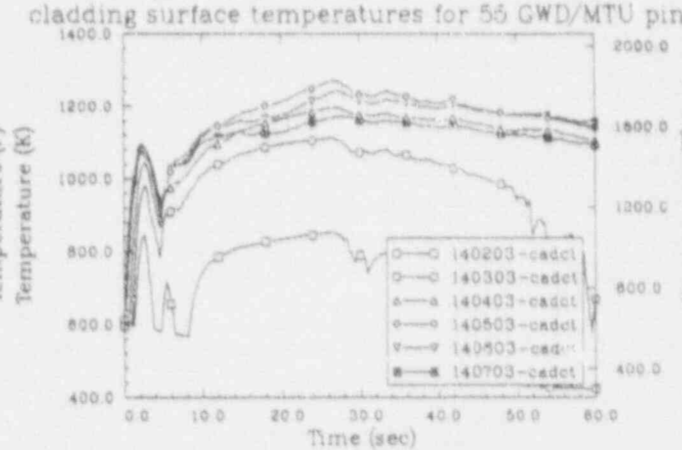
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 55 GWD/MTU pin



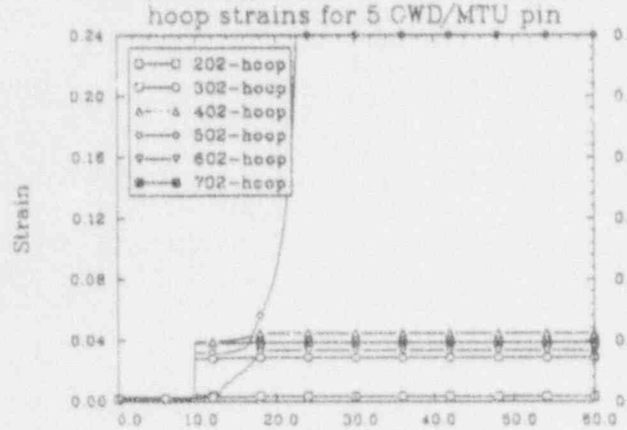
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



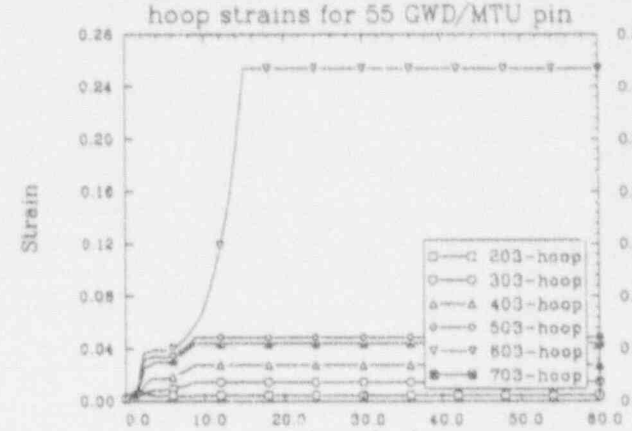
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
cladding surface temperatures for 55 GWD/MTU pin



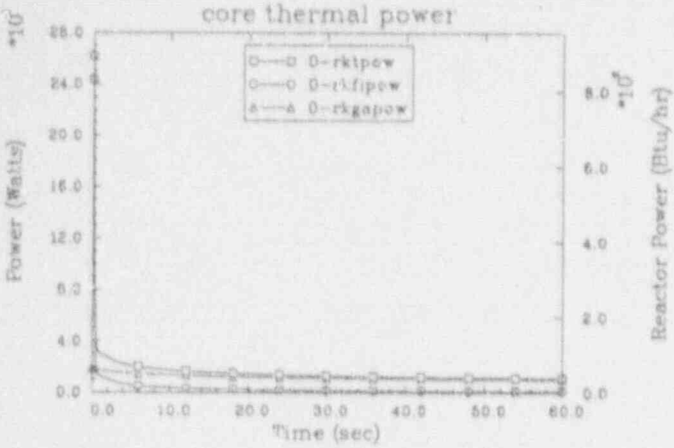
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin



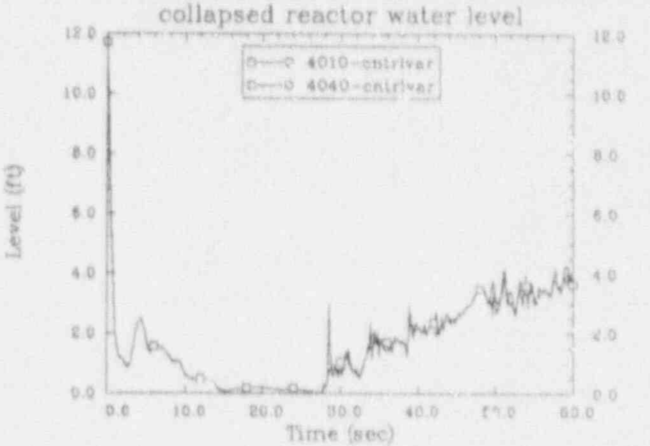
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hoop strains for 55 GWD/MTU pin



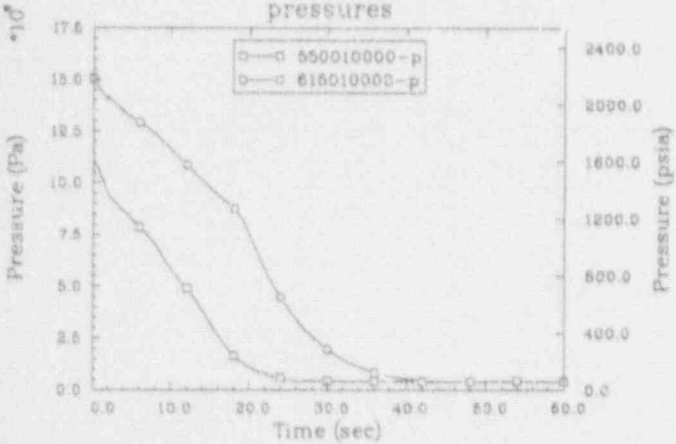
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
core thermal power



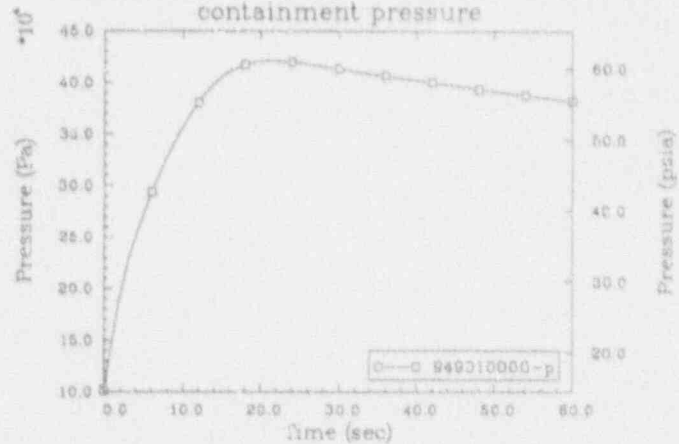
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
collapsed reactor water level



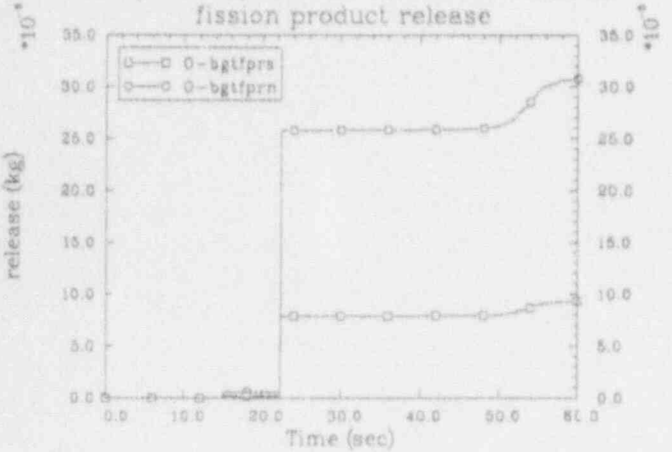
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
pressures



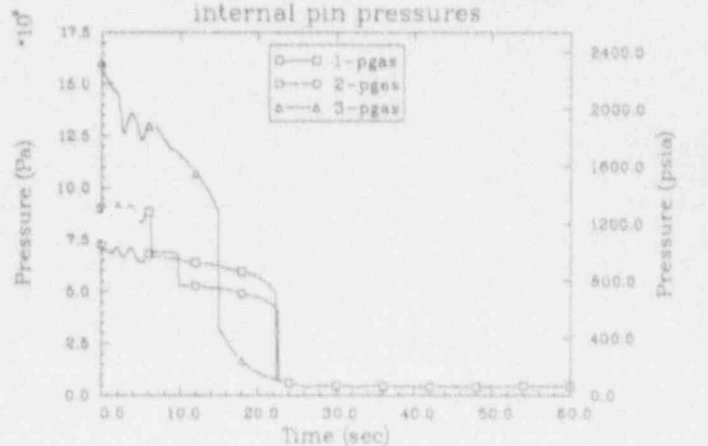
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
containment pressure



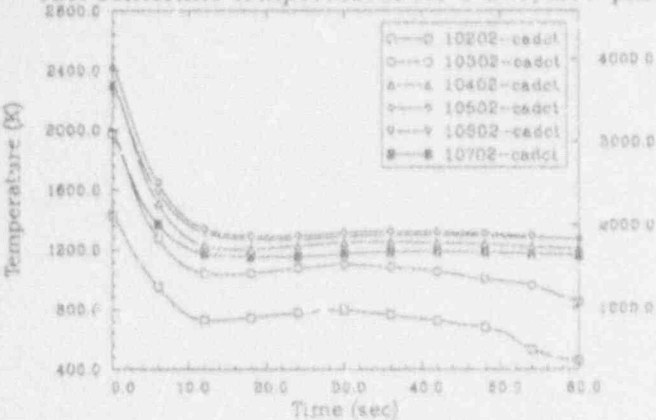
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fission product release



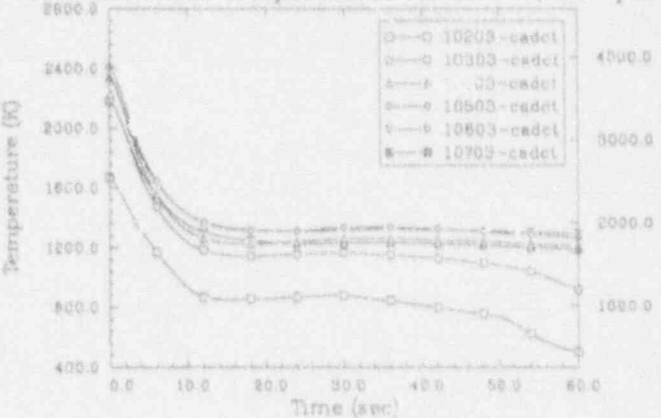
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
internal pin pressures



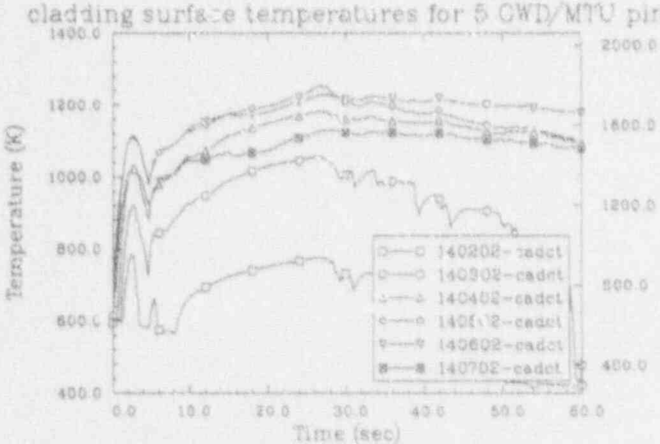
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



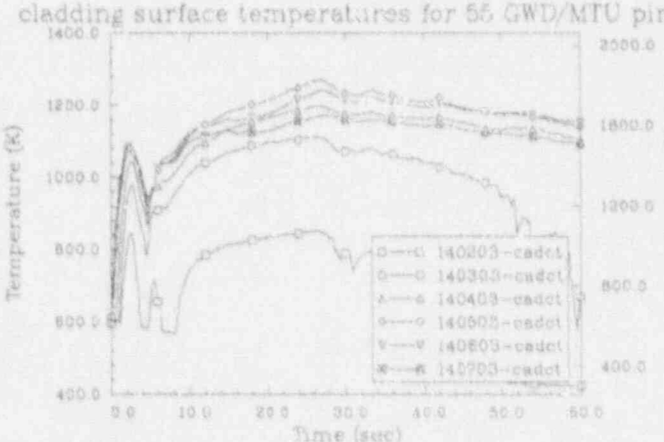
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 55 GWD/MTU pin



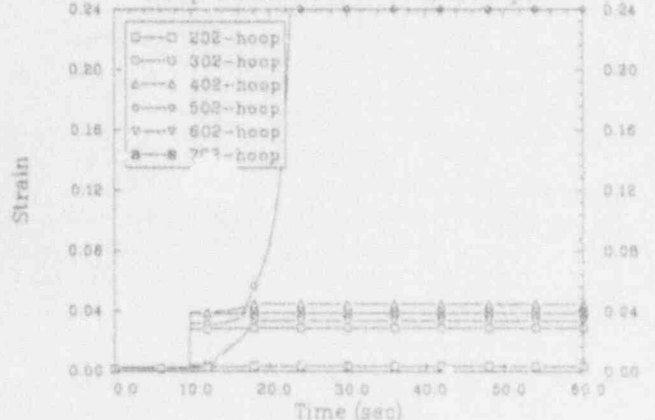
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



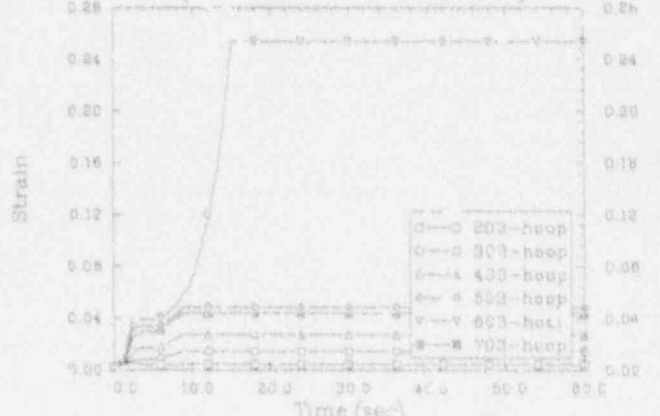
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
cladding surface temperatures for 55 GWD/MTU pin



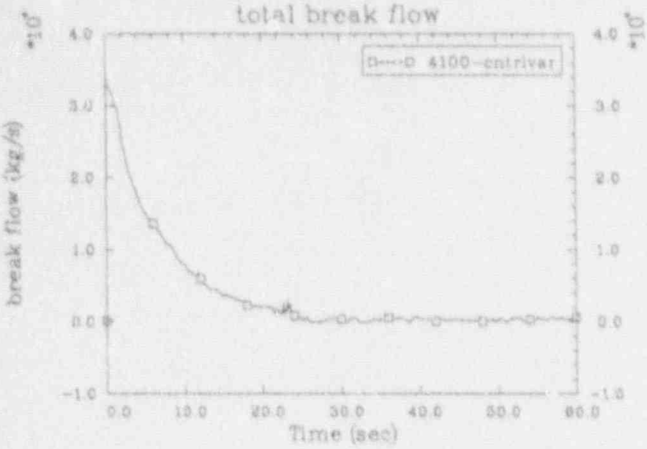
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin



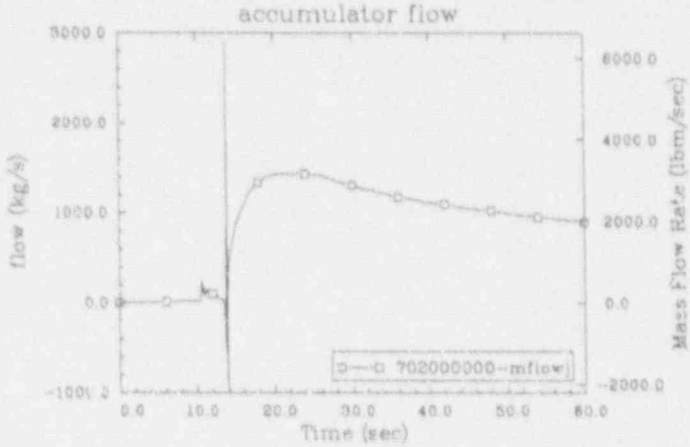
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hoop strains for 55 GWD/MTU pin



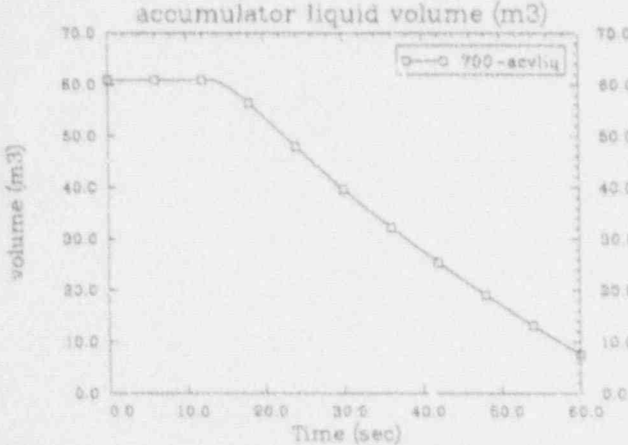
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
total break flow



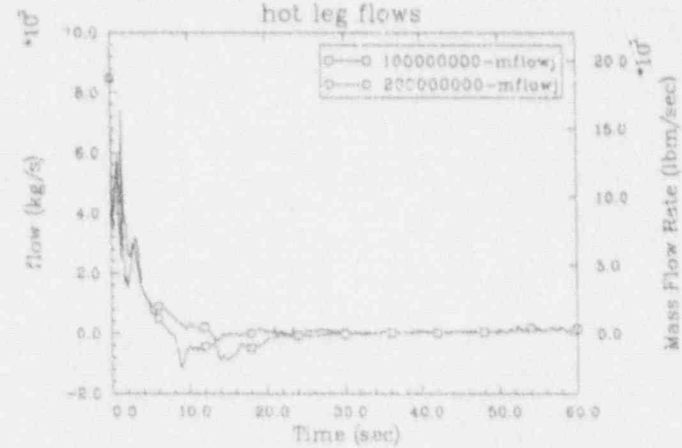
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
accumulator flow



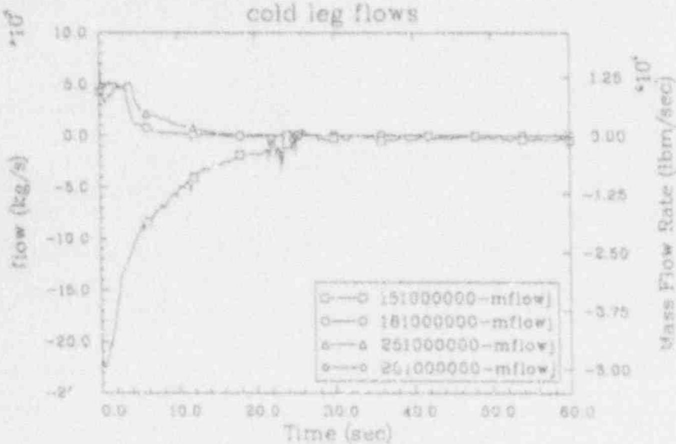
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)



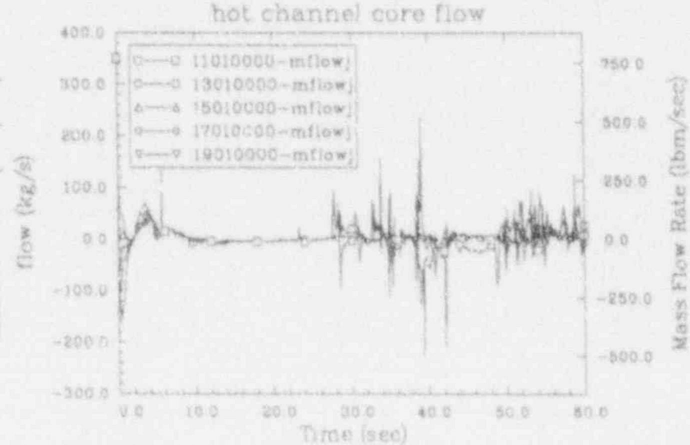
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hot leg flows

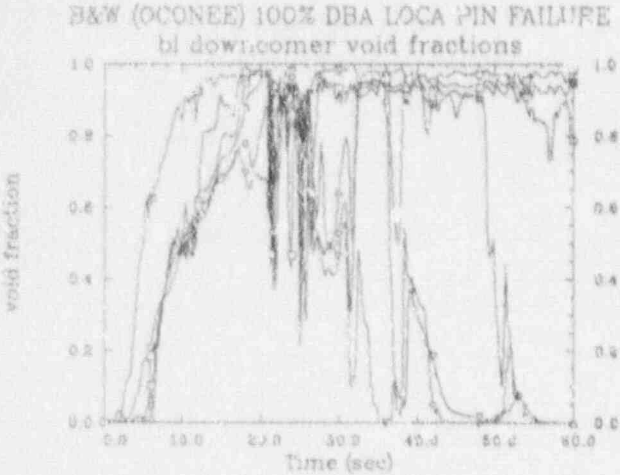


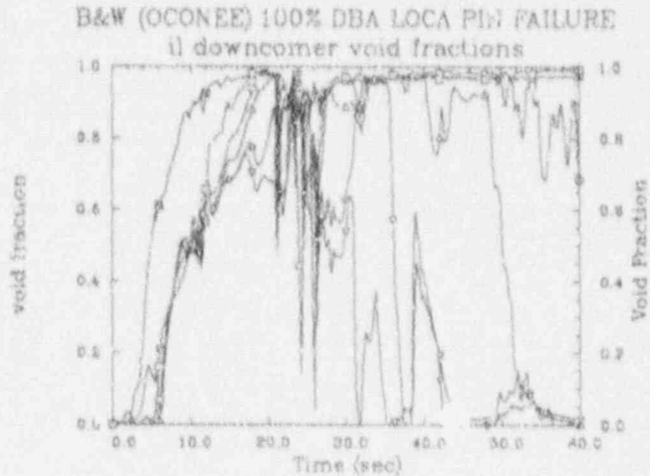
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
cold leg flows

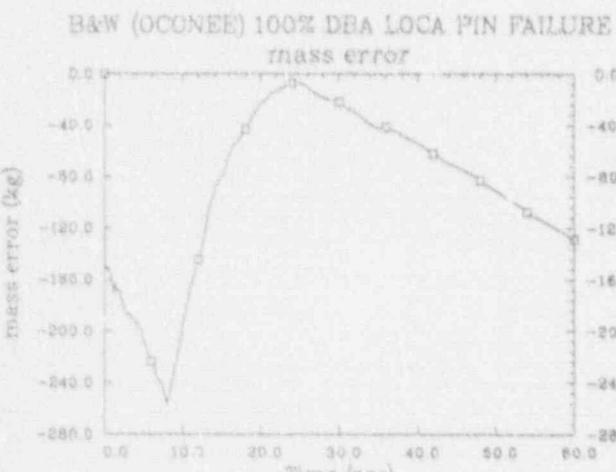


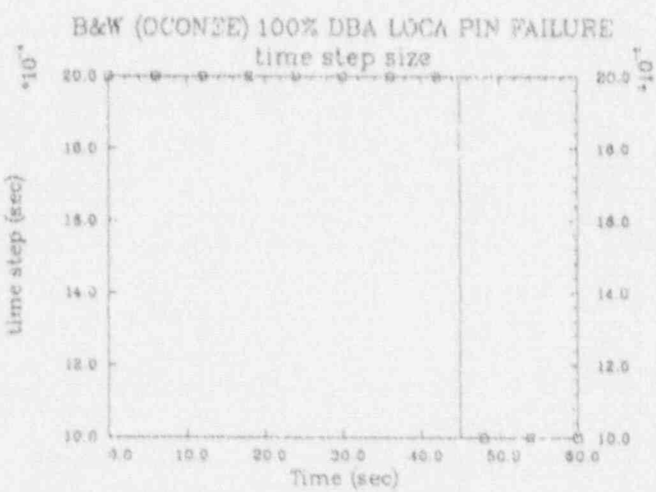
B&W (OCONEE) 100% DBA LOCA PIN FAILURE
hot channel core flow

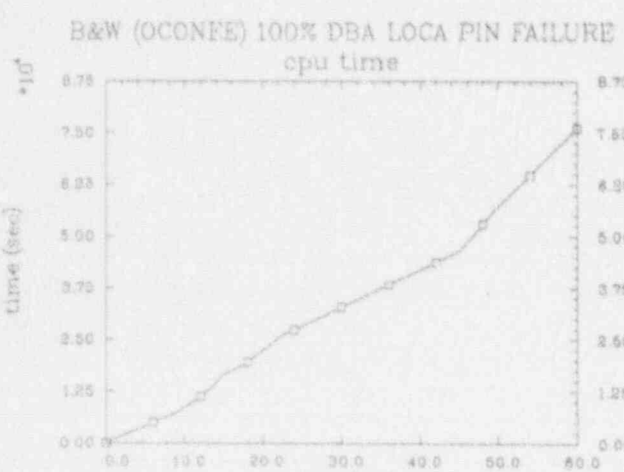


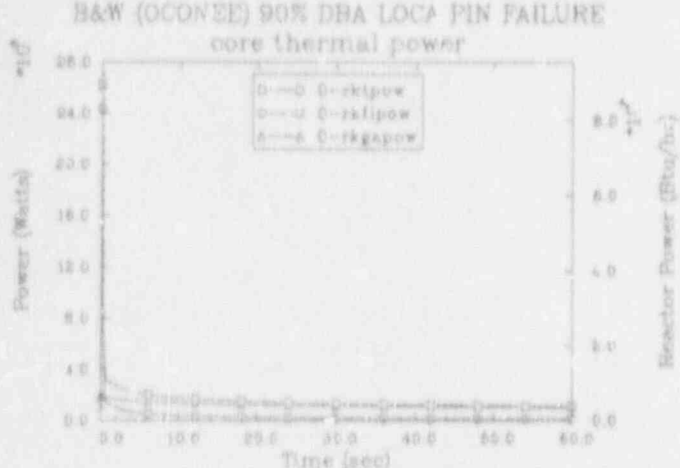

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)


B&W (OCONEE) 100% DBA LOCA PIN FAILURE
il downcomer void fractions
void fraction
Void Fraction
Time (sec)

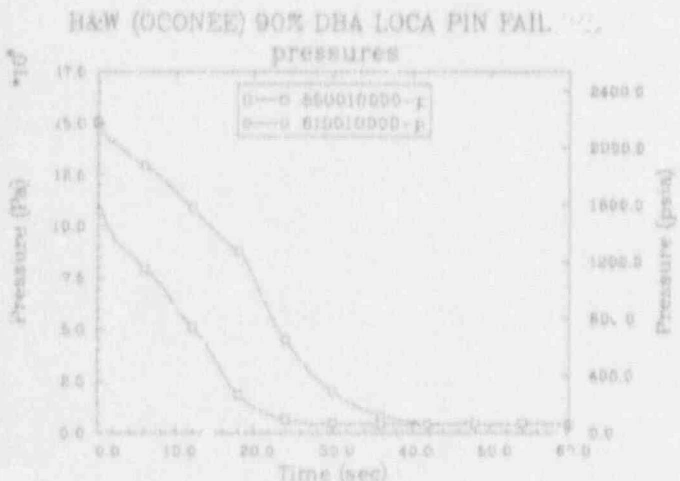

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

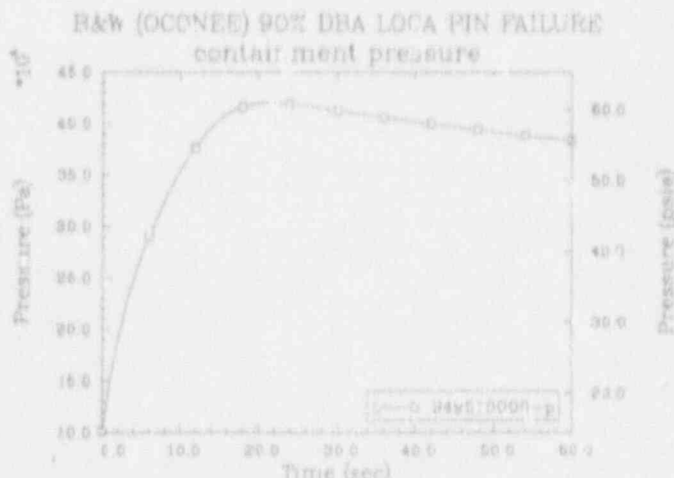

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)

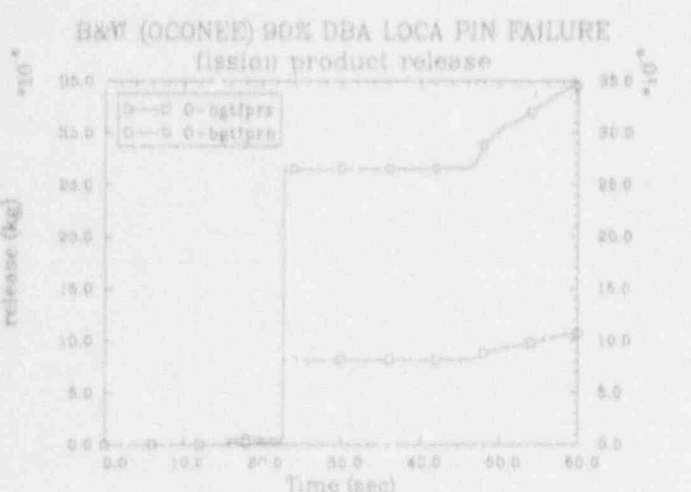

B&W (OCONEE) 100% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

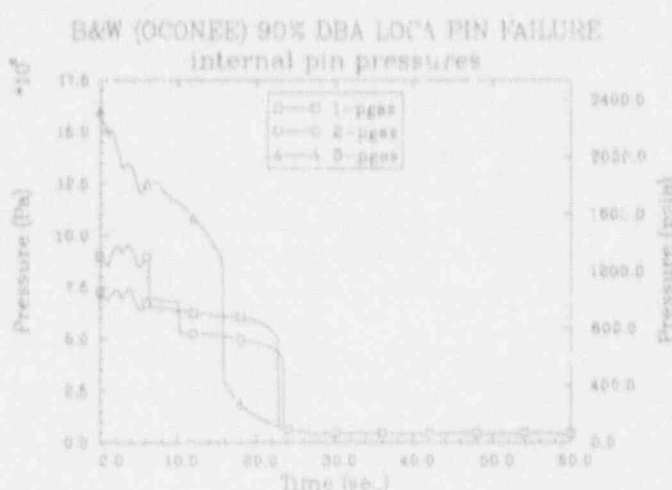

B&W (OCONEE) 90% DBA LOCA PIN FAILURE
core thermal power
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


B&W (OCONEE) 90% DBA LOCA PIN FAILURE
collapsed reactor water level
Level (ft)
Time (sec)

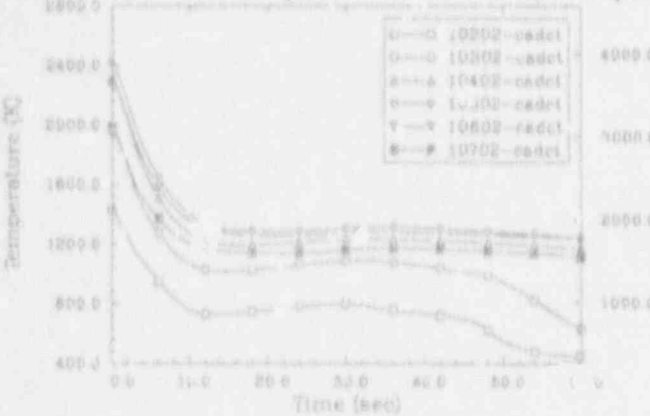

pressures
Pressure (Pa)
Pressure (psia)
Time (sec)


B&W (OCONEE) 90% DBA LOCA PIN FAILURE
Pressure (Pa)
Pressure (psia)
Time (sec)

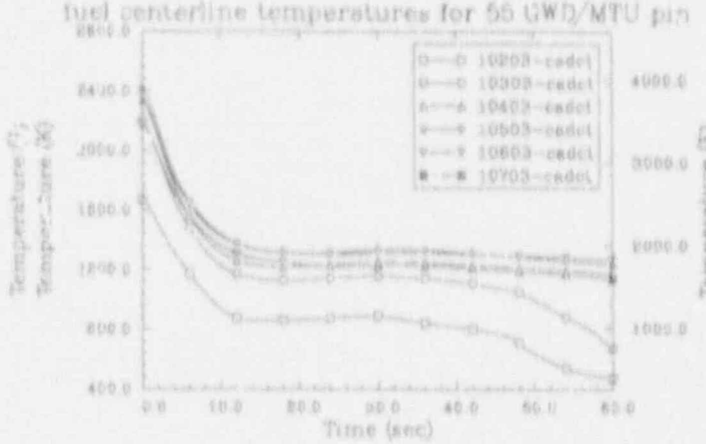

B&W (OCONEE) 90% DBA LOCA PIN FAILURE
fission product release
release (kg)
Time (sec)


B&W (OCONEE) 90% DBA LOCA PIN FAILURE
internal pin pressures
Pressure (Pa)
Pressure (psia)

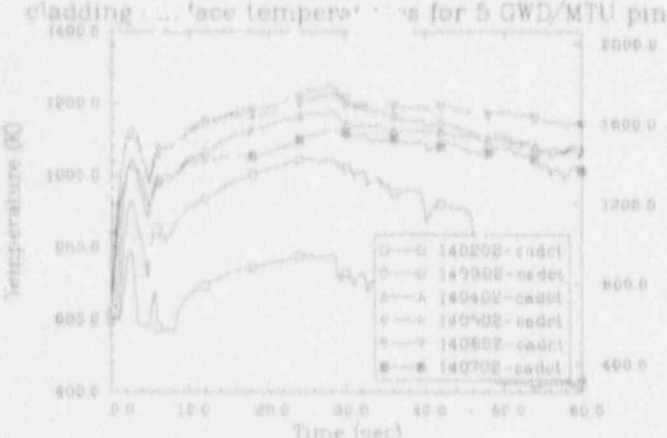
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



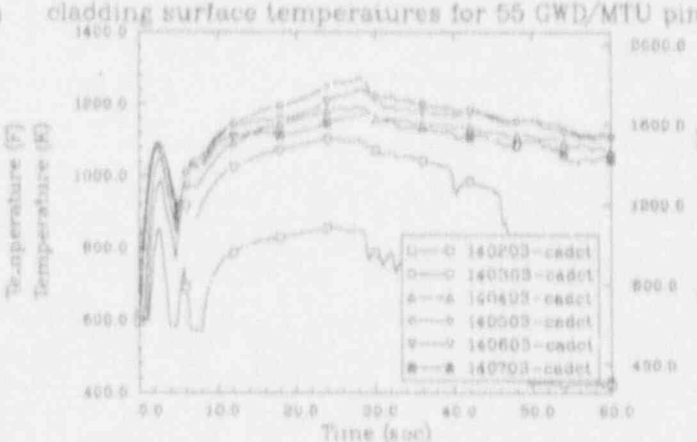
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
fuel centerline temperatures for 55 GWD/MTU pin



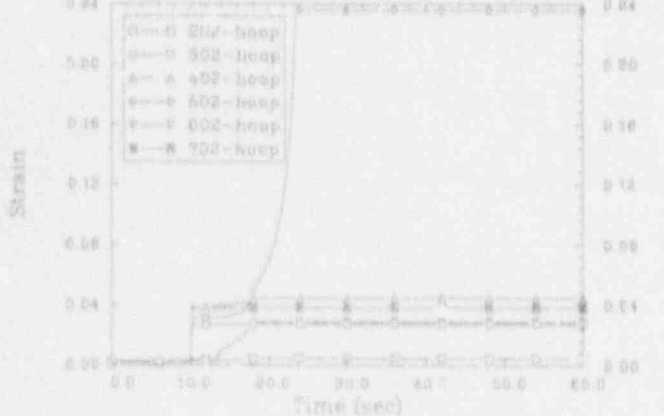
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



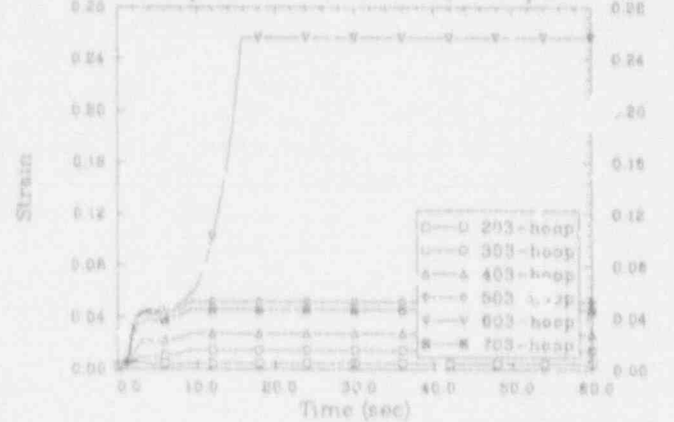
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
cladding surface temperatures for 55 GWD/MTU pin

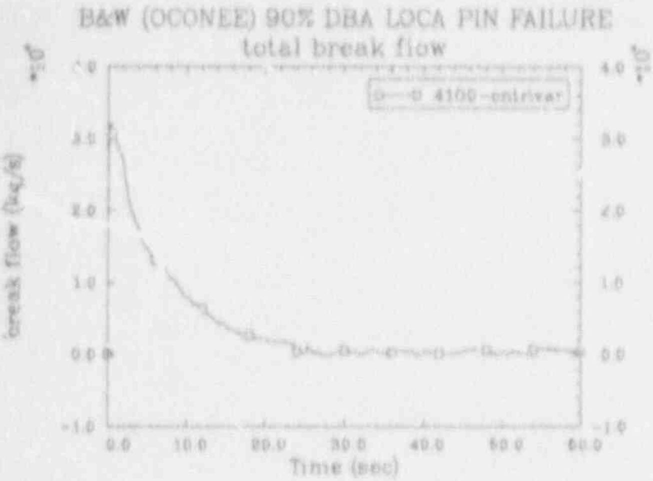


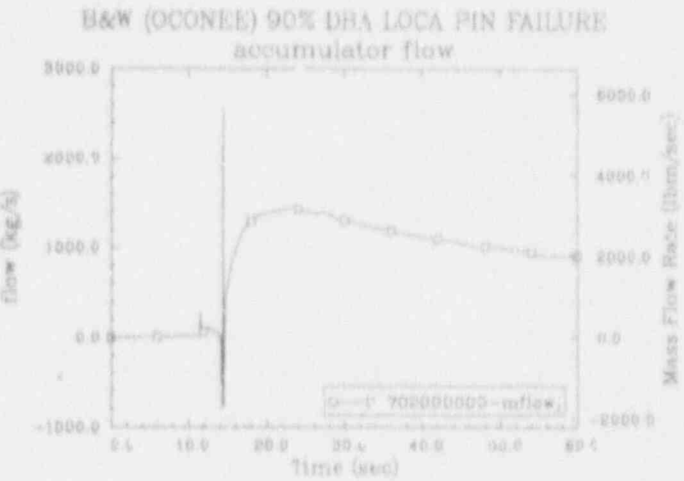
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin

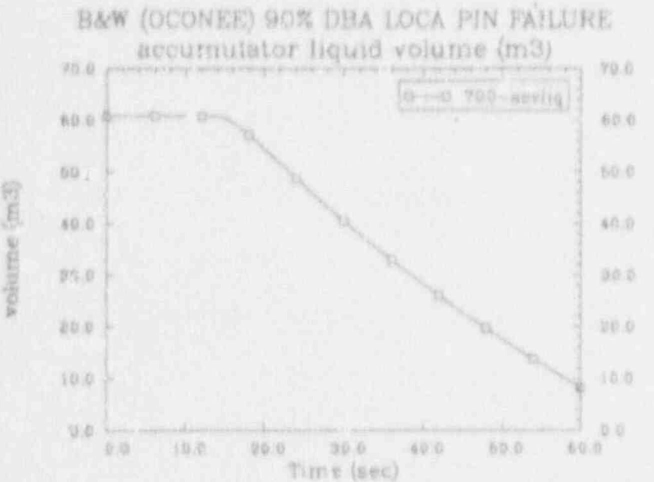


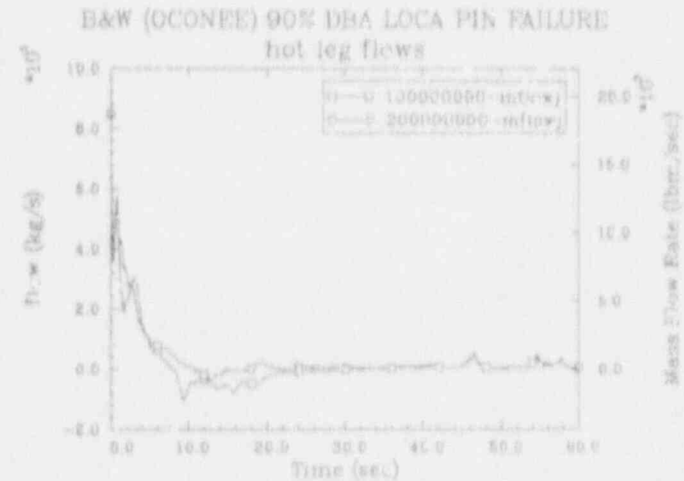
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
hoop strains for 55 GWD/MTU pin

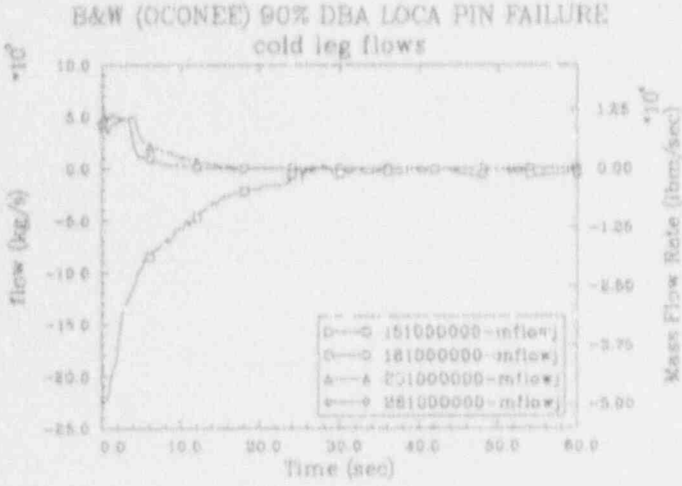


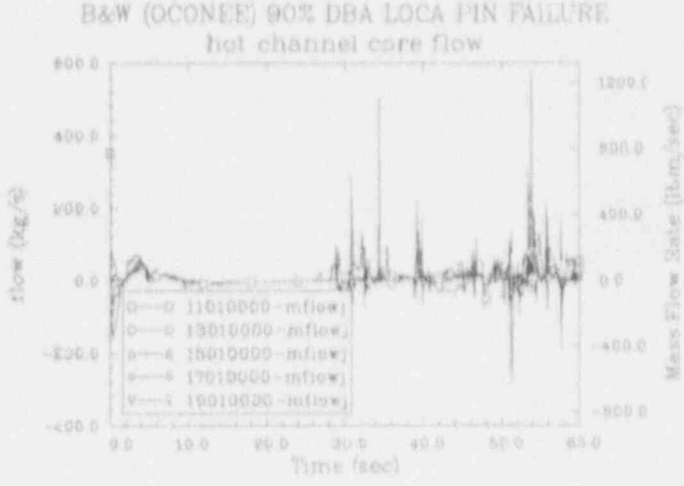

B&W (OCONEE) 90% DBA LOCA PIN FAILURE
total break flow
4100-cntrlvar
break flow (kg/s)
Time (sec)

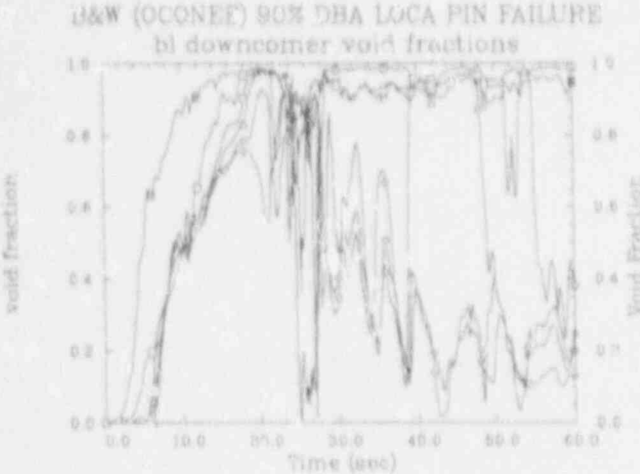

B&W (OCONEE) 90% DBA LOCA PIN FAILURE
accumulator flow
702000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)


B&W (OCONEE) 90% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)
700-acvliq
volume (m3)
Time (sec)

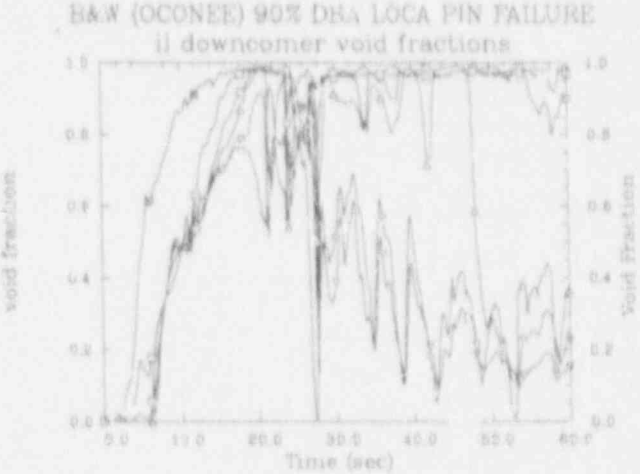

B&W (OCONEE) 90% DBA LOCA PIN FAILURE
hot leg flows
100000000-mflowj
200000000-mflowj
Mass Flow Rate (lbm/sec)
Time (sec)


B&W (OCONEE) 90% DBA LOCA PIN FAILURE
cold leg flows
151000000-mflowj
161000000-mflowj
251000000-mflowj
261000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

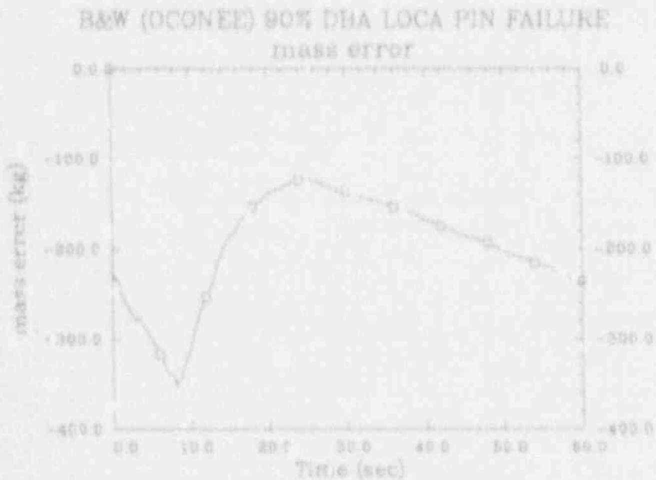

B&W (OCONEE) 90% DBA LOCA PIN FAILURE
hot channel core flow
11010000-mflowj
13010000-mflowj
15010000-mflowj
17010000-mflowj
19010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)



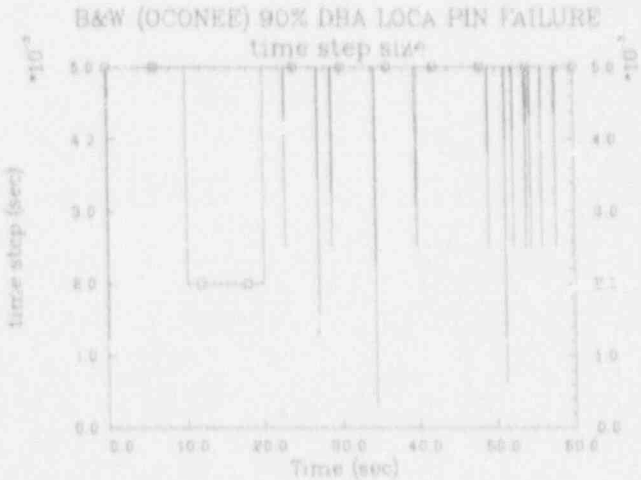
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
bl downcomer void fractions
Void fraction
Time (sec)



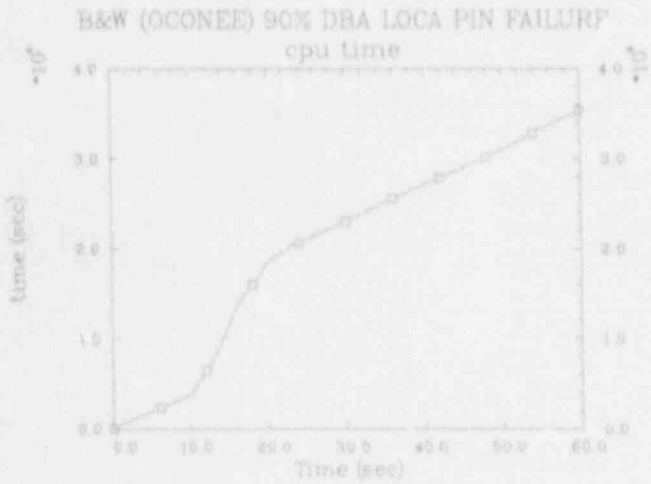
B&W (OCONEE) 90% DBA LOCA PIN FAILURE
il downcomer void fractions
Void fraction
Time (sec)



B&W (OCONEE) 90% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

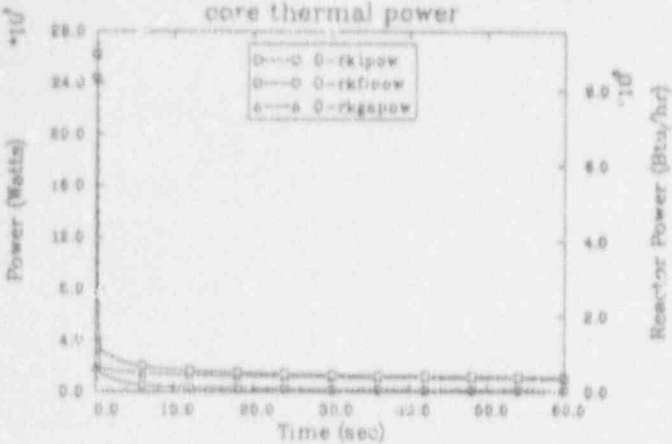


B&W (OCONEE) 90% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)

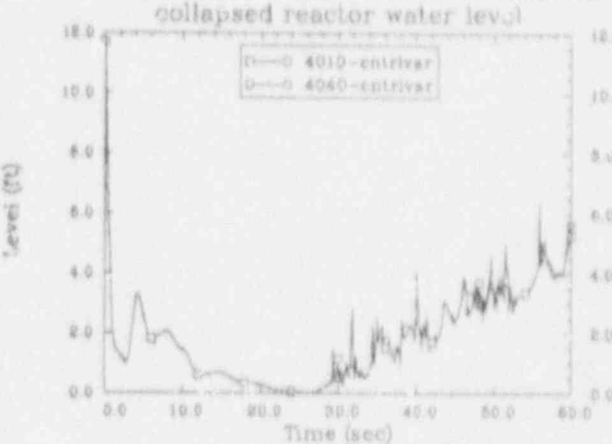


B&W (OCONEE) 90% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

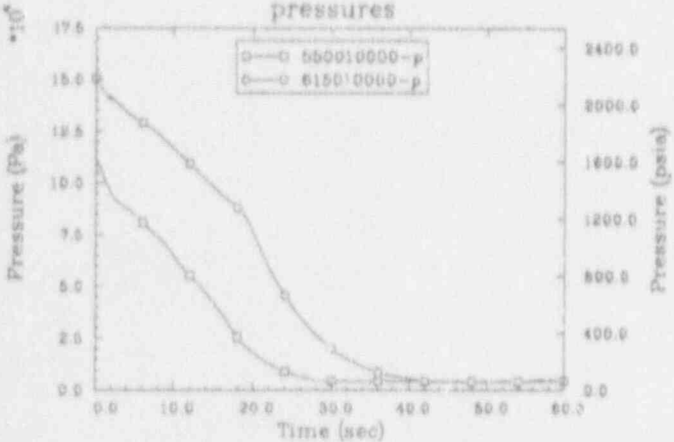
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
core thermal power



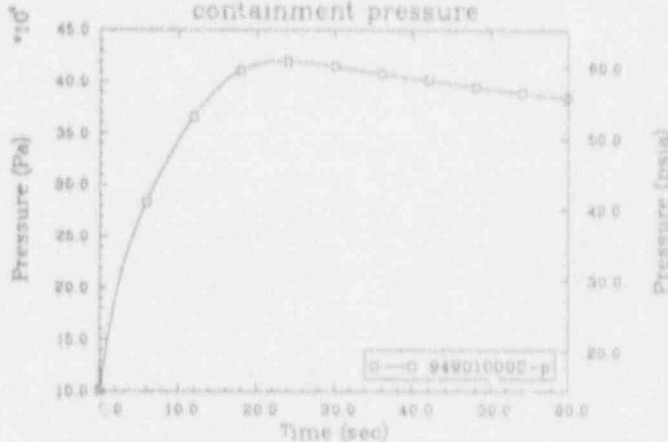
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
collapsed reactor water level



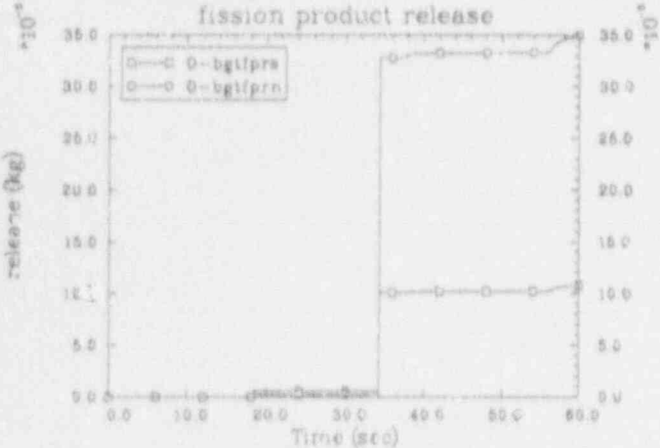
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
pressures



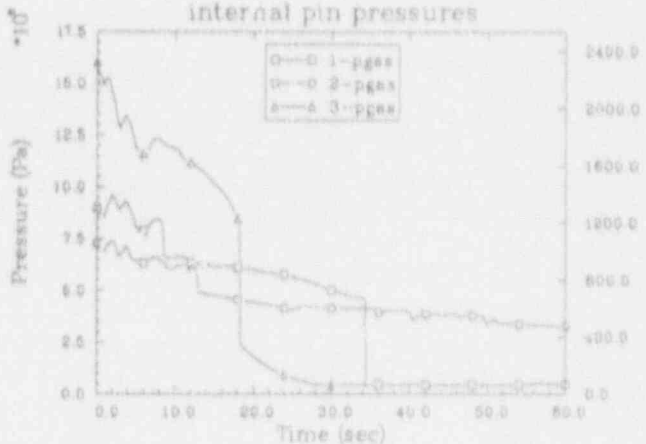
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
containment pressure



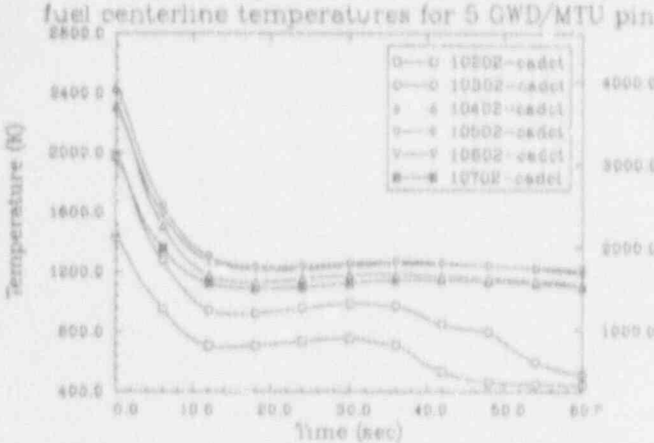
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
fission product release



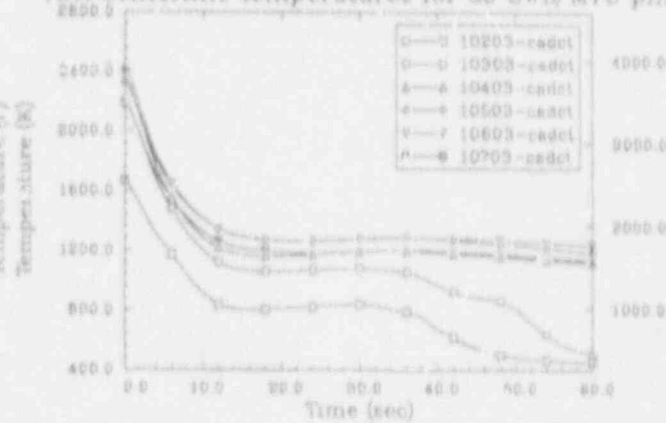
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
internal pin pressures



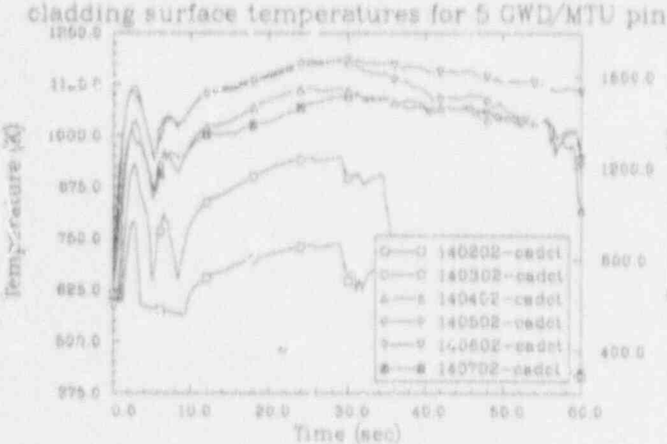
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



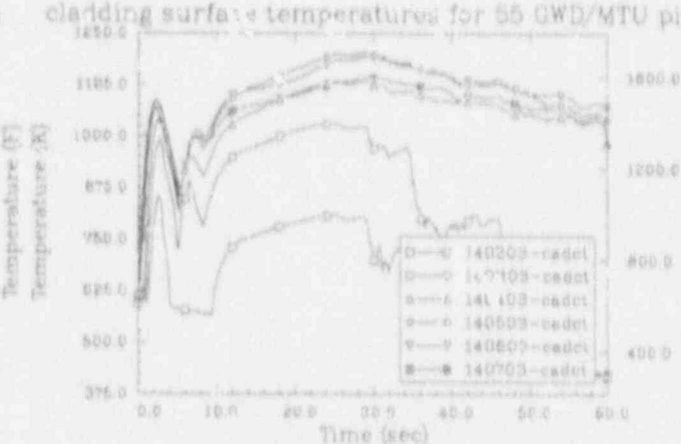
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
fuel centerline temperatures for 55 GWD/MTU pin



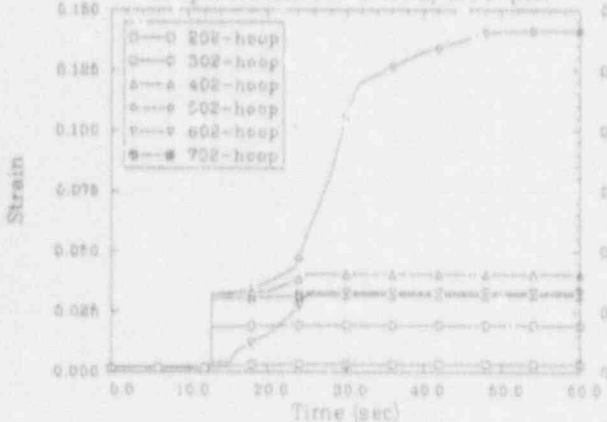
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



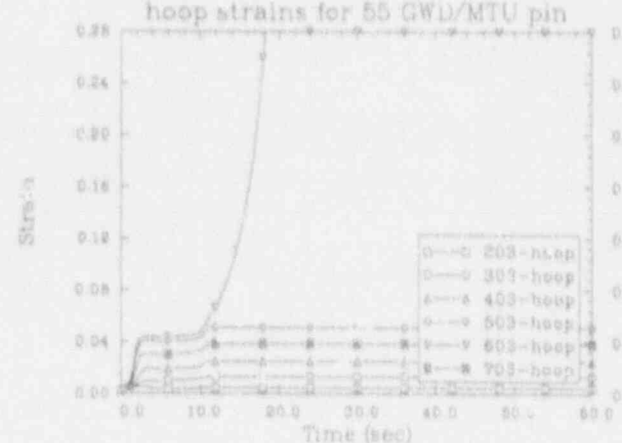
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
cladding surface temperatures for 55 GWD/MTU pin

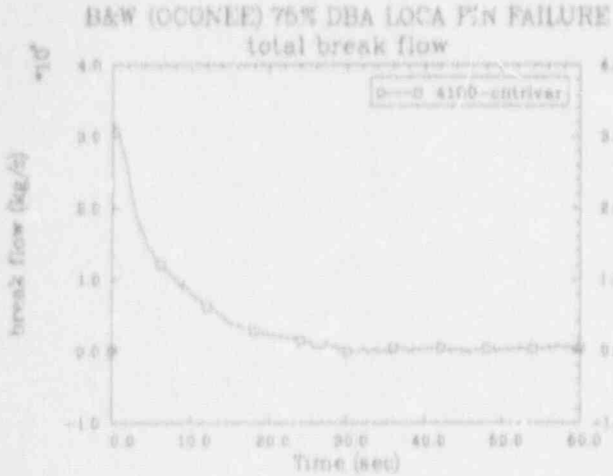


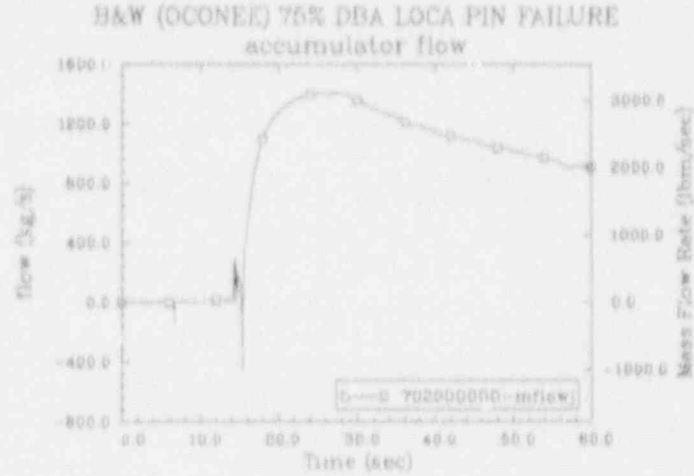
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin

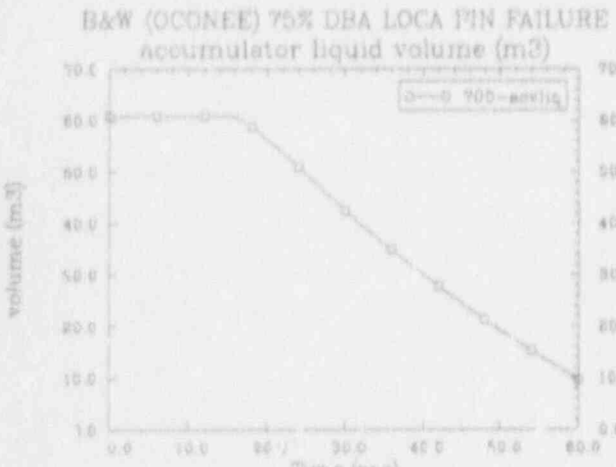


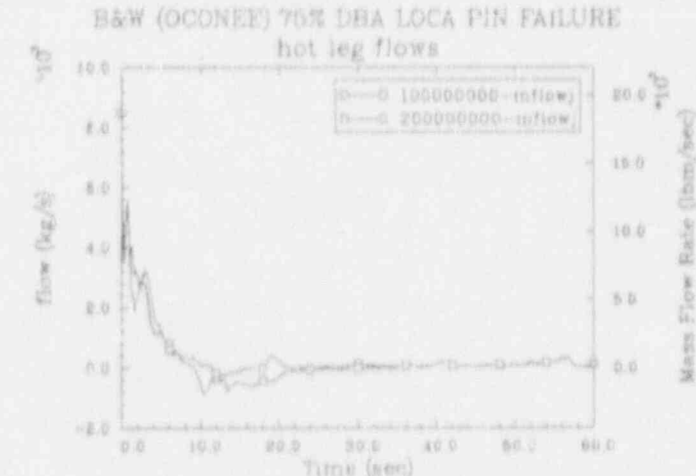
B&W (OCONEE) 75% DBA LOCA PIN FAILURE
hoop strains for 55 GWD/MTU pin

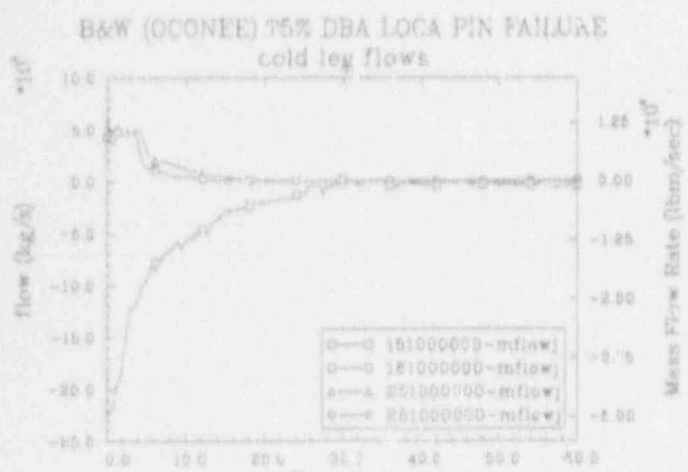


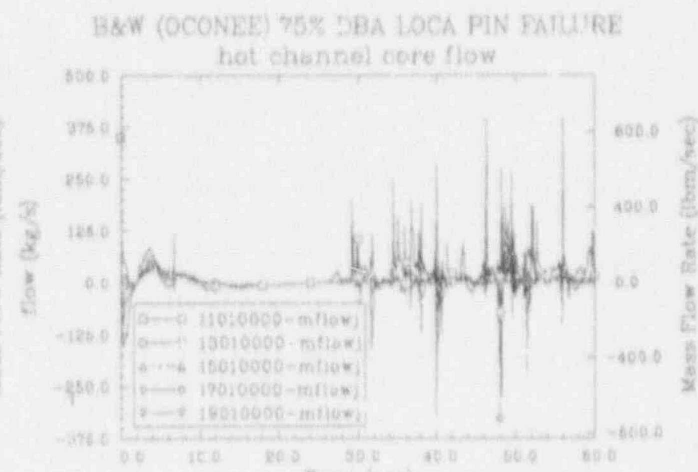

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
total break flow
4100-cntrlvar
break flow (kg/s)
Time (sec)

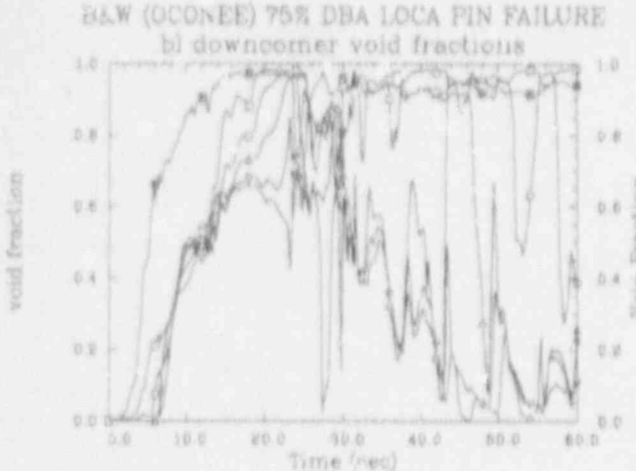

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
accumulator flow
702000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

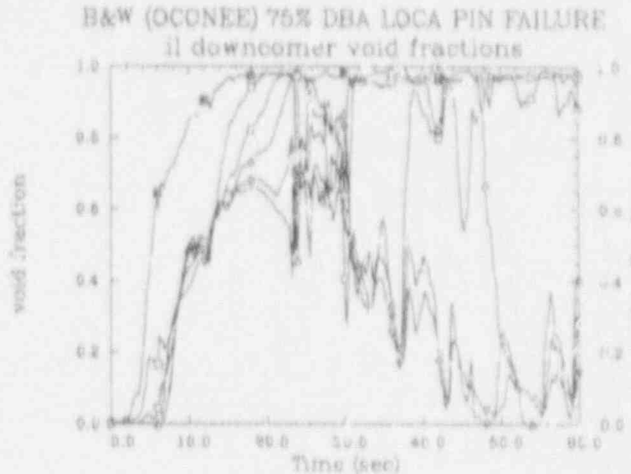

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)
700-acvliq
volume (m3)
Time (sec)

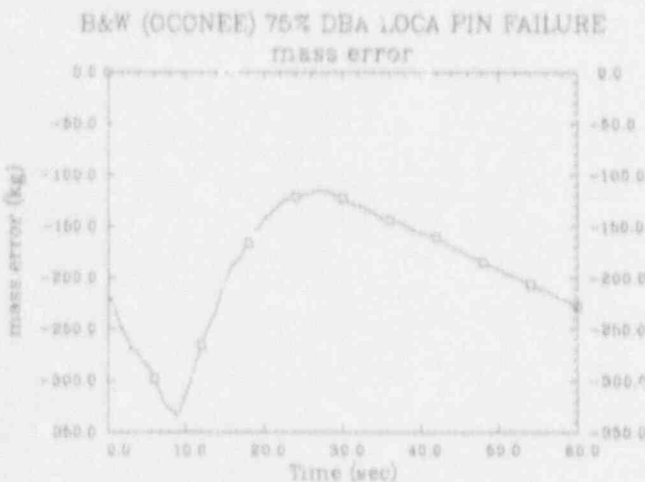

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
hot leg flows
100000000-mflowj
200000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

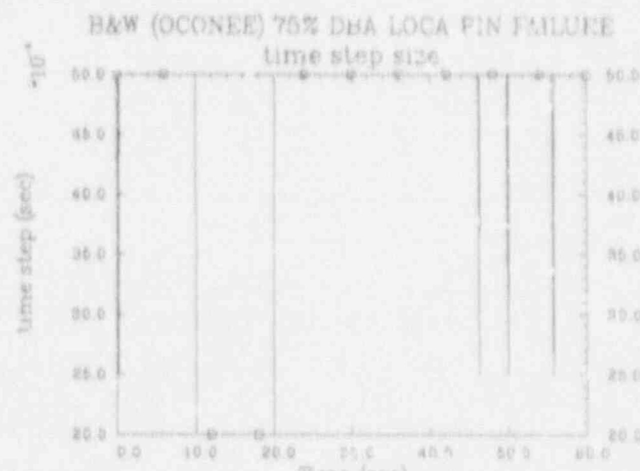

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
cold leg flows
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

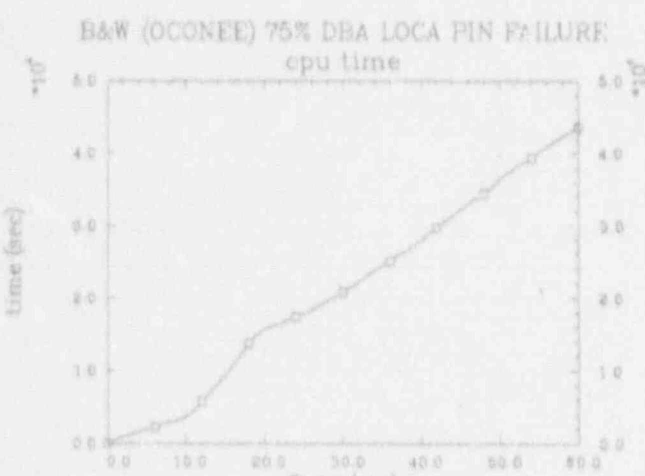

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
hot channel core flow
11010000-mflowj
13010000-mflowj
15010000-mflowj
17010000-mflowj
19010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

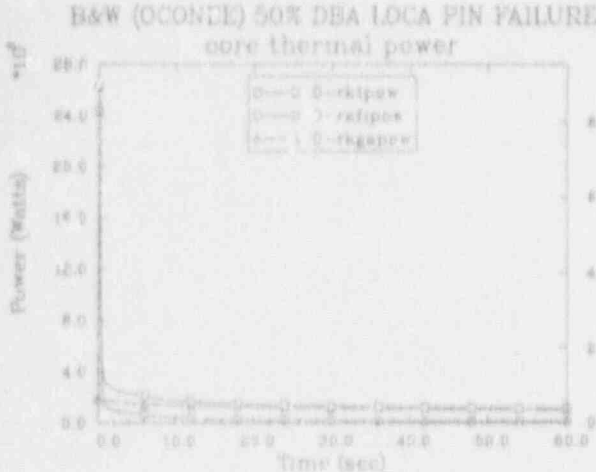

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
b) downcomer void fractions
void fraction
Void Fraction
Time (sec)

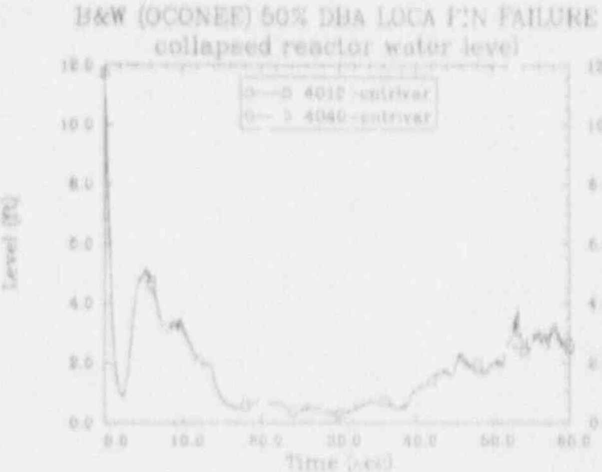

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
i) downcomer void fractions
void fraction
Void Fraction
Time (sec)

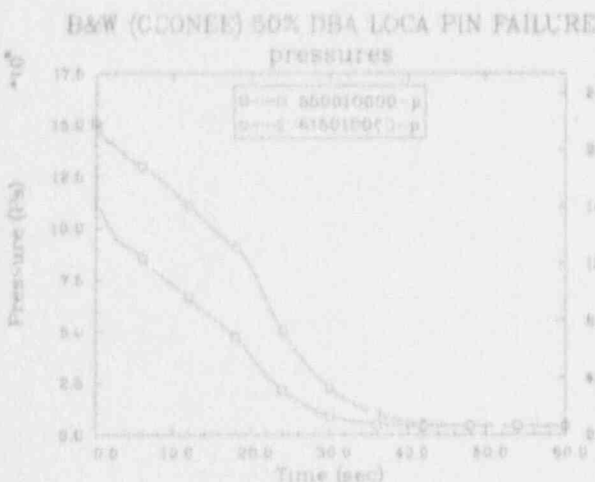

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

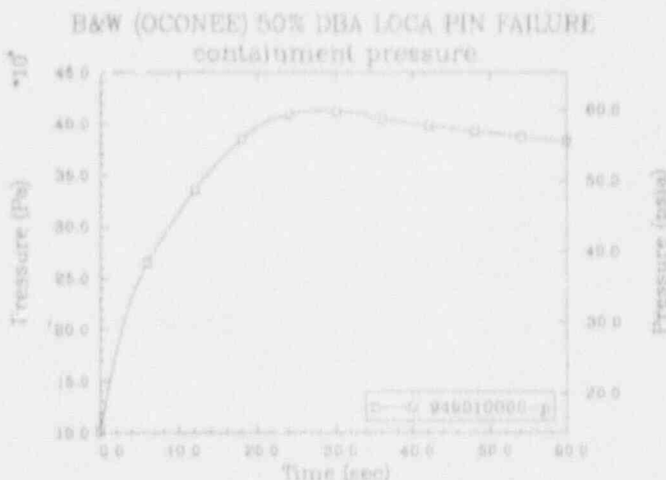

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)

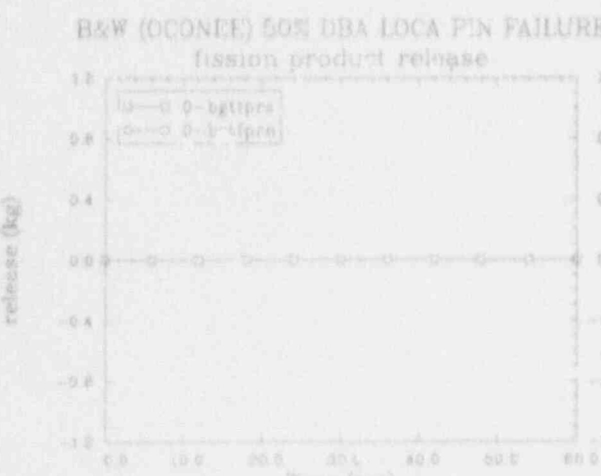

B&W (OCONEE) 75% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

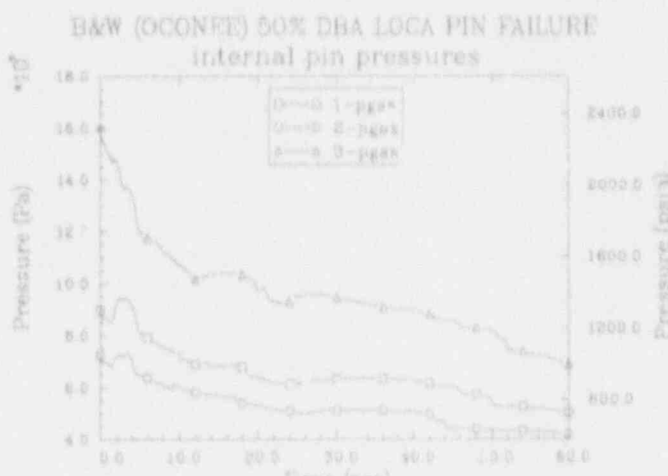

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
core thermal power
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


B&W (OCONEE) 50% DBA LOCA PIN FAILURE
collapsed reactor water level
Level (ft)

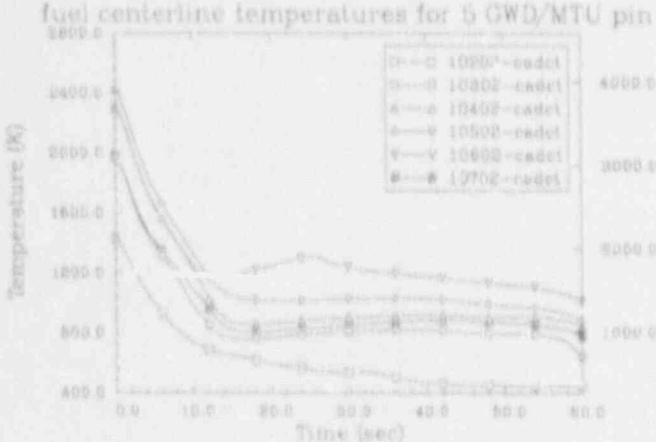

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
pressures
Pressure (Pa)
Pressure (psia)
Time (sec)


B&W (OCONEE) 50% DBA LOCA PIN FAILURE
containment pressure
Pressure (Pa)
Pressure (psia)
Time (sec)

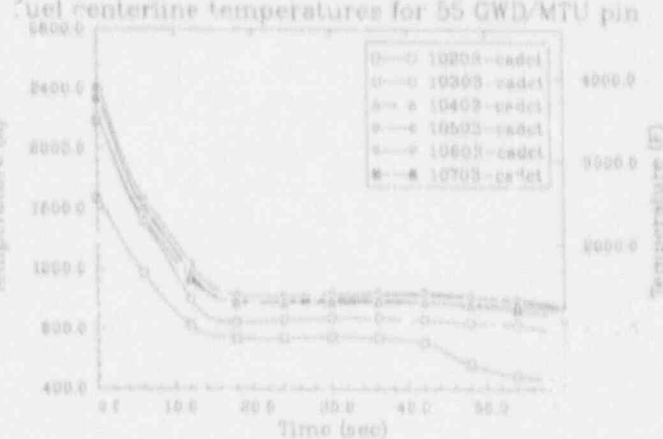

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
fission product release
release (kg)
Time (sec)


B&W (OCONEE) 50% DBA LOCA PIN FAILURE
internal pin pressures
Pressure (Pa)
Pressure (psia)
Time (sec)

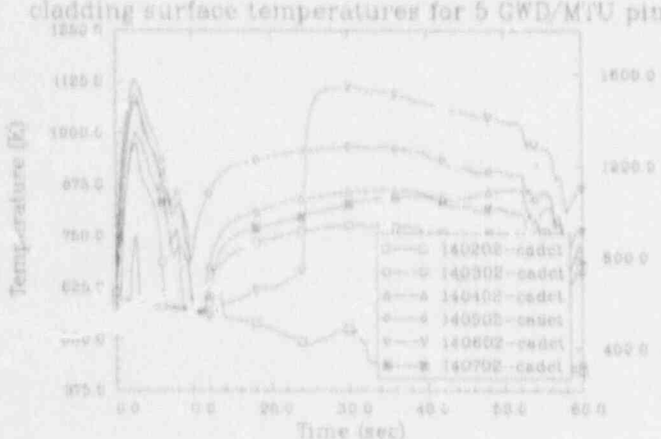
B&W (OCONEE) 50% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



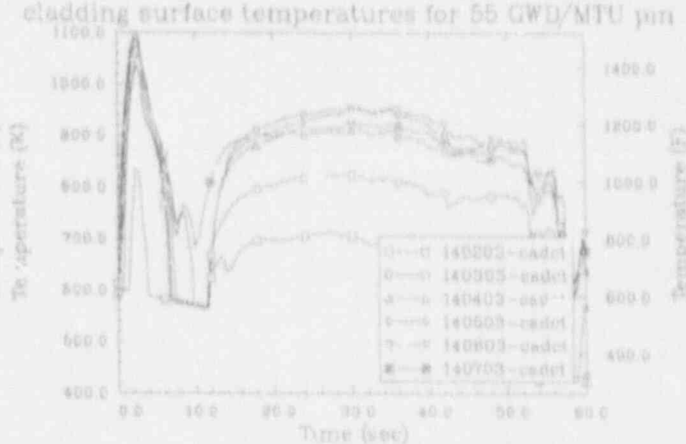
B&W (OCONEE) 50% DBA LOCA PIN FAILURE
fuel centerline temperatures for 55 GWD/MTU pin



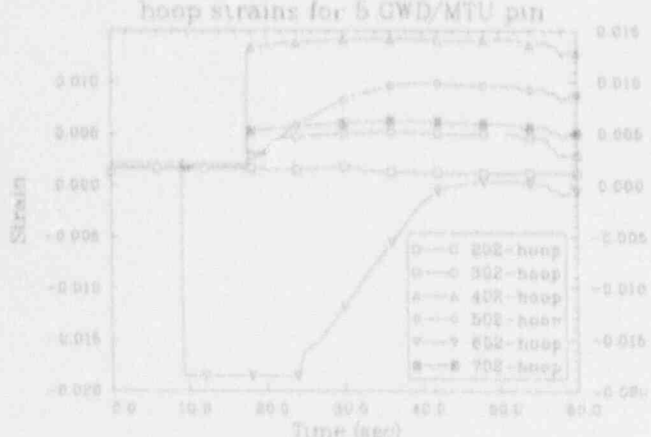
B&W (OCONEE) 50% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



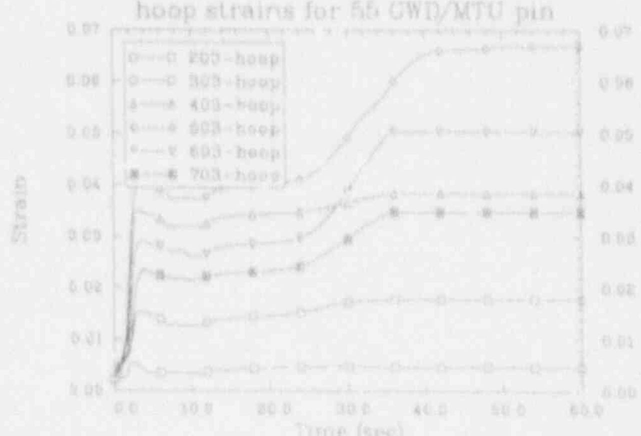
B&W (OCONEE) 50% DBA LOCA PIN FAILURE
cladding surface temperatures for 55 GWD/MTU pin

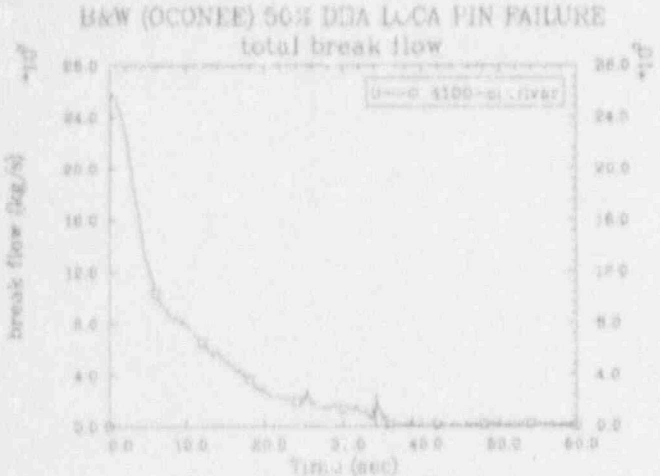


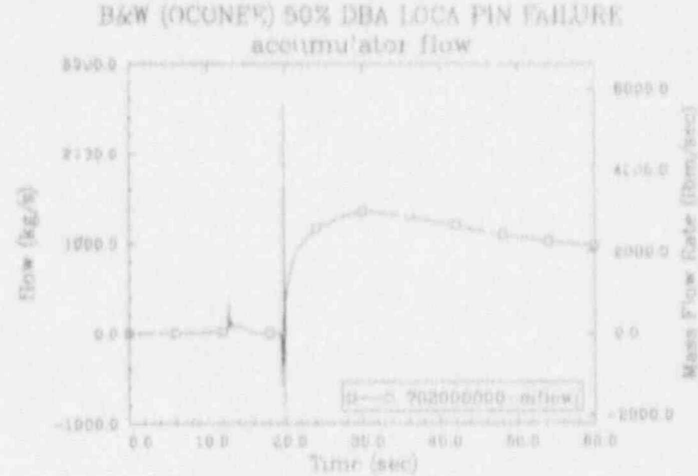
B&W (OCONEE) 50% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin

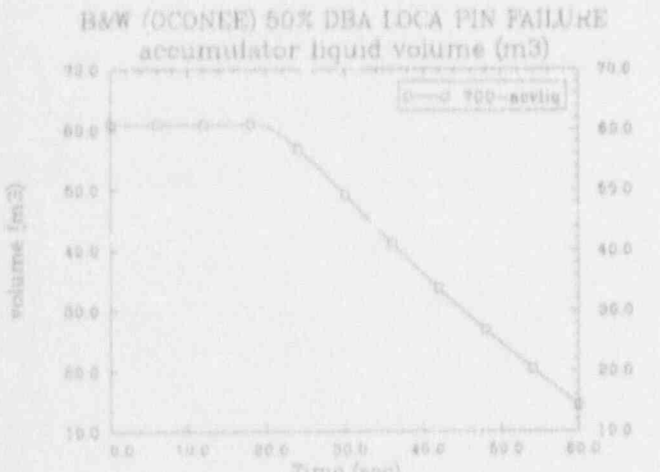


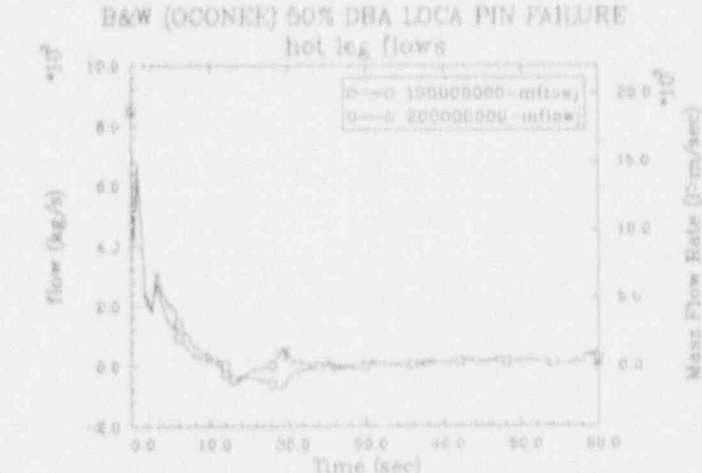
B&W (OCONEE) 50% DBA LOCA PIN FAILURE
hoop strains for 55 GWD/MTU pin

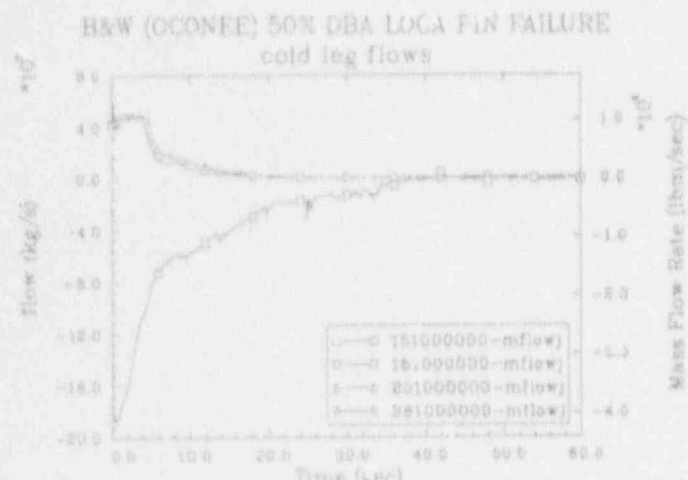


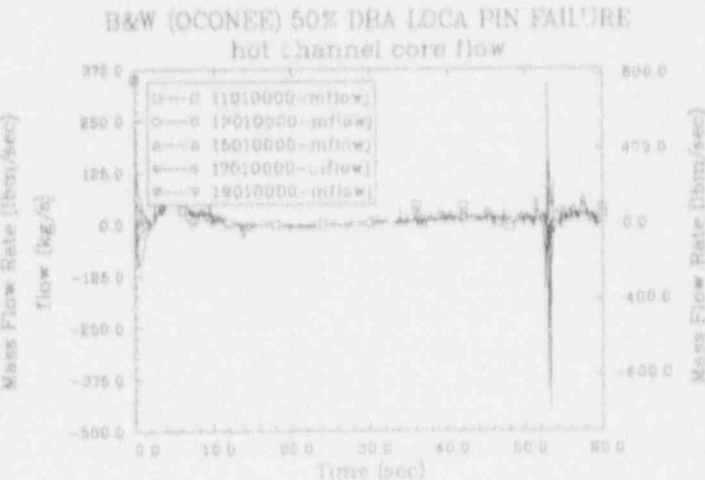

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
total break flow
break flow (kg/s)
Time (sec)

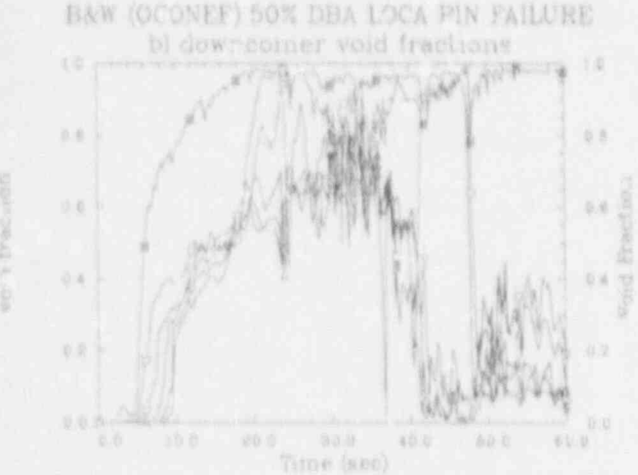

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
accumulator flow
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)
702000000-mflowj

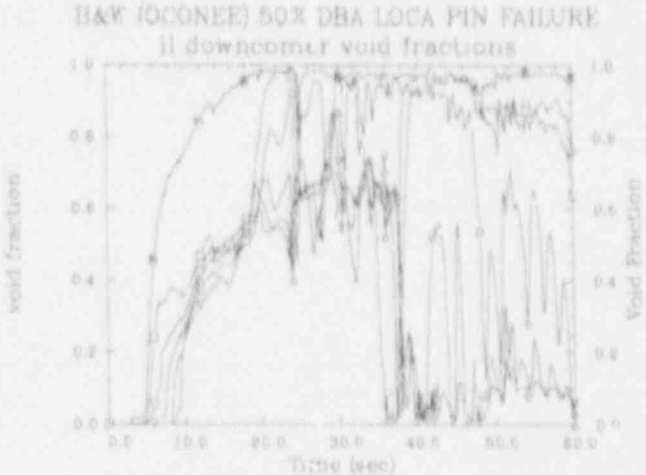

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)
volume (m3)
Time (sec)
700-acvliq

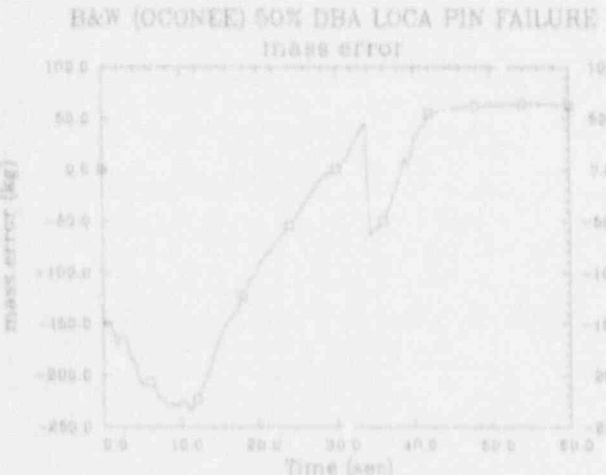

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
hot leg flows
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)
100000000-mflowj
200000000-mflowj

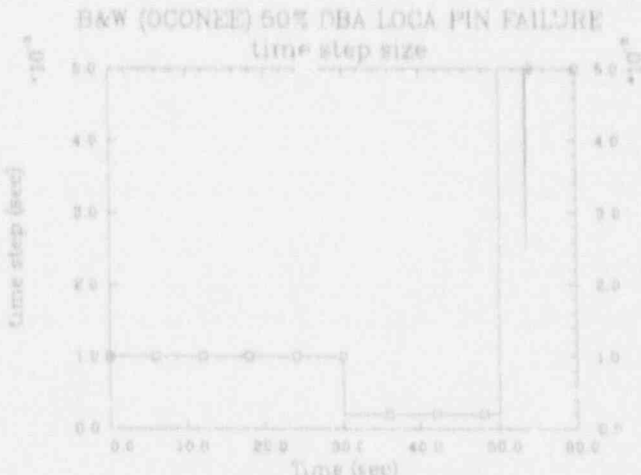

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
cold leg flows
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)
151000000-mflowj
201000000-mflowj
251000000-mflowj

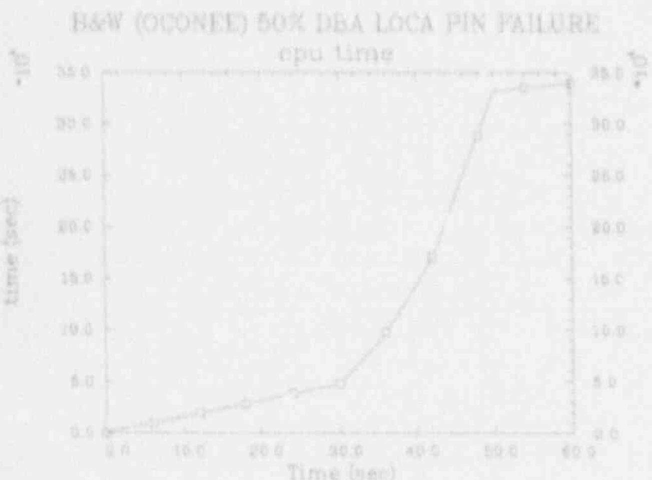

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
hot channel core flow
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)
11010000-mflowj
13010000-mflowj
15010000-mflowj
19010000-mflowj

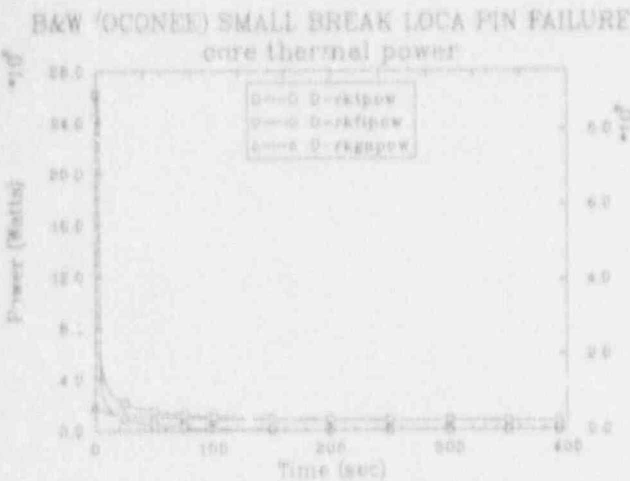

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

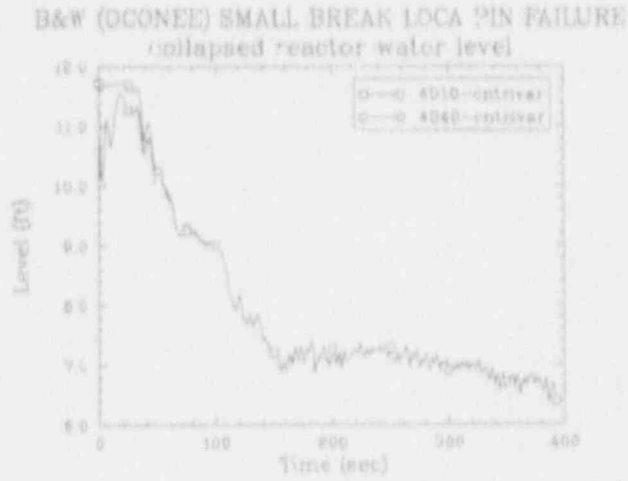

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
il downcomer void fractions
void fraction
Void Fraction
Time (sec)

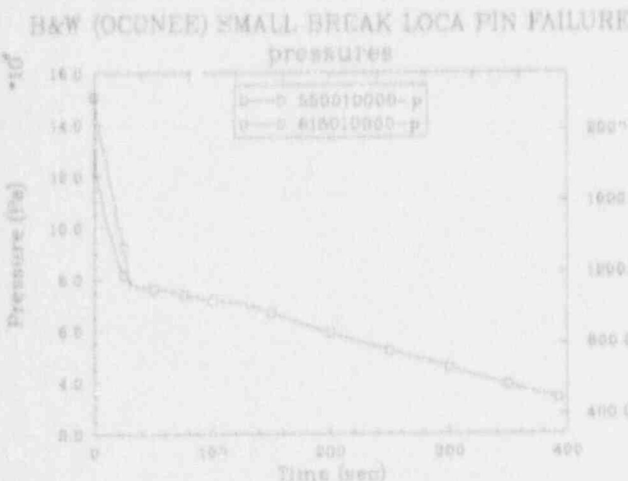

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

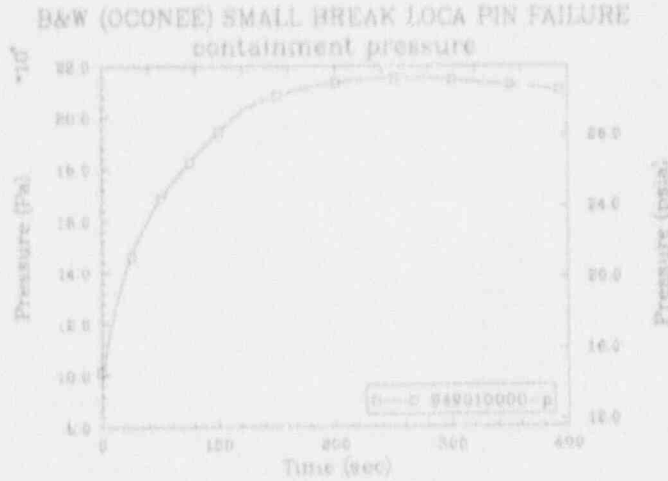

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)

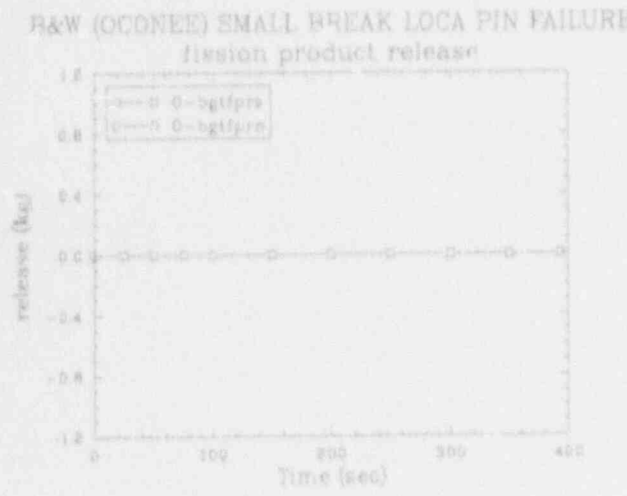

B&W (OCONEE) 50% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

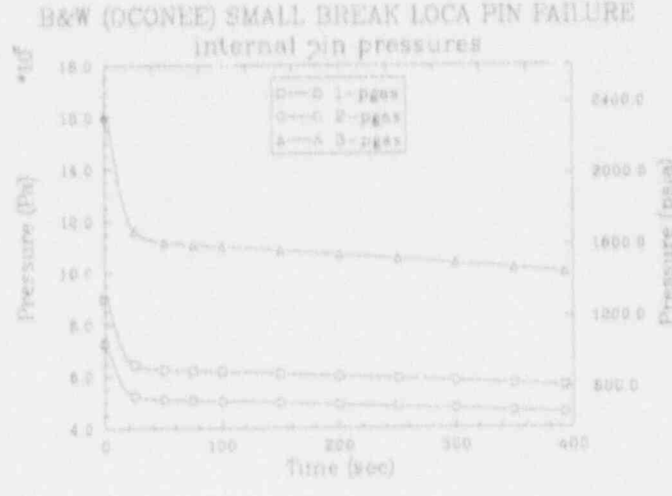

B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
core thermal power
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
collapsed reactor water level
Level (ft)
Time (sec)

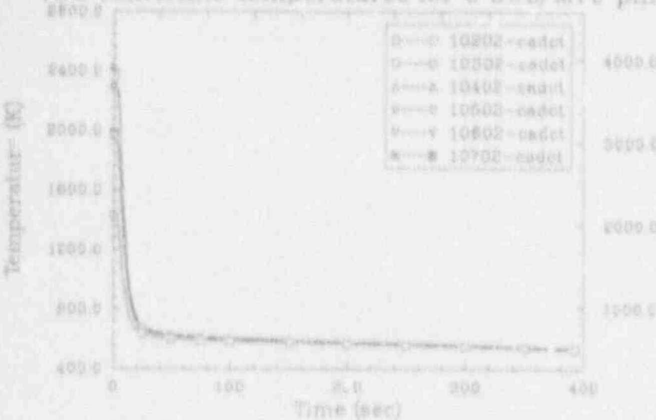

B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
pressures
Pressure (Pa)
Pressure (psia)
Time (sec)


B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
containment pressure
Pressure (Pa)
Pressure (psia)
Time (sec)

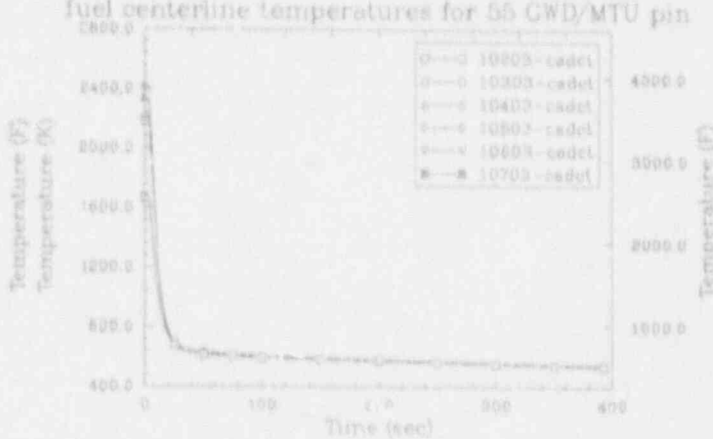

B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
fission product release
release (kg)
Time (sec)


B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
internal pin pressures
Pressure (Pa)
Pressure (psia)
Time (sec)

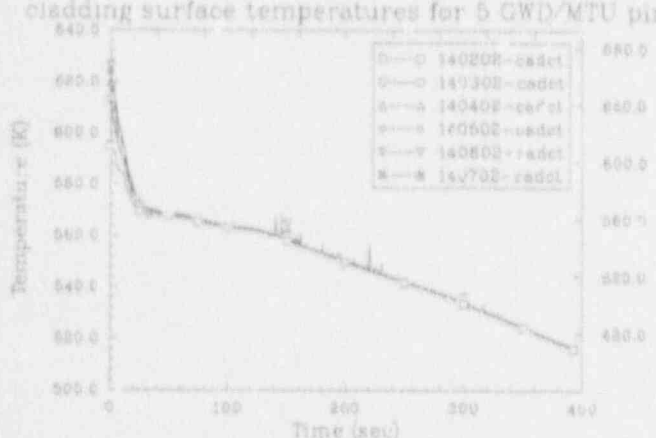
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



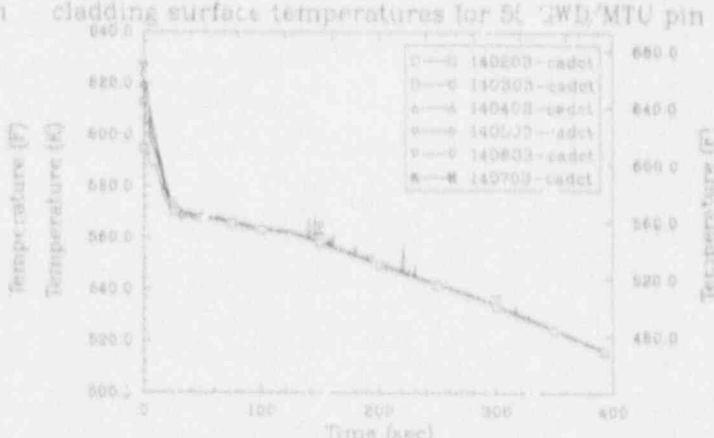
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
fuel centerline temperatures for 55 GWD/MTU pin



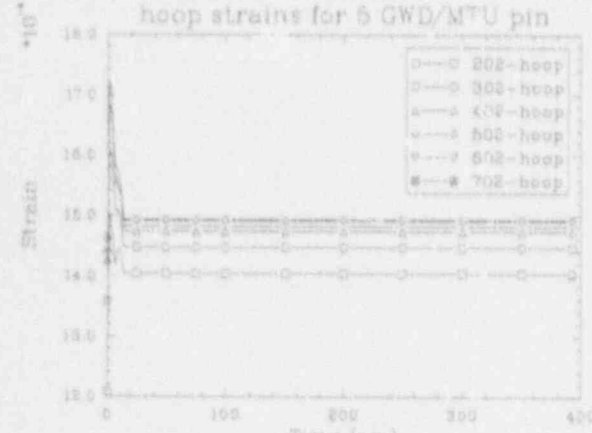
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



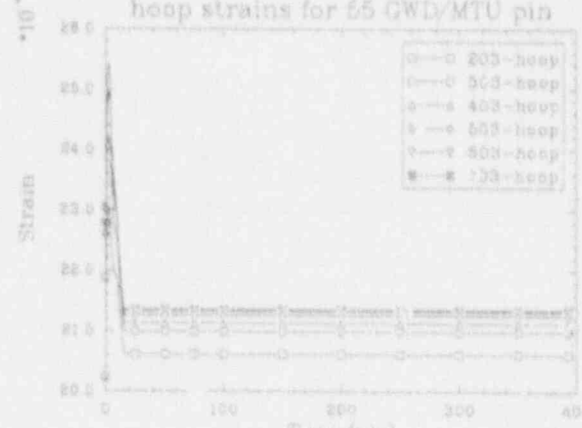
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
cladding surface temperatures for 55 GWD/MTU pin



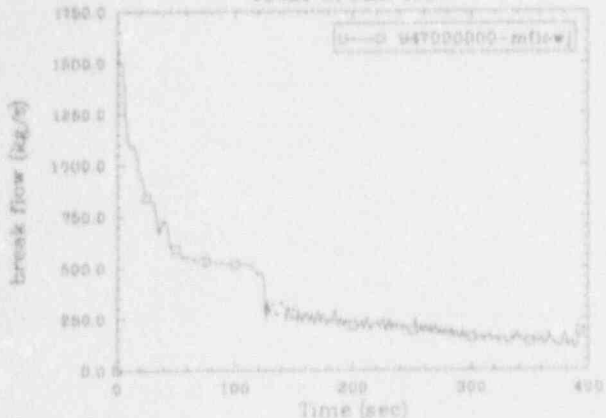
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin



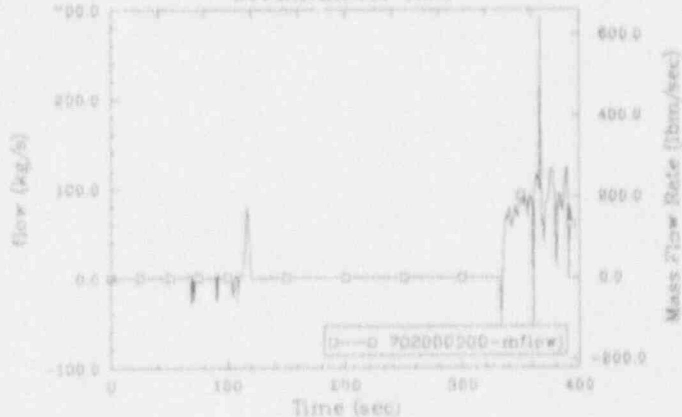
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
hoop strains for 55 GWD/MTU pin



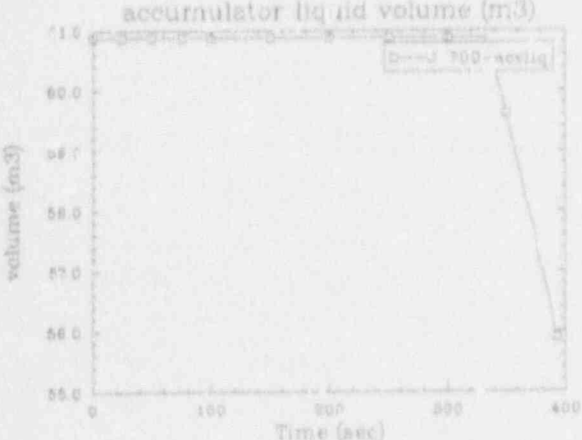
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
total break flow



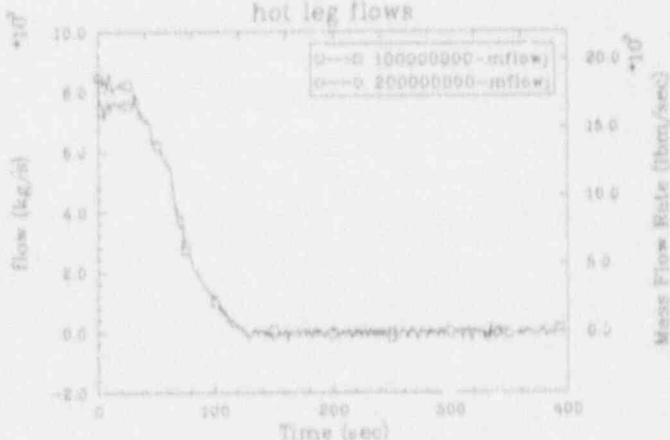
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
accumulator flow



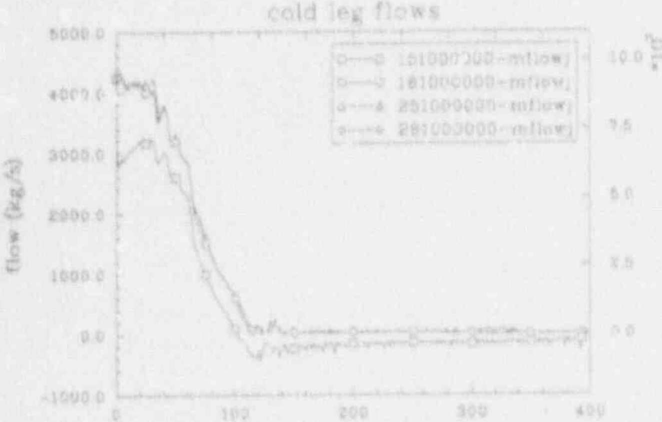
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
accumulator liquid volume (m3)



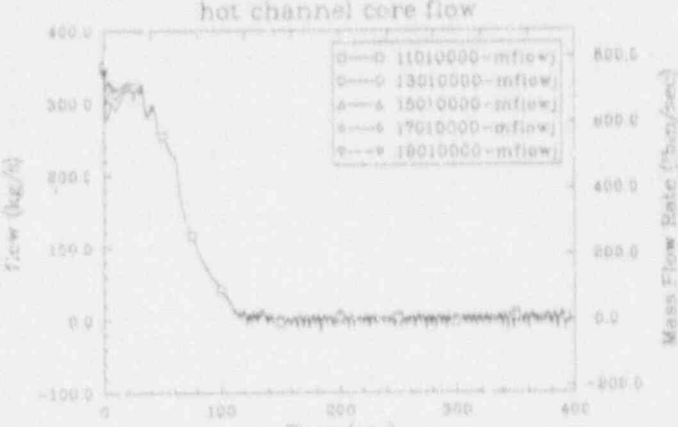
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
hot leg flows



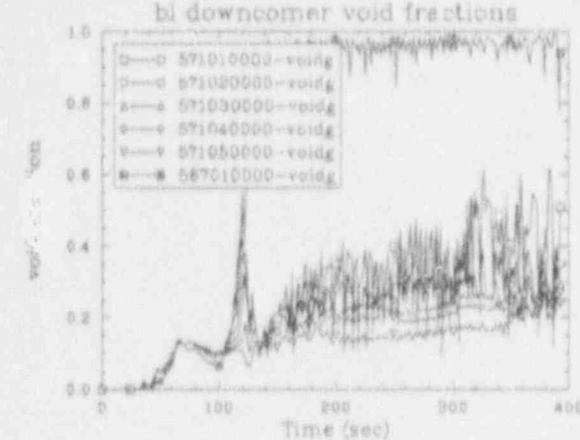
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
cold leg flows



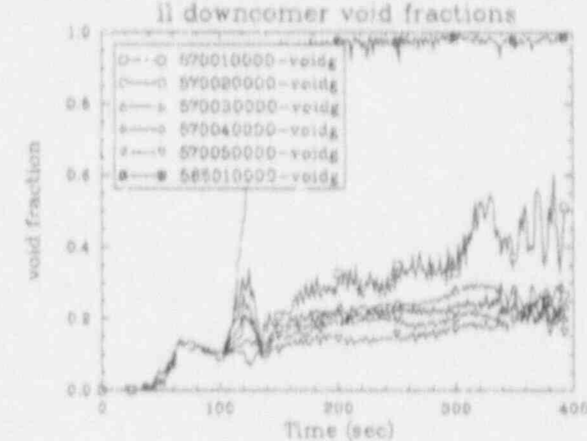
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
hot channel core flow



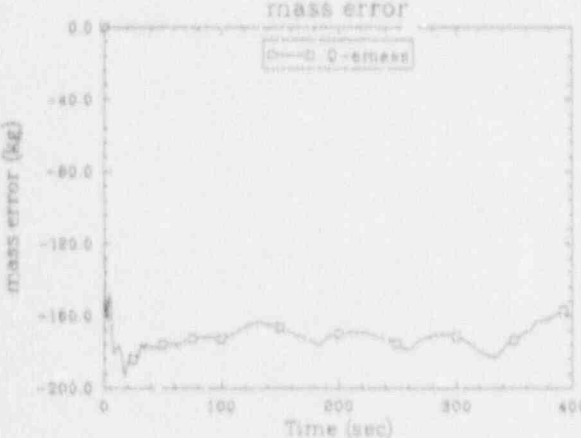
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
bl downcomer void fractions



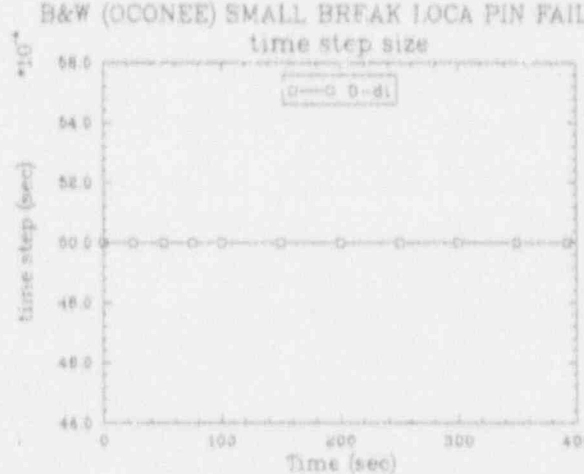
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
ll downcomer void fractions



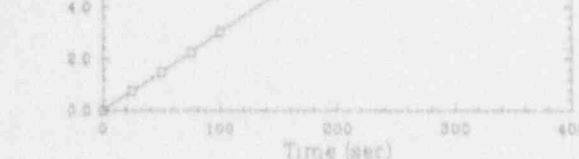
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
mass error



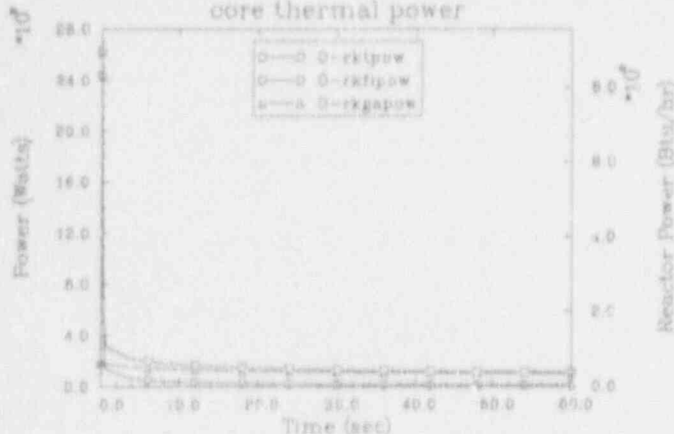
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
time step size



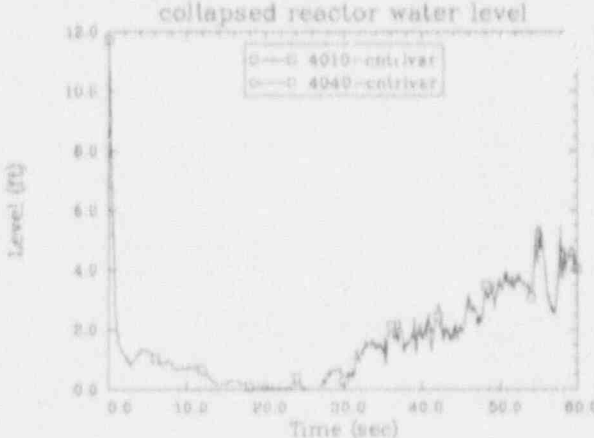
B&W (OCONEE) SMALL BREAK LOCA PIN FAILURE
cpu time



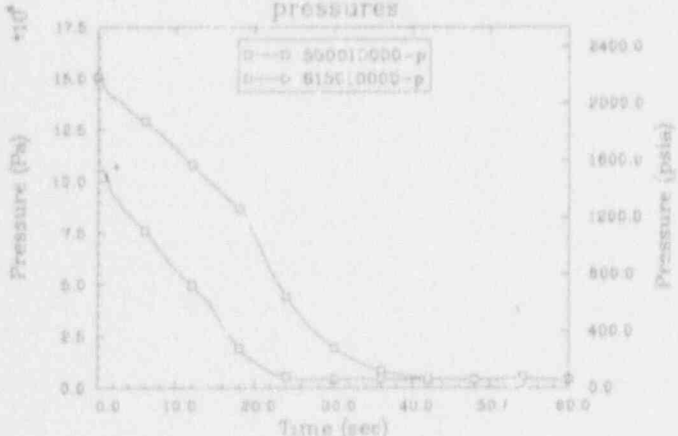
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
core thermal power



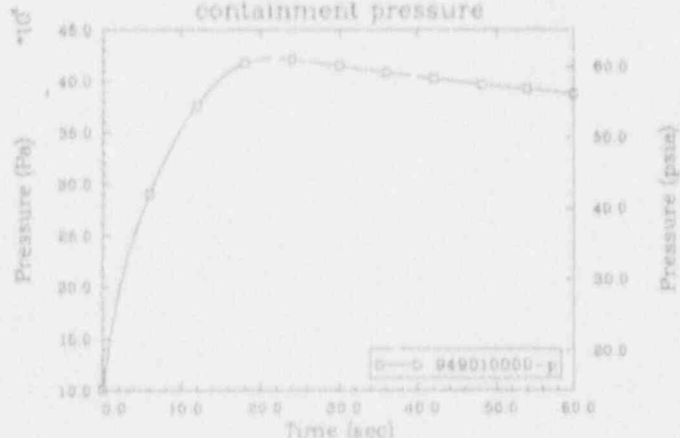
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
collapsed reactor water level



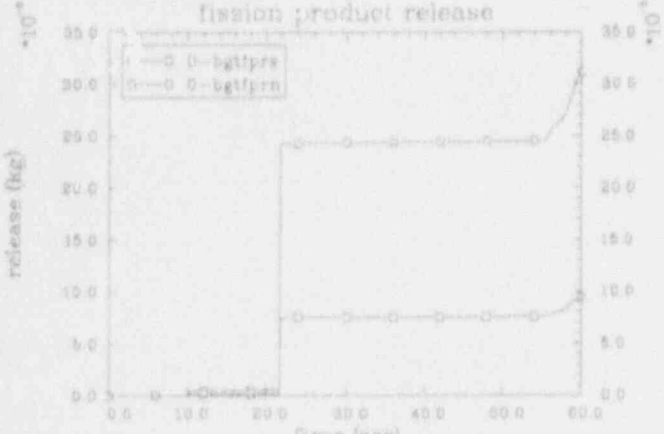
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
pressures



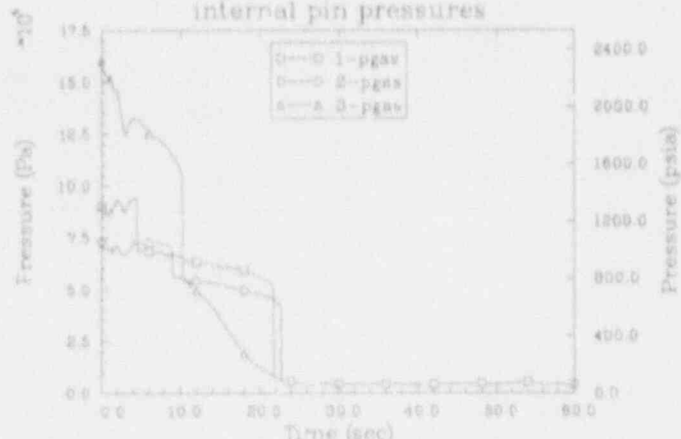
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
containment pressure



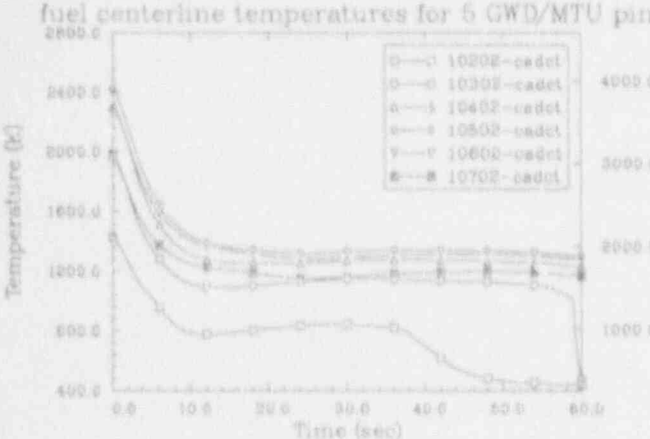
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
fission product release



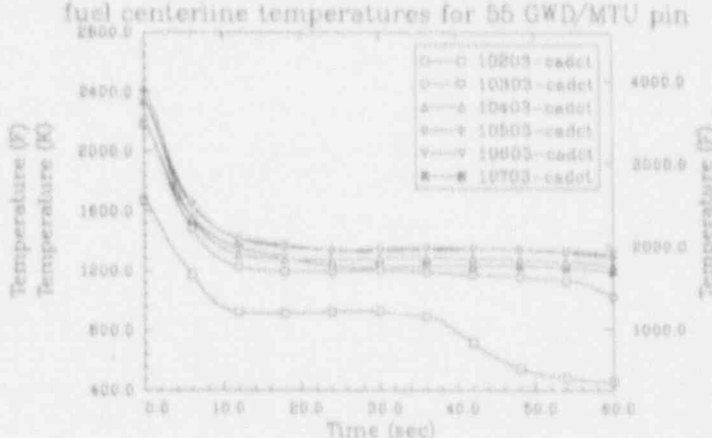
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
internal pin pressures



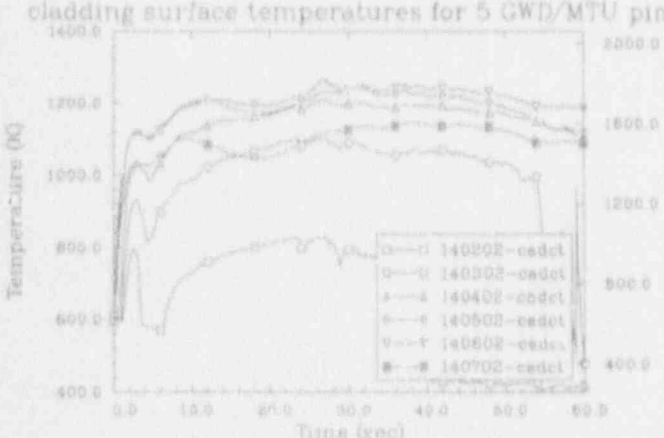
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
fuel centerline temperatures for 5 GWD/MTU pin



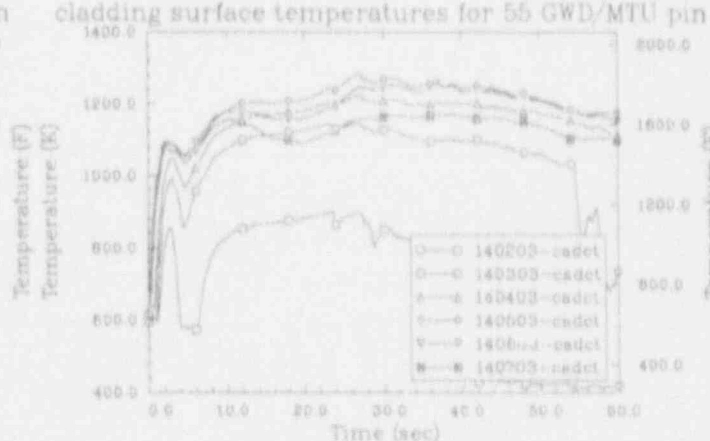
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
fuel centerline temperatures for 55 GWD/MTU pin



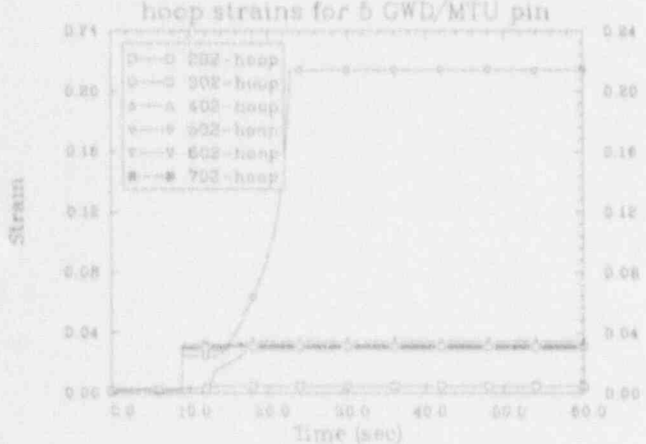
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
cladding surface temperatures for 5 GWD/MTU pin



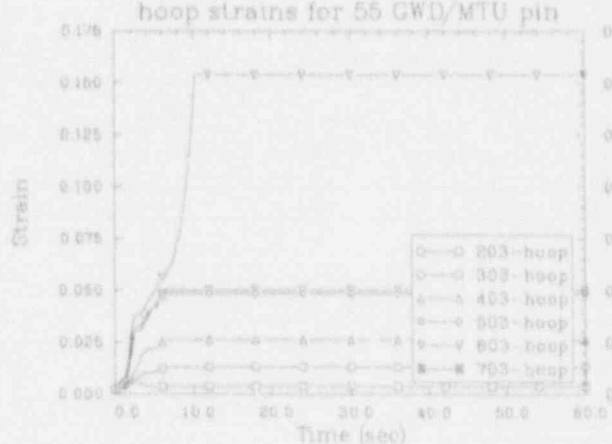
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
cladding surface temperatures for 55 GWD/MTU pin

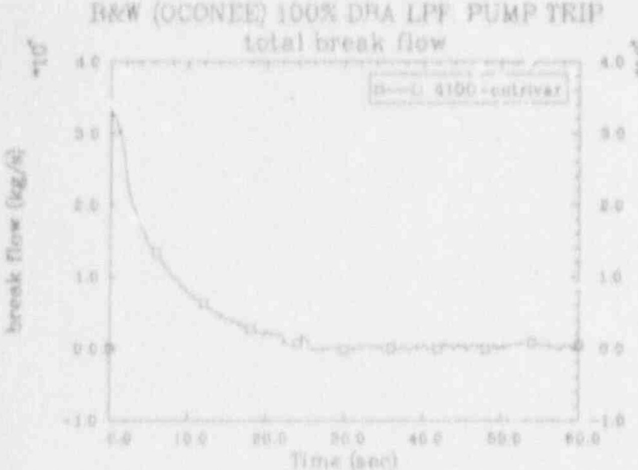


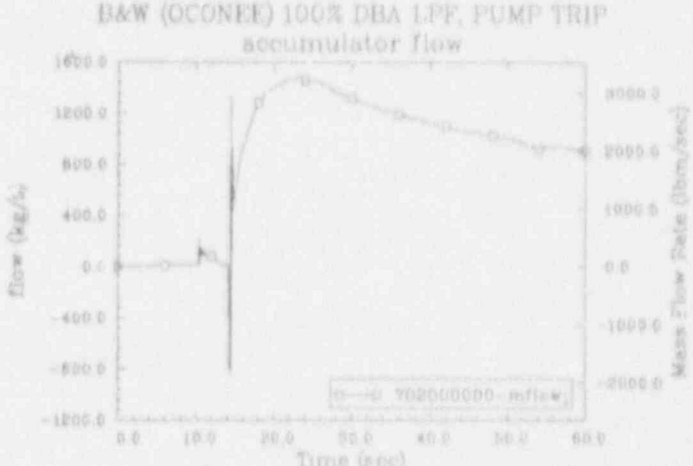
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
hoop strains for 5 GWD/MTU pin

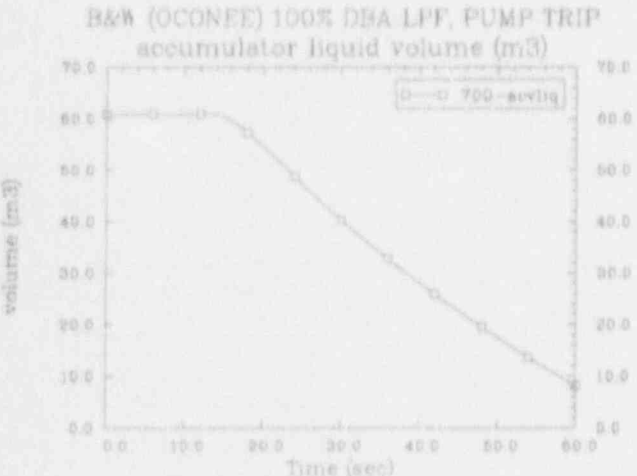


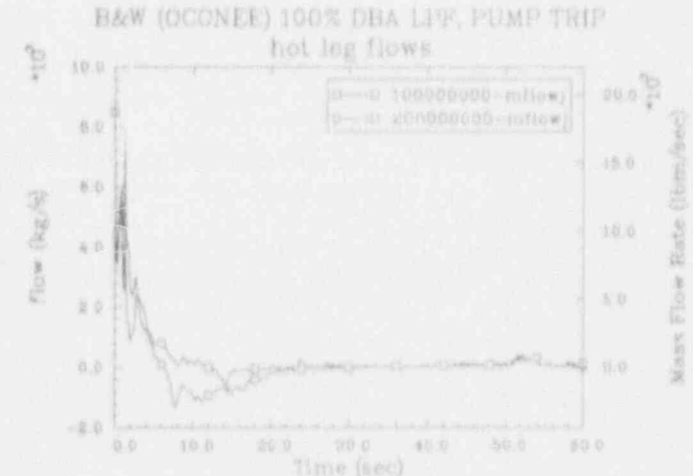
B&W (OCONEE) 100% DBA LPF, PUMP TRIP
hoop strains for 55 GWD/MTU pin

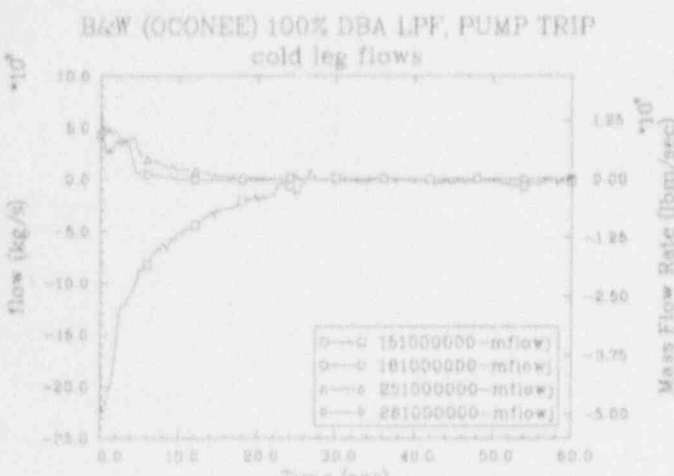


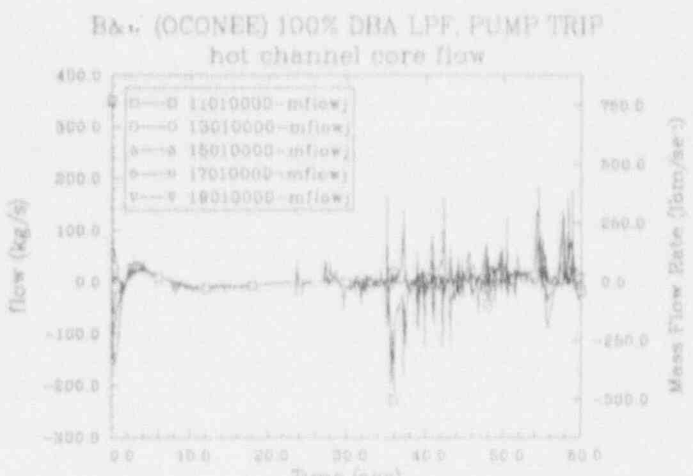

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
total break flow
*10^3
4100-cntrlvar
break flow (kg/s)
Time (sec)

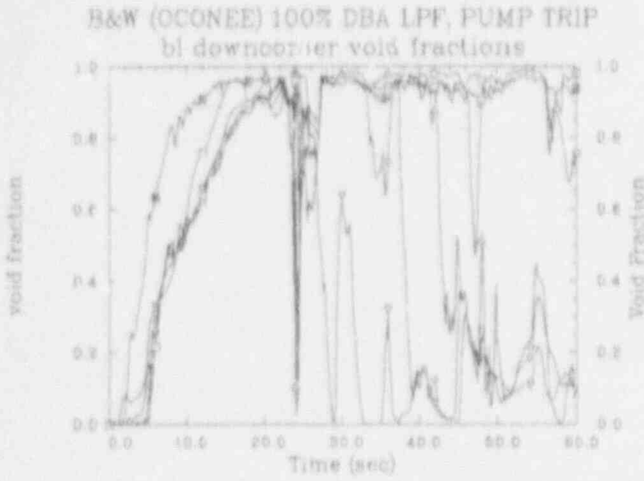

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
accumulator flow
702000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

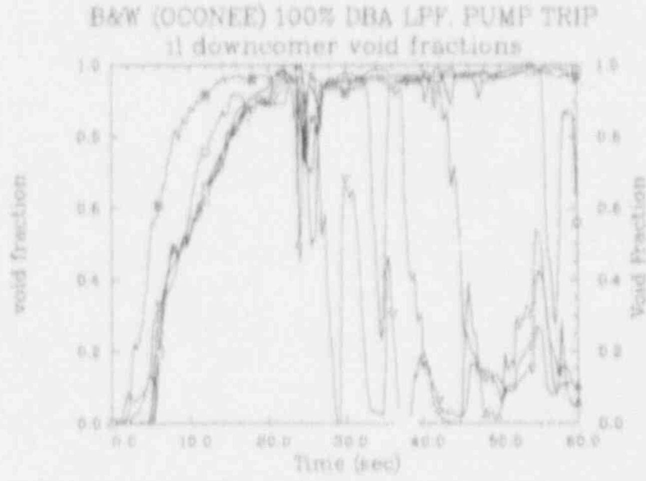

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
accumulator liquid volume (m3)
700-acvliq
volume (m3)
Time (sec)

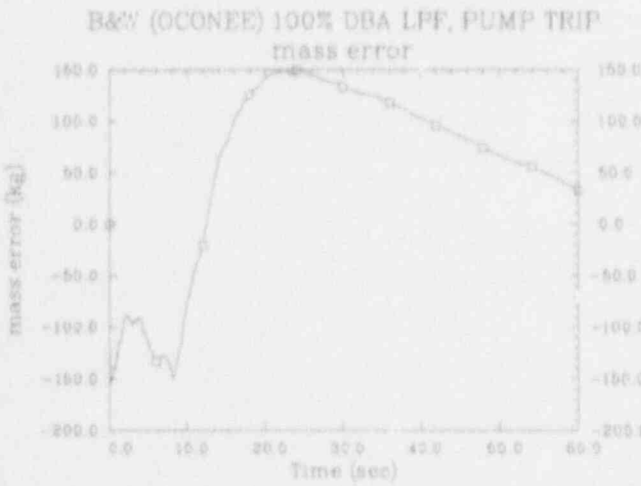

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
hot leg flows
*10^3
100000000-mflowj
200000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

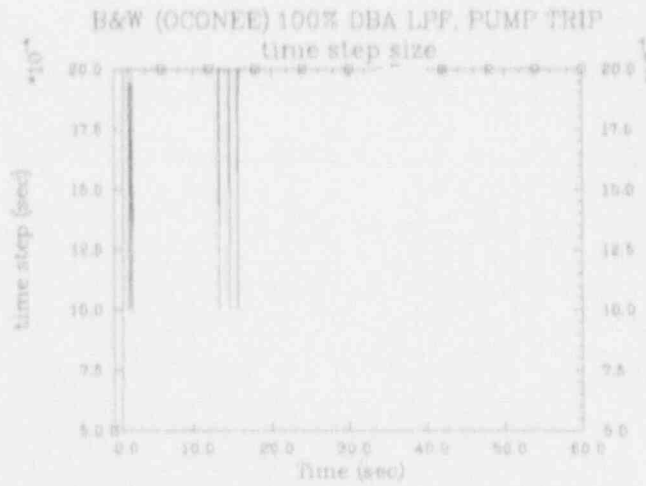

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
cold leg flows
*10^3
151000000-mflowj
161000000-mflowj
251000000-mflowj
261000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

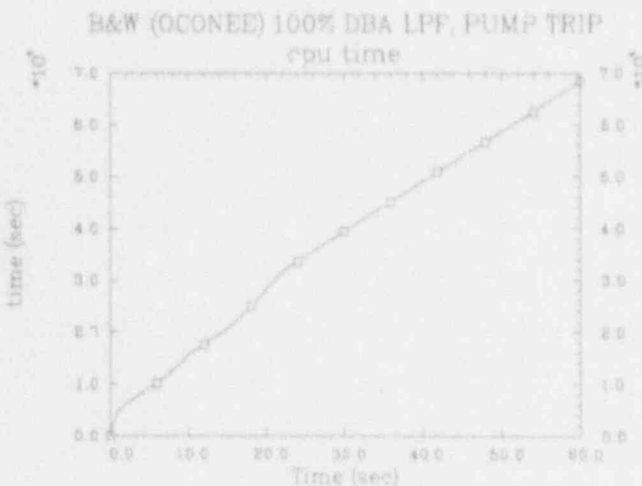

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
hot channel core flow
11010000-mflowj
13010000-mflowj
15010000-mflowj
17010000-mflowj
19010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

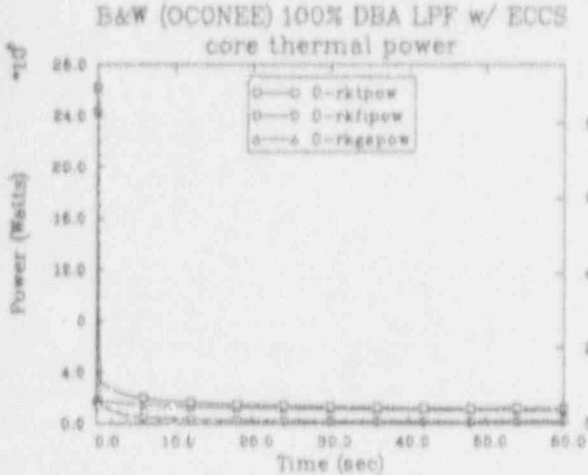

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

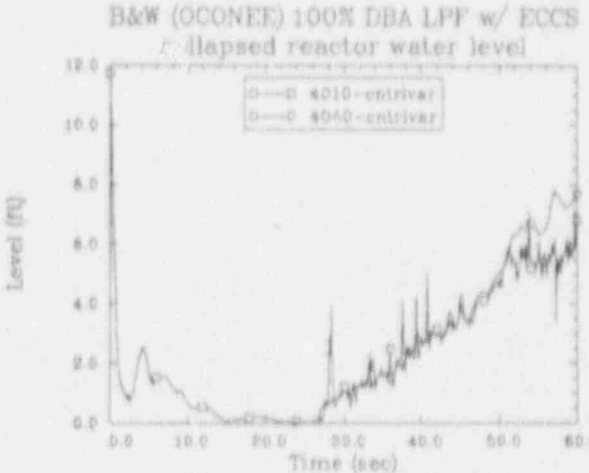

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
il downcomer void fractions
void fraction
Void Fraction
Time (sec)

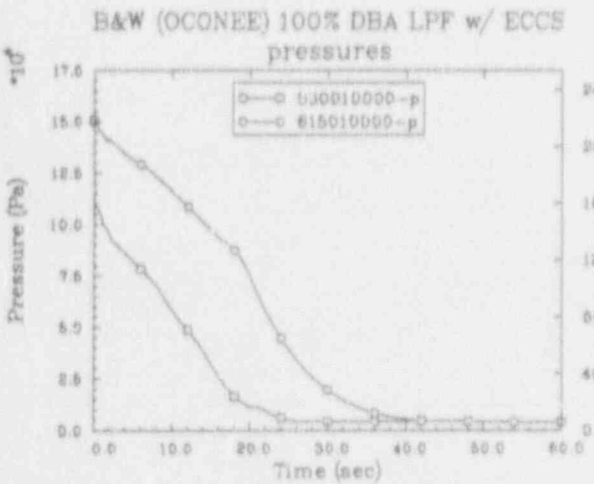

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
mass error
mass error (kg)
Time (sec)

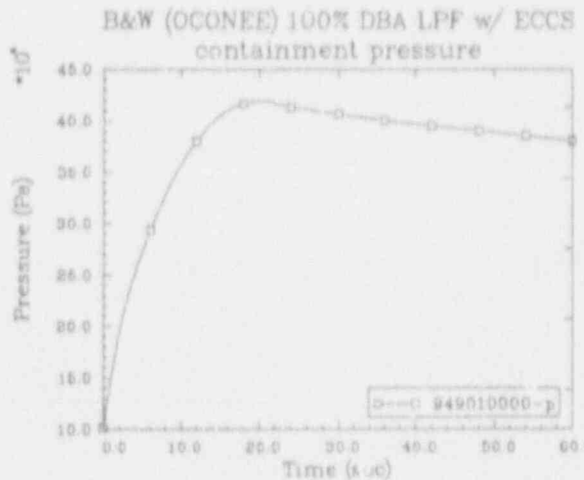

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
time step size
time step (sec)
Time (sec)

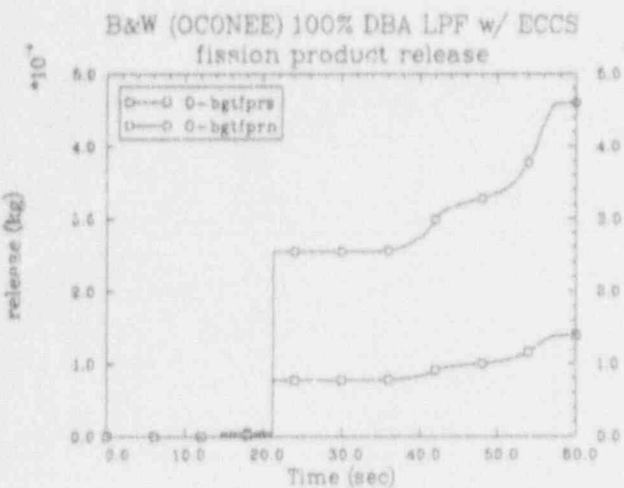

B&W (OCONEE) 100% DBA LPF, PUMP TRIP
cpu time
time (sec)
Time (sec)

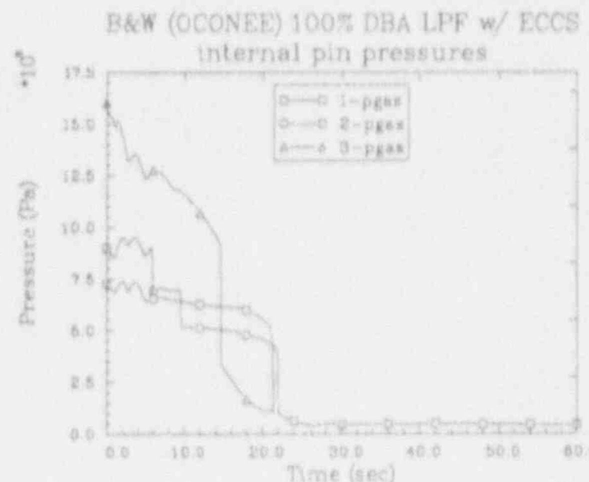

B&W (OCONEE) 100% DBA LPF w/ ECCS
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)

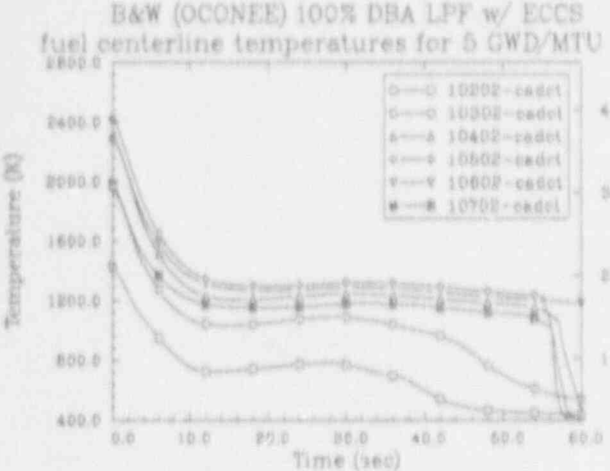

B&W (OCONEE) 100% DBA LPF w/ ECCS
4010-cntrlvar
4050-cntrlvar
Level (ft)
Time (sec)

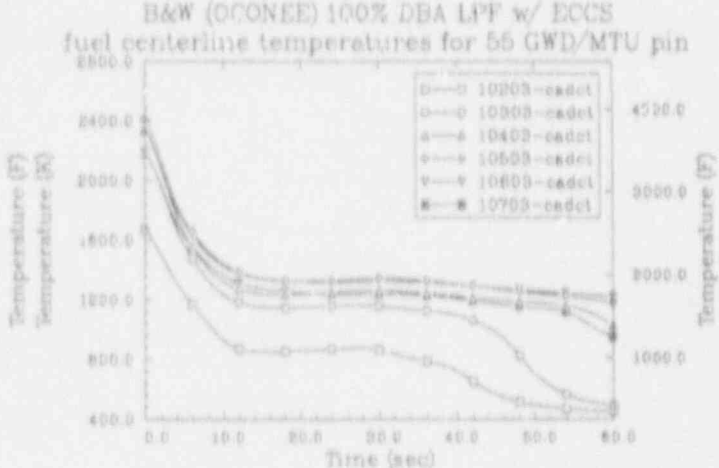

B&W (OCONEE) 100% DBA LPF w/ ECCS
pressures
615010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)

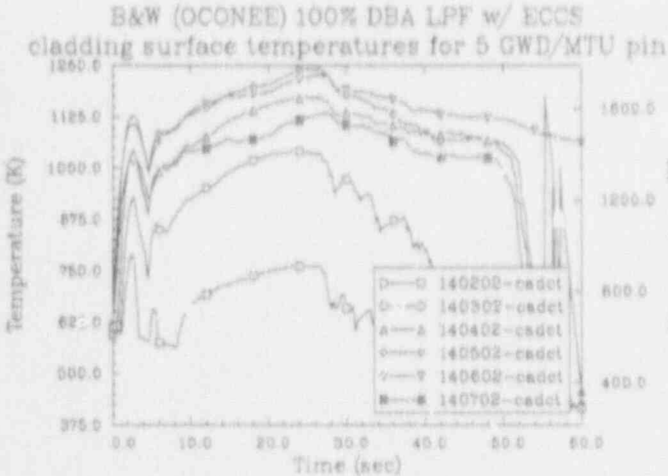

B&W (OCONEE) 100% DBA LPF w/ ECCS
containment pressure
949010000-p
Pressure (Pa)
Pressure (psia)

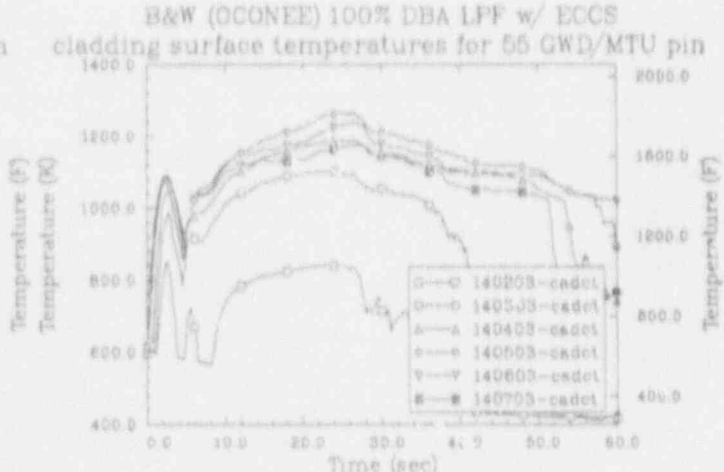

B&W (OCONEE) 100% DBA LPF w/ ECCS
0-bgtfprs
0-bgtfprn
Time (sec)

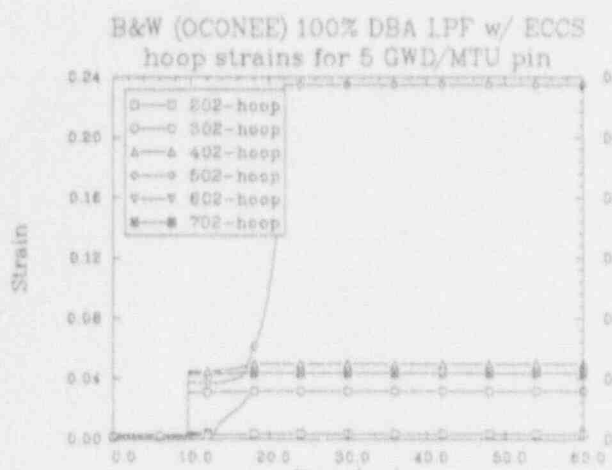

B&W (OCONEE) 100% DBA LPF w/ ECCS
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

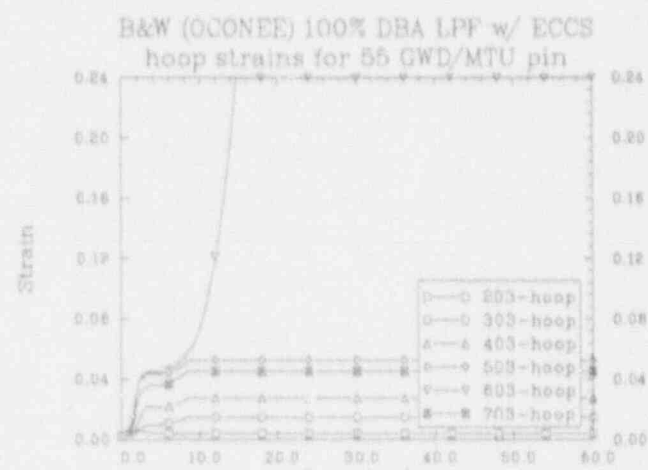

B&W (OCONEE) 100% DBA LPF w/ ECCS
fuel centerline temperatures for 5 GWD/MTU pin
10202-cadct
10302-cadct
10402-cadct
10502-cadct
10602-cadct
10702-cadct
Temperature (K)
Temperature (F)
Time (sec)

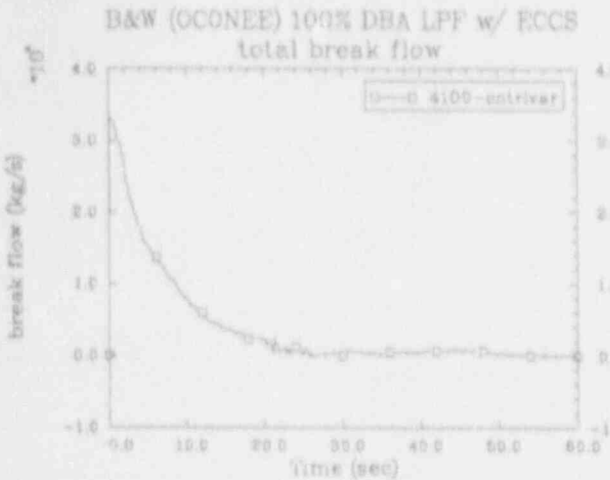

B&W (OCONEE) 100% DBA LPF w/ ECCS
fuel centerline temperatures for 55 GWD/MTU pin
10203-cadct
10303-cadct
10403-cadct
10503-cadct
10603-cadct
10703-cadct
Temperature (K)
Temperature (F)
Time (sec)

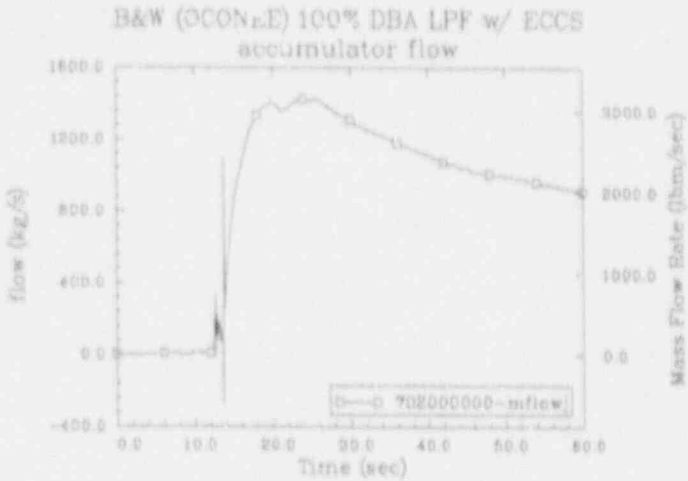

B&W (OCONEE) 100% DBA LPF w/ ECCS
cladding surface temperatures for 5 GWD/MTU pin
140202-cadct
140302-cadct
140402-cadct
140502-cadct
140602-cadct
140702-cadct
Temperature (K)
Temperature (F)
Time (sec)

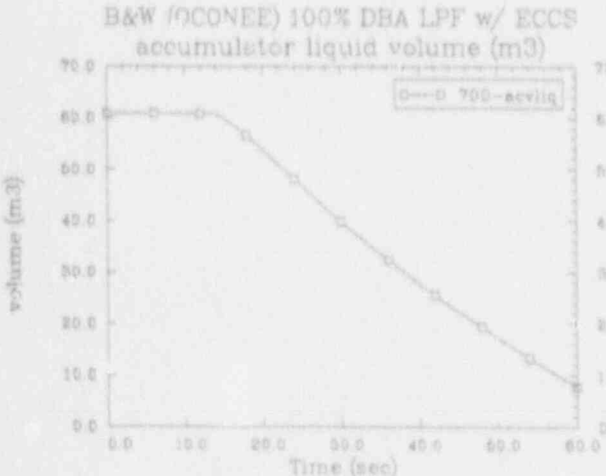

B&W (OCONEE) 100% DBA LPF w/ ECCS
cladding surface temperatures for 55 GWD/MTU pin
140203-cadct
140303-cadct
140403-cadct
140503-cadct
140603-cadct
140703-cadct
Temperature (K)
Temperature (F)
Time (sec)

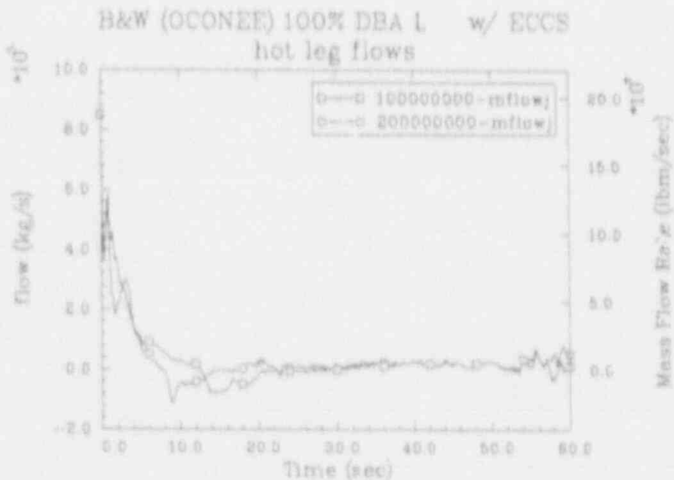

B&W (OCONEE) 100% DBA LPF w/ ECCS
hoop strains for 5 GWD/MTU pin
202-hoop
302-hoop
402-hoop
502-hoop
602-hoop
702-hoop
Strain
Time (sec)

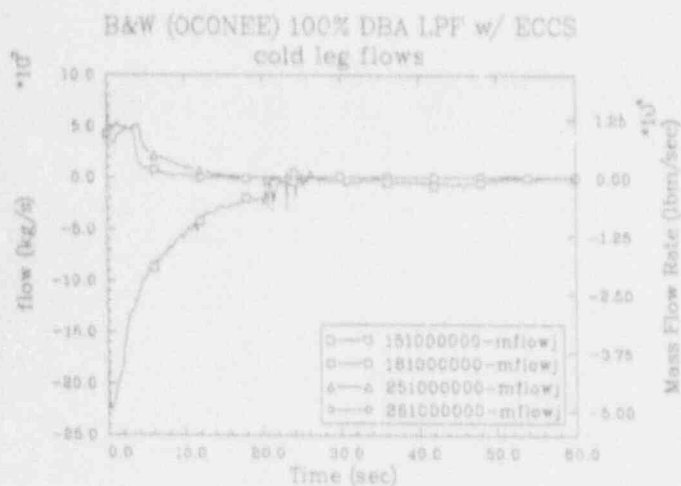

B&W (OCONEE) 100% DBA LPF w/ ECCS
hoop strains for 55 GWD/MTU pin
203-hoop
303-hoop
403-hoop
503-hoop
603-hoop
703-hoop
Strain
Time (sec)

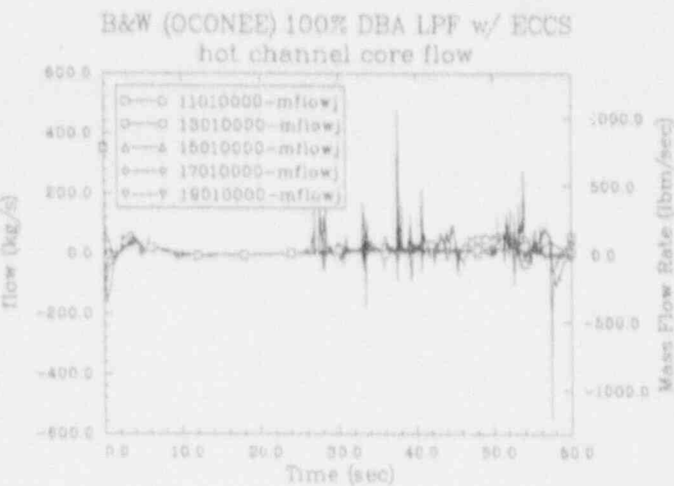

B&W (OCONEE) 100% DBA LPF w/ ECCS
total break flow
4100-cntrlvar
break flow (kg/s)
Time (sec)

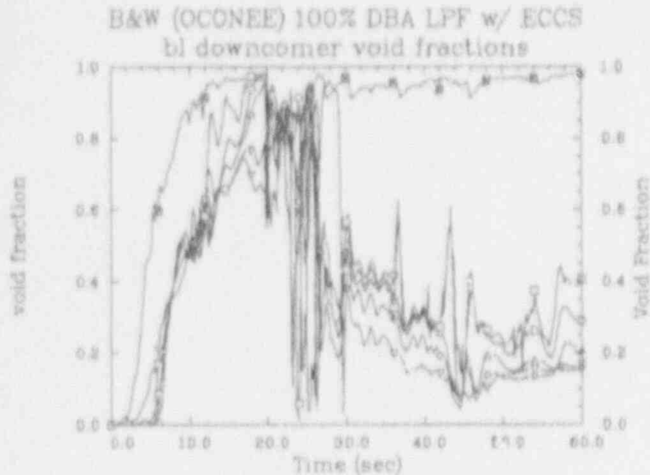

B&W (OCONEE) 100% DBA LPF w/ ECCS
accumulator flow
702000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

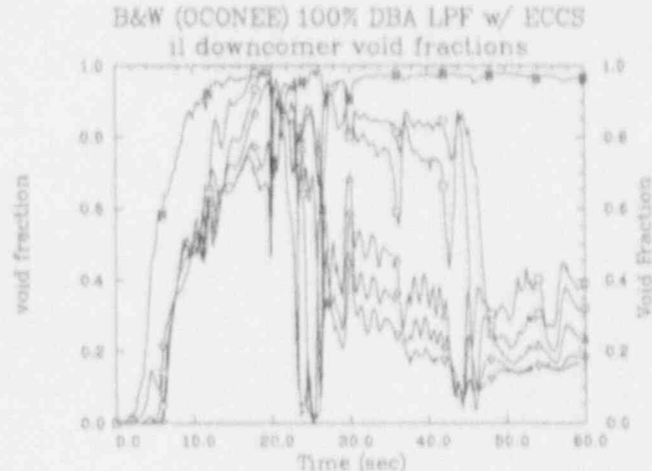

B&W (OCONEE) 100% DBA LPF w/ ECCS
accumulator liquid volume (m3)
700-acvliq
volume (m3)
Time (sec)

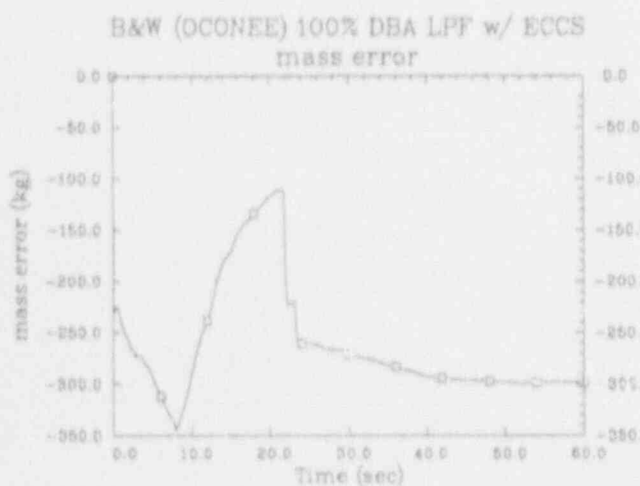

hot leg flows
100000000-mflowj
200000000-mflowj
flow (kg/s)
Time (sec)

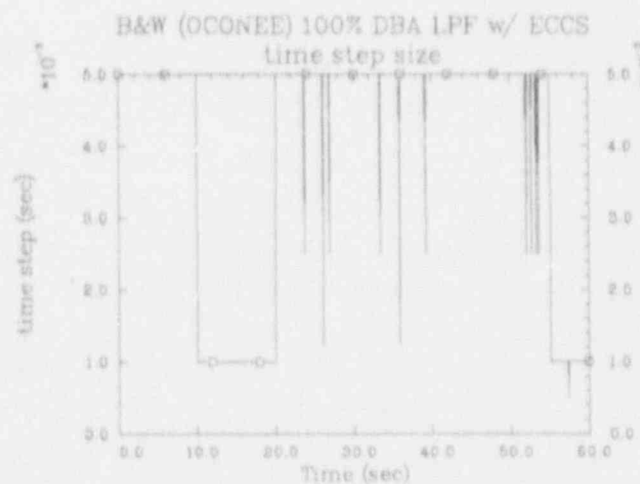

B&W (OCONEE) 100% DBA LPF w/ ECCS
cold leg flows
151000000-mflowj
181000000-mflowj
251000000-mflowj
281000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

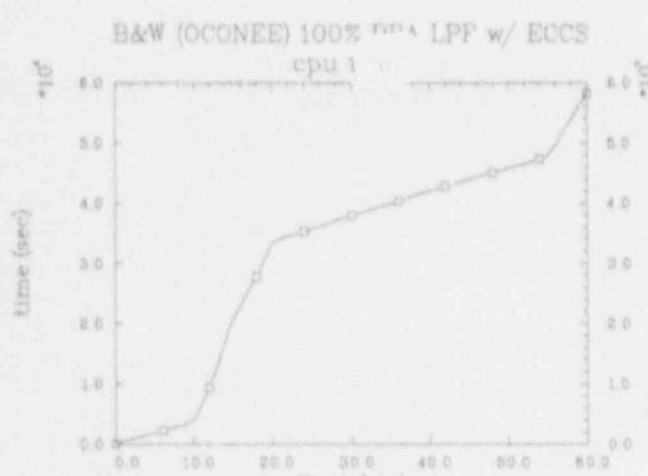

B&W (OCONEE) 100% DBA LPF w/ ECCS
hot channel core flow
11010000-mflowj
13010000-mflowj
15010000-mflowj
17010000-mflowj
19010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

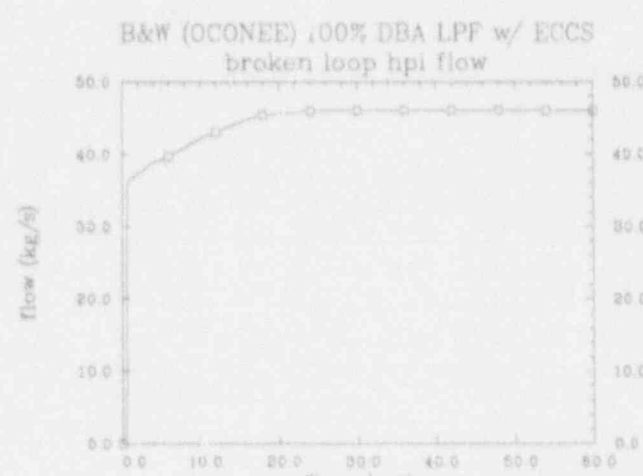

B&W (OCONEE) 100% DBA LPF w/ ECCS
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

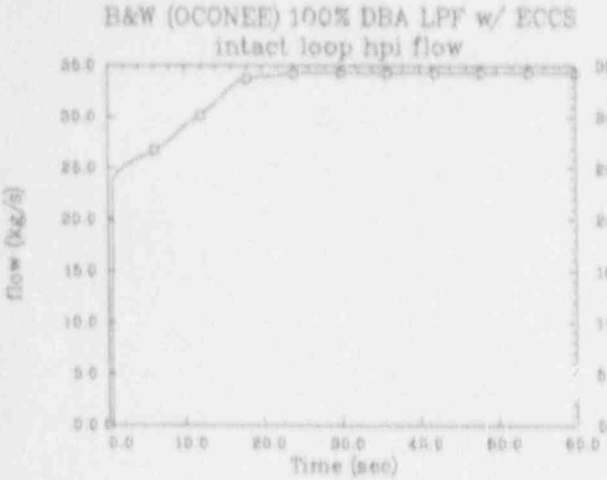

B&W (OCONEE) 100% DBA LPF w/ ECCS
il downcomer void fractions
void fraction
Void Fraction
Time (sec)


B&W (OCONEE) 100% DBA LPF w/ ECCS
mass error
mass error (kg)
Time (sec)

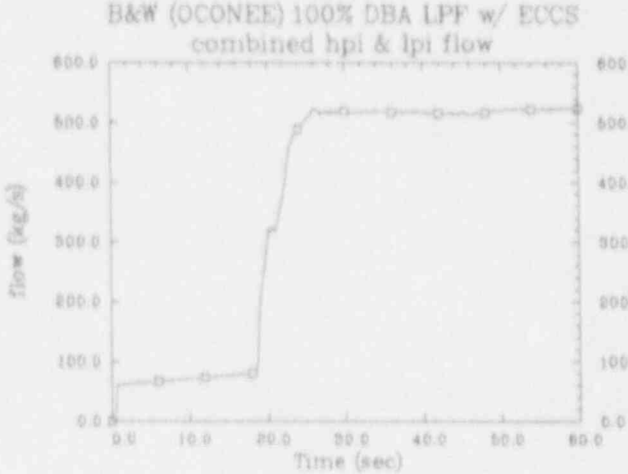

B&W (OCONEE) 100% DBA LPF w/ ECCS
time step size
time step (sec)
Time (sec)


LPF w/ ECCS
time (sec)
Time (sec)

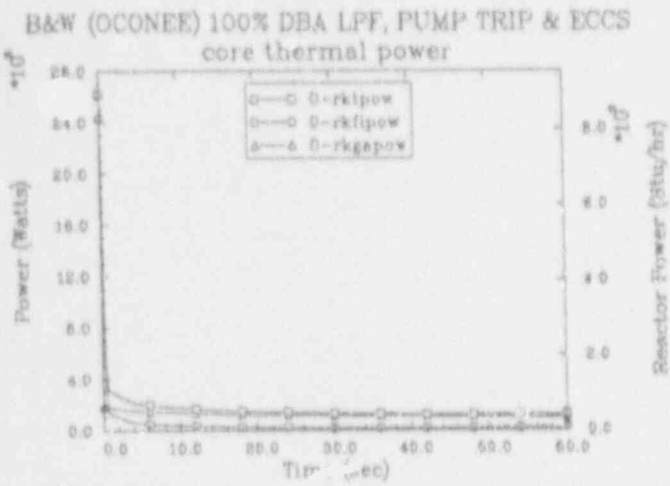

B&W (OCONEE)
DBA LPF w/ ECCS
broken loop hpi flow
flow (kg/s)
Time (sec)

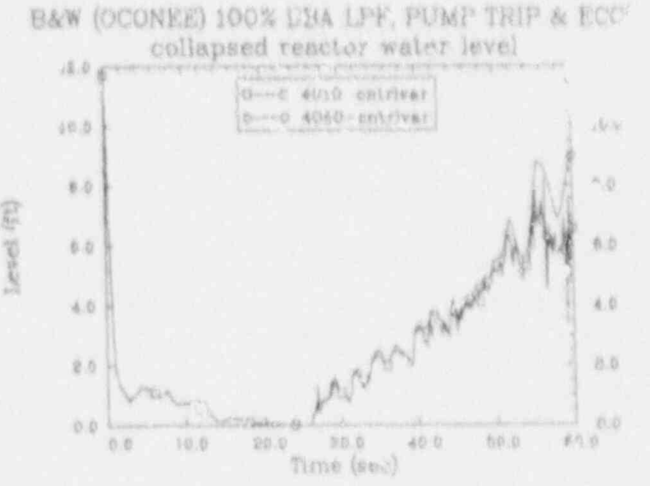


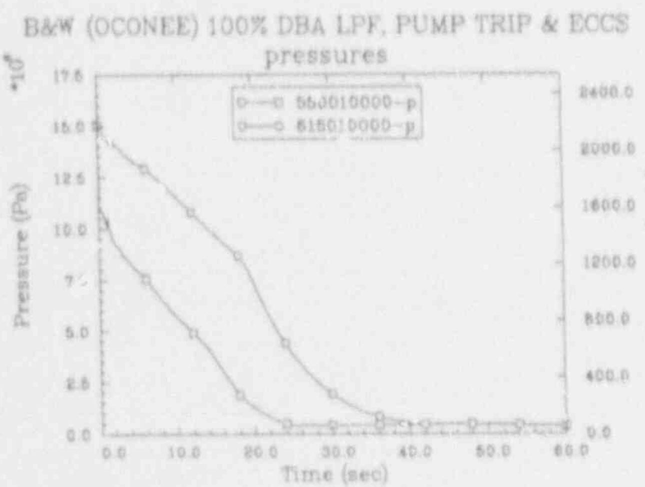
B&W (OCONEE) 100% DBA LPF w/ ECCS
intact loop hpi flow
flow (kg/s)
Time (sec)

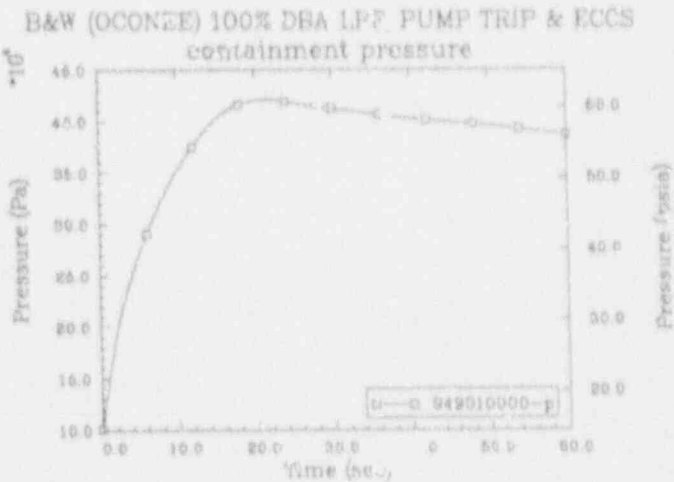


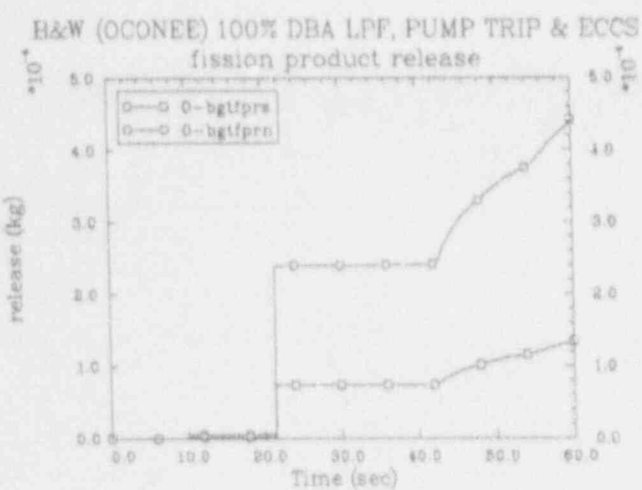
B&W (OCONEE) 100% DBA LPF w/ ECCS
combined hpi & lpi flow
flow (kg/s)
Time (sec)

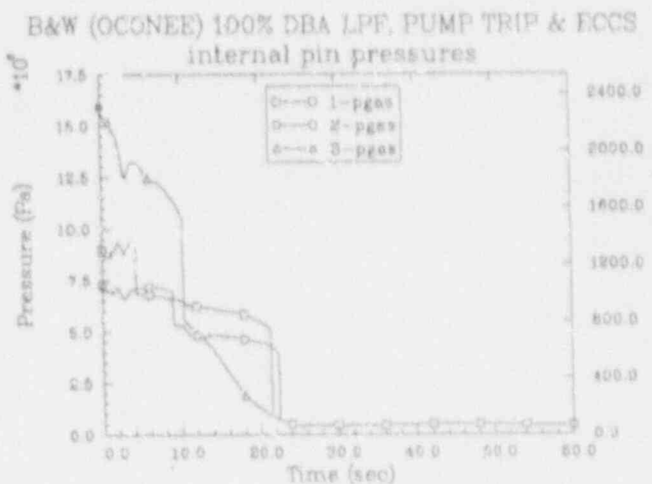

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


collapsed reactor water level
Level (ft)

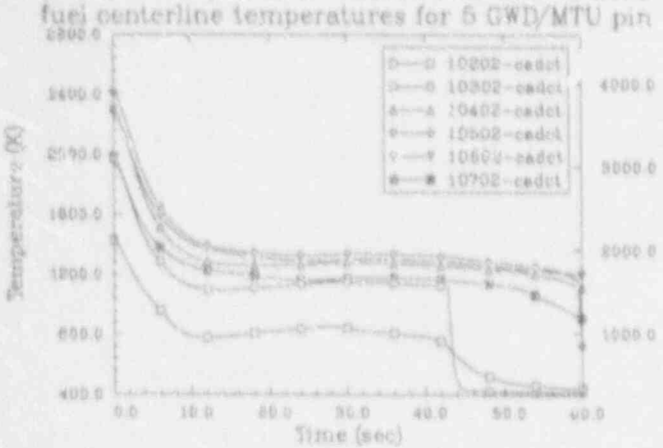

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
pressures
615010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)


containment pressure
949010000-p
Pressure (Pa)
Pressure (psia)

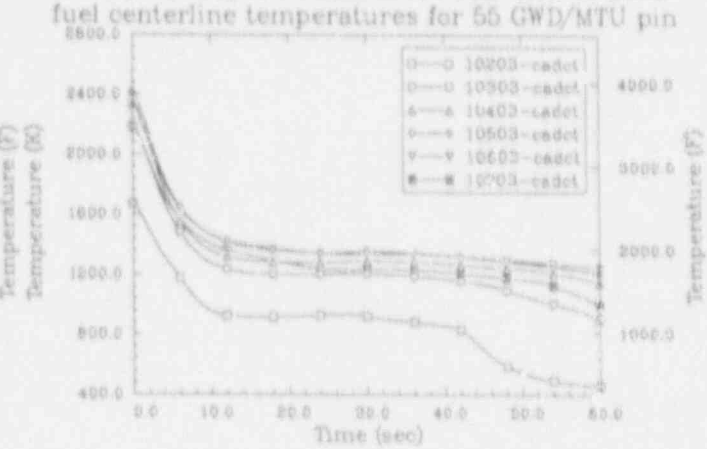

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
fission product release
0-bgtfprs
0-bgtfprn
release (kg)
Time (sec)


B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

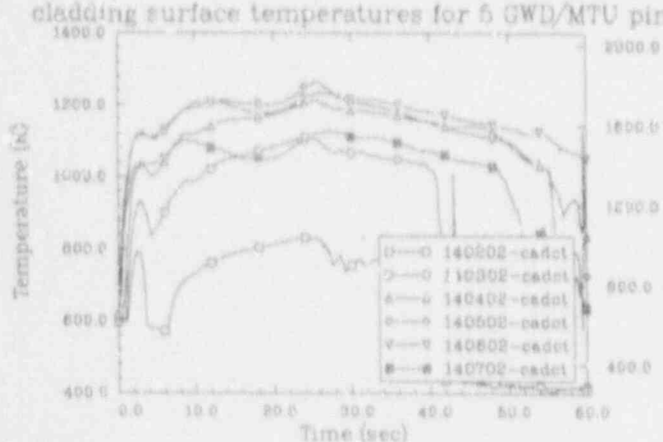
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
fuel centerline temperatures for 5 GWD/MTU pin



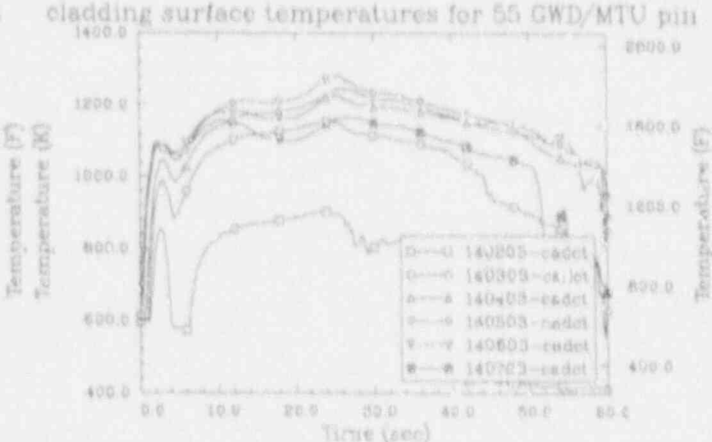
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
fuel centerline temperatures for 55 GWD/MTU pin



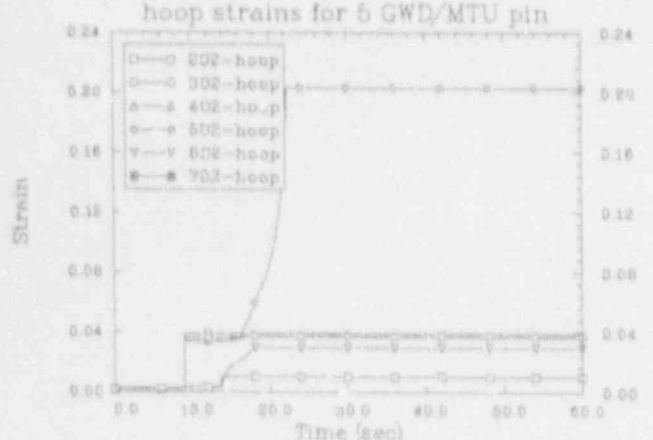
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
cladding surface temperatures for 5 GWD/MTU pin



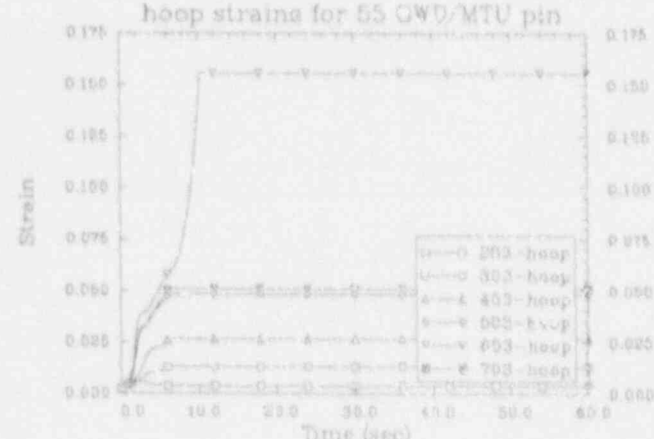
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
cladding surface temperatures for 55 GWD/MTU pin

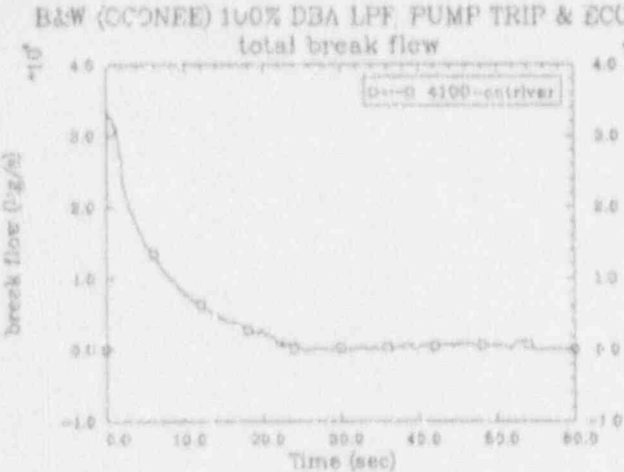


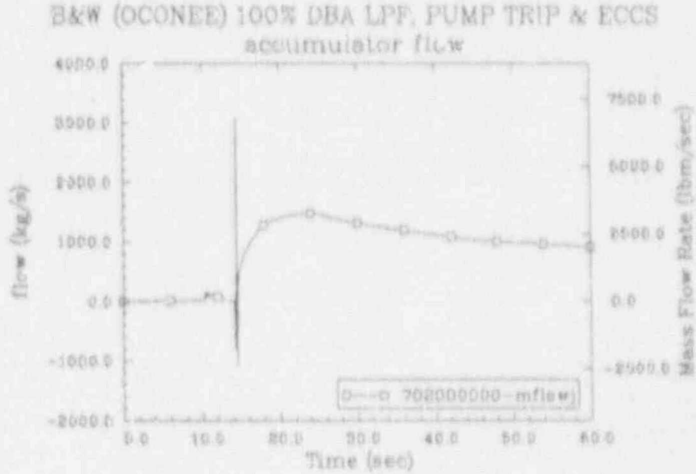
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
hoop strains for 5 GWD/MTU pin

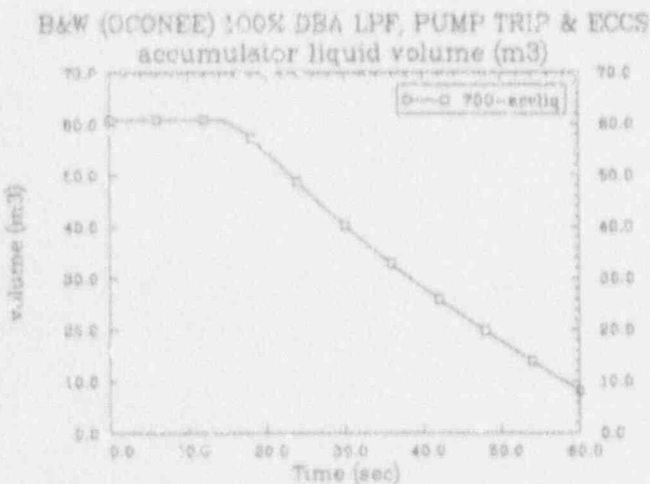


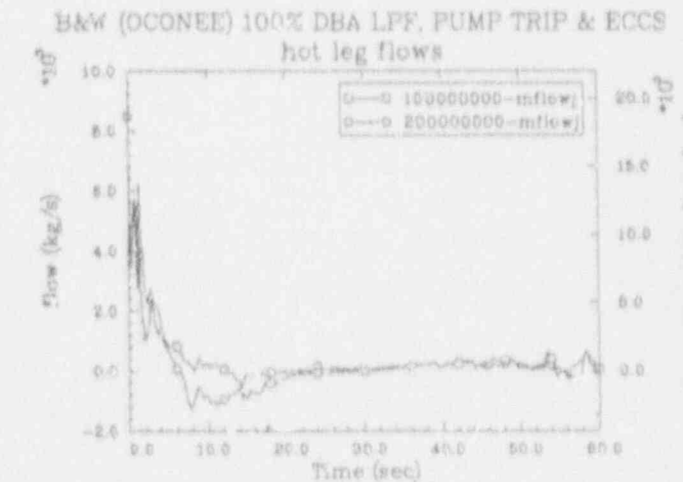
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
hoop strains for 55 GWD/MTU pin

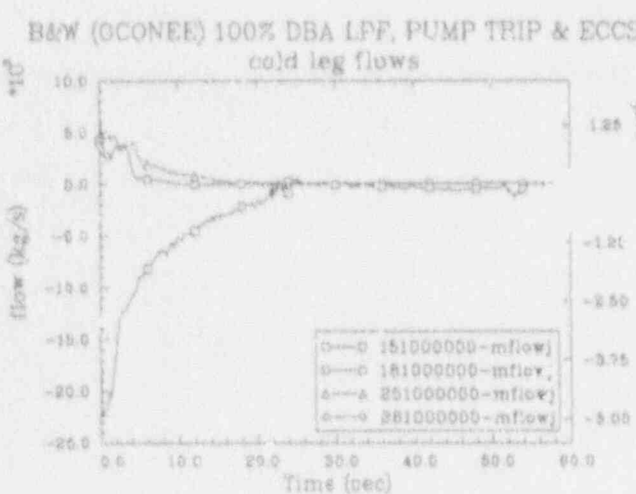


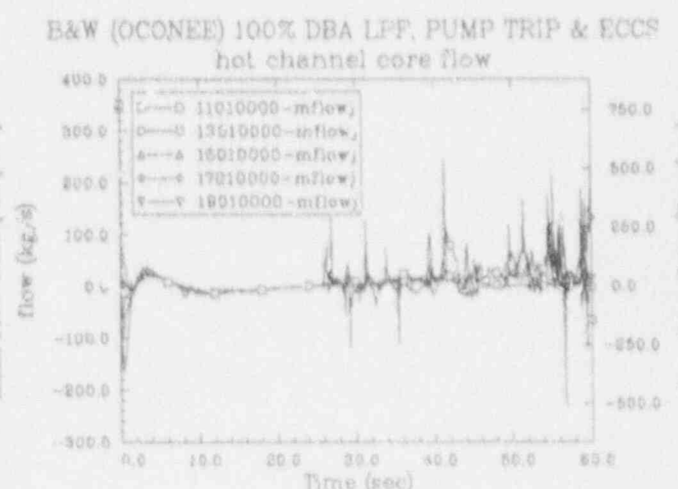

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
total break flow
4100-cntrlvar
break flow (kg/s)
Time (sec)

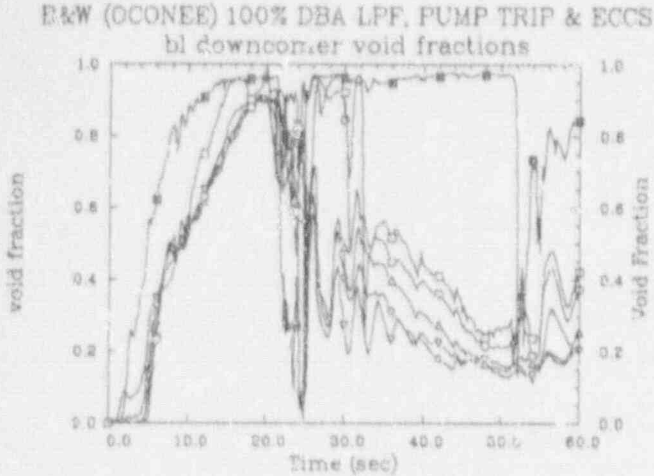

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
accumulator flow
702000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

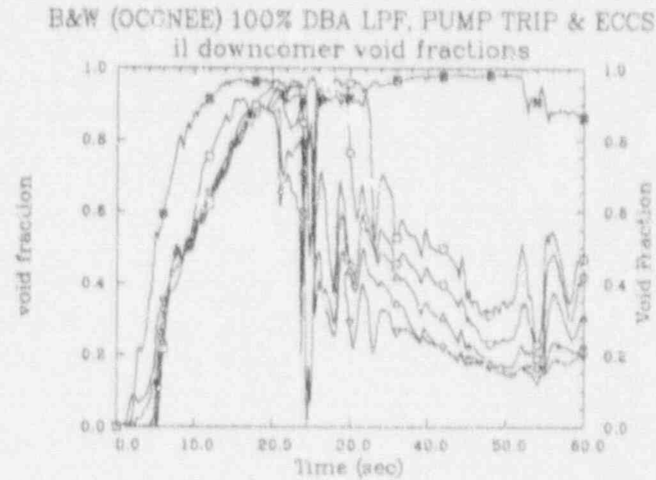

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
accumulator liquid volume (m3)
700-acvliq
volume (m3)
Time (sec)

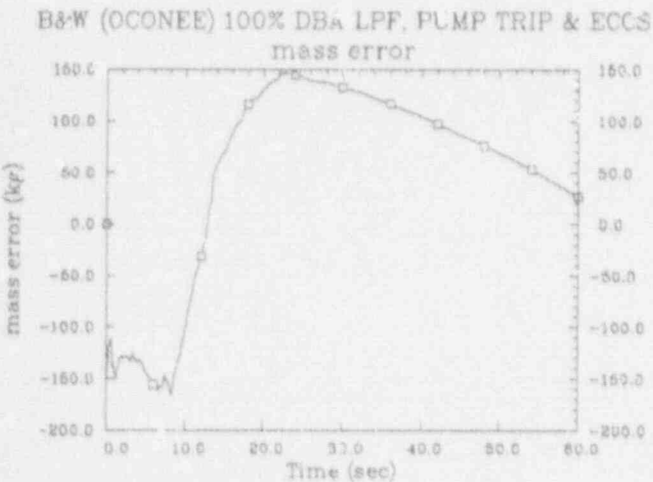

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
hot leg flows
100000000-mflowj
200000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

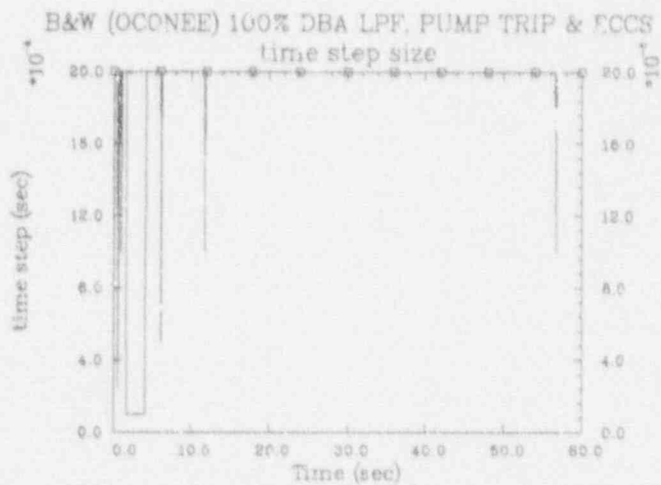

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
cold leg flows
151000000-mflowj
181000000-mflowj
251000000-mflowj
281000000-mflowj
flow (kg/s)
Time (sec)

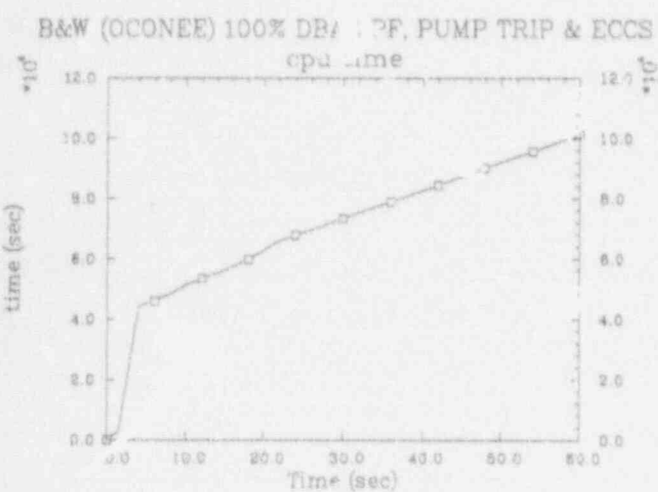

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
hot channel core flow
11010000-mflowj
13510000-mflowj
16010000-mflowj
17010000-mflowj
18010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

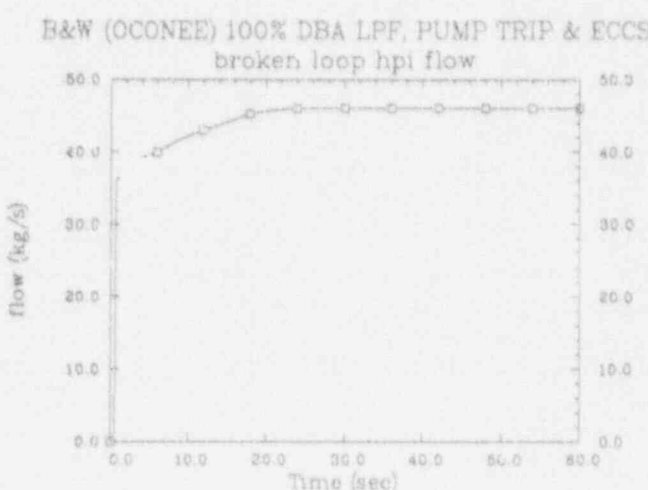

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)


B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
il downcomer void fractions
void fraction
Void Fraction
Time (sec)

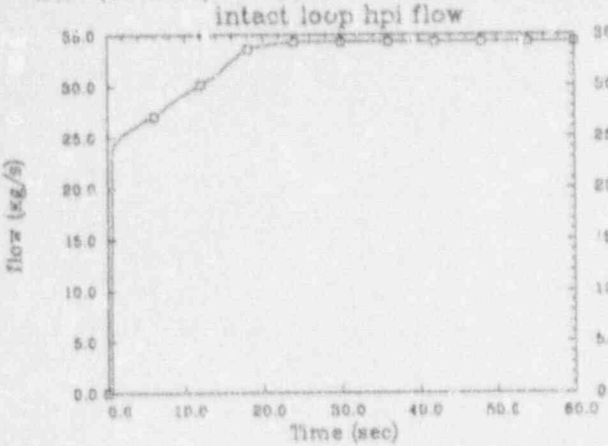

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
mass error
mass error (kg)
Time (sec)


B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
time step size
time step (sec)
Time (sec)

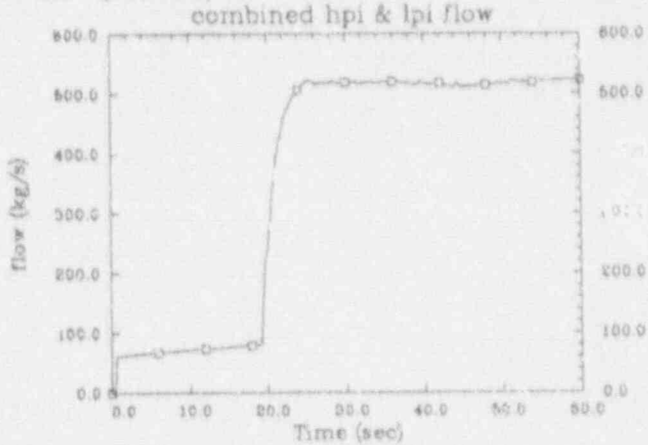

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
cpu time
time (sec)
Time (sec)

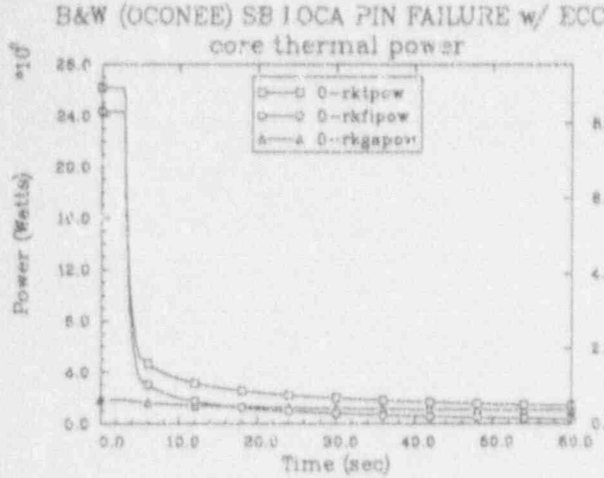

B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
broken loop hpi flow
flow (kg/s)
Time (sec)

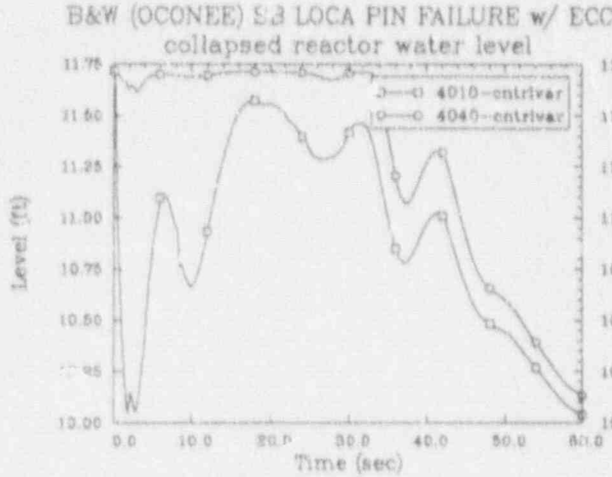
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
intact loop hpi flow

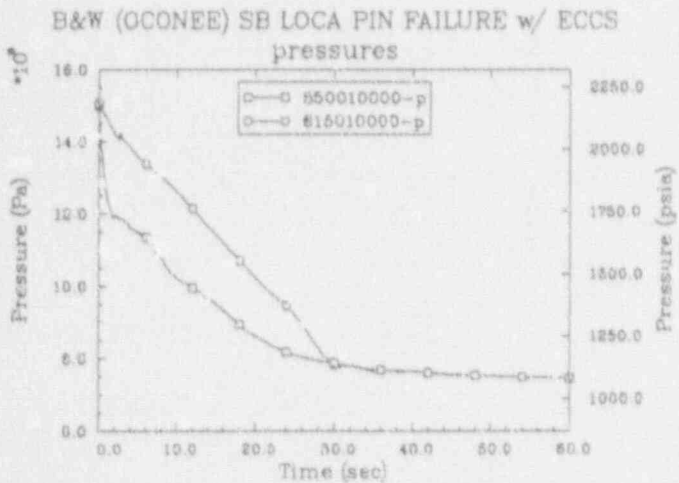


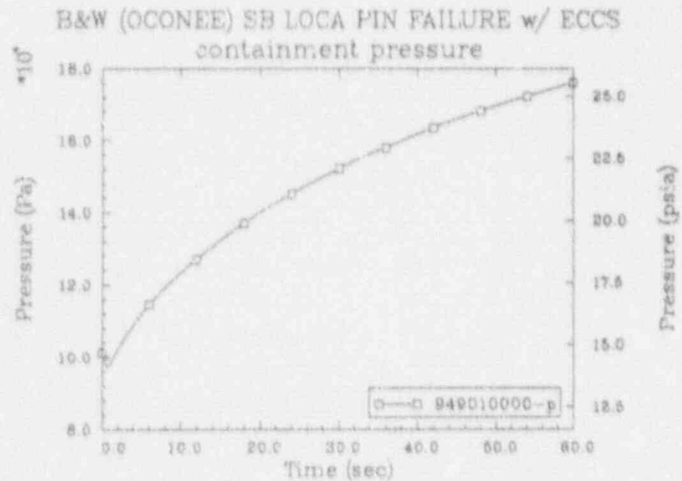
B&W (OCONEE) 100% DBA LPF, PUMP TRIP & ECCS
combined hpi & lpi flow

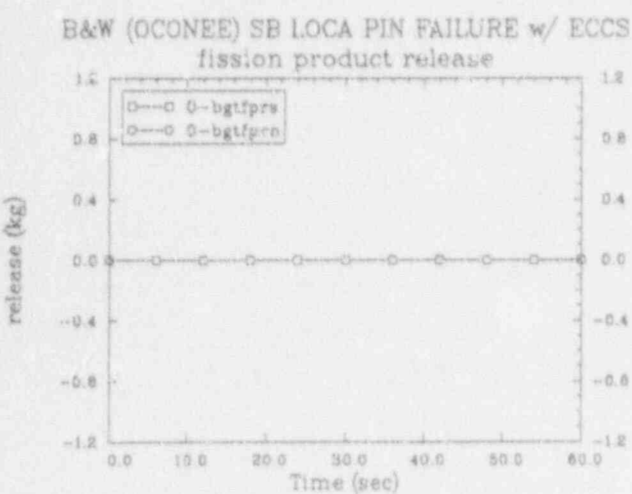


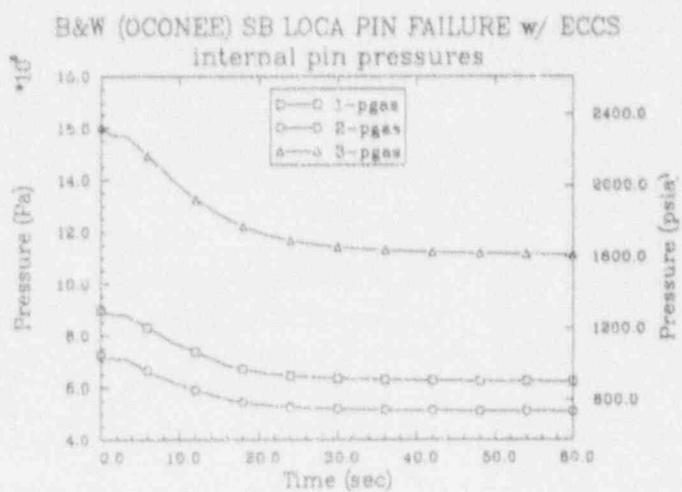

B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
collapsed reactor water level
4010-cntrlvar
4040-cntrlvar
Level (ft)
Time (sec)

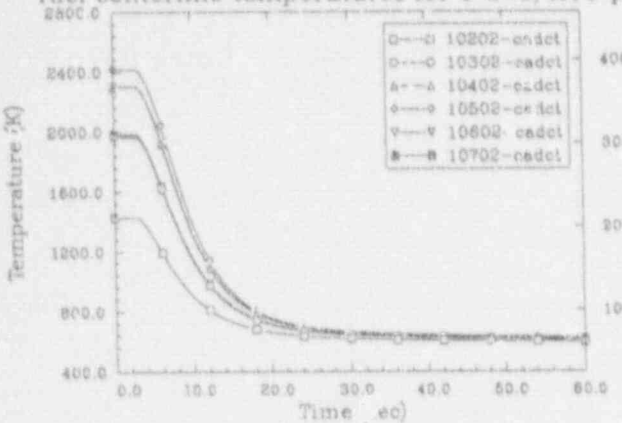

B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
pressures
550010000-p
615010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)


B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
containment pressure
949010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)

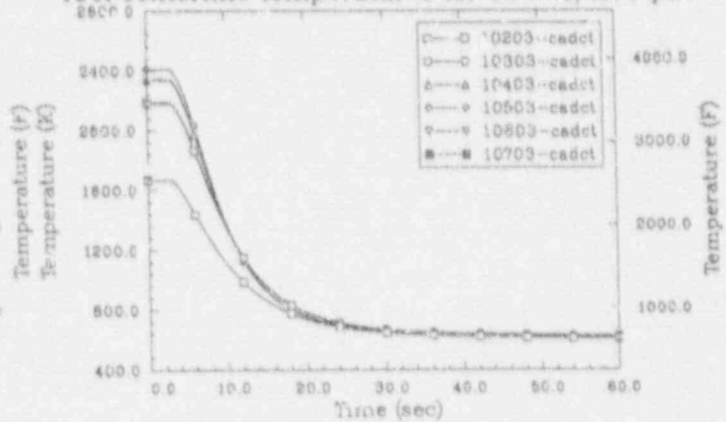

B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
fission product release
0-bgtfprs
0-bgtfprn
release (kg)
Time (sec)


B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

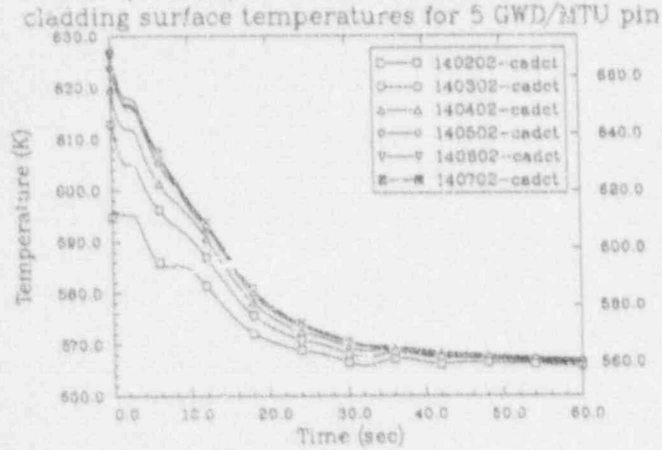
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
fuel centerline temperatures for 5 GWD/MTU pin



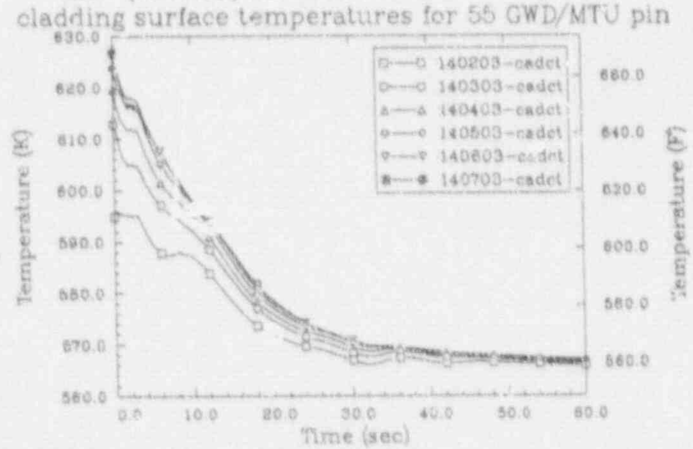
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
fuel centerline temperatures for 55 GWD/MTU pin



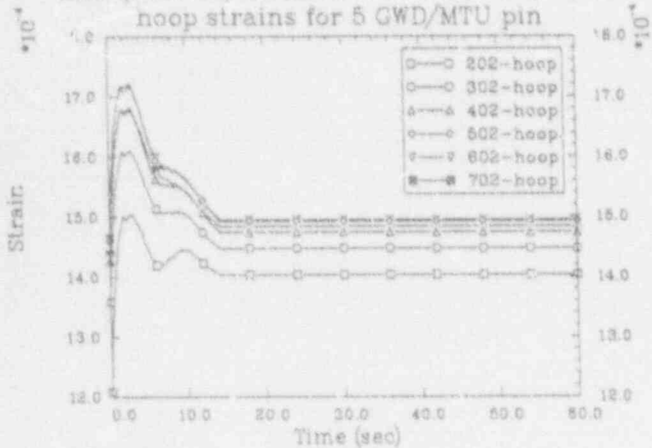
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
cladding surface temperatures for 5 GWD/MTU pin



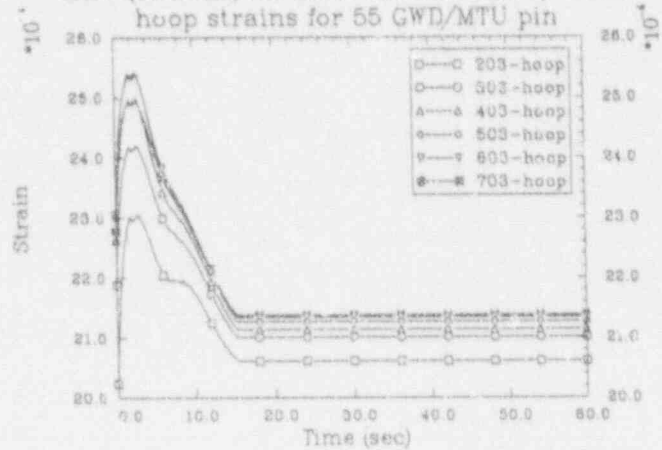
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
cladding surface temperatures for 55 GWD/MTU pin

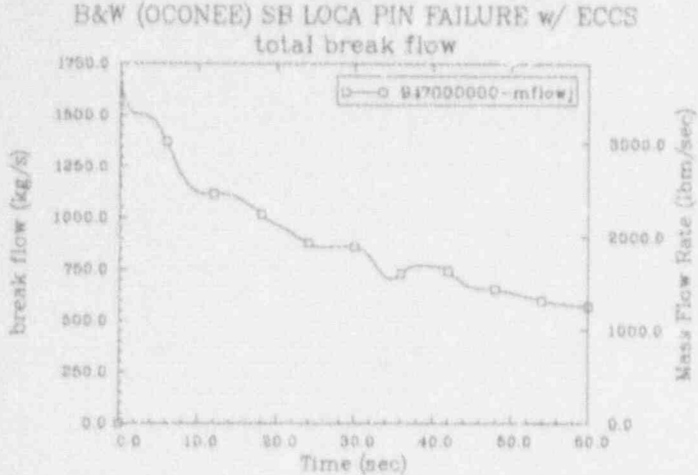


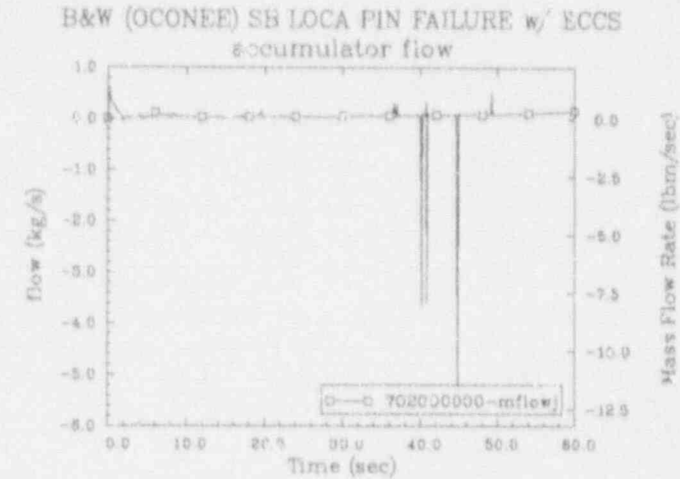
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
hoop strains for 5 GWD/MTU pin

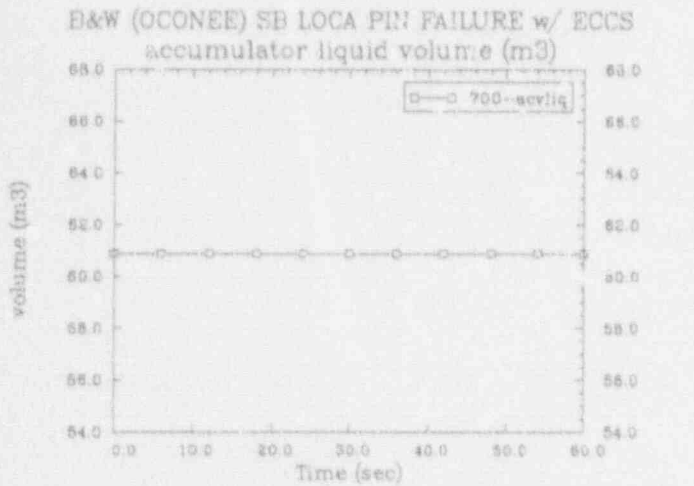


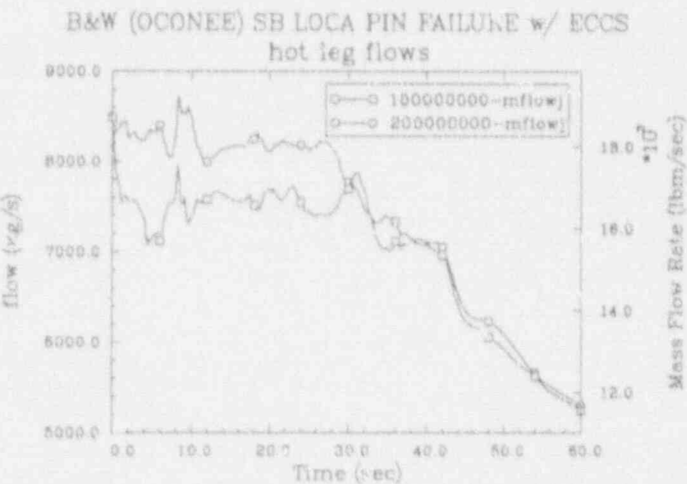
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
hoop strains for 55 GWD/MTU pin

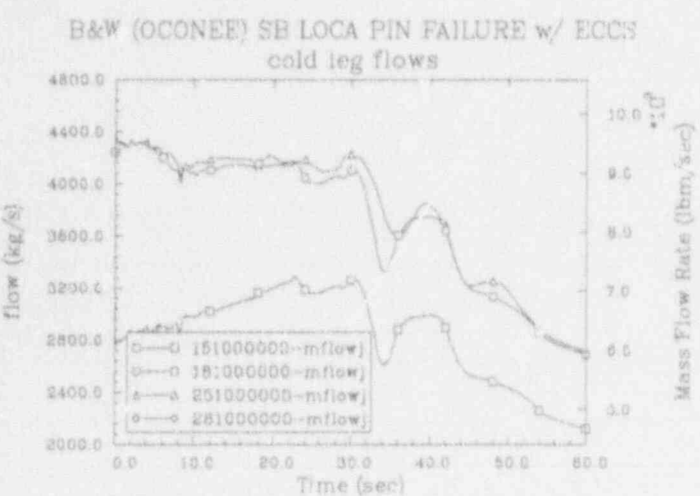


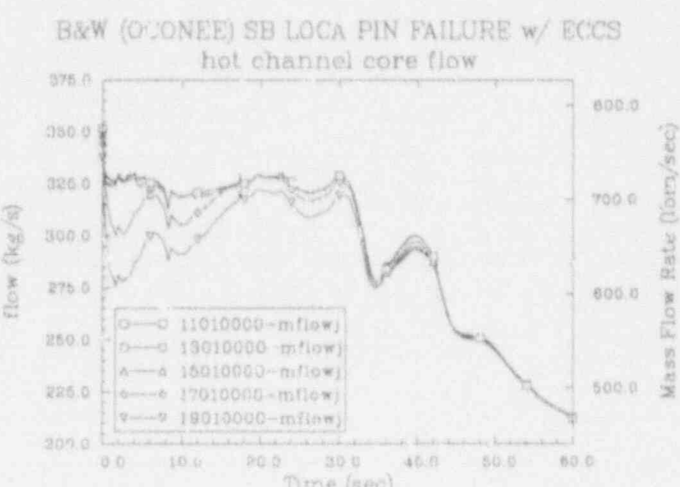

B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
total break flow
947000000-mflowj
break flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)


B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
accumulator flow
702000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

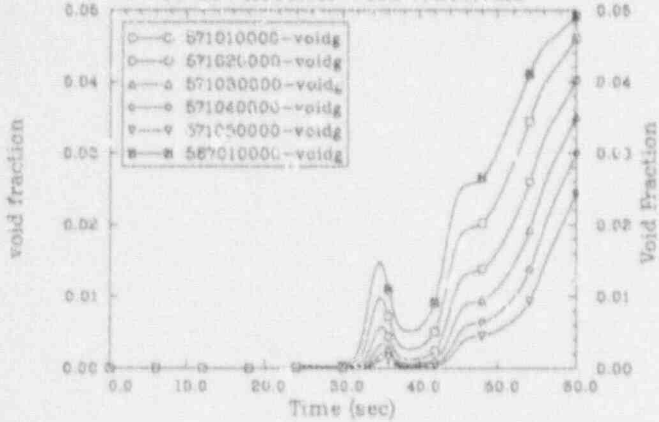

B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
accumulator liquid volume (m3)
700-acvliq
volume (m3)
Time (sec)


B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
hot leg flows
100000000-mflowj
200000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

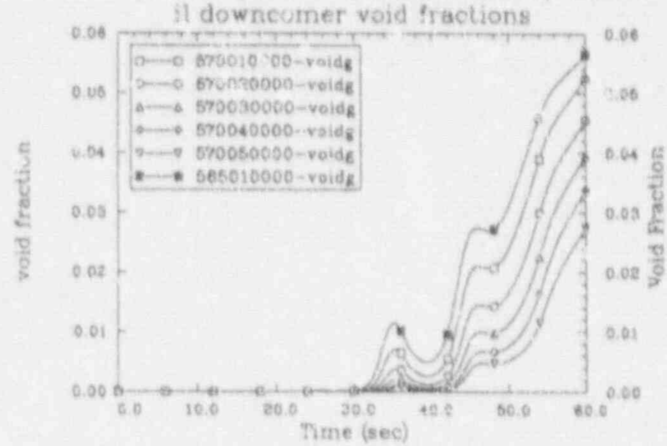

B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
cold leg flows
151000000-mflowj
181000000-mflowj
251000000-mflowj
281000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)


B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
hot channel core flow
11010000-mflowj
13010000-mflowj
15010000-mflowj
17010000-mflowj
19010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

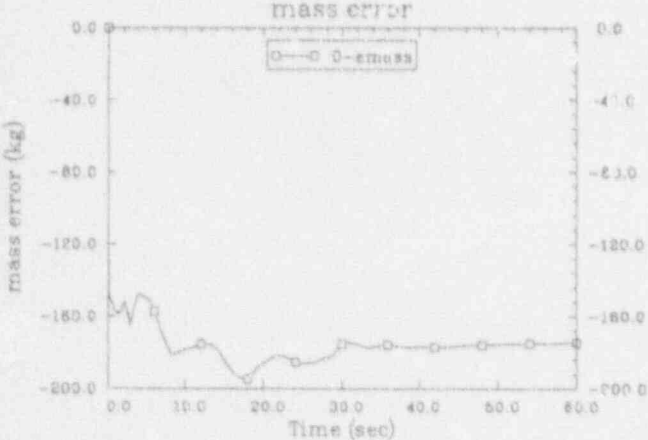
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
bl downcomer void fractions



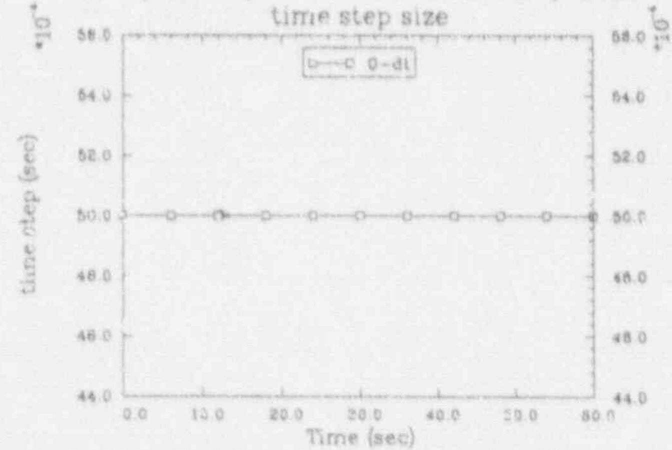
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
il downcomer void fractions



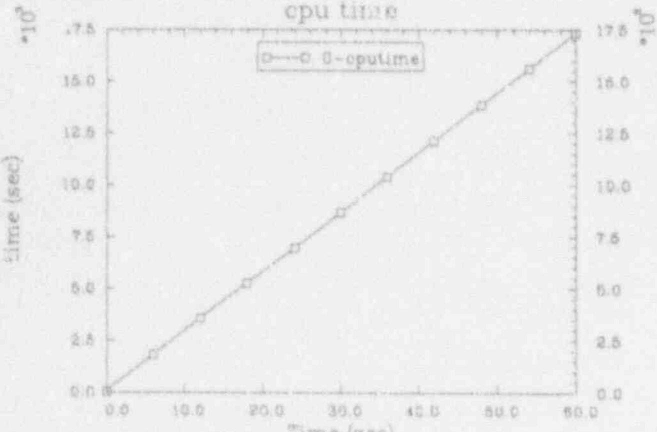
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
mass error



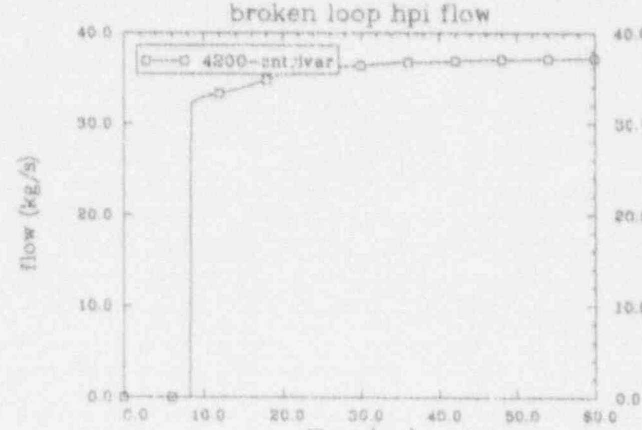
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
time step size

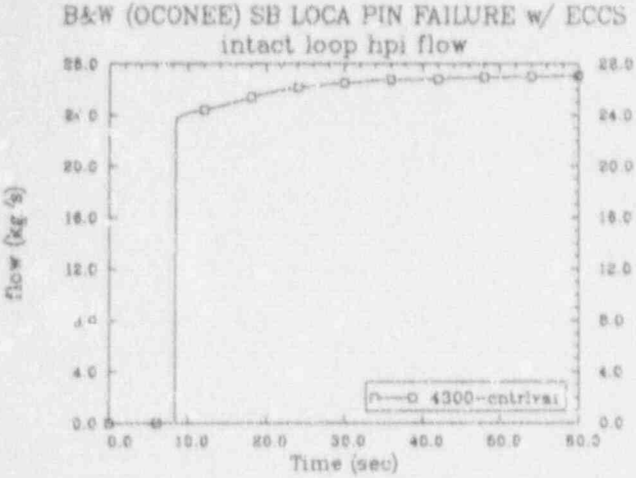


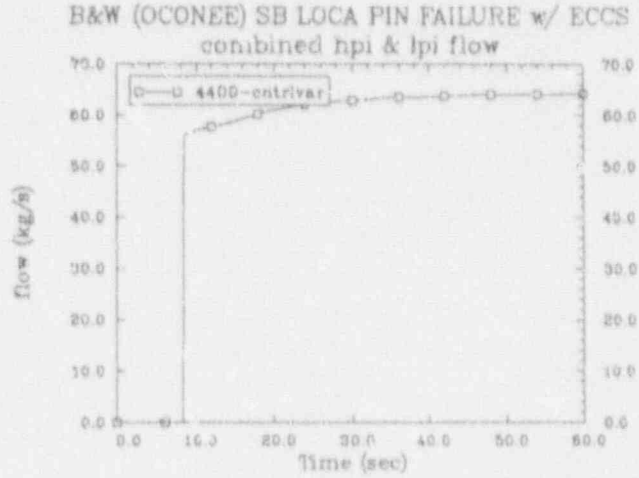
B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
cpu time



B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
broken loop hpi flow




B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
intact loop hpi flow
flow (kg/s)
Time (sec)
4300-cntrlvar

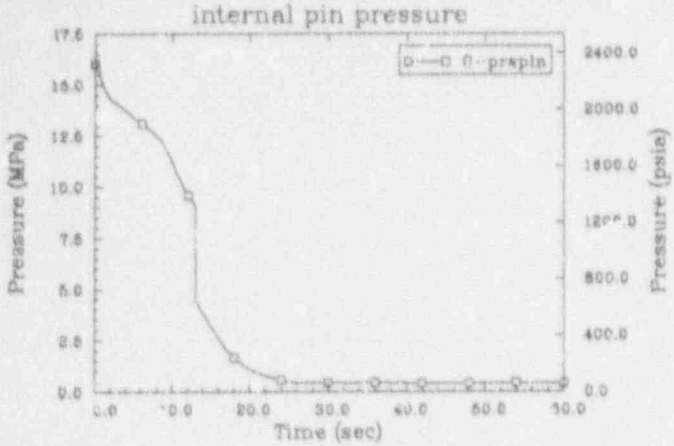

B&W (OCONEE) SB LOCA PIN FAILURE w/ ECCS
combined hpi & lpi flow
flow (kg/s)
Time (sec)
4400-cntrlvar

K-1.2 FRAP-T6 Plotted Results for Oconee

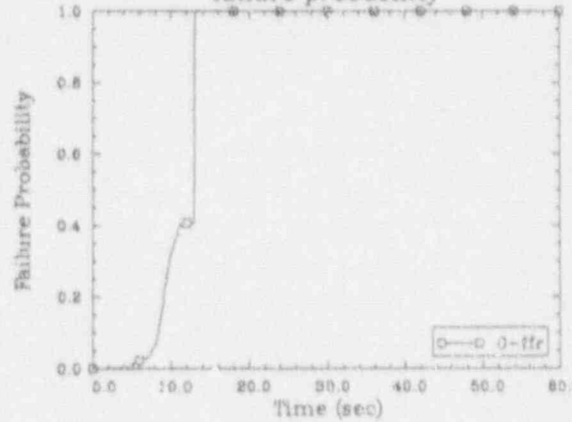
Table K-2. Description of FRAP-T6 plot variables for Oconee.

Variable	Description
0-ffr	Failure probability
0-prspln	Internal pin pressure (psia, Pa)
n-cladhsn	Cladding hoop strain at axial node n
n-cladote	Cladding surface temperature at axial node n (°F, K)
n-ctemp	Fuel centerline temperature at axial node n (°F, K)
n-ooxtn	Oxide thickness at axial node n (in., mm)

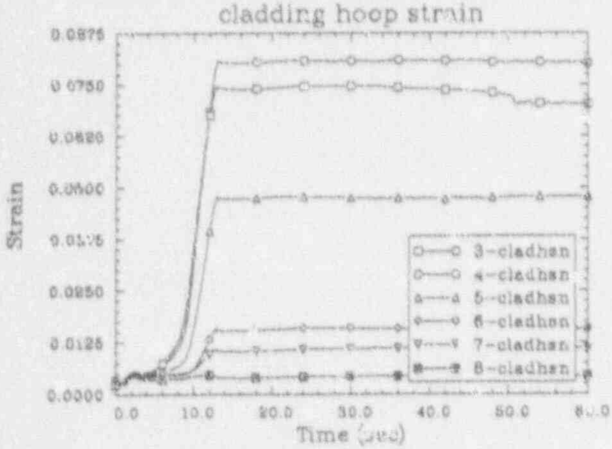
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63
internal pin pressure



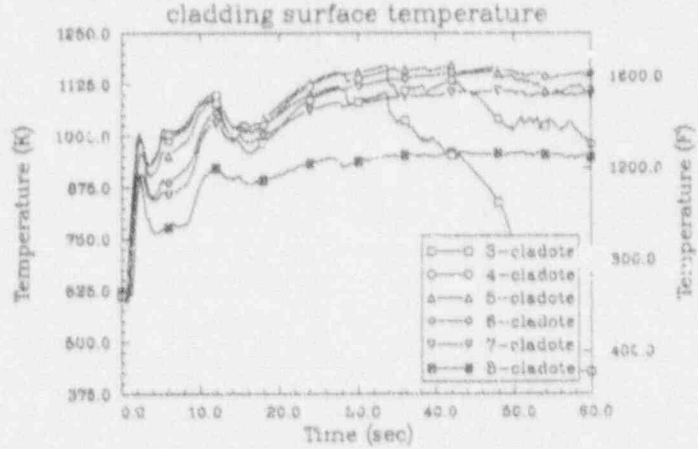
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63
failure probability



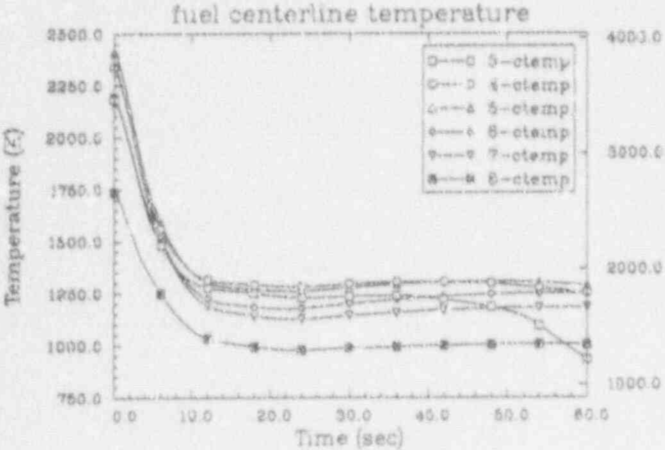
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63
cladding hoop strain



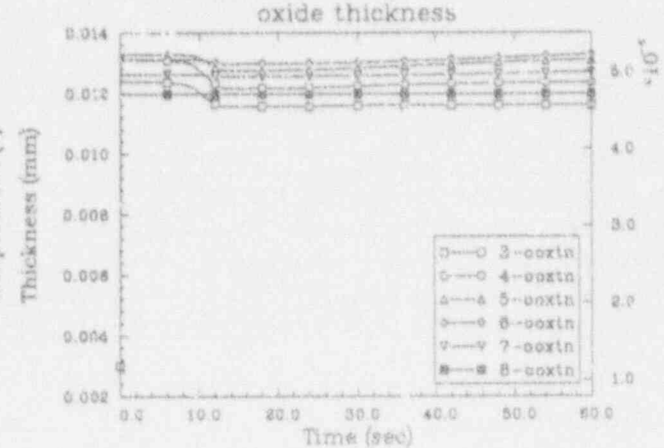
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63
cladding surface temperature



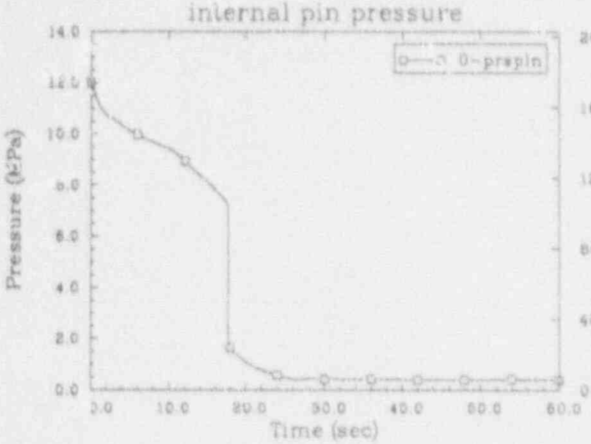
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63
fuel centerline temperature



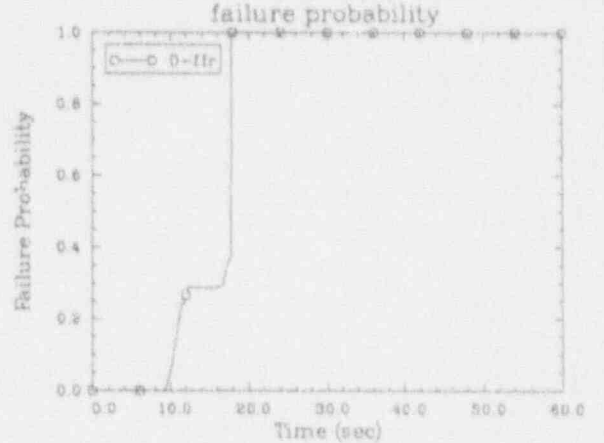
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63
oxide thickness



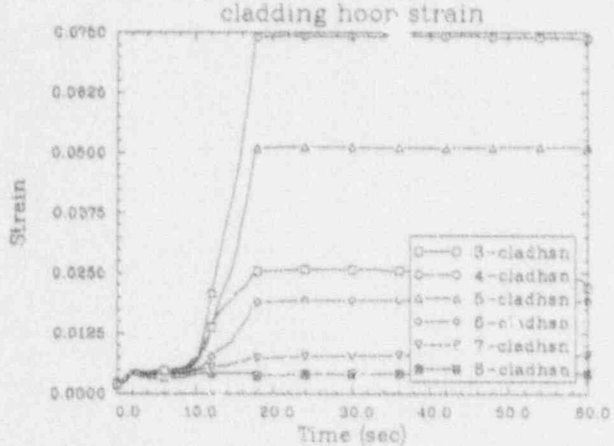
OCONEE 100%DFA 35 GWD/MTU PIN---PF 2.63
internal pin pressure



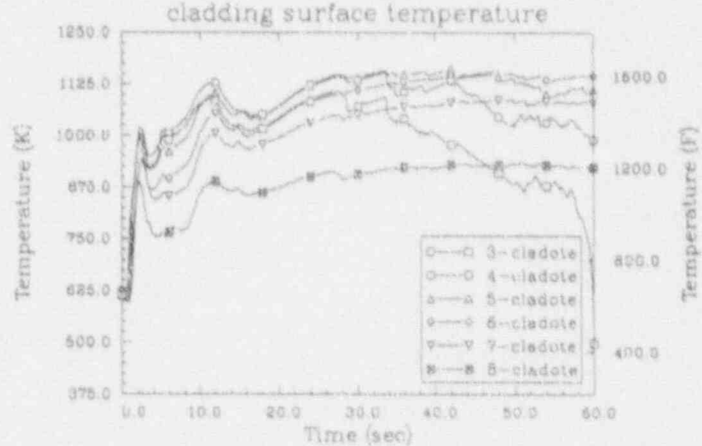
OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.63
failure probability



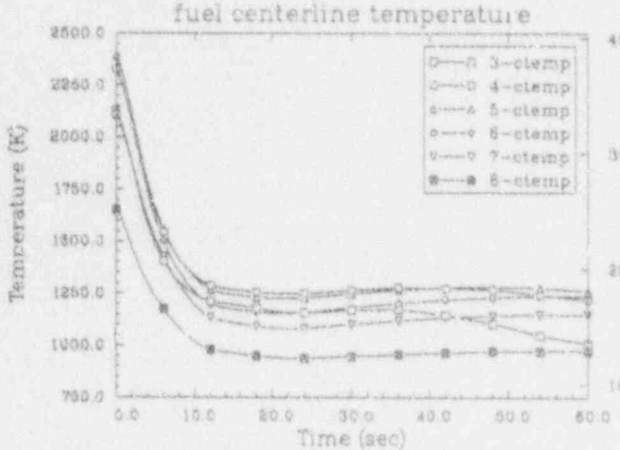
OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.63
cladding hoop strain



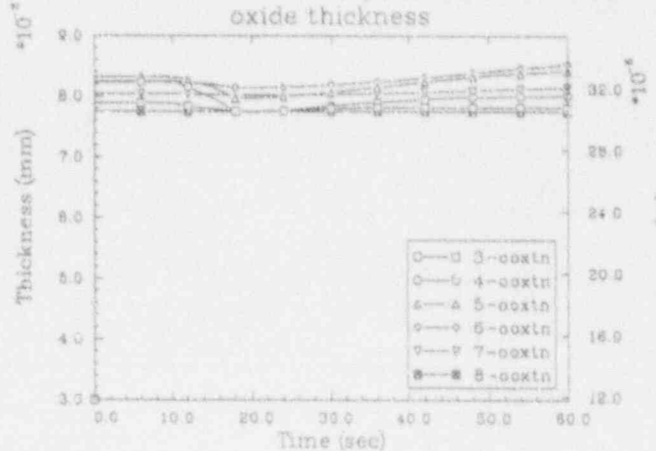
OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.63
cladding surface temperature

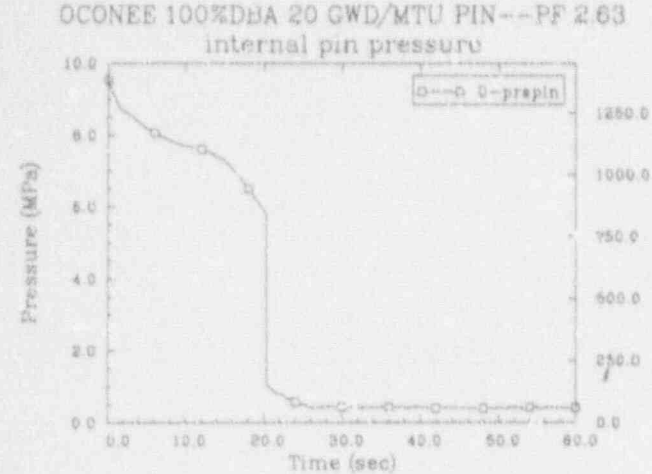


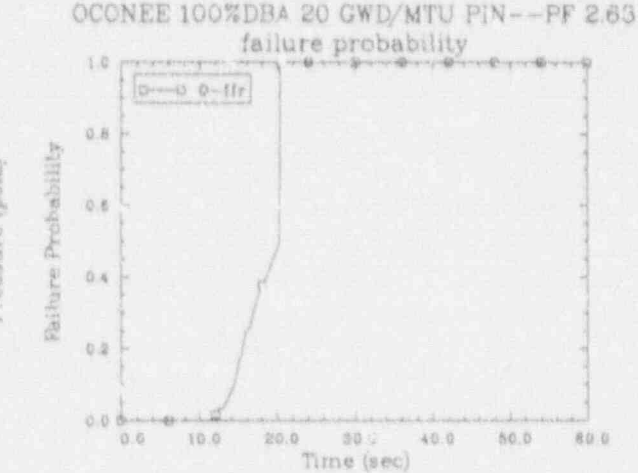
OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.63
fuel centerline temperature

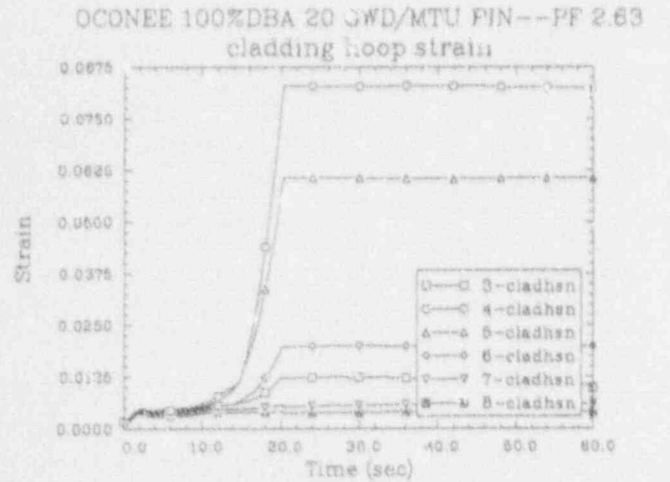


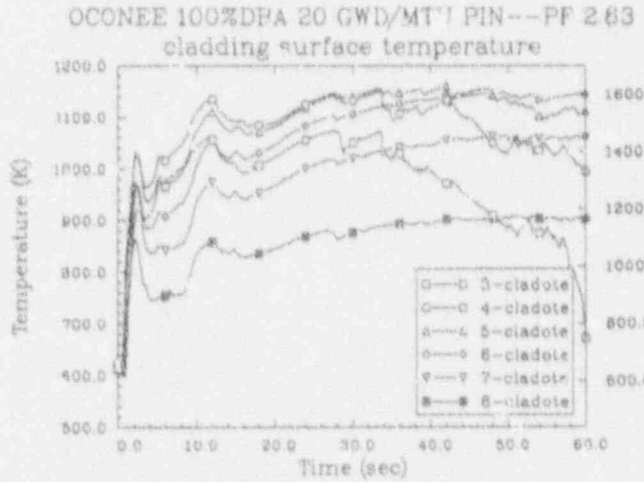
OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.63
oxide thickness

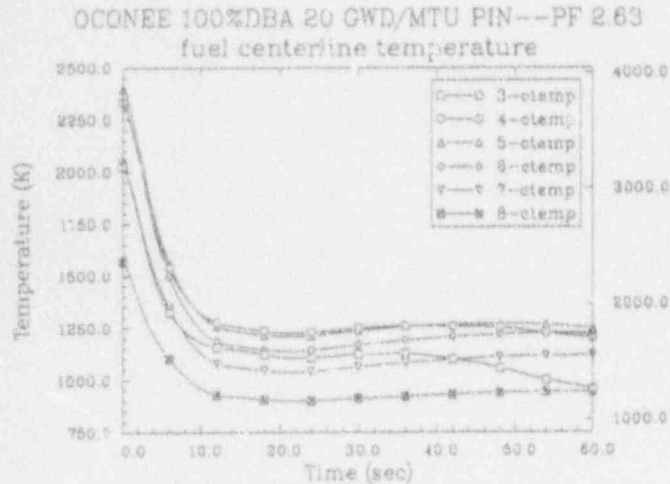


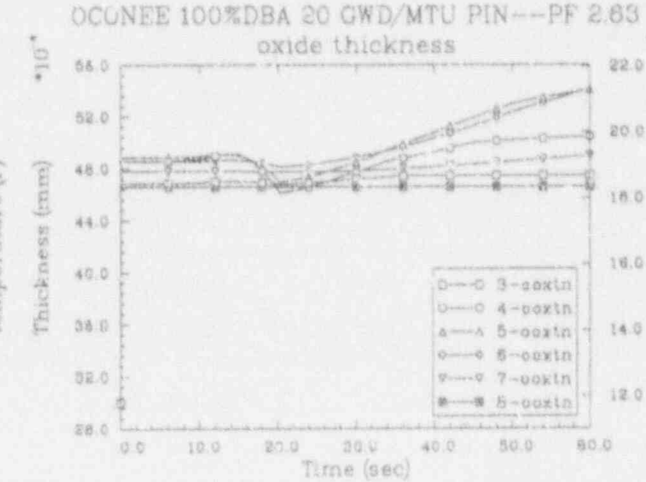

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

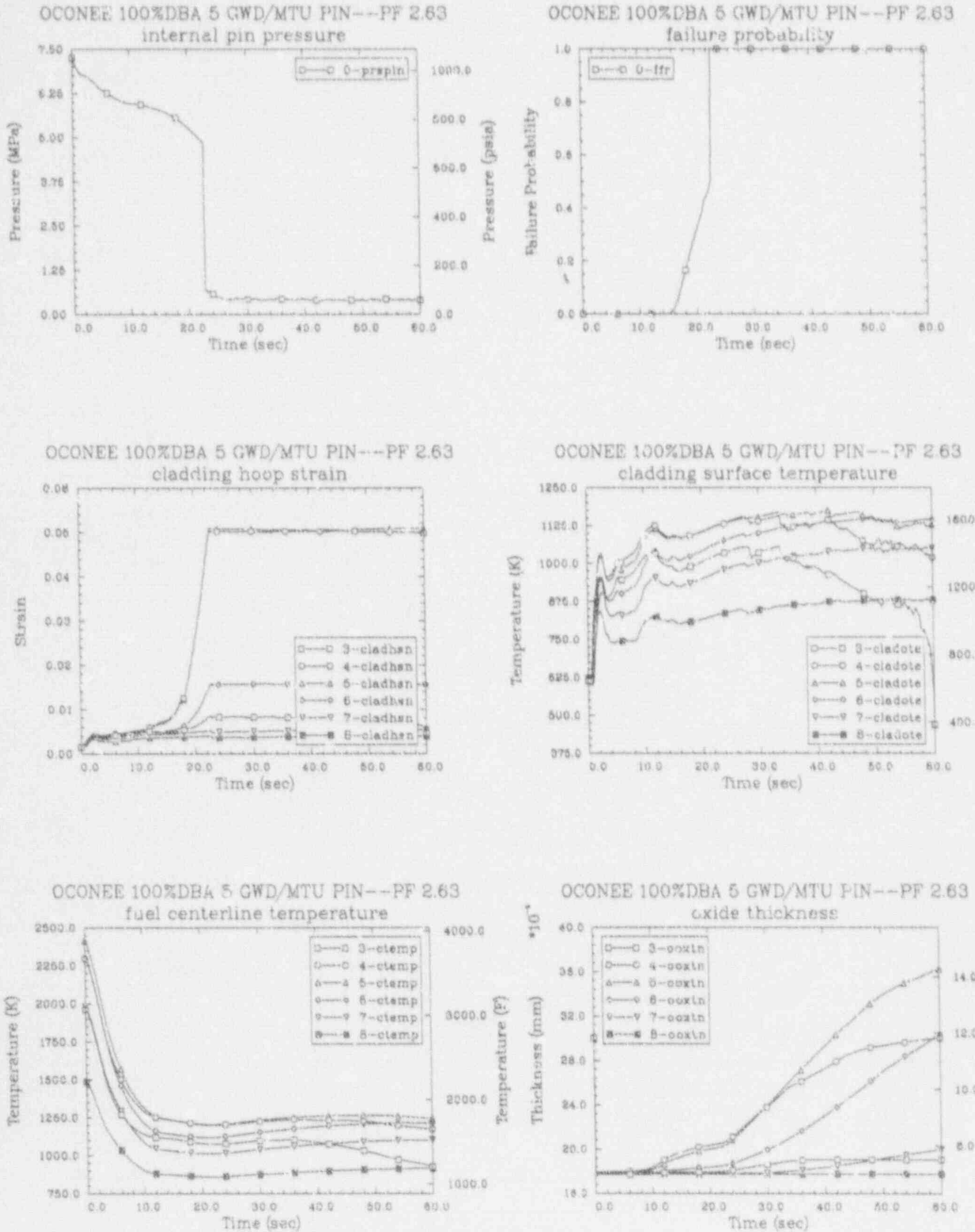

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

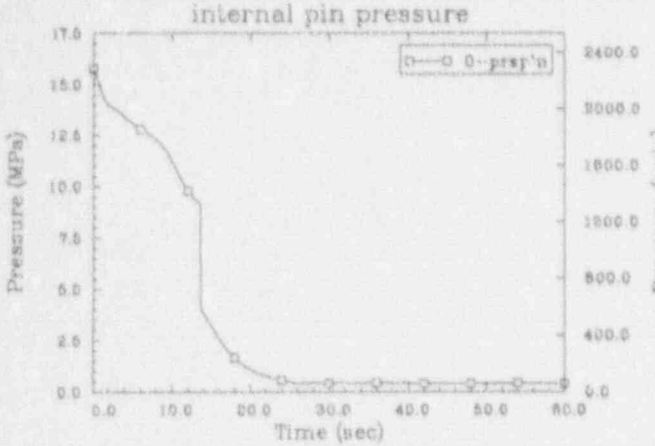

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

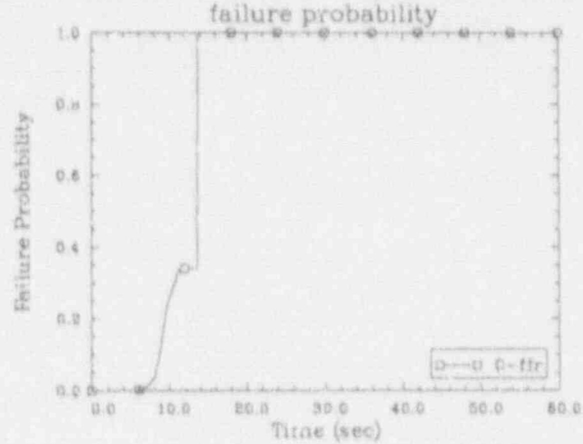


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
Thickness (mm)
(in)
Time (sec)

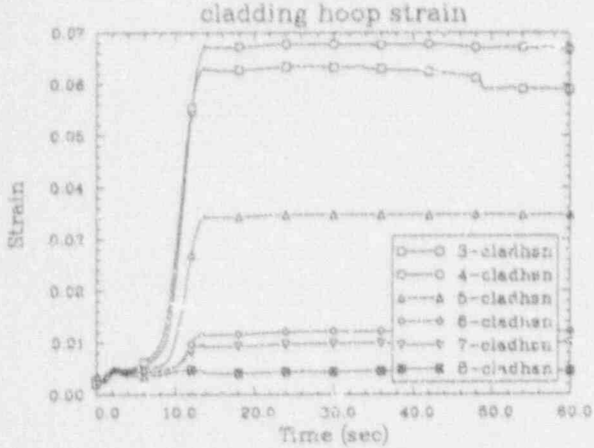
OCONEE 100%DBA 55 GWD/TU PIN--PF 2.4
internal pin pressure



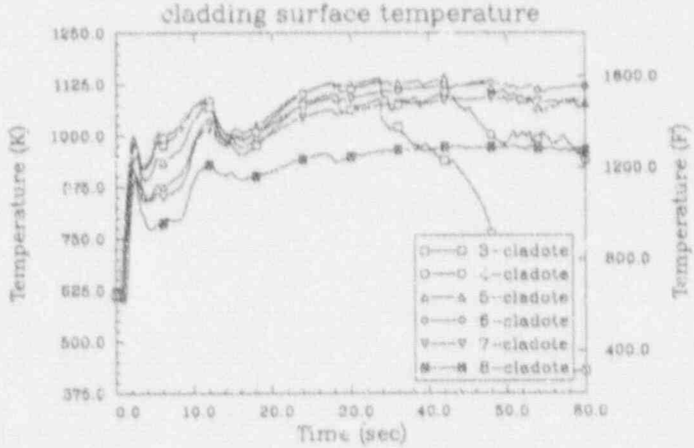
OCONEE 100%DBA 55 GWD/TU PIN--PF 2.4
failure probability



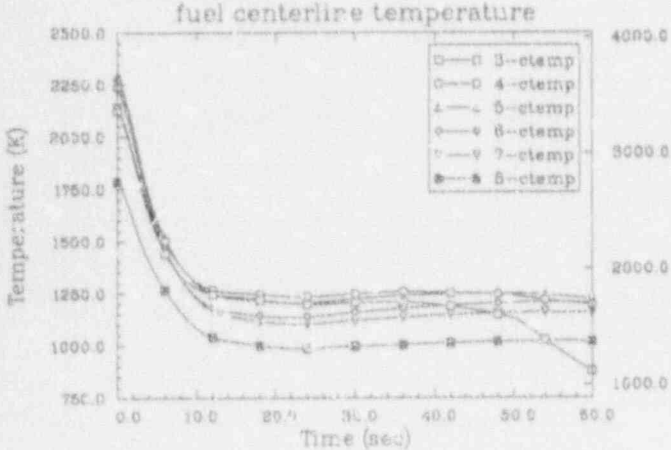
OCONEE 100%DBA 55 GWD/TU PIN--PF 2.4
cladding hoop strain



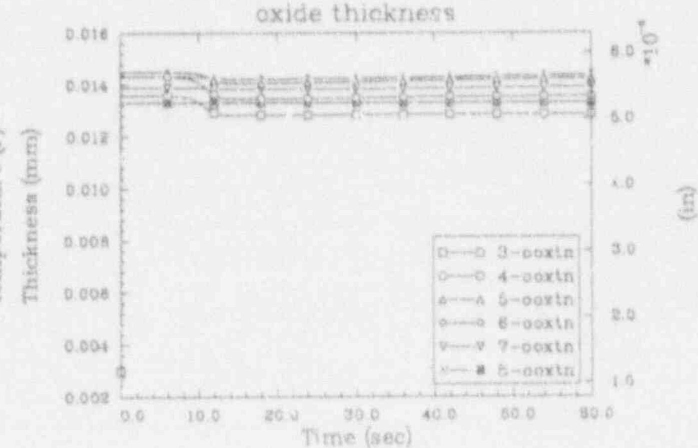
OCONEE 100%DBA 55 GWD/TU PIN--PF 2.4
cladding surface temperature



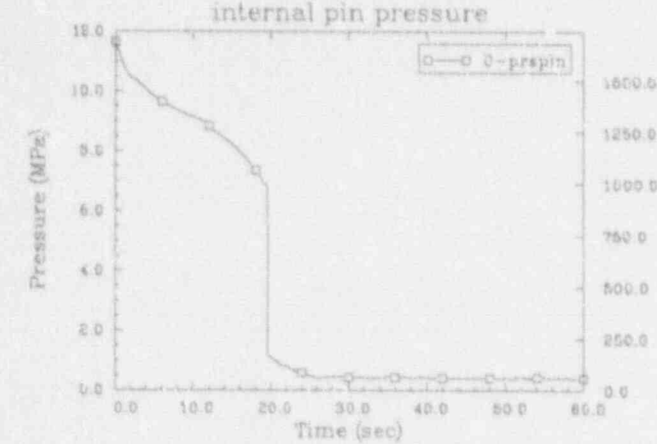
OCONEE 100%DBA 55 GWD/TU PIN--PF 2.4
fuel centerline temperature



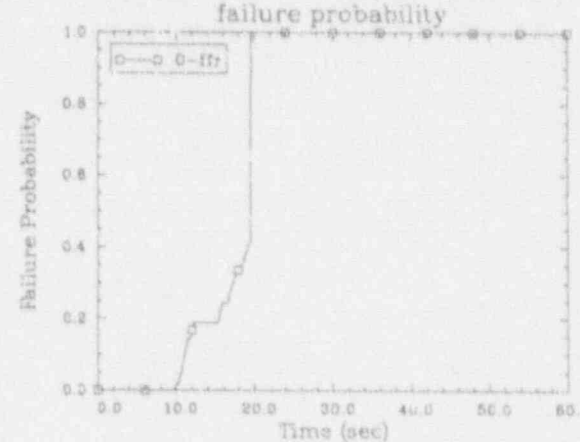
OCONEE 100%DBA 55 GWD/TU PIN--PF 2.4
oxide thickness



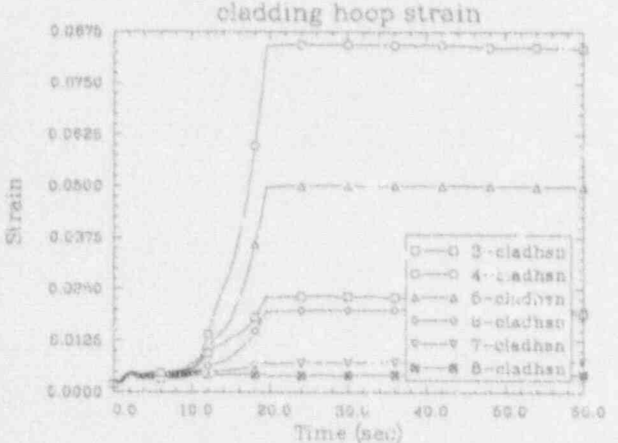
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4
internal pin pressure



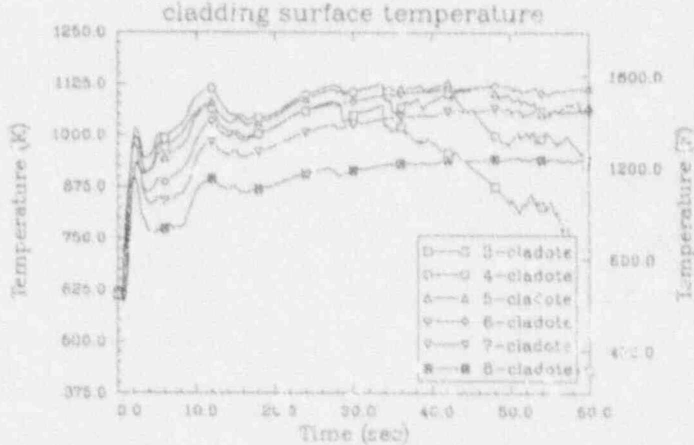
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4
failure probability



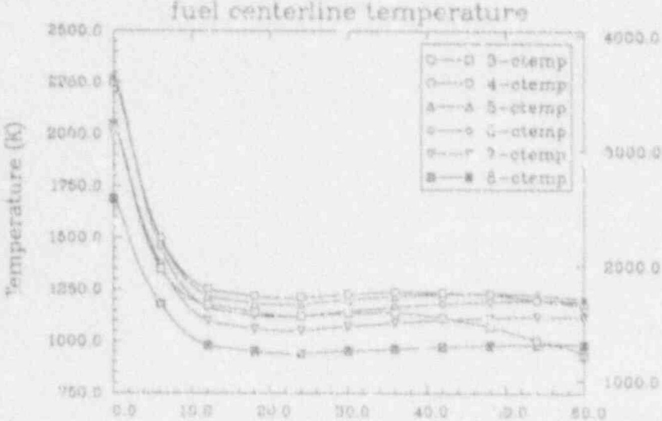
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4
cladding hoop strain



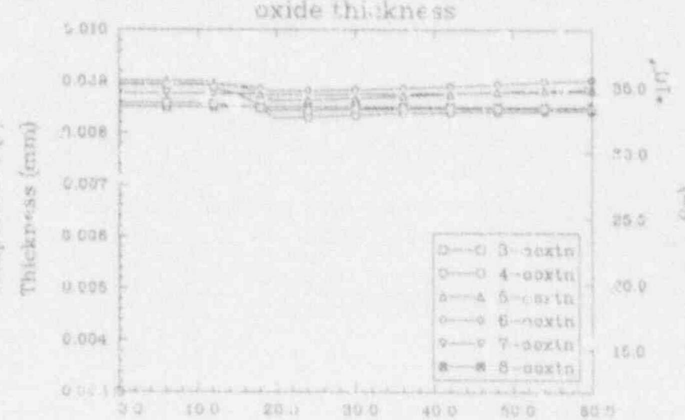
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4
cladding surface temperature



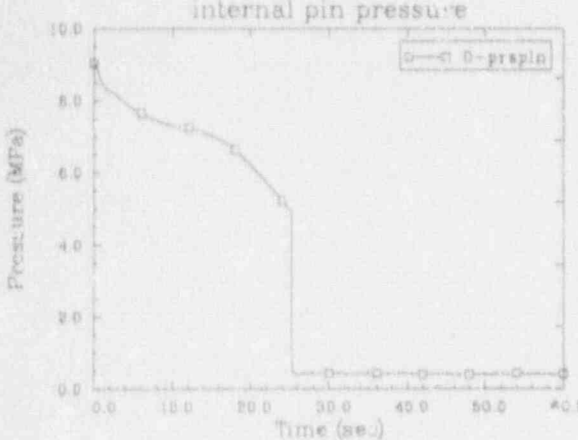
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4
fuel centerline temperature



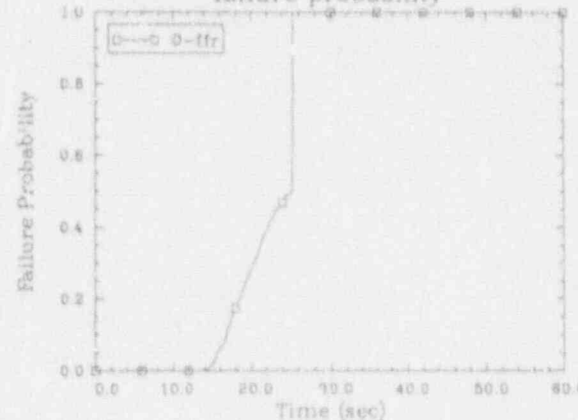
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4
oxide thickness



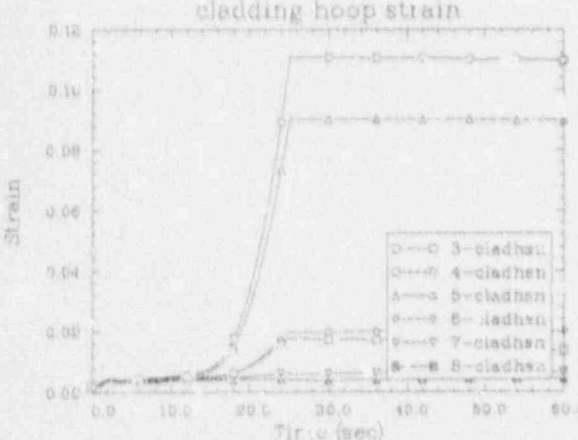
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4
internal pin pressure



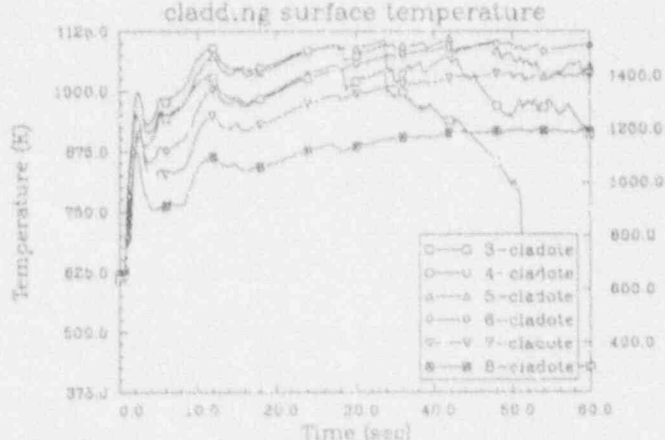
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4
failure probability



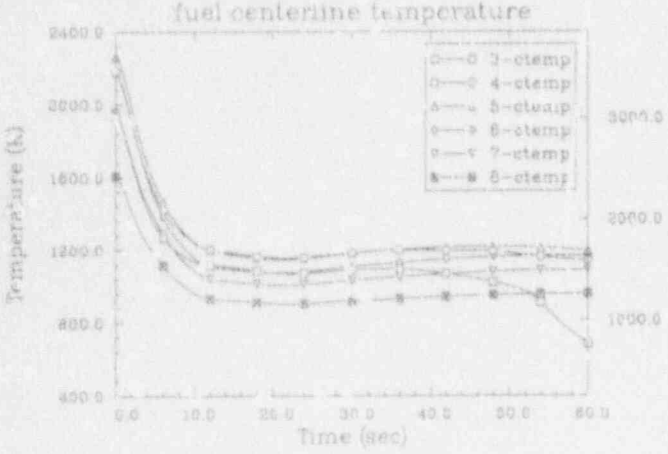
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4
cladding hoop strain



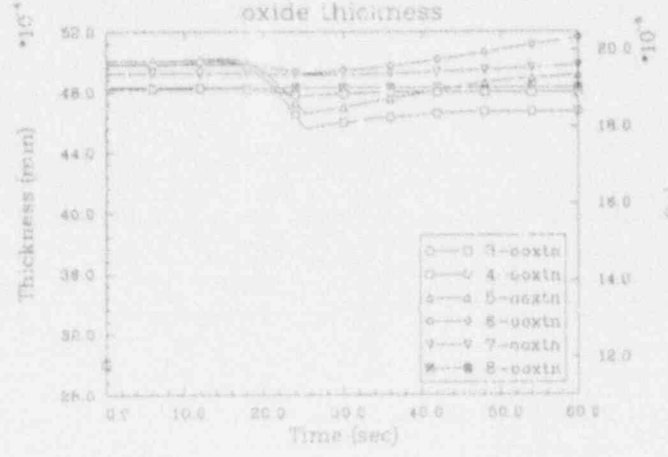
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4
cladding surface temperature

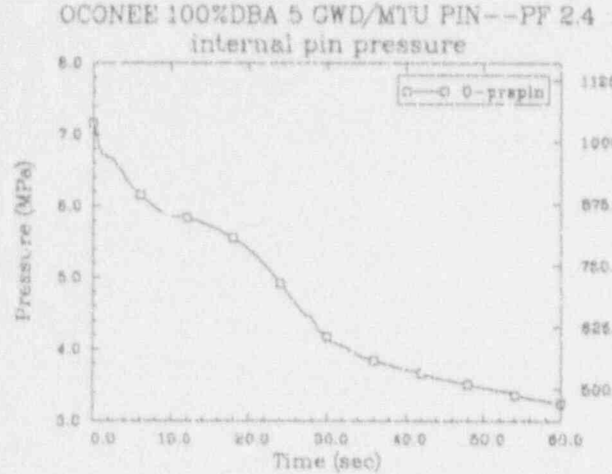


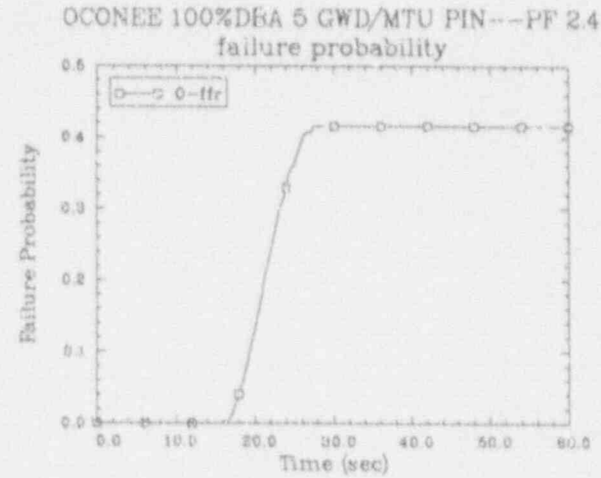
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4
fuel centerline temperature

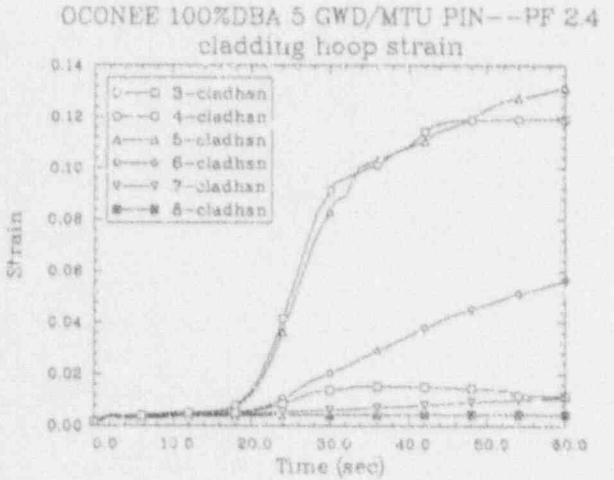


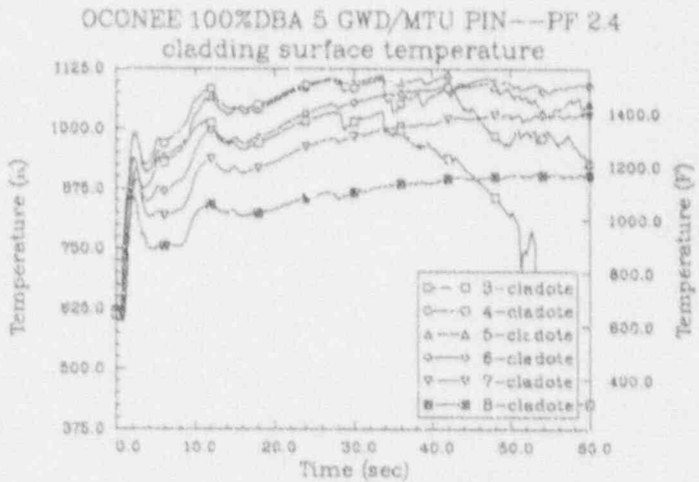
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4
oxide thickness

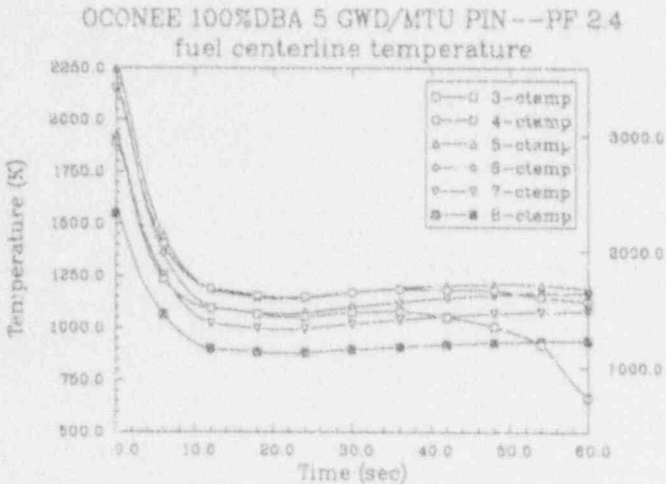


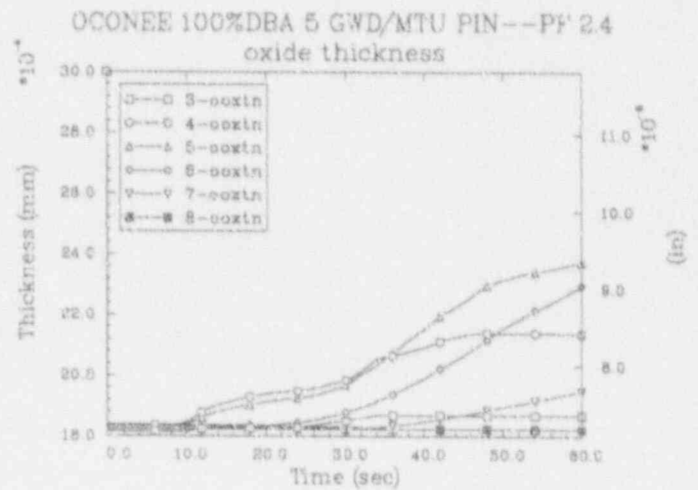

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4
failure probability
0-ffr
Failure Probability
Time (sec)

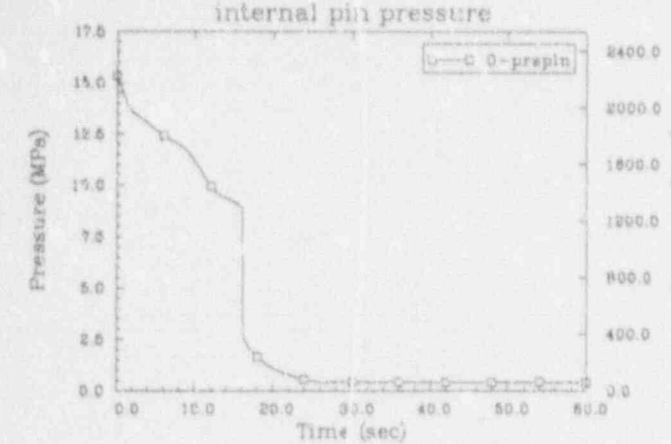

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

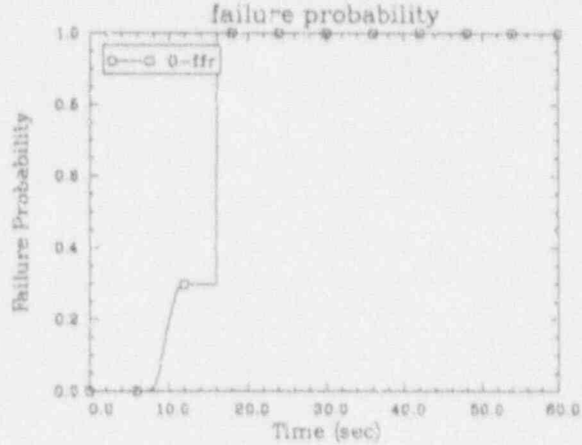

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

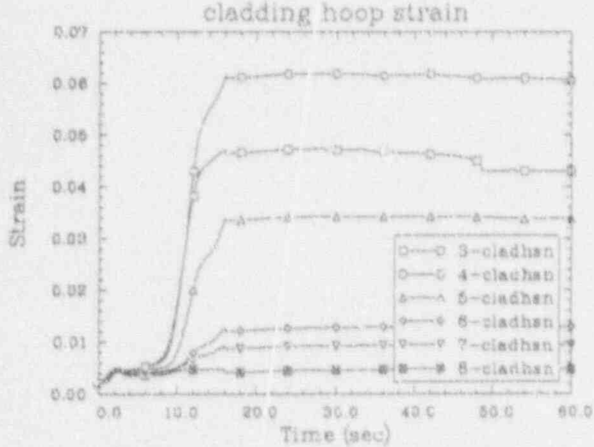
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2
internal pin pressure



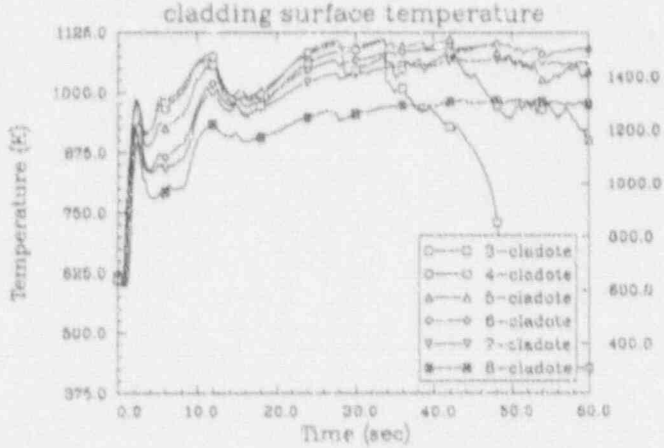
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2
failure probability



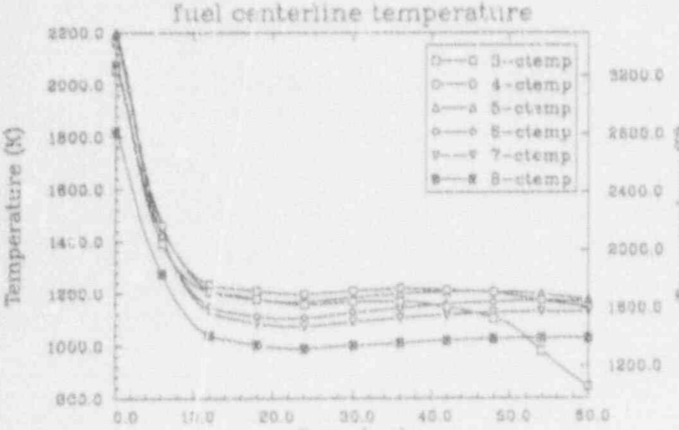
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2
cladding hoop strain



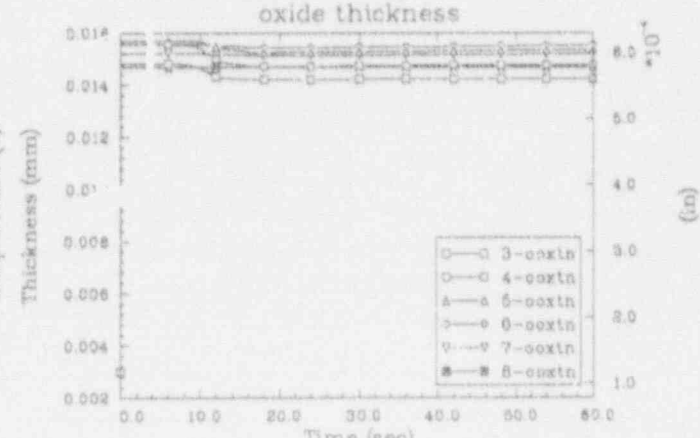
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2
cladding surface temperature

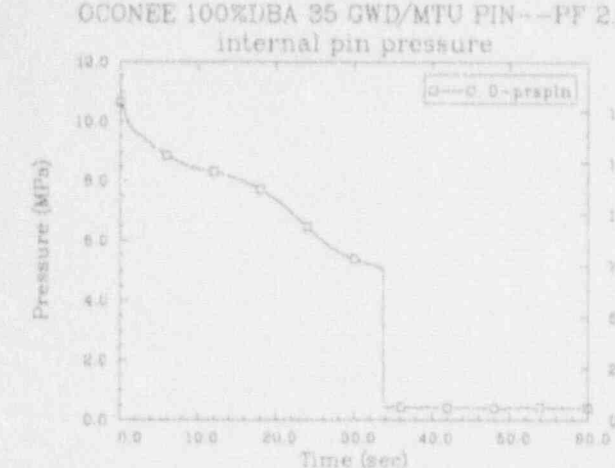


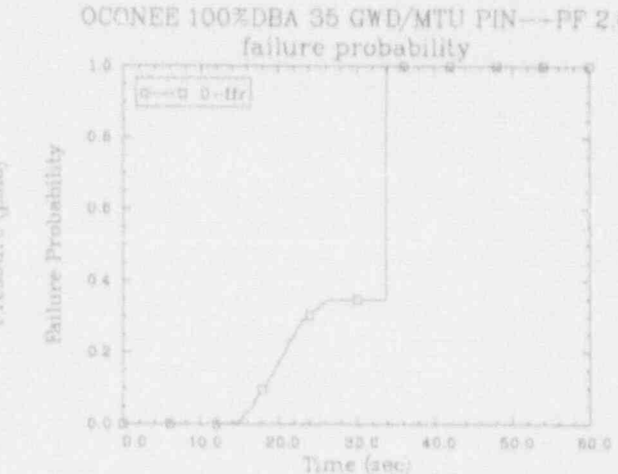
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2
fuel centerline temperature

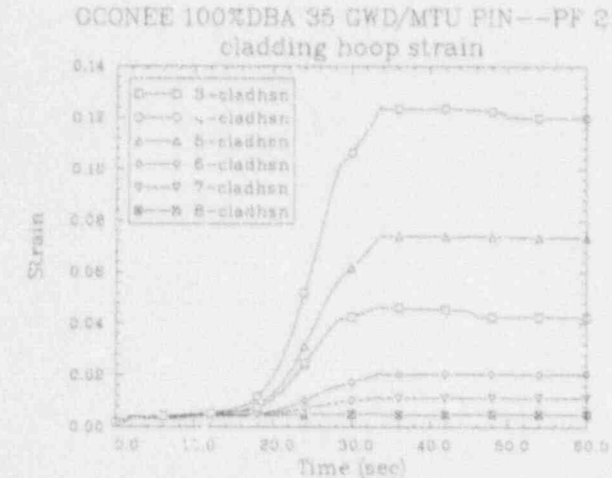


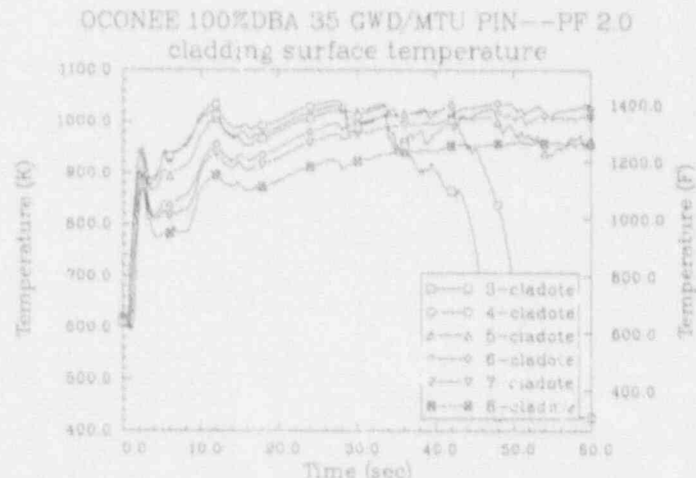
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2
oxide thickness

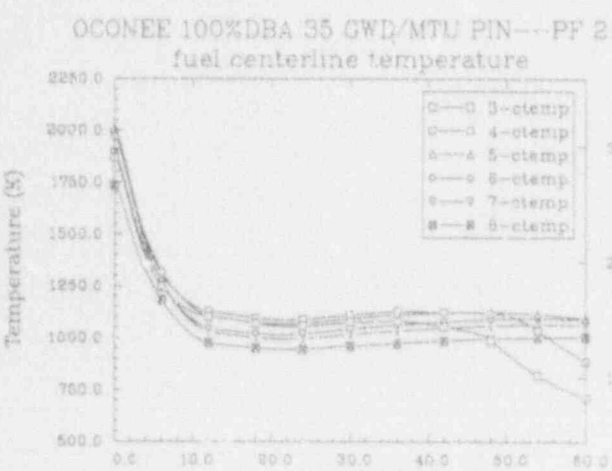


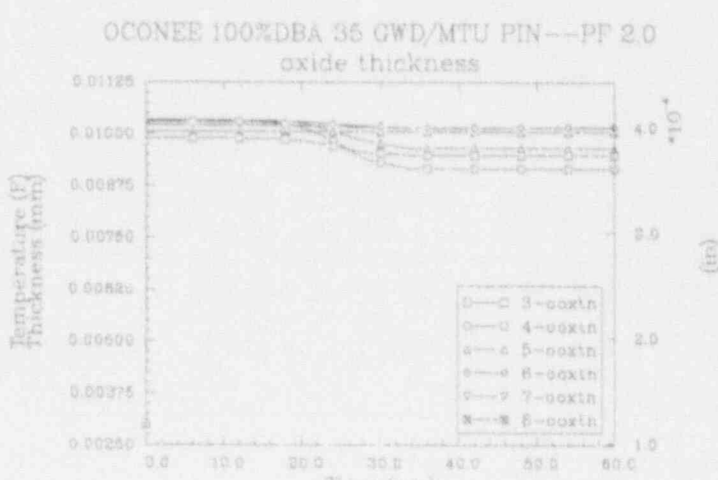

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

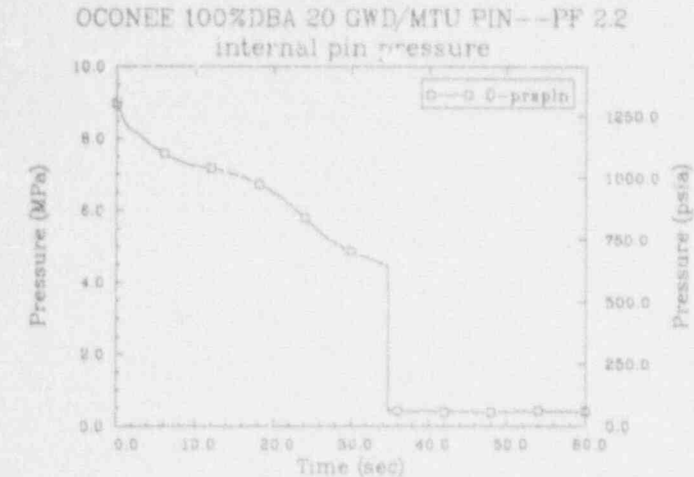

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

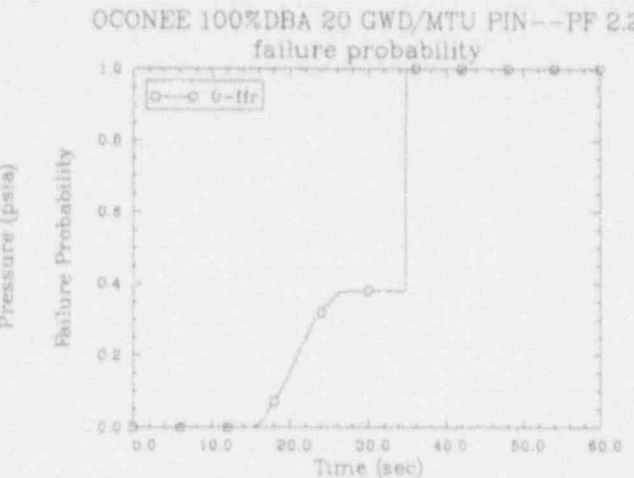

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

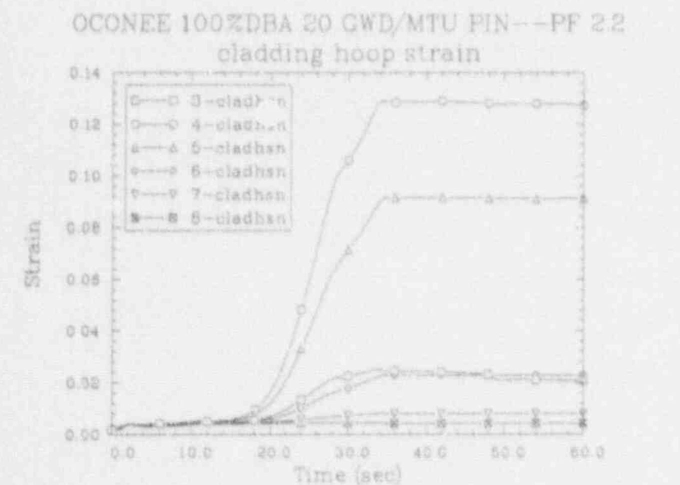

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
Temperature (K)
Temperature (F)
Time (sec)

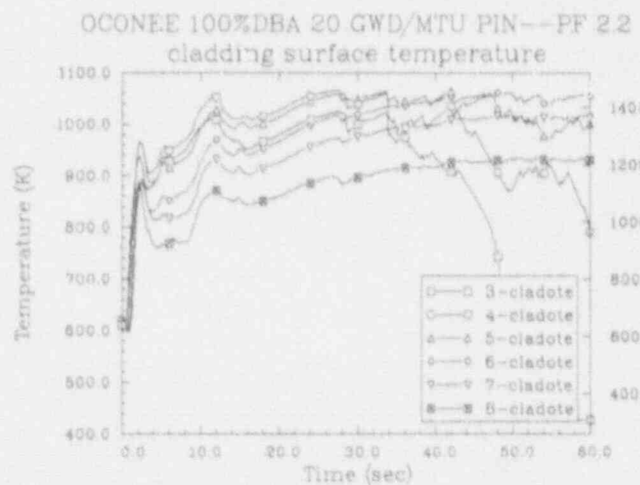

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Time (sec)

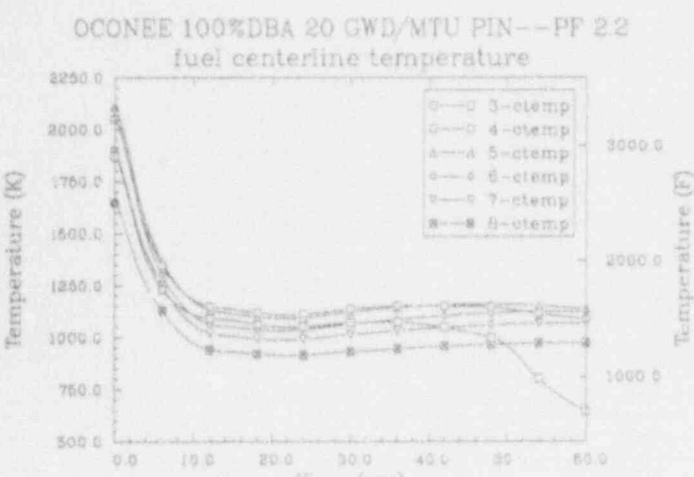

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

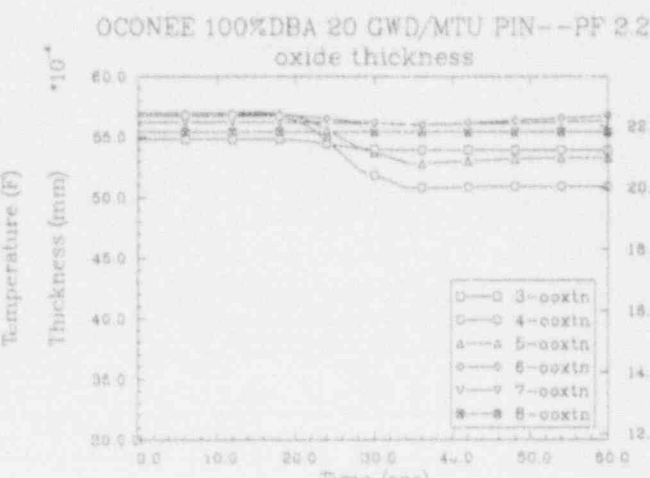

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

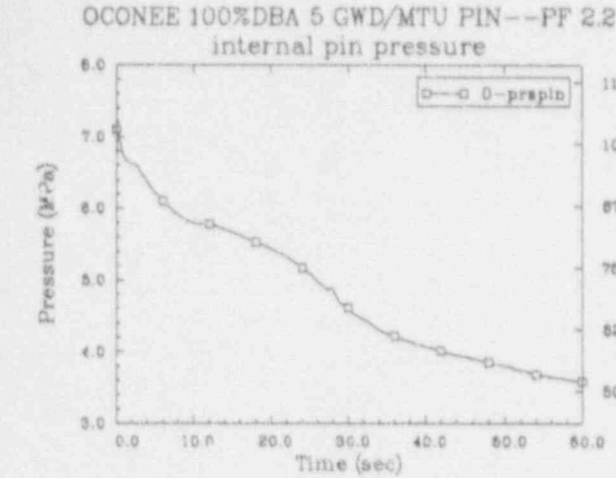

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

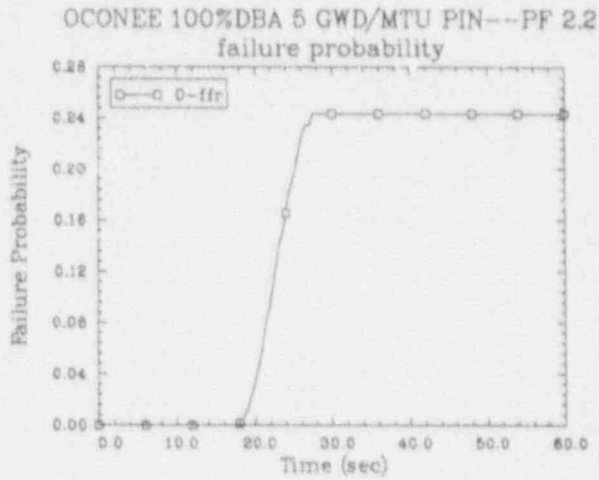

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

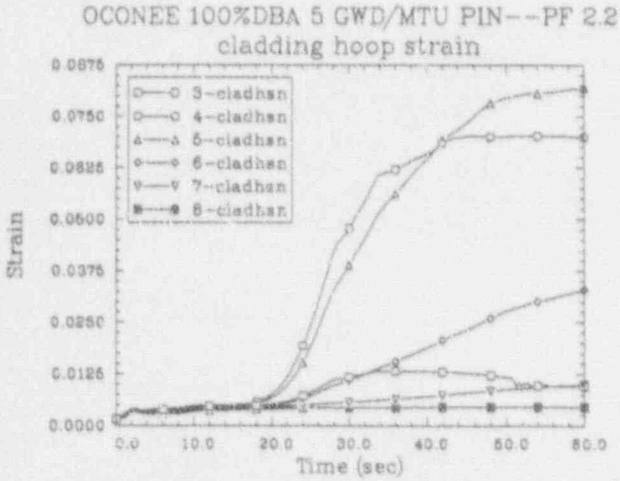

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

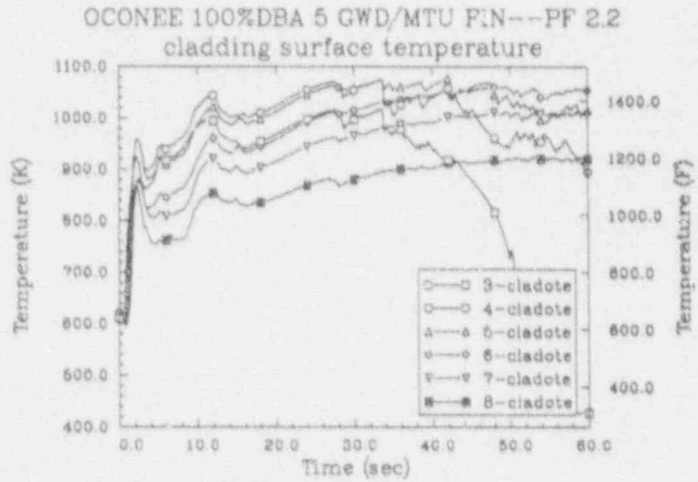

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)

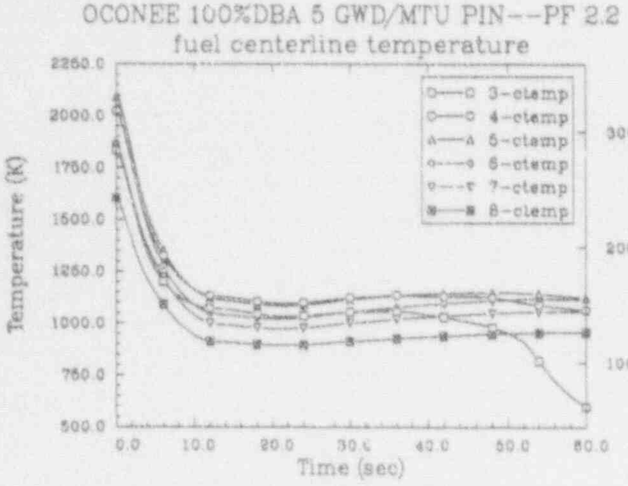

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

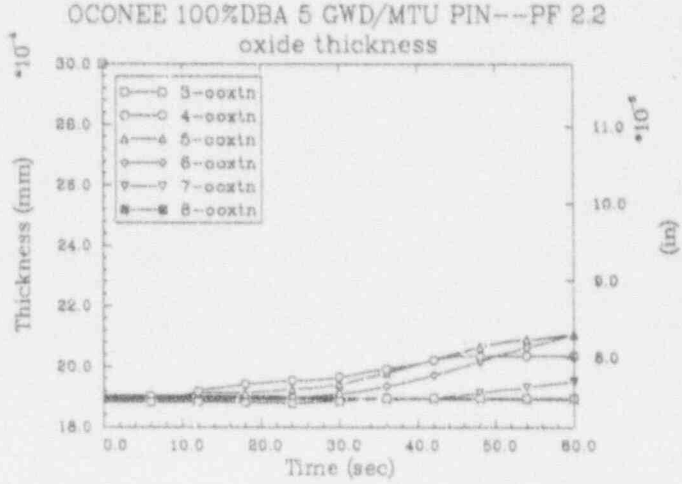

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

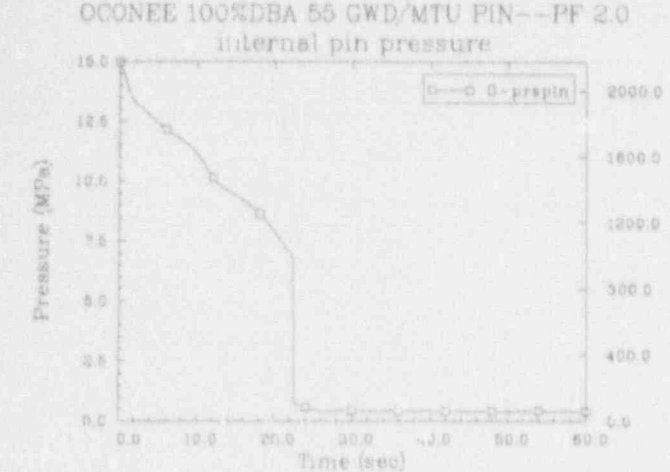

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

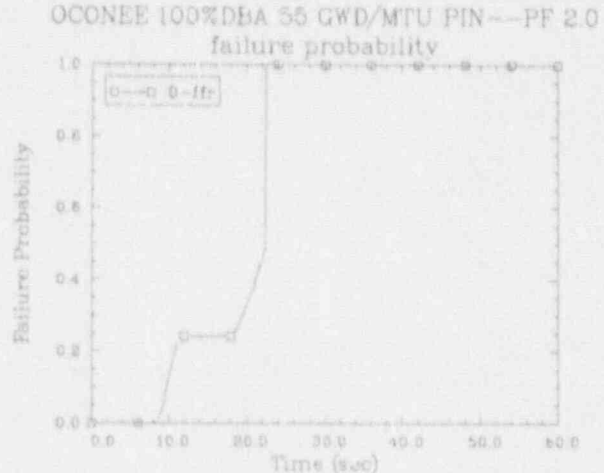

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

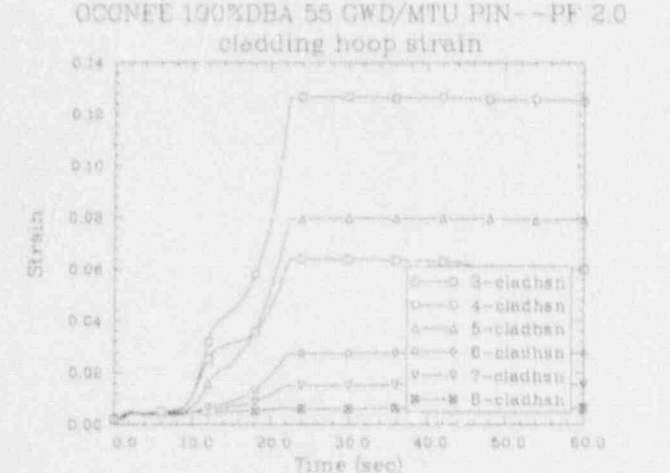

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

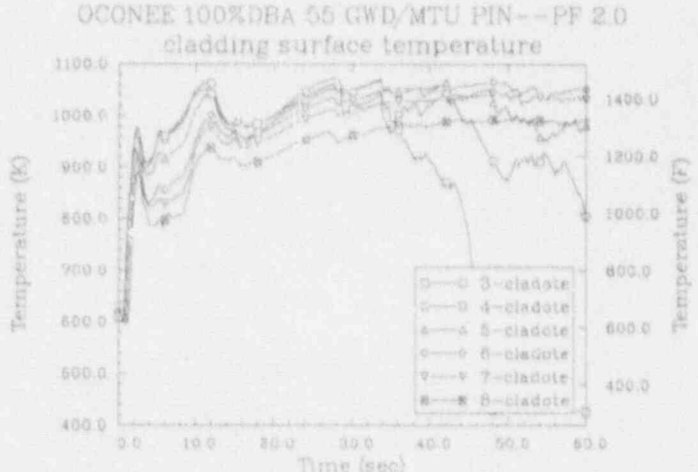

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

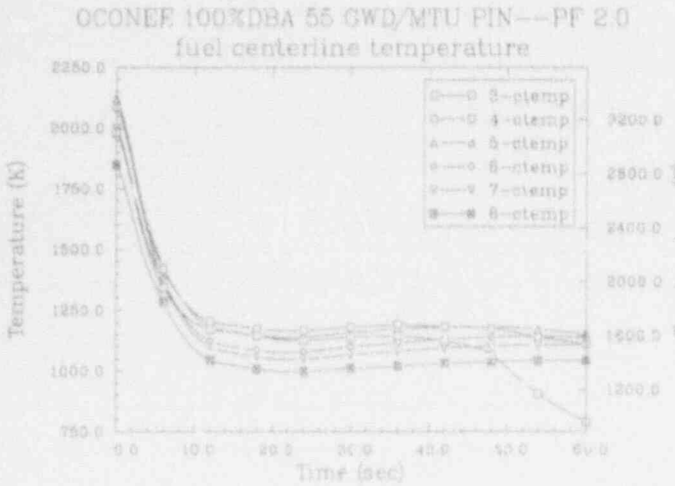

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

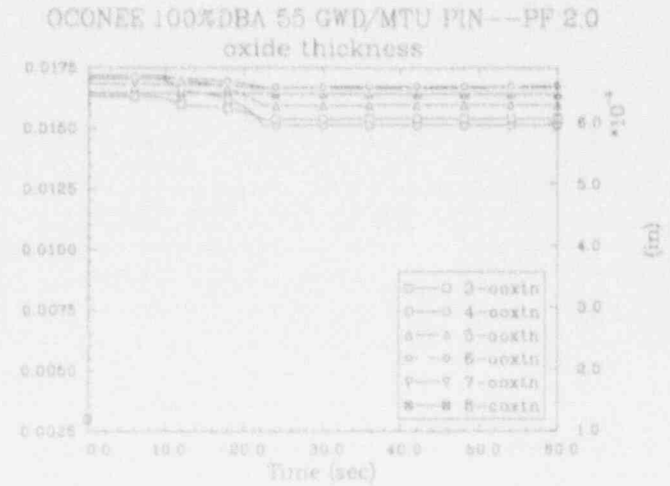

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin

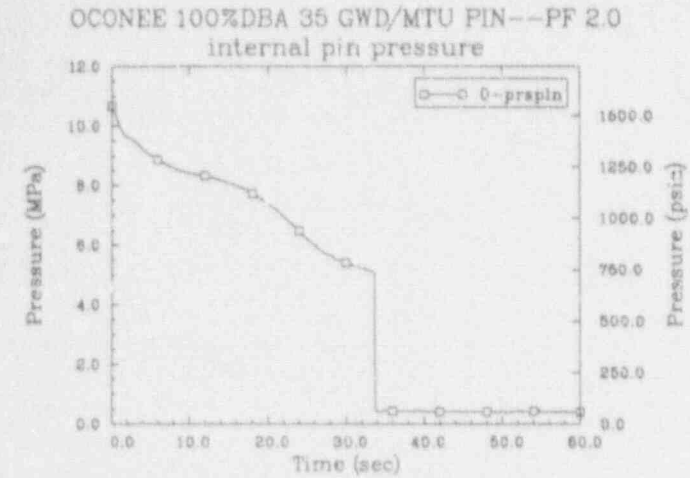

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0
failure probability
Failure Probability
Time (sec)
0-ffr

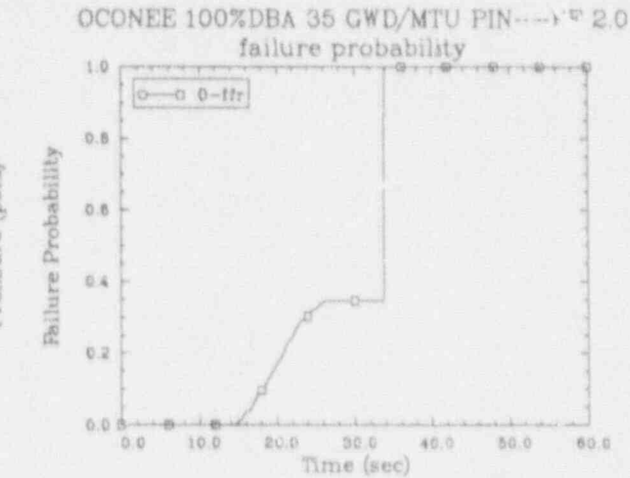

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn

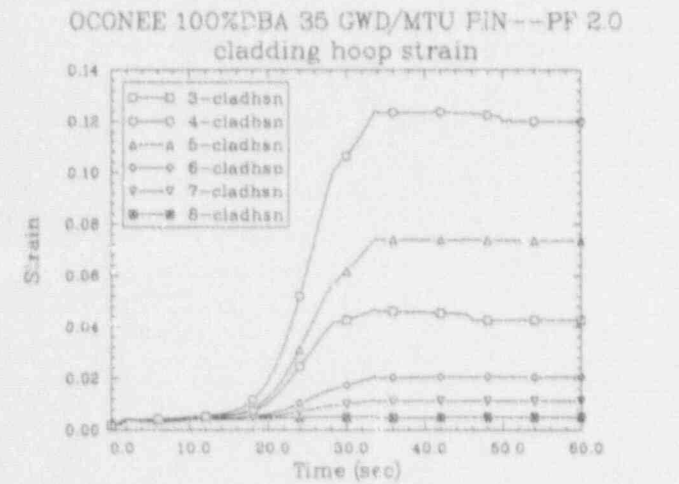

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

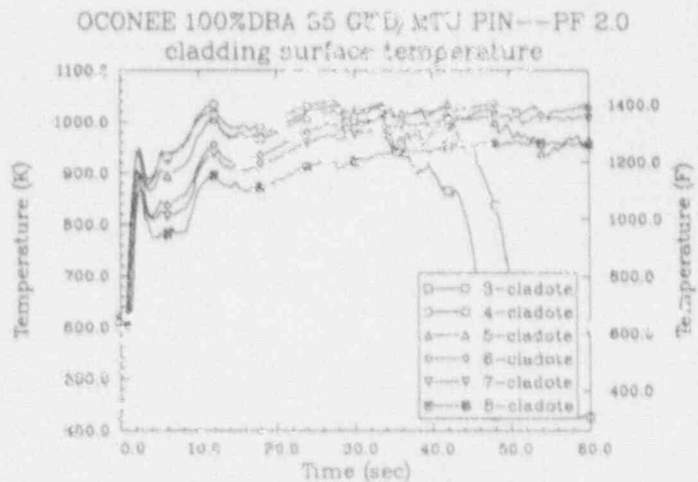

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp

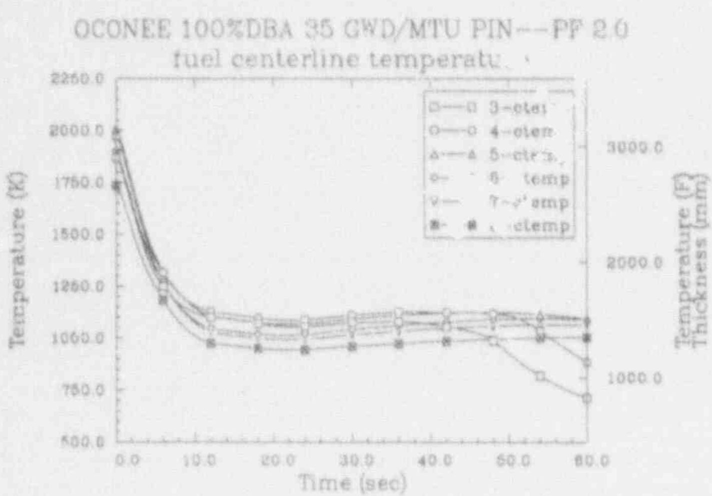

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxth
6-ooxtn
7-ooxtn
8-coxtn

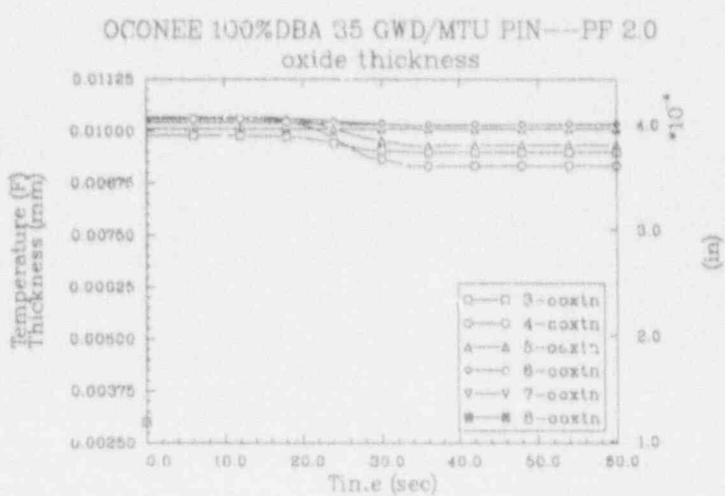

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

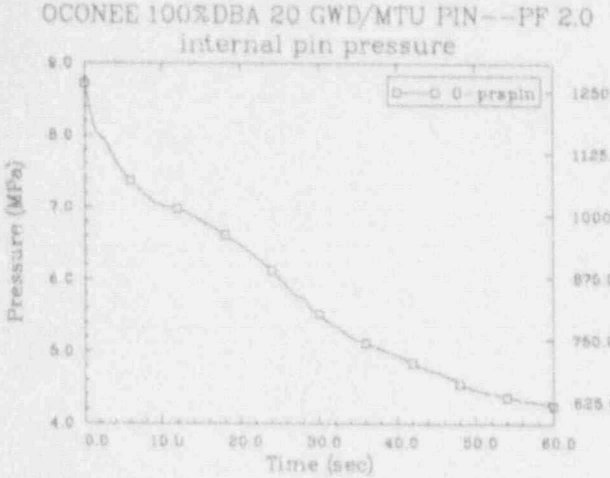

failure probability
0-ffr
Failure Probability
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

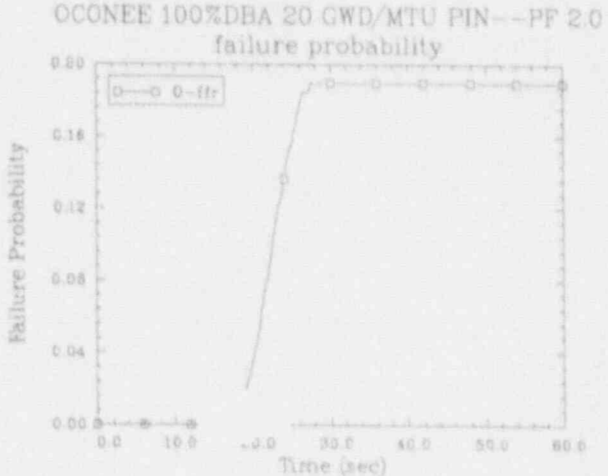

cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
4-ctem
Temperature (K)
Temperature (F)
Time (sec)

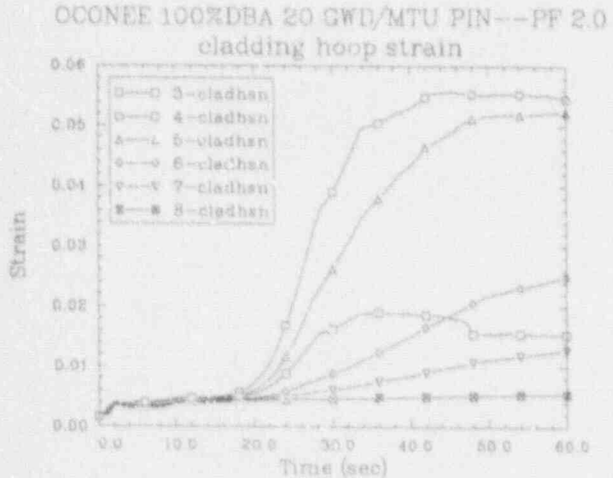

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)



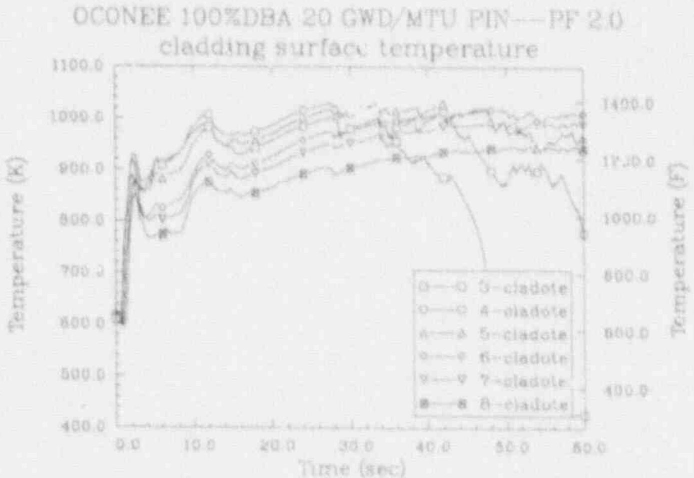
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin



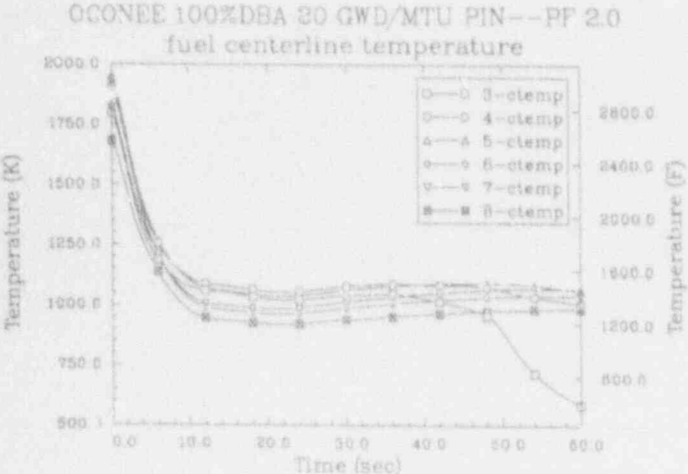
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0
failure probability
Failure Probability
Time (sec)
0-ffr



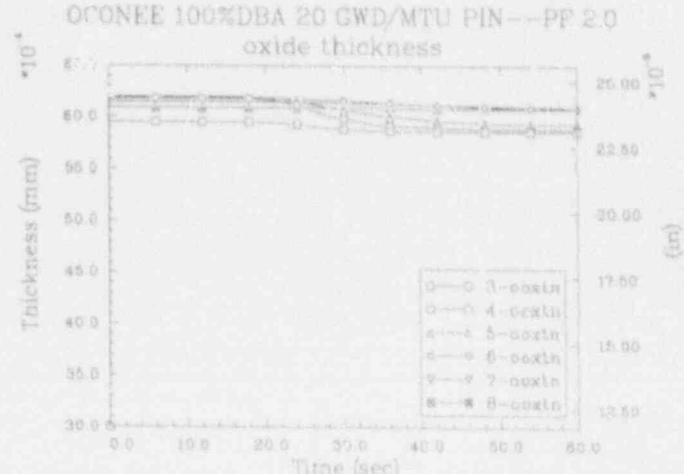
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn



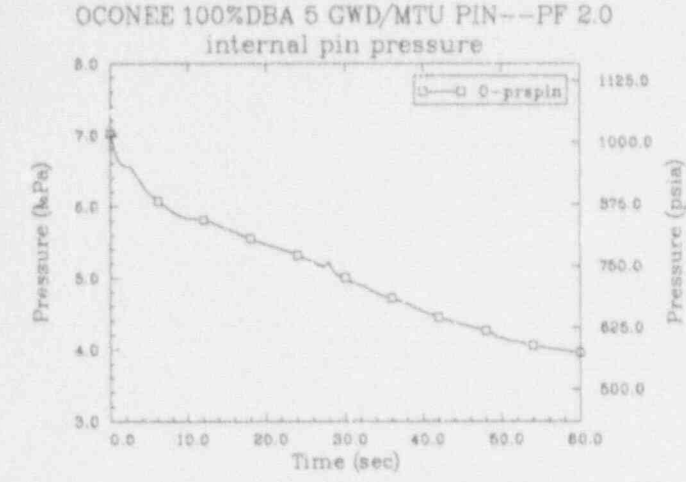
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

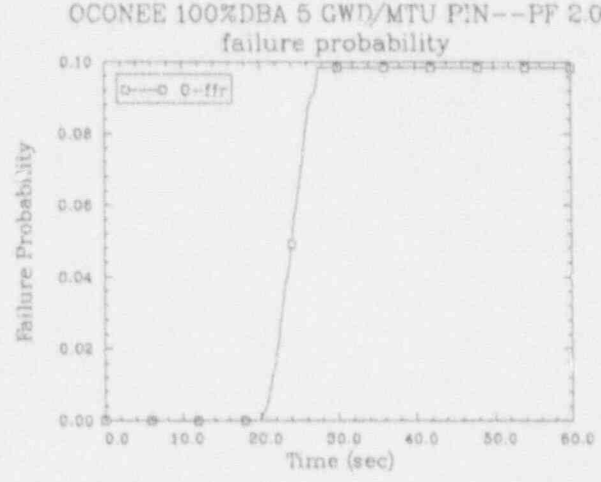


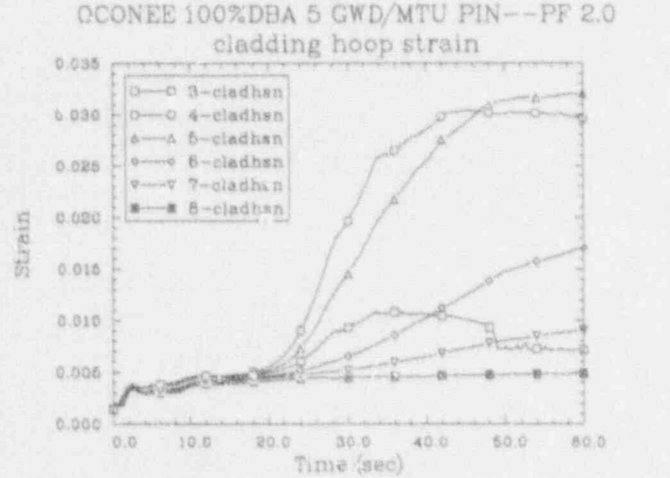
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp

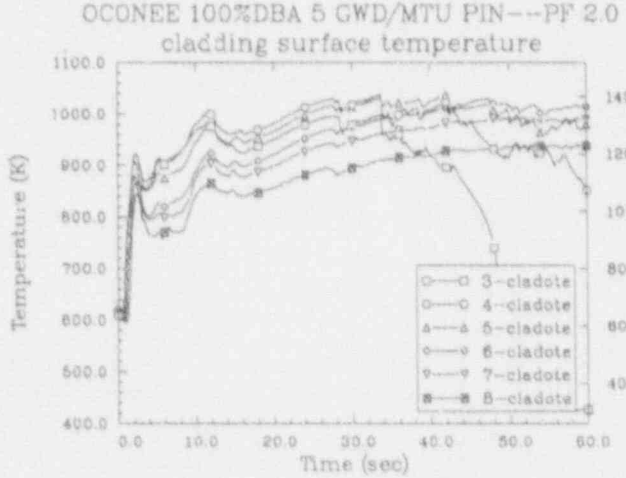


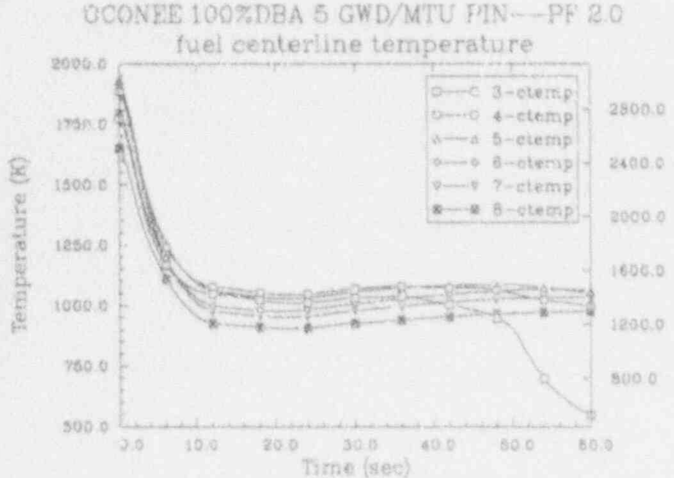
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin

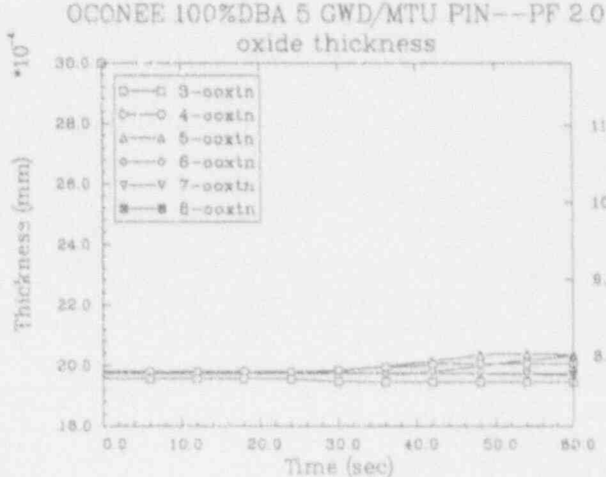

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

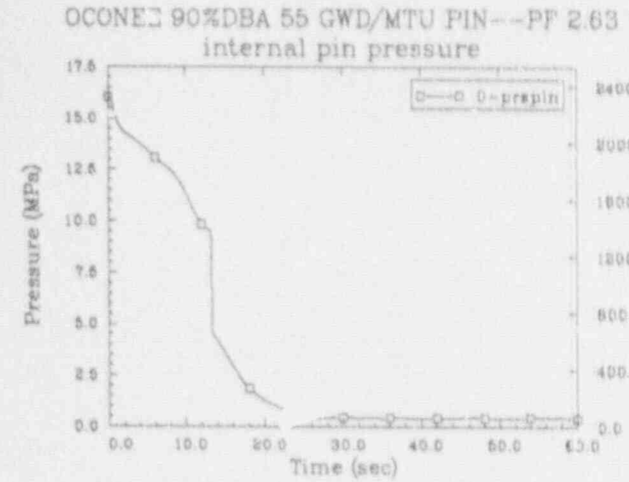

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

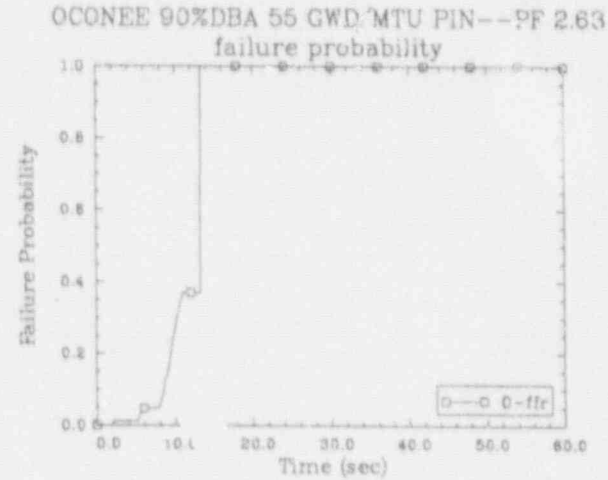

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

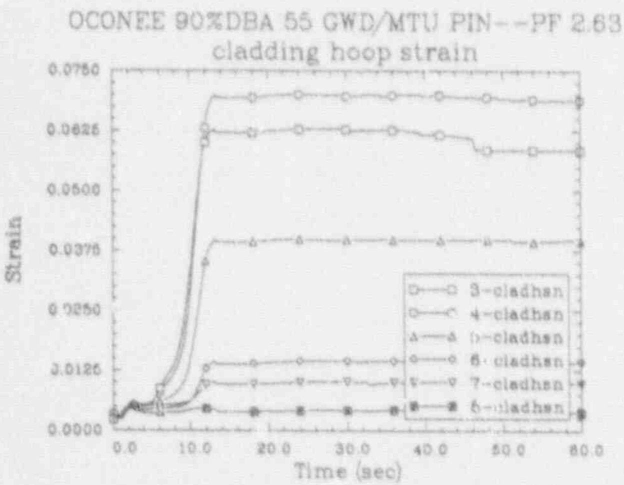

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

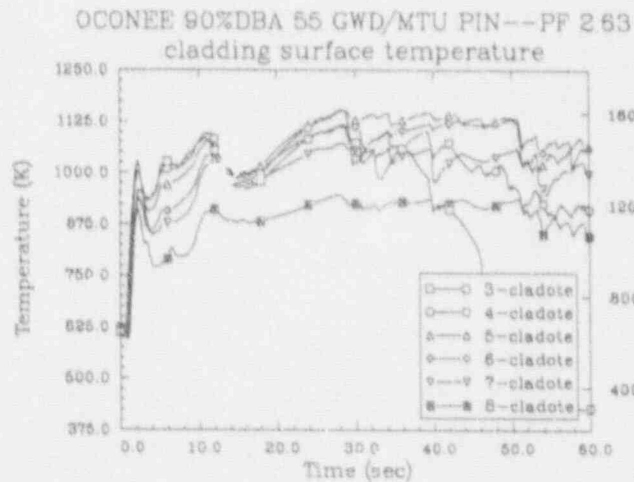

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

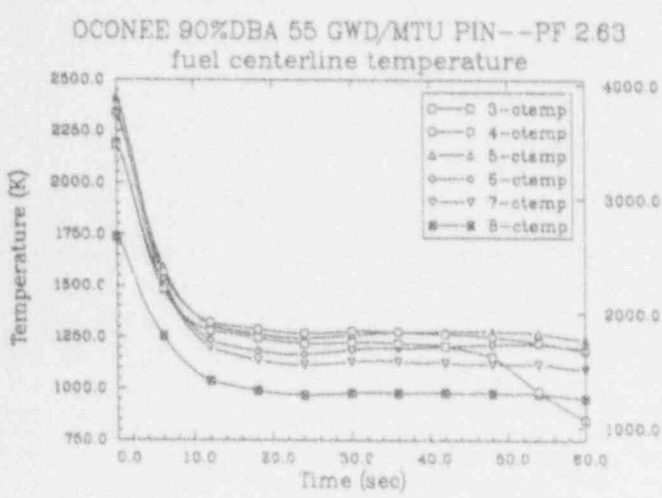

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

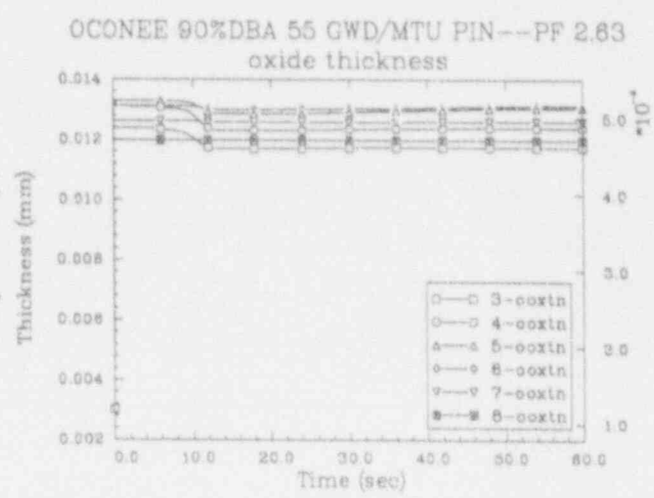

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

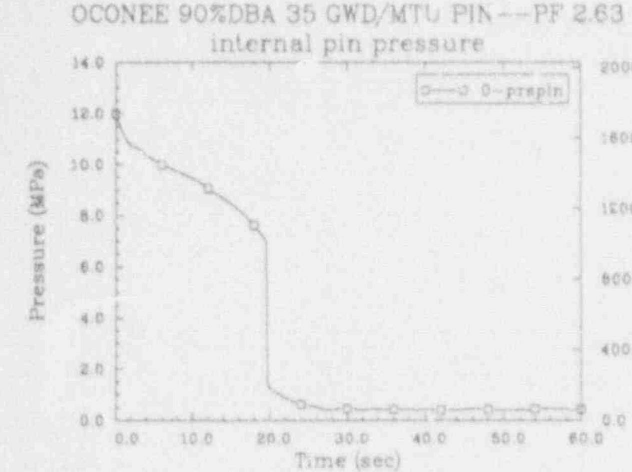

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)

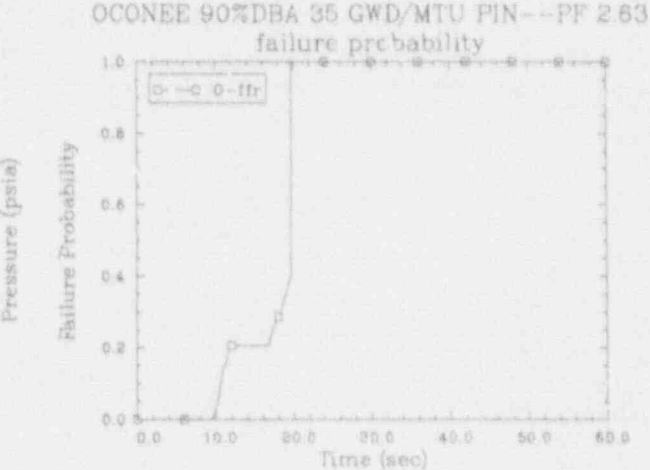

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

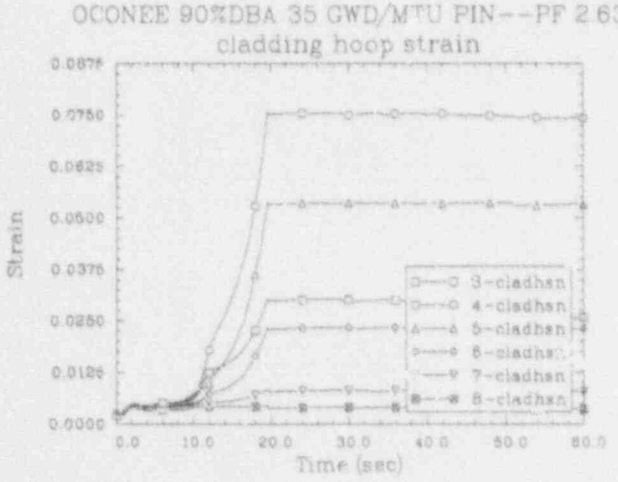

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

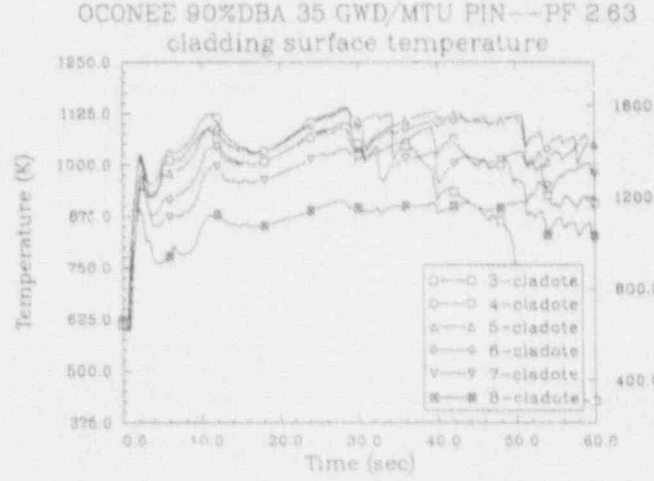

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

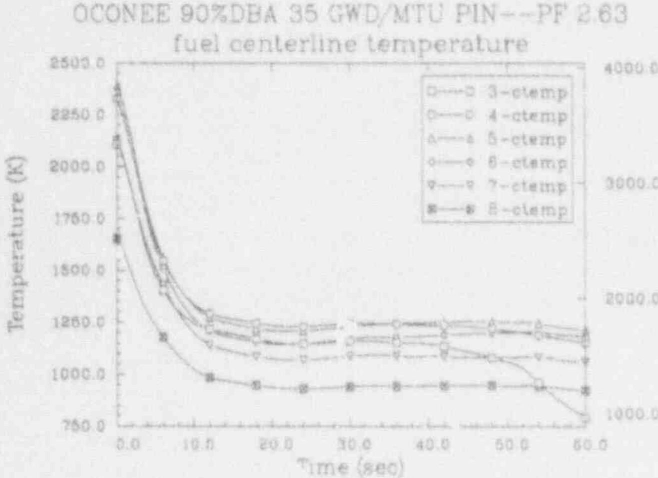

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

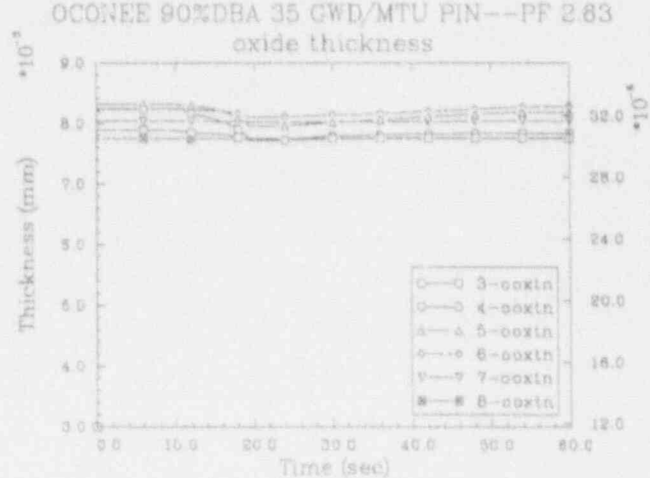

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

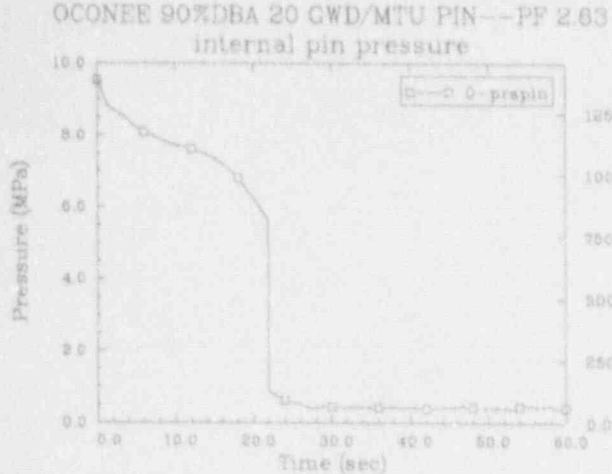

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)

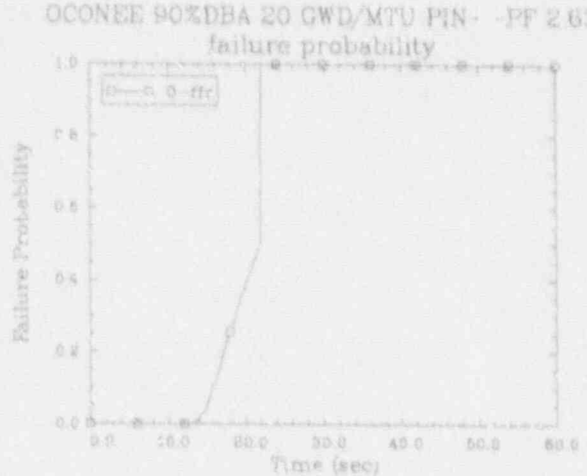

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

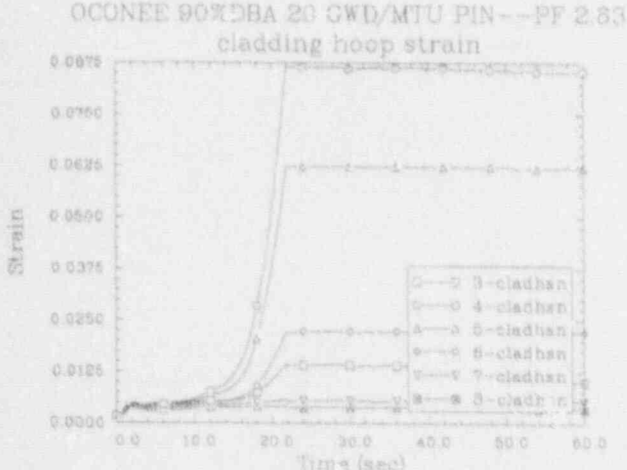

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

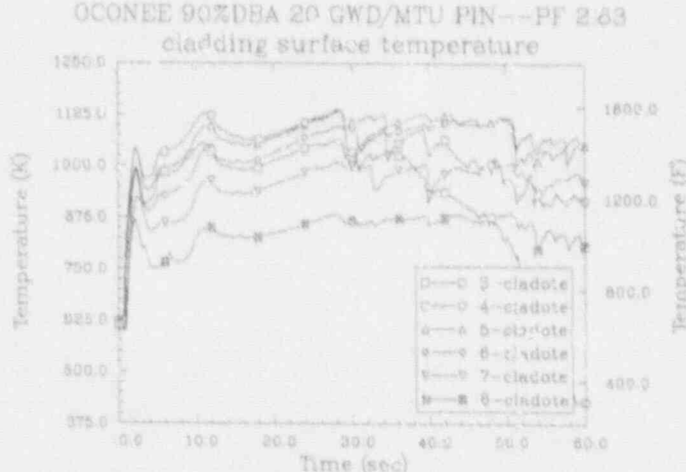

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

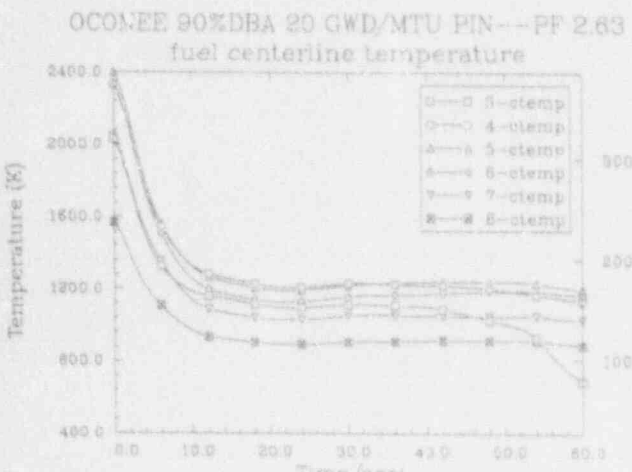

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

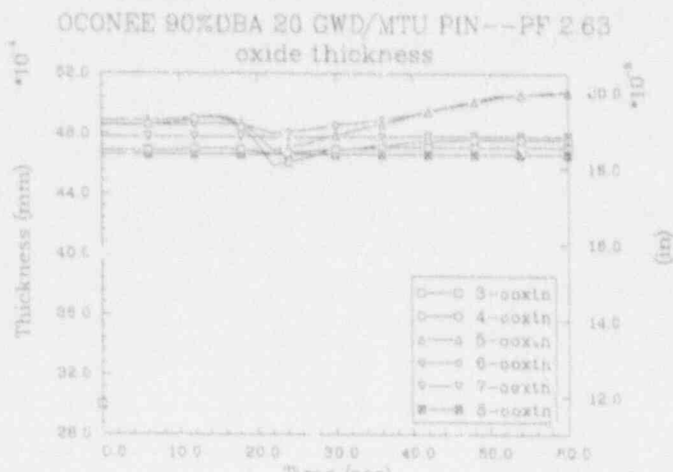

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

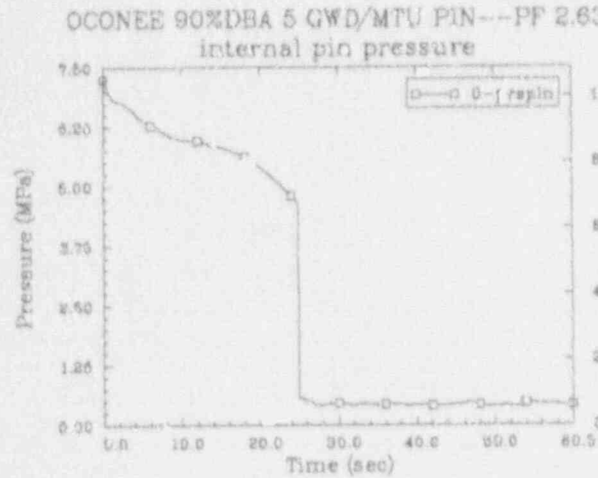

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)

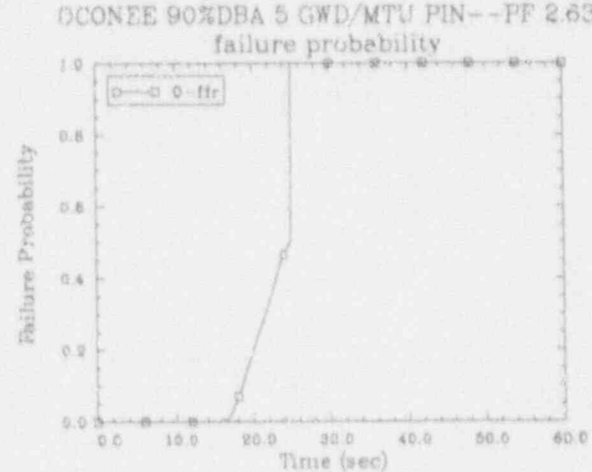

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

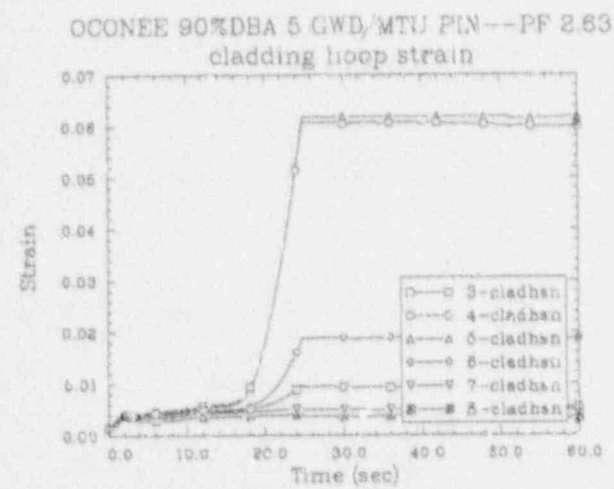

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

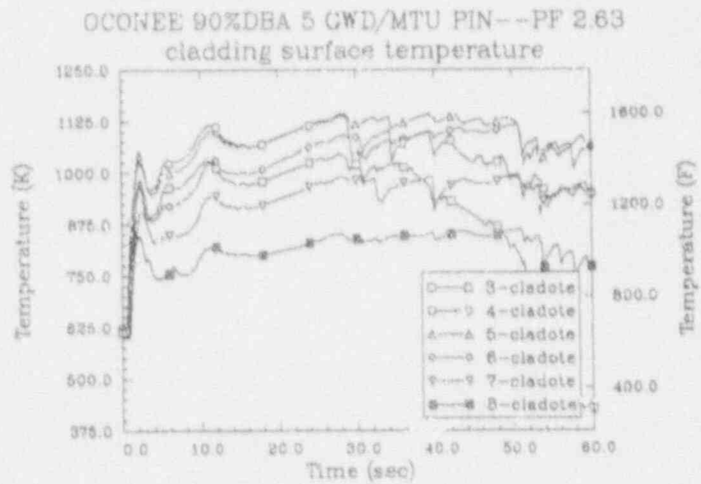

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

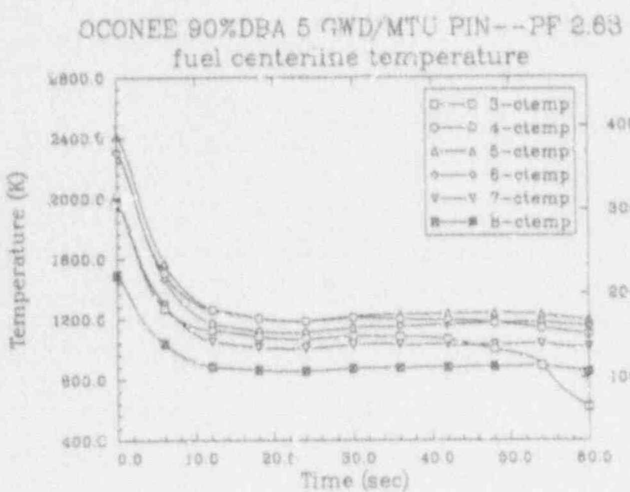

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

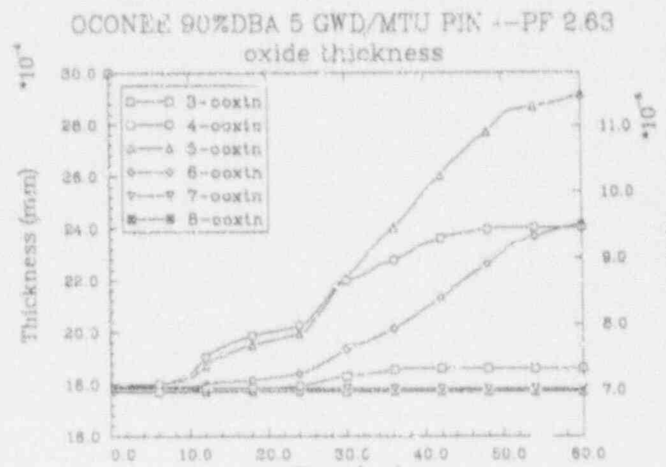

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.63
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

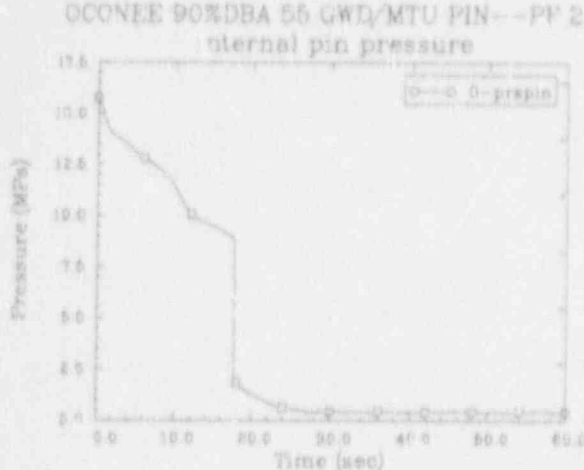

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.63
failure probability
Failure Probability
Time (sec)

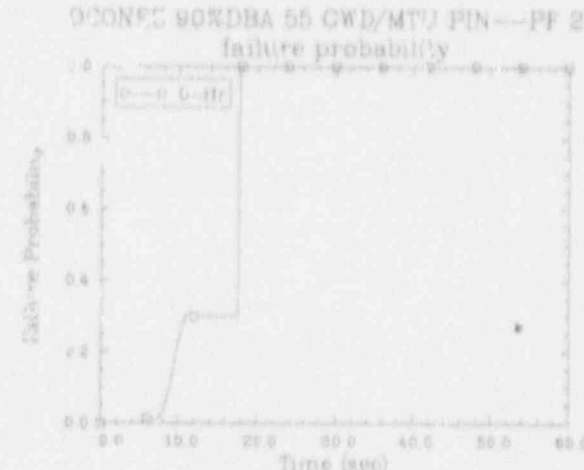

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.63
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn

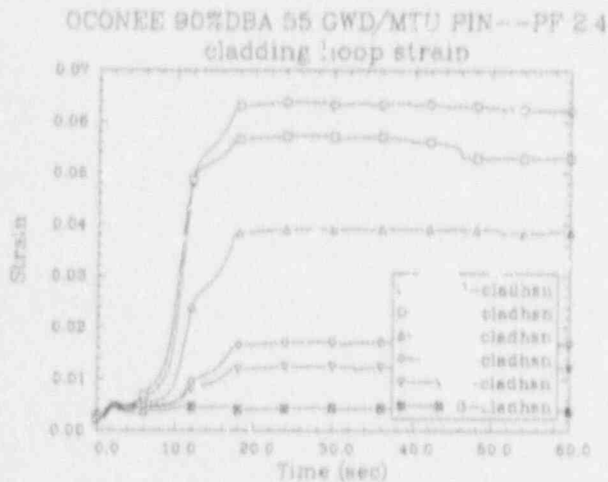

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.63
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

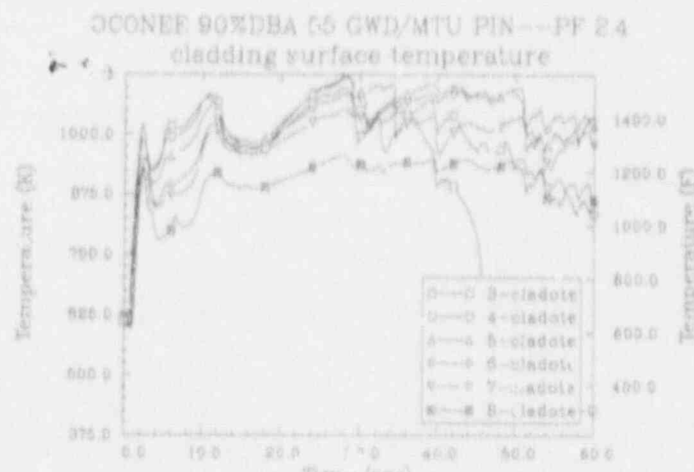

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.63
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp

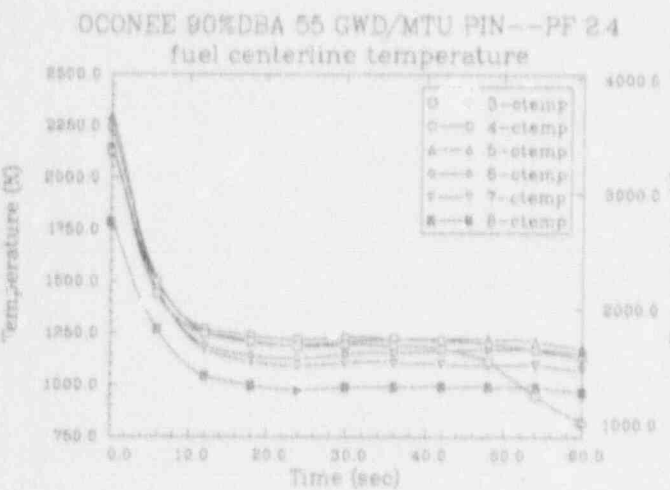

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.63
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

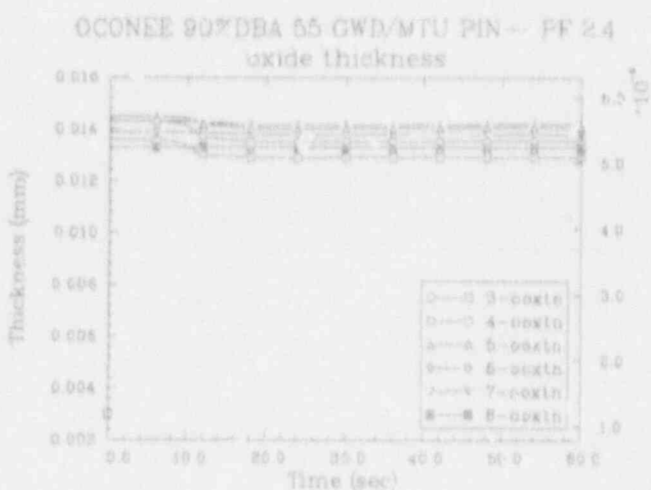

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.4
nternal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


failure probability
Failure Probability
Time (sec)

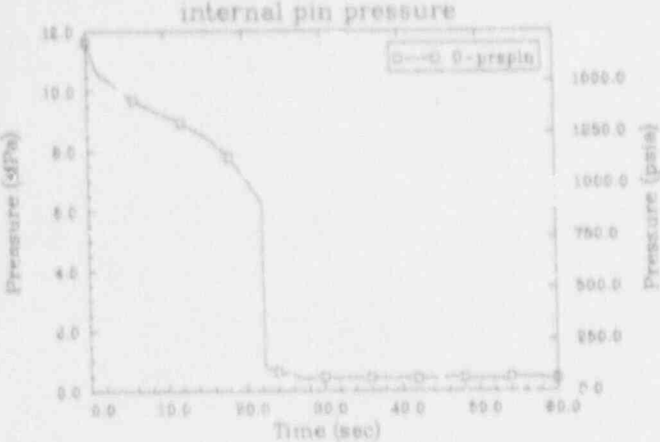

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.4
cladding hoop strain
Strain
Time (sec)


OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.4
cladding surface temperature
3-cladote
4-cladote
5-cladote
8-cladote
Temperature (K)
Temperature (F)

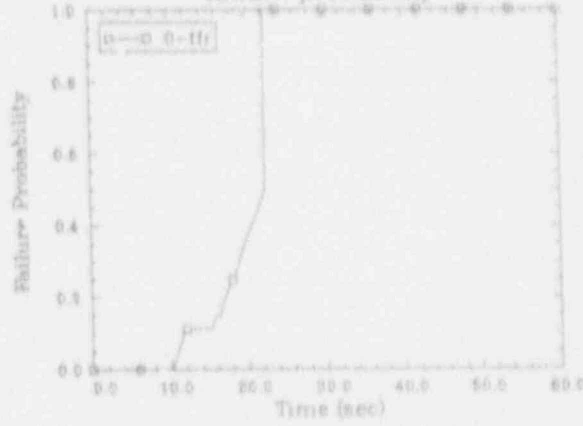

OCONEE 90%DBA 55 GWD/MTU PIN--PF 2.4
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (F)
Time (sec)


OCONEE 90%DBA 55 GWD/MTU PIN-- PF 2.4
oxide thickness
Thickness (mm)
(in)
Time (sec)

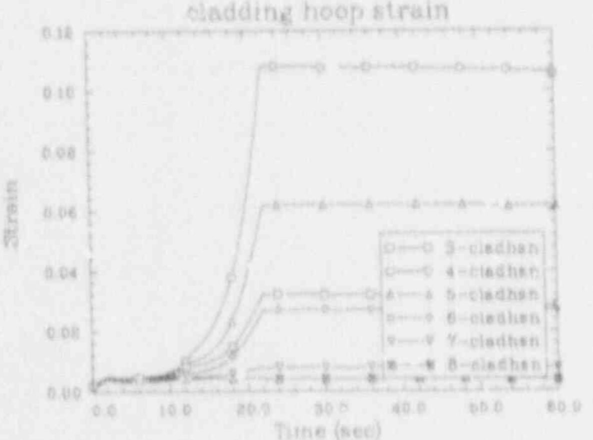
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.4
internal pin pressure



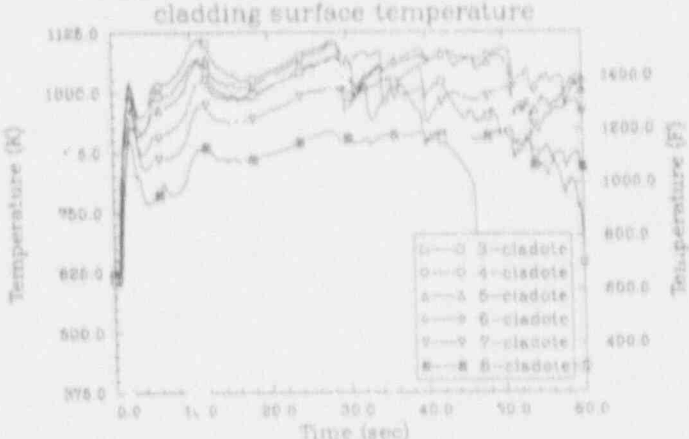
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.4
failure probability



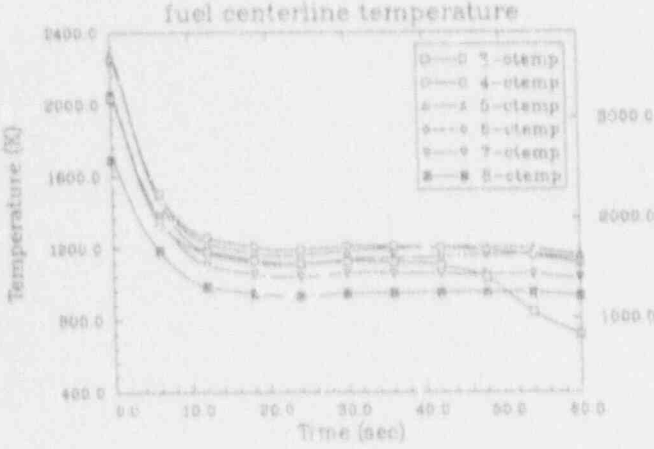
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.4
cladding hoop strain



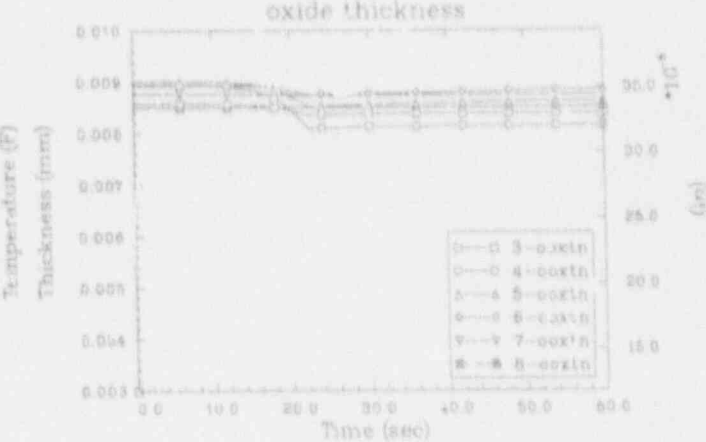
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.4
cladding surface temperature

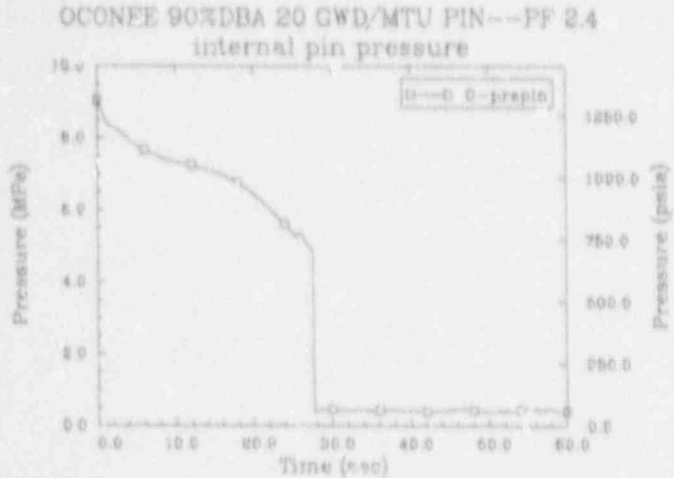


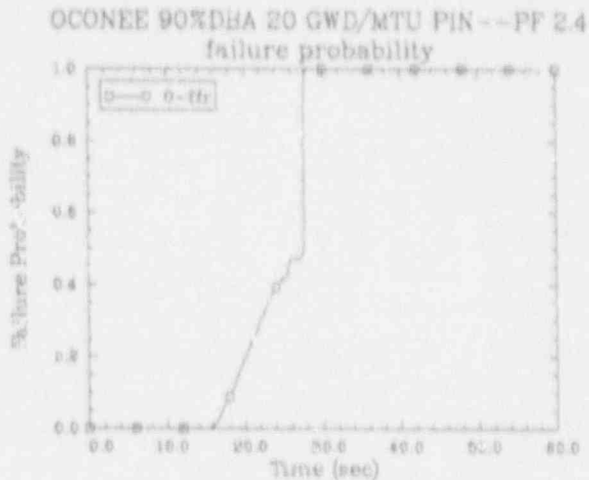
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.4
fuel centerline temperature

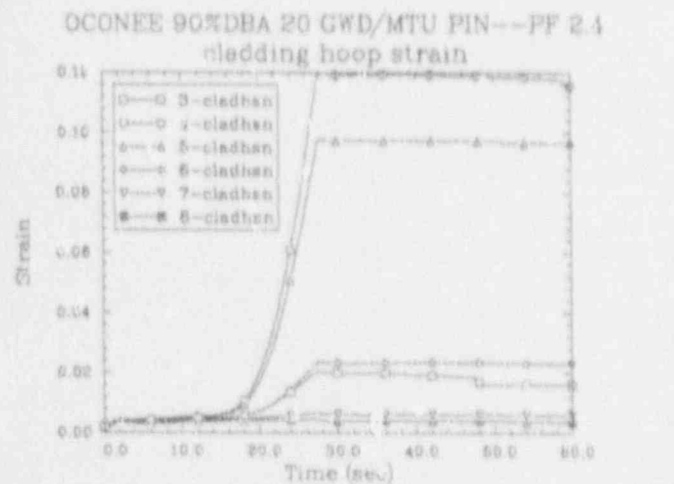


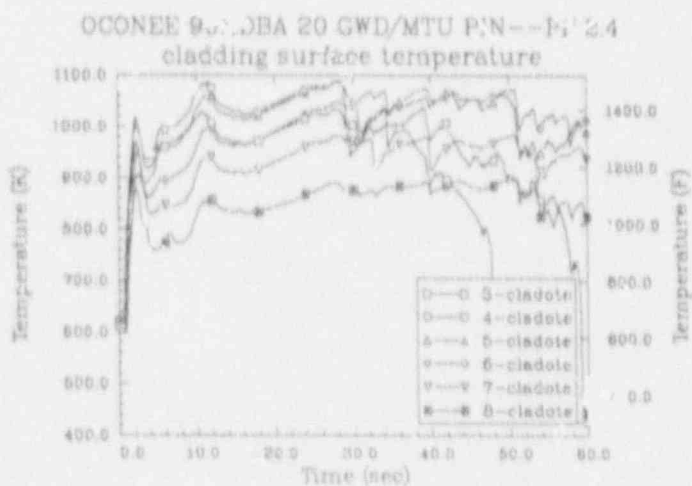
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.4
oxide thickness

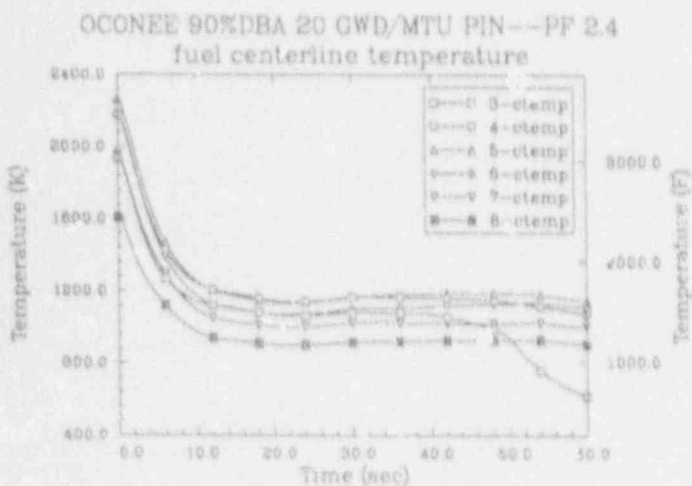


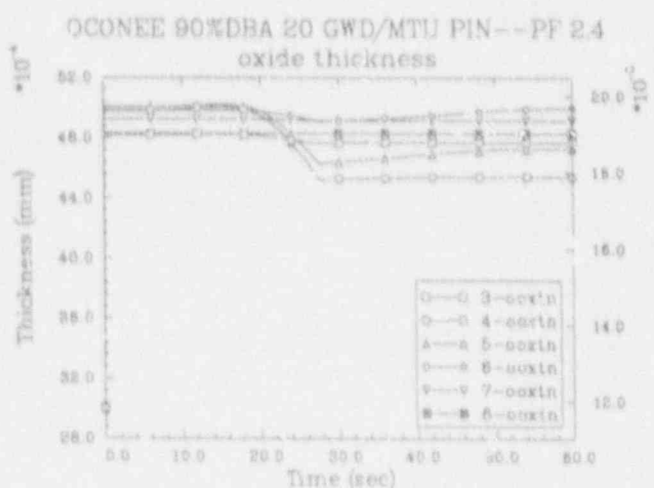

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.4
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

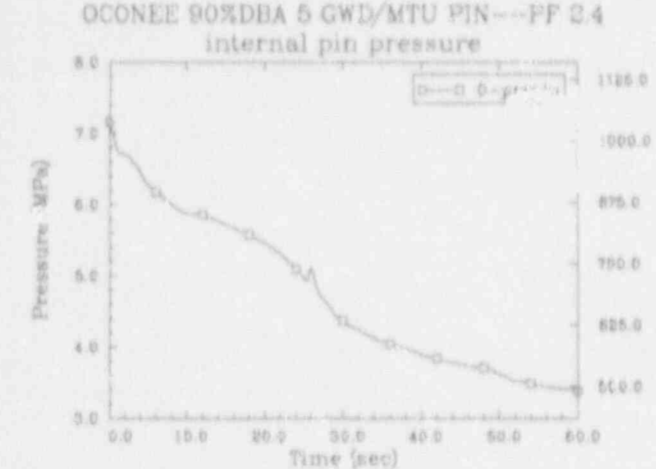

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.4
failure probability
0-ffr
Time (sec)


OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.4
cladding hoop strain
3-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain

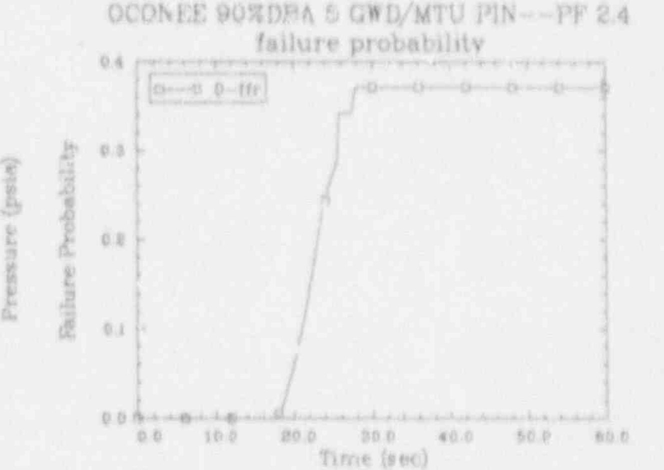

cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.4
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

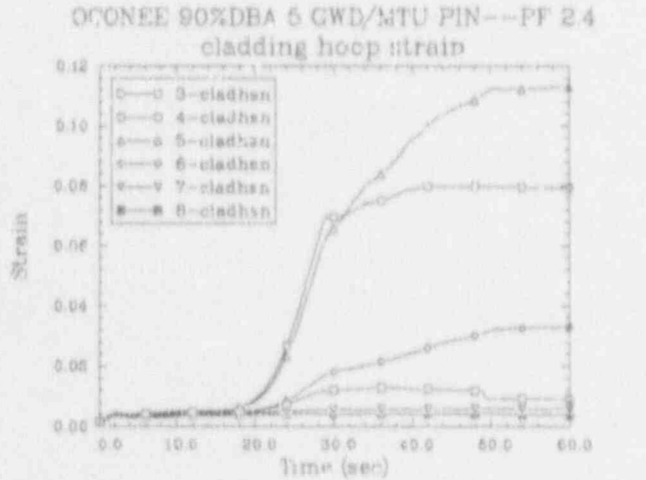

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.4
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)



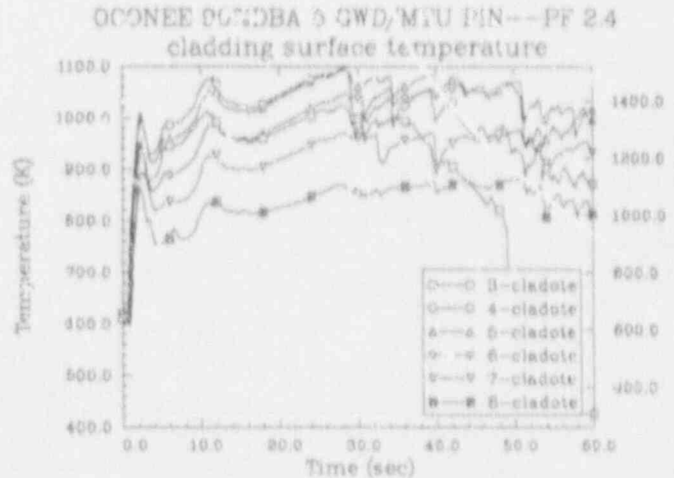
OCONEE 90%DBA 5 GWD/MTU PIN---PF 2.4
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)



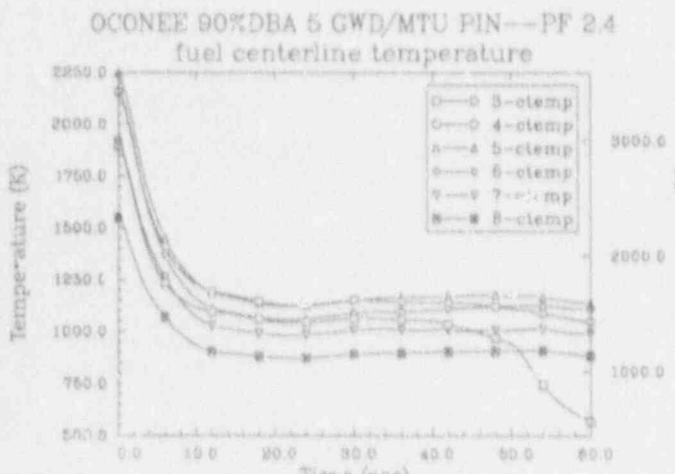
OCONEE 90%DBA 5 GWD/MTU PIN---PF 2.4
failure probability
0-ffr
Failure Probability
Time (sec)



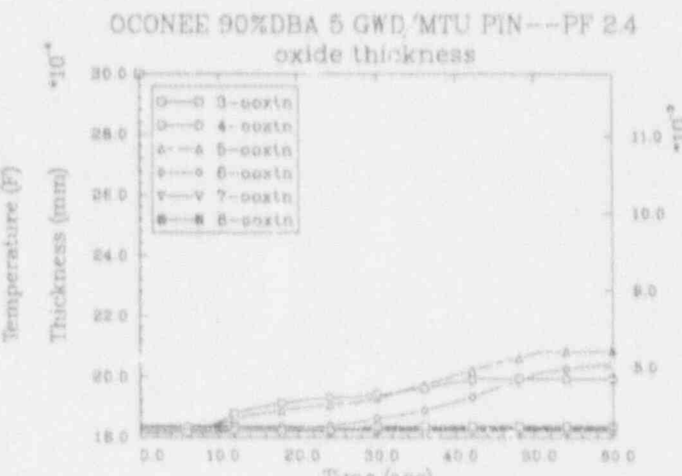
OCONEE 90%DBA 5 GWD/MTU PIN---PF 2.4
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)



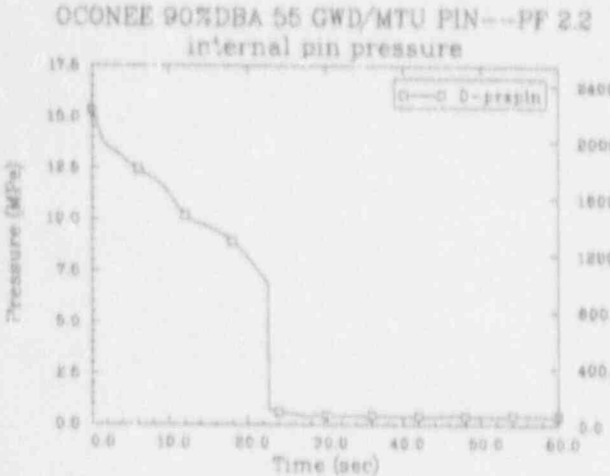
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

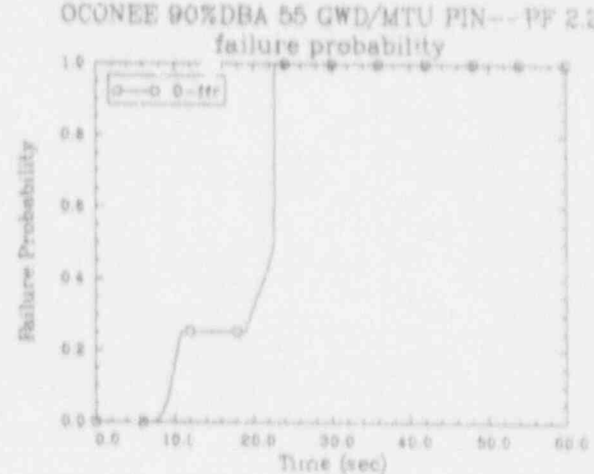


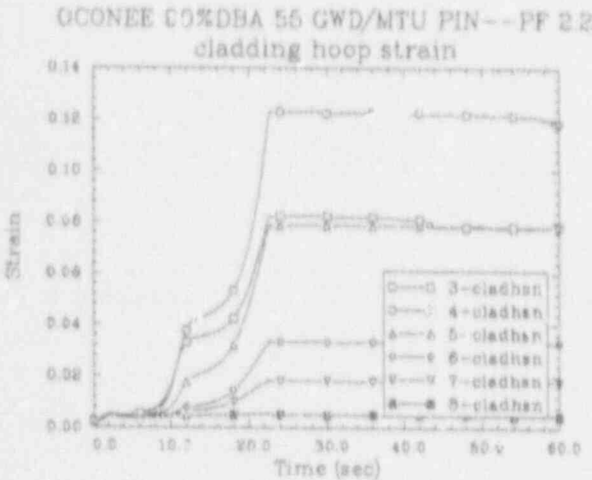
OCONEE 90%DBA 5 GWD/MTU PIN---PF 2.4
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

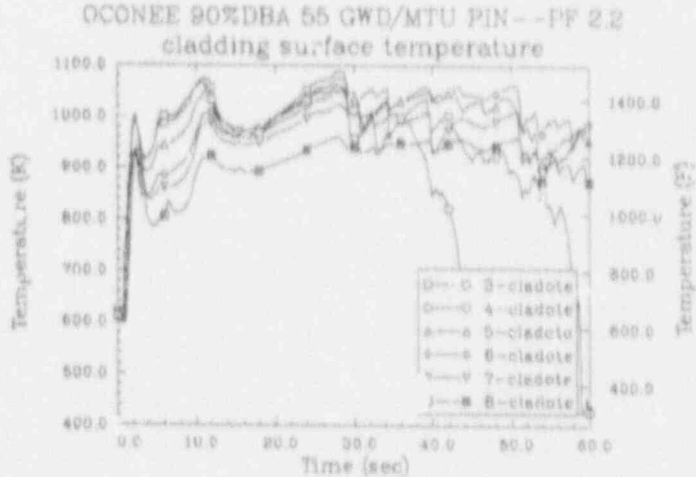


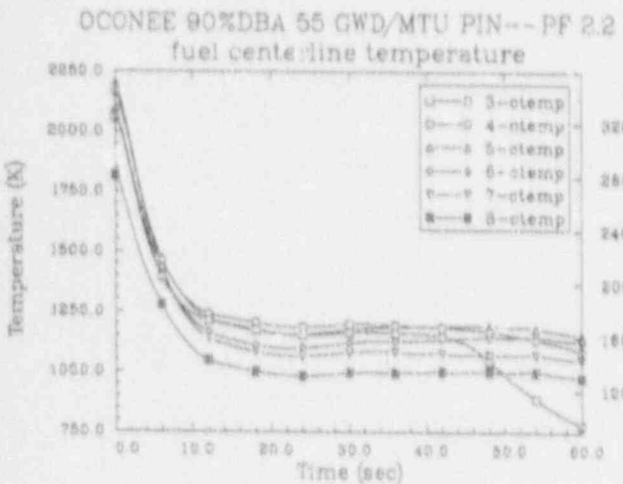
OCONEE 90%DBA 5 GWD/MTU PIN---PF 2.4
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

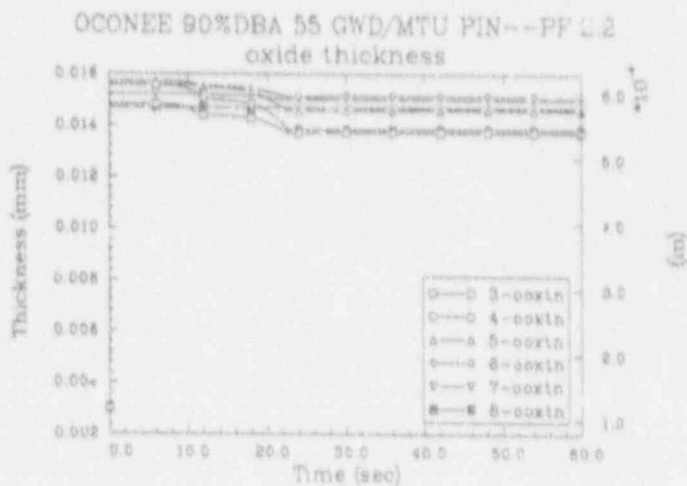

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

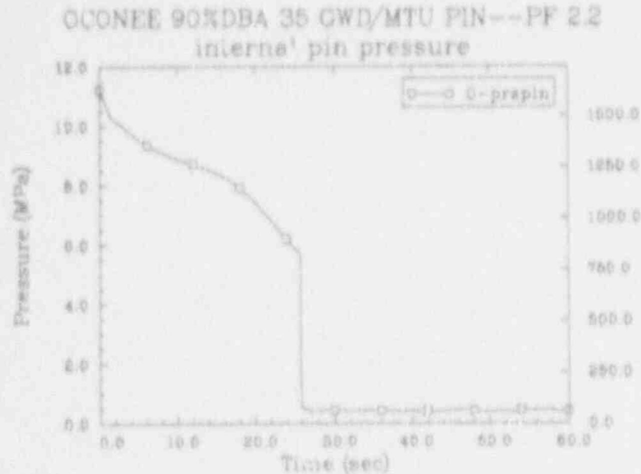

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

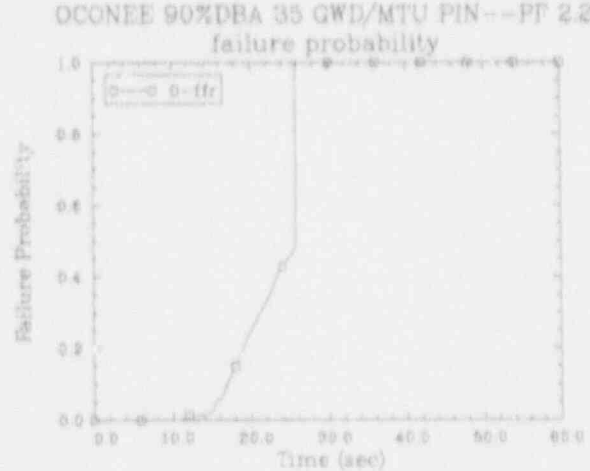

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

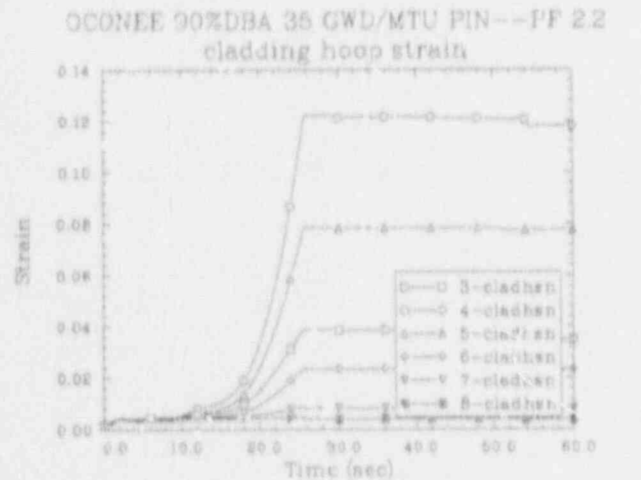

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.2
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Temperature (F)
Time (sec)

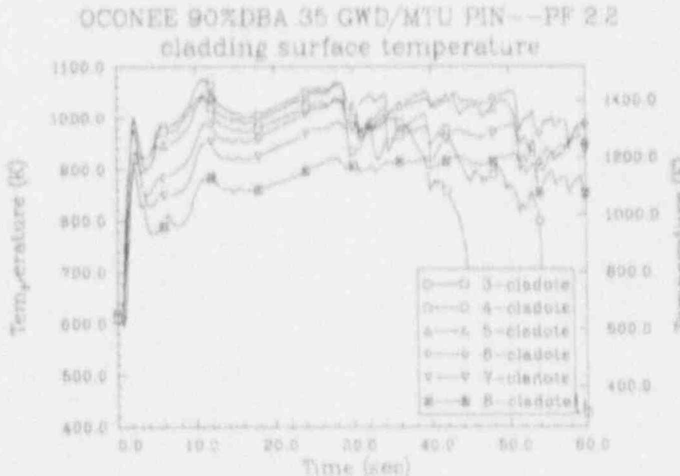

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

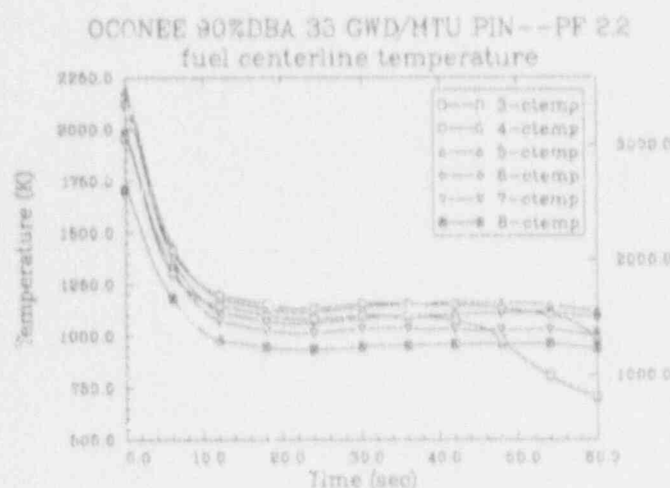

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

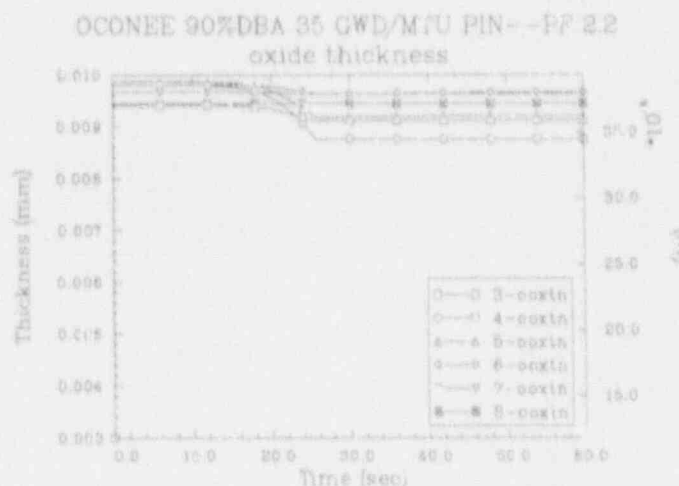

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

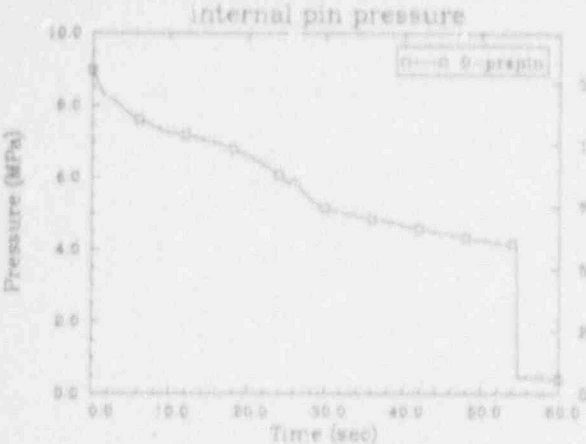

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

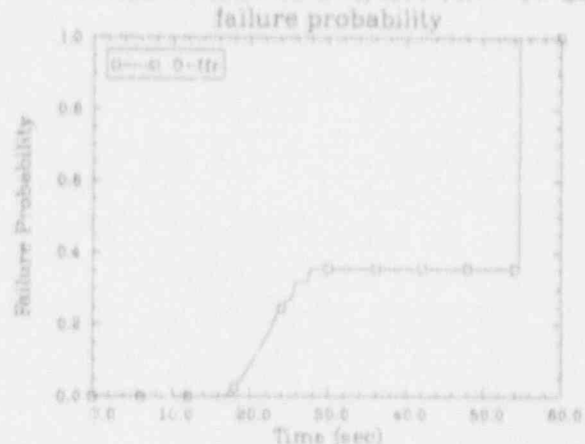

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

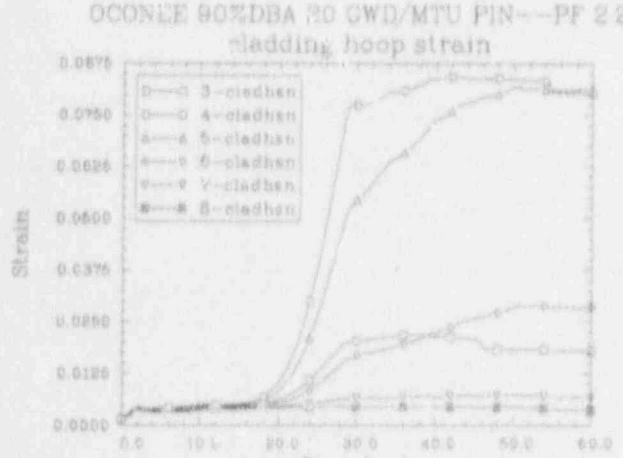

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

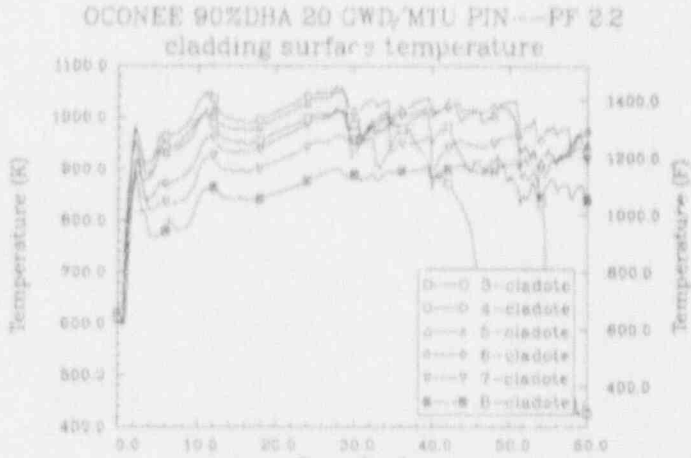

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

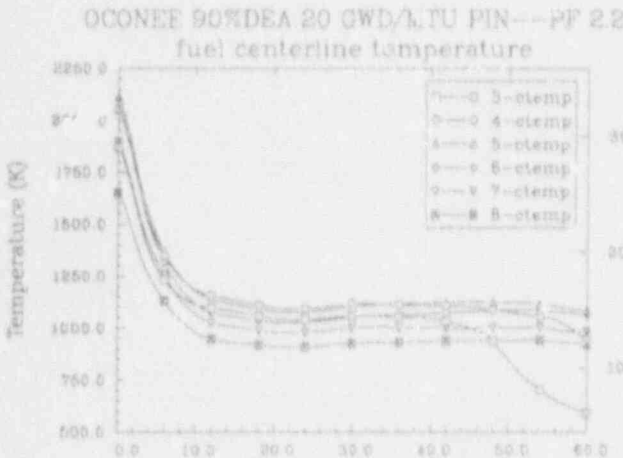

OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.2
oxide thickness
3-oxxtn
4-oxxtn
5-oxxtn
6-oxxtn
7-oxxtn
8-oxxtn
Thickness (mm)
Time (sec)

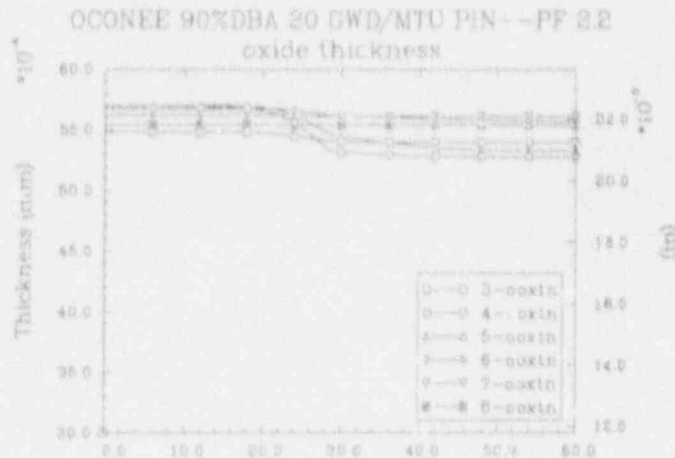

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

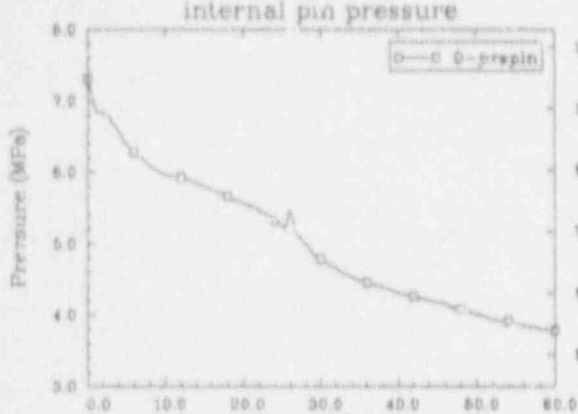

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

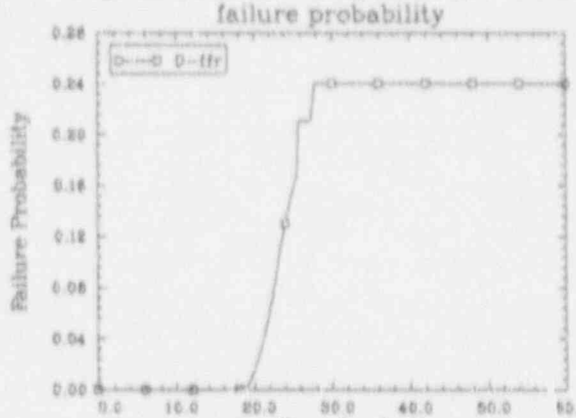

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (μm)
(in)
Time (sec)

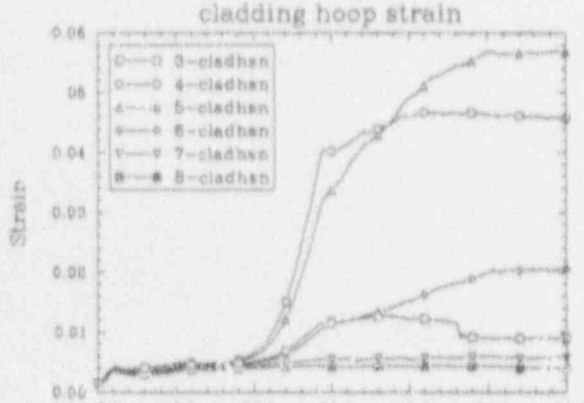
OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure



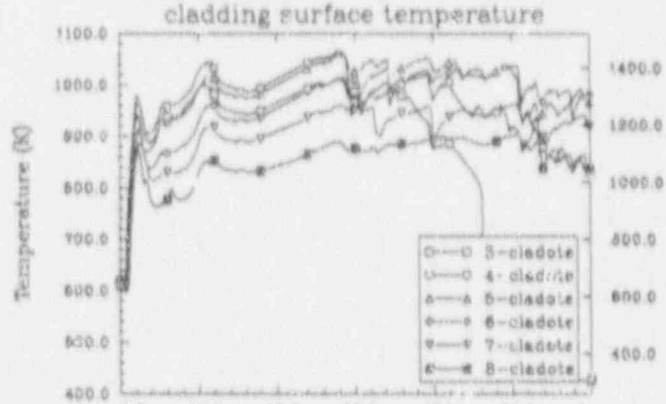
OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.2
failure probability



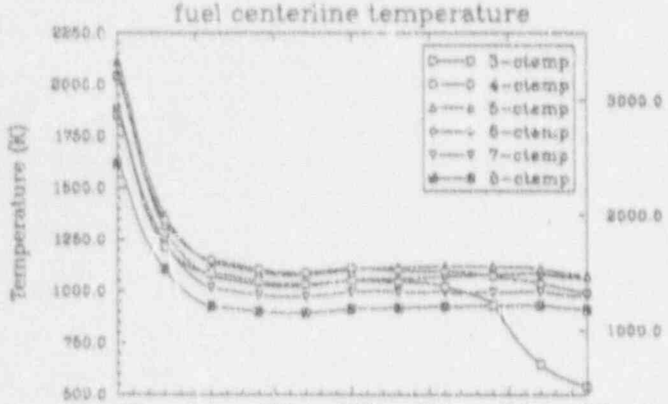
OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.2
cladding hoop strain



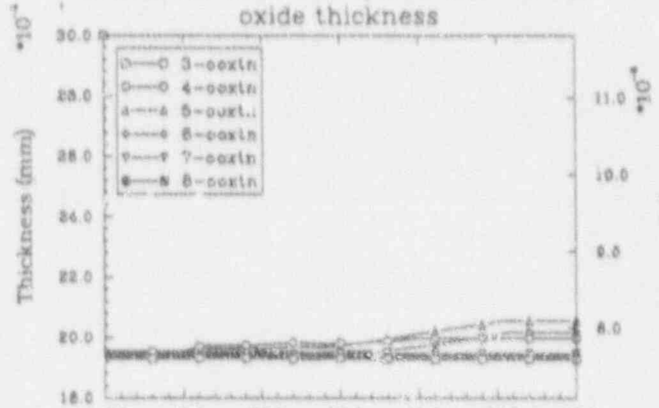
OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.2
cladding surface temperature

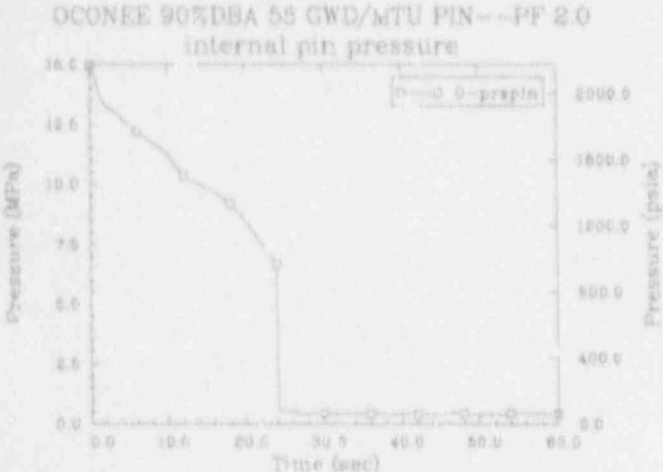


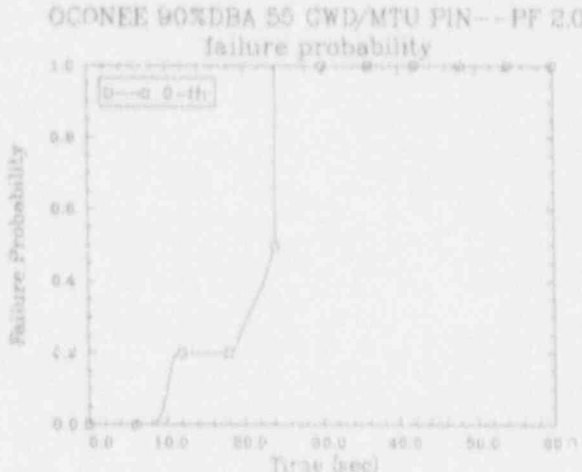
OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.2
fuel centerline temperature

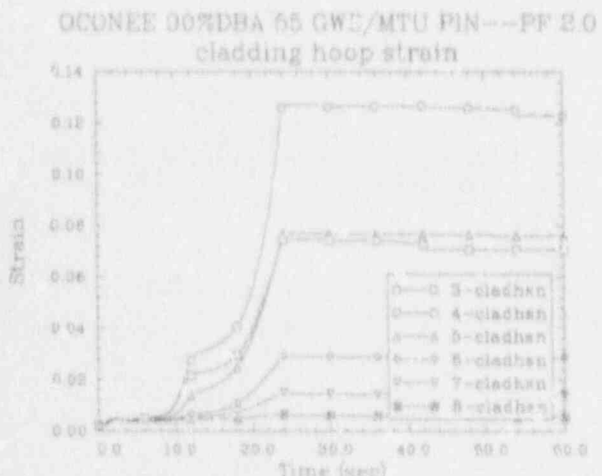


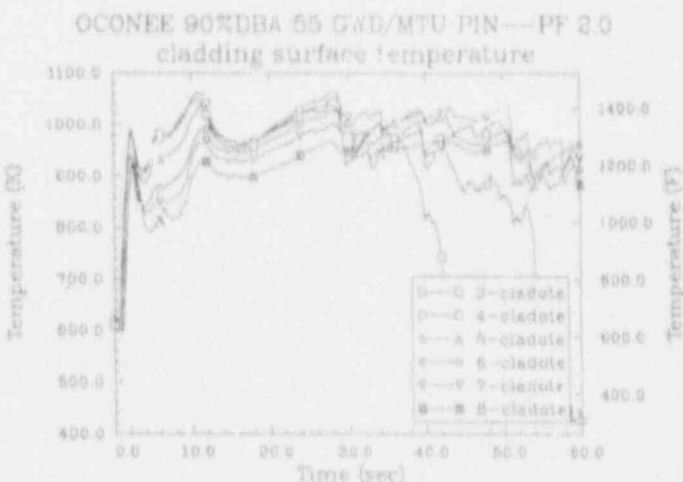
OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.2
oxide thickness

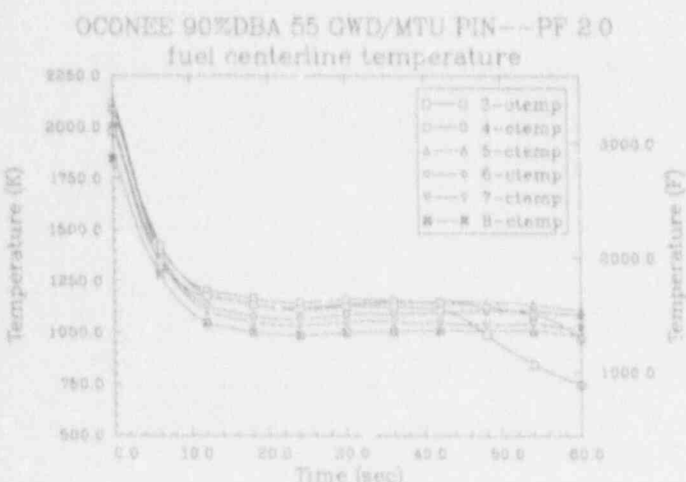


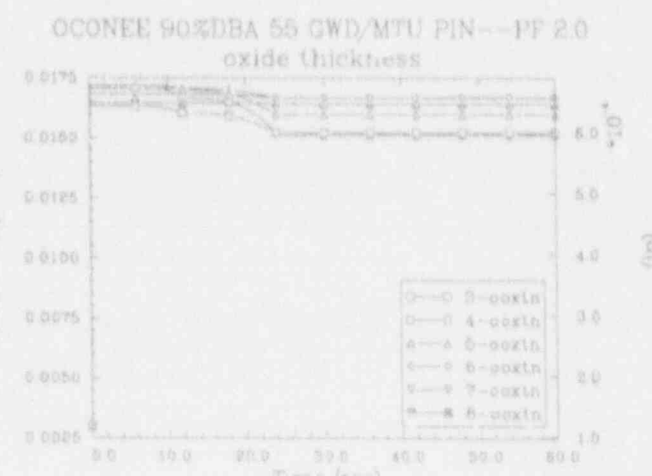

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

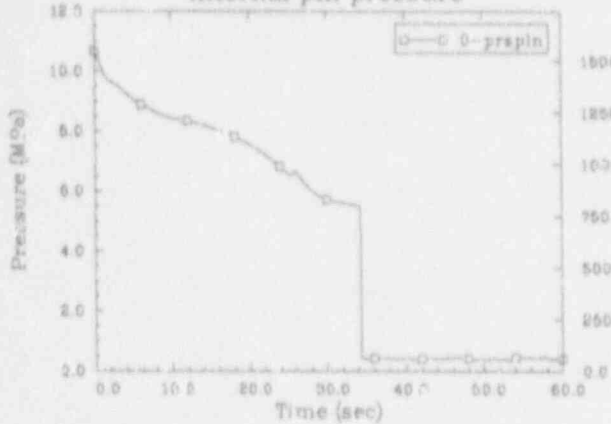

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

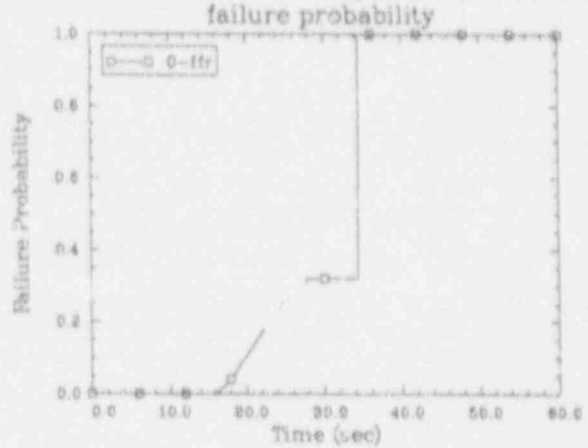

OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 90%DBA 55 GWD/MTU PIN---PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

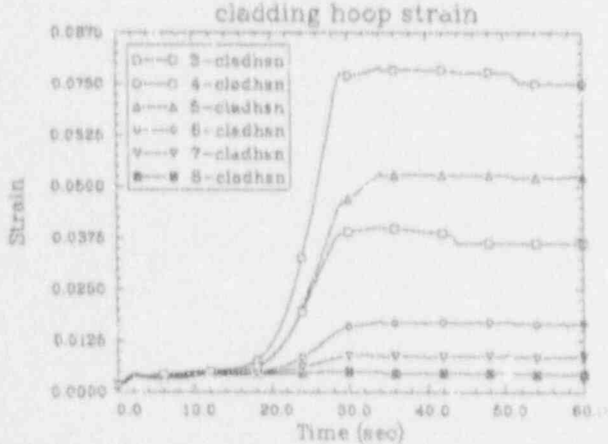
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure



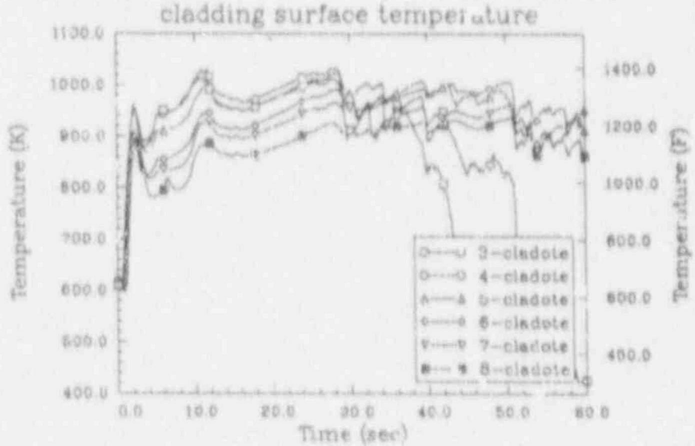
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.0
failure probability



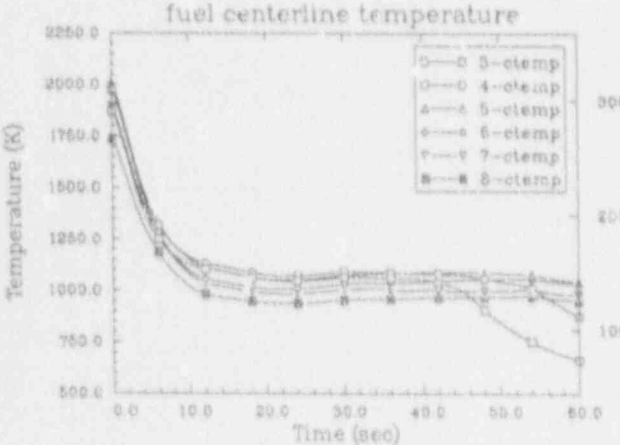
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain



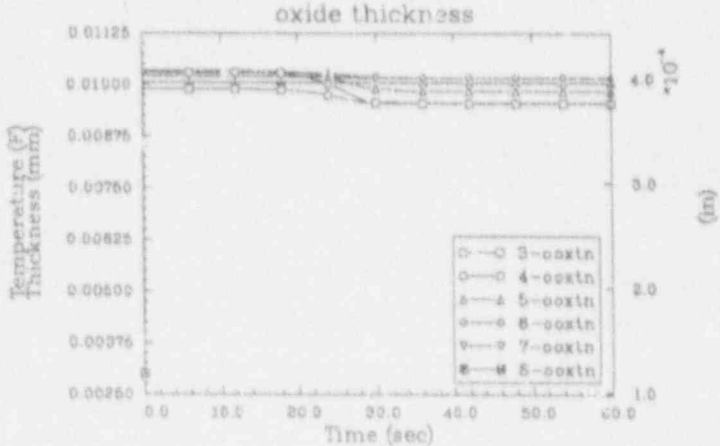
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature

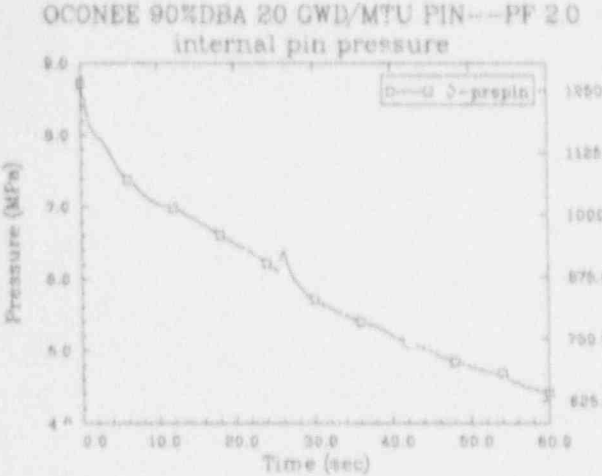


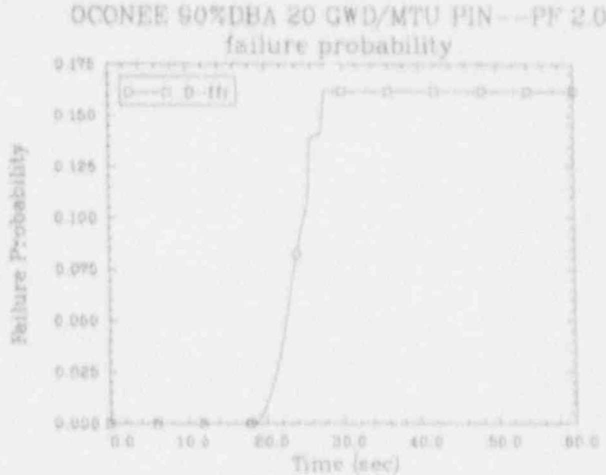
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature

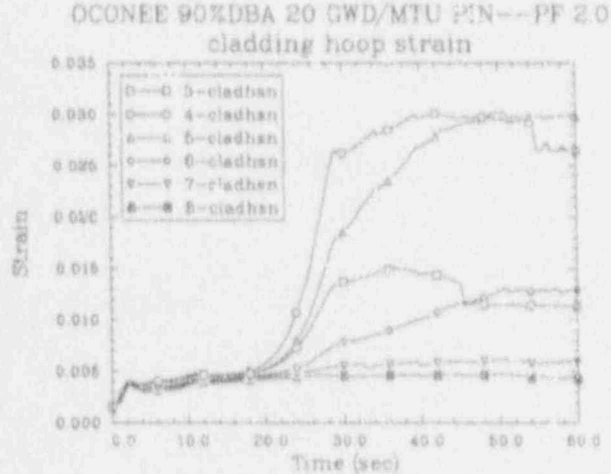


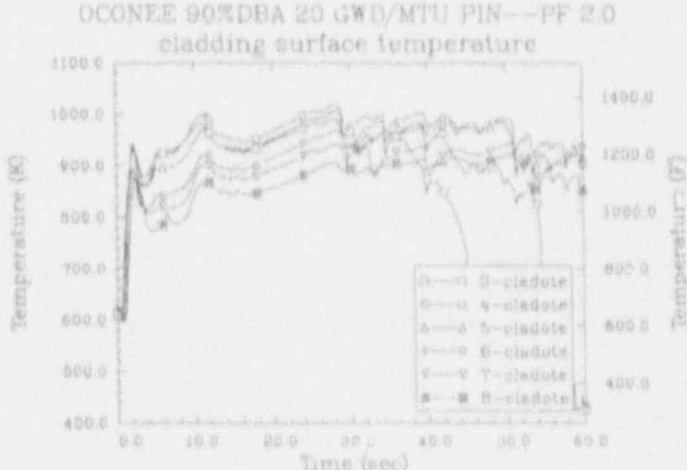
OCONEE 90%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness

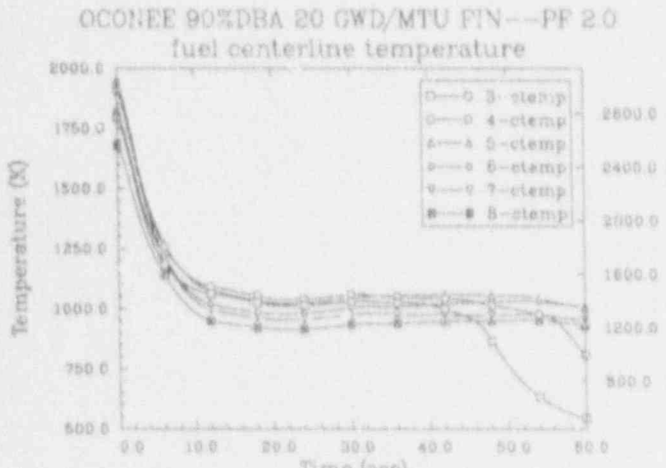


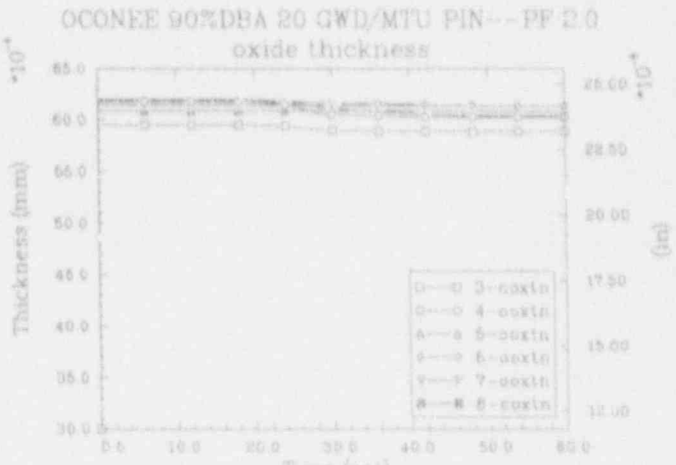

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.0
internal pin pressure
3-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

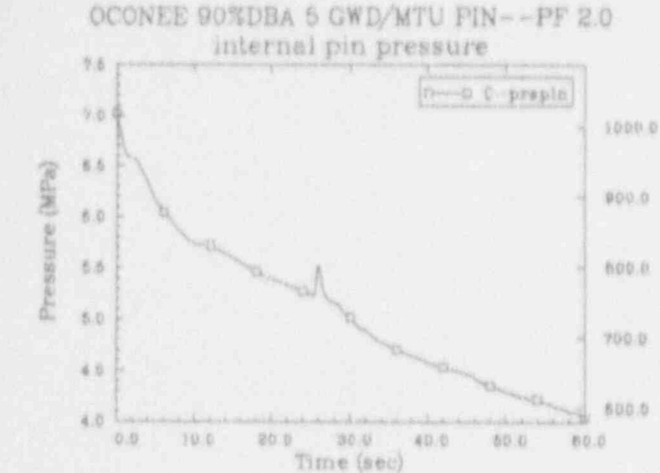

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.0
failure probability
Failure Probability
Time (sec)

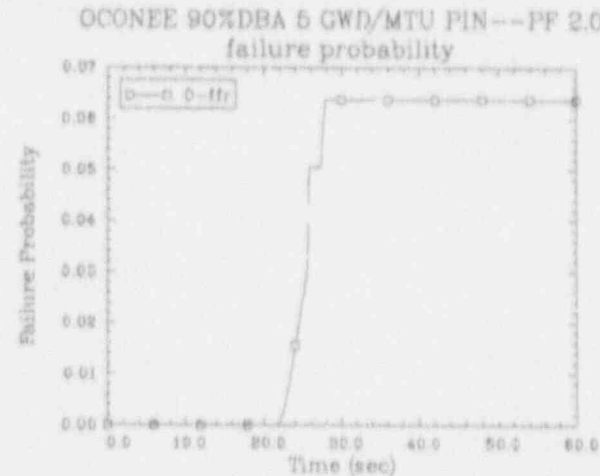

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhan
4-cladhan
5-cladhan
6-cladhan
7-cladhan
8-cladhan
Strain
Time (sec)

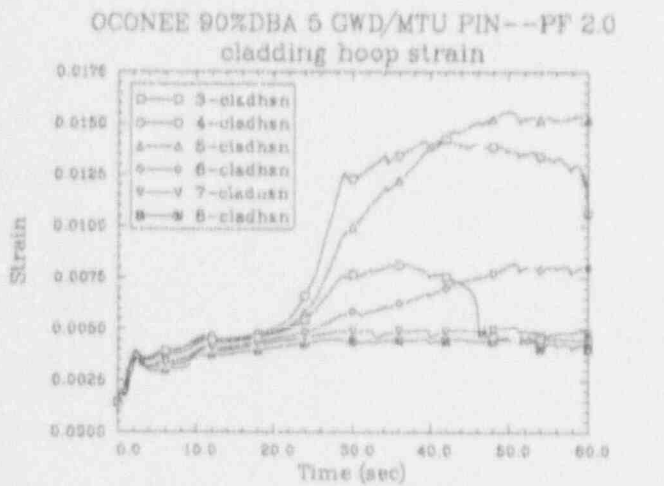

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

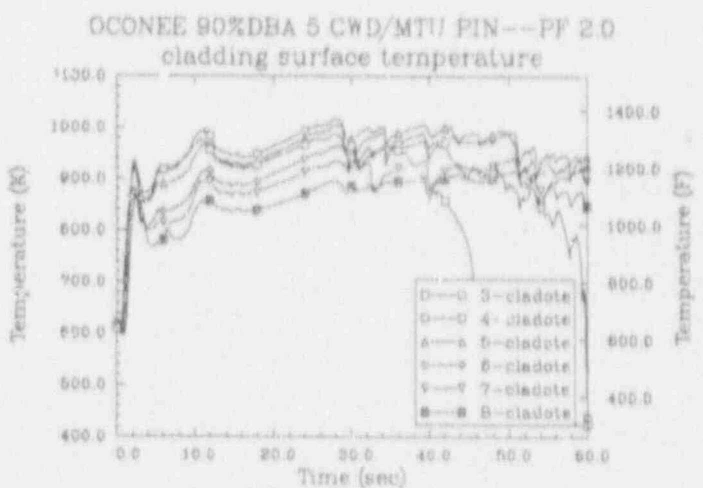

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

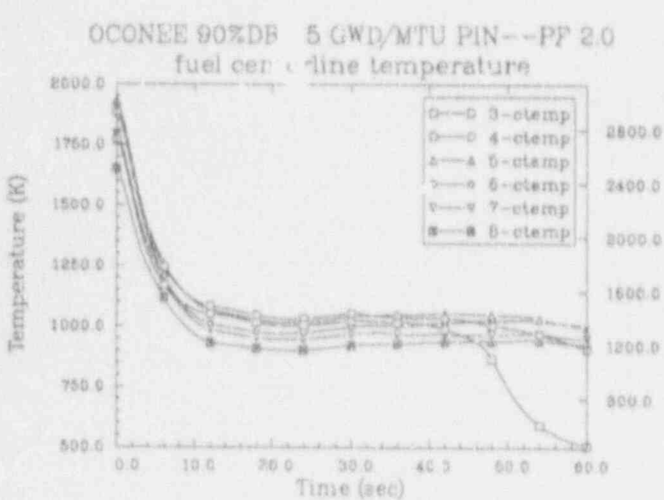

OCONEE 90%DBA 20 GWD/MTU PIN--PF 2.0
oxide thickness
3-coxtn
4-coxtn
5-coxtn
6-coxtn
7-coxtn
8-coxtn
Thickness (mm)
(in)
Time (sec)

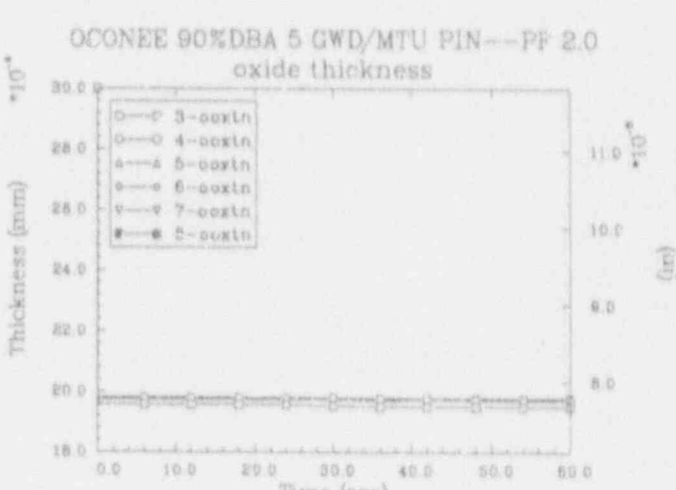

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure
C-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

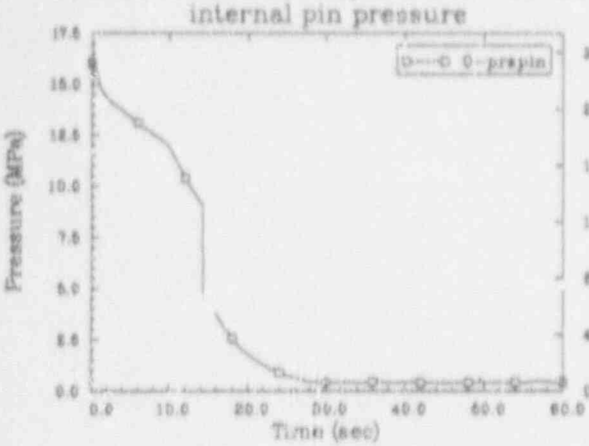

OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

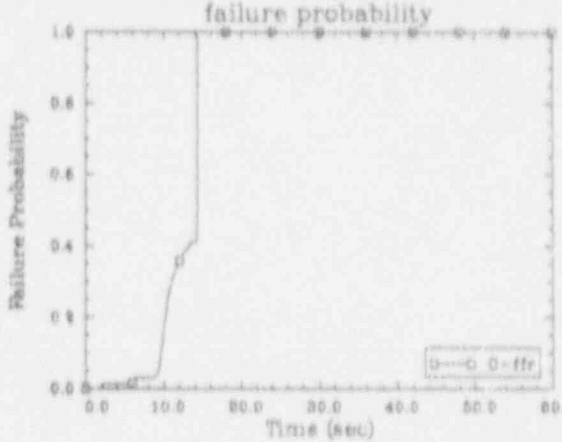

3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 90%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
Thickness (mm)
(in)
Time (sec)

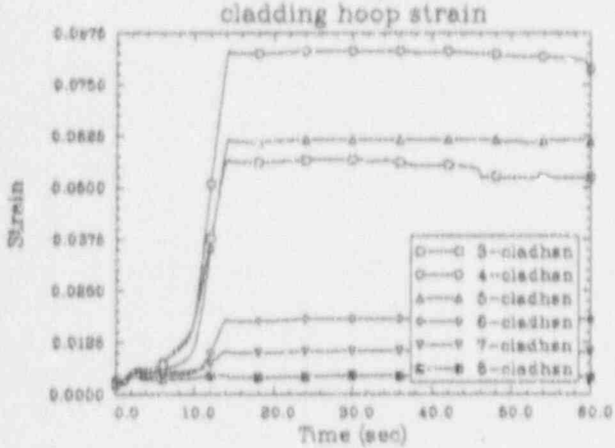
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.63
internal pin pressure



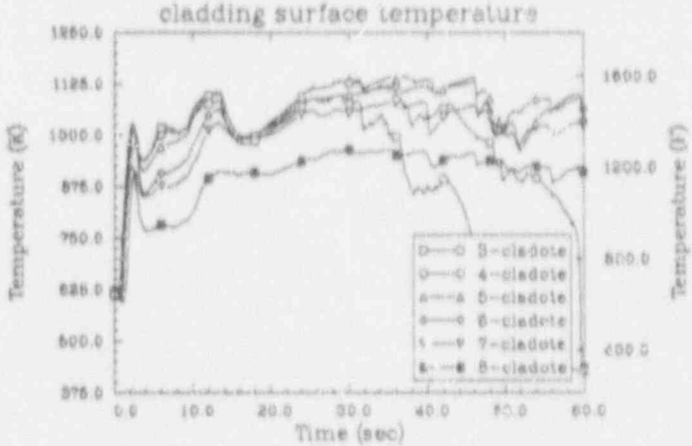
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.63
failure probability



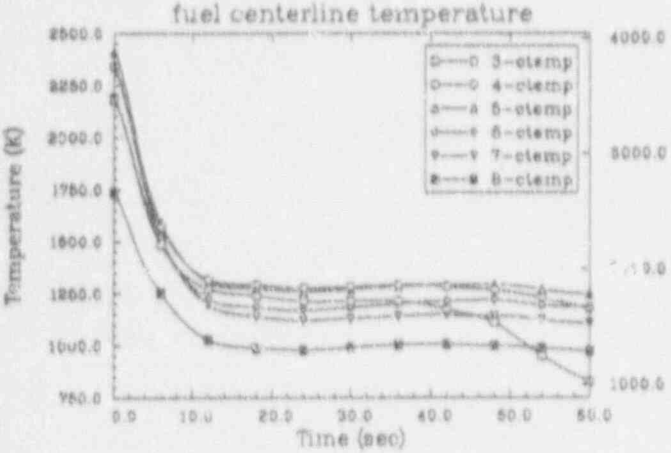
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.63
cladding hoop strain



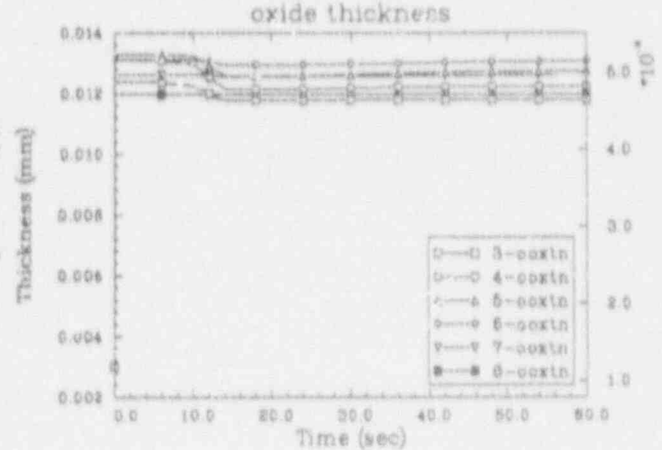
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.63
cladding surface temperature

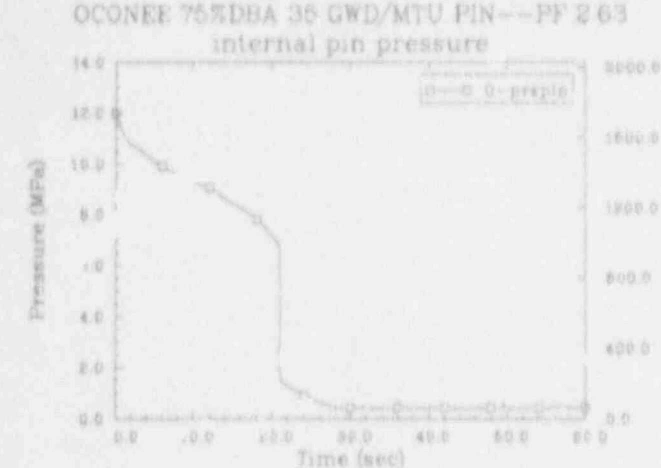


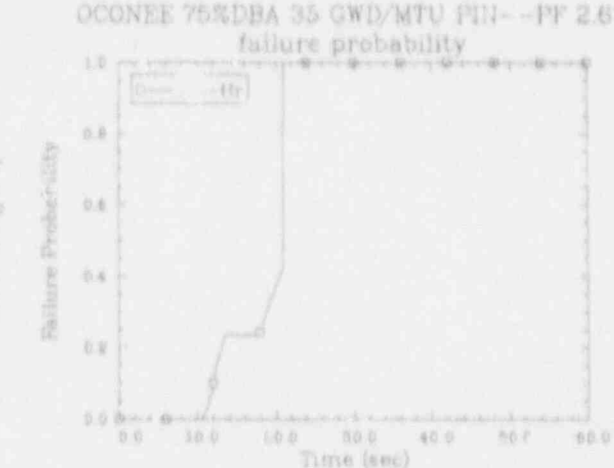
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.63
fuel centerline temperature

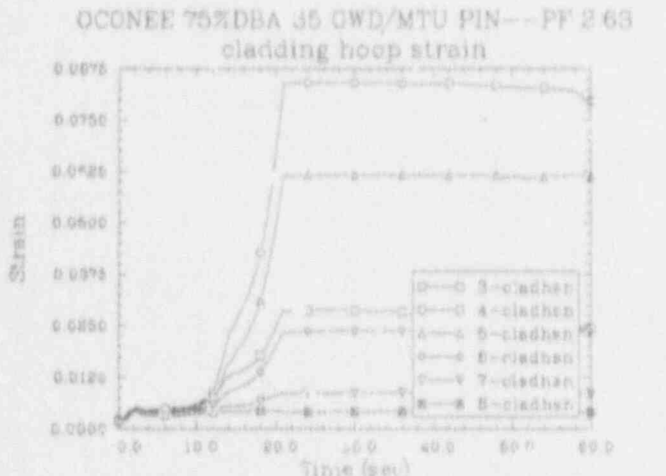


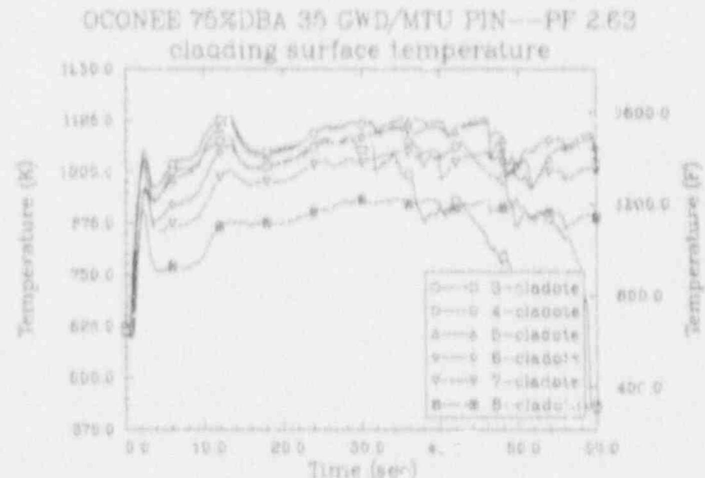
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.63
oxide thickness

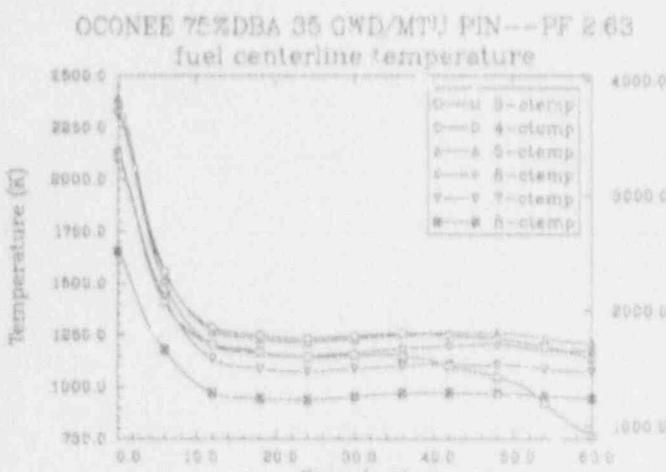


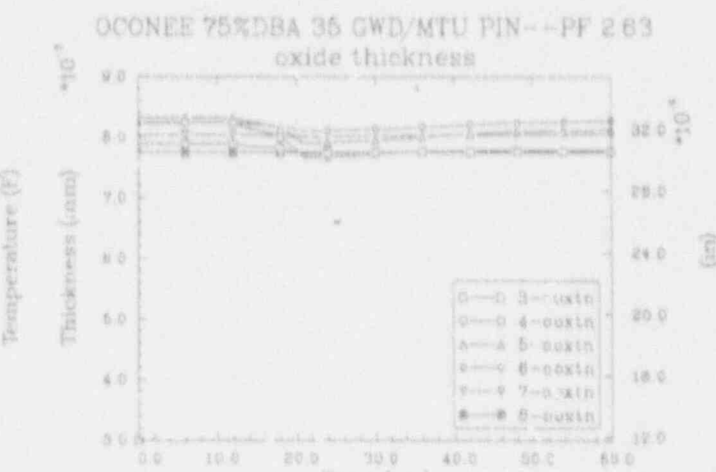

OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prepis
Pressure (MPa)
Pressure (psia)
Time (sec)

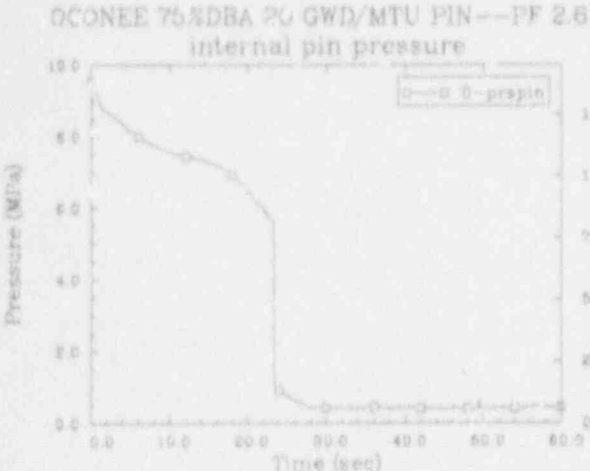

OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.63
failure probability
Failure Probability
Time (sec)

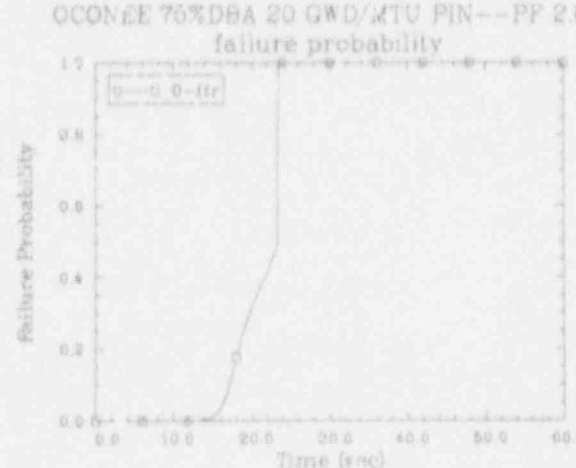

OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

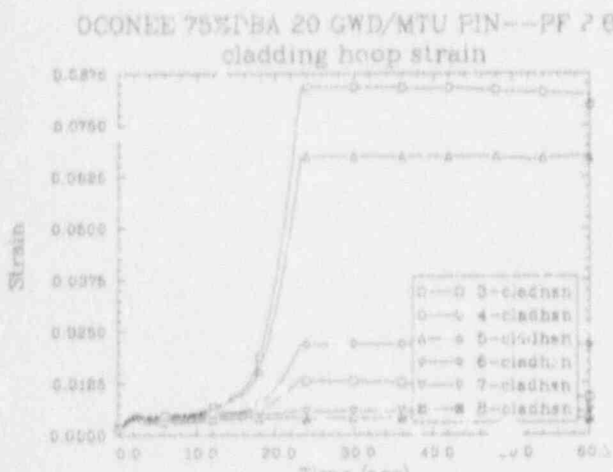

OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
7-cladote
Temperature (K)
Temperature (F)

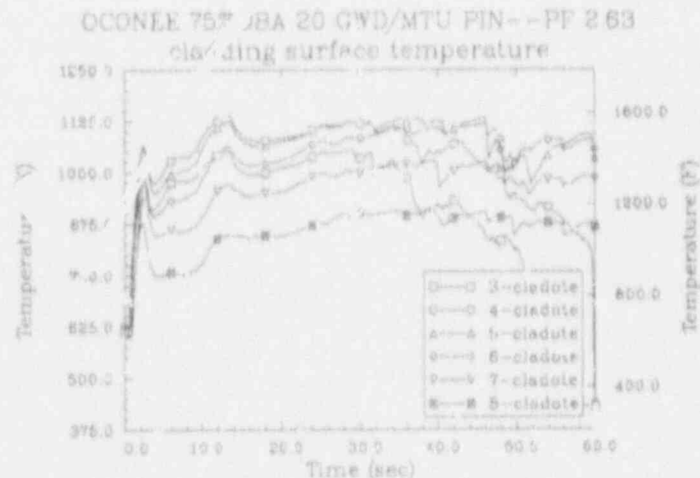

OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

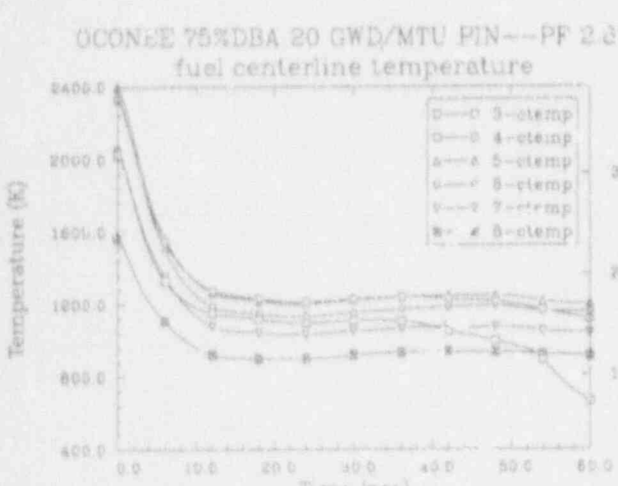

OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.63
oxide thickness
4-ooxtn
6-ooxtn
8-ooxtn
Time (sec)

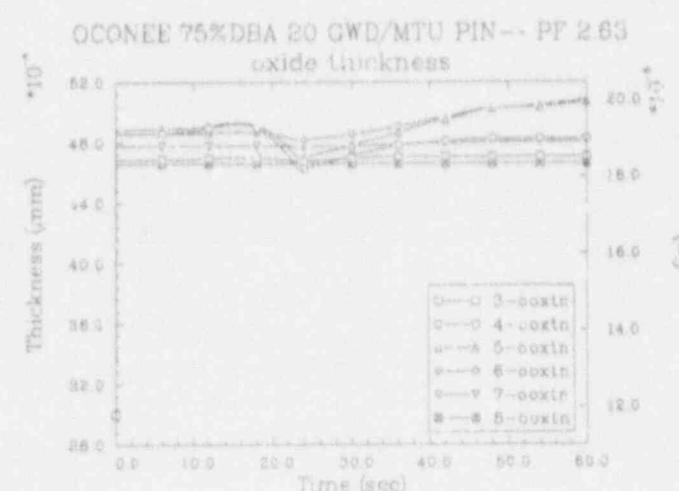

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.63
failure probability
Failure Probability
Time (sec)

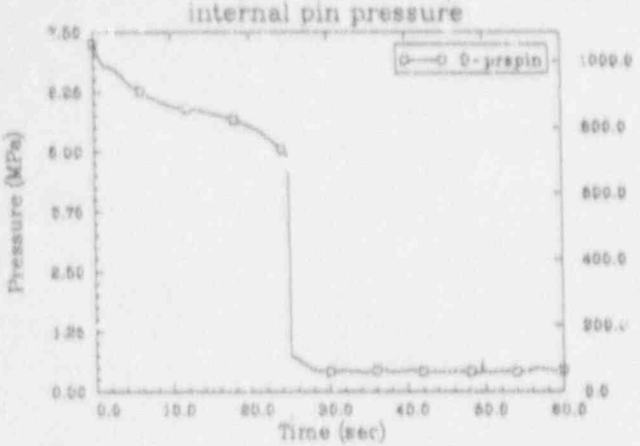

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (F)
Time (sec)

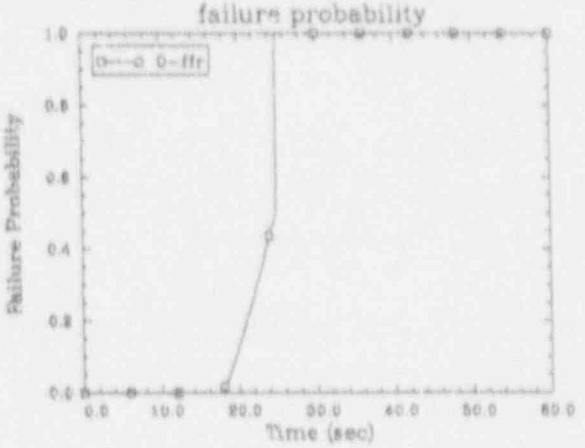

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 75%DBA 20 GWD/MTU PIN-- PF 2.63
oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
Thickness (mm)
(in)
Time (sec)

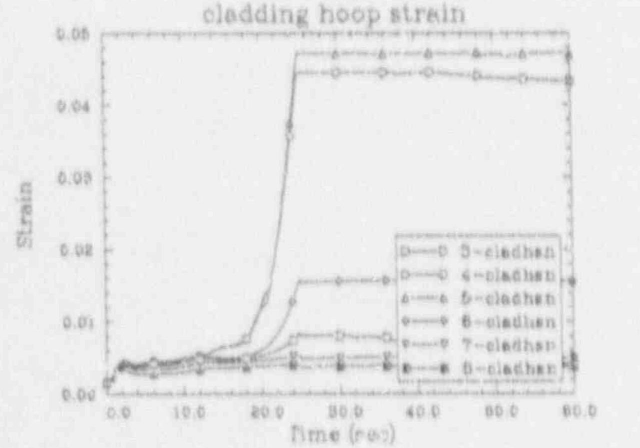
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.63
internal pin pressure



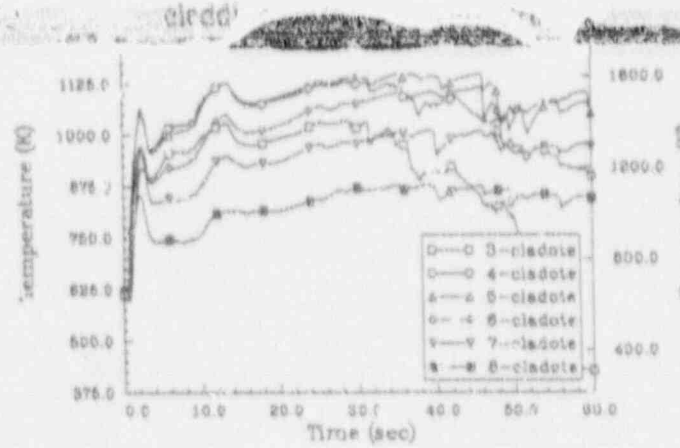
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.63
failure probability



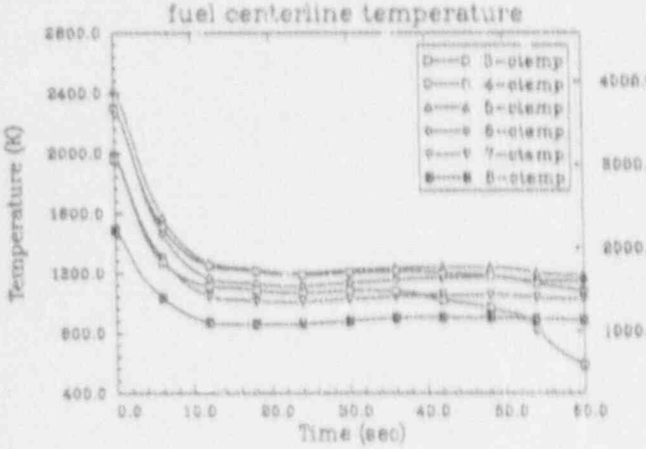
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.63
cladding hoop strain



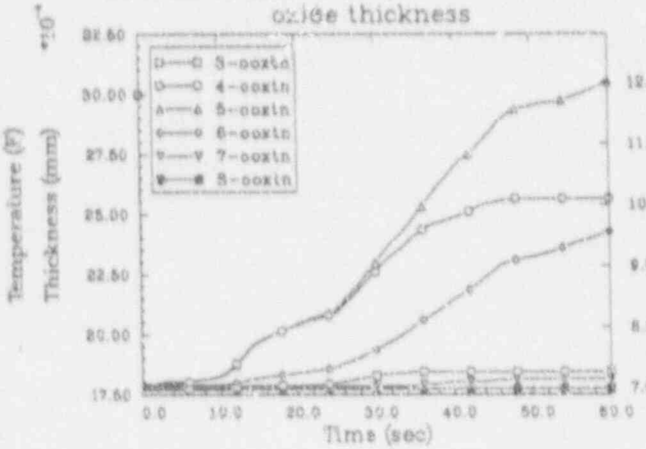
ONEE 75%DB -PF 2.63
cladd



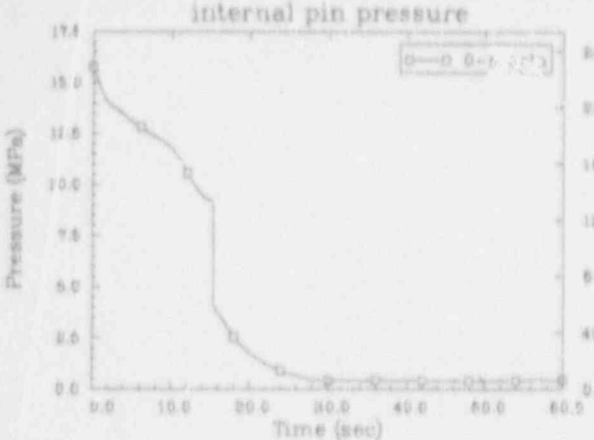
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.63
fuel centerline temperature



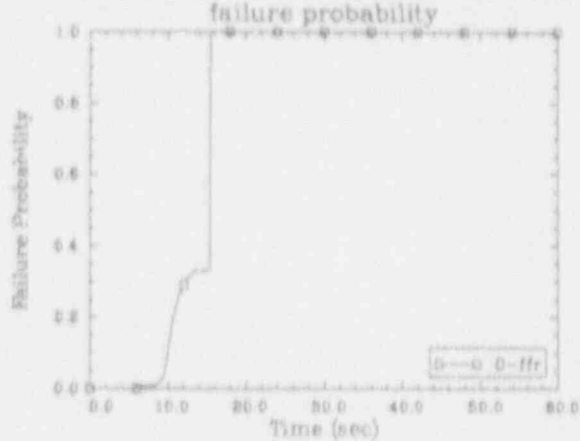
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.63
oxide thickness



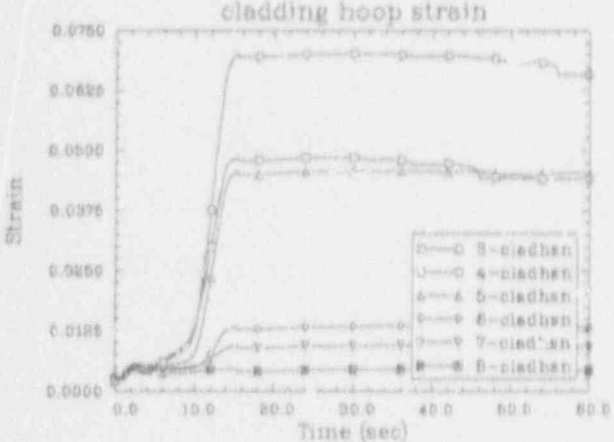
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.4
internal pin pressure



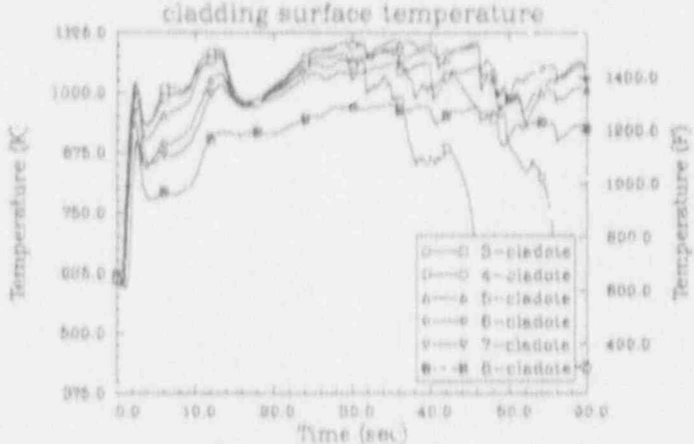
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.4
failure probability



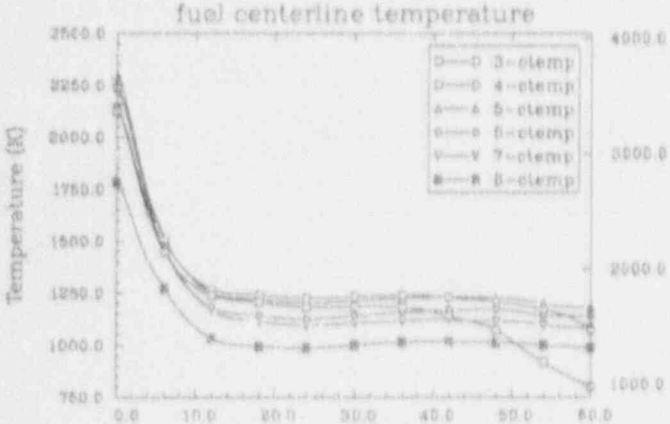
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.4
cladding hoop strain



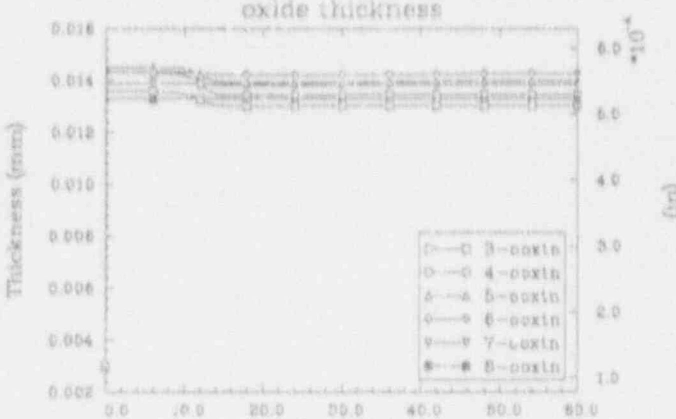
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.4
cladding surface temperature



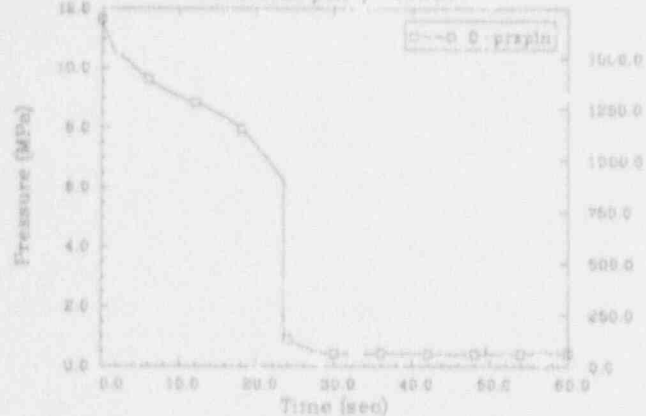
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.4
fuel centerline temperature



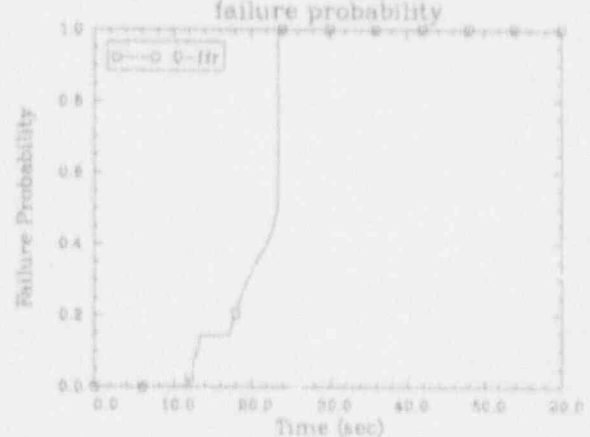
OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.4
oxide thickness



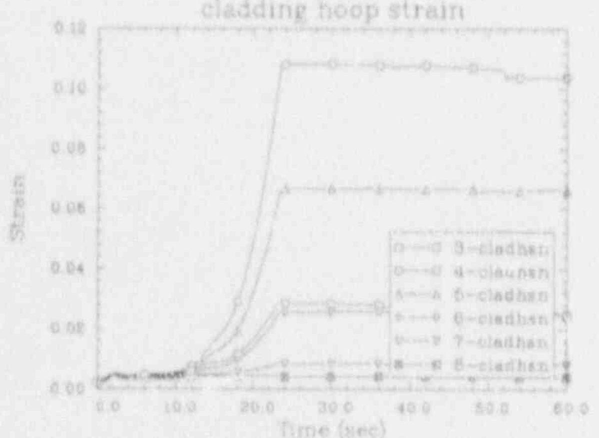
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.4
internal pin pressure



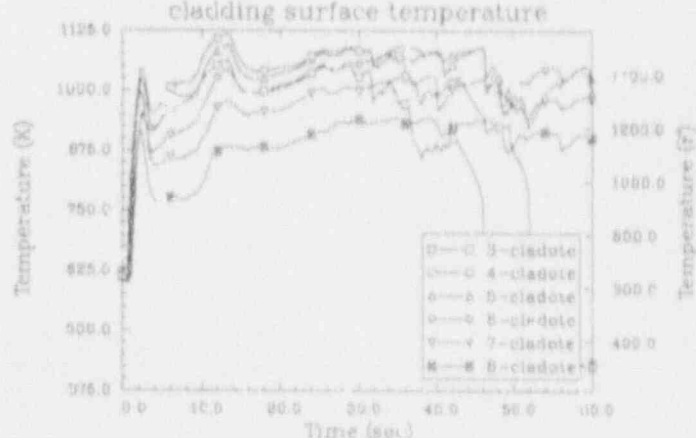
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.4
failure probability



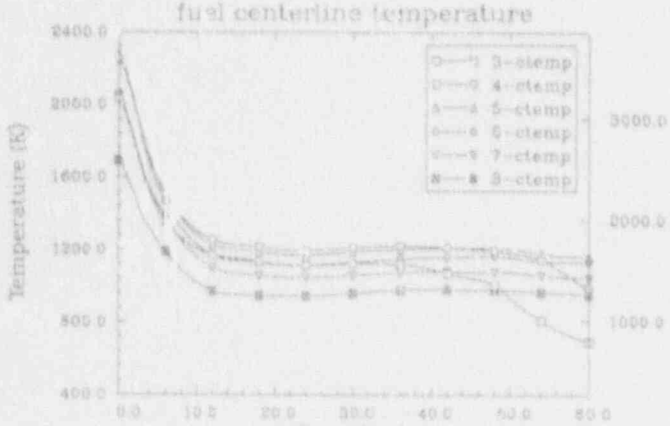
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.4
cladding hoop strain



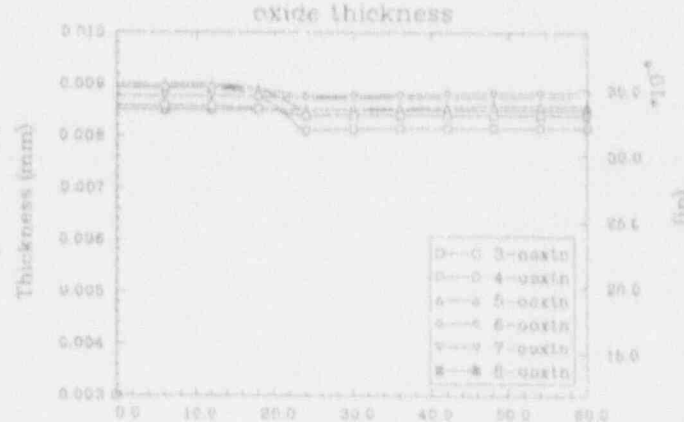
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.4
cladding surface temperature

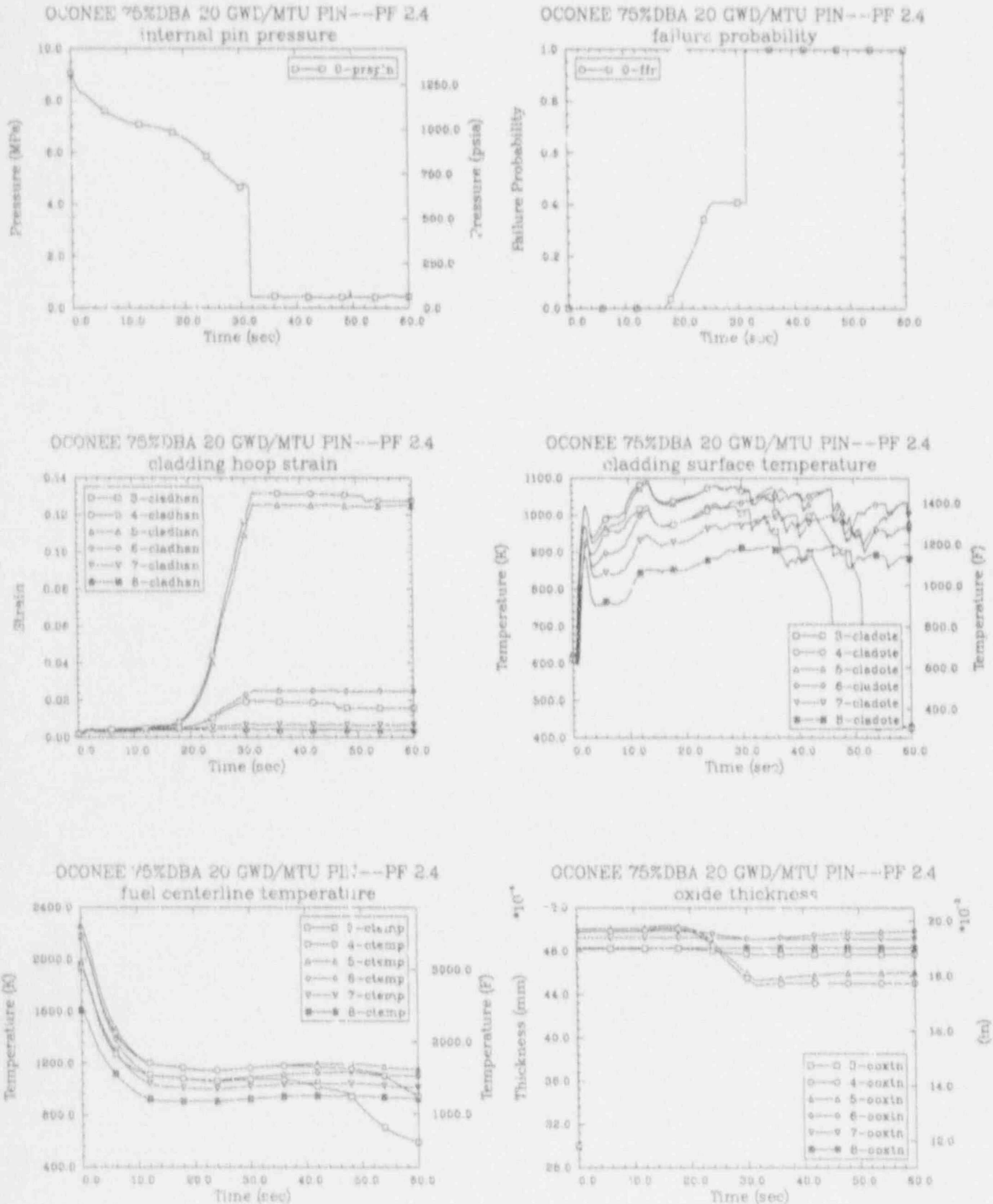


OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.4
fuel centerline temperature



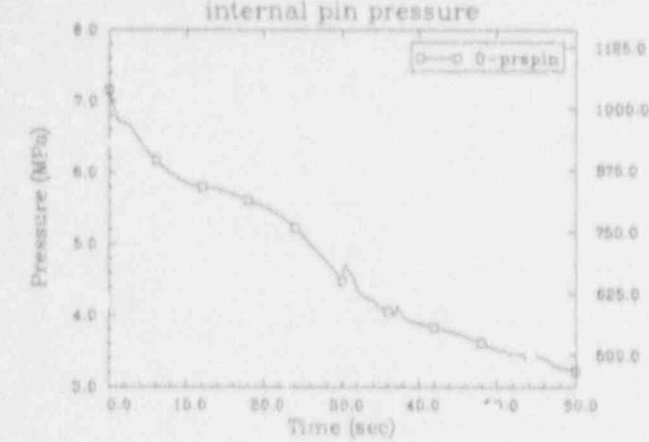
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.4
oxide thickness



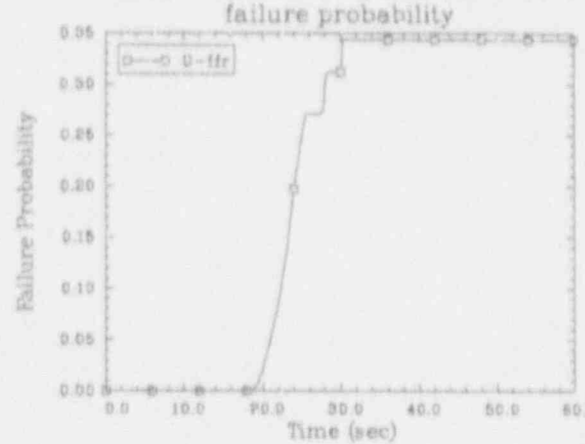


OCONEE 75%DBA 20 GWD/MTU PIN---PF 2.4
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prsg'n
OCONEE 75%DBA 20 GWD/MTU PIN---PF 2.4
failure probability
Failure Probability
Time (sec)
0-ffr
OCONEE 75%DBA 20 GWD/MTU PIN---PF 2.4
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
OCONEE 75%DBA 20 GWD/MTU PIN---PF 2.4
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
OCONEE 75%DBA 20 GWD/MTU PIN---PF 2.4
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
OCONEE 75%DBA 20 GWD/MTU PIN---PF 2.4
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

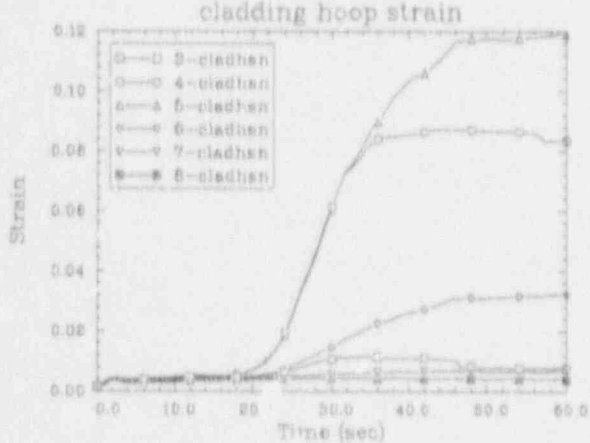
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.4
internal pin pressure



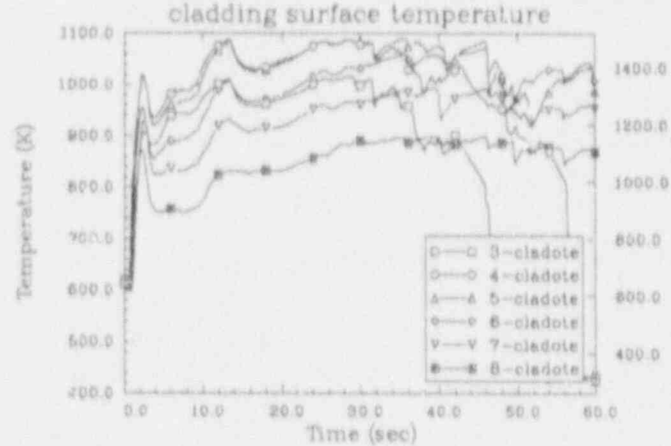
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.4
failure probability



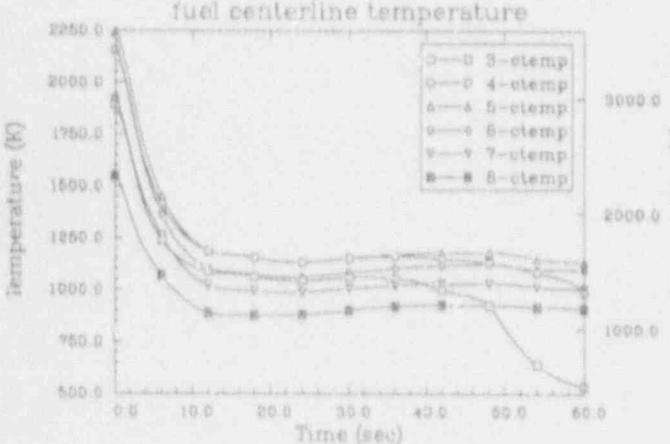
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.4
cladding hoop strain



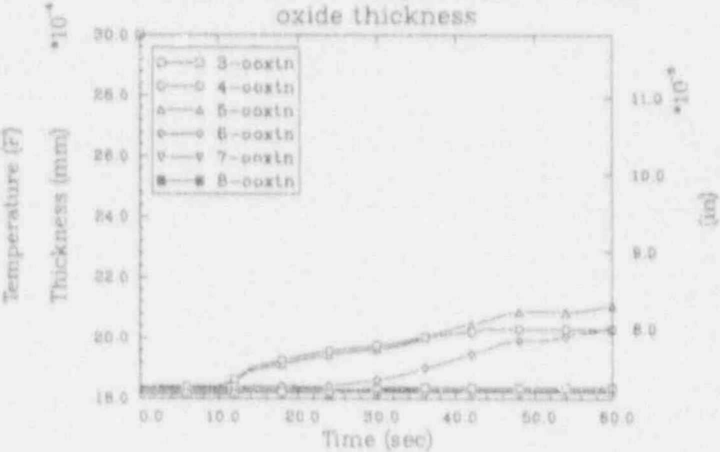
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.4
cladding surface temperature

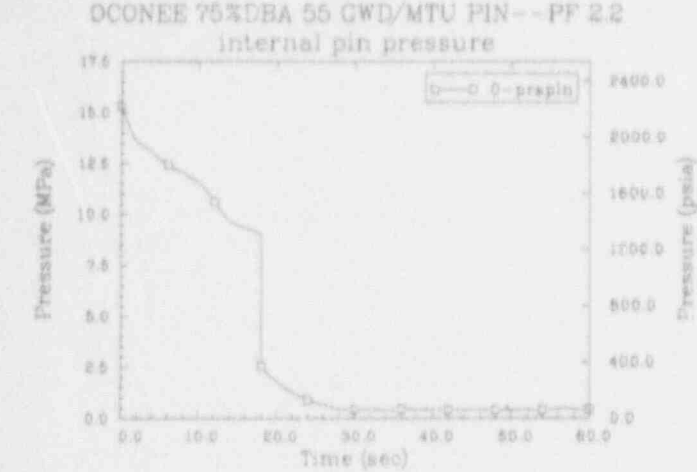


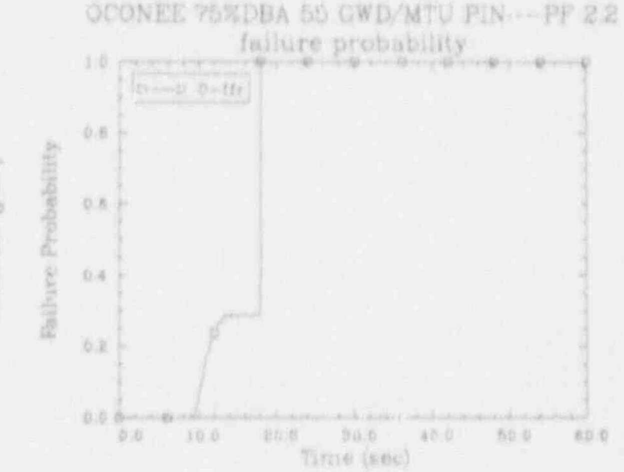
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.4
fuel centerline temperature

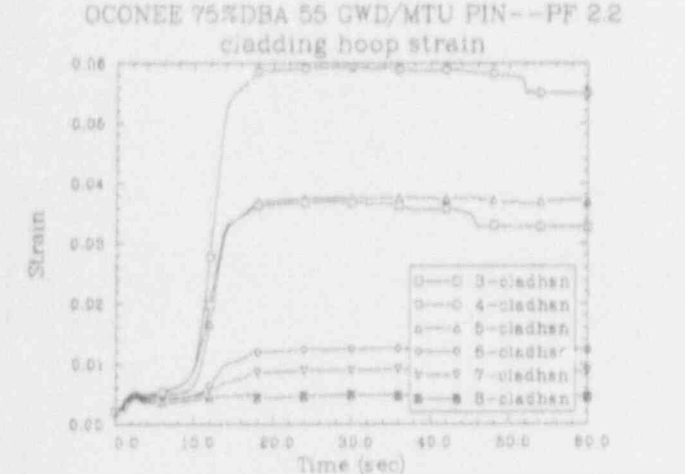


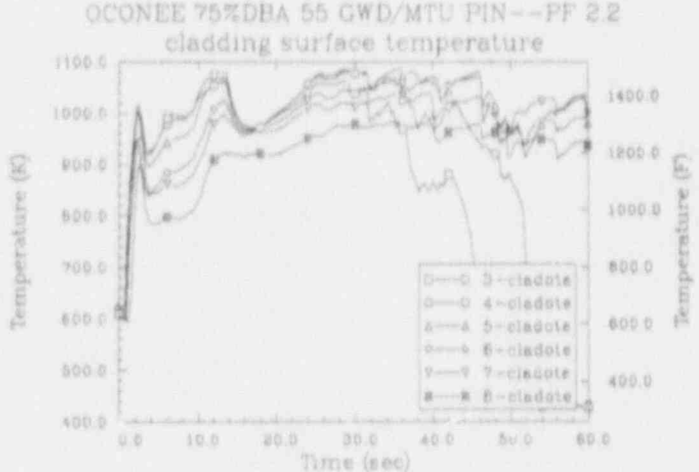
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.4
oxide thickness

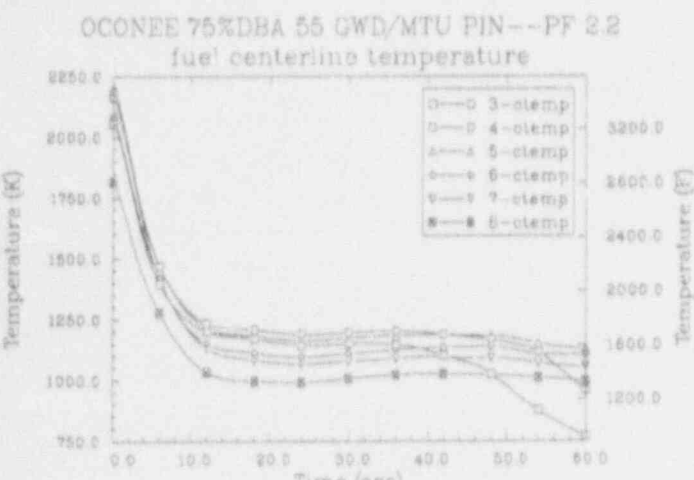


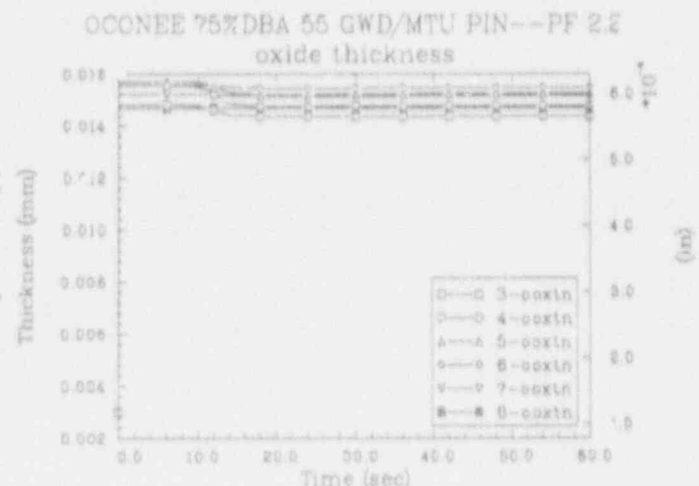

OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

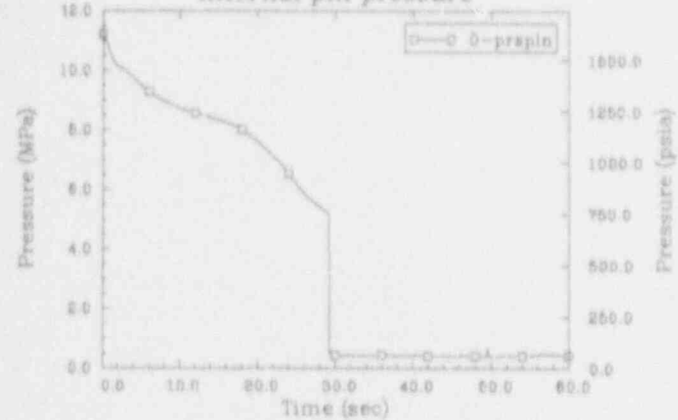

OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

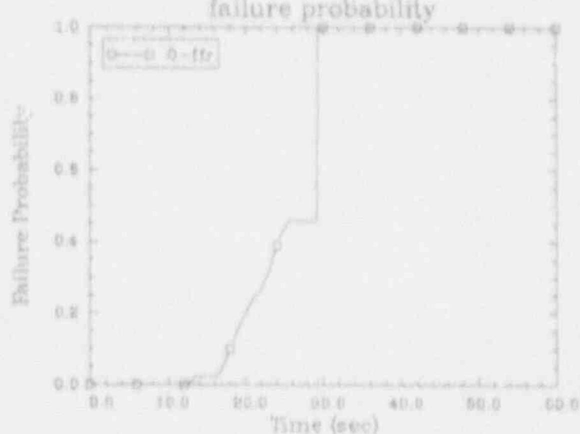

OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

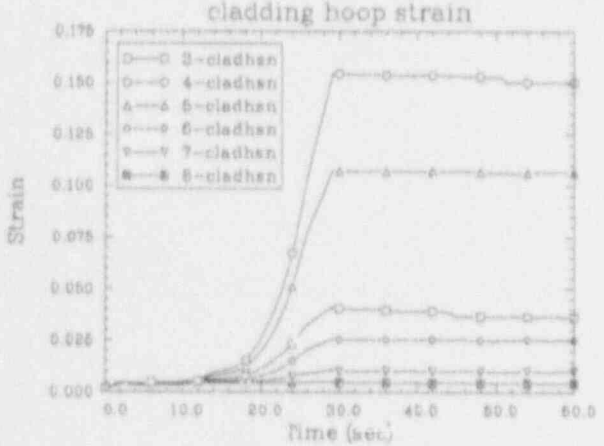
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.2
internal pin pressure



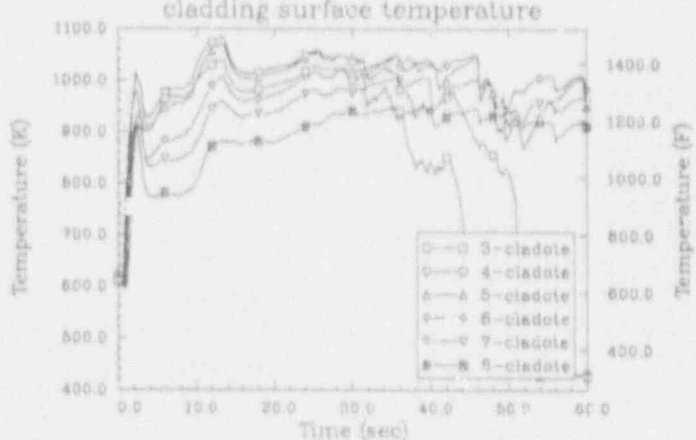
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.2
failure probability



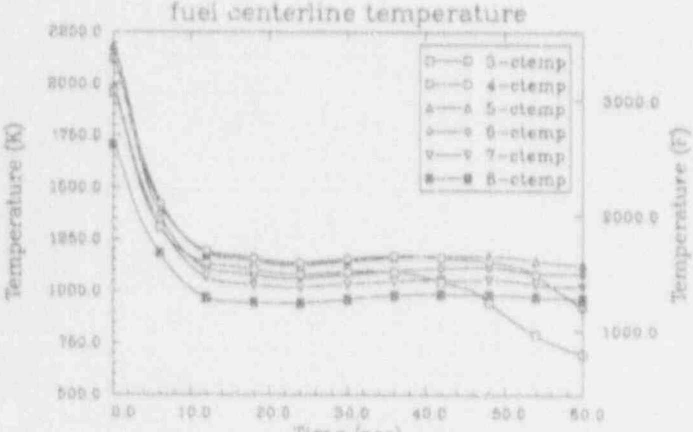
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.2
cladding hoop strain



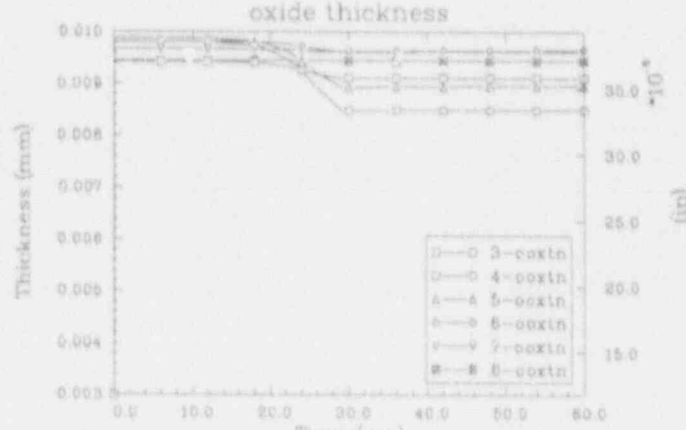
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.2
cladding surface temperature

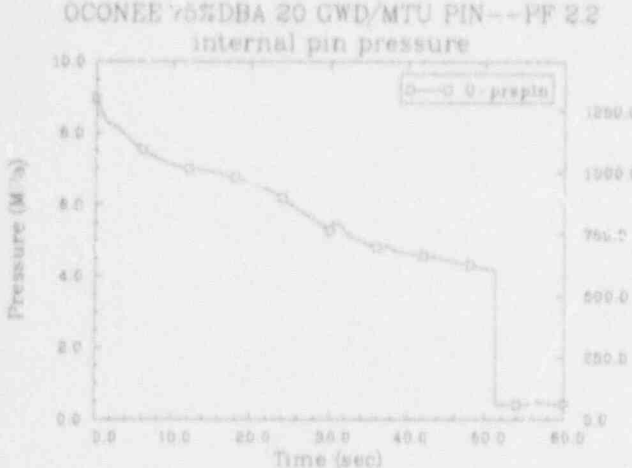


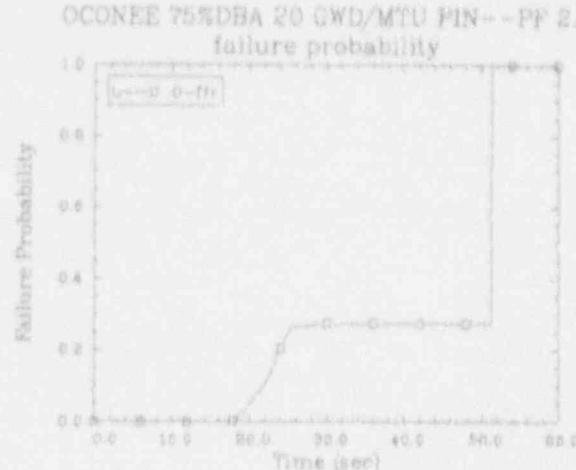
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.2
fuel centerline temperature

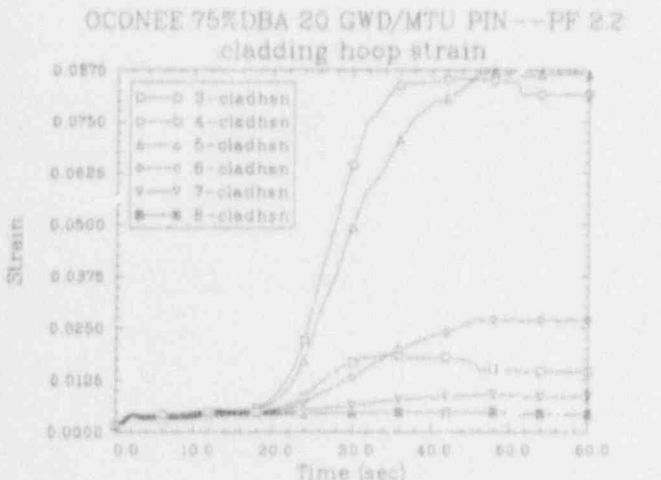


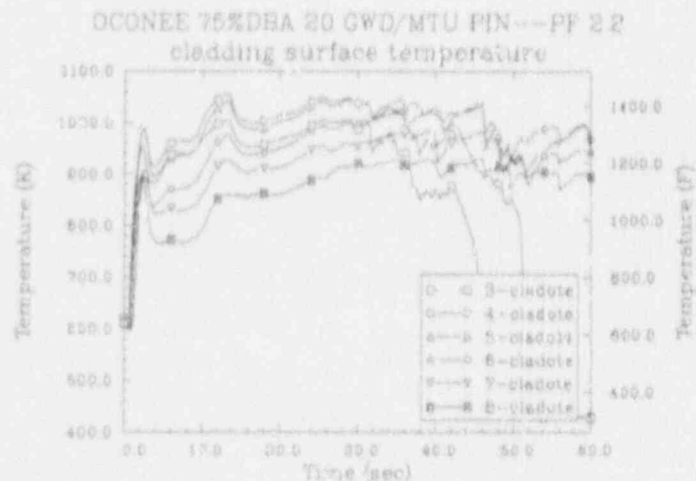
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.2
oxide thickness

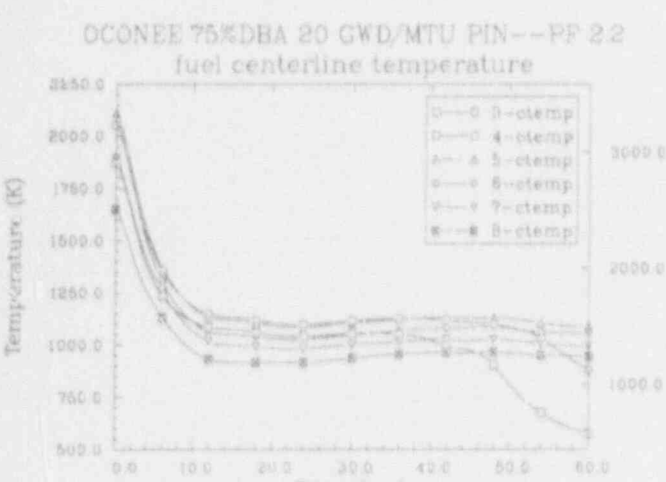


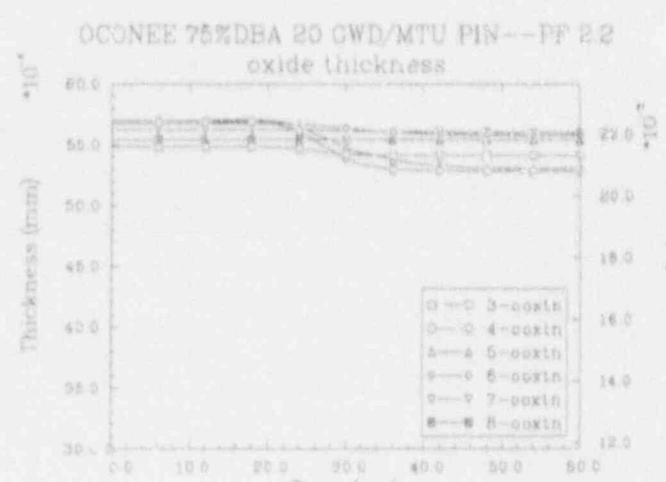

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

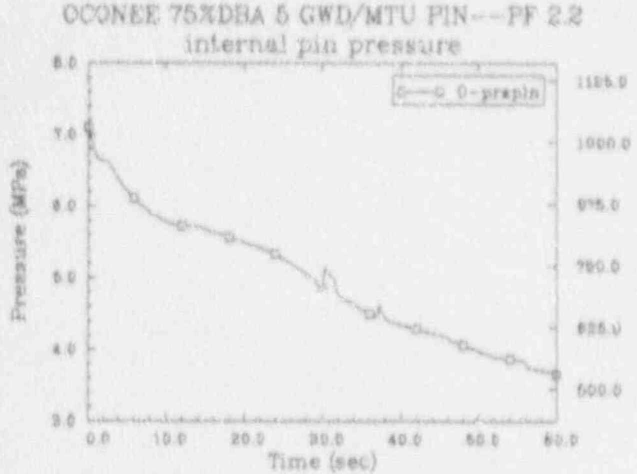

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

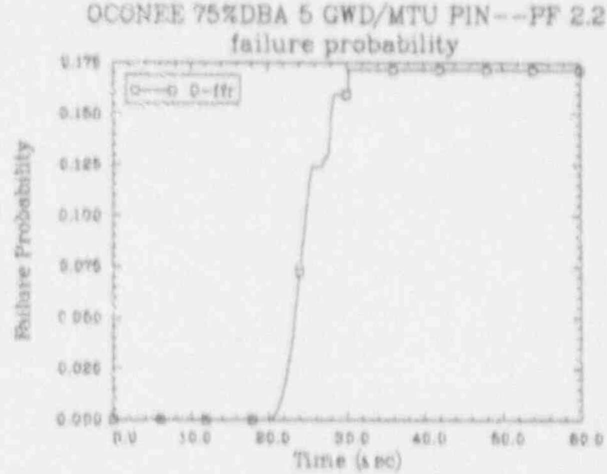

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

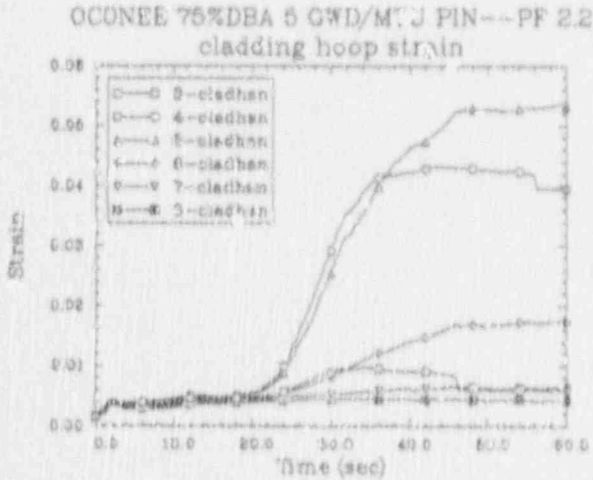

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

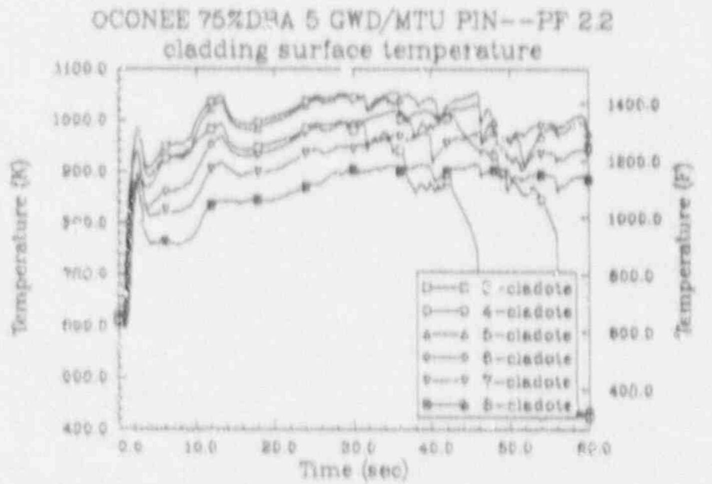

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

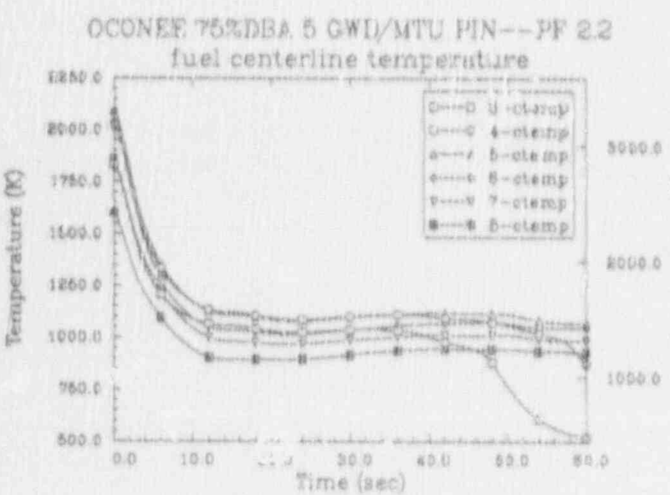

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

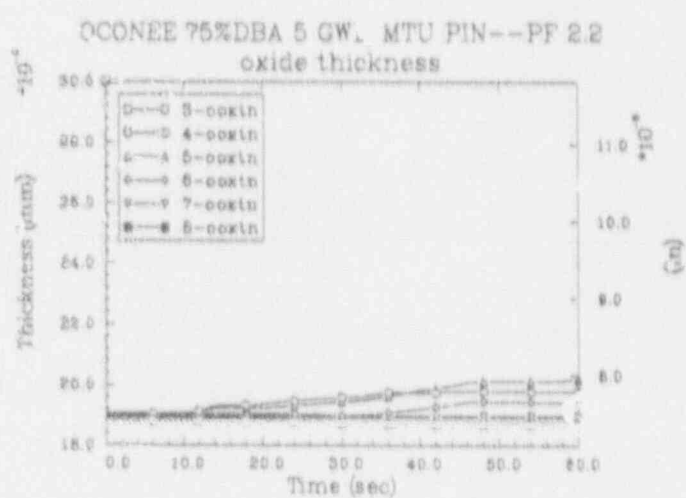

OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

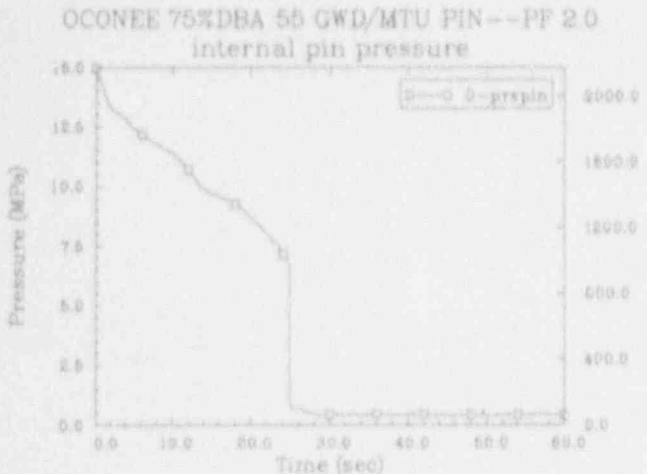

OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

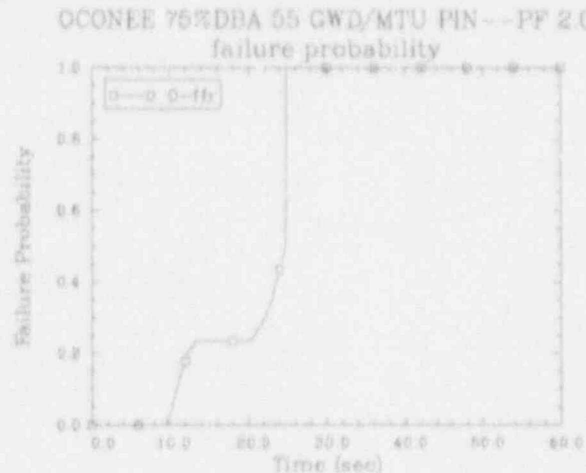

cladding hoop strain
Strain
Time (sec)

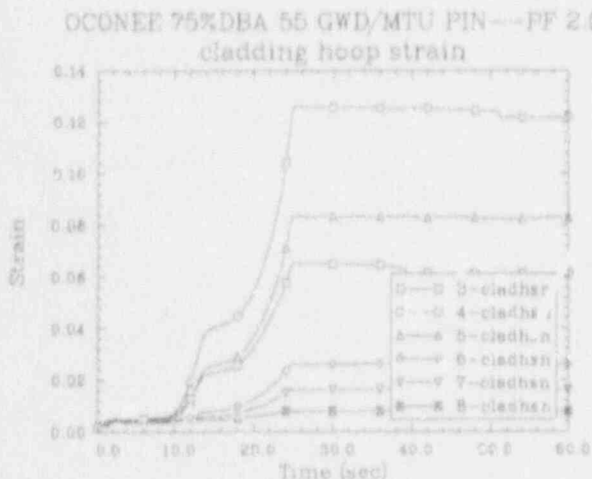

cladding surface temperature
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

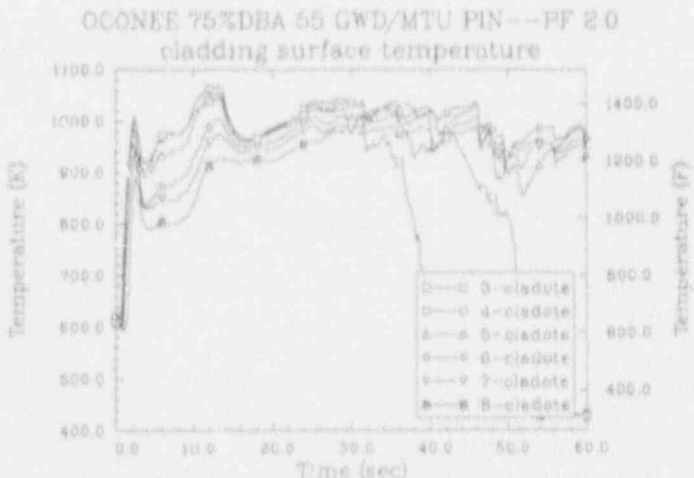

OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.2
fuel centerline temperature
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Time (sec)

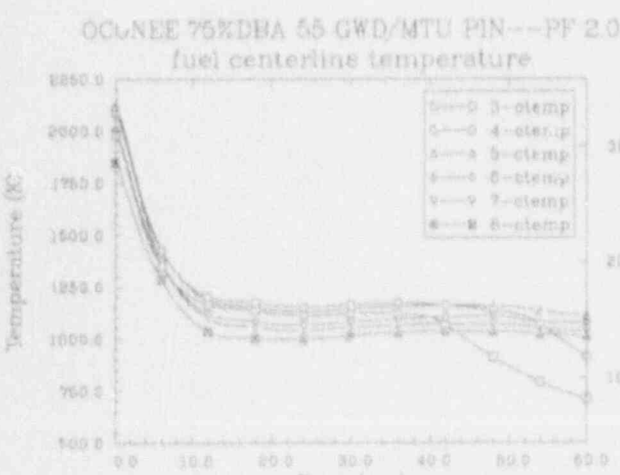

oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
Time (sec)

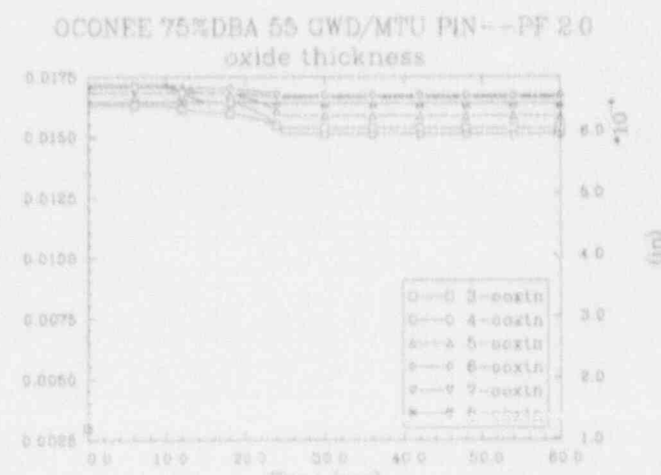

OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prespin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

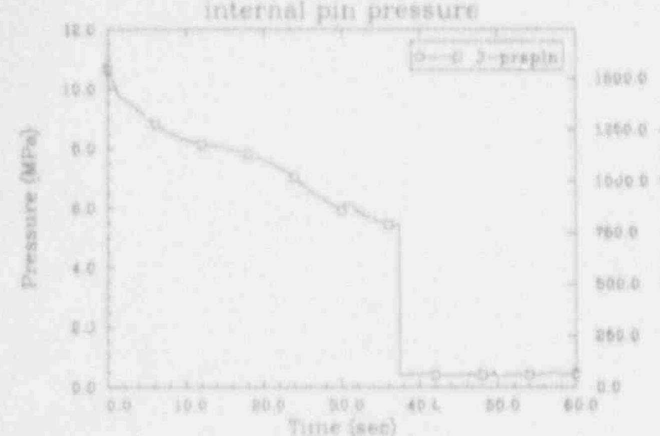

OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.0
cladding hoop strain
Strain
Time (sec)


OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

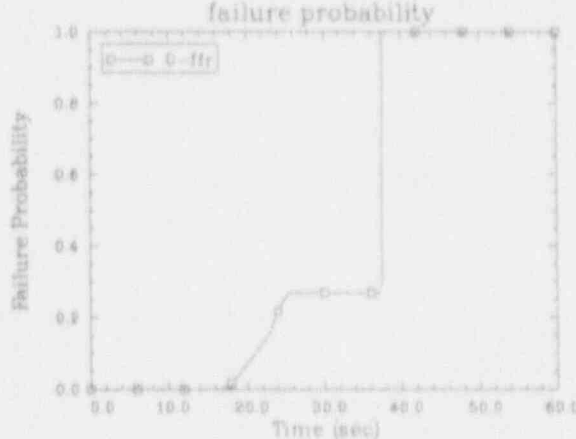

OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 75%DBA 55 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
Thickness (mm)
(in)
Time (sec)

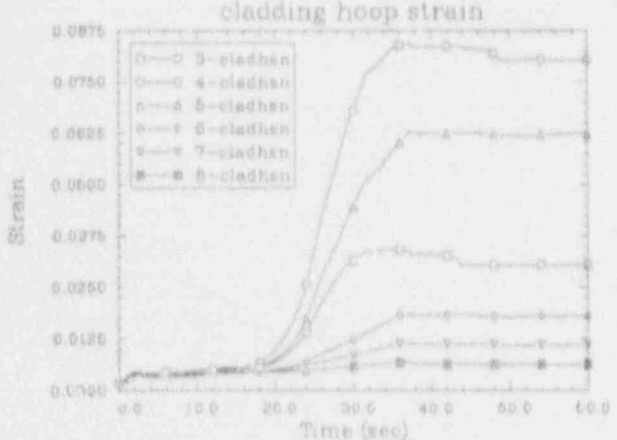
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure



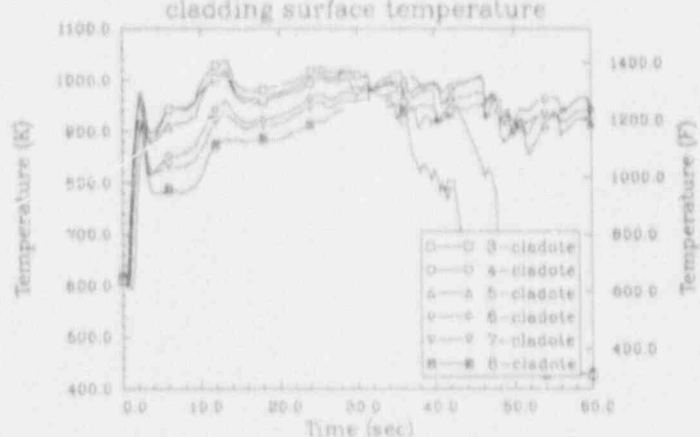
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.0
failure probability



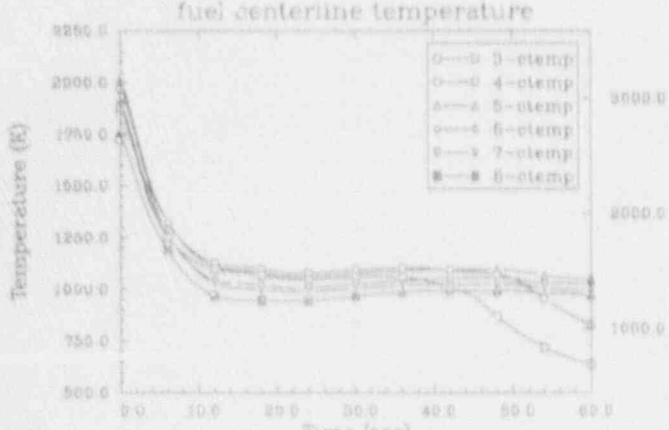
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain



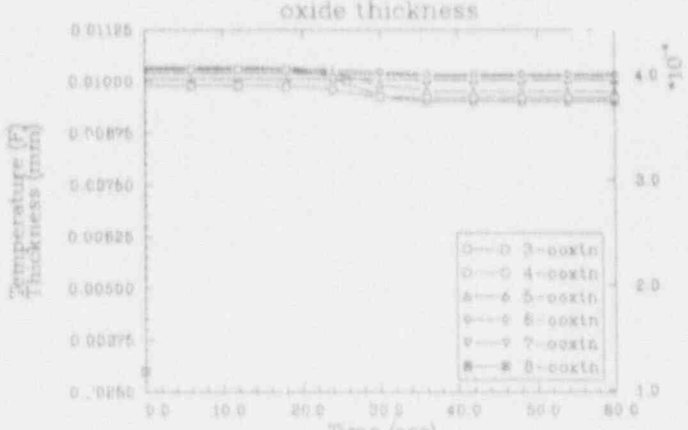
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature

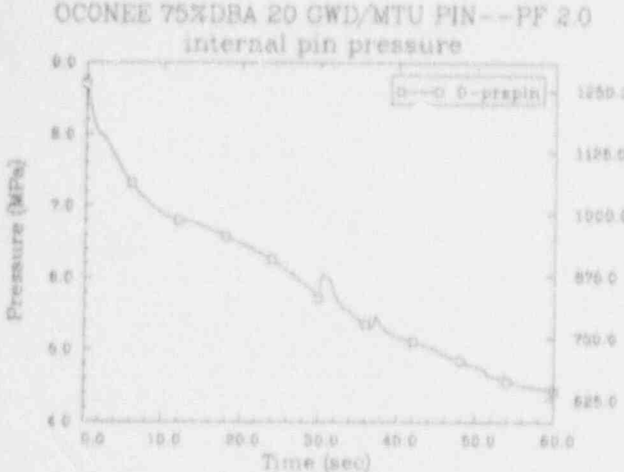


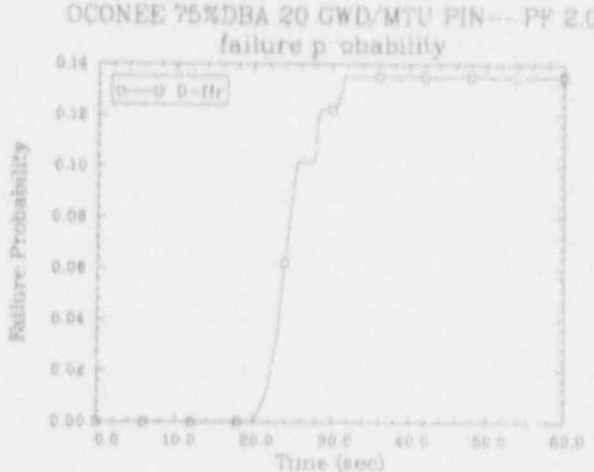
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature

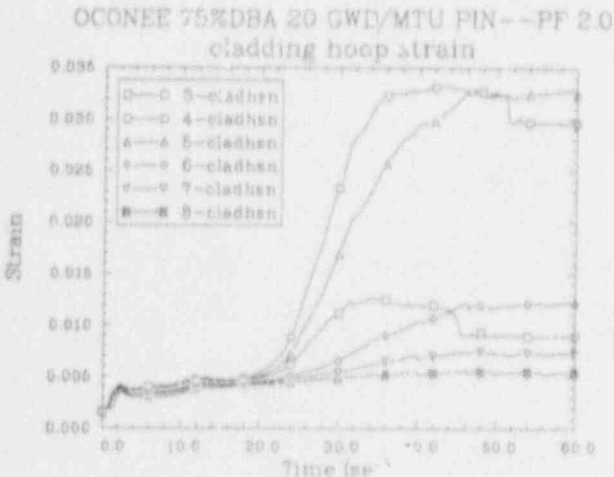


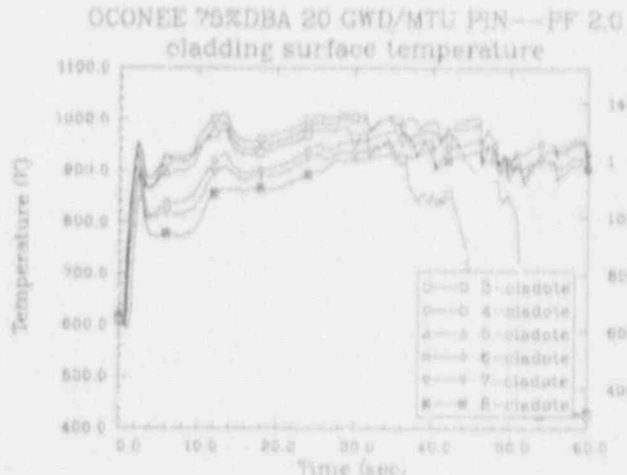
OCONEE 75%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness

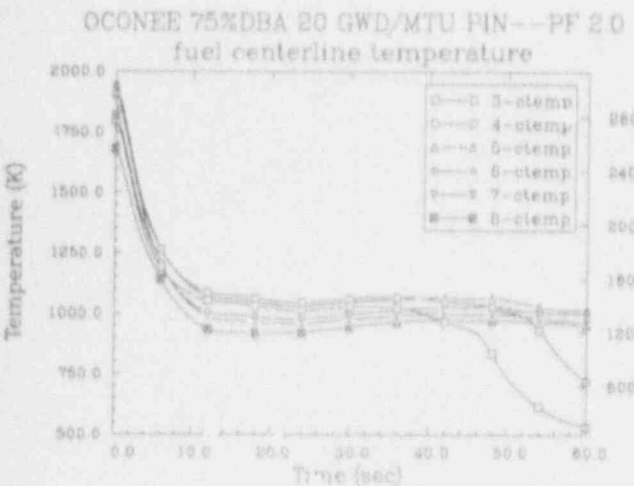


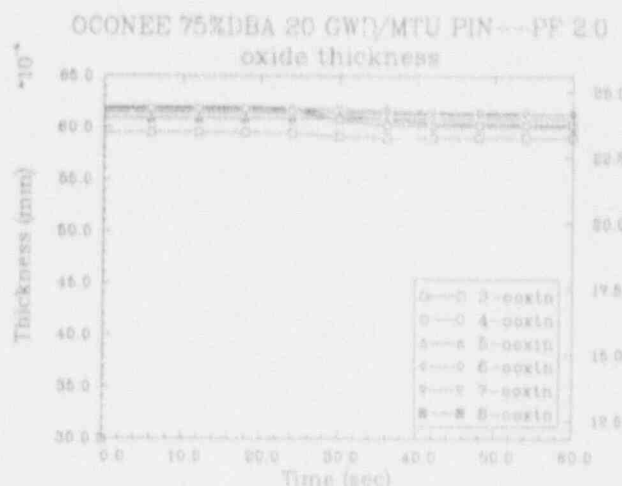

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.0
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.0
Failure Probability
Time (sec)

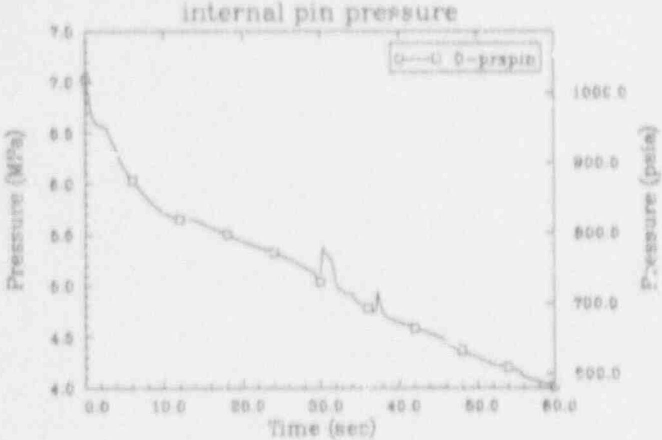

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain


OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.0
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

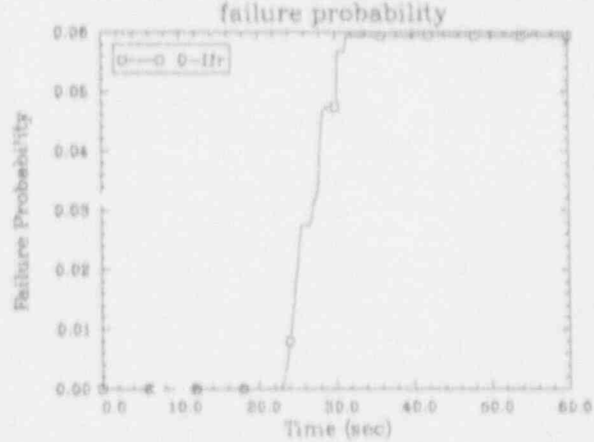

OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)


OCONEE 75%DBA 20 GWD/MTU PIN--PF 2.0
oxide thickness
Thickness (mm)
(in)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Time (sec)

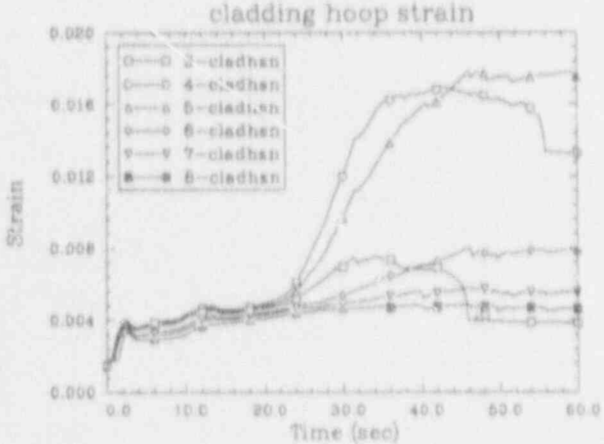
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure



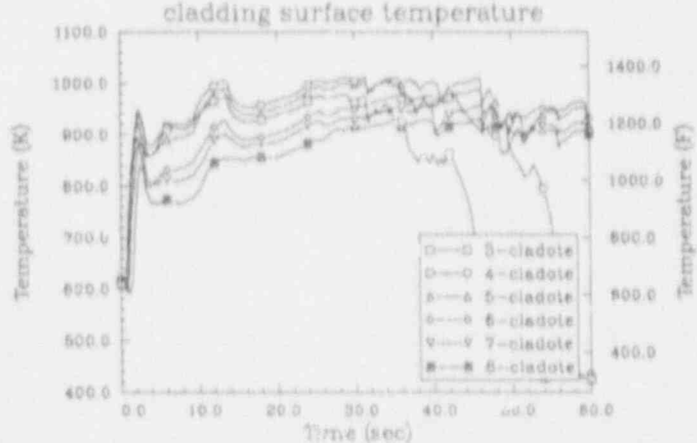
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.0
failure probability



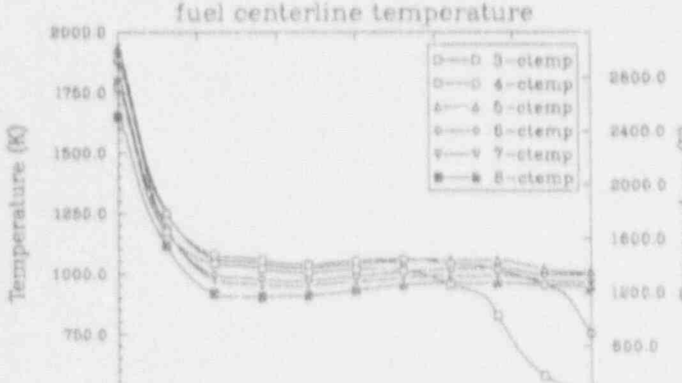
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain



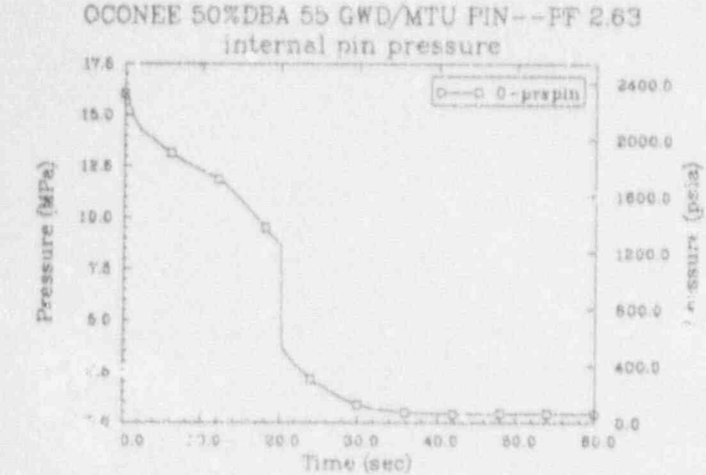
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature

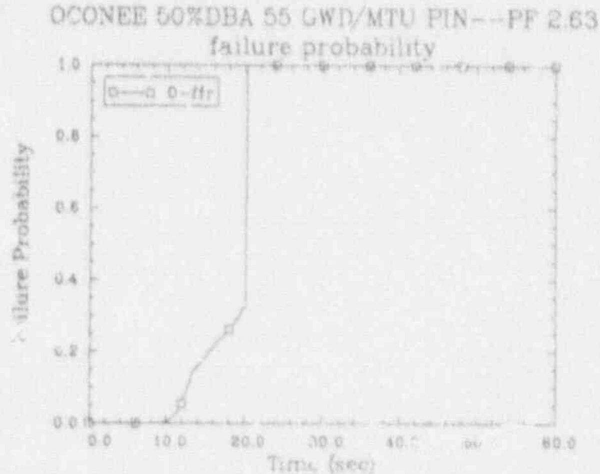


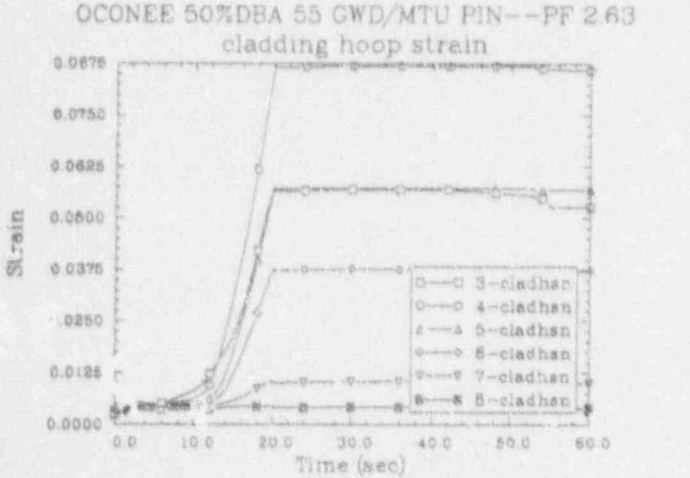
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.0
fuel centerline temperature

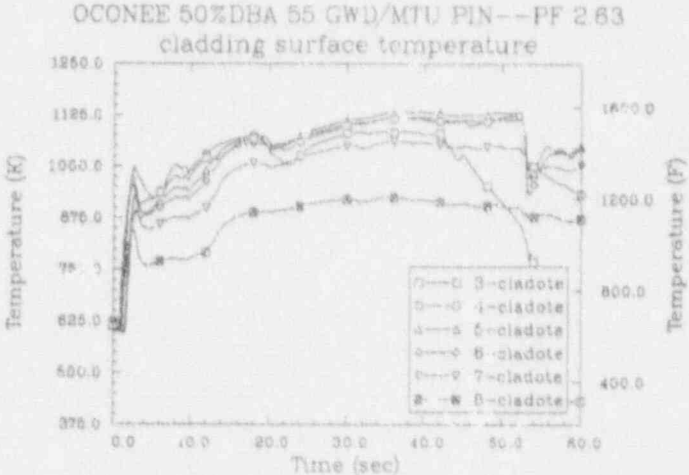


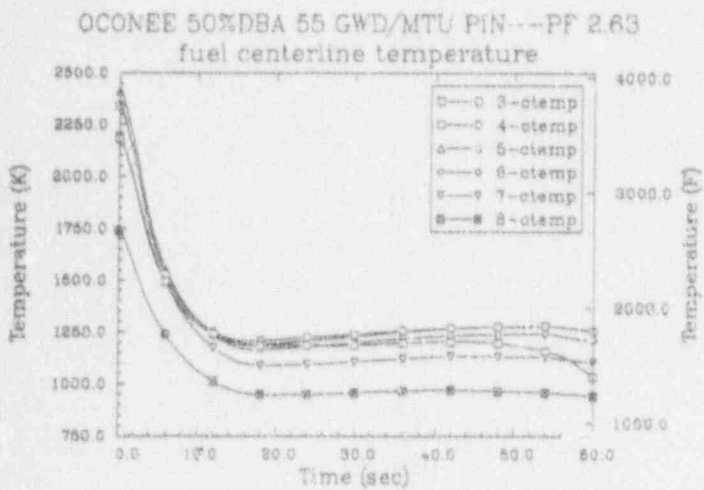
OCONEE 75%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness

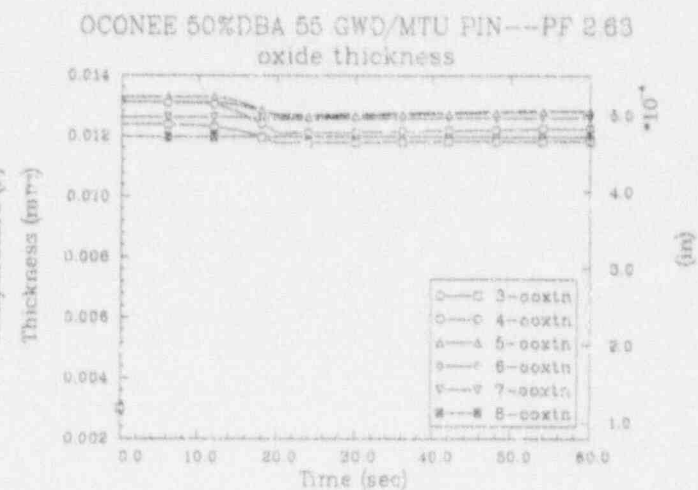

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Time (sec)

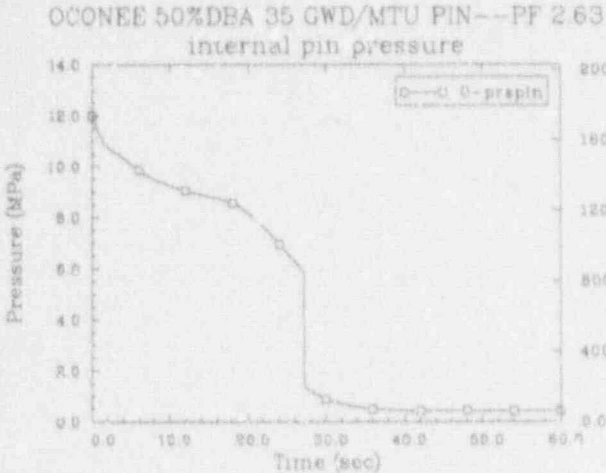

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.63
failure probability
0-ffr

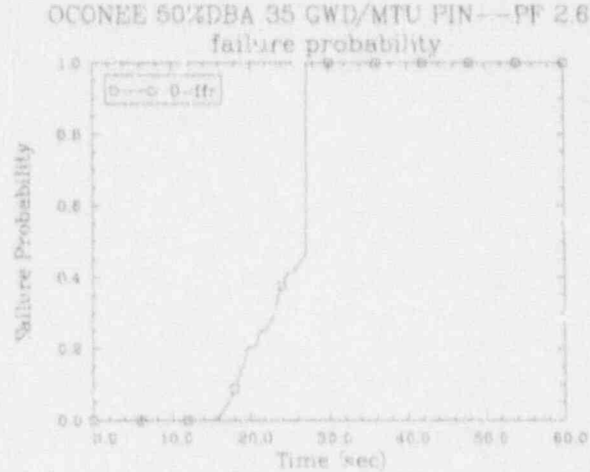

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

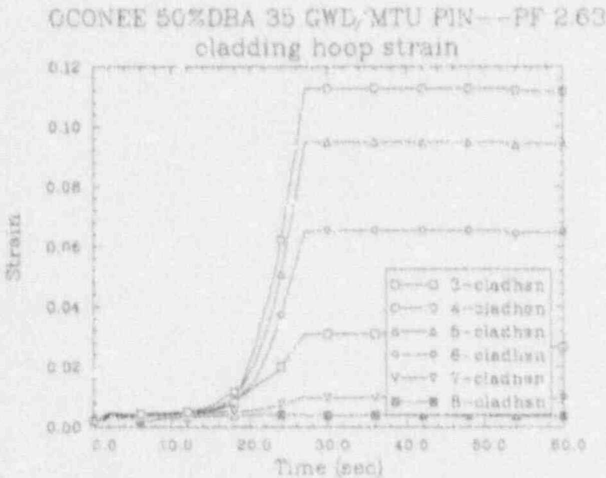

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

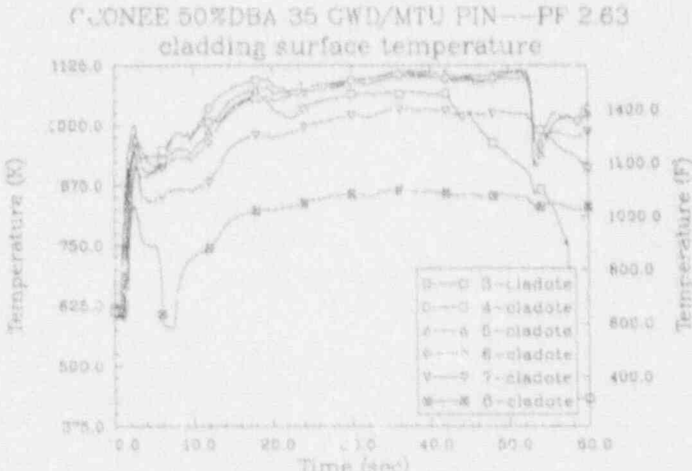

OCONEE 50%DBA 55 GWD/MTU PIN---PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

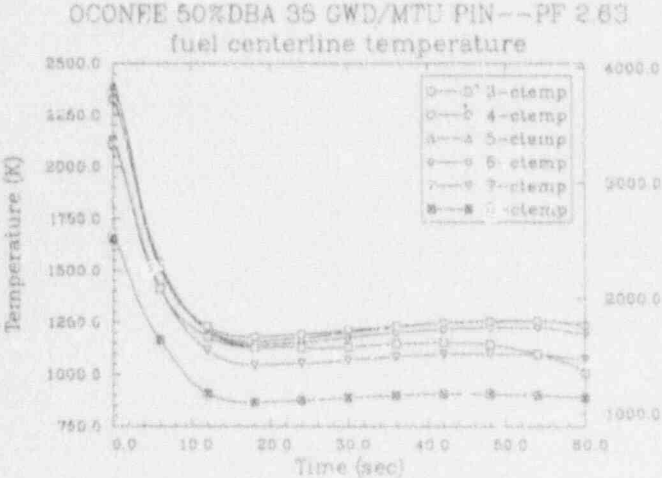

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
(in)
Time (sec)

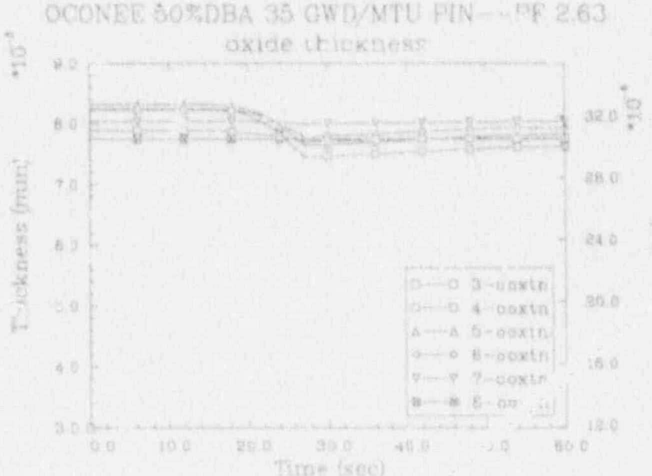

OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.63
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin

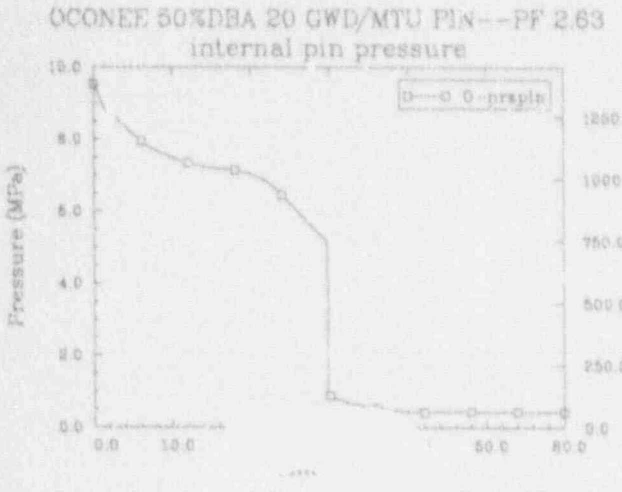

OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.63
failure probability
Failure Probability
Time (sec)
0-ffr

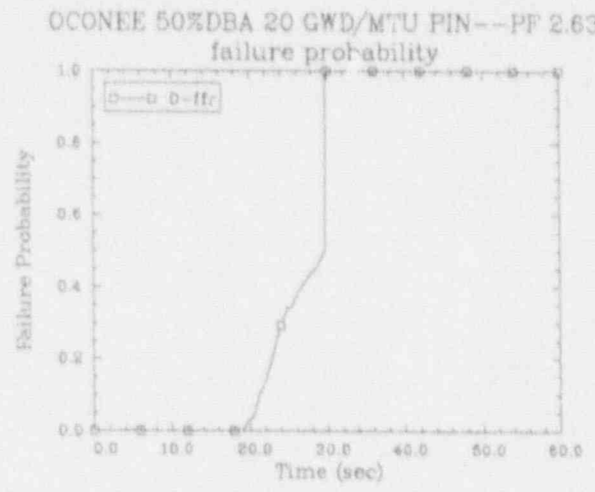

OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.63
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn

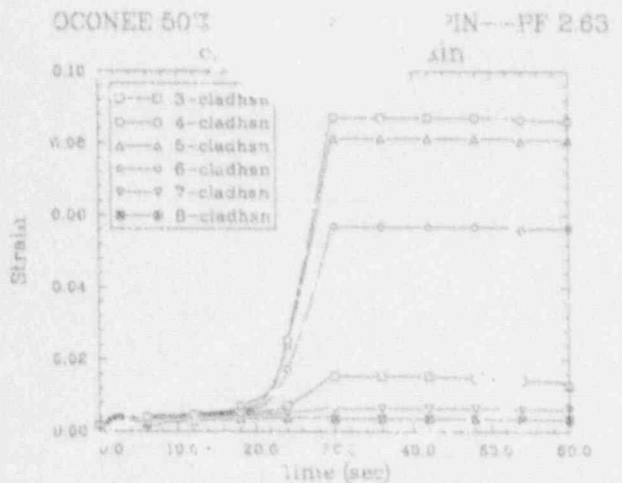

cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

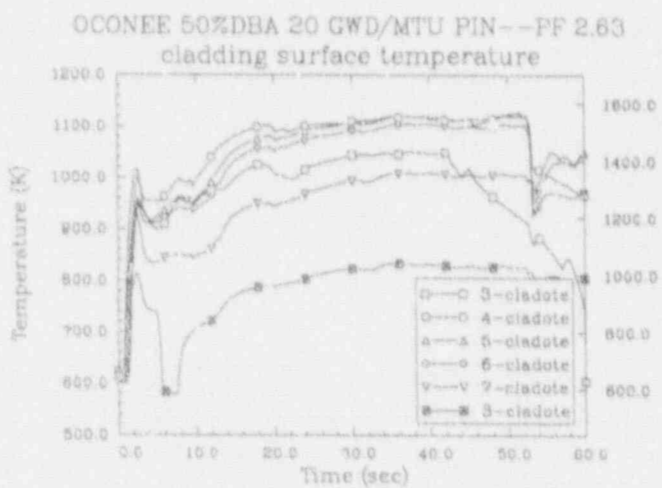

OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.63
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp

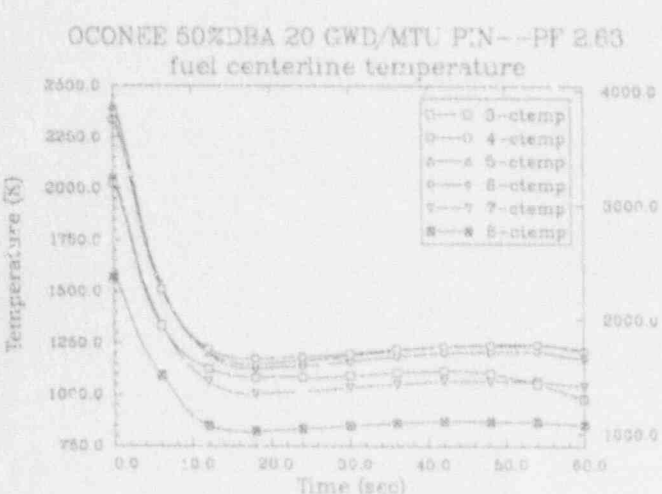

OCONEE 50%DBA 35 GWD/MTU PIN--
oxide thickness
Time (sec)
3-oxtn
4-oxtn
5-oxtn
6-oxtn

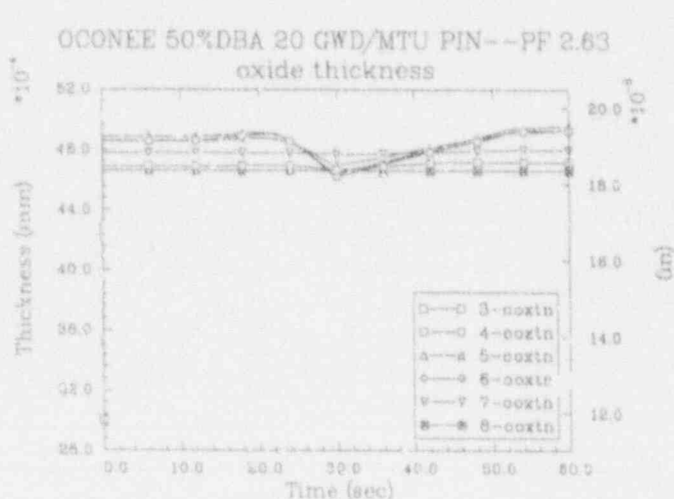

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)

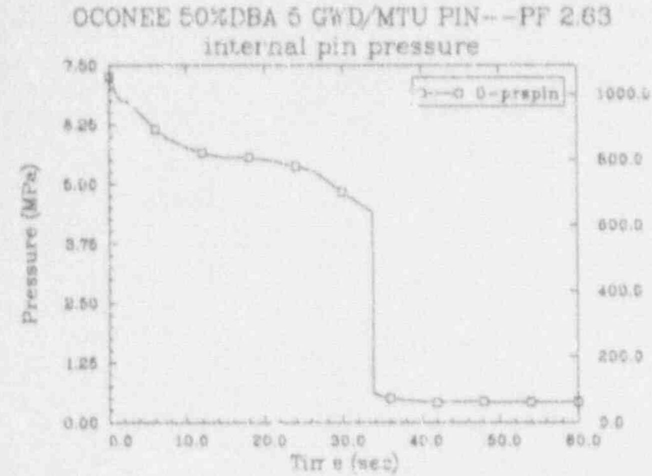

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)

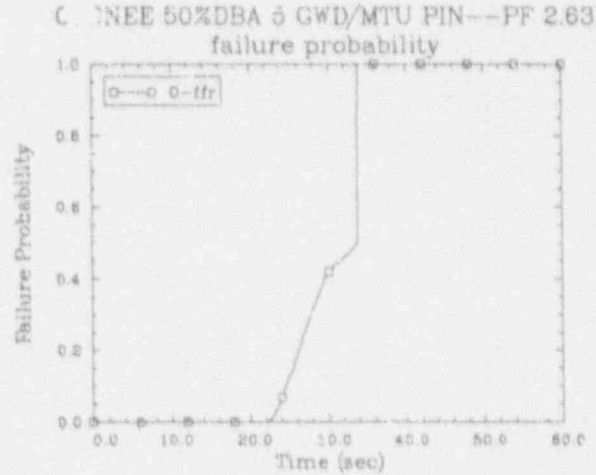

OCONEE 50%
PIN--PF 2.63
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Time (sec)

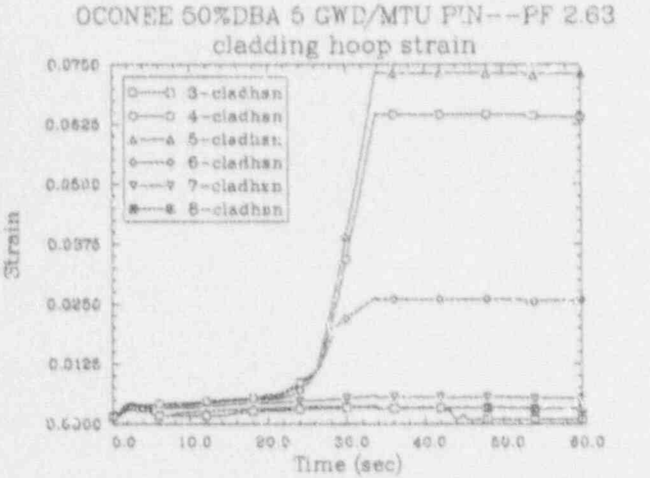

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

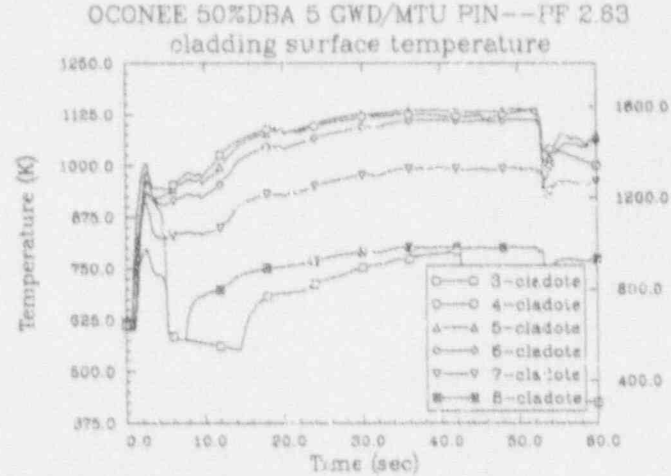

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

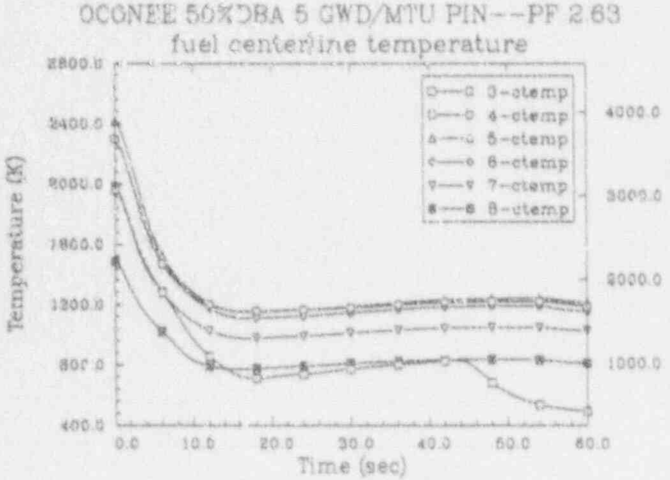

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

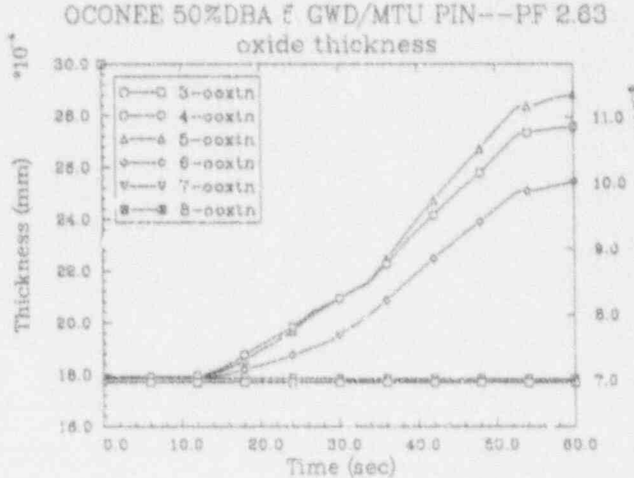

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

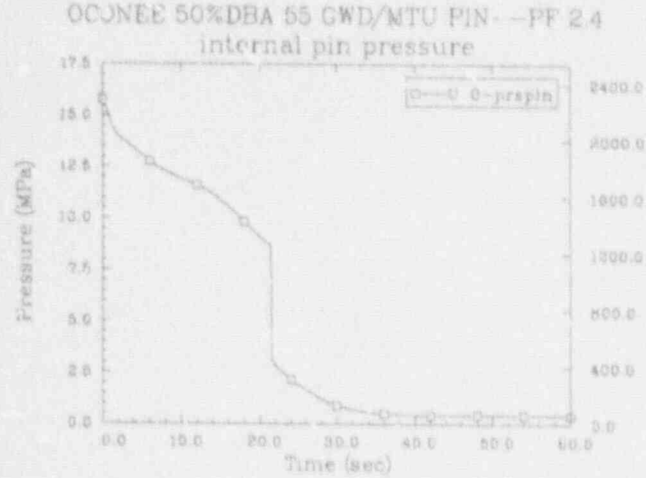

NEE 50%DBA 5 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)

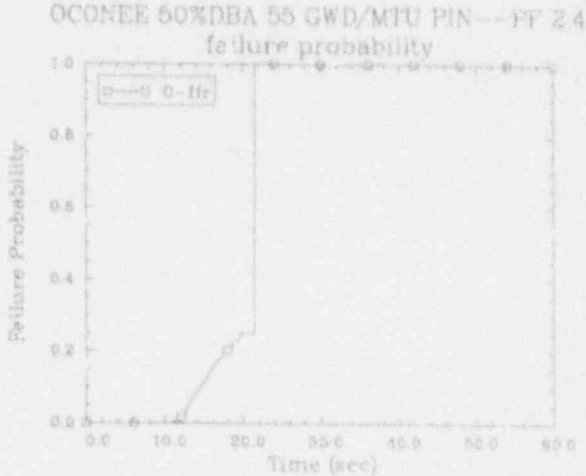

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

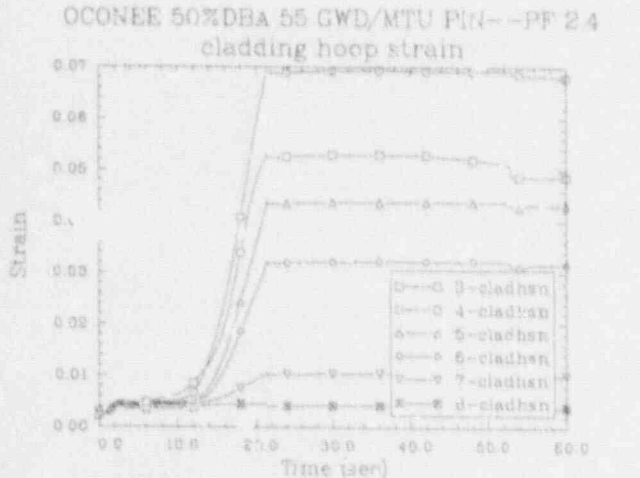

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

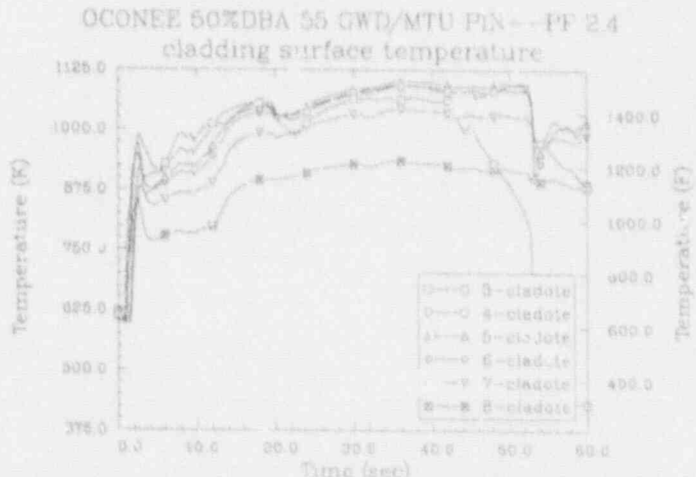

fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

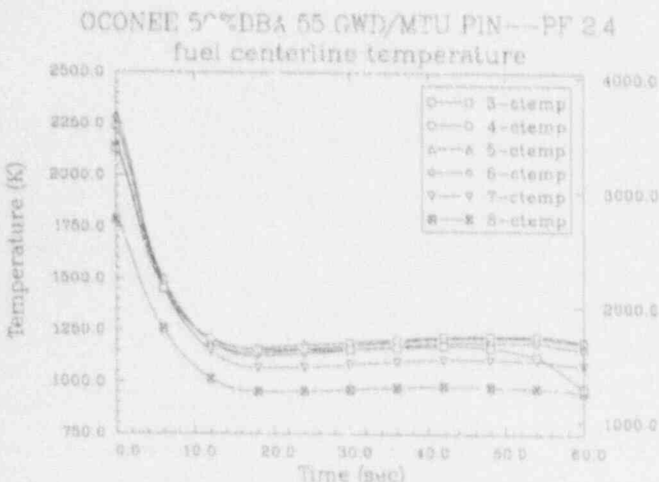

oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

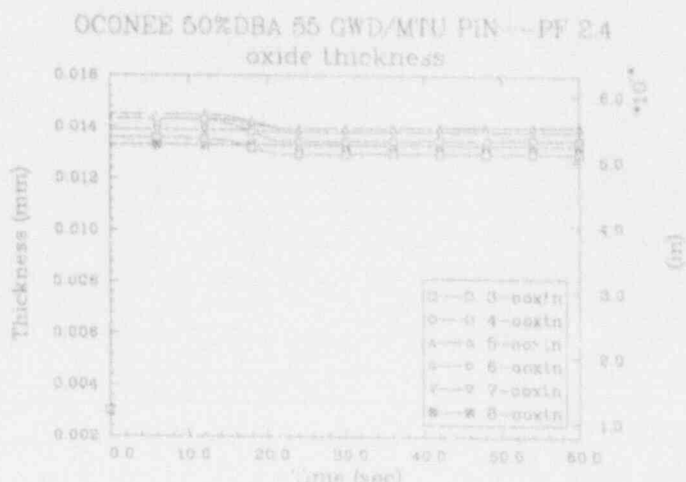

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.4
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.4
failure probability
0-ffr
Failure Probability
Time (sec)

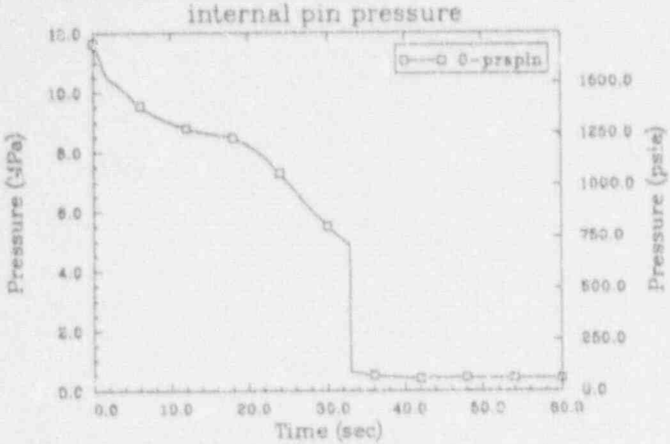

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.4
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.4
cladding surface temperature
3-cladote
4-cladote
7-cladote
8-cladote
Temperature (K)
Time (sec)

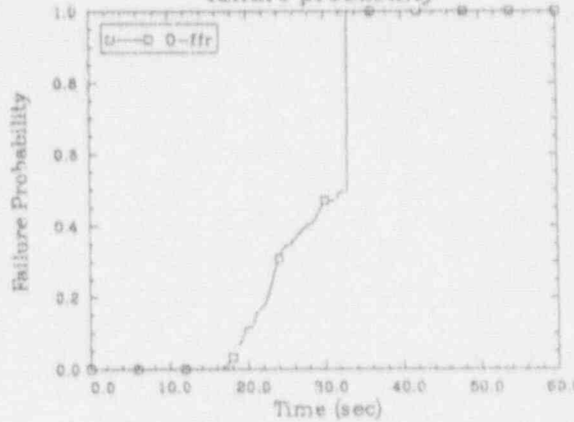

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.4
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.4
oxide thickness
3-oxin
4-oxin
6-oxin
7-oxin
8-oxin
Thickness (mm)
(in)
Time (sec)

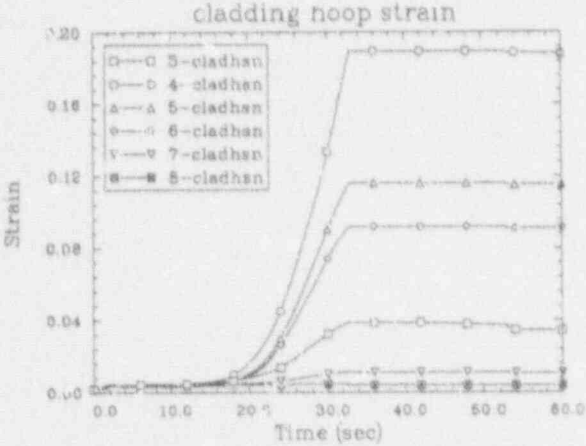
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.4
internal pin pressure



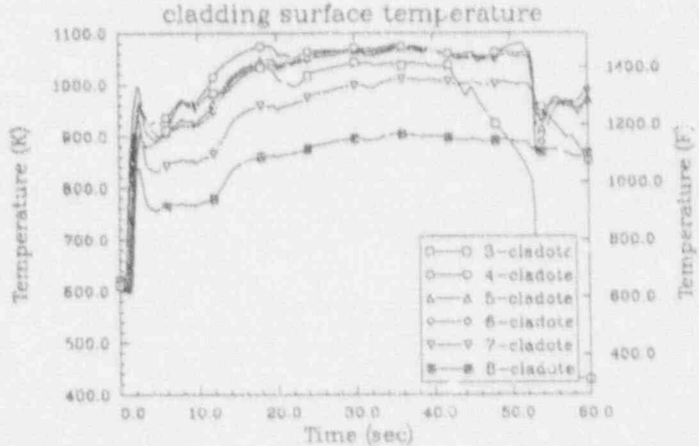
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.4
failure probability



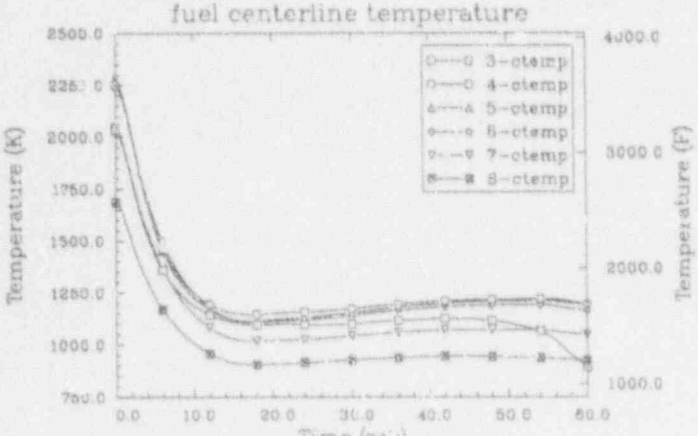
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.4
cladding hoop strain



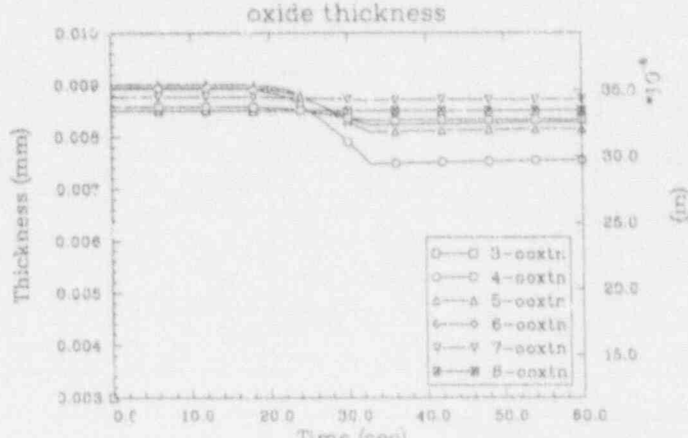
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.4
cladding surface temperature



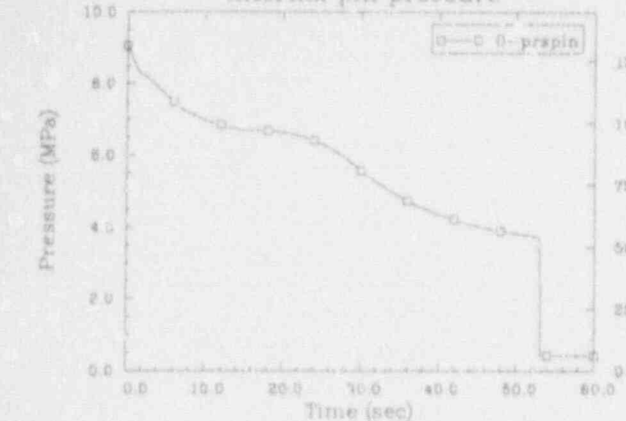
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.4
fuel centerline temperature



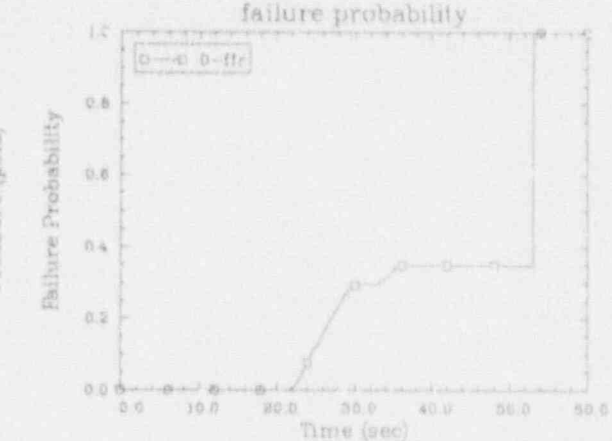
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.4
oxide thickness



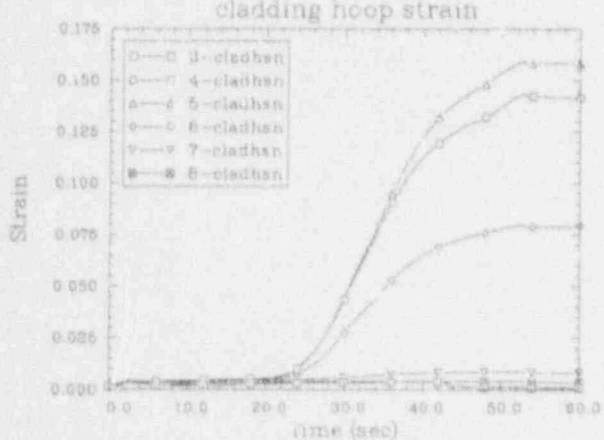
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.4
internal pin pressure



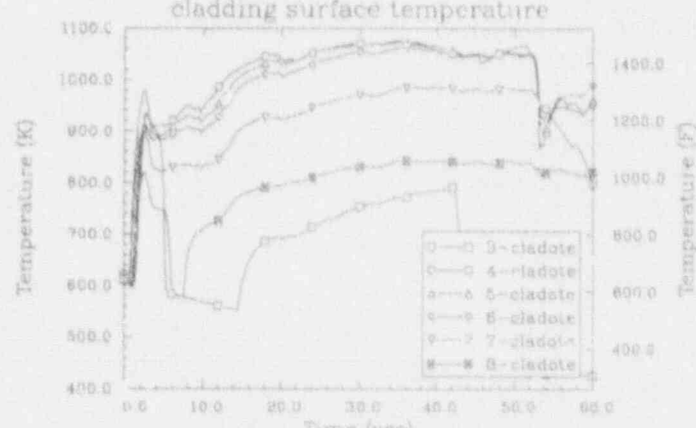
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.4
failure probability



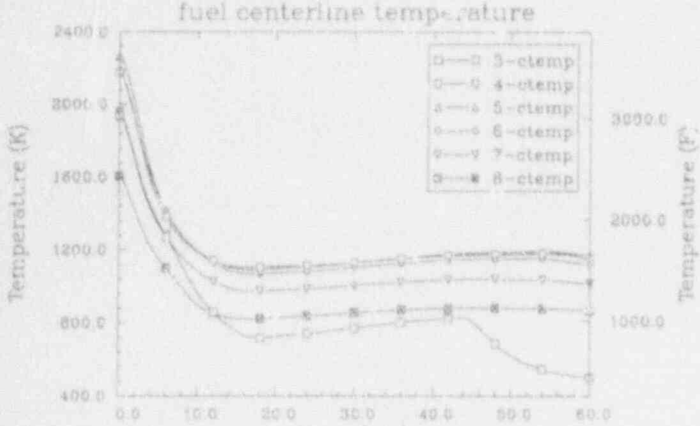
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.4
cladding hoop strain



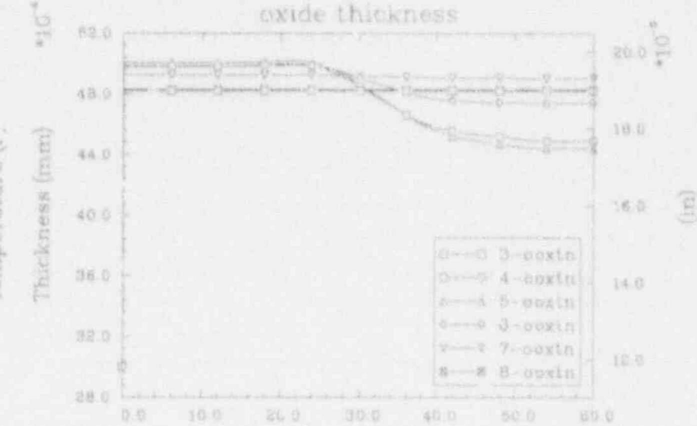
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.4
cladding surface temperature

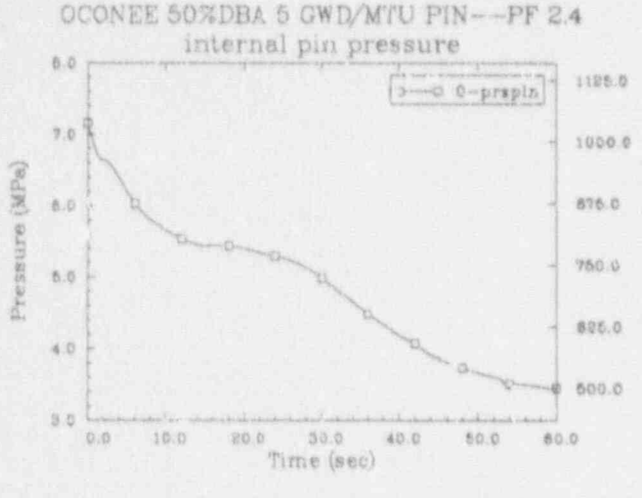


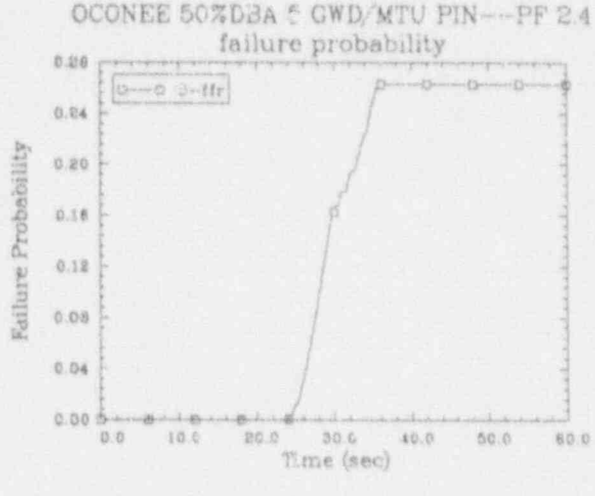
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.4
fuel centerline temperature

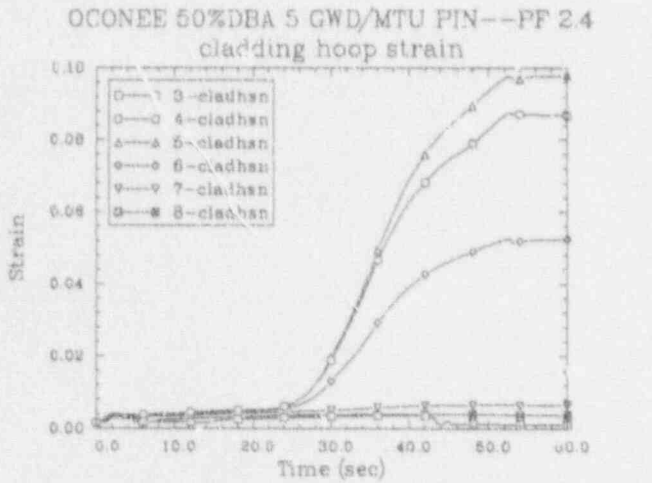


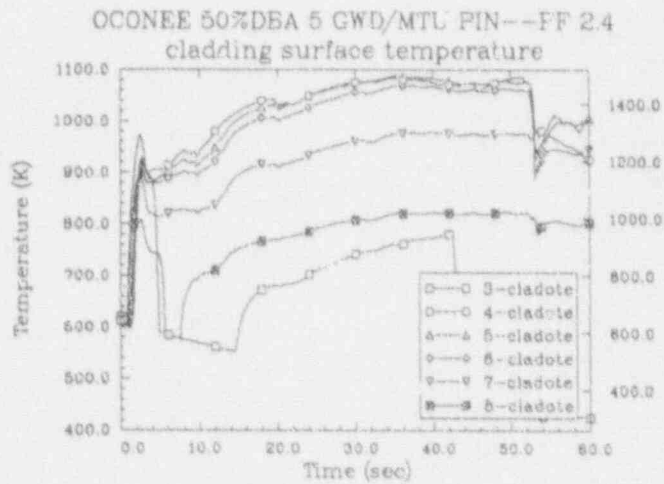
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.4
oxide thickness

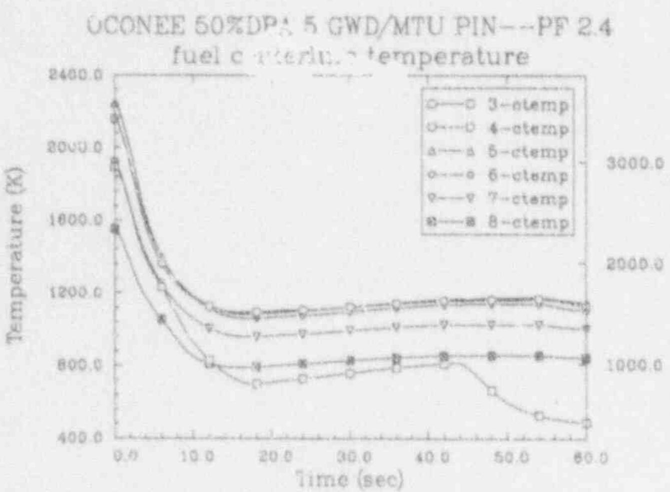


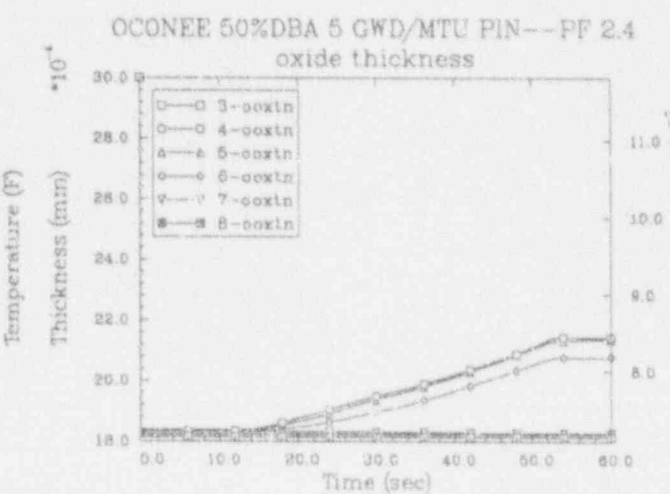

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.4
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.4
failure probability
0-ffr
Failure Probability
Time (sec)

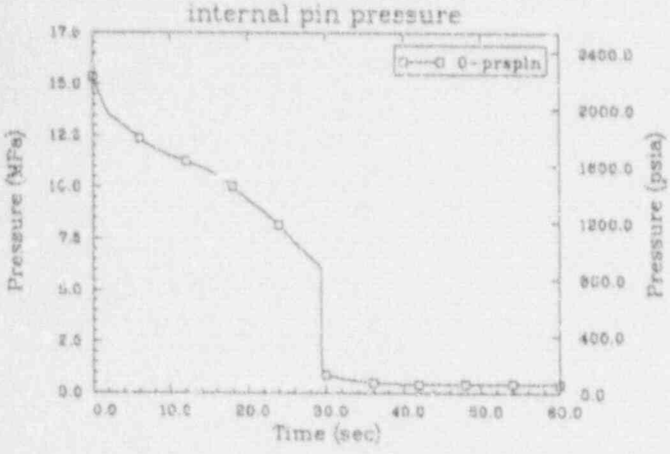

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.4
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.4
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

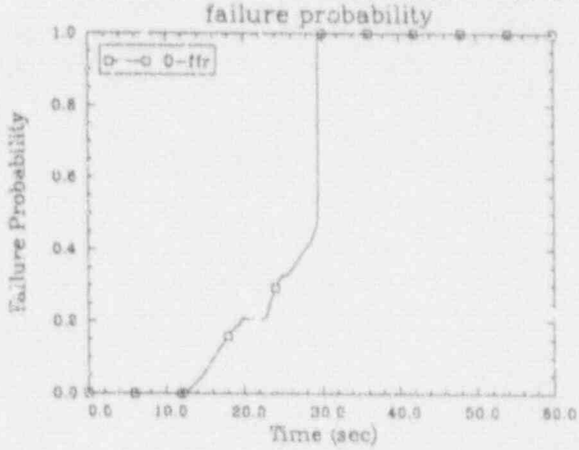

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.4
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.4
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

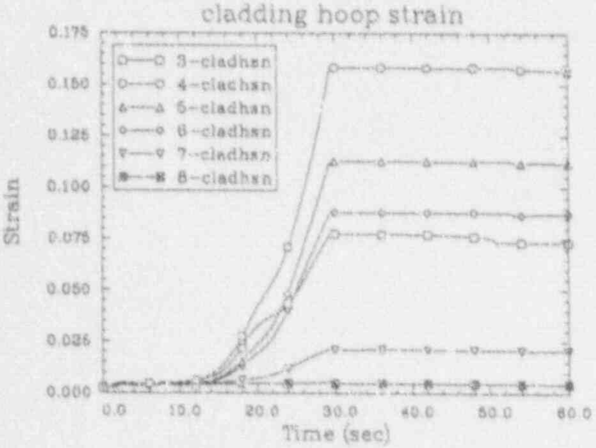
OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.2
internal pin pressure



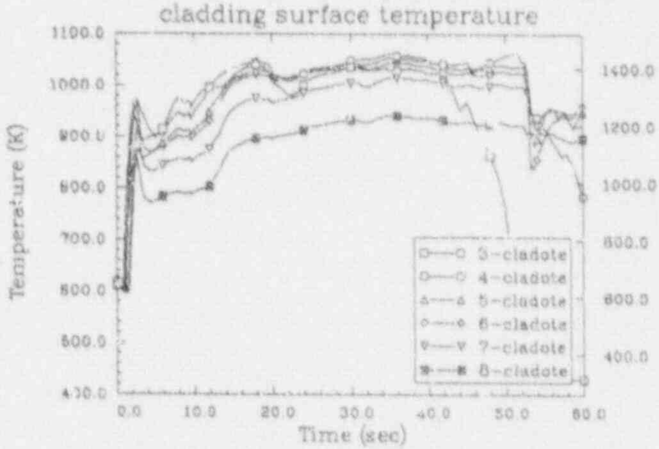
OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.2
failure probability



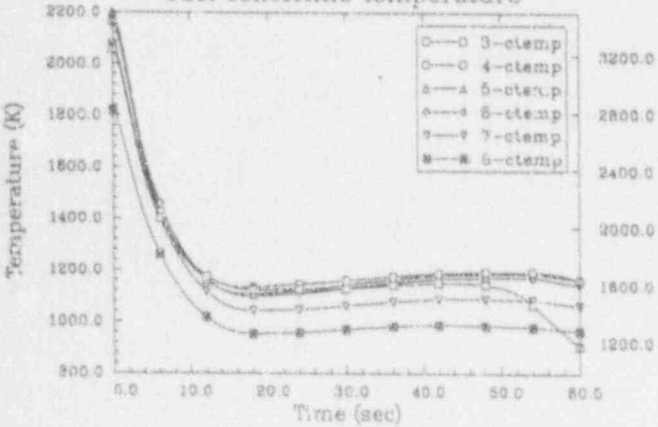
OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.2
cladding hoop strain



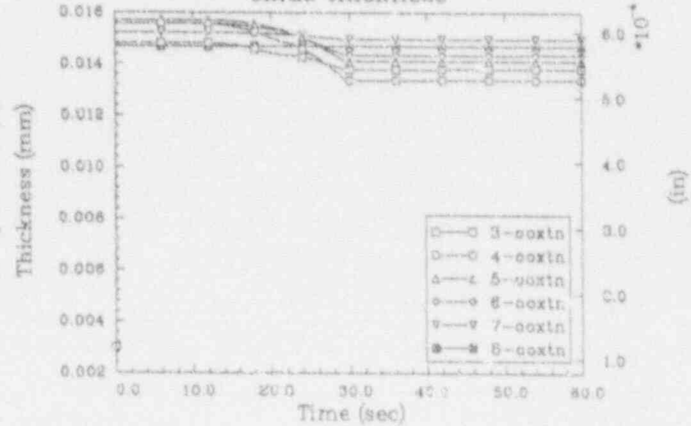
OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.2
cladding surface temperature

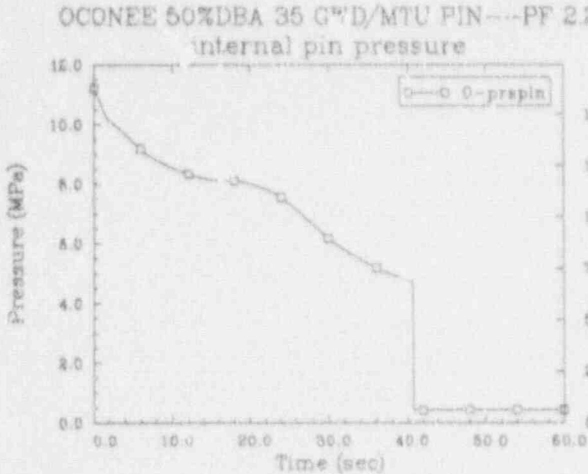


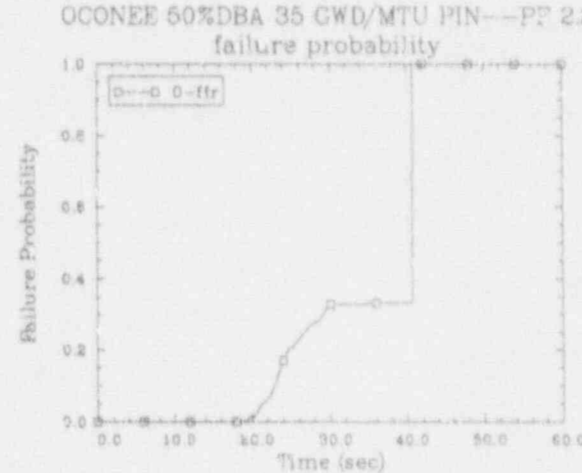
OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.2
fuel centerline temperature

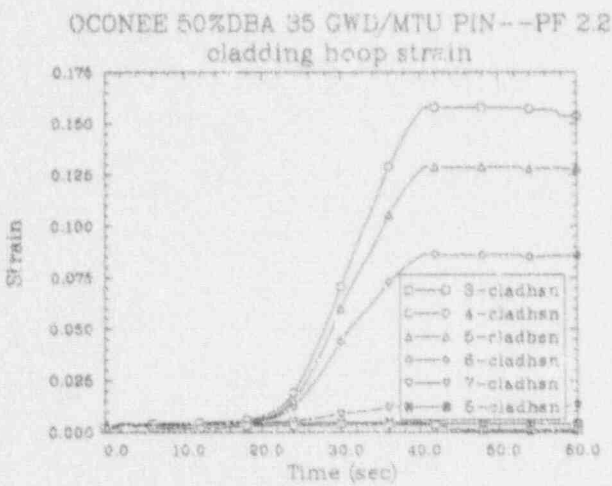


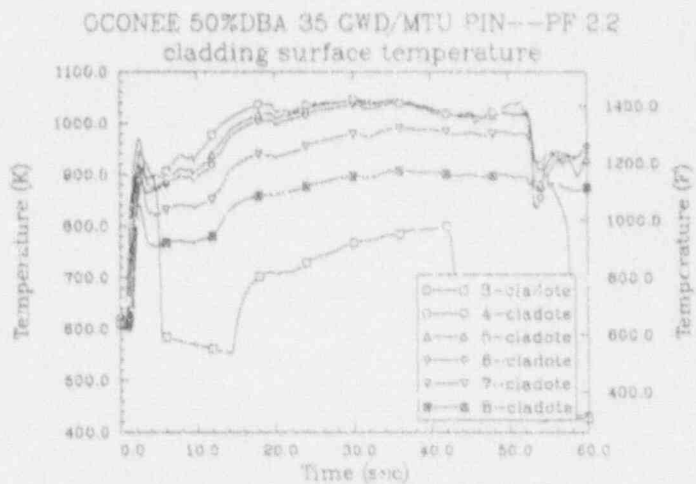
OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.2
oxide thickness

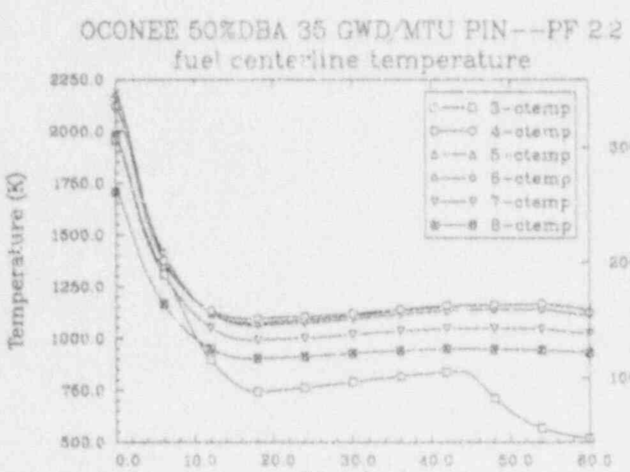


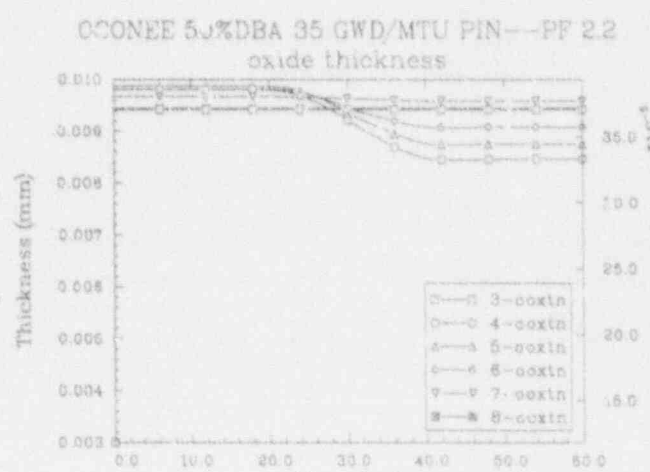

OCONEE 50%DBA 35 GWD/MTU PIN---PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

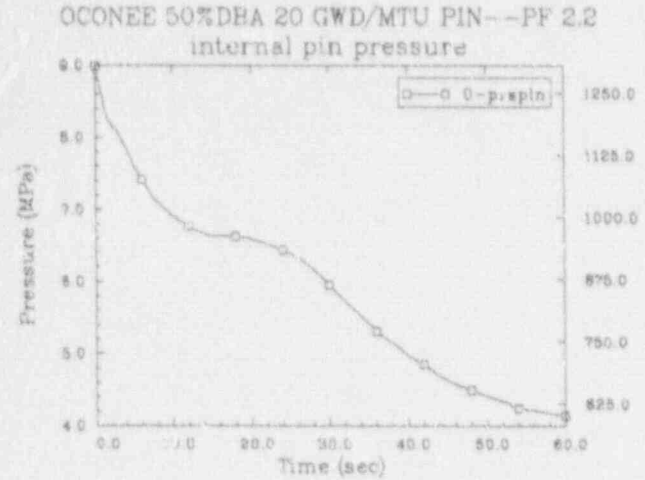

OCONEE 50%DBA 35 GWD/MTU PIN---PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

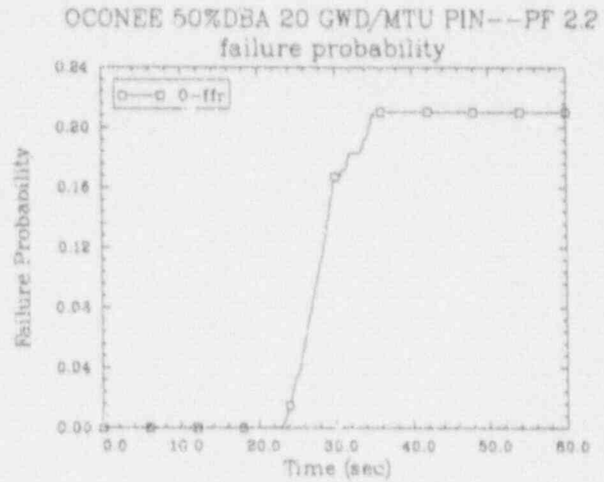

OCONEE 50%DBA 35 GWD/MTU PIN---PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

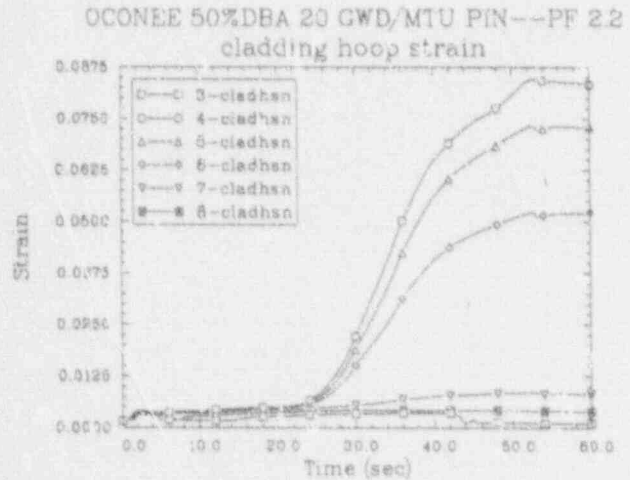

OCONEE 50%DBA 35 GWD/MTU PIN---PF 2.2
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Temperature (F)
Time (sec)

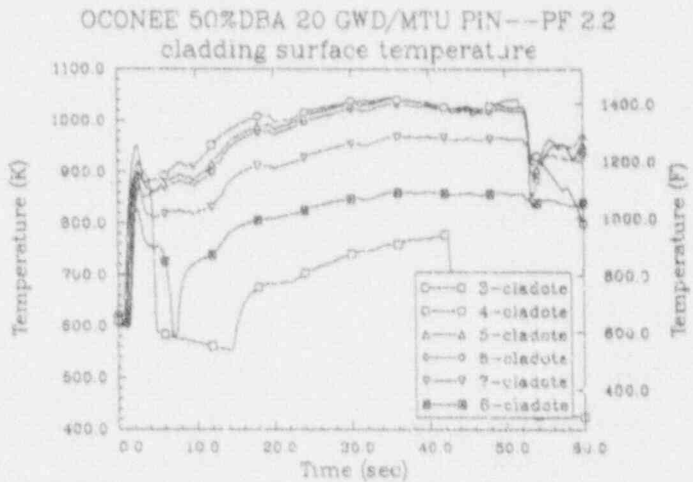

OCONEE 50%DBA 35 GWD/MTU PIN---PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

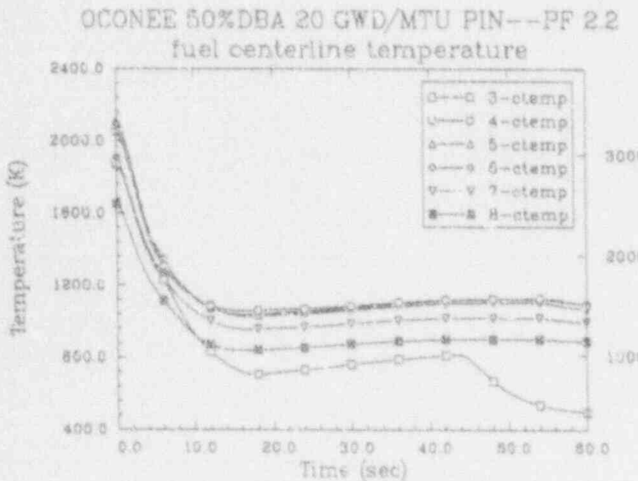

OCONEE 50%DBA 35 GWD/MTU PIN---PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

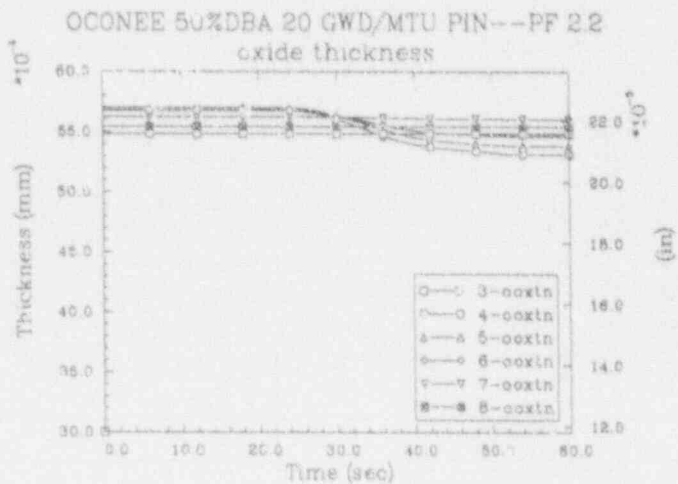

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

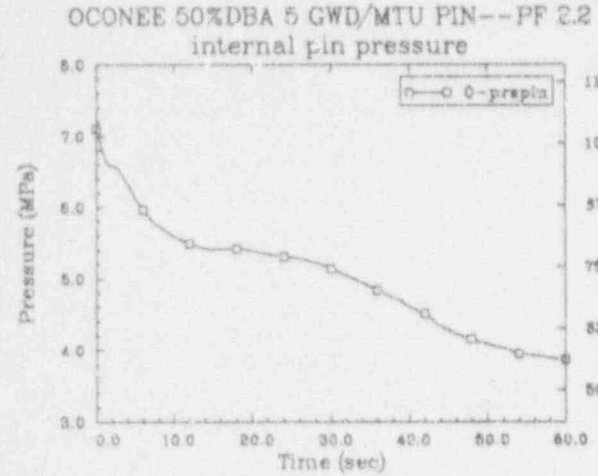

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.2
failure probability
Failure Probability
Time (sec)

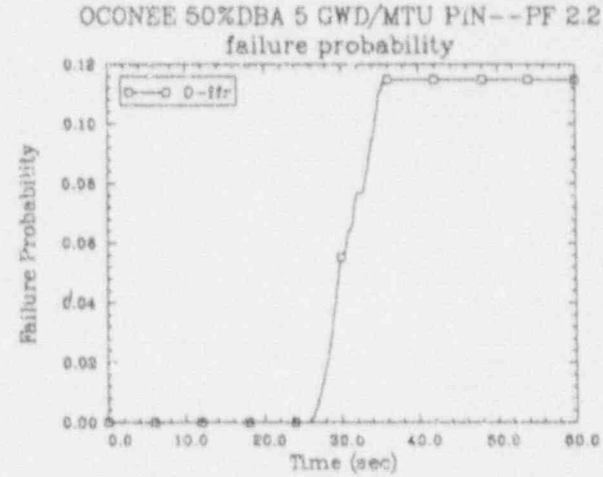

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain
Strain
Time (sec)

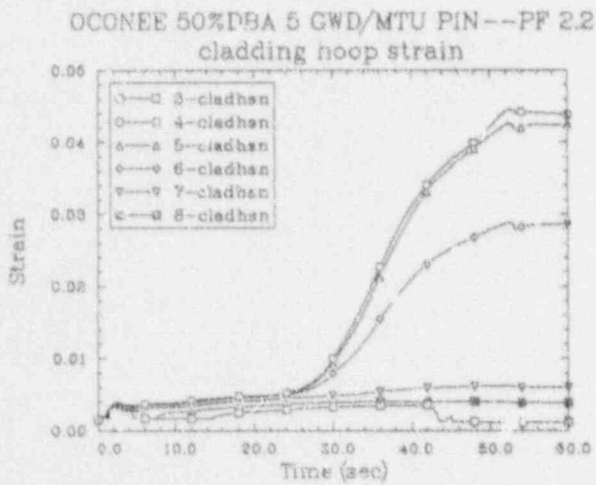

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.2
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)

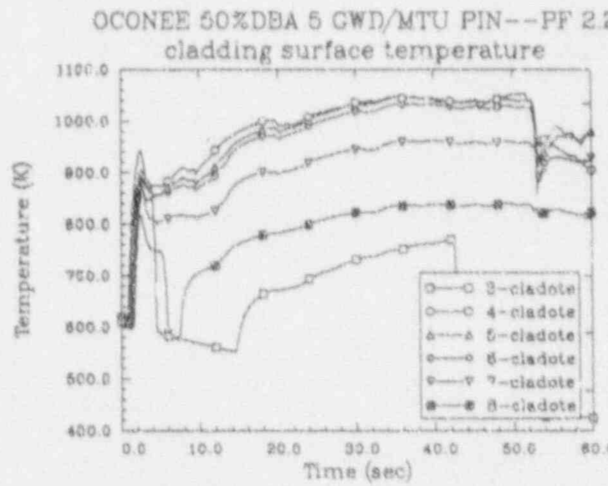

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.2
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)

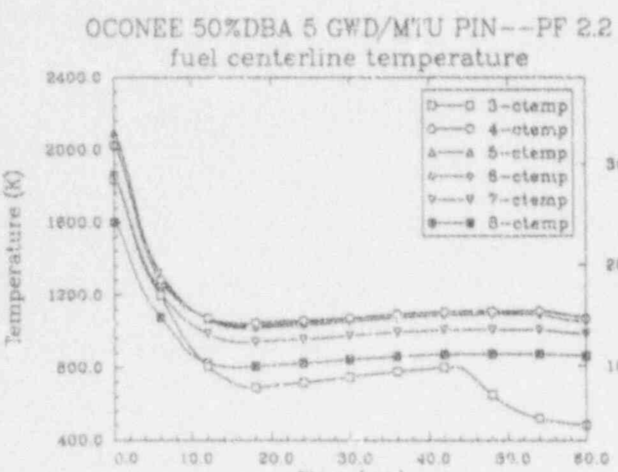

OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.2
oxide thickness
Thickness (mm)
(in)
Time (sec)

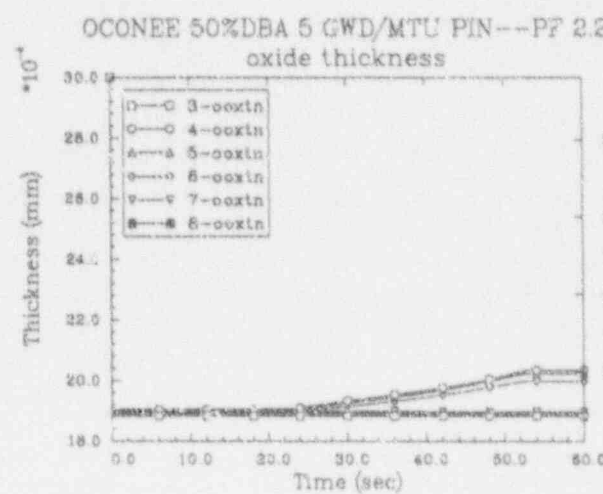

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

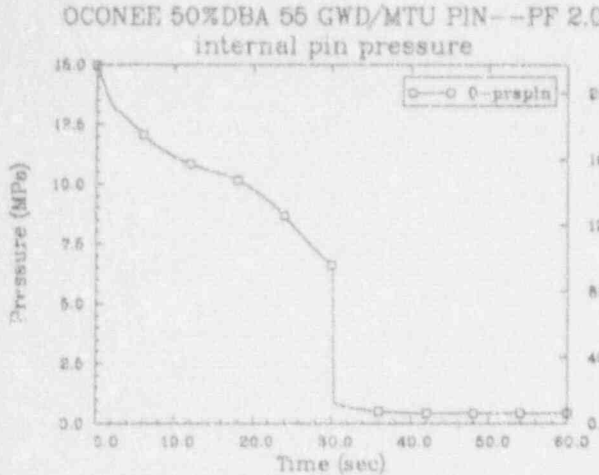

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

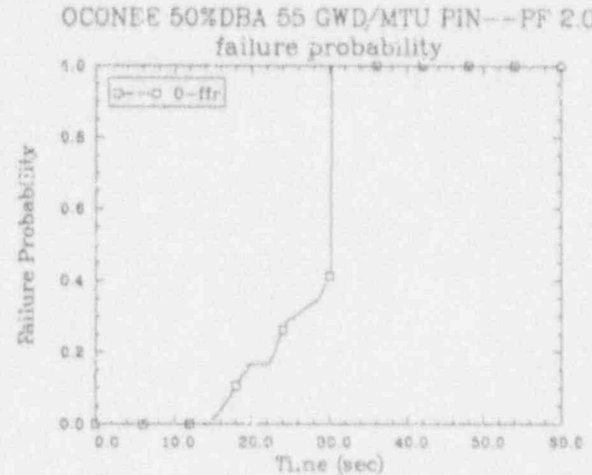

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

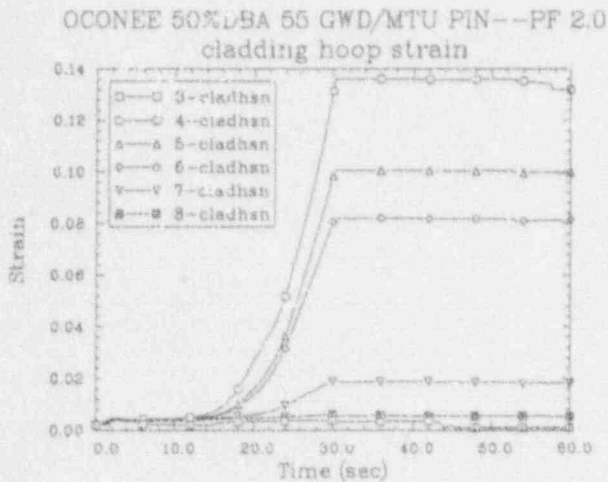

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

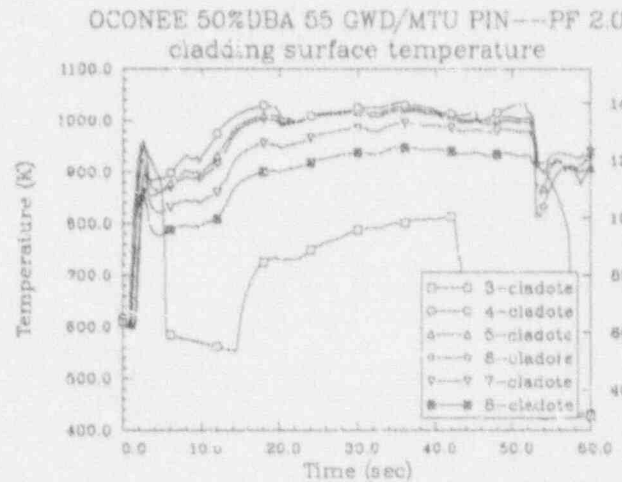

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

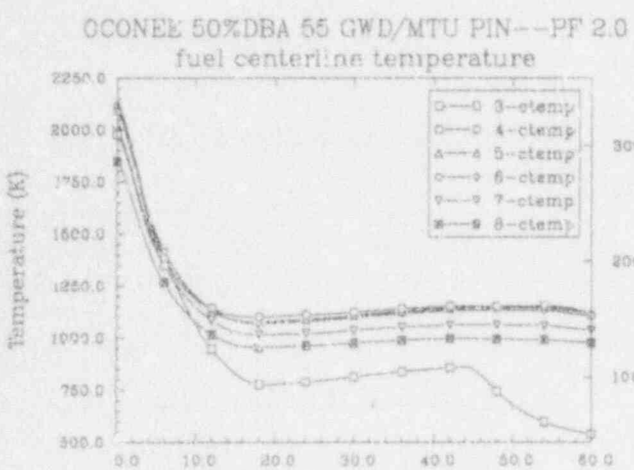

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in.)
Time (sec)

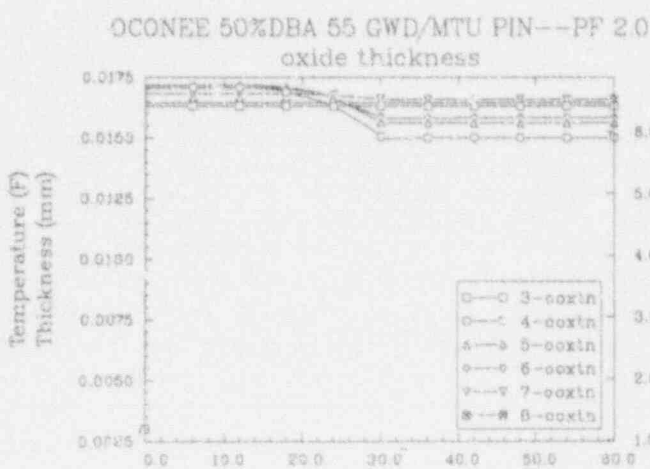

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

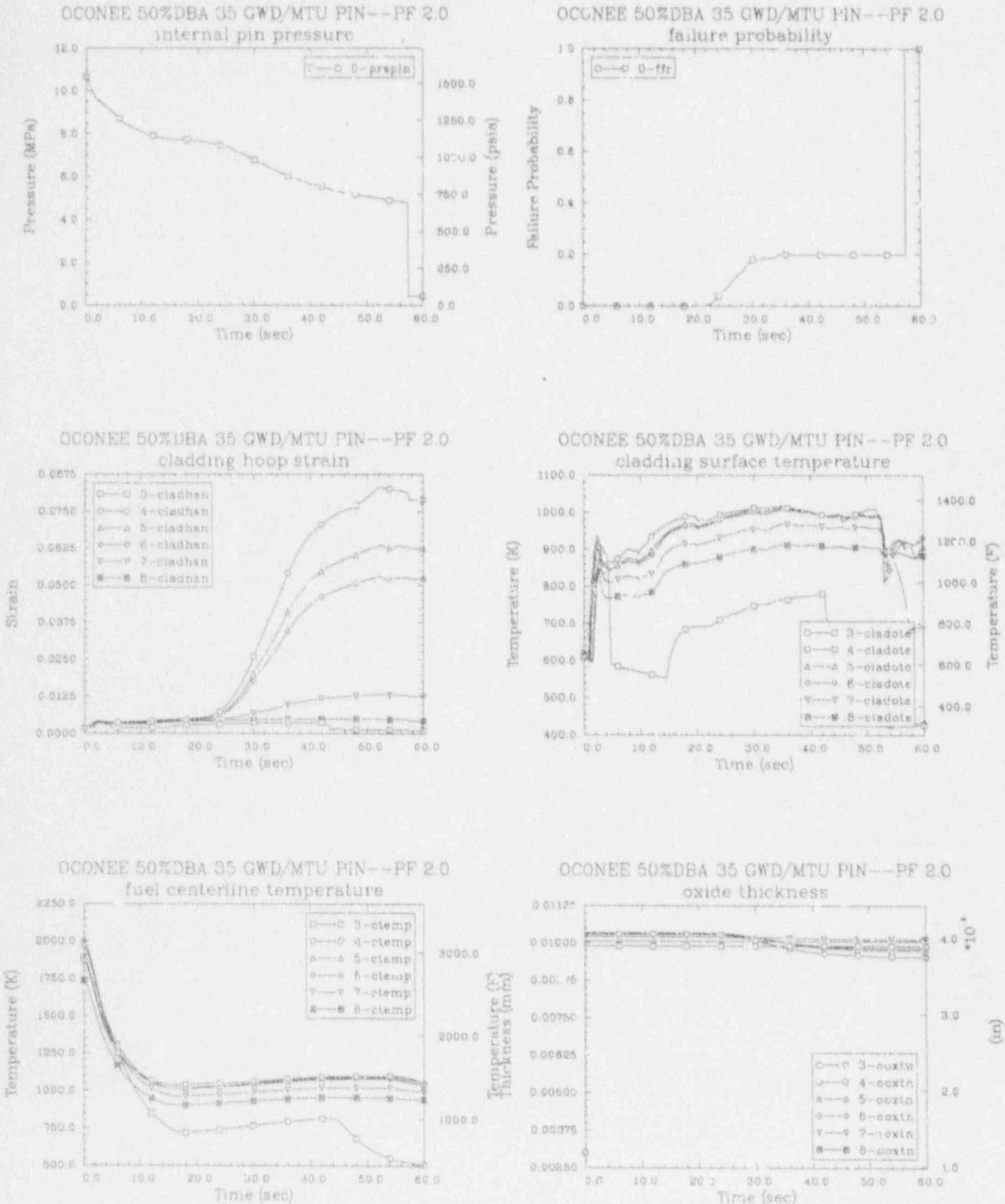

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)


OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

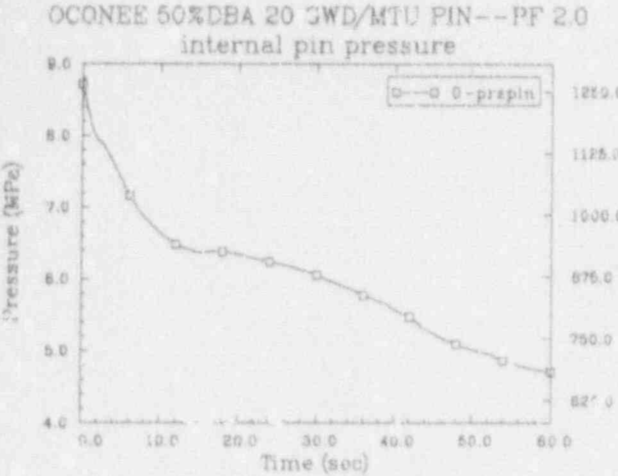

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

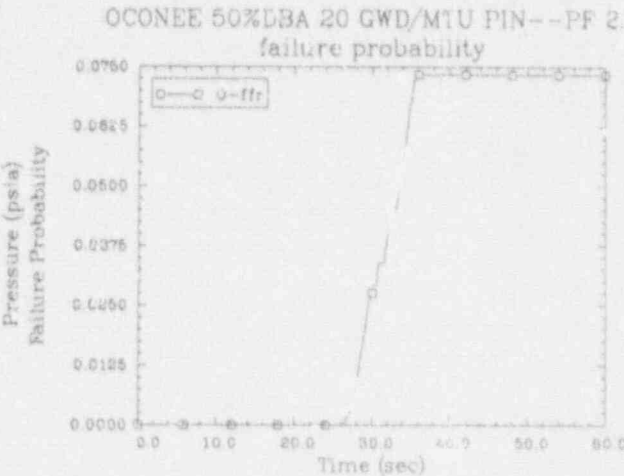

OCONEE 50%DBA 55 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)



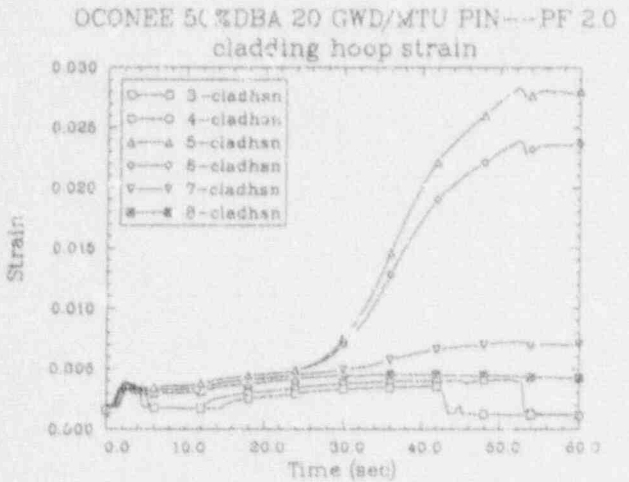
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Time (sec)
OCONEE 50%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)



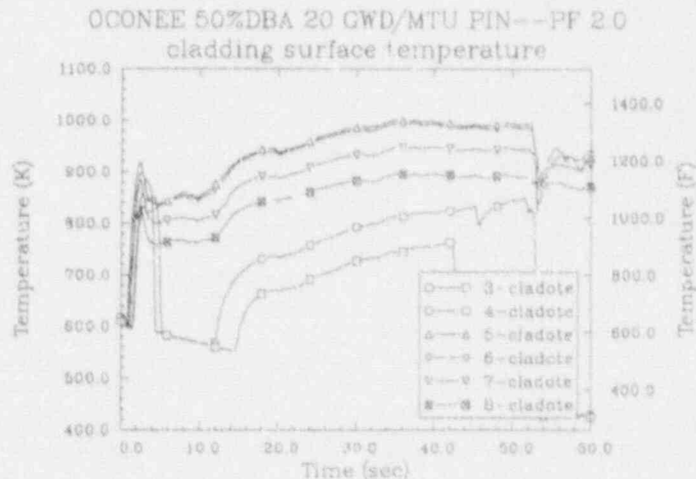
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)



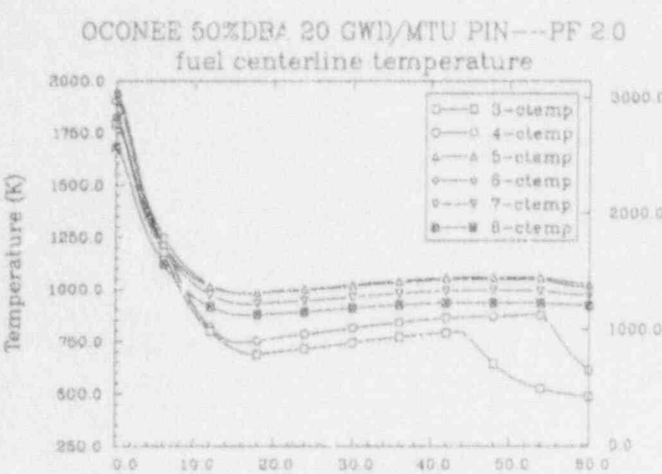
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)



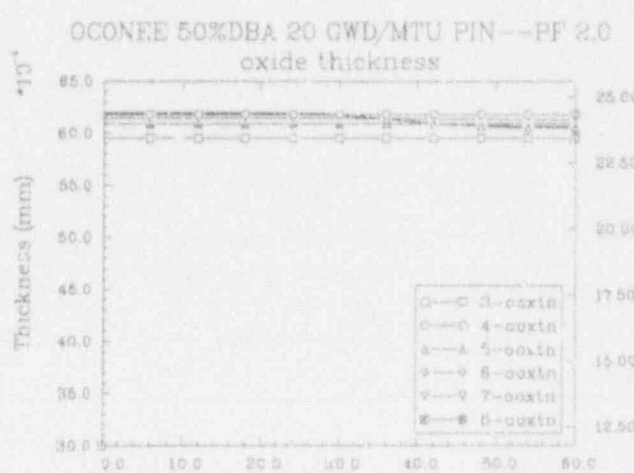
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhan
4-cladhan
5-cladhan
6-cladhan
7-cladhan
8-cladhan
Strain
Time (sec)



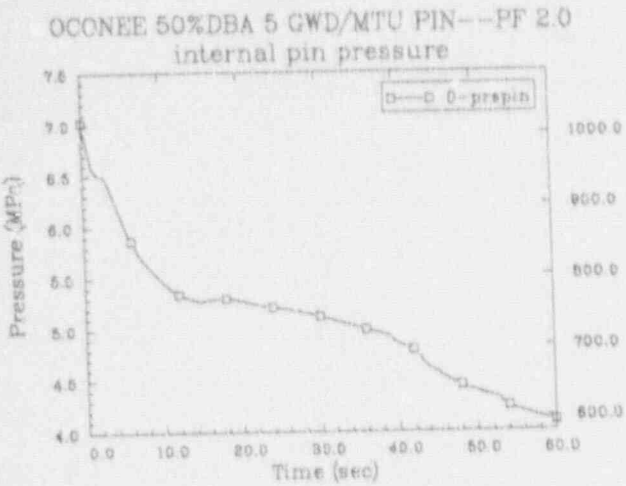
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

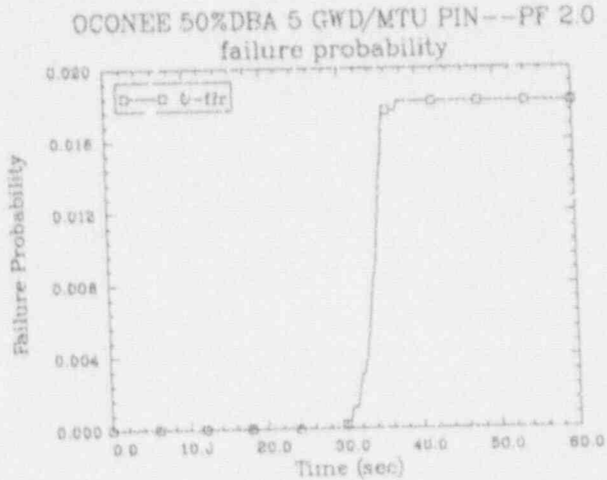


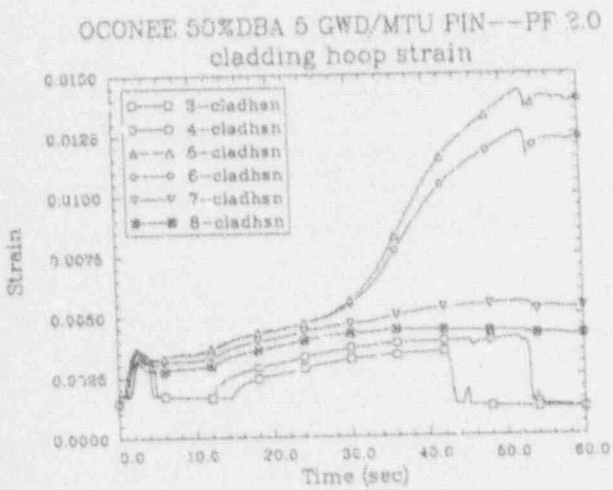
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

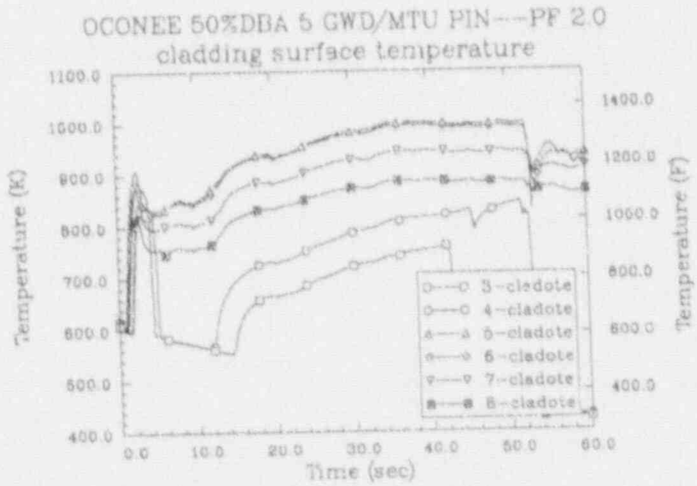


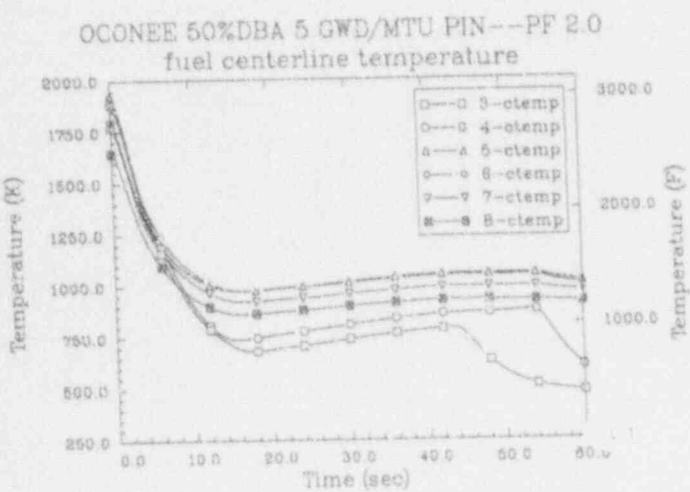
OCONEE 50%DBA 20 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
Time (sec)

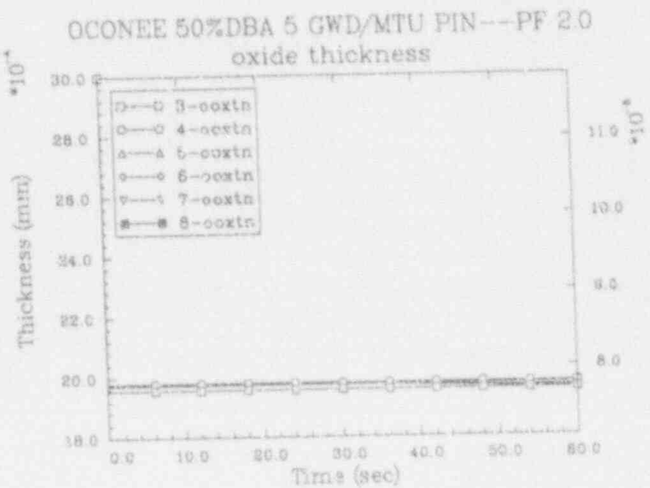

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

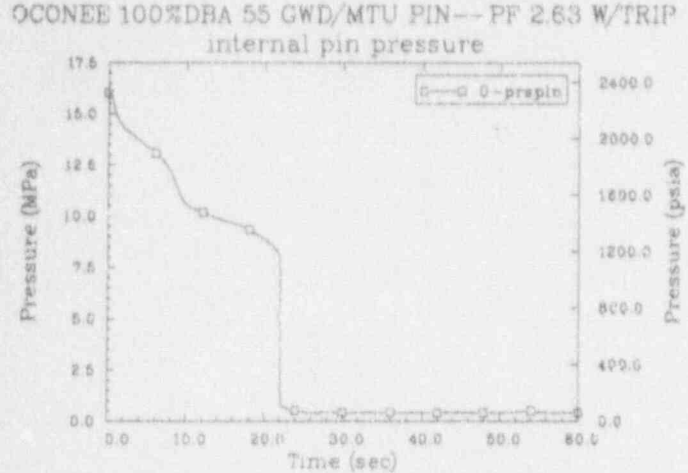

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.0
failure probability
0-flr
Failure Probability
Time (sec)

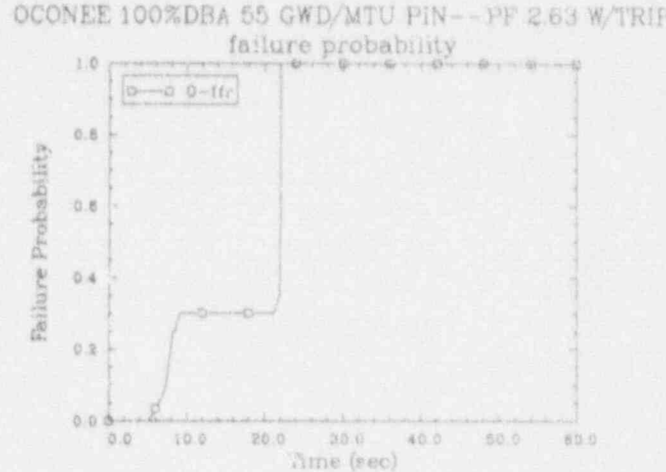

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

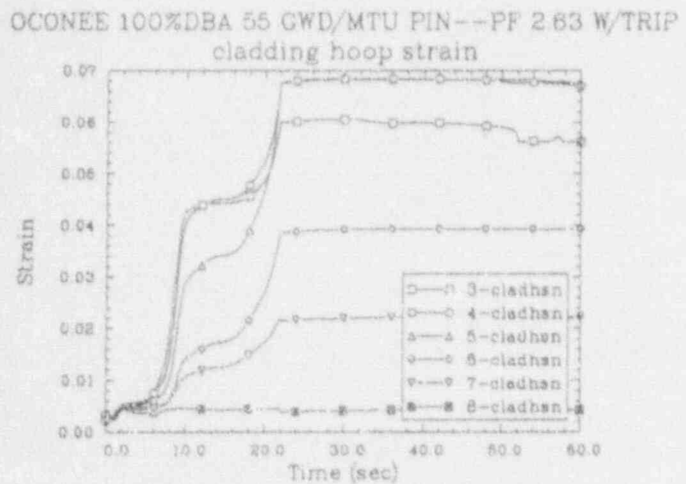

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

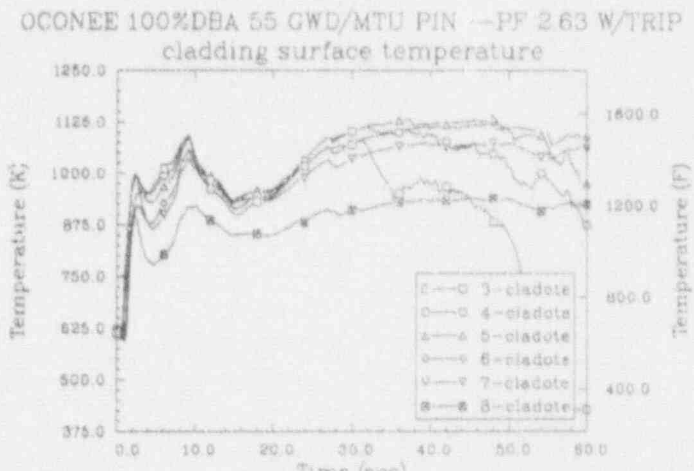

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

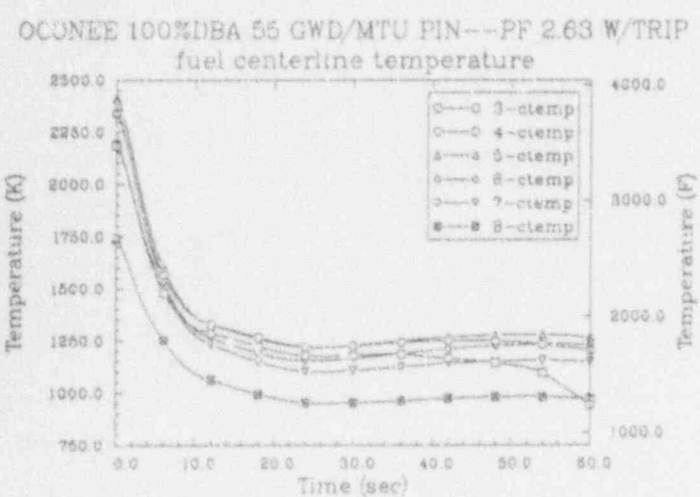

OCONEE 50%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

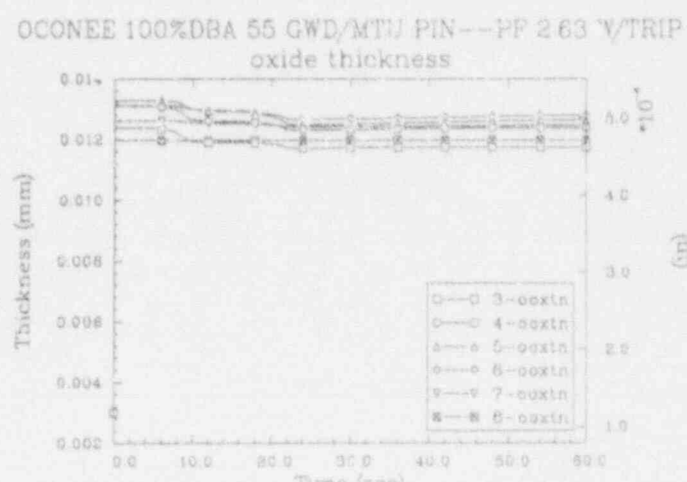

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/TRIP
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

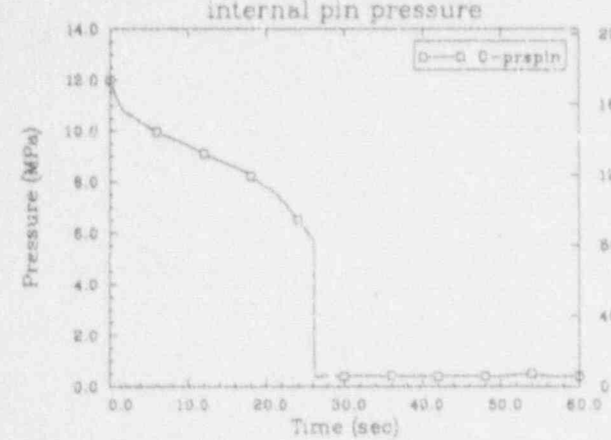

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

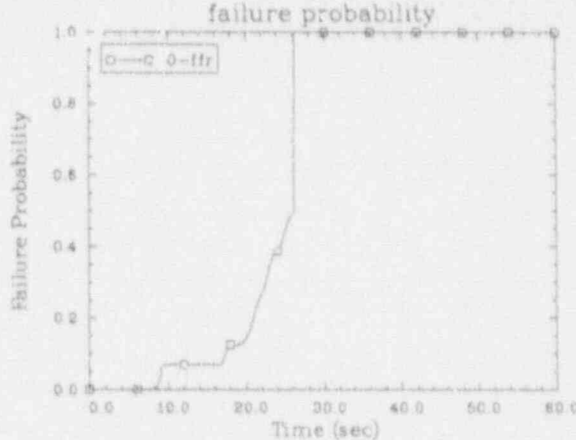

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

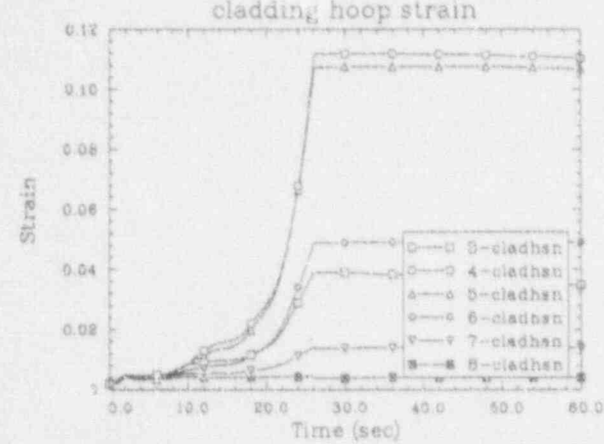
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/TRIP
internal pin pressure



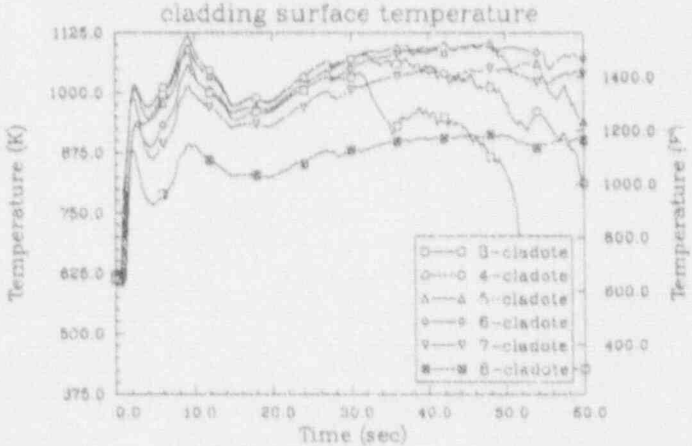
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/TRIP
failure probability



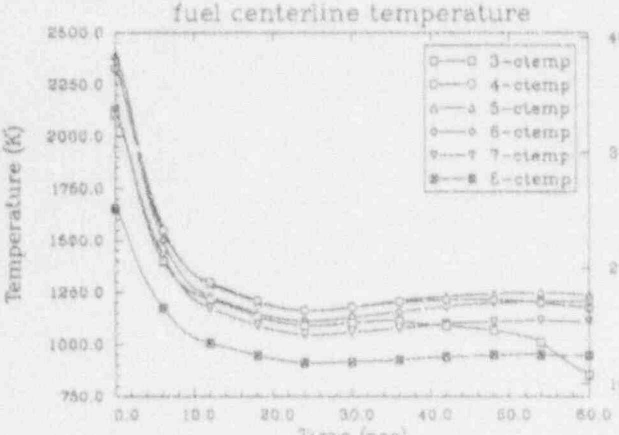
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/TRIP
cladding hoop strain



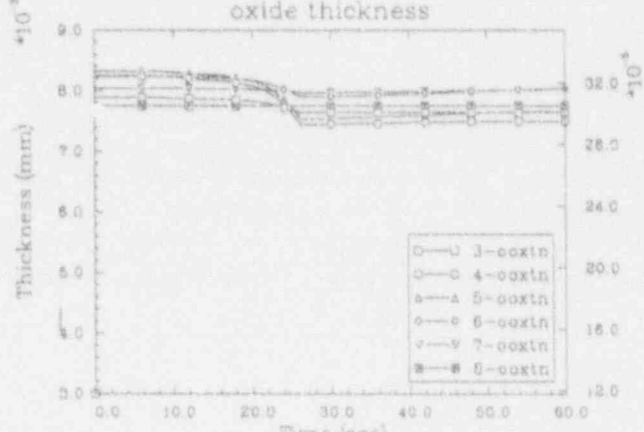
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/TRIP
cladding surface temperature



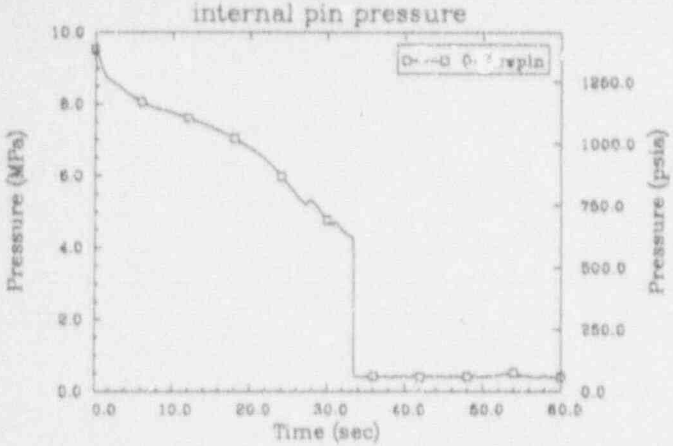
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/TRIP
fuel centerline temperature



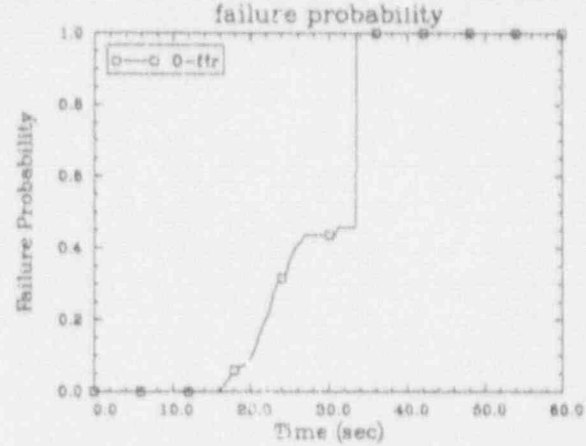
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/TRIP
oxide thickness



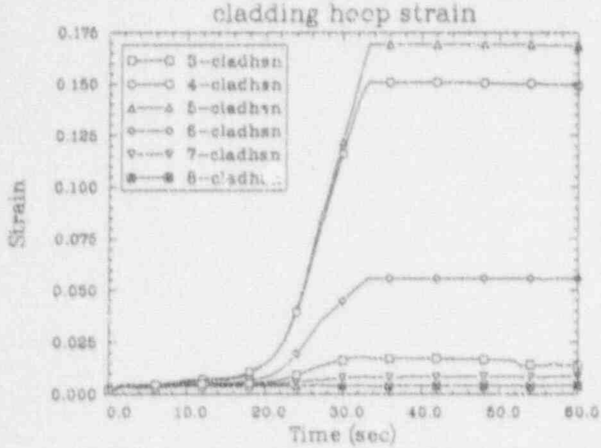
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/TRIP
internal pin pressure



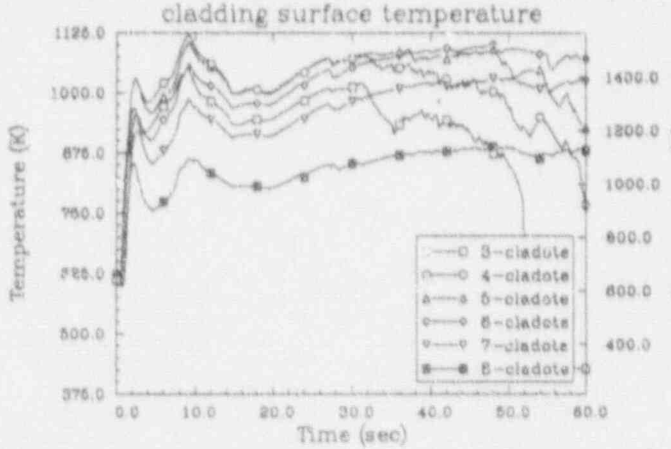
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/TRIP
failure probability



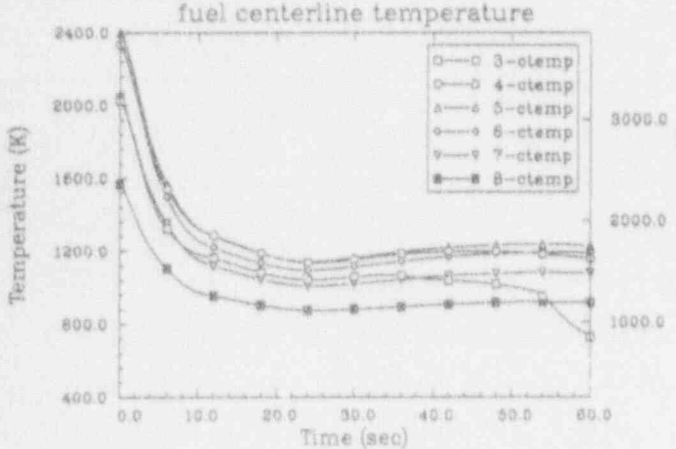
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/TRIP
cladding hoop strain



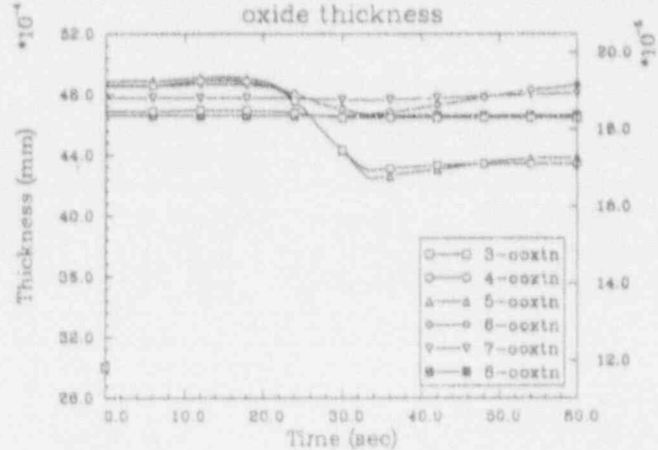
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/TRIP
cladding surface temperature

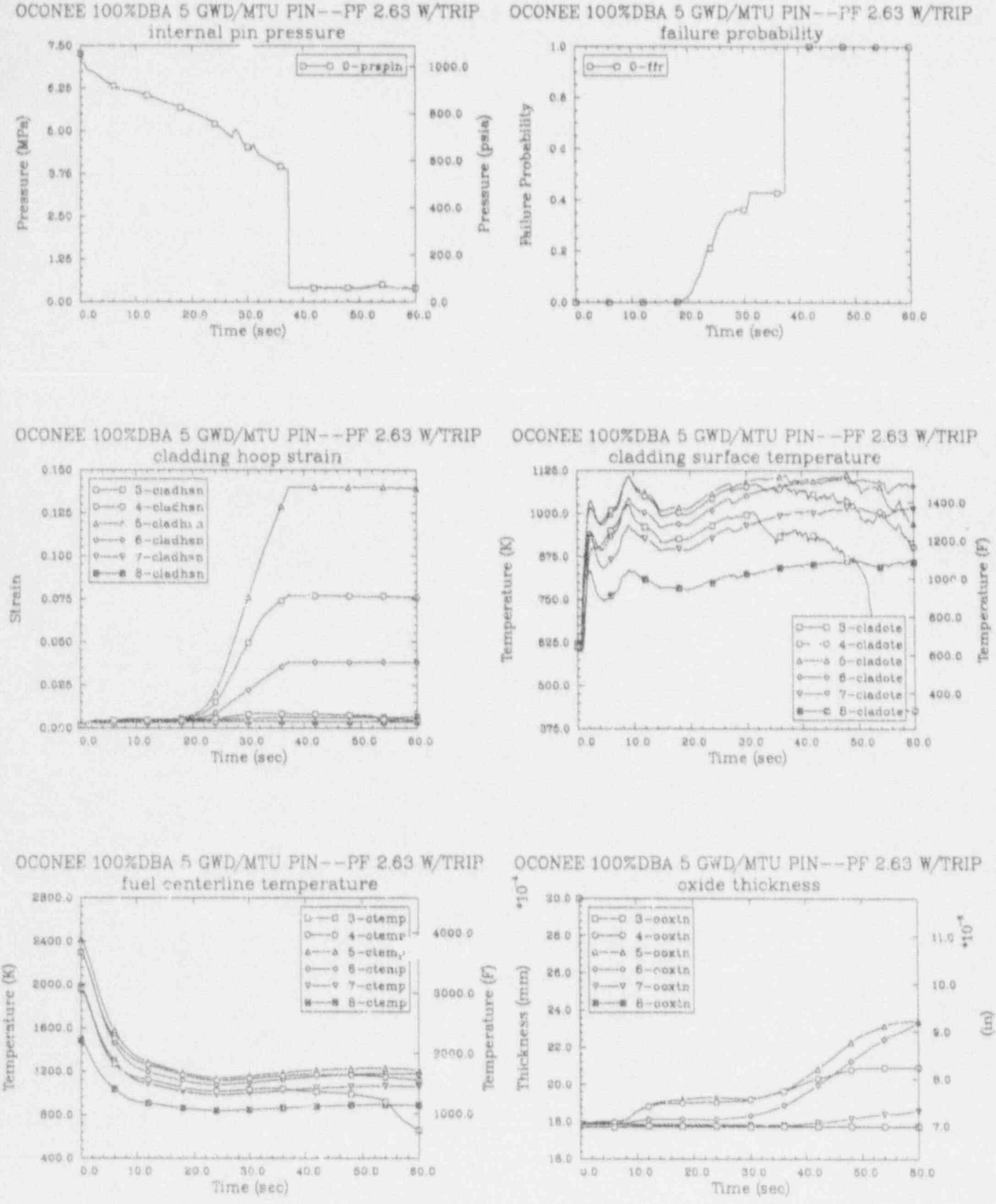


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/TRIP
fuel centerline temperature

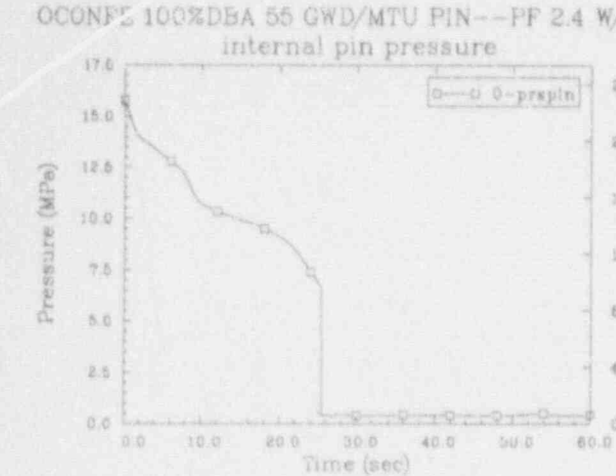


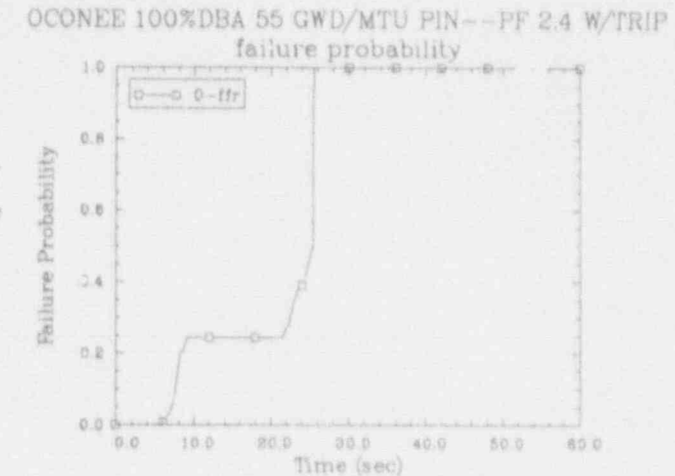
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/TRIP
oxide thickness

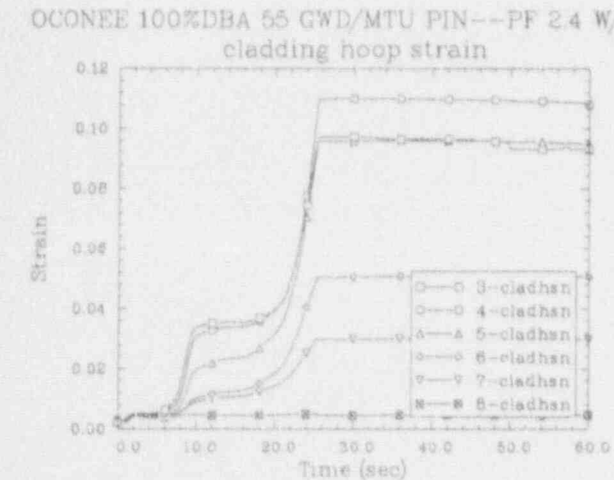


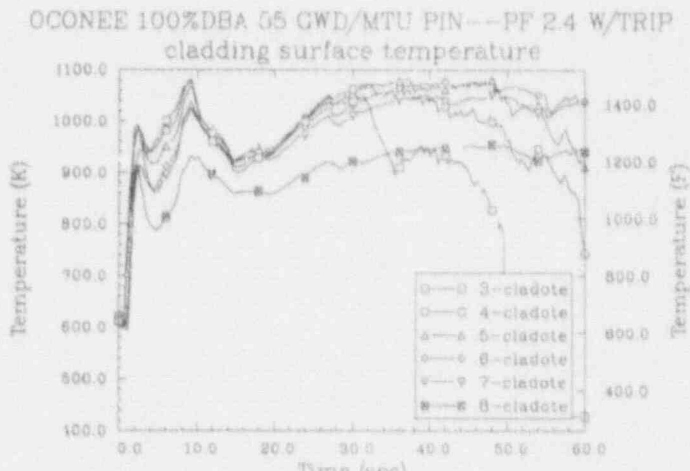


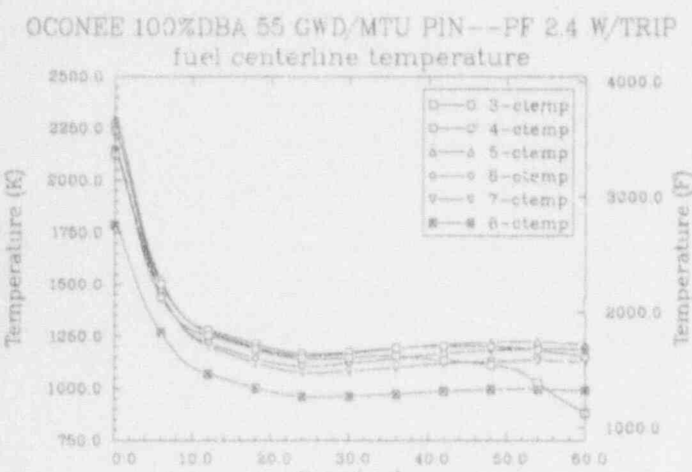
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/TRIP
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/TRIP
failure probability
Failure Probability
Time (sec)
0-ffr
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/TRIP
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/TRIP
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/TRIP
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/TRIP
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

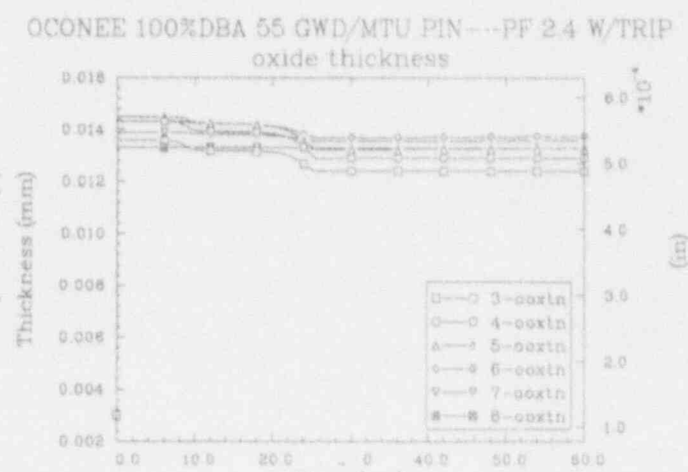

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

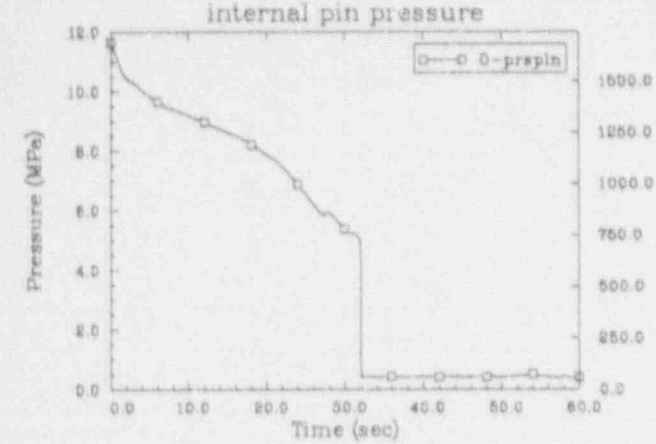

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/TRIP
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Temperature (F)
Time (sec)

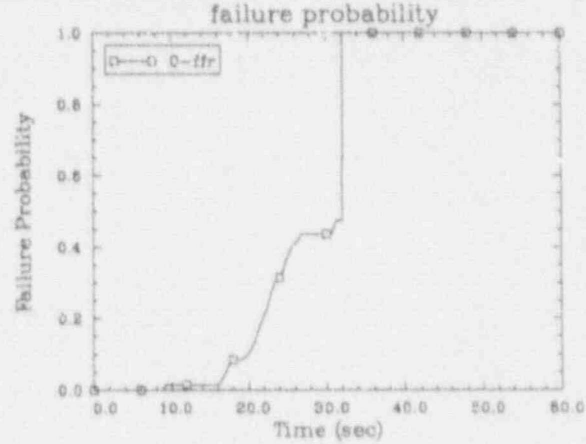

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

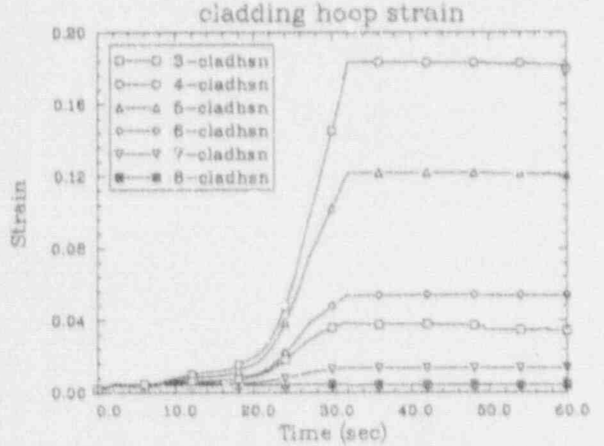
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/TRIP
internal pin pressure



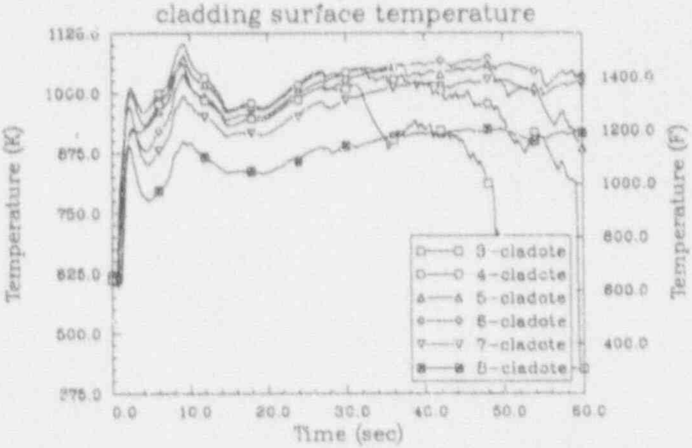
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/TRIP
failure probability



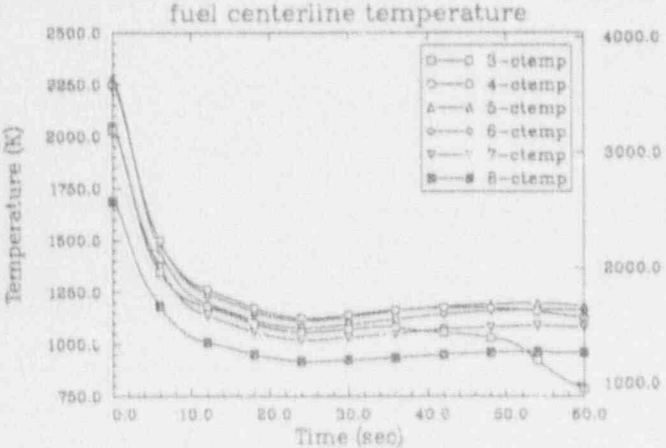
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/TRIP
cladding hoop strain



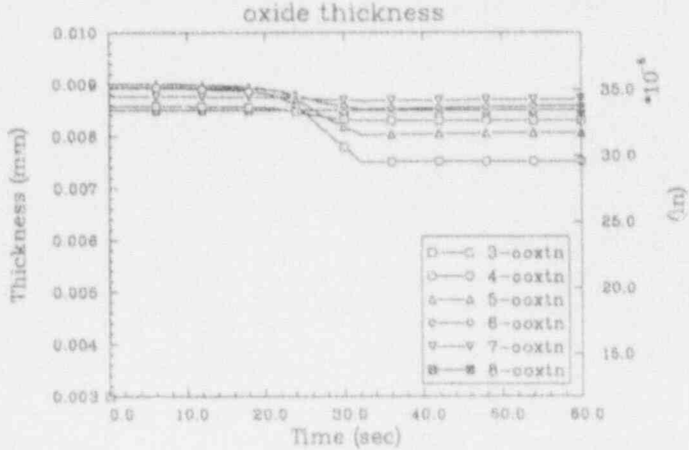
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/TRIP
cladding surface temperature



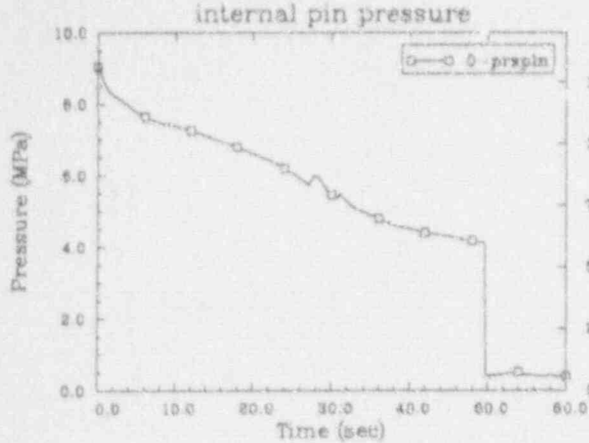
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/TRIP
fuel centerline temperature



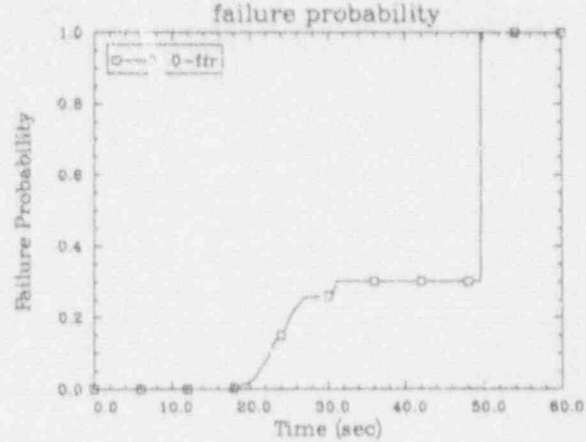
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/TRIP
oxide thickness



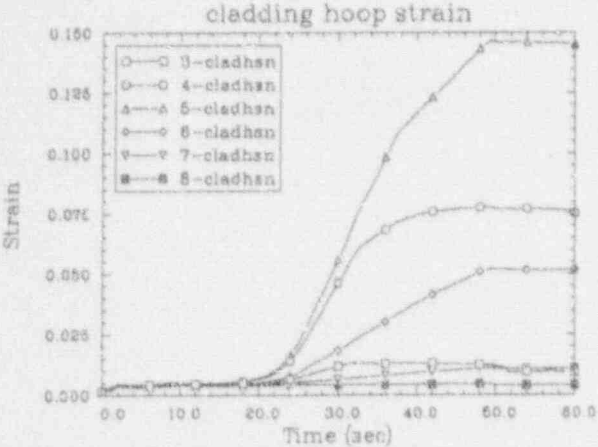
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/TRIP
internal pin pressure



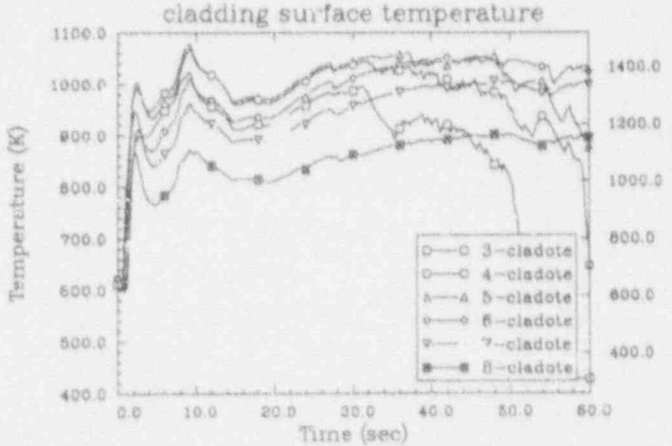
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/TRIP
failure probability



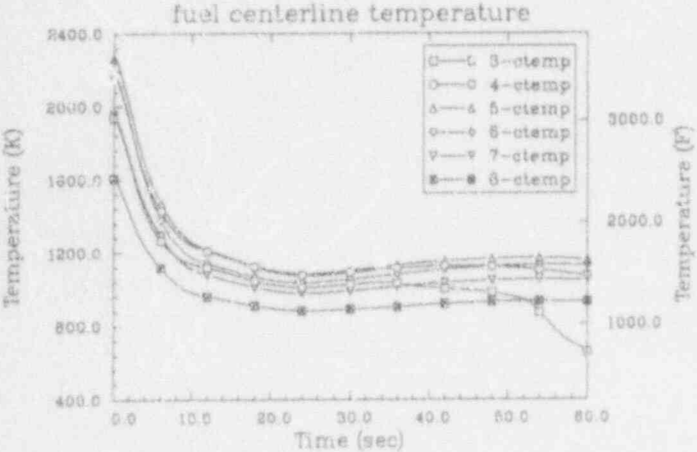
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/TRIP
cladding hoop strain



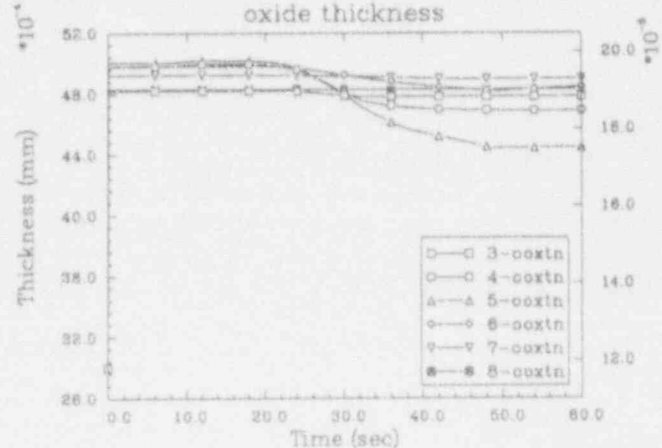
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/TRIP
cladding surface temperature

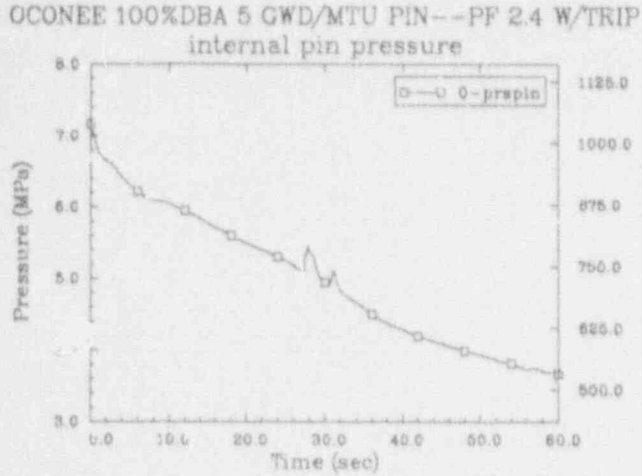


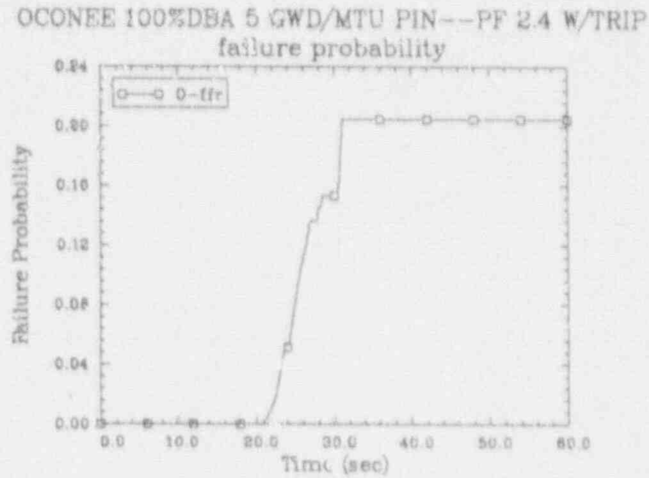
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/TRIP
fuel centerline temperature

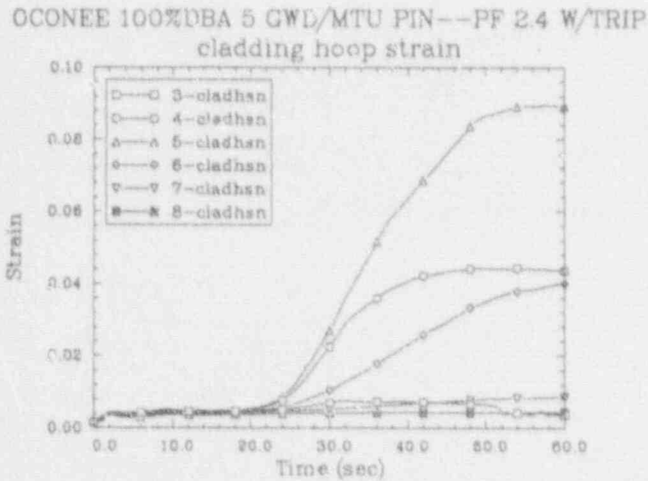


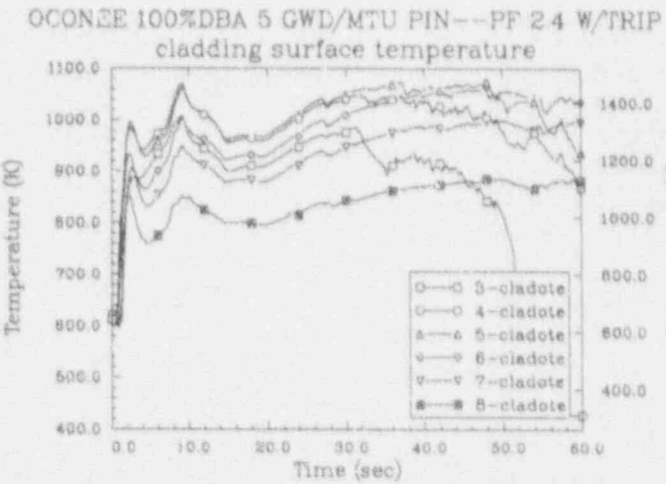
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/TRIP
oxide thickness

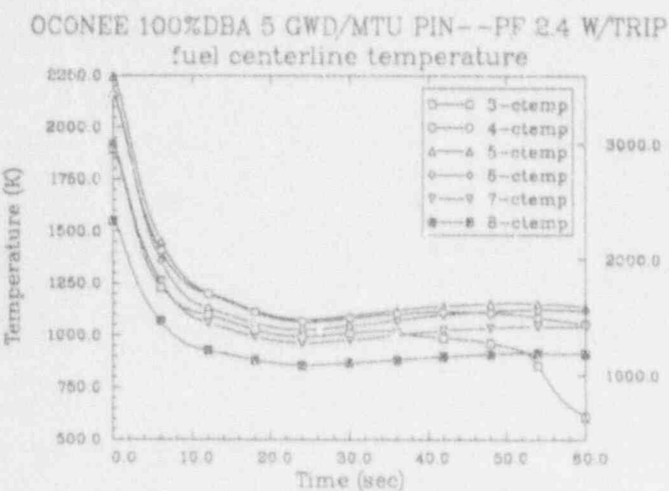


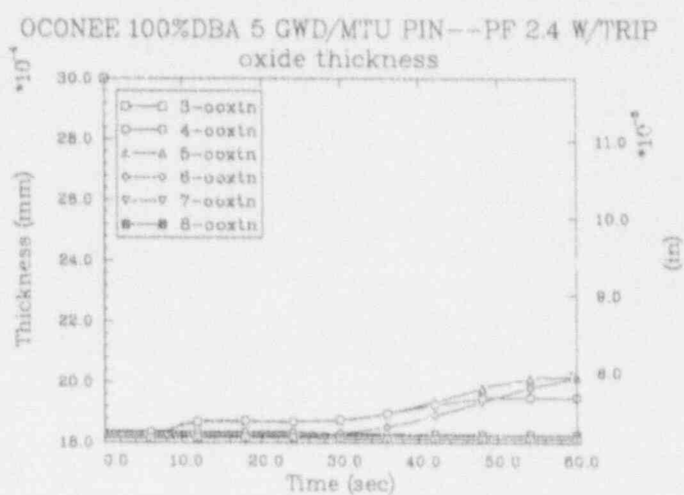

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

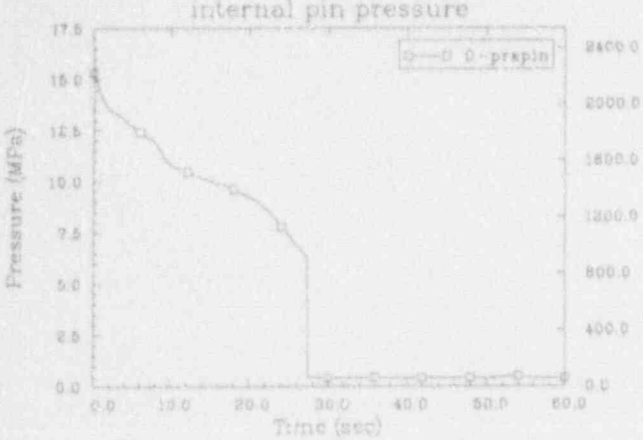

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

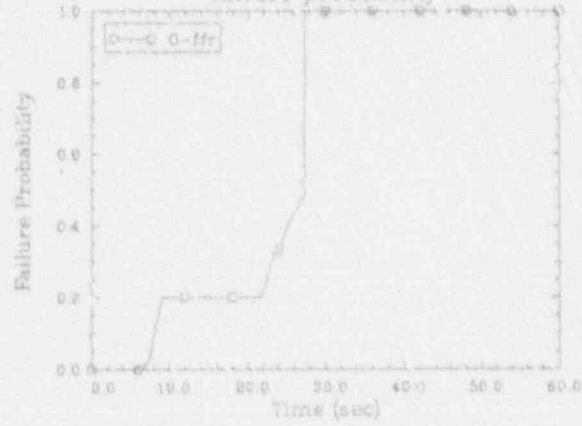

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

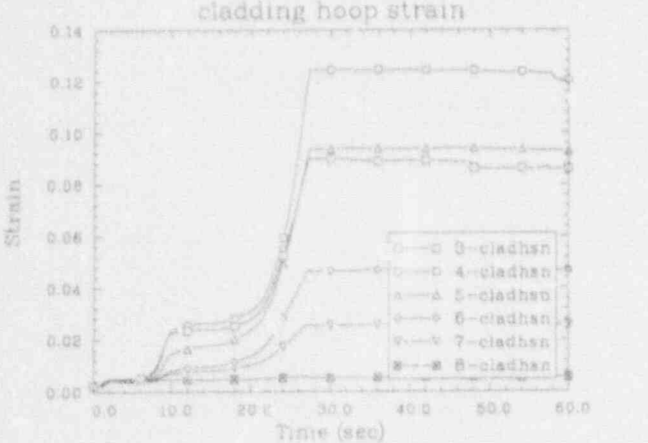
OCONEE 100%DBA 55 GWD/MTU PIN---PF 2.2 W/TRIP
internal pin pressure



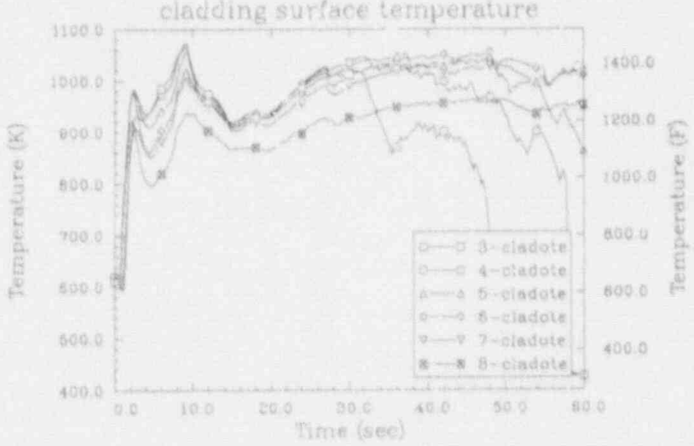
OCONEE 100%DBA 55 GWD/MTU PIN---PF 2.2 W/TRIP
failure probability



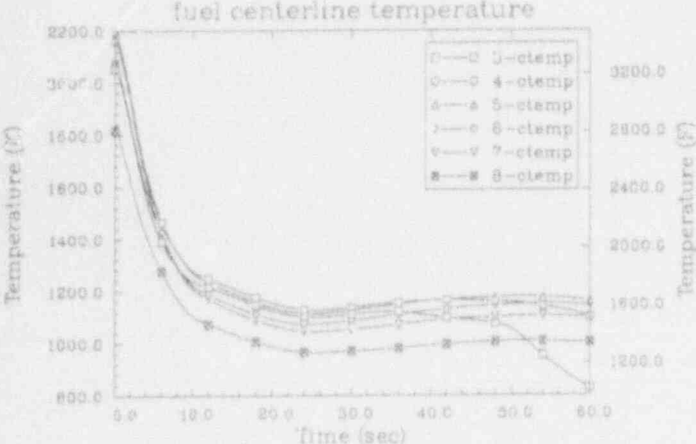
OCONEE 100%DBA 55 GWD/MTU PIN---PF 2.2 W/TRIP
cladding hoop strain



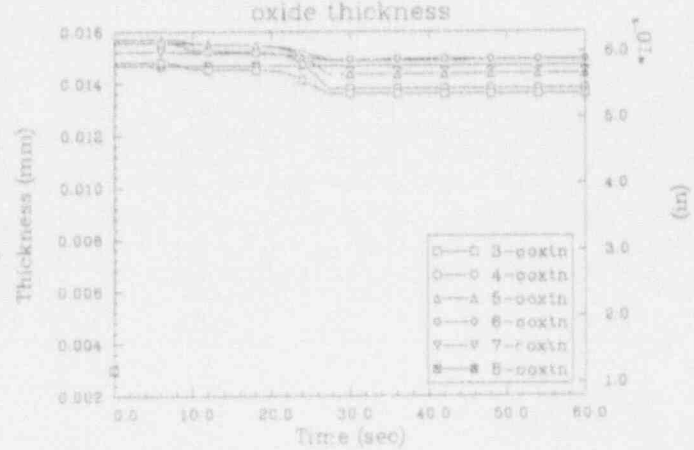
OCONEE 100%DBA 55 GWD/MTU PIN---PF 2.2 W/TRIP
cladding surface temperature

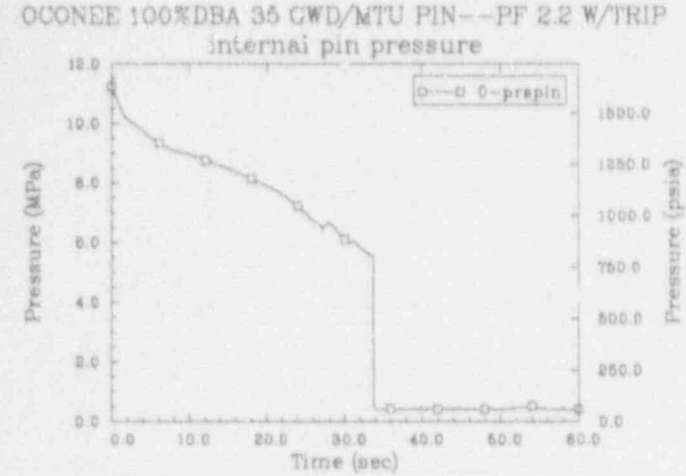


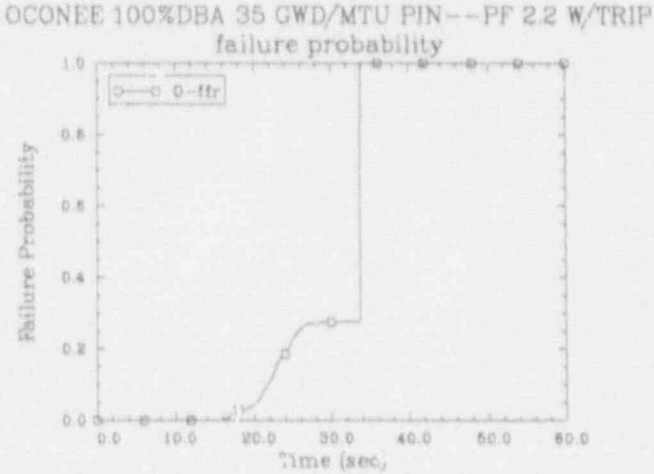
OCONEE 100%DBA 55 GWD/MTU PIN---PF 2.2 W/TRIP
fuel centerline temperature

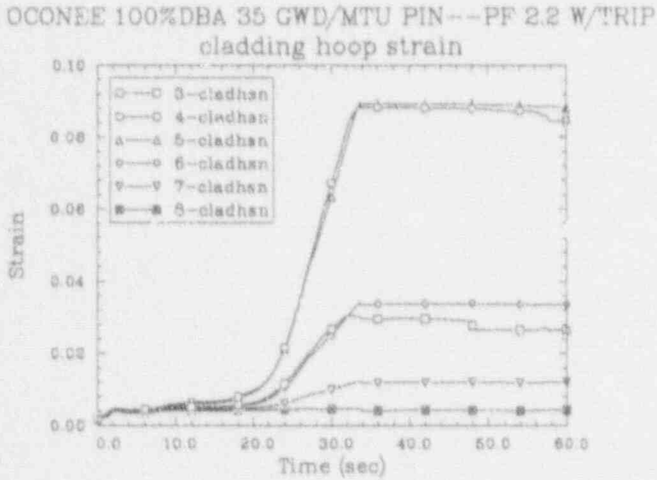


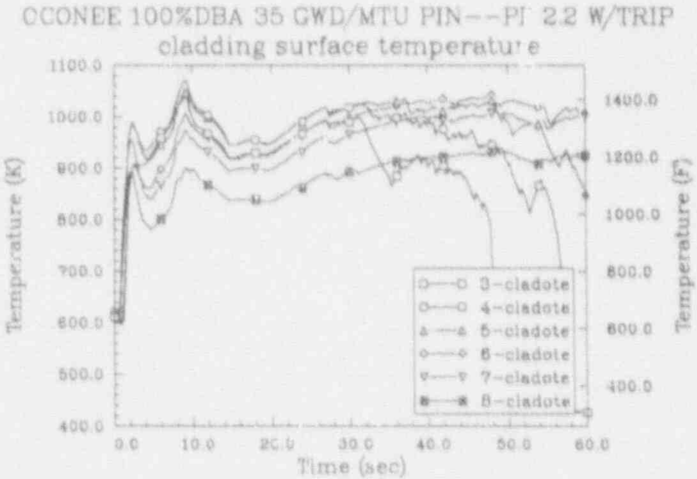
OCONEE 100%DBA 55 GWD/MTU PIN---PF 2.2 W/TRIP
oxide thickness

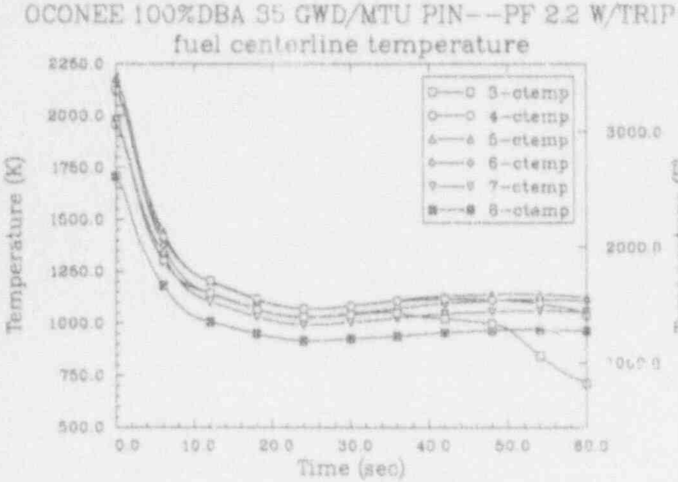


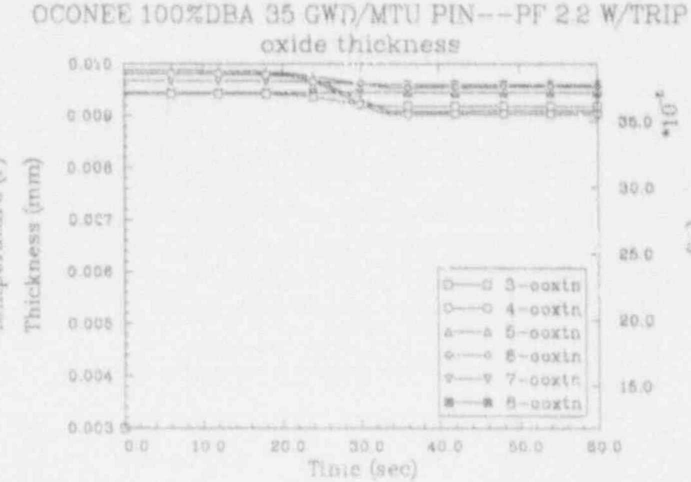

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

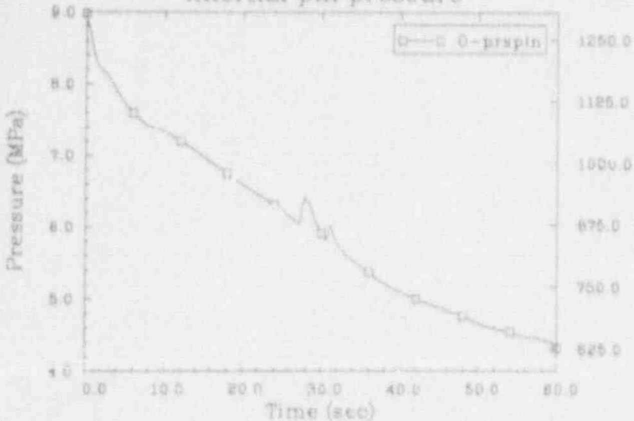

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

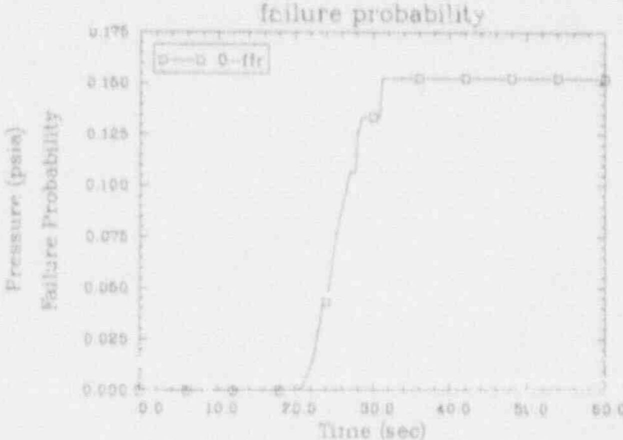

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/TRIP
oxide thickness
3-eoxtn
4-eoxtn
5-eoxtn
6-eoxtn
7-eoxtn
8-eoxtn
Thickness (mm)
(in)
Time (sec)

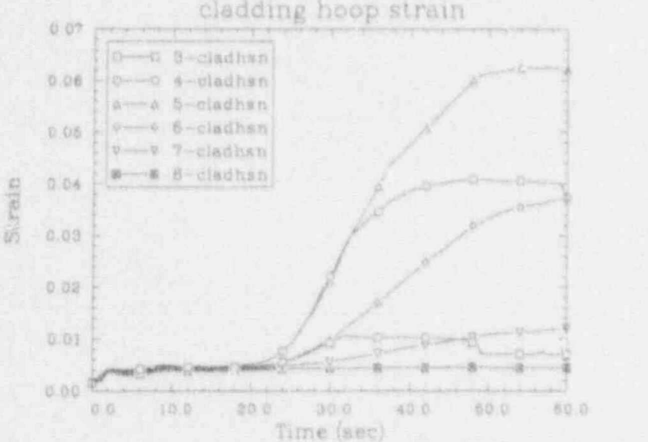
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/TRIP
internal pin pressure



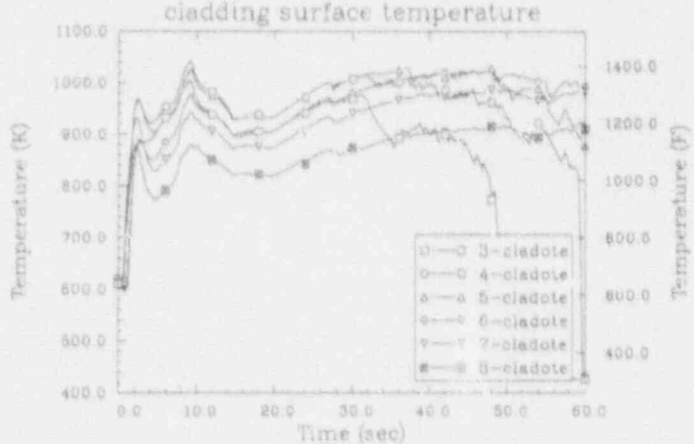
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/TRIP
failure probability



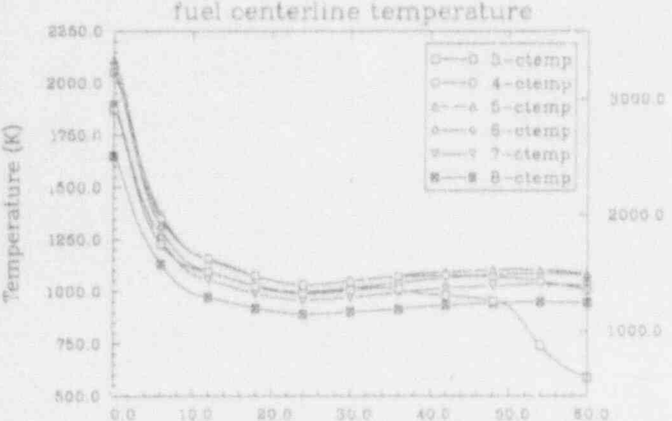
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/TRIP
cladding hoop strain



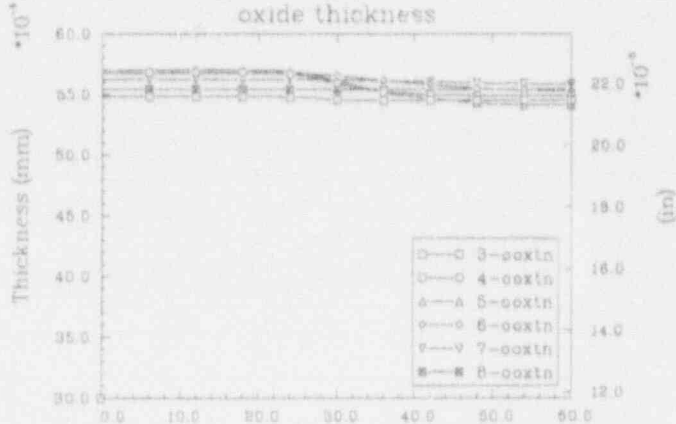
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/TRIP
cladding surface temperature

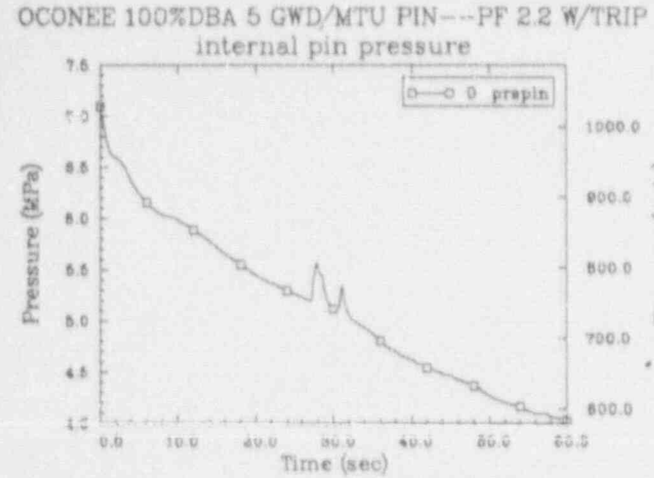


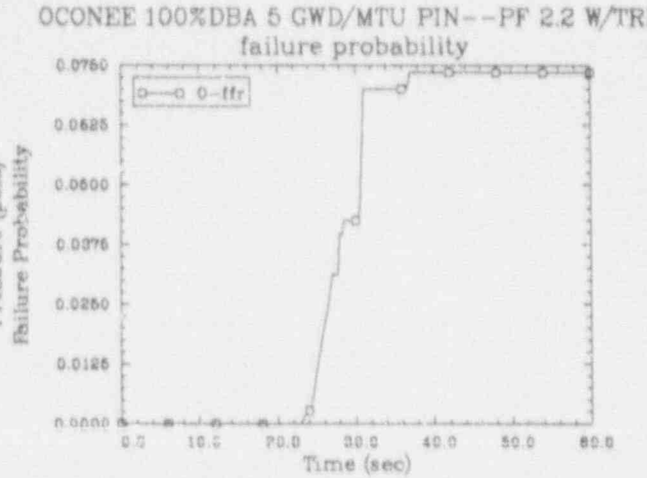
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/TRIP
fuel centerline temperature

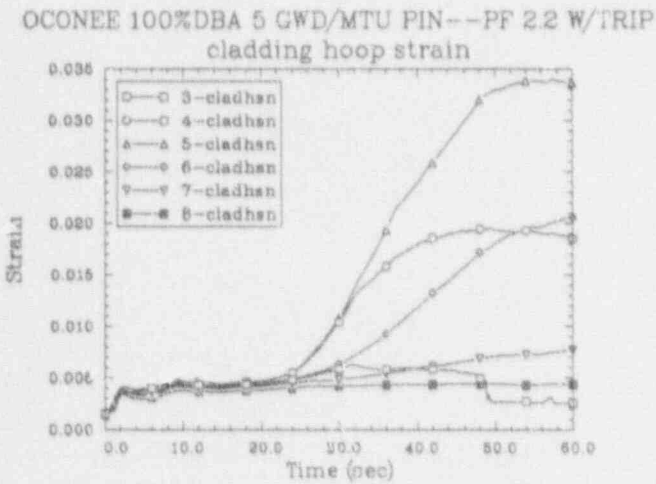


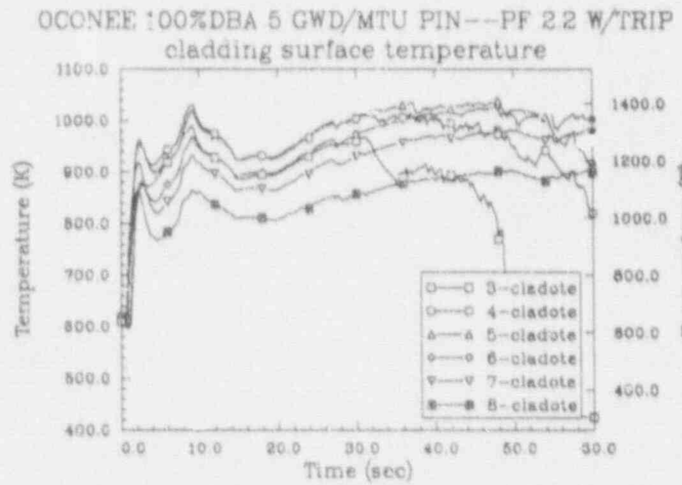
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/TRIP
oxide thickness

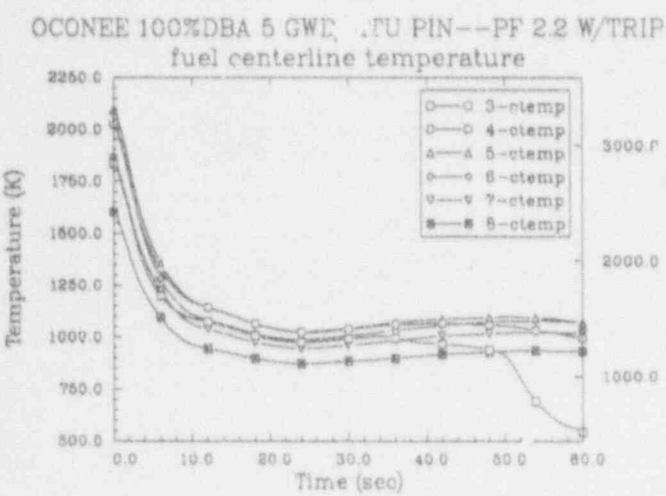


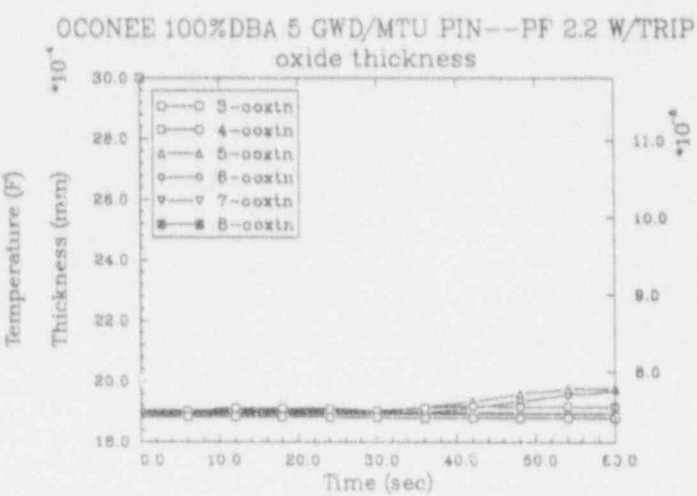

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/TRIP
internal pin pressure
0 prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

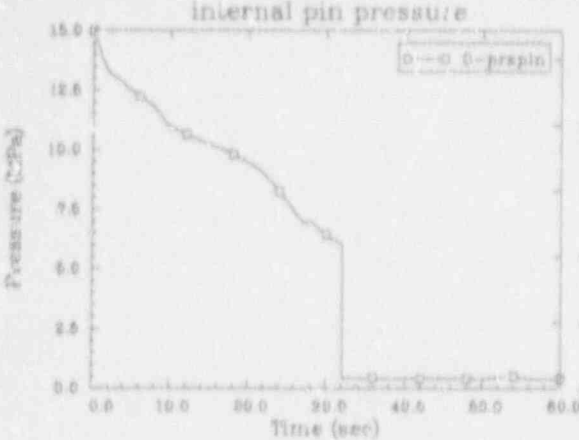

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

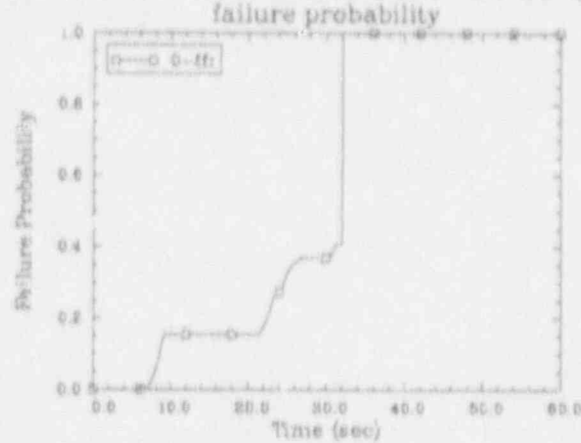

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

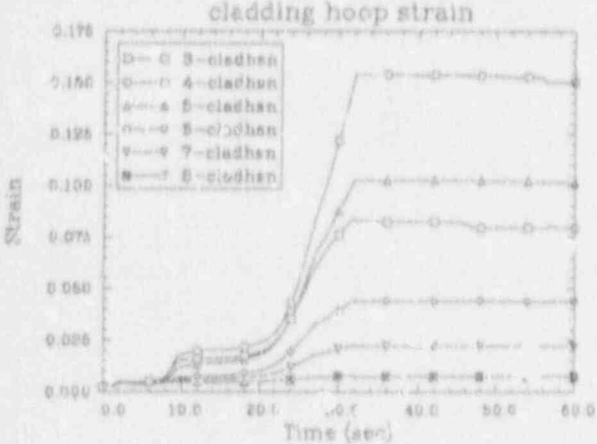
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/TRIP
internal pin pressure



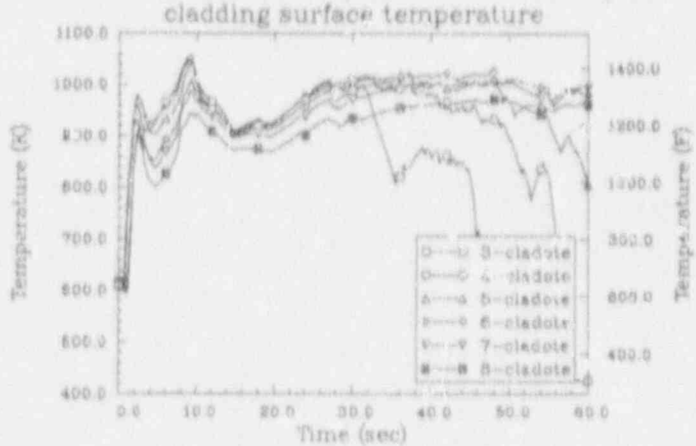
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/TRIP
failure probability



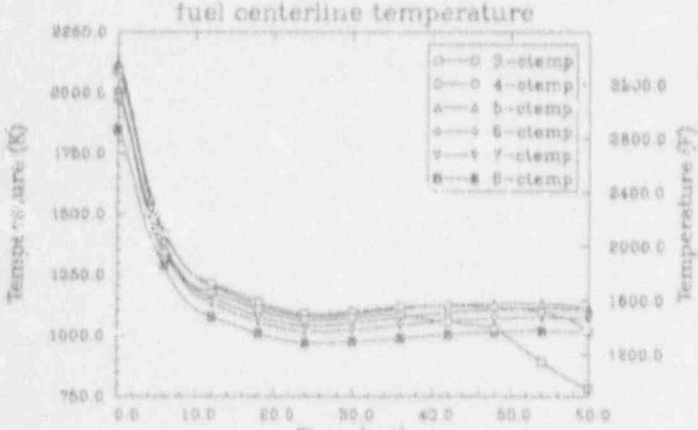
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/TRIP
cladding hoop strain



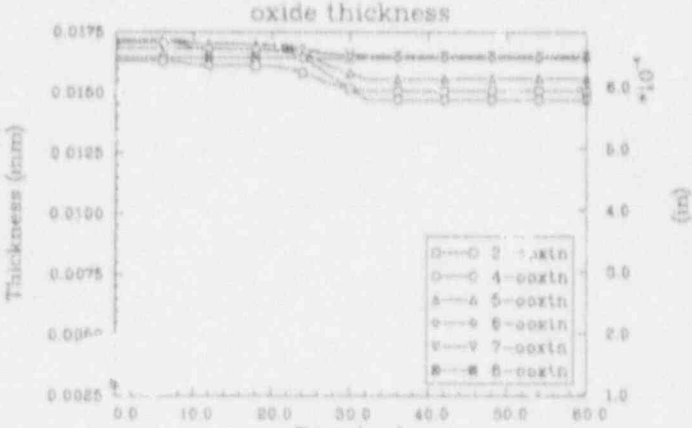
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/TRIP
cladding surface temperature

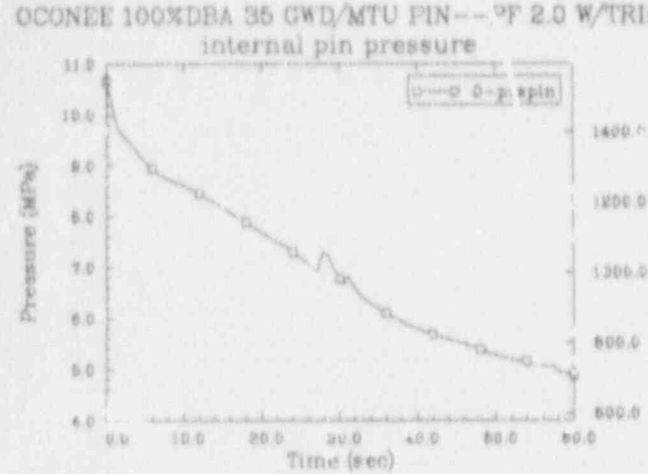


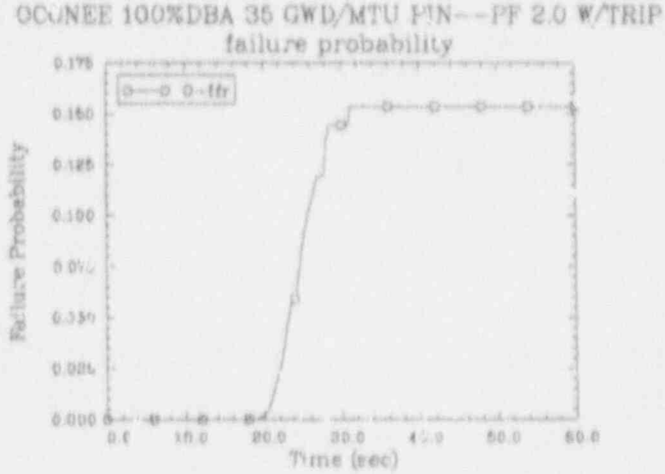
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/TRIP
fuel centerline temperature

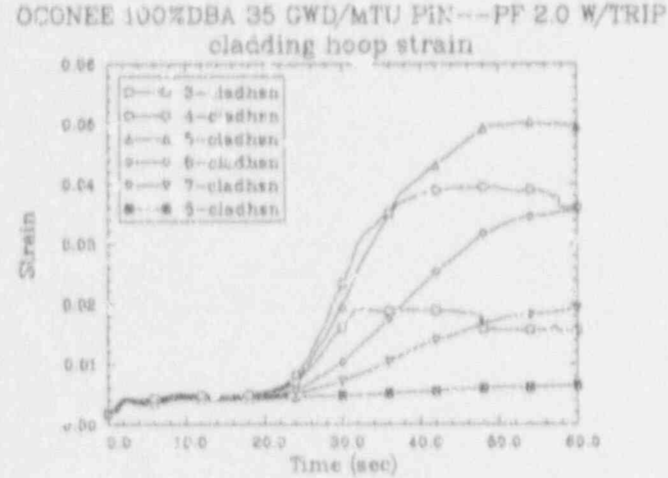


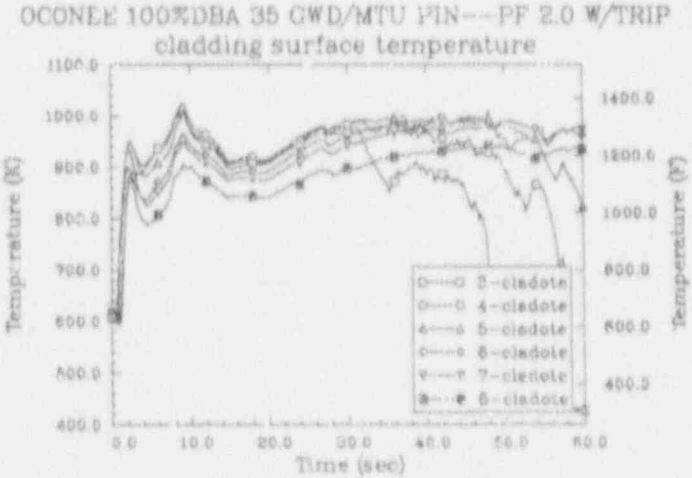
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/TRIP
oxide thickness

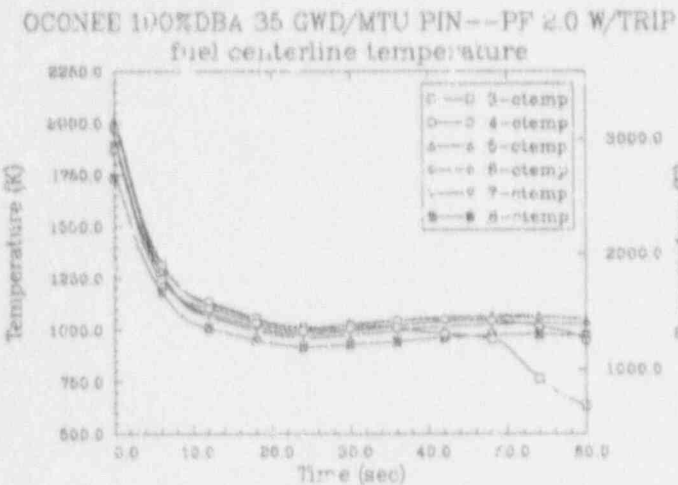


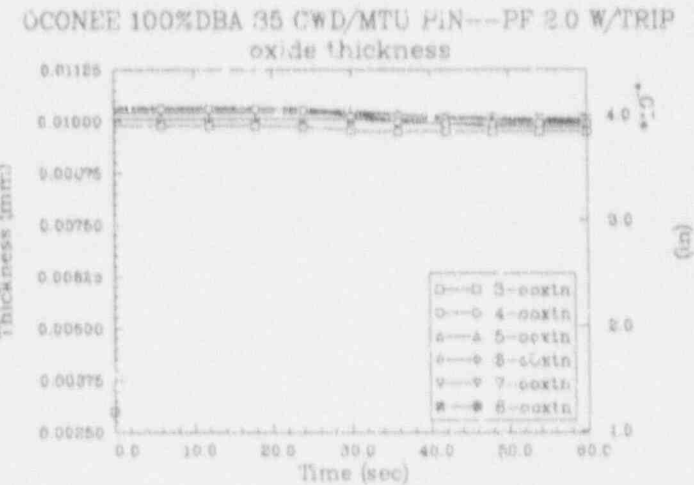

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/TRIP
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/TRIP
failure probability
Failure Probability
Time (sec)

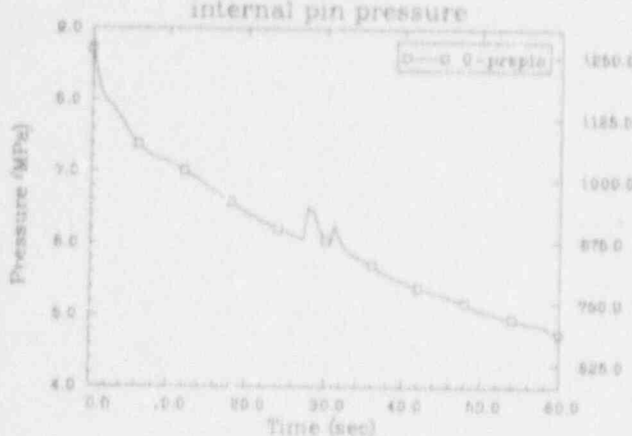

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/TRIP
cladding hoop strain
Strain
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/TRIP
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)

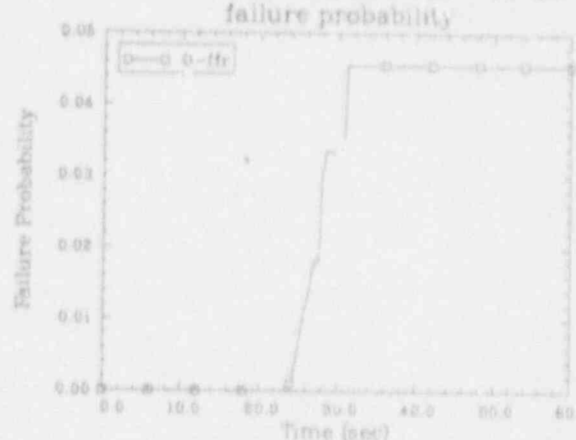

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/TRIP
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/TRIP
oxide thickness
Time (sec)

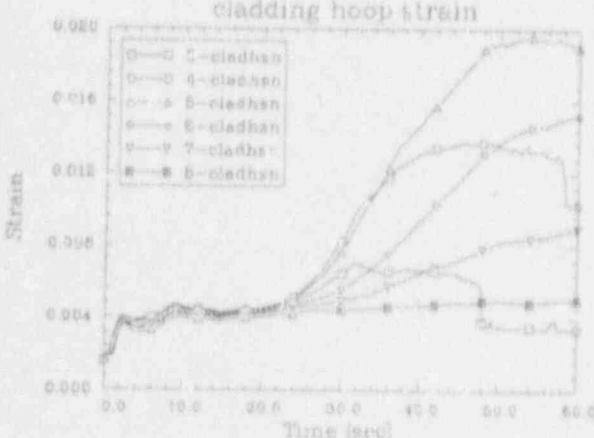
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/TRIP
internal pin pressure



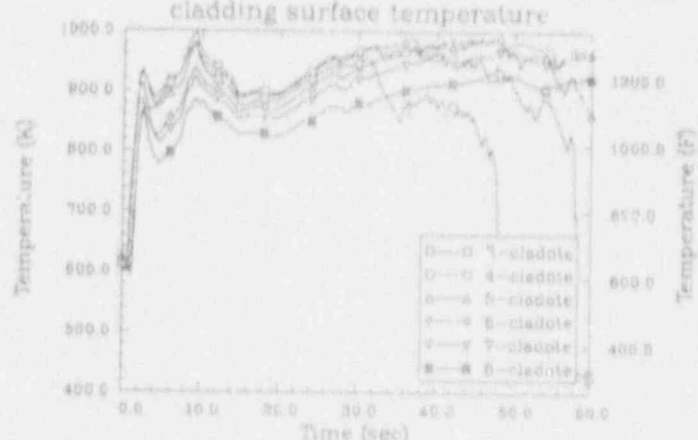
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/TRIP
failure probability



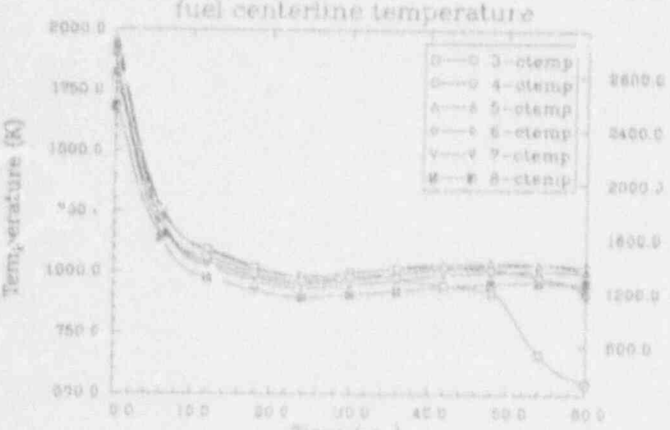
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/TRIP
cladding hoop strain



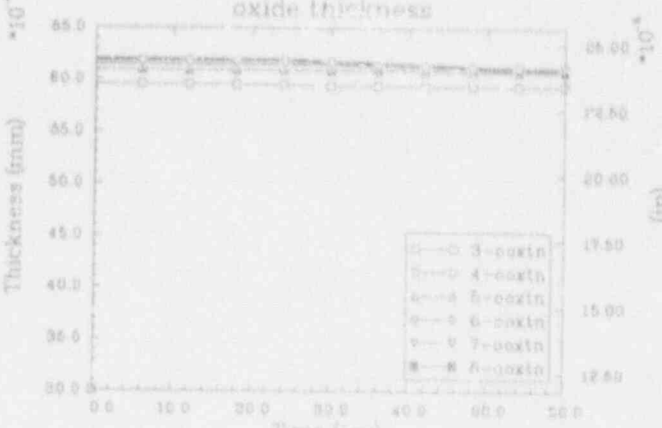
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/TRIP
cladding surface temperature

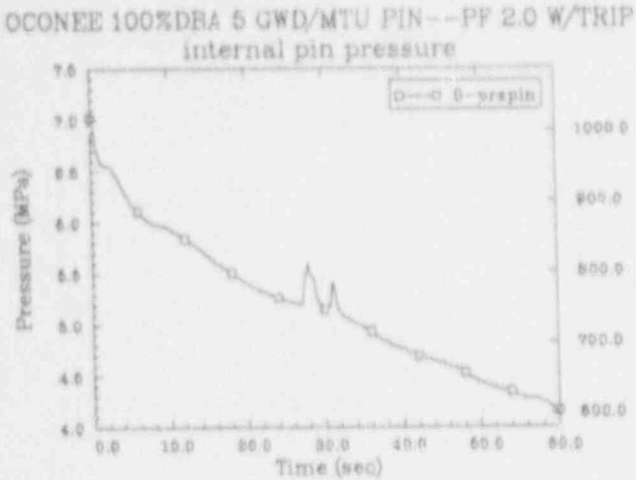


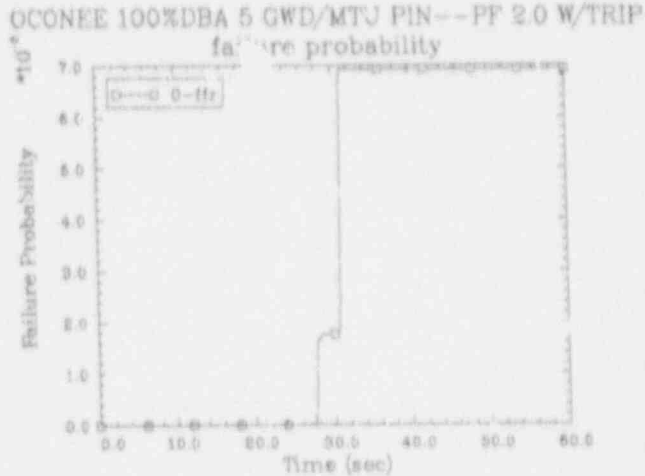
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/TRIP
fuel centerline temperature

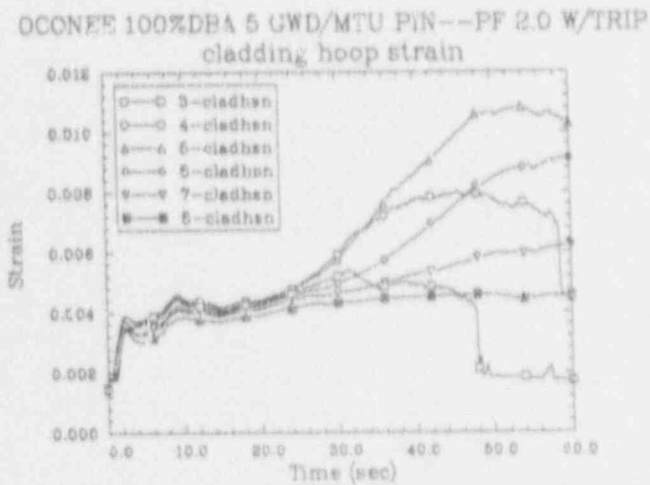


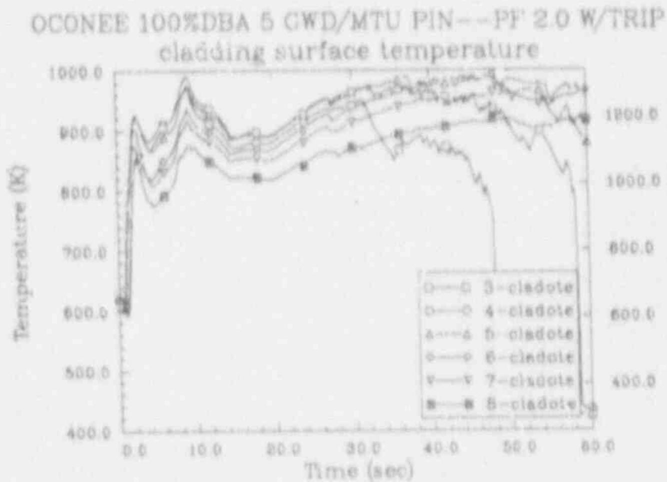
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/TRIP
oxide thickness

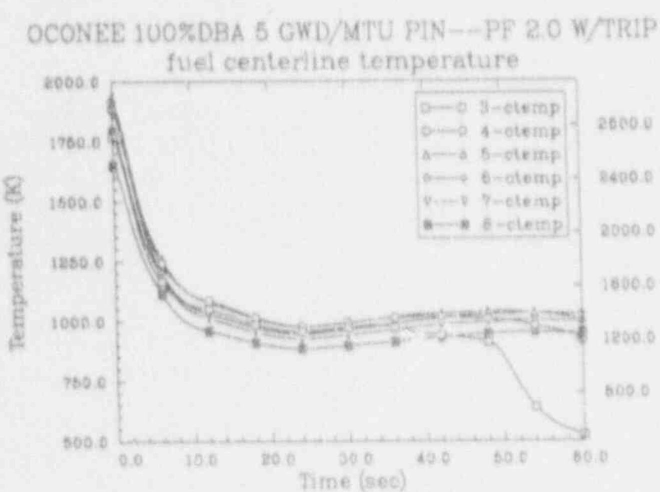


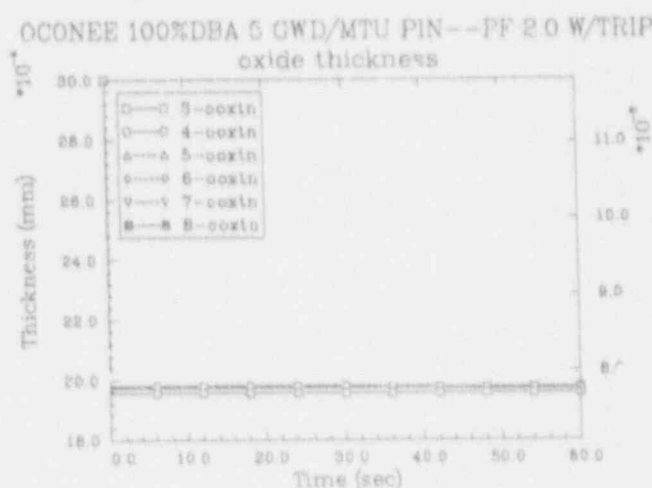

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

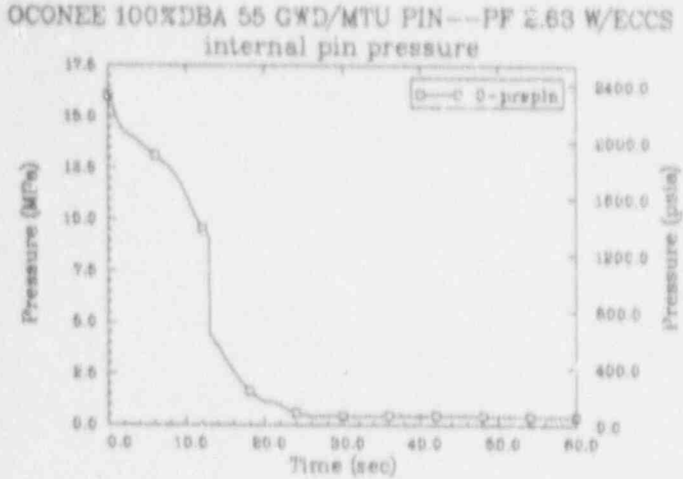

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

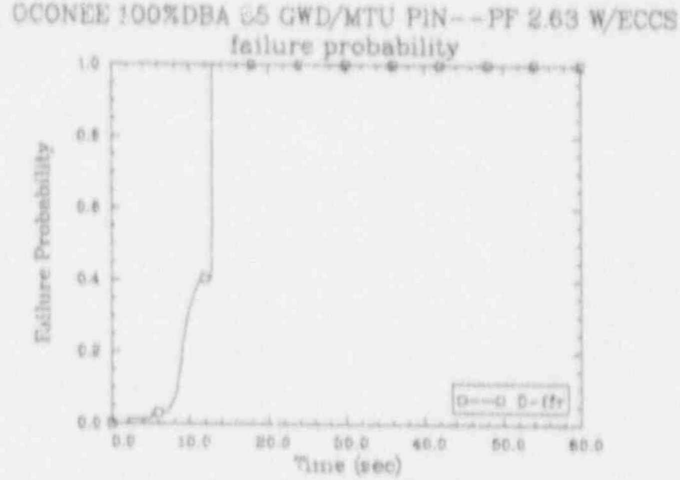

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

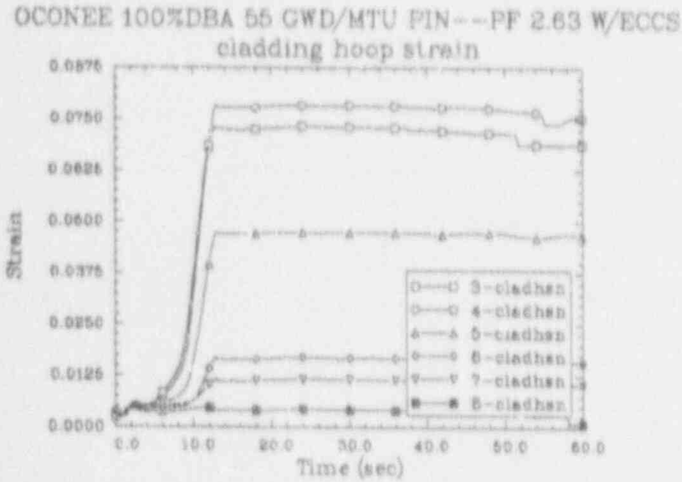

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

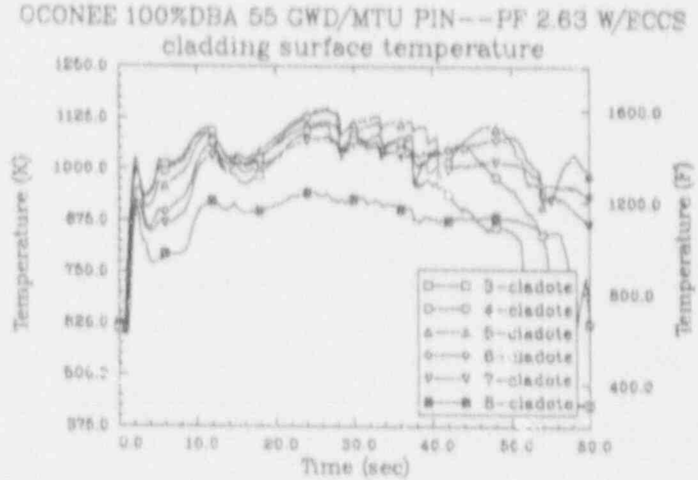

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

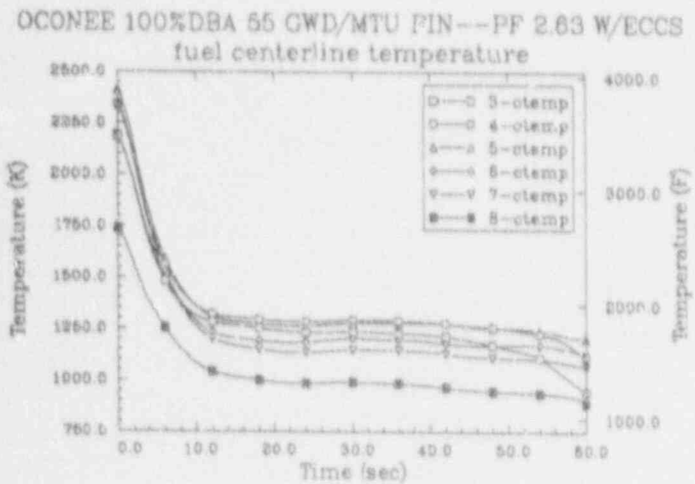

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/TRIP
oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
Thickness (mm)
(in)
Time (sec)

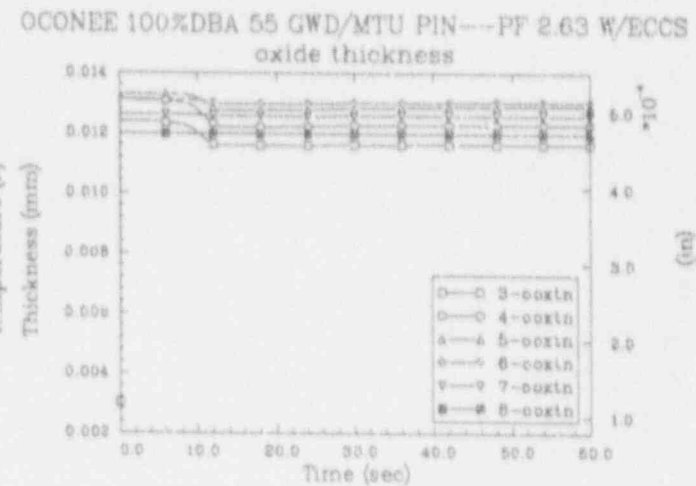

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

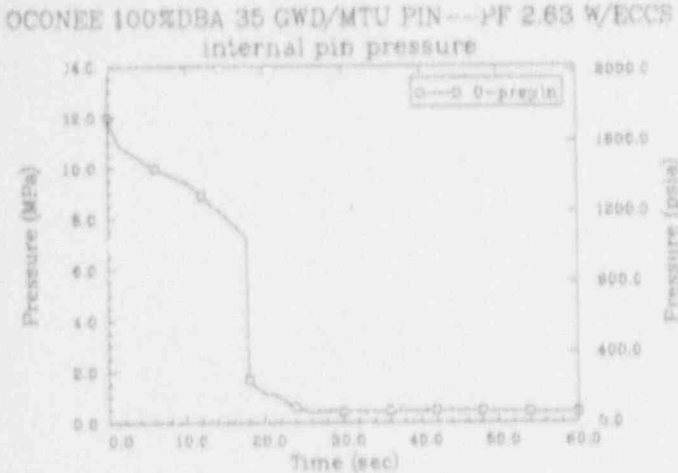

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability
Failure Probability
0-ffr
Time (sec)

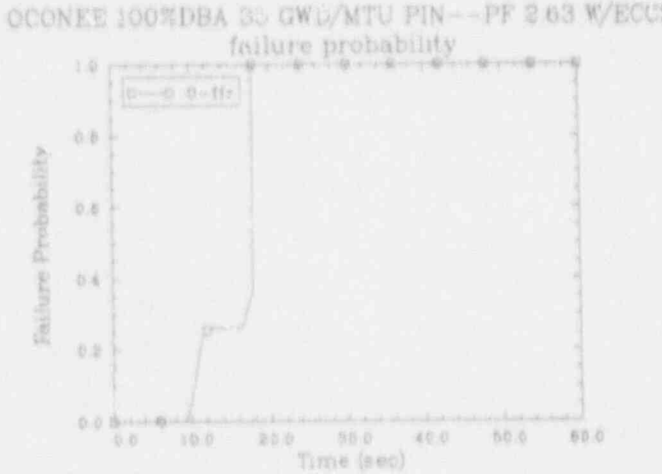

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/ECCS
cladding hoop strain
Strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Time (sec)

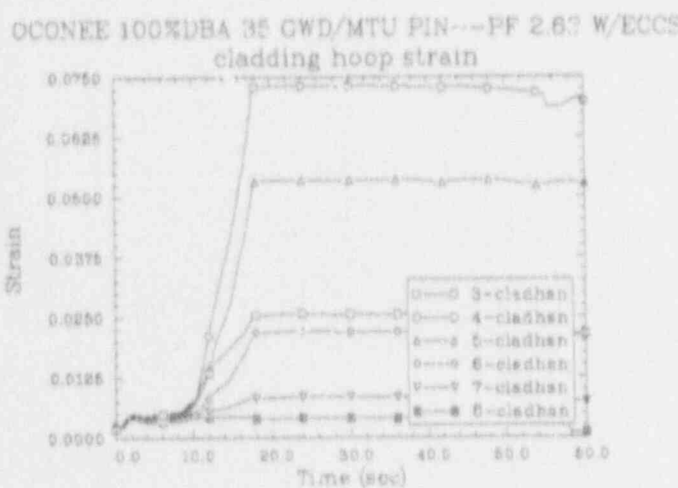

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/ECCS
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Time (sec)

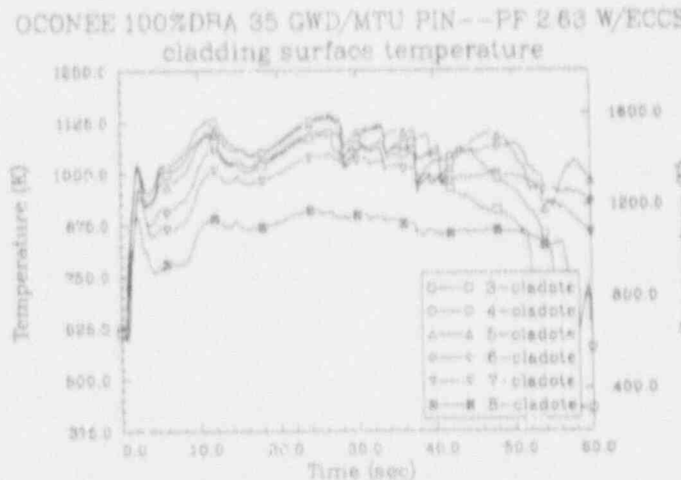

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

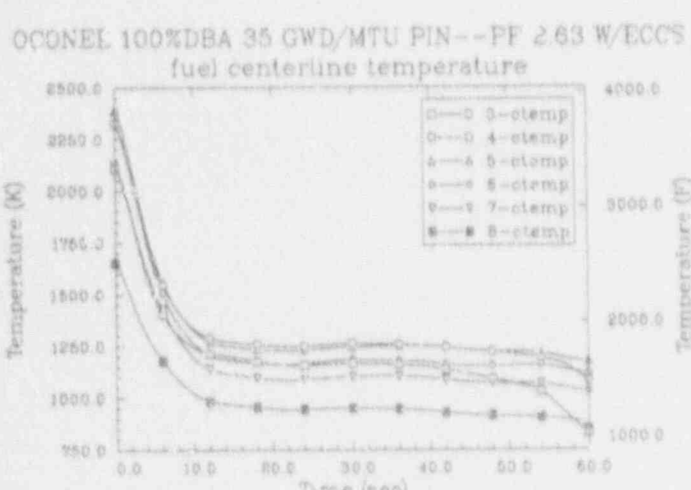

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/ECCS
oxide thickness
Thickness (mm)
(in)
3-cooxtn
4-cooxtn
5-cooxtn
6-cooxtn
7-cooxtn
8-cooxtn
Time (sec)

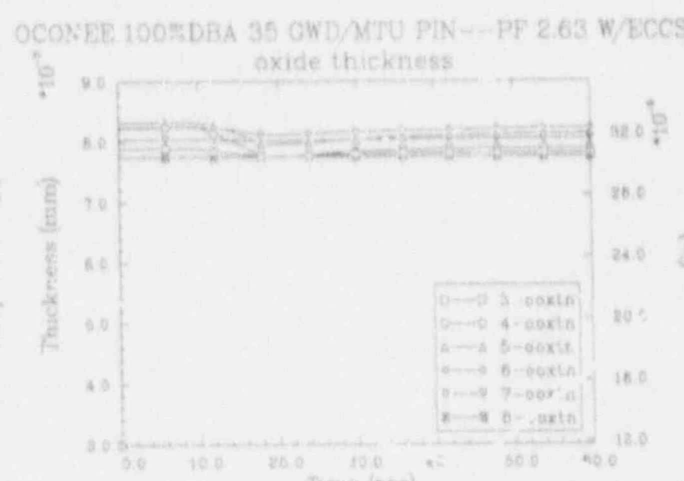

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability
Failure Probability
Time (sec)

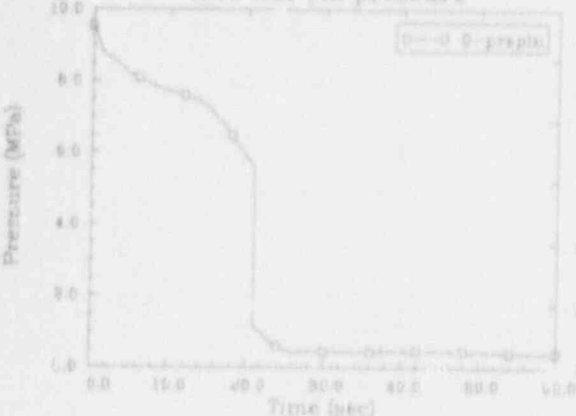

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/ECCS
cladding hoop strain
Strain
3-cladhan
4-cladhan
5-cladhan
6-cladhan
7-cladhan
8-cladhan
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/ECCS
cladding surface temperature
Temperature (K)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Time (sec)

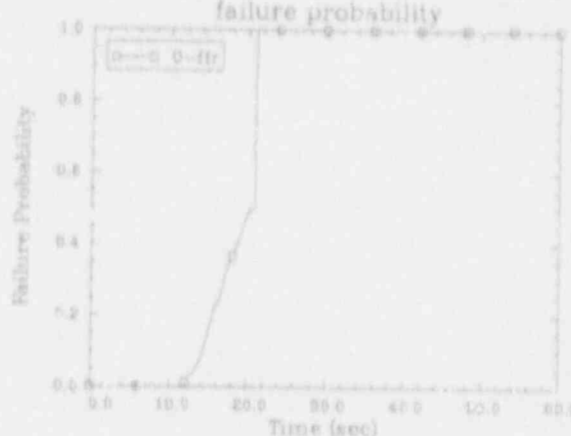

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/ECCS
oxide thickness
Thickness (mm)
Time (sec)

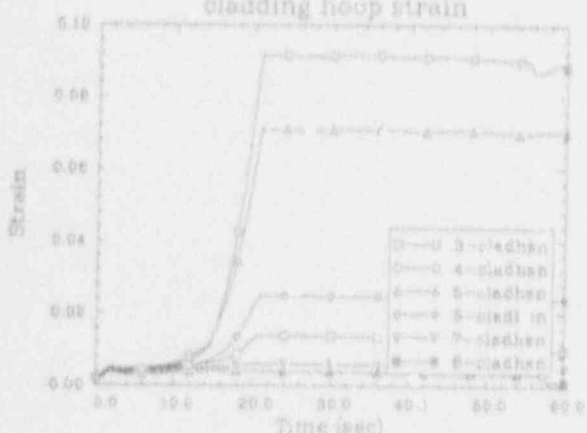
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure



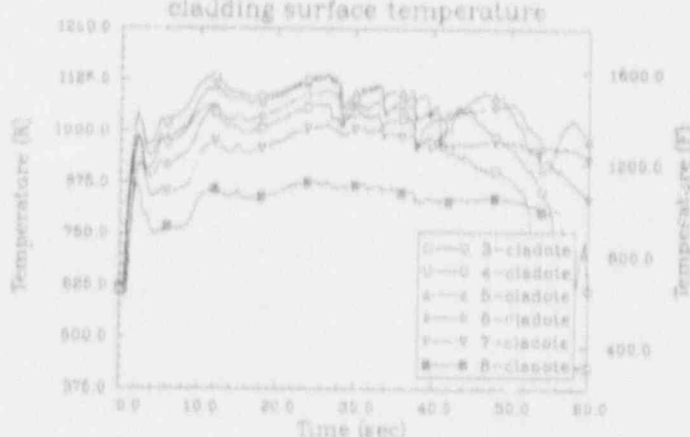
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability



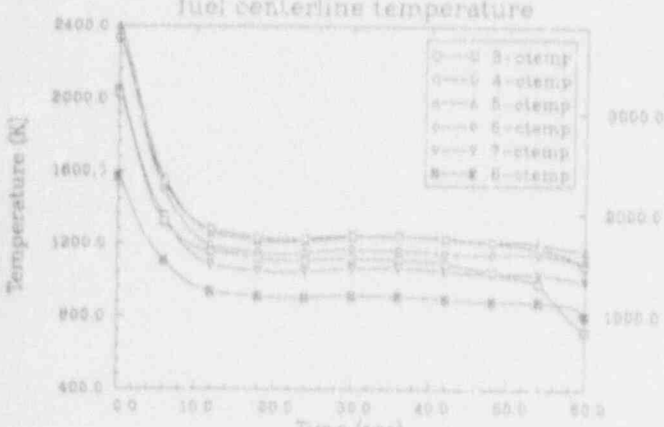
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/ECCS
cladding hoop strain



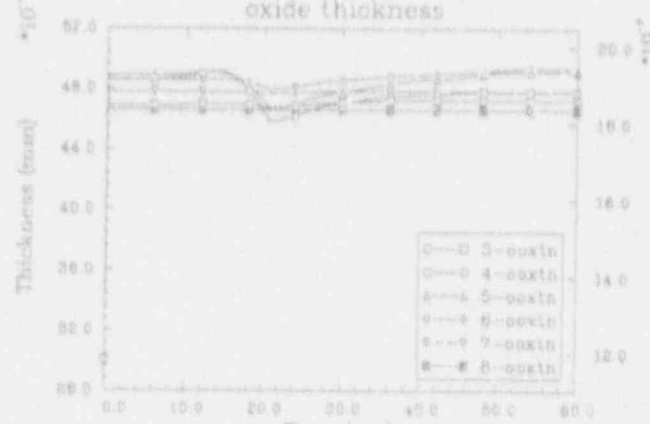
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/ECCS
cladding surface temperature

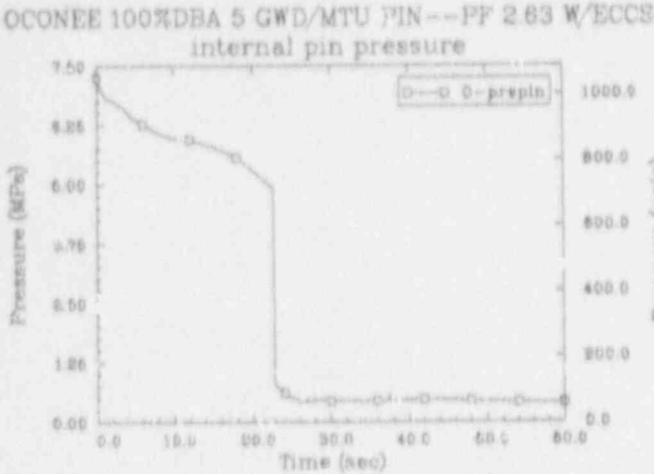


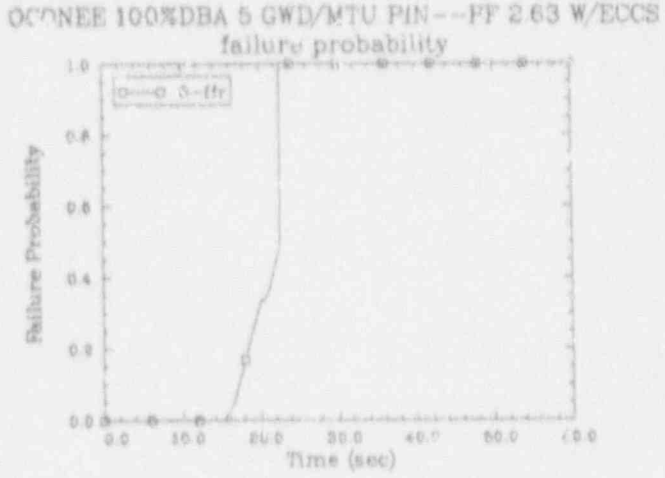
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/ECCS
fuel centerline temperature

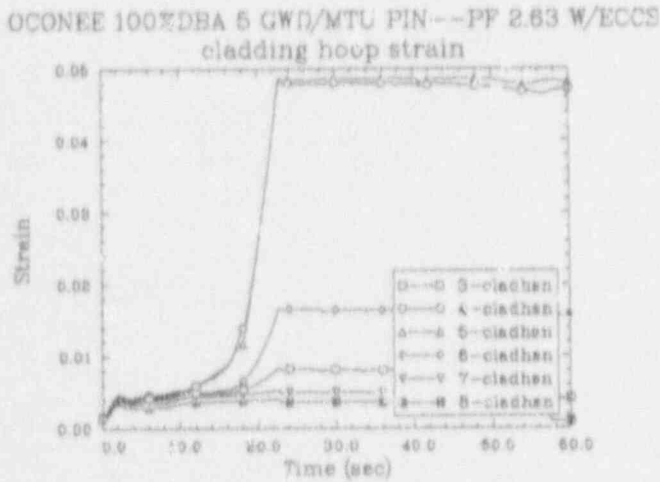


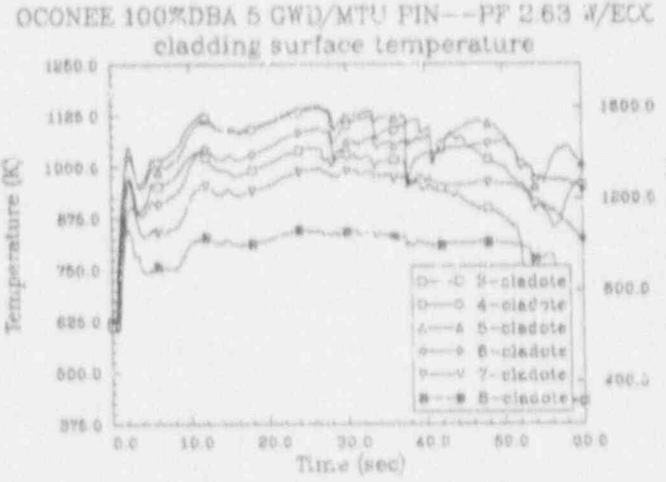
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/ECCS
oxide thickness

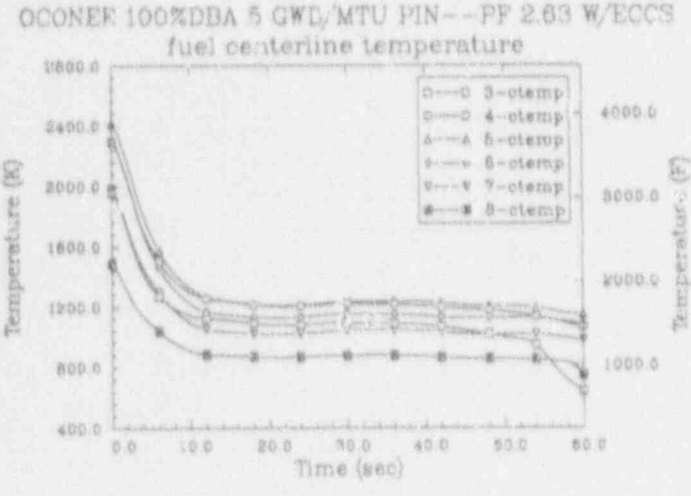


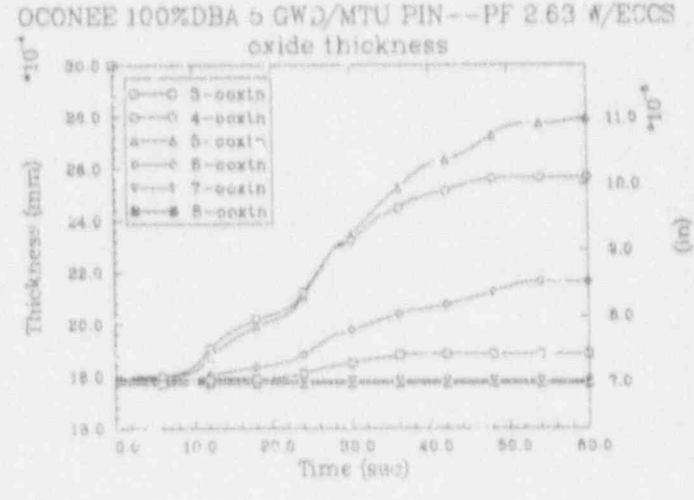

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prepin

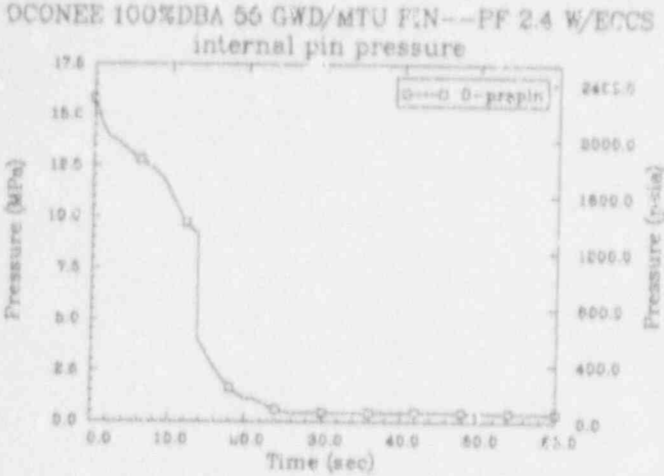

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability
Failure Probability
Time (sec)

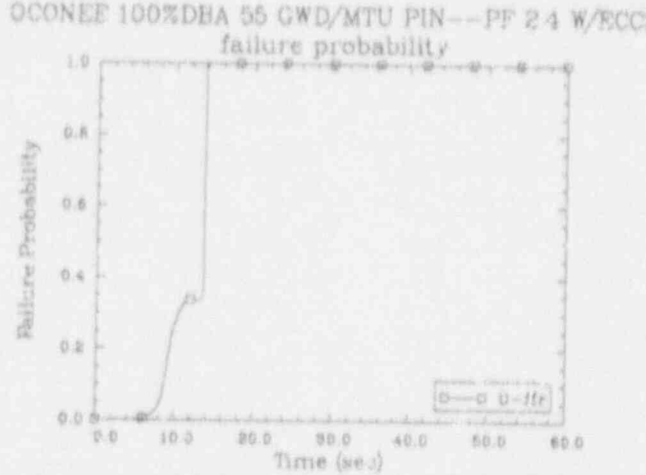

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/ECCS
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn

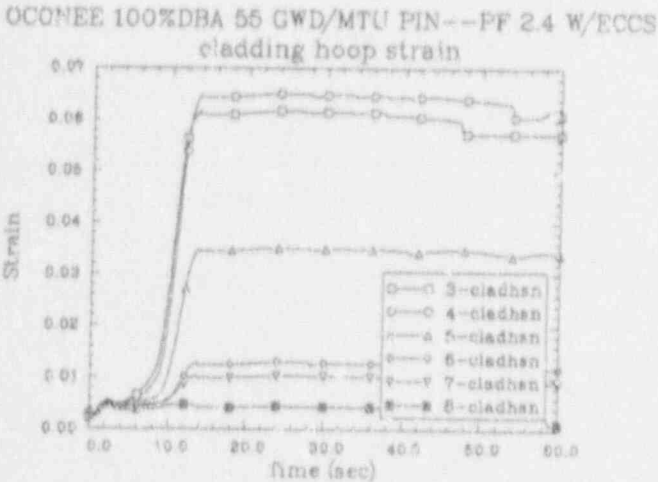

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/ECC
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

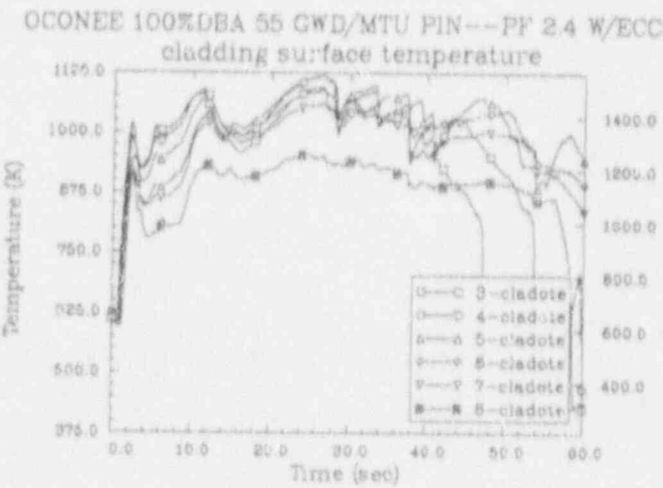

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/ECCS
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp

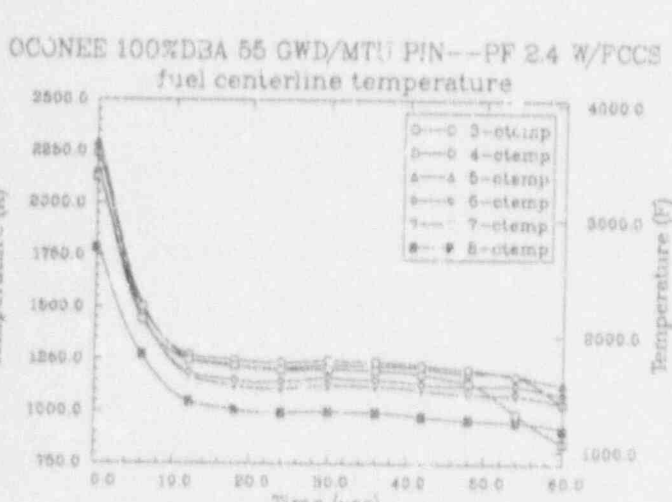

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/ECCS
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

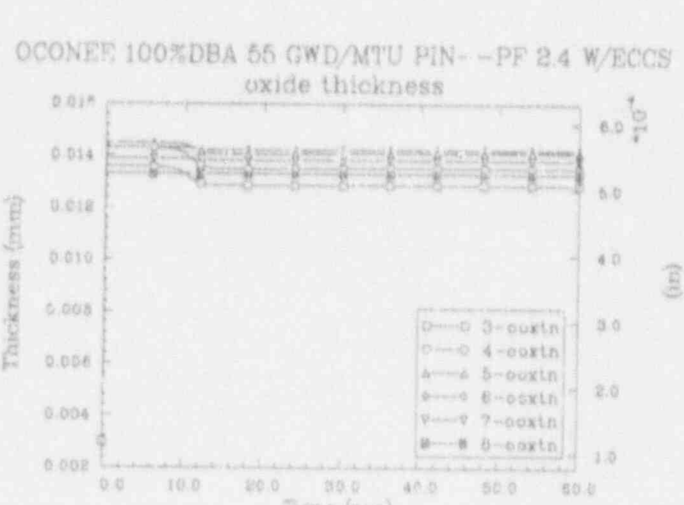

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/ECCS
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/ECCS
failure probability
Failure Probability
Time (sec)

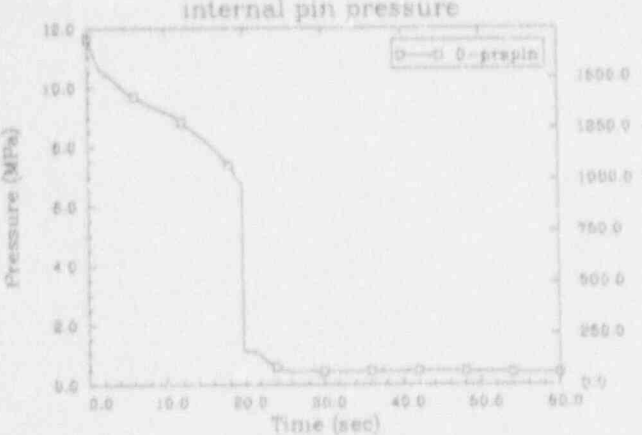

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

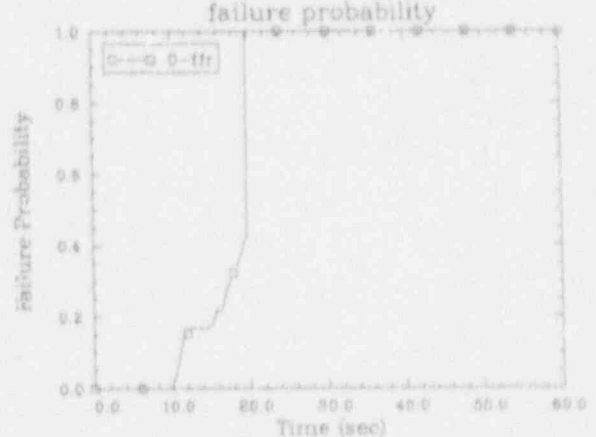

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

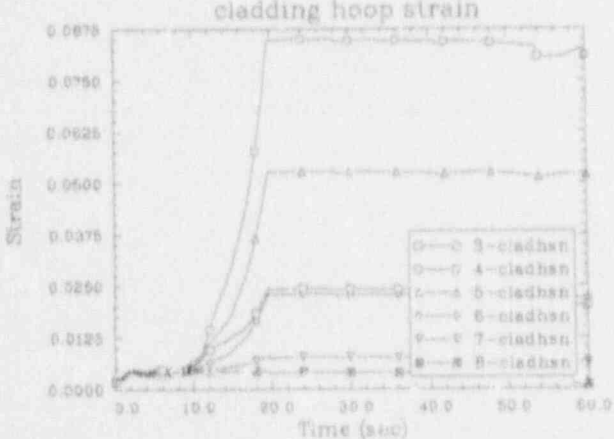
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/ECCS
internal pin pressure



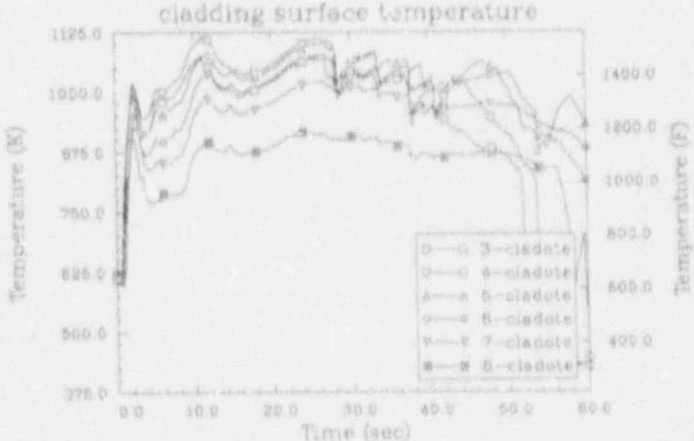
OCONEE 0%DBA 35 GWD/MTU PIN--PF 2.4 W/ECCS
failure probability



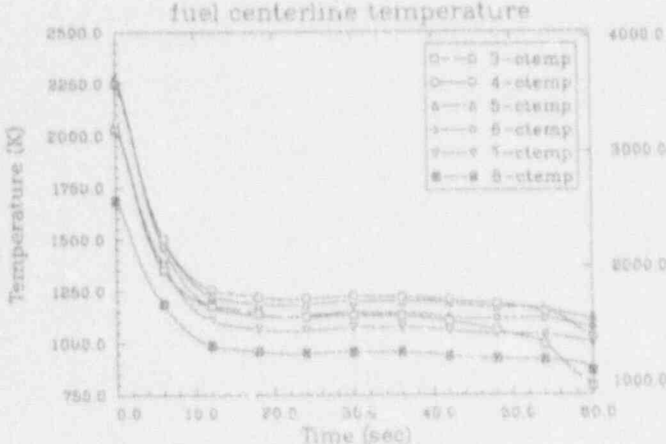
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/ECCS
cladding hoop strain



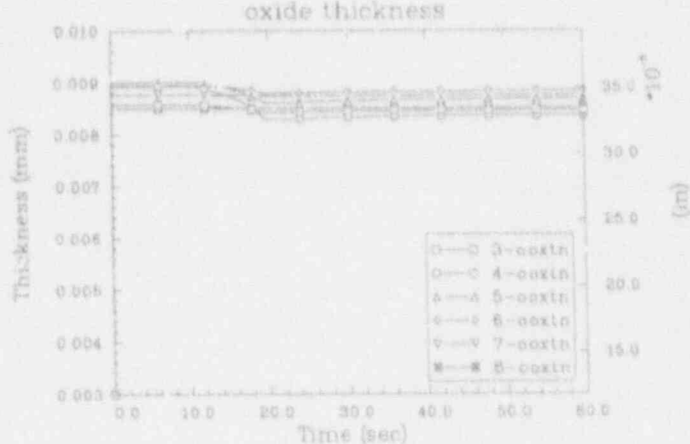
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/ECCS
cladding surface temperature

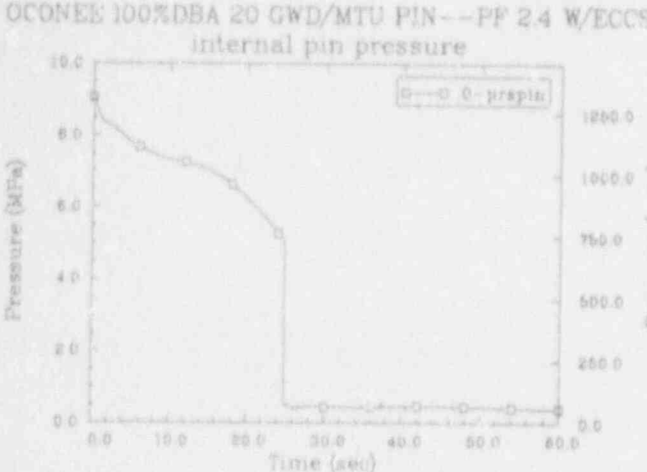


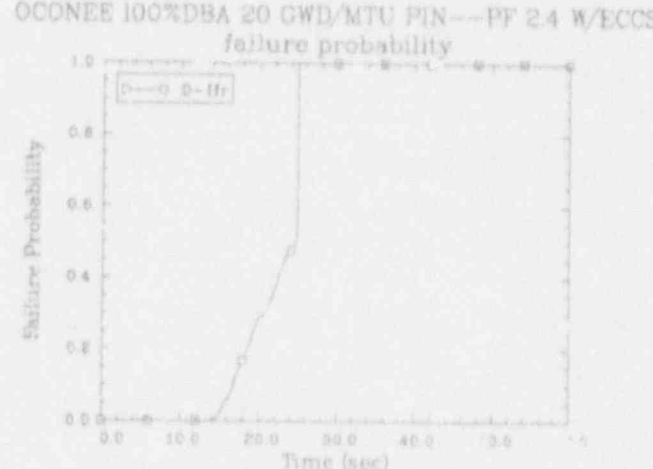
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/ECCS
fuel centerline temperature

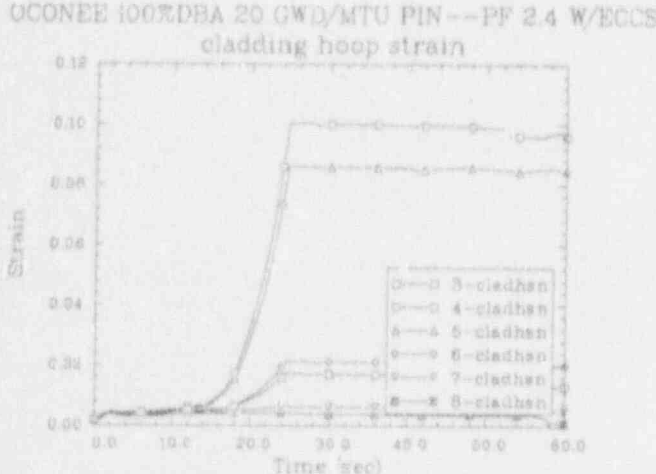


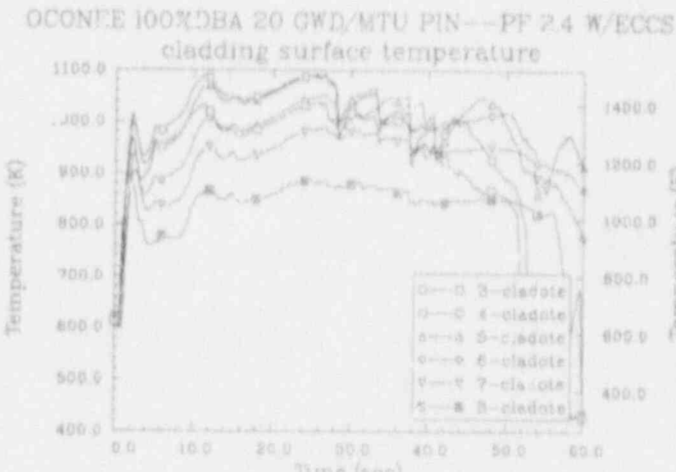
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/ECCS
oxide thickness

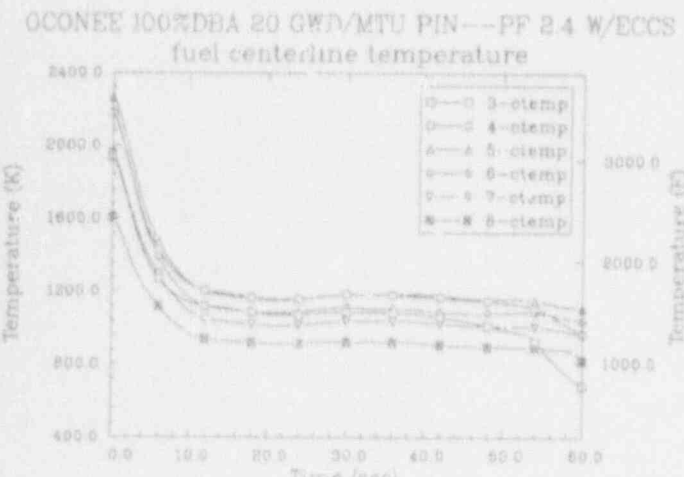


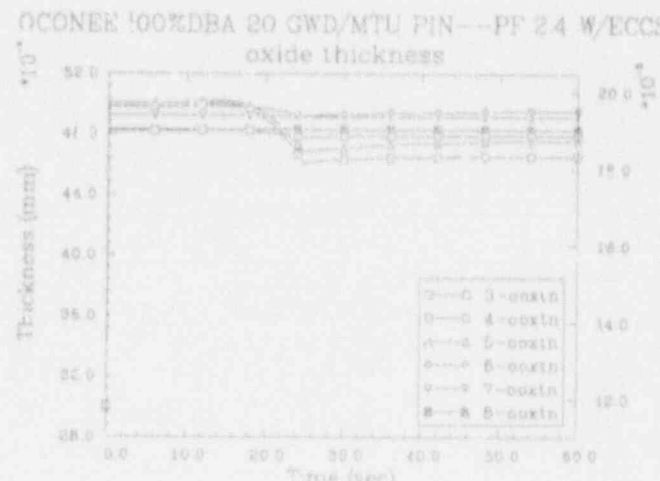

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

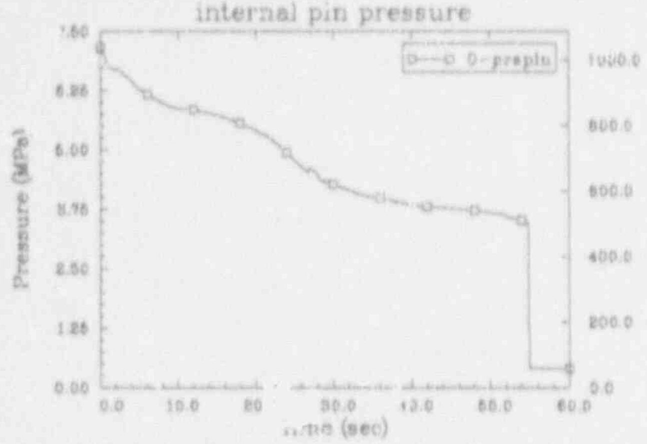

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F°)
Time (sec)

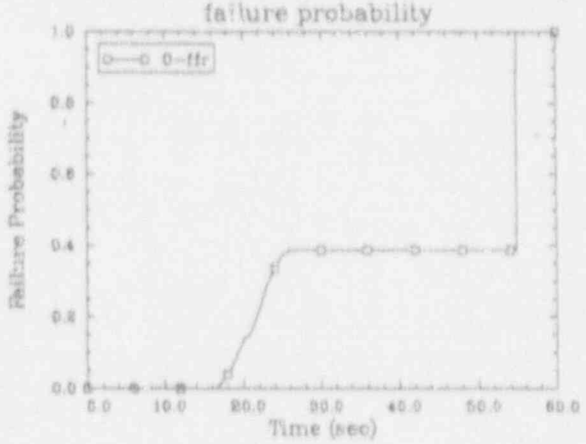

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/ECCS
oxide thickness
3-oxxtn
4-oxxtn
5-oxxtn
6-oxxtn
7-oxxtn
8-oxxtn
Thickness (mm)
(in)
Time (sec)

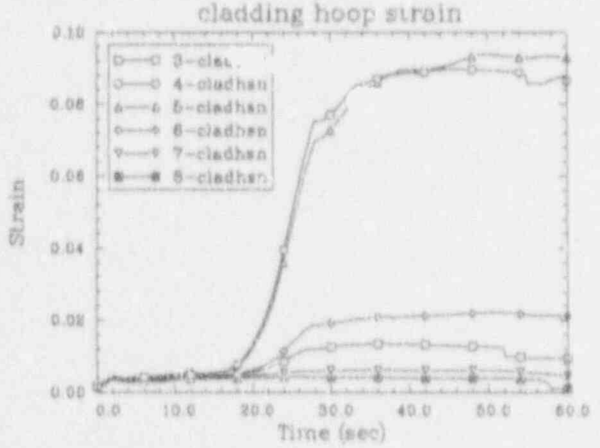
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/ECCS
internal pin pressure



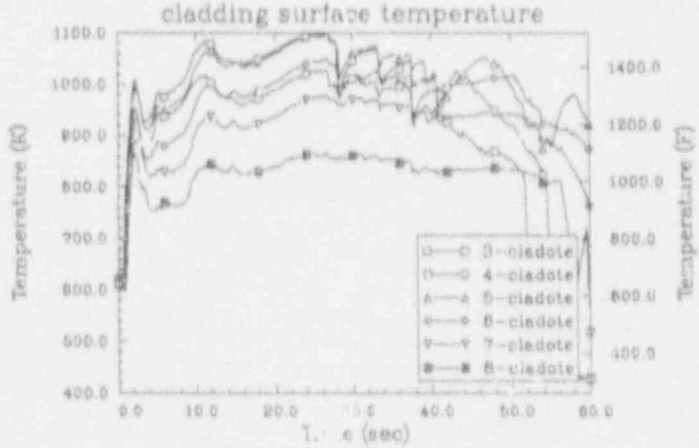
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/ECCS
failure probability



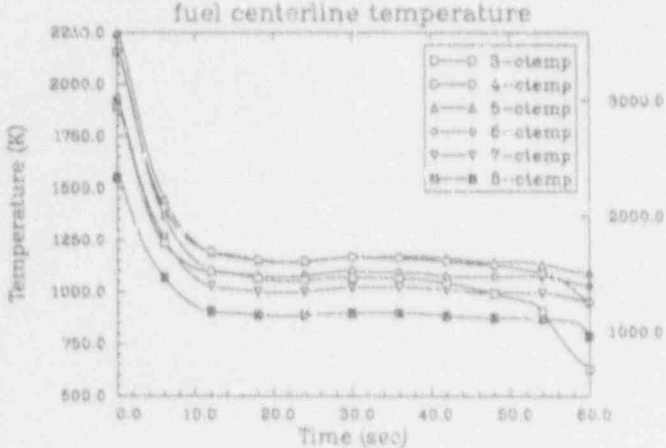
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/ECCS
cladding hoop strain



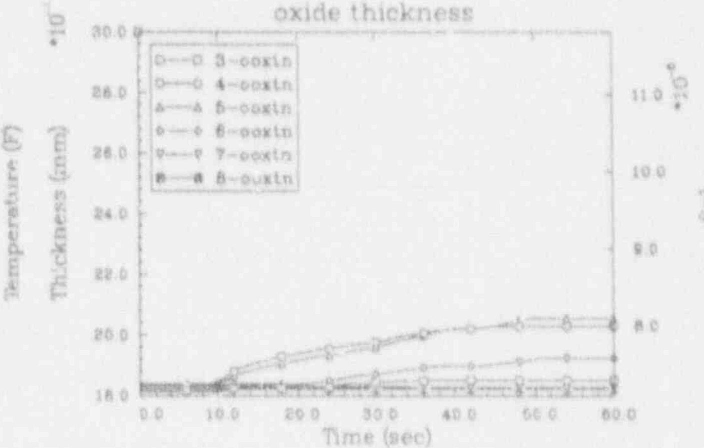
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/ECCS
cladding surface temperature



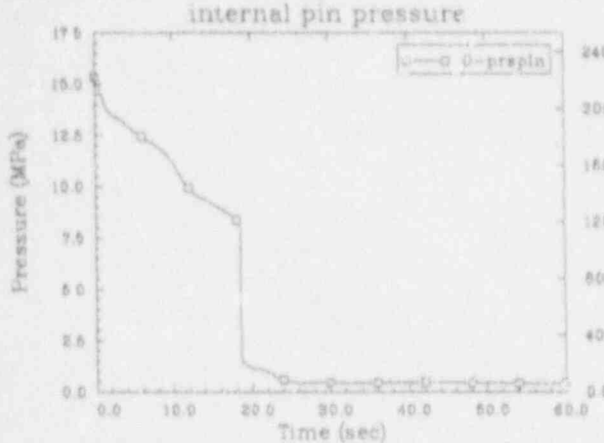
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/ECCS
fuel centerline temperature



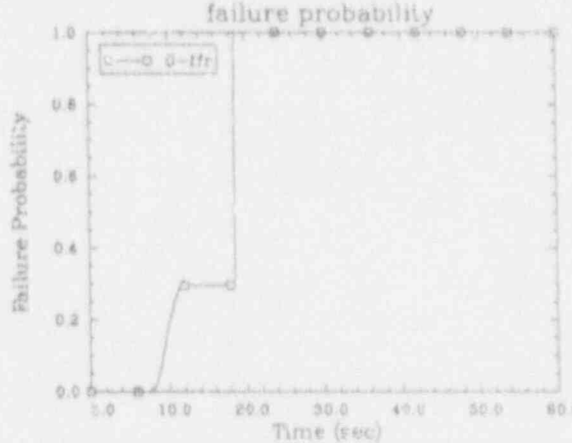
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/ECCS
oxide thickness



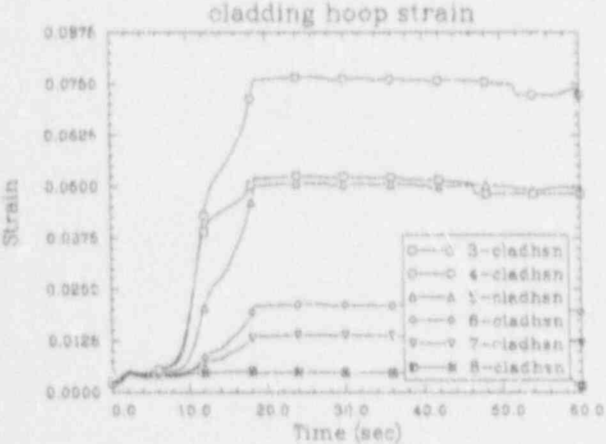
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/ECCS
internal pin pressure



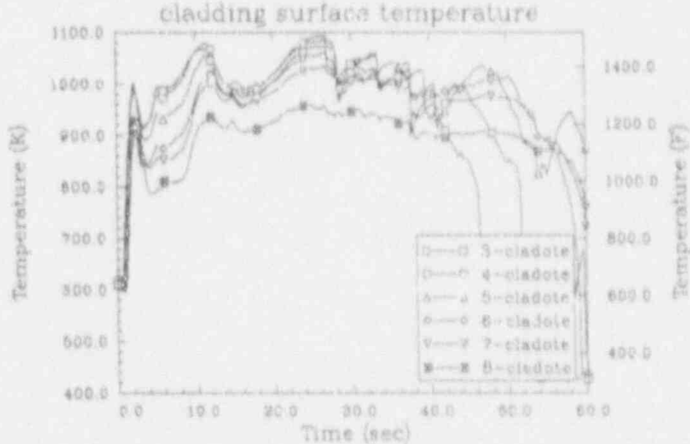
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/ECCS
failure probability



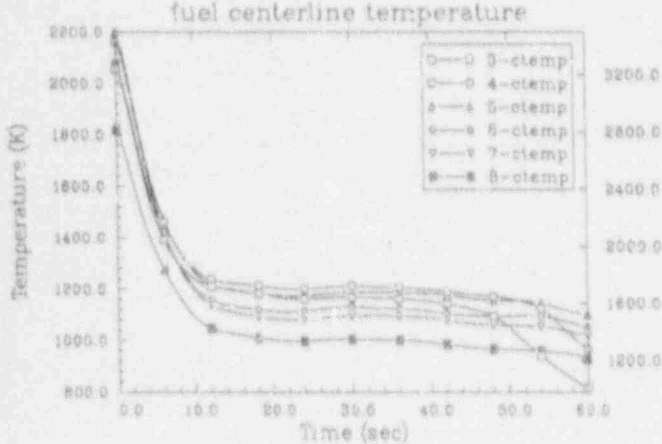
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/ECCS
cladding hoop strain



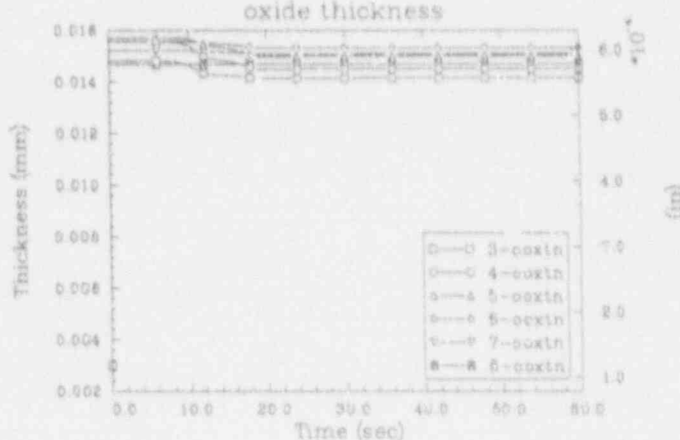
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/ECCS
cladding surface temperature



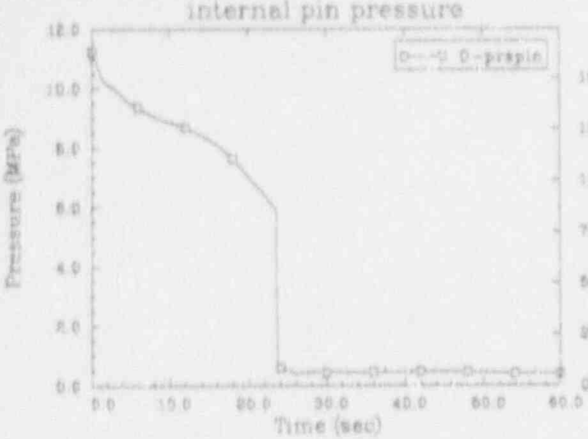
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/ECCS
fuel centerline temperature



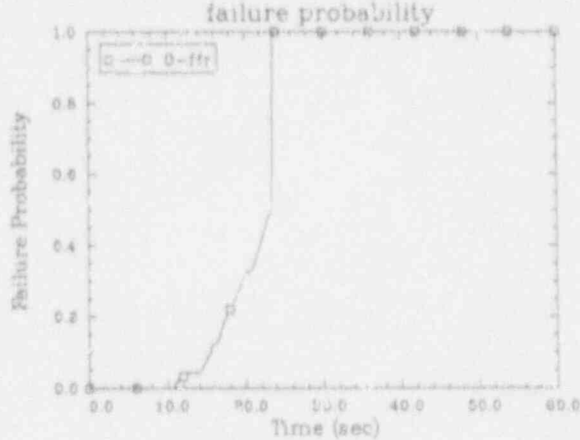
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/ECCS
oxide thickness



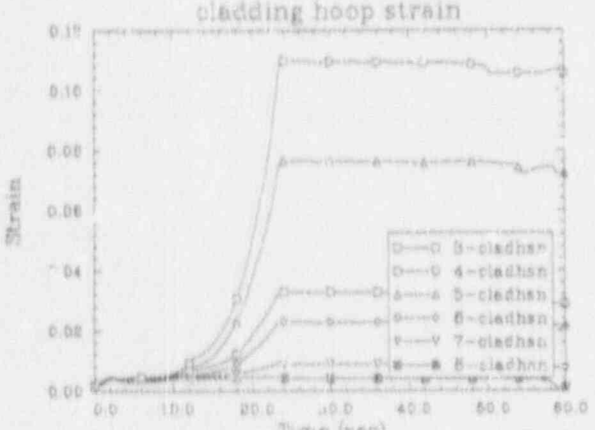
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/ECCS
internal pin pressure



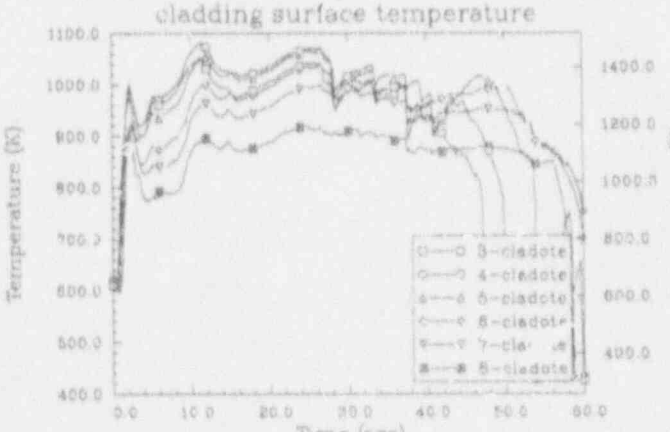
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/ECCS
failure probability



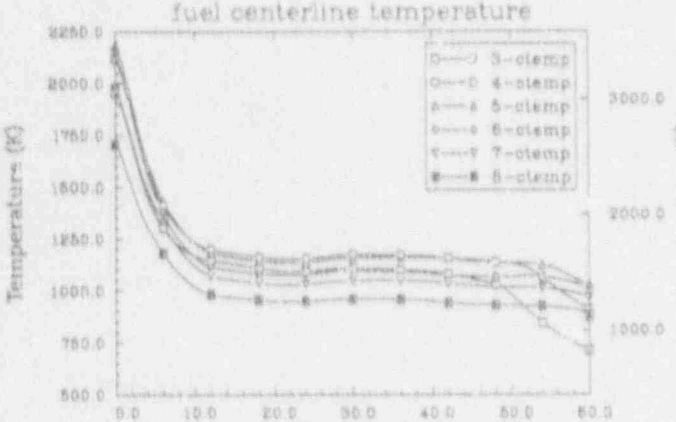
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/ECCS
cladding hoop strain



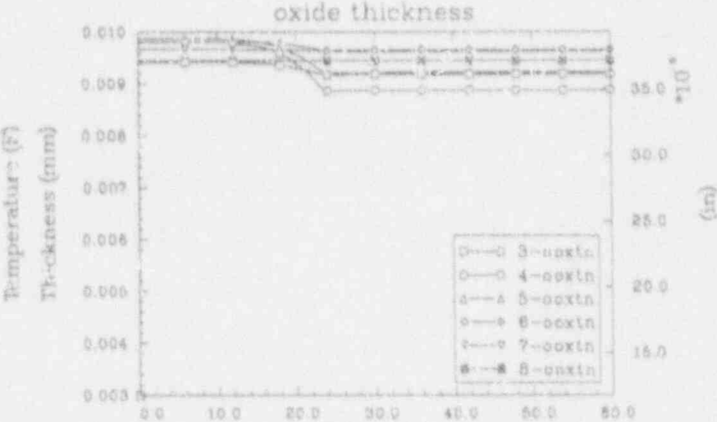
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/ECCS
cladding surface temperature



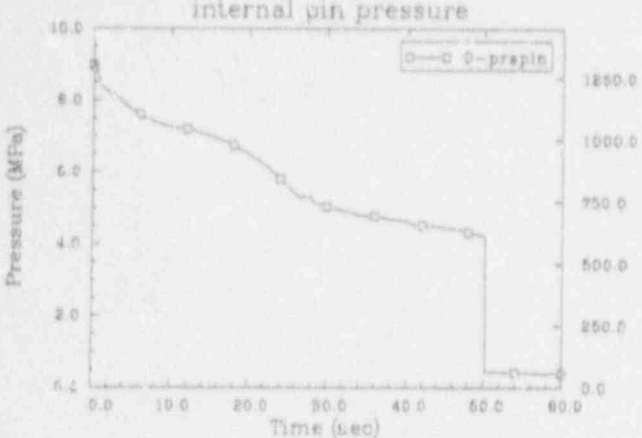
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/ECCS
fuel centerline temperature



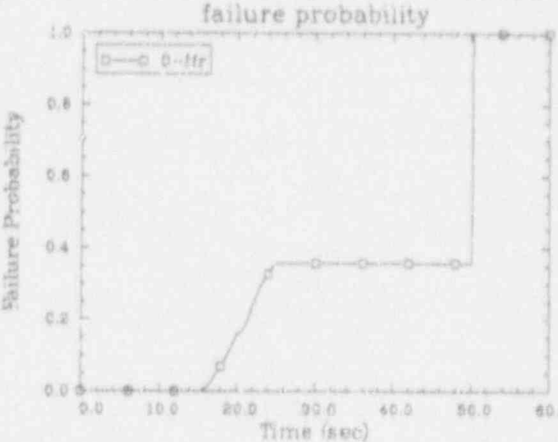
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/ECCS
oxide thickness



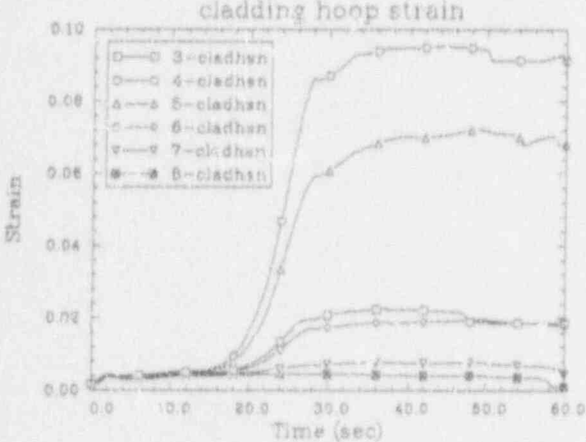
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/ECCS
internal pin pressure



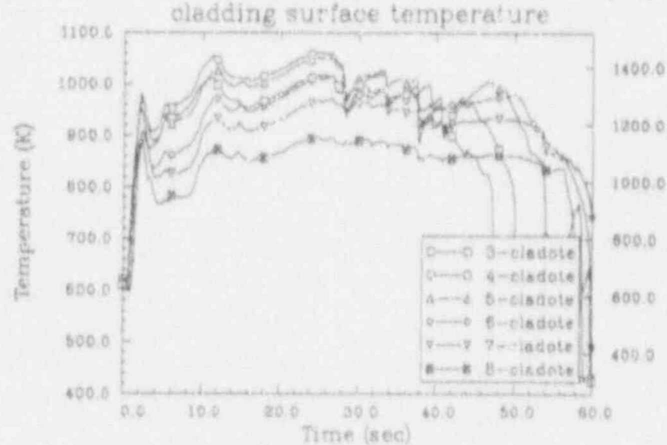
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/ECCS
failure probability



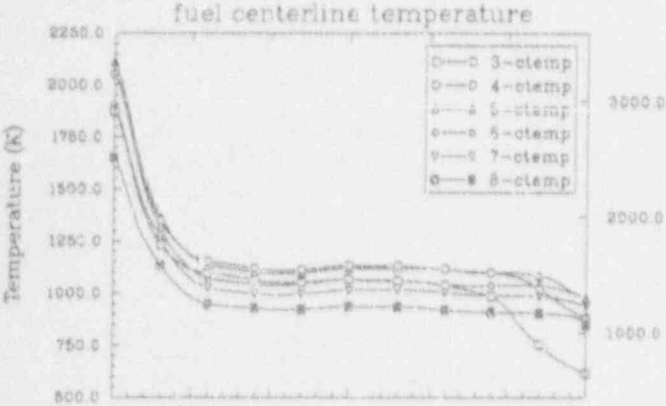
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/ECCS
cladding hoop strain



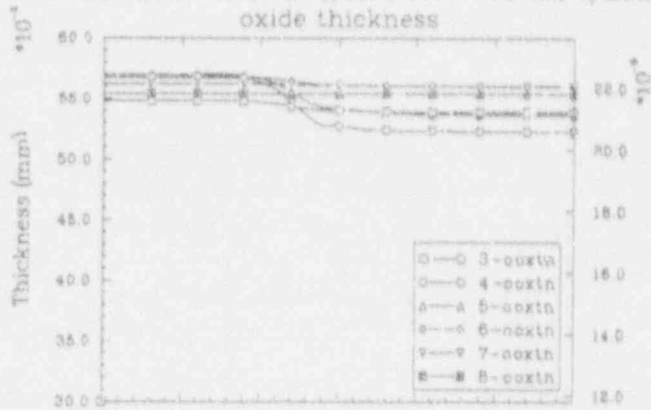
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/ECCS
cladding surface temperature



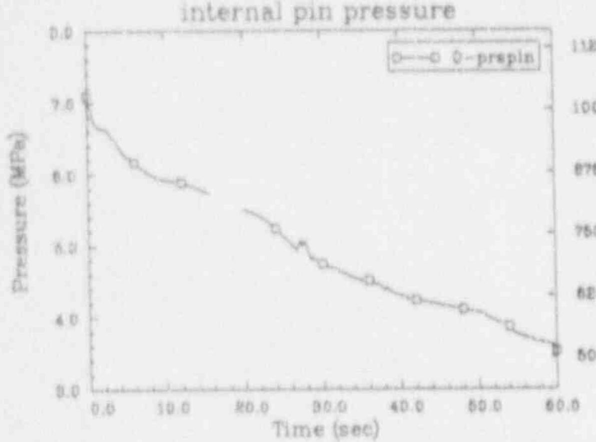
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/ECCS
fuel centerline temperature



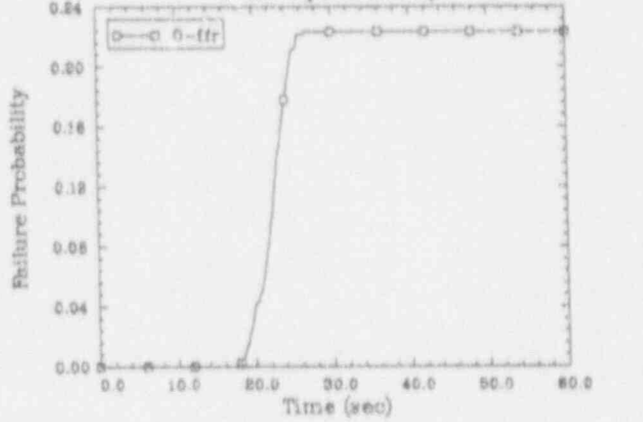
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/ECCS
oxide thickness



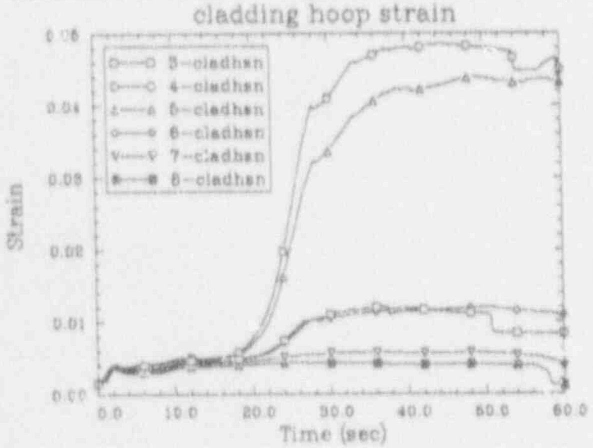
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/ECCS
internal pin pressure



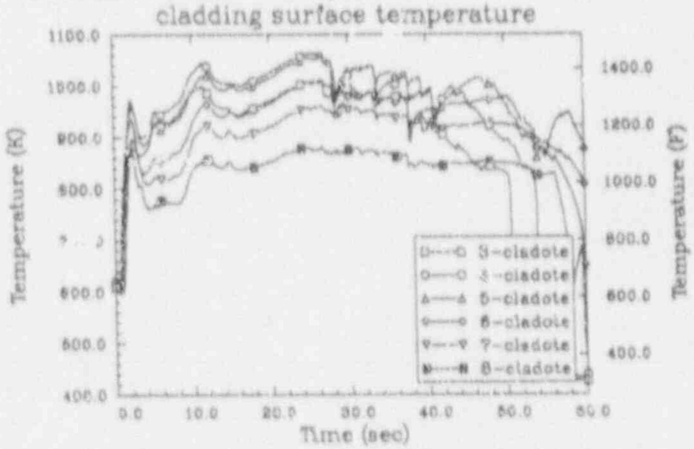
OCONEE 100%DBA 5 GWD/MTU PIN---PF 2.2 W/ECCS
failure probability



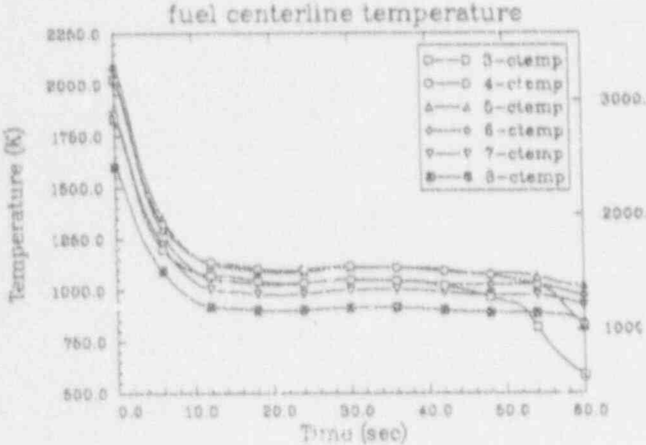
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/ECCS
cladding hoop strain



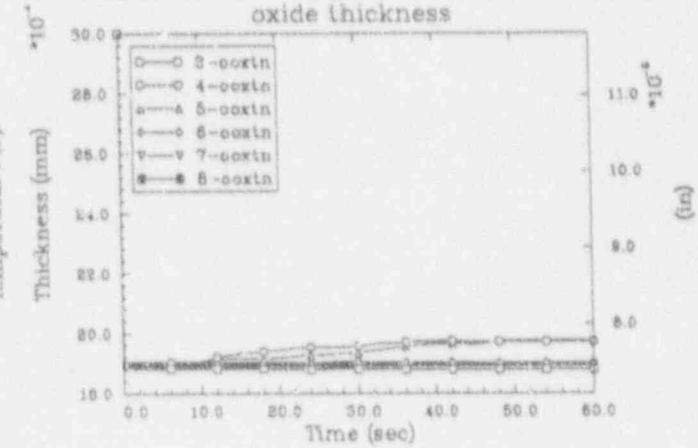
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/ECCS
cladding surface temperature



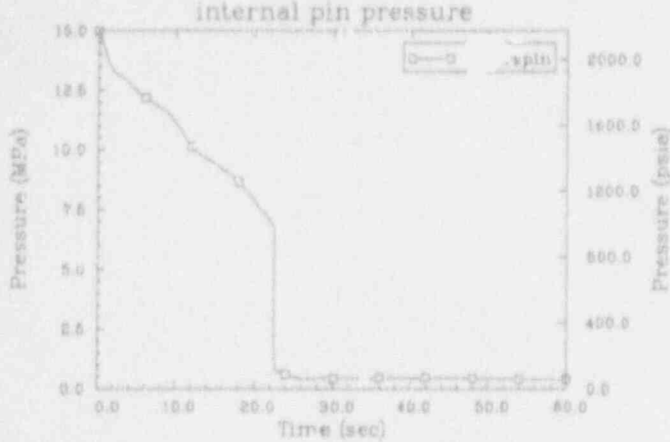
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/ECCS
fuel centerline temperature



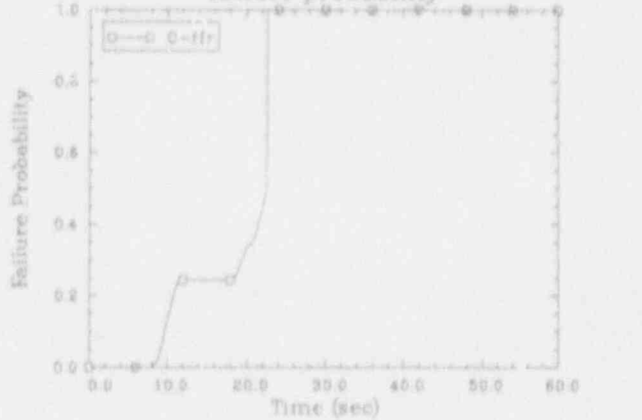
OCONEE 100%DBA 5 GWD/MTU PIN---PF 2.2 W/ECCS
oxide thickness



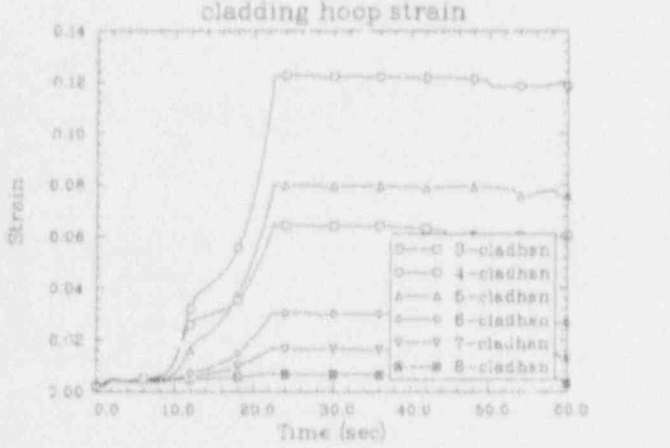
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/ECCS
internal pin pressure



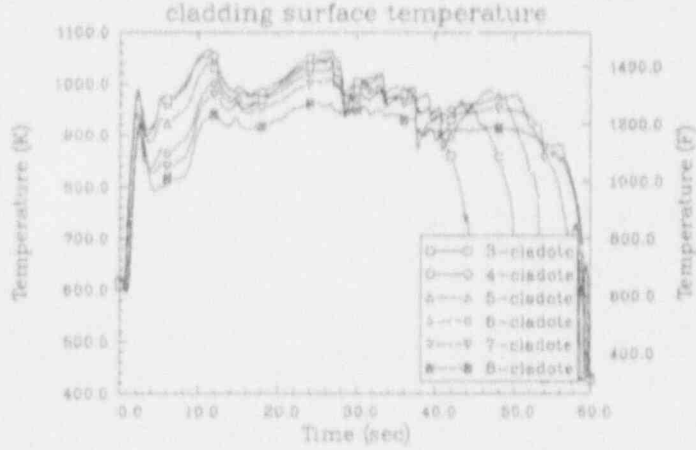
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/ECCS
failure probability



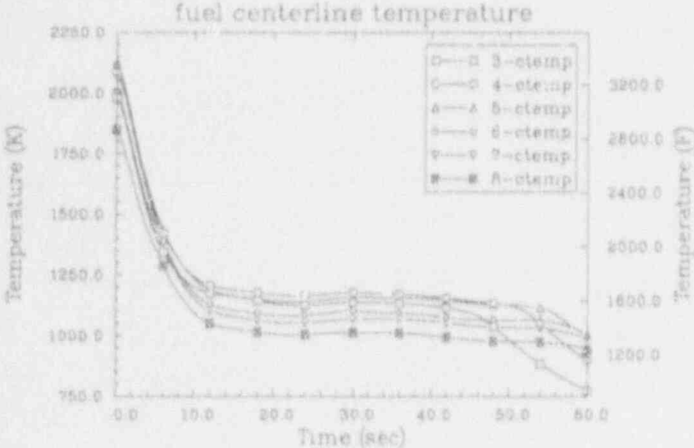
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/ECCS
cladding hoop strain



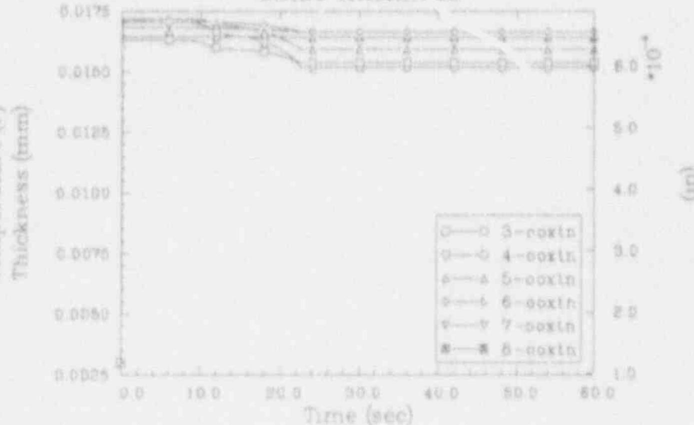
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/ECCS
cladding surface temperature

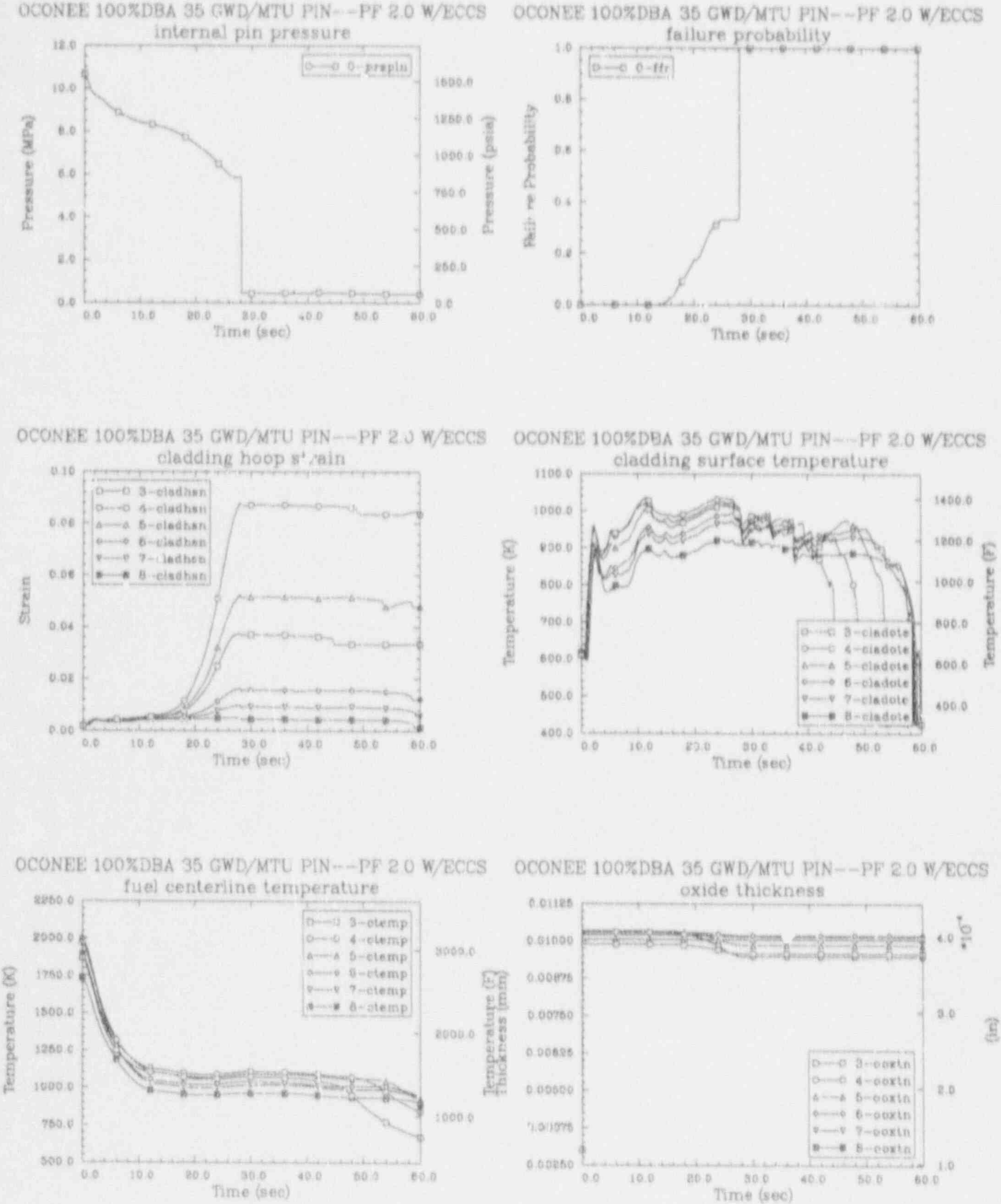


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/ECCS
fuel centerline temperature

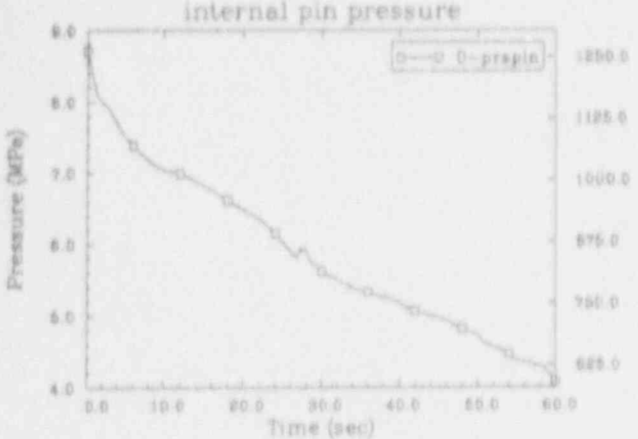


OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/ECCS
oxide thickness

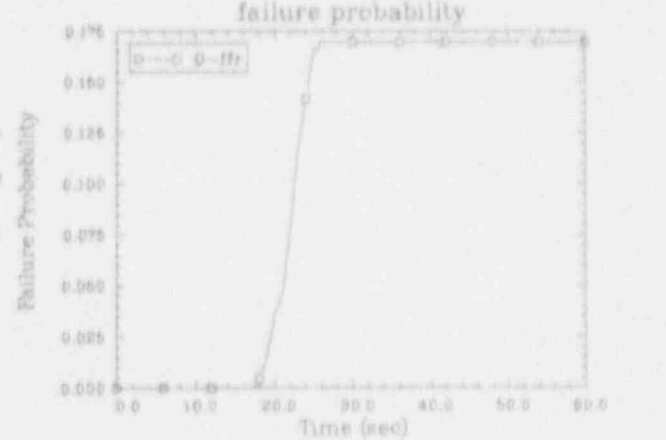



OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/ECCS
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

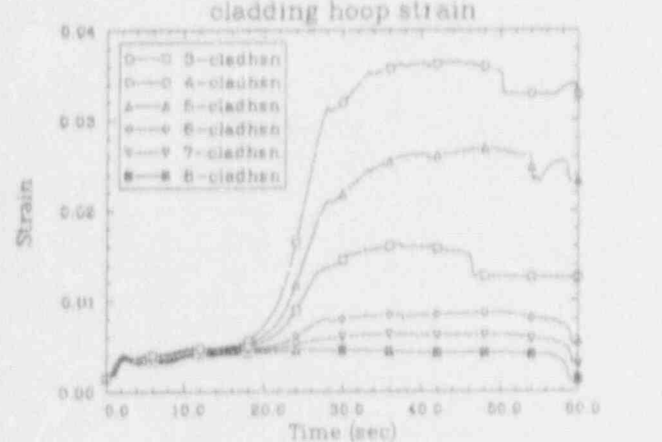
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/ECCS
internal pin pressure



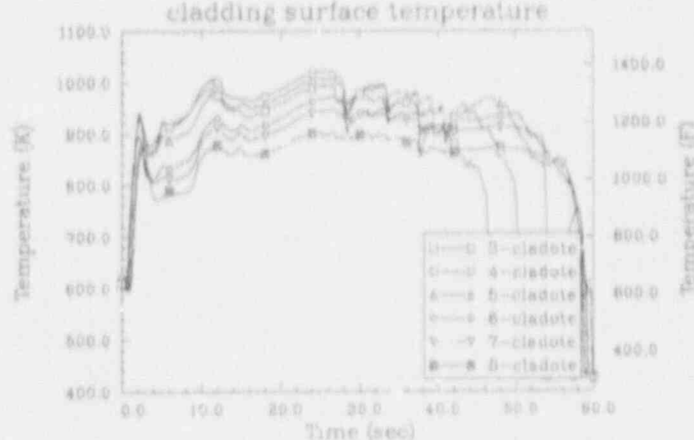
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/ECCS
failure probability



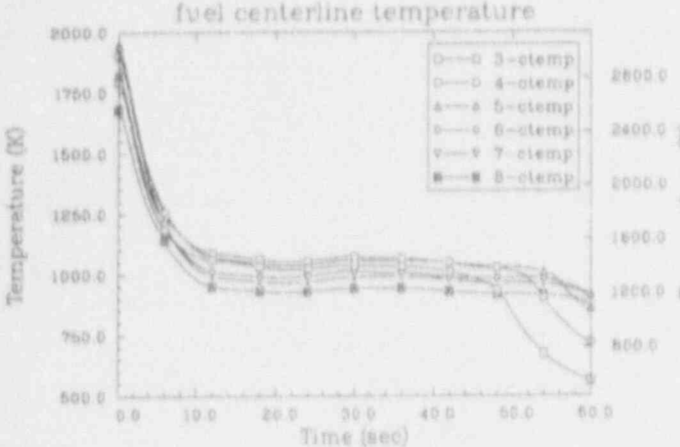
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/ECCS
cladding hoop strain



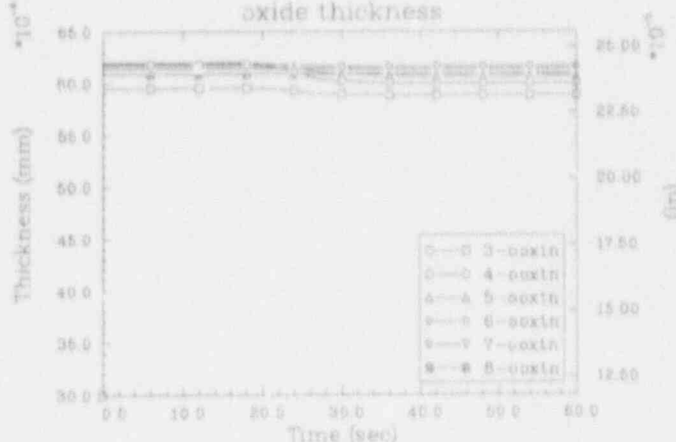
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/ECCS
cladding surface temperature

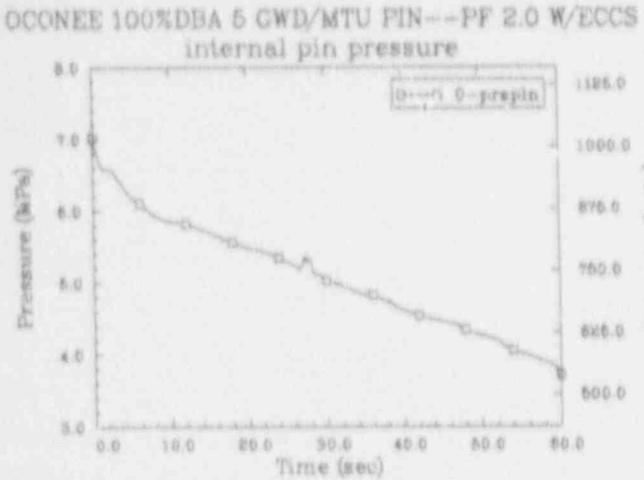


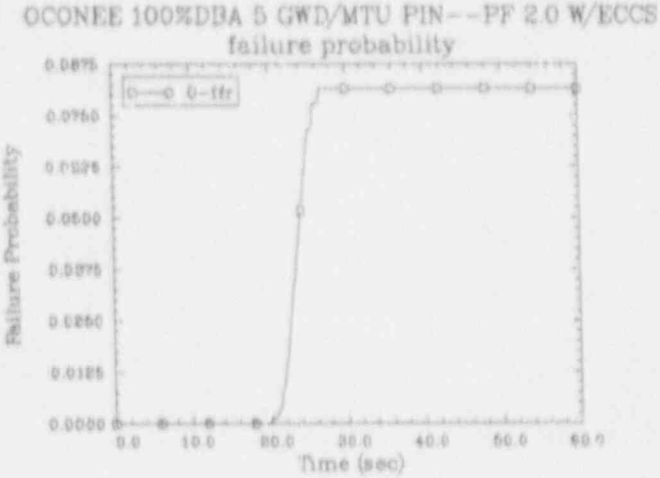
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/ECCS
fuel centerline temperature

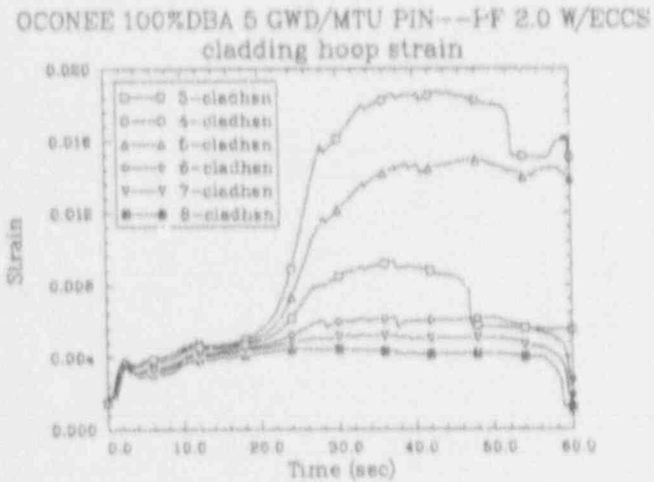


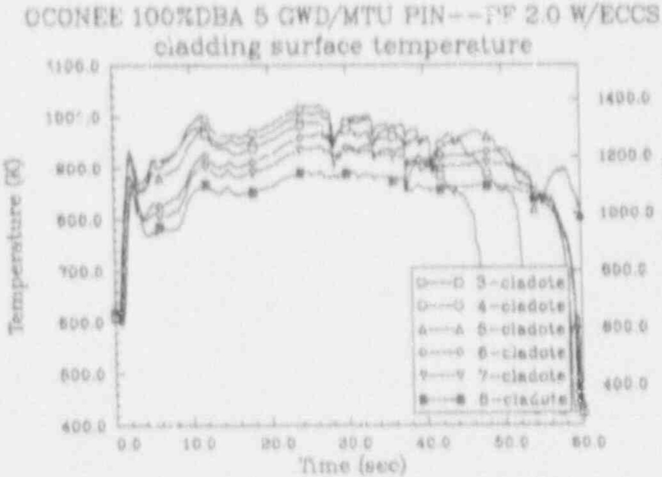
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/ECCS
oxide thickness

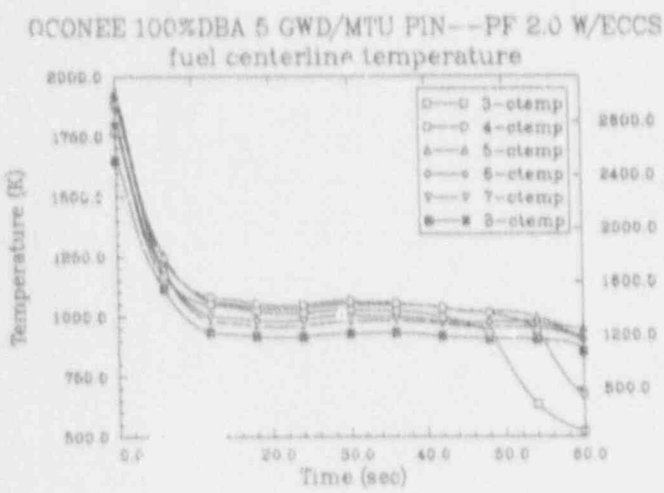


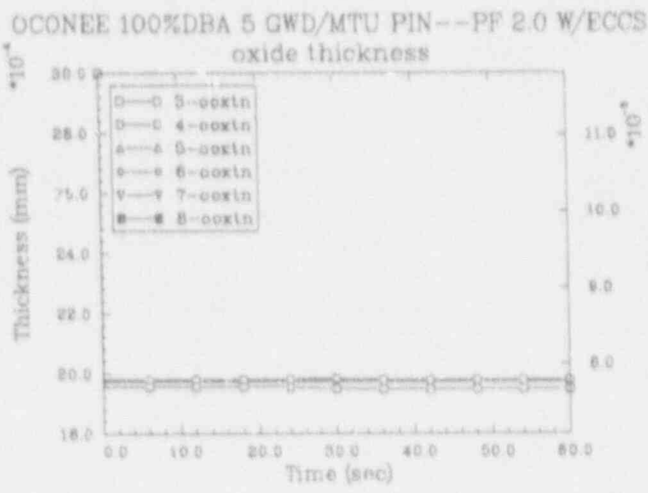

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/ECCS
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

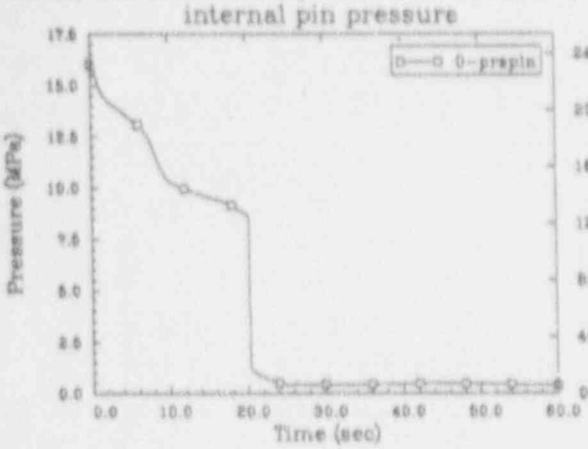

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

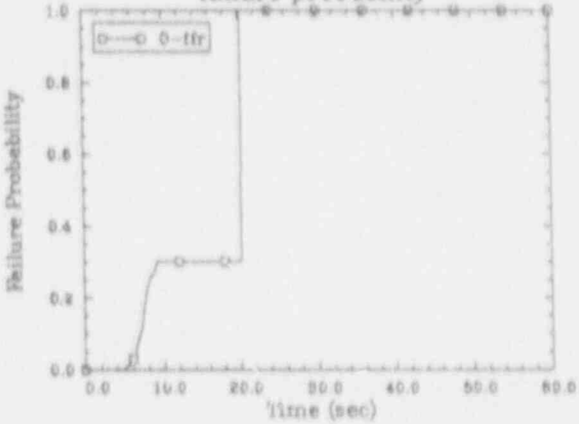

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

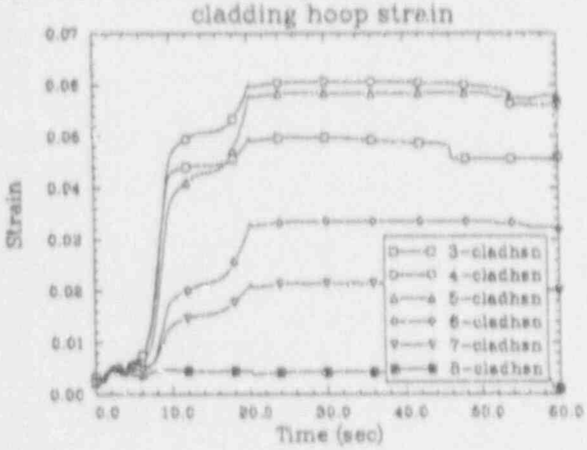
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/E&PT
internal pin pressure



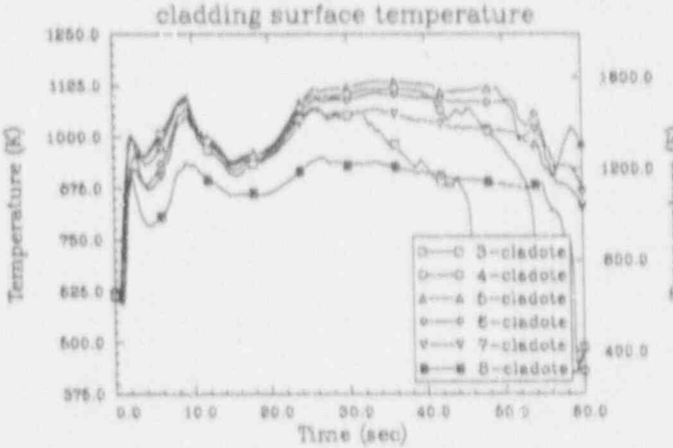
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/E&PT
failure probability



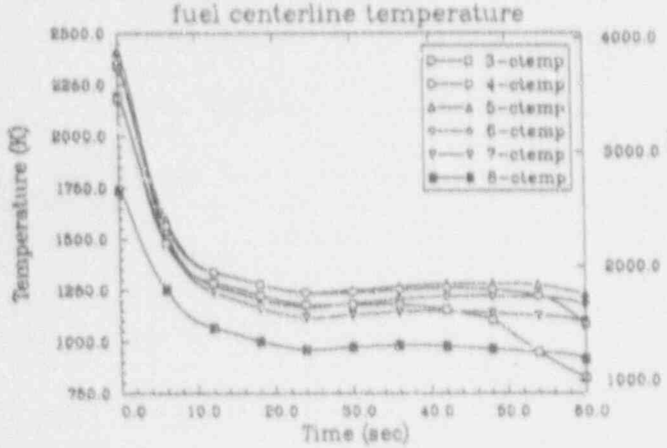
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/E&PT
cladding hoop strain



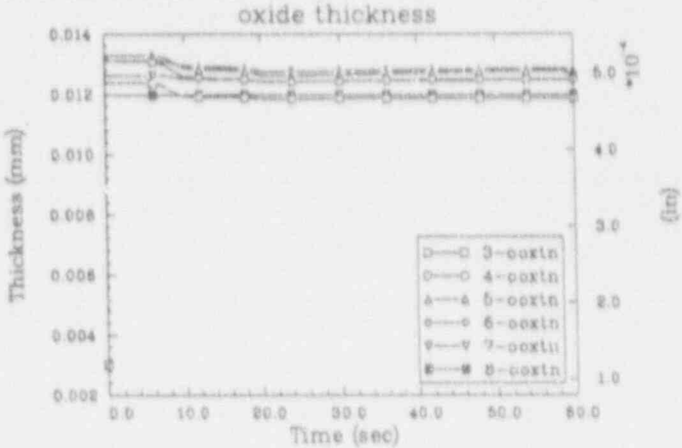
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/E&PT
cladding surface temperature

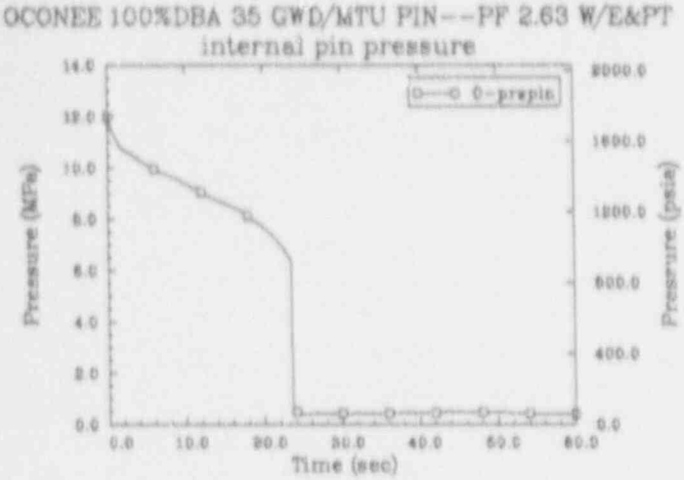


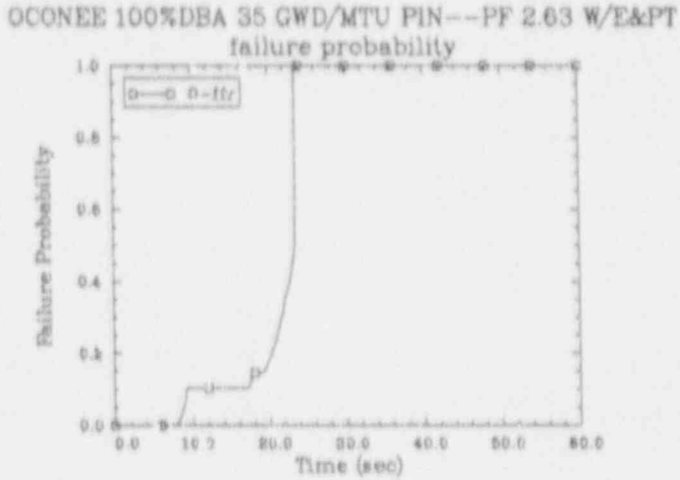
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/E&PT
fuel centerline temperature

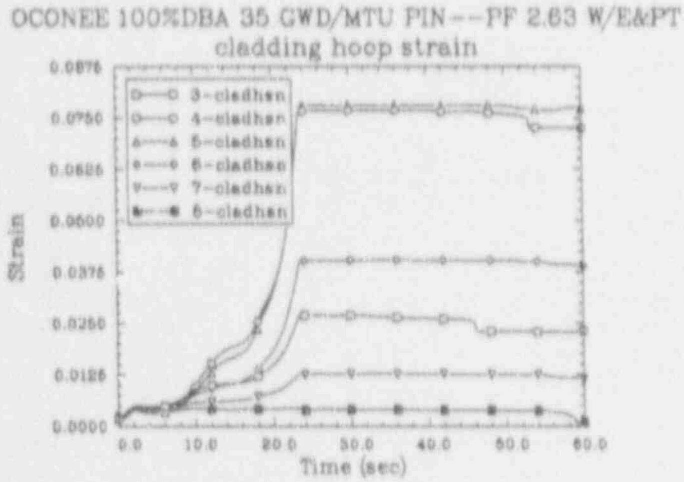


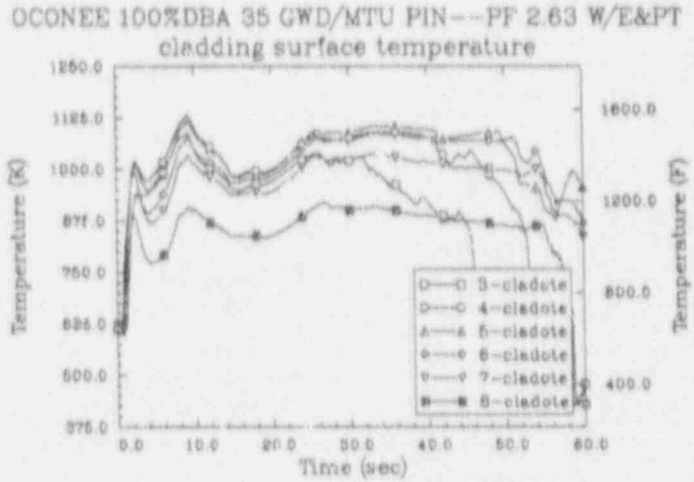
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/E&PT
oxide thickness

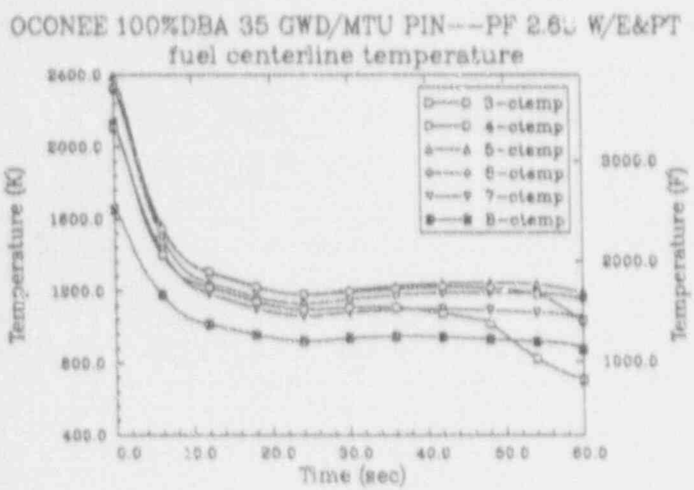


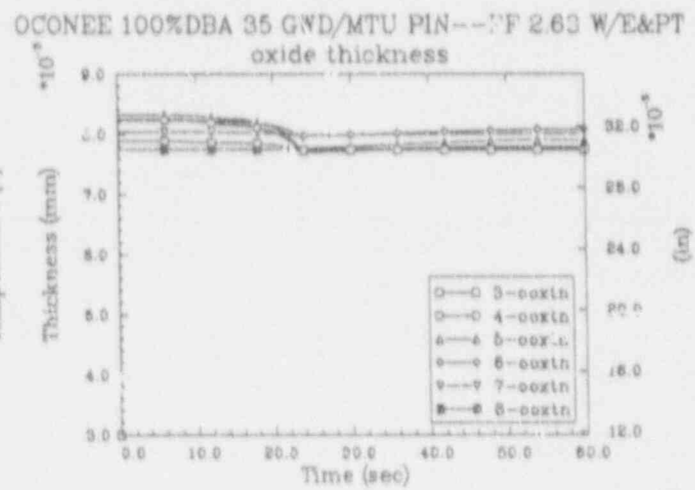

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/E&PT
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

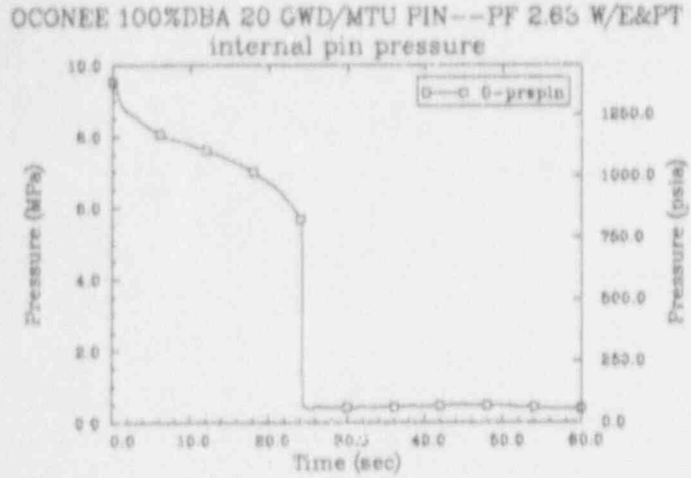

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/E&PT
failure probability
0-ftr
Failure Probability
Time (sec)

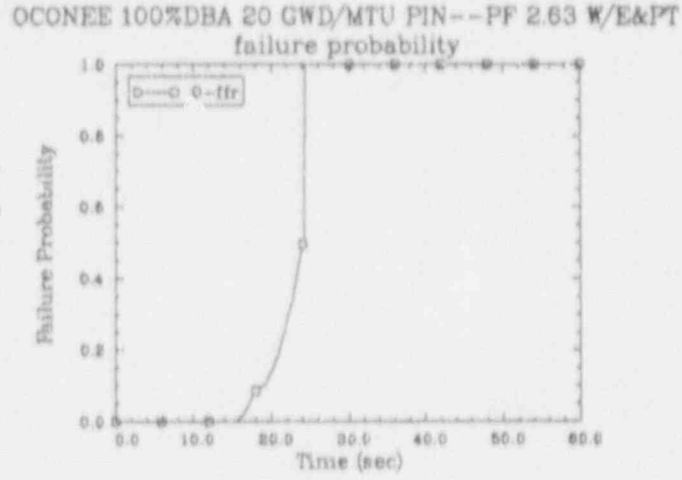

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

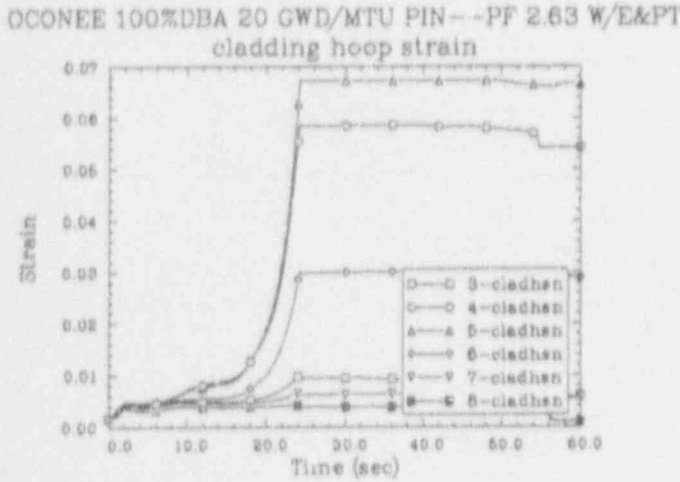

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

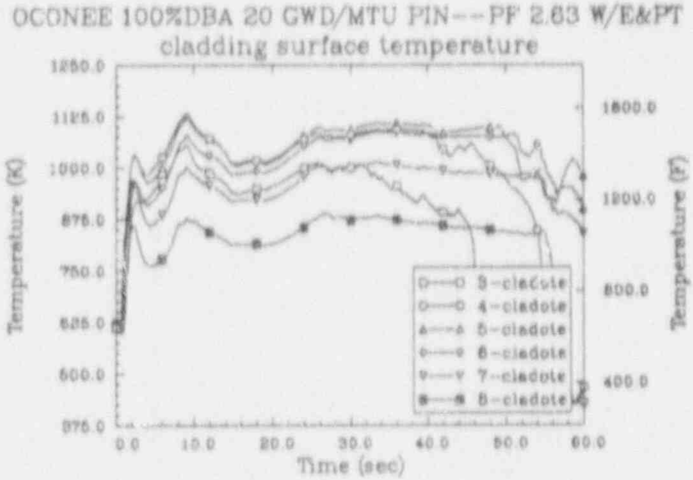

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

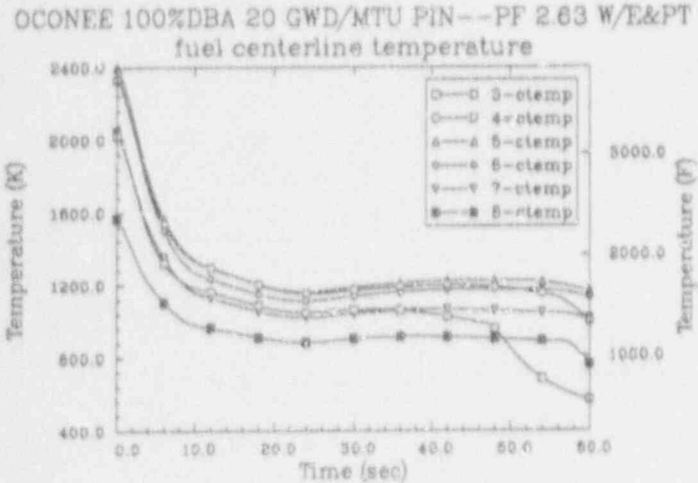

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

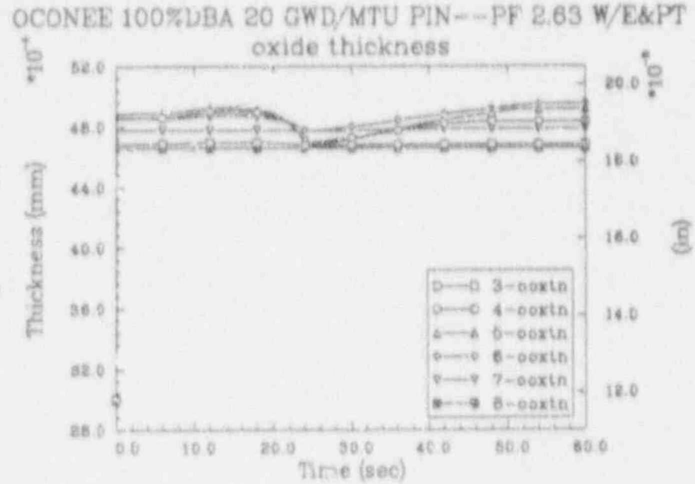

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/E&PT
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

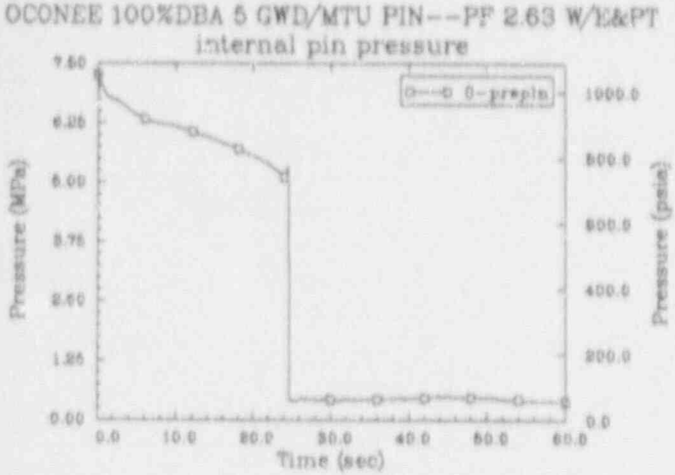

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

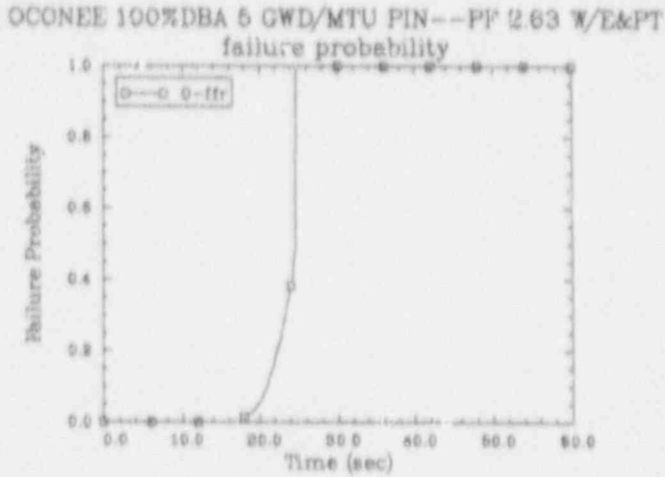

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

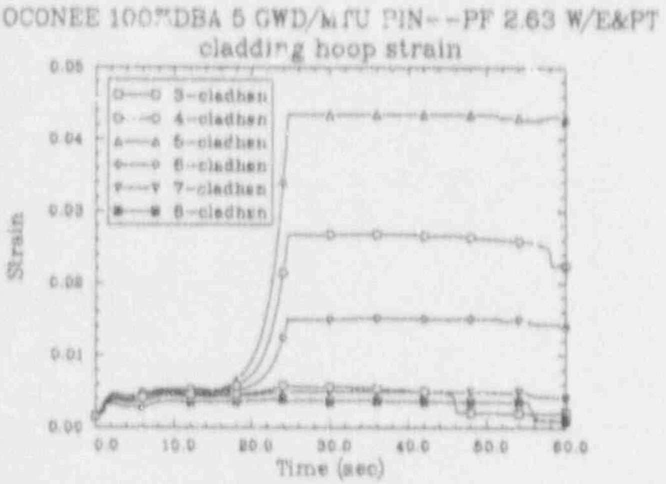

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

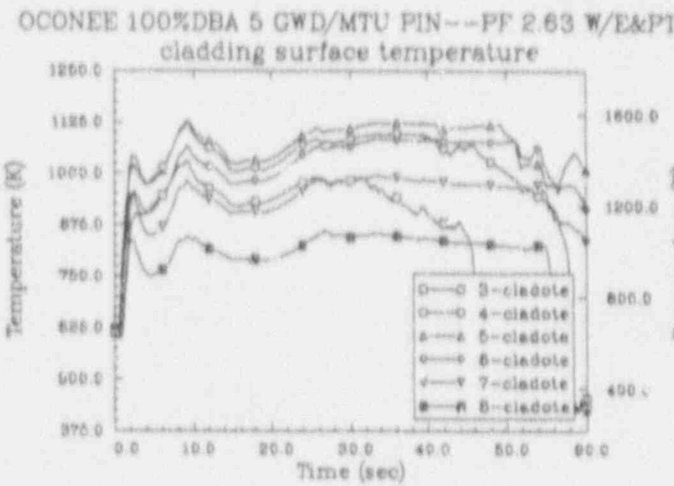

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

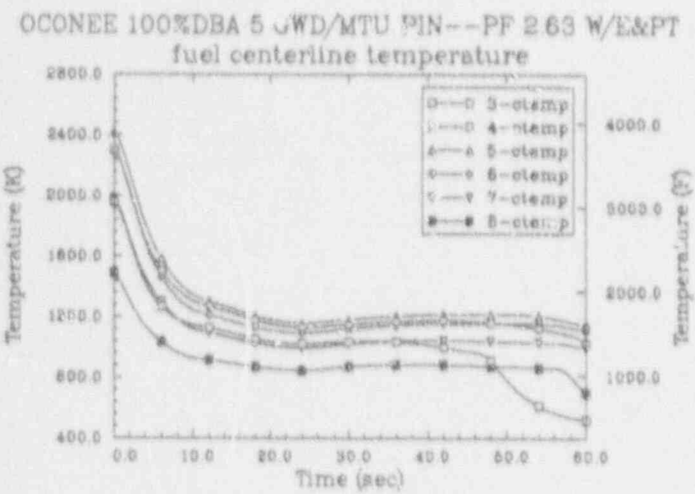

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

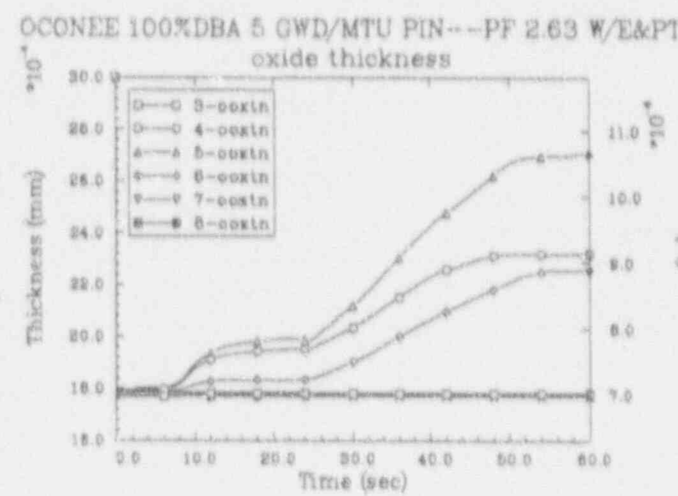

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/E&PT
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

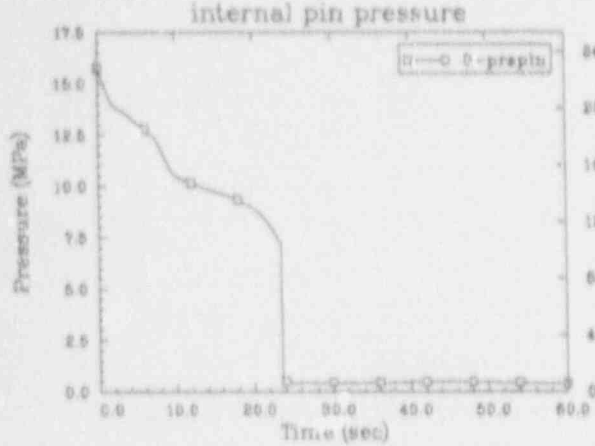

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

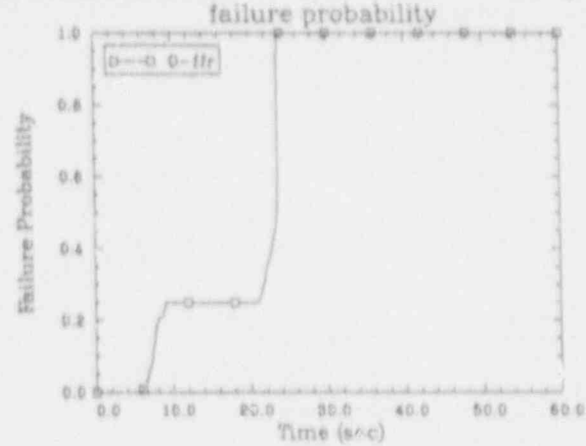

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/E&PT
fuel centerline temperature
3-ctemp
5-ctemp
6-ctemp
7-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

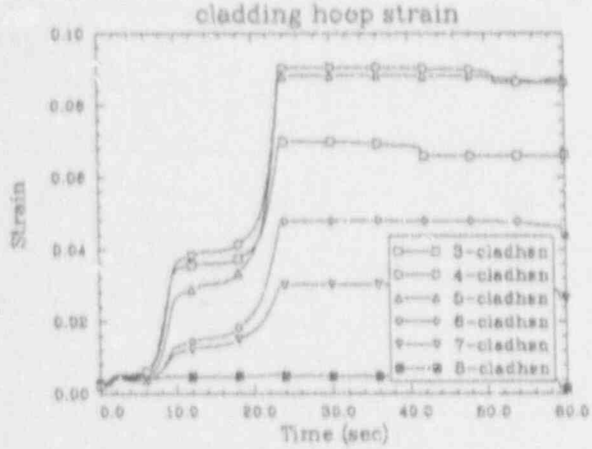
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/E&PT
internal pin pressure



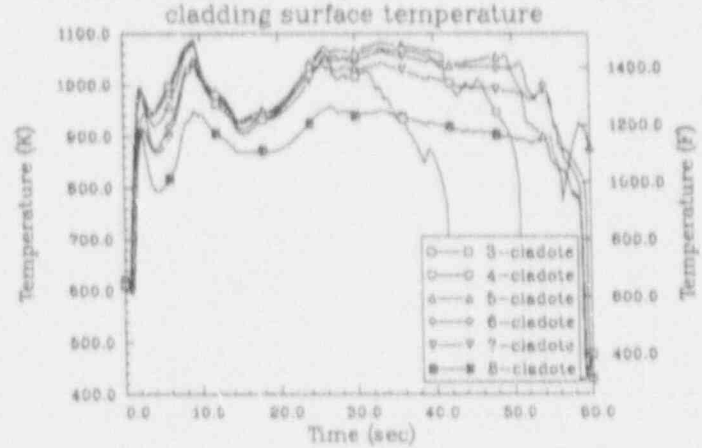
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/E&PT
failure probability



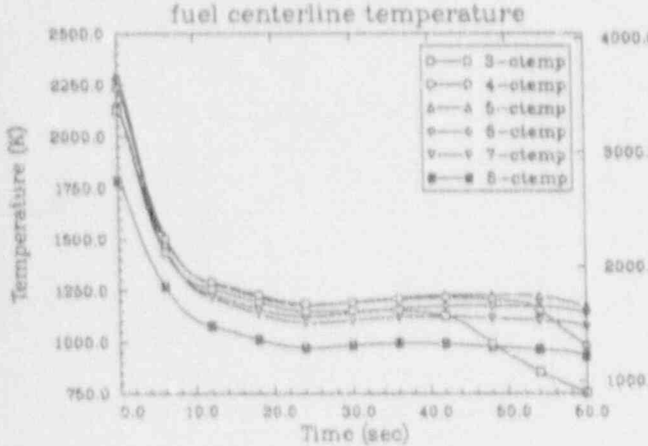
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/E&PT
cladding hoop strain



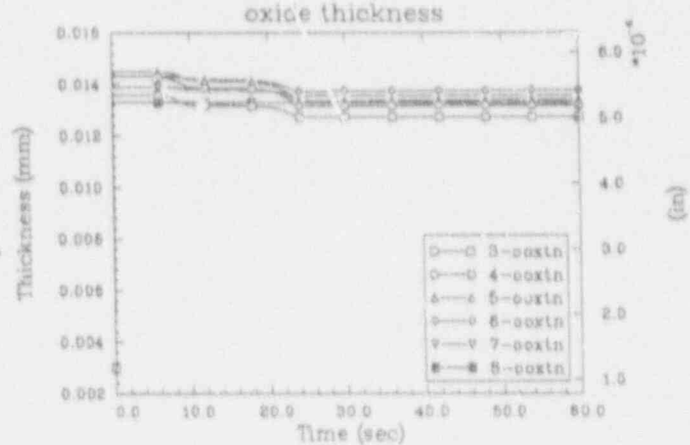
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/E&PT
cladding surface temperature

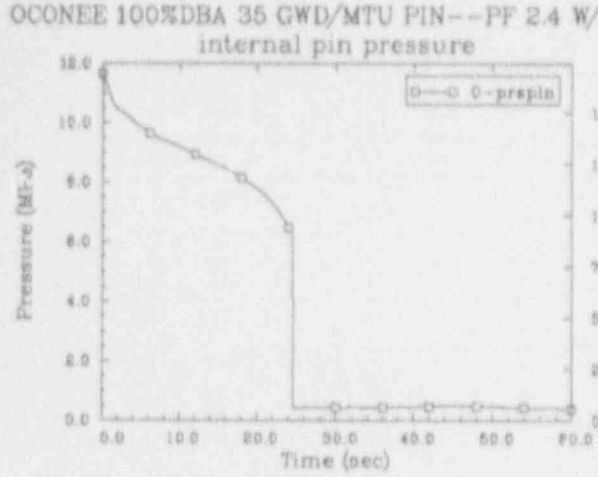


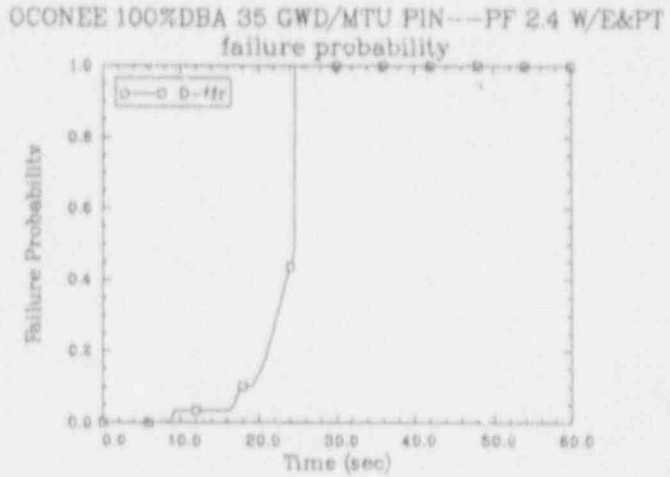
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/E&PT
fuel centerline temperature

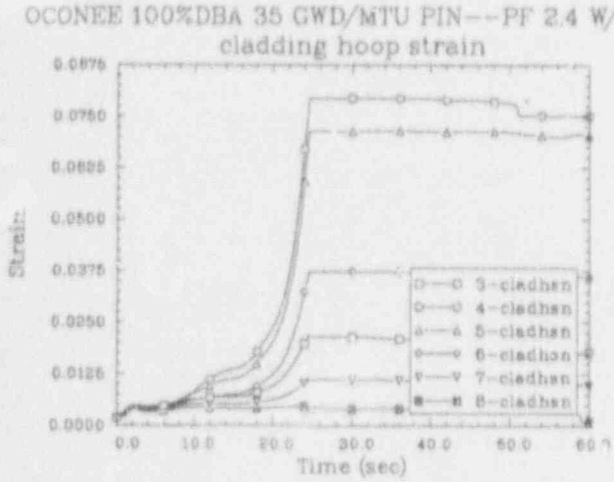


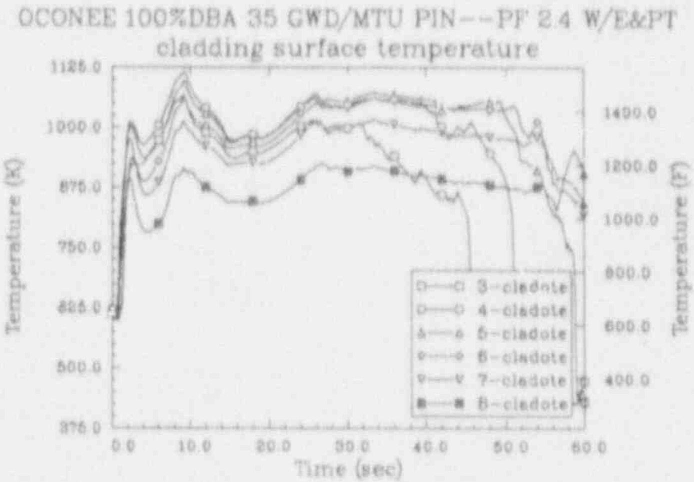
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/E&PT
oxide thickness

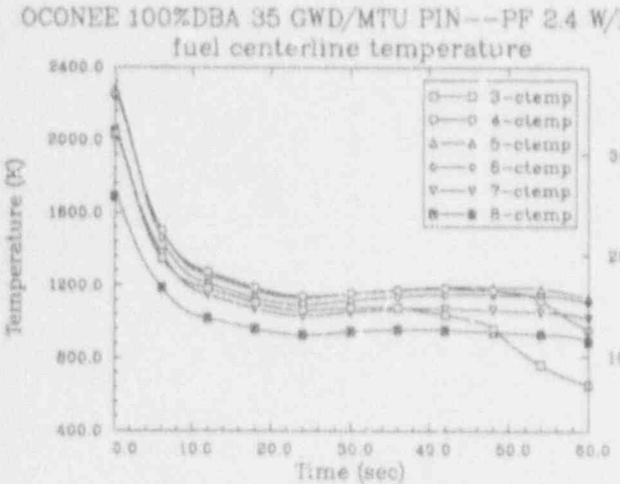


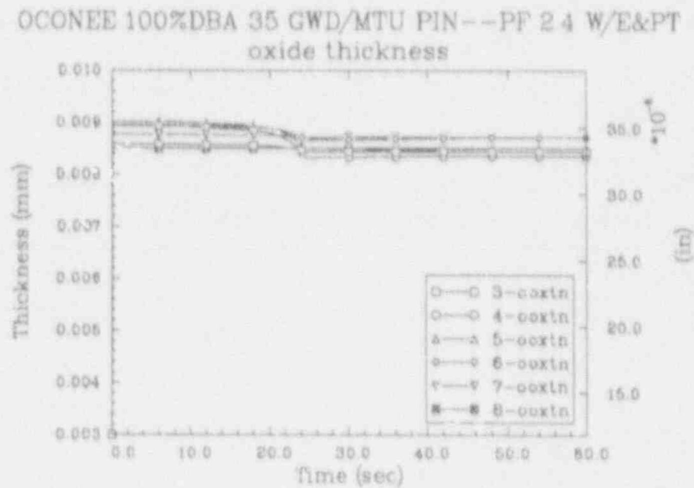

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/E&PT
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

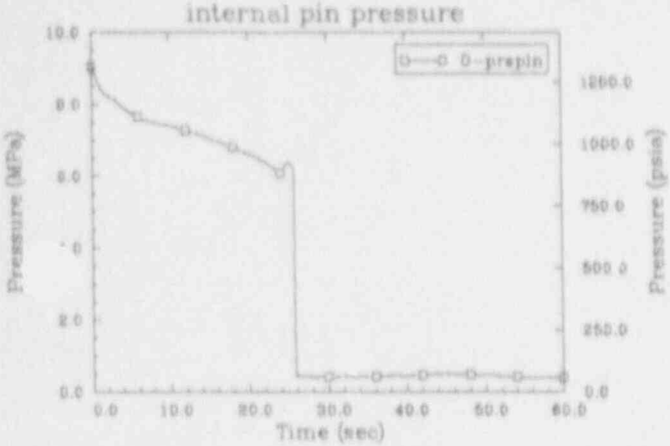

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

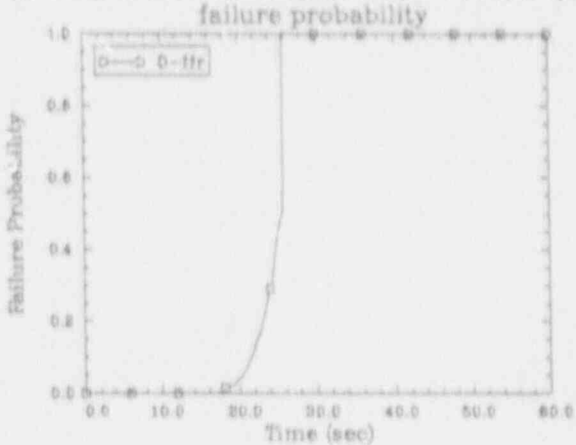

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.4 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

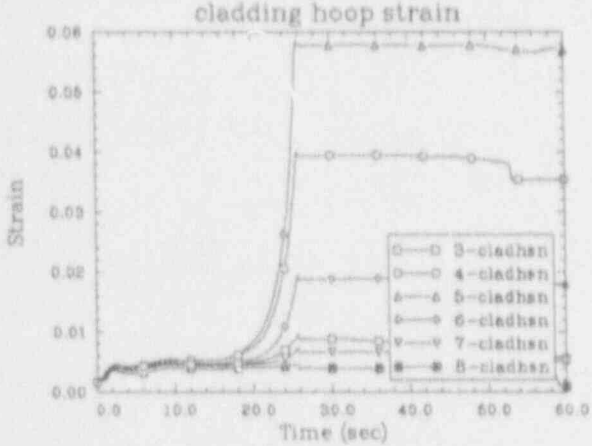
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/E&PT
internal pin pressure



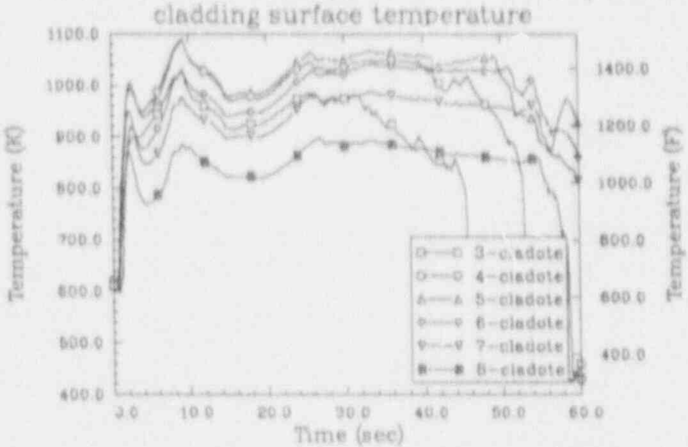
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/E&PT
failure probability



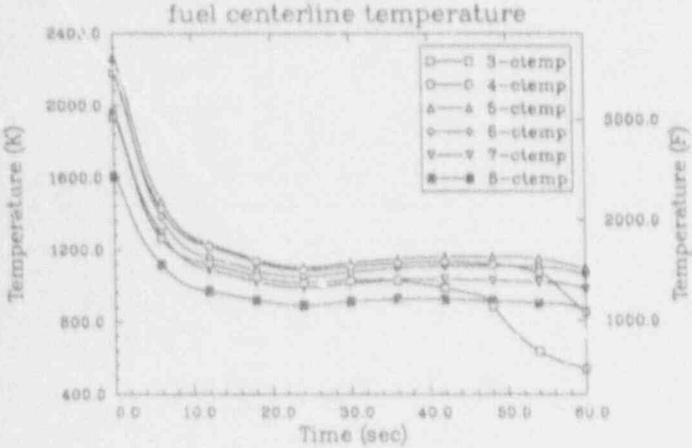
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/E&PT
cladding hoop strain



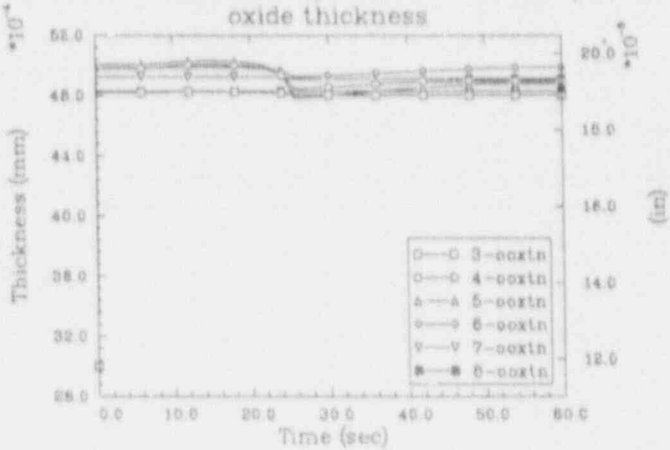
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/E&PT
cladding surface temperature

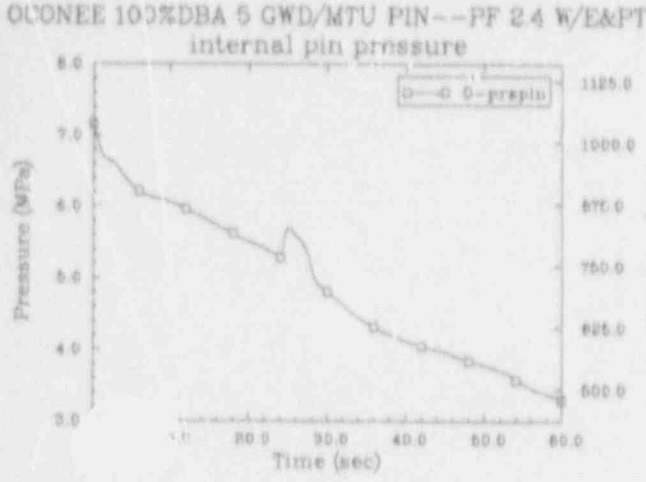


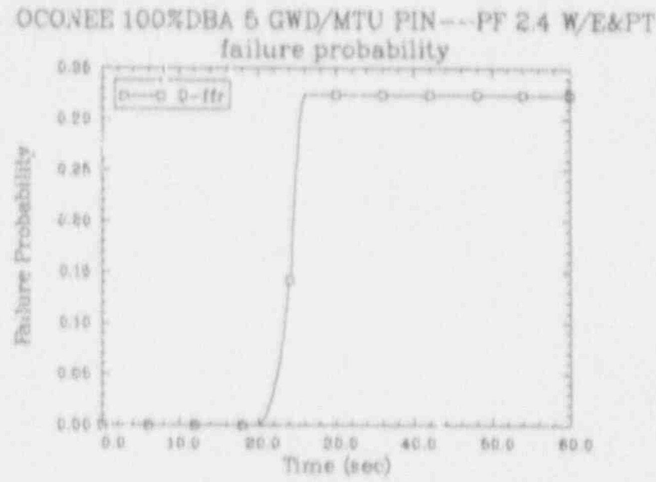
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/E&PT
fuel centerline temperature

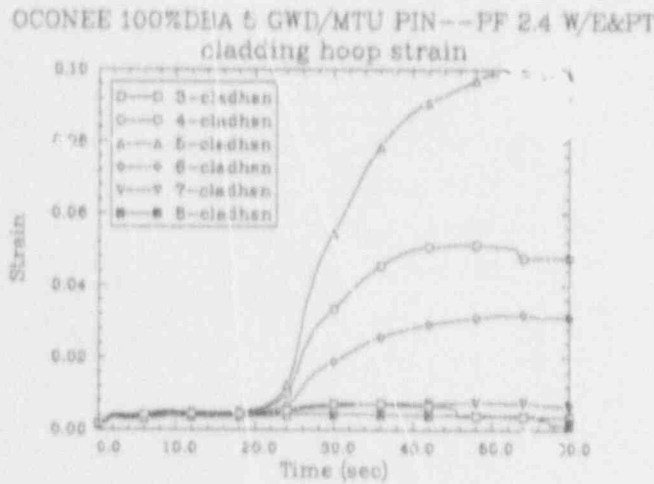


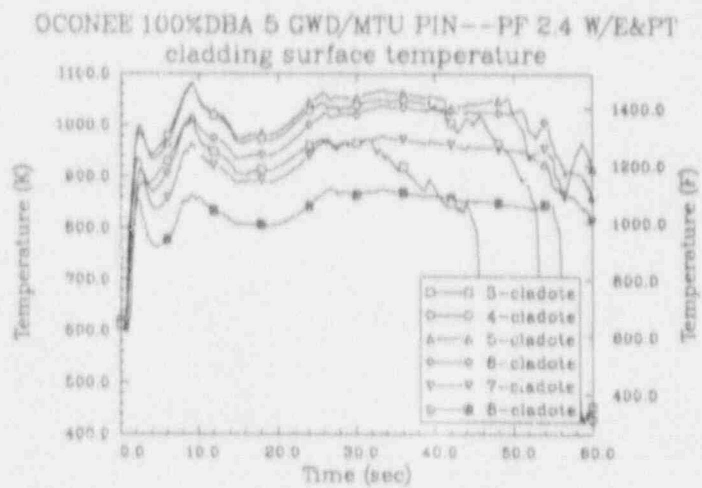
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/E&PT
oxide thickness

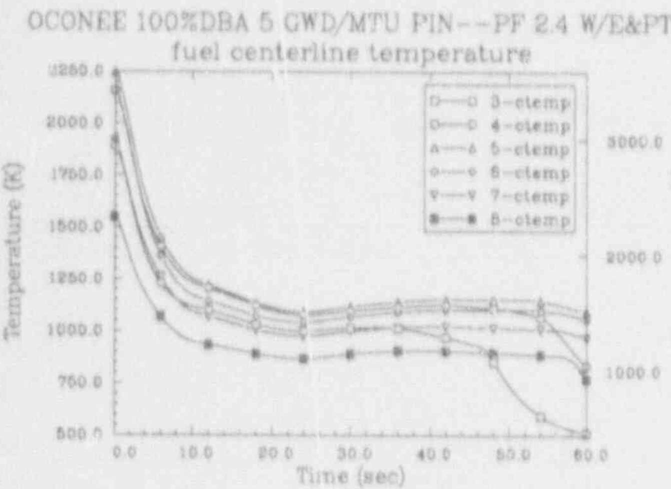


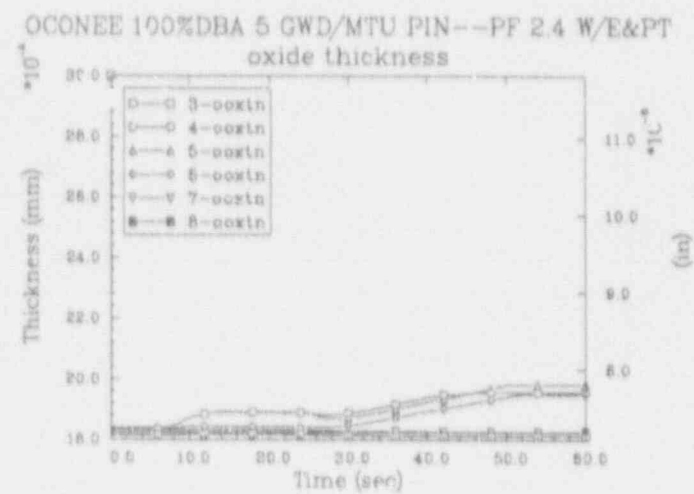

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/E&PT
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

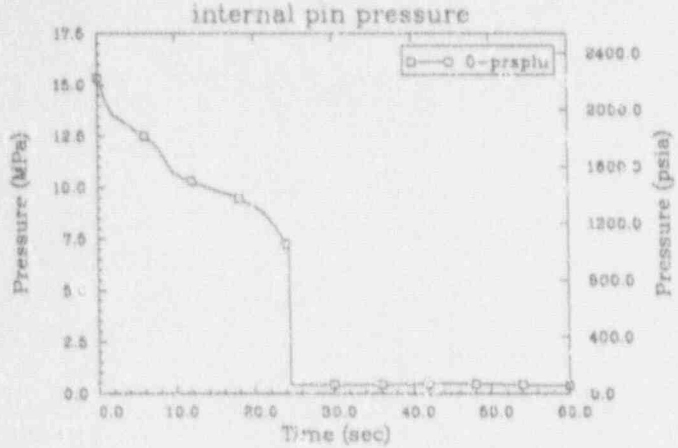

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

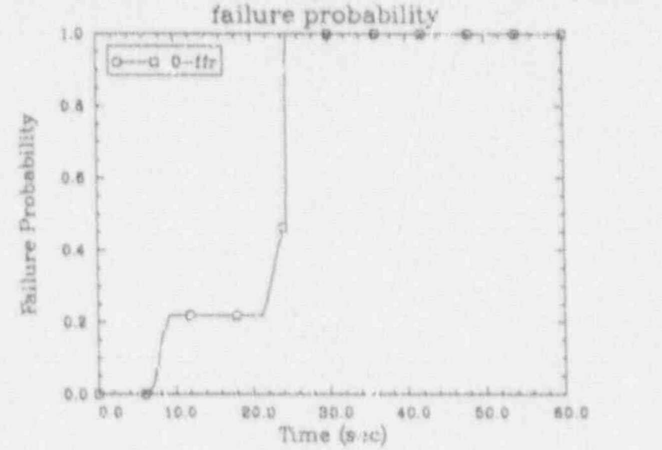

OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

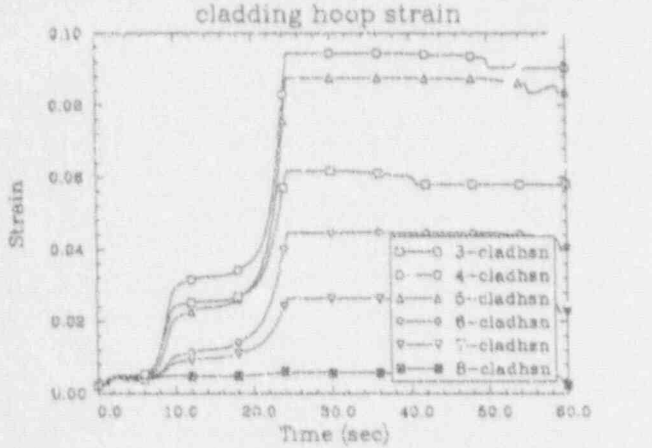
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/E&PT
internal pin pressure



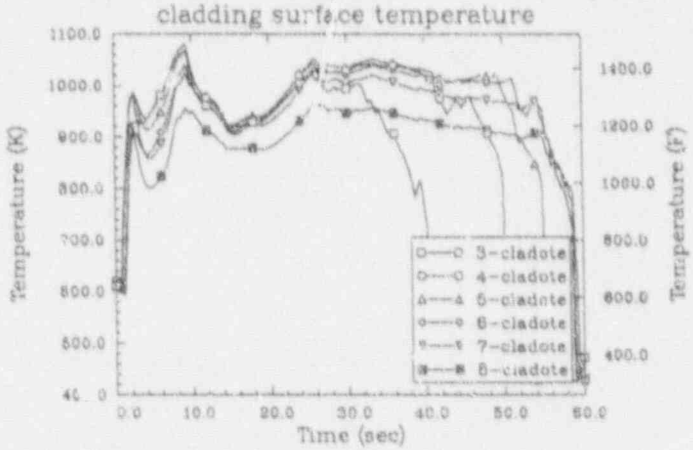
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/E&PT
failure probability



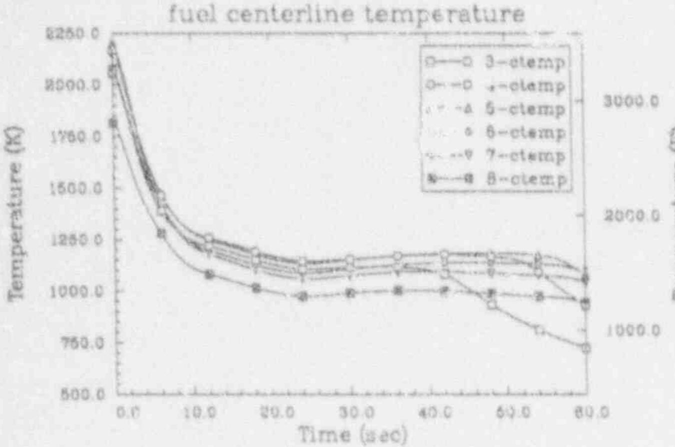
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/E&PT
cladding hoop strain



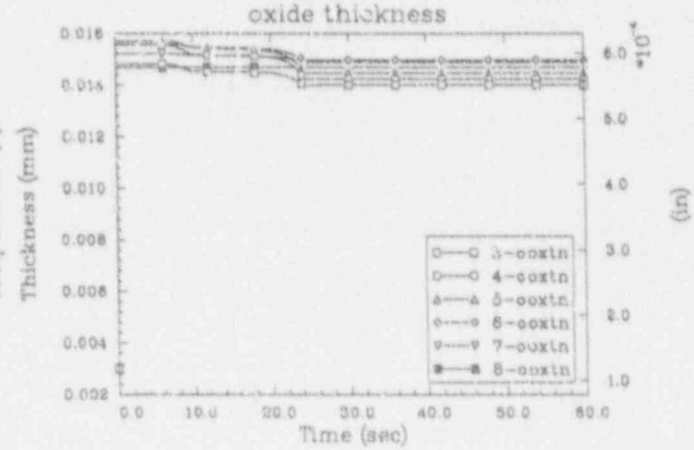
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/E&PT
cladding surface temperature



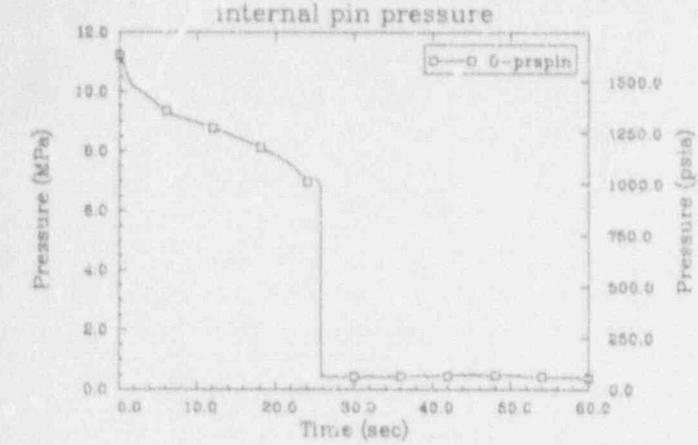
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/E&PT
fuel centerline temperature



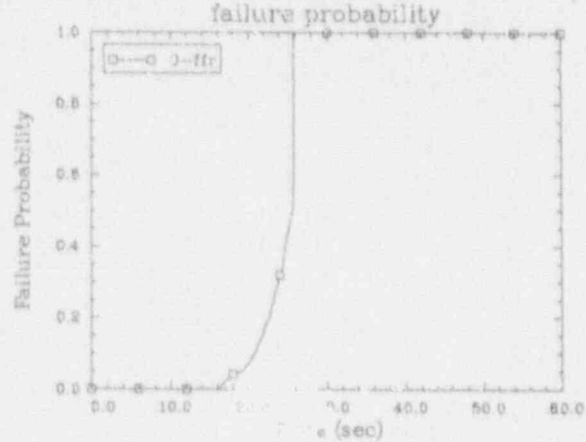
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/E&PT
oxide thickness



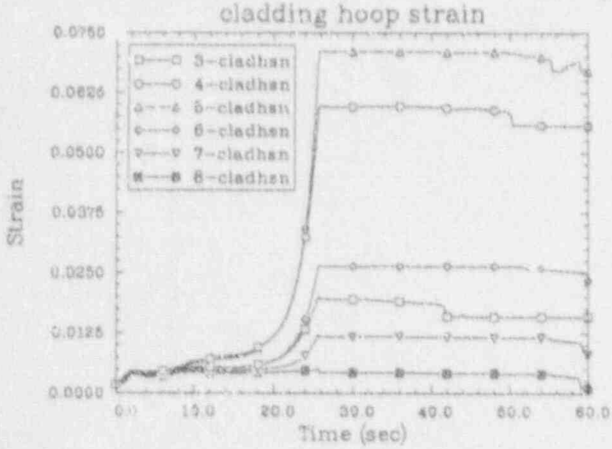
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/E&PT
internal pin pressure



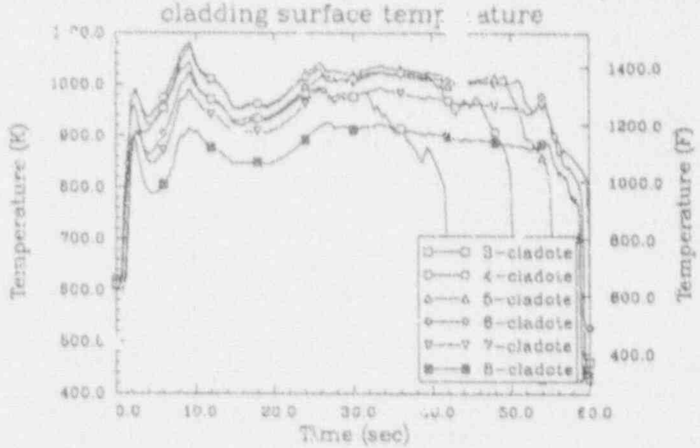
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/E&PT
failure probability



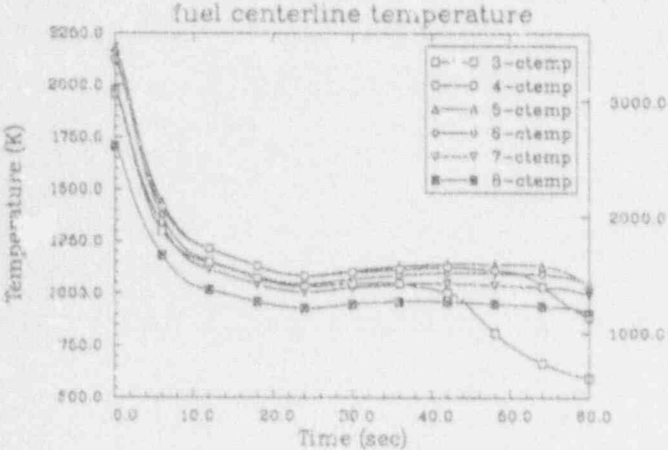
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/E&PT
cladding hoop strain



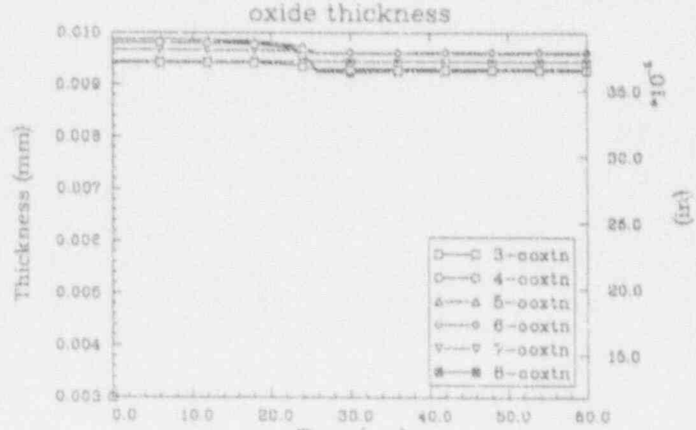
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/E&PT
cladding surface temperature

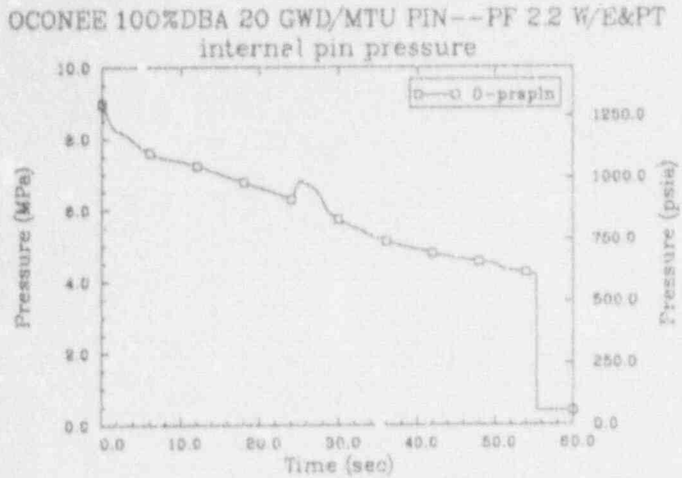


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/E&PT
fuel centerline temperature

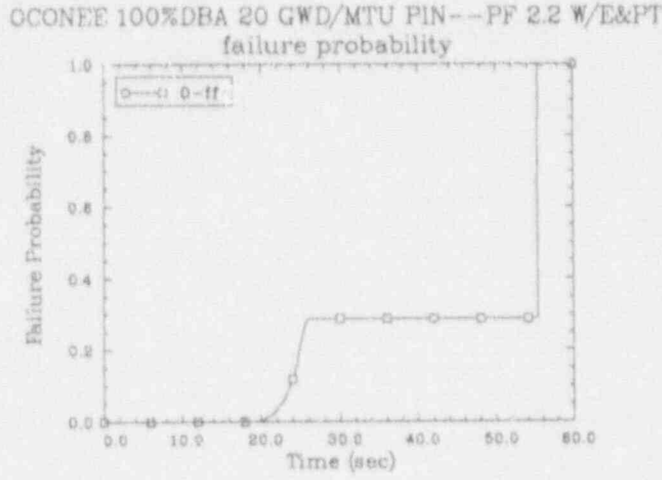


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/E&PT
oxide thickness

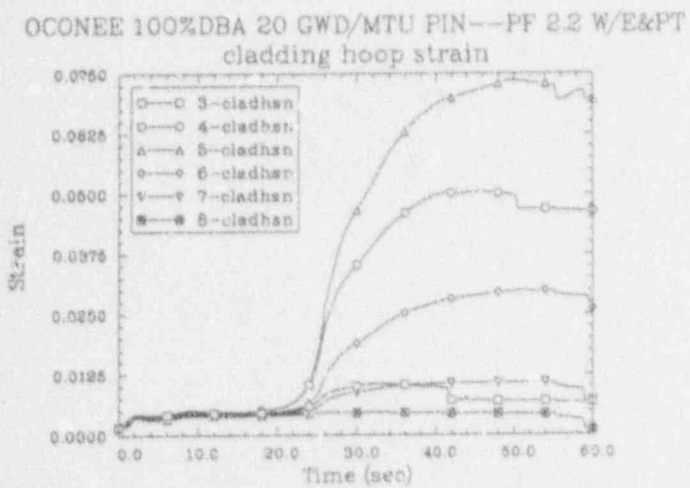




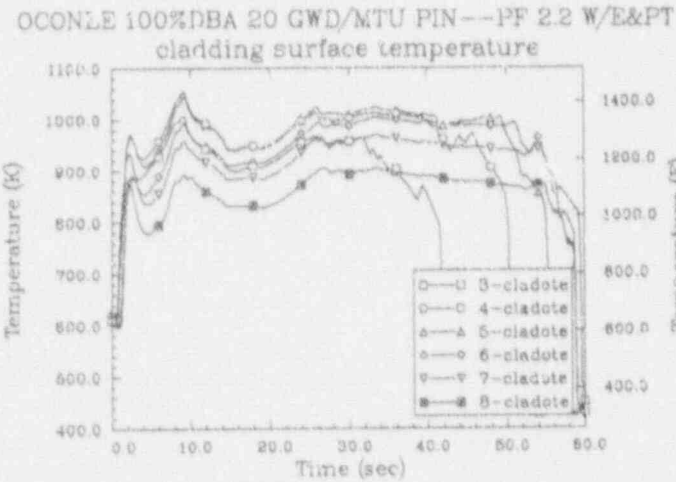
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/E&PT
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)



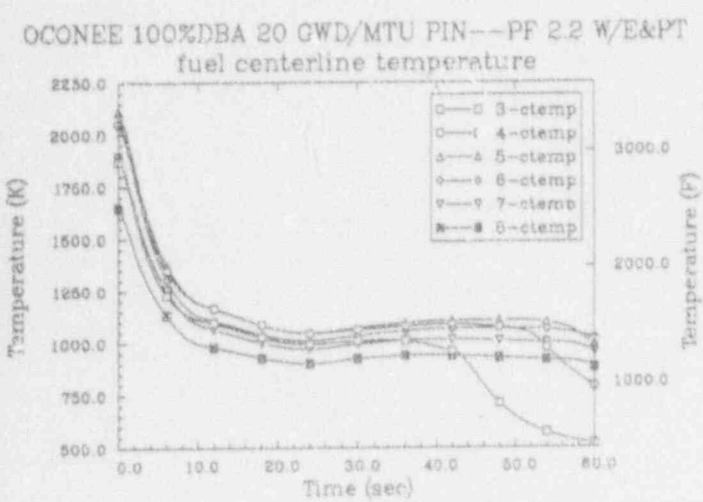
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/E&PT
failure probability
0-ff
Failure Probability
Time (sec)



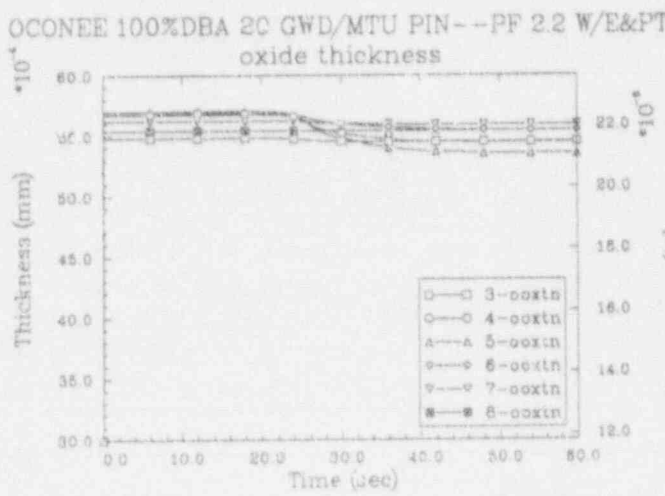
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)



OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

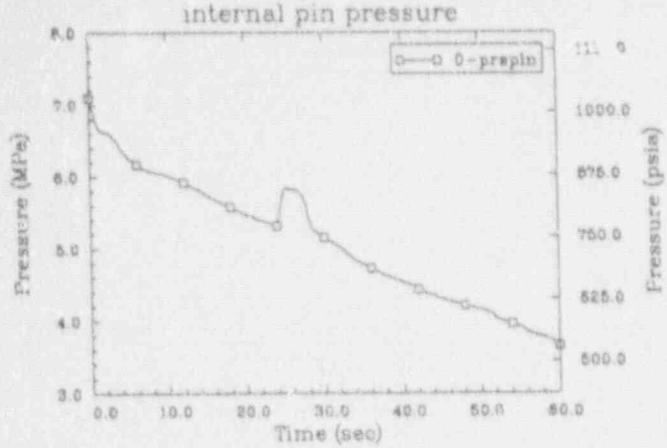


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

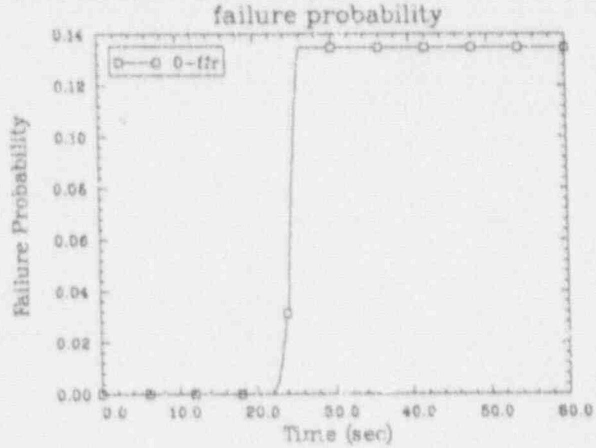


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

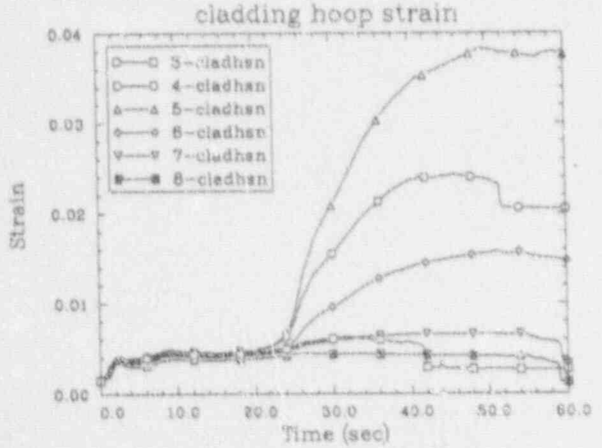
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/E&PT
internal pin pressure



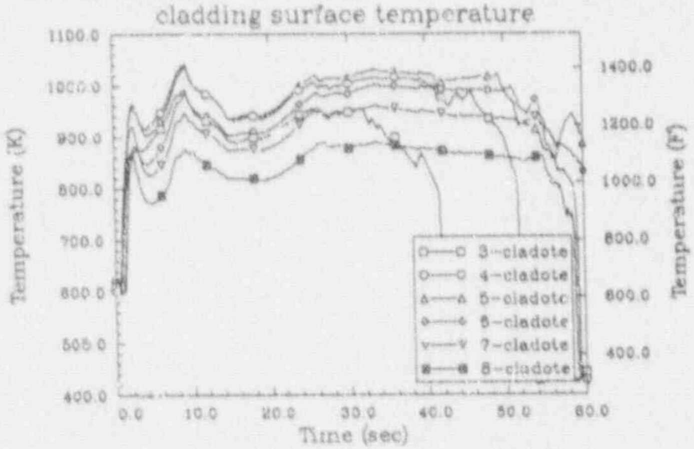
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/E&PT
failure probability



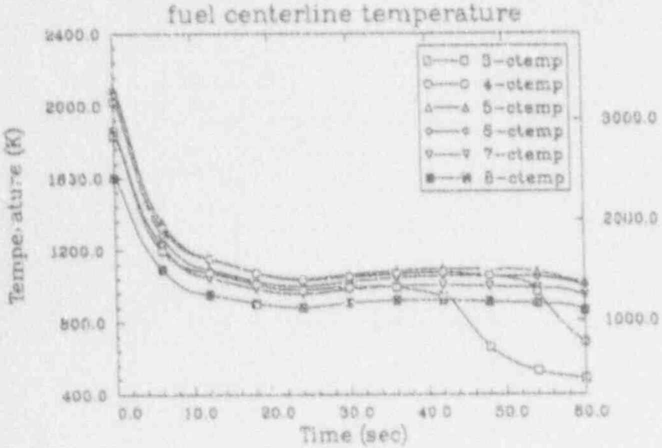
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/E&PT
cladding hoop strain



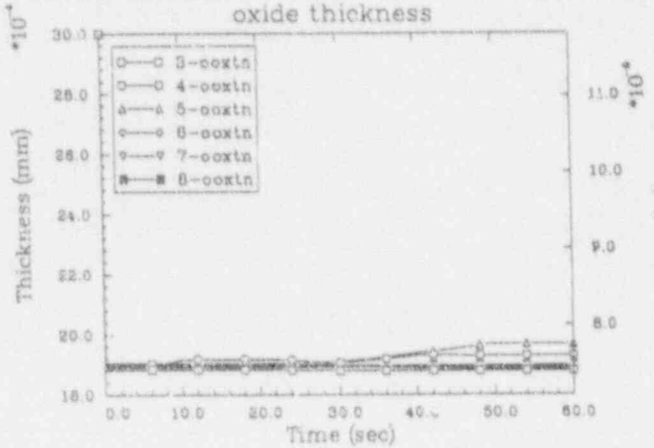
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/E&PT
cladding surface temperature



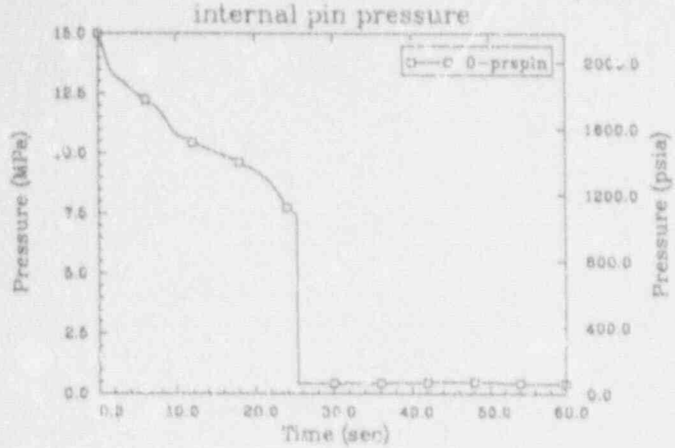
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/E&PT
fuel centerline temperature



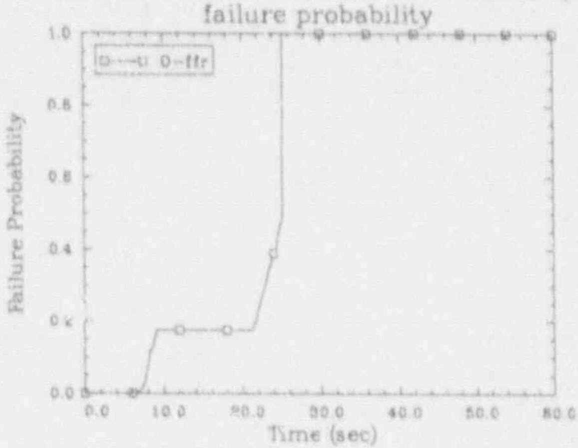
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/E&PT
oxide thickness



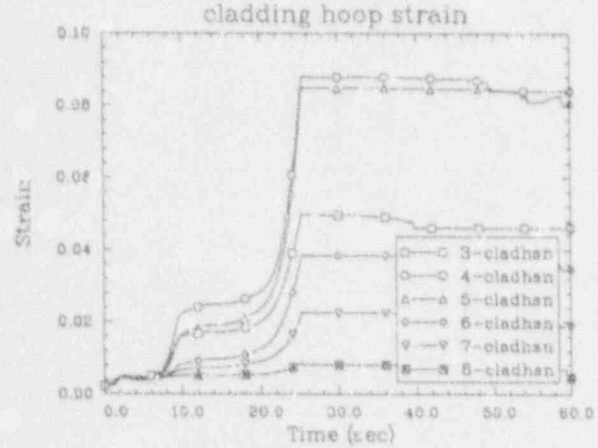
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/E&PT
internal pin pressure



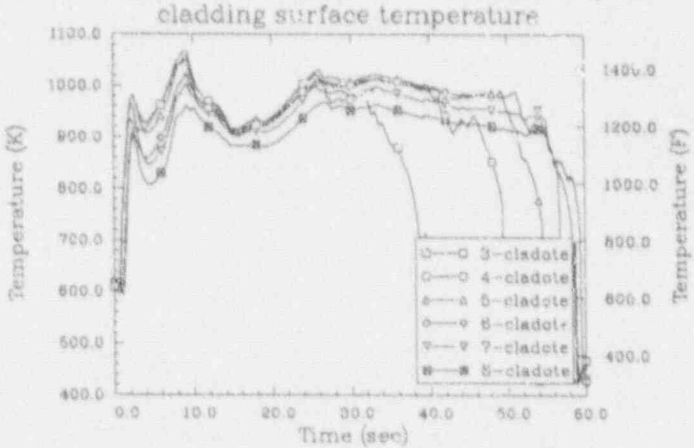
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/E&PT
failure probability



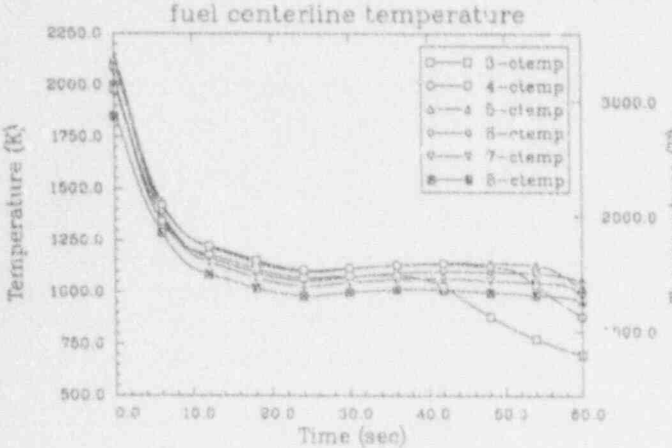
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/E&PT
cladding hoop strain



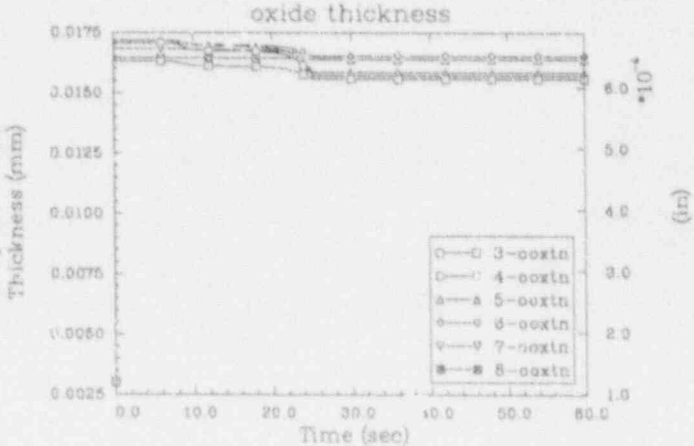
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/E&PT
cladding surface temperature

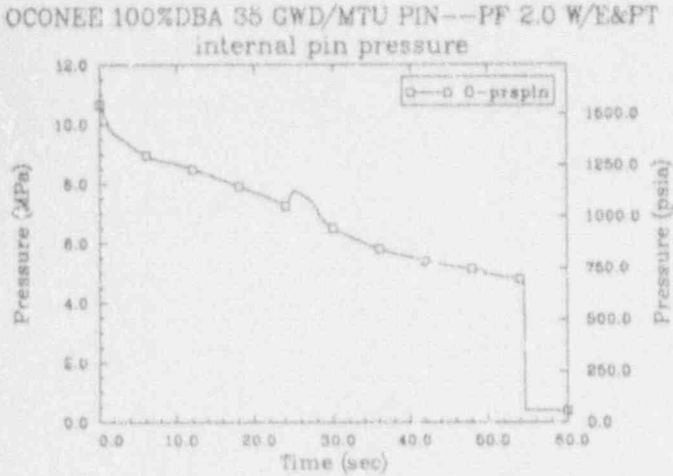


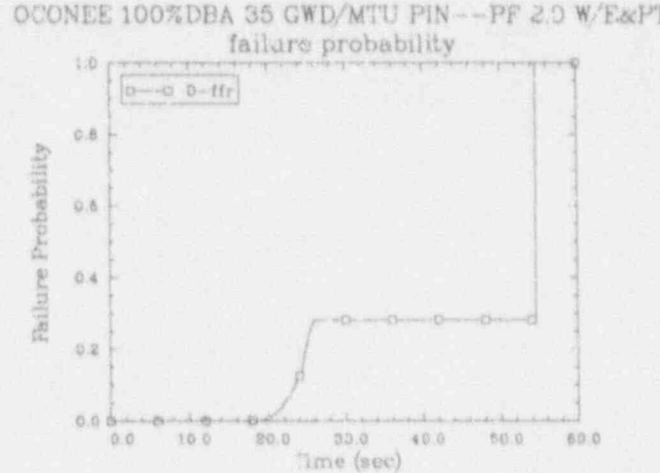
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/E&PT
fuel centerline temperature

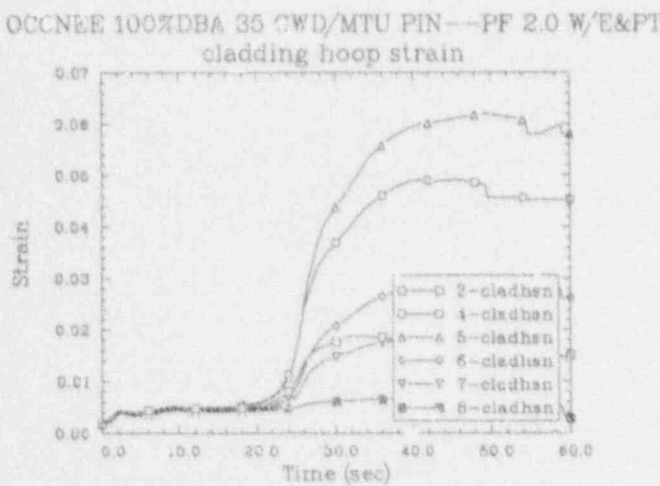


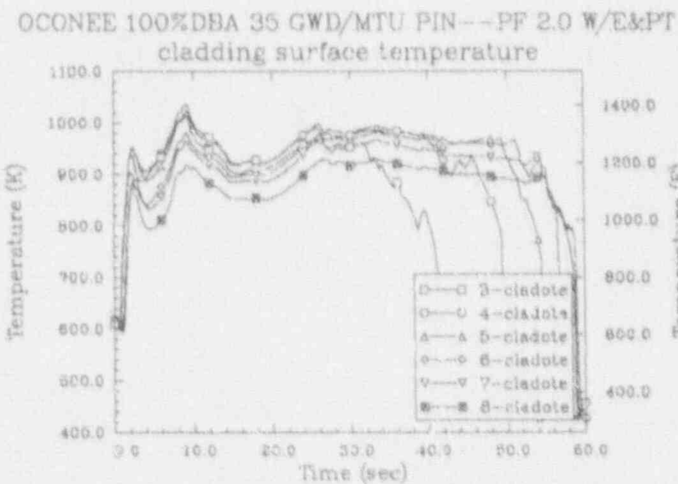
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/E&PT
oxide thickness

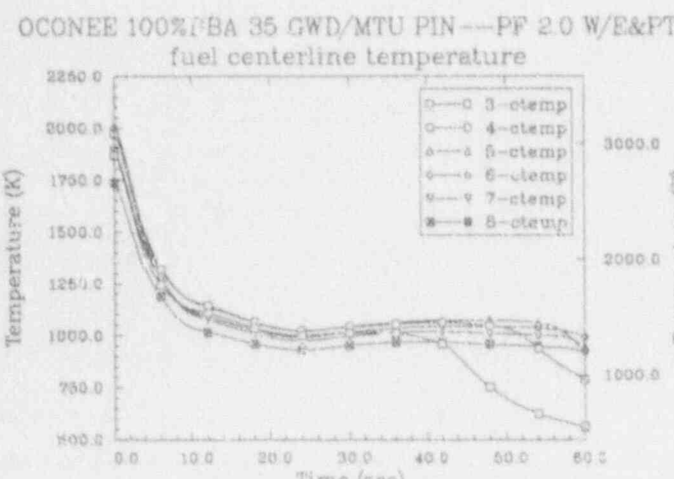


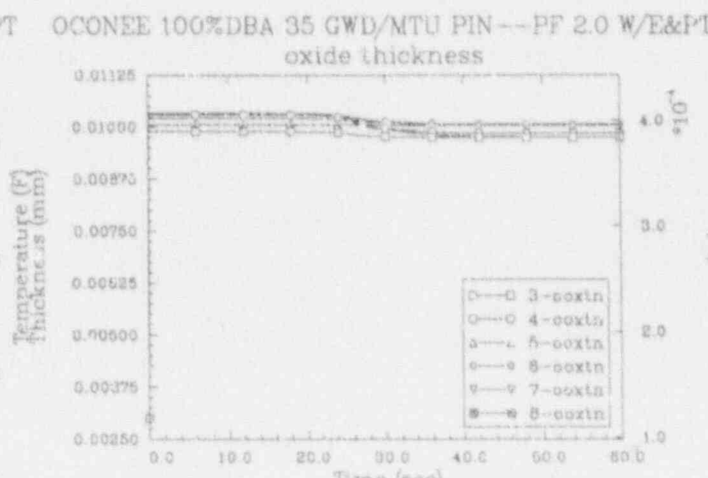

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/E&PT
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

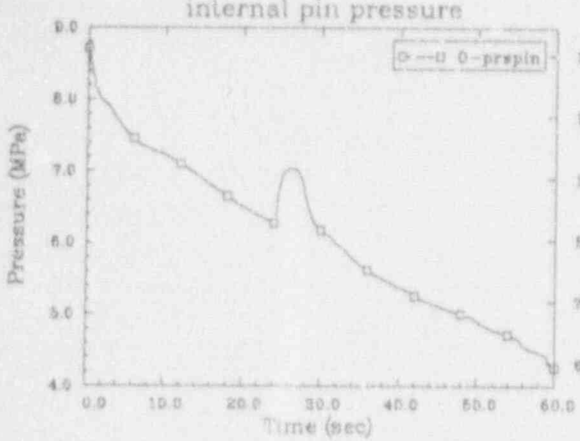

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/E&PT
cladding hoop strain
Strain
2-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/E&PT
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Time (sec)

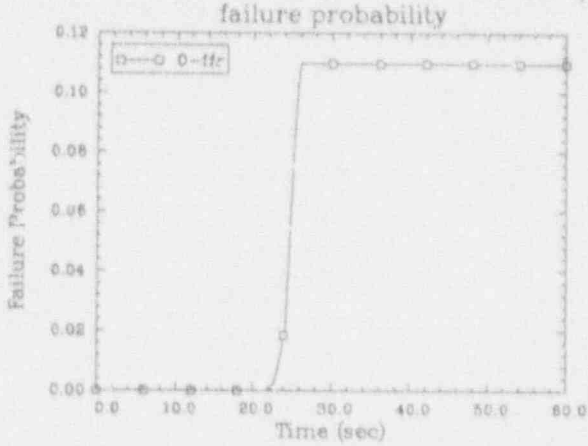

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/E&PT
fuel centerline temperature
Temperature (K)
Temperature (F)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/E&PT
oxide thickness
Thickness (mm)
(in)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Time (sec)

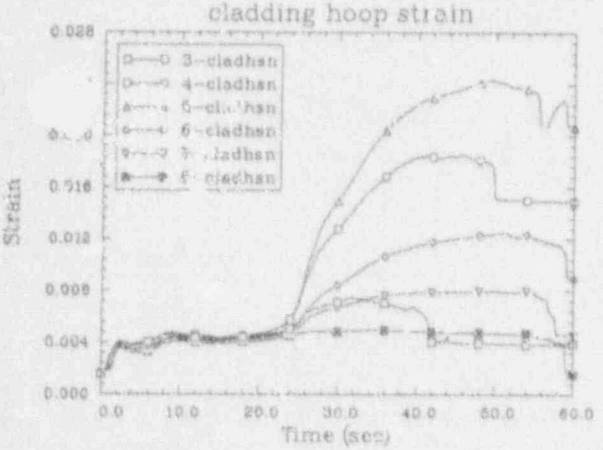
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/E&PT
internal pin pressure



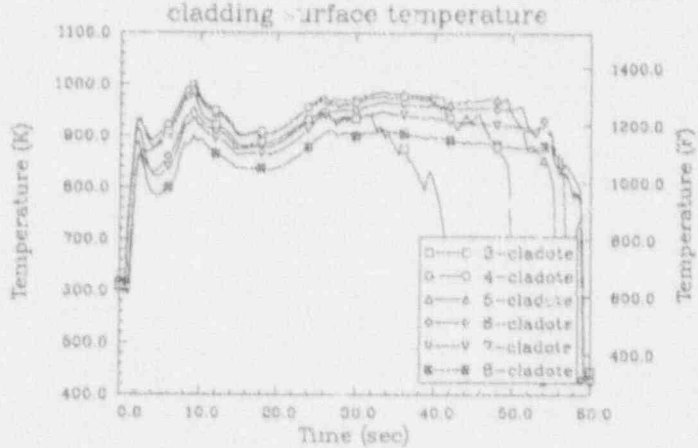
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/E&PT
failure probability



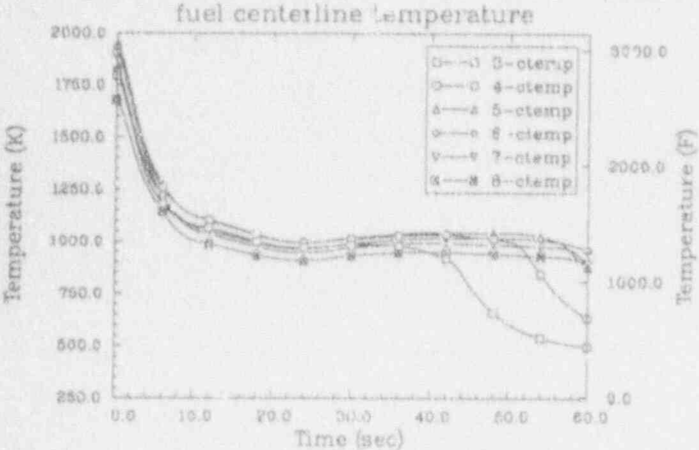
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/E&PT
cladding hoop strain



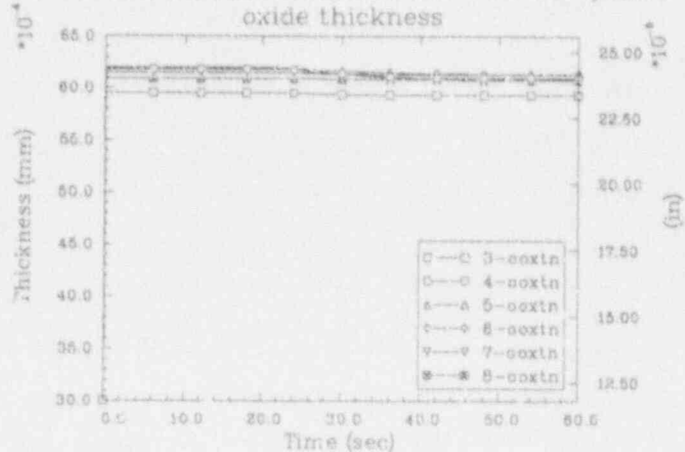
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/E&PT
cladding surface temperature



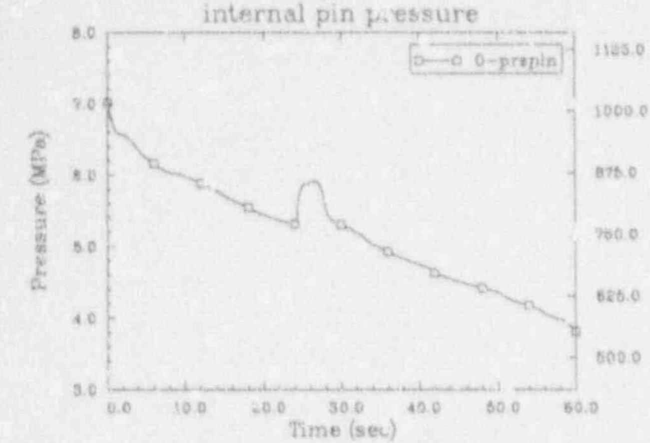
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/E&PT
fuel centerline temperature



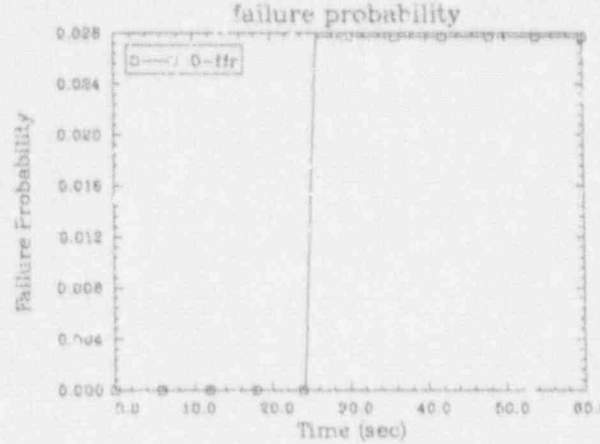
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/E&PT
oxide thickness



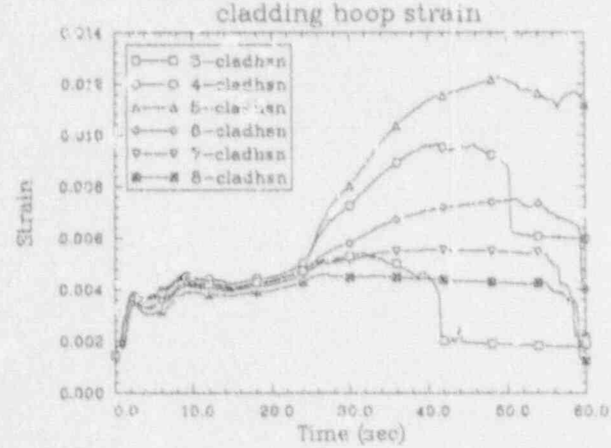
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/E&PT
internal pin pressure



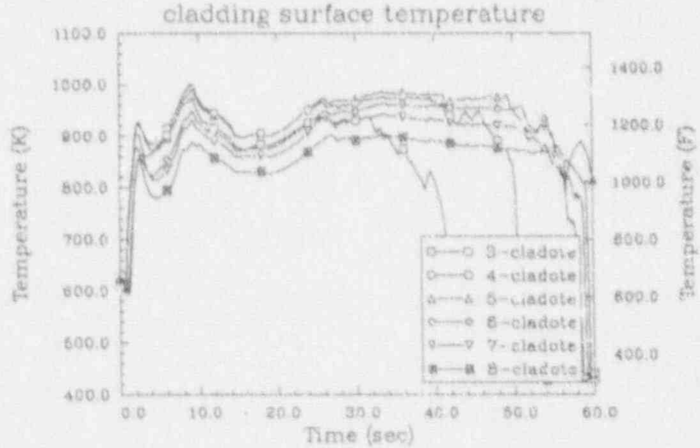
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/E&PT
failure probability



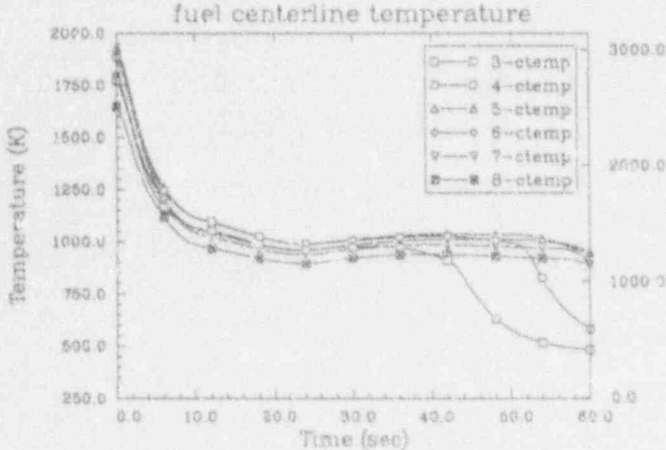
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/E&PT
cladding hoop strain



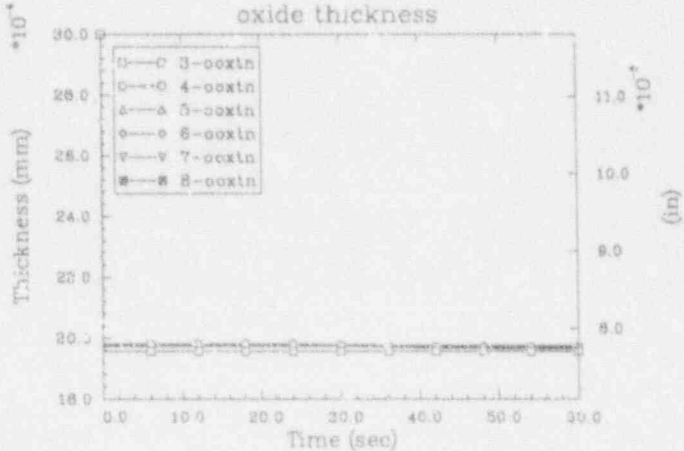
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/E&PT
cladding surface temperature



OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/E&PT
fuel centerline temperature

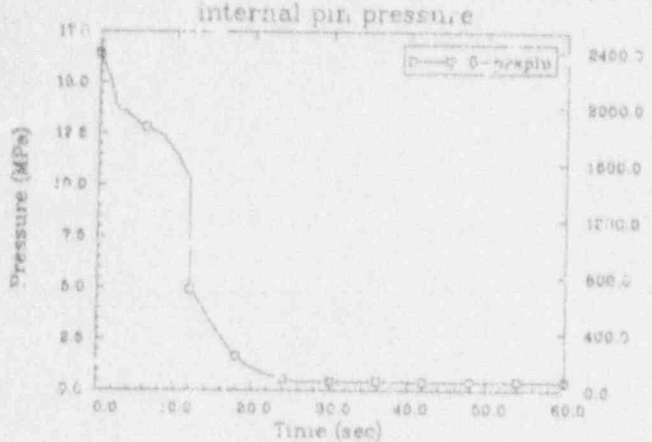


OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/E&PT
oxide thickness



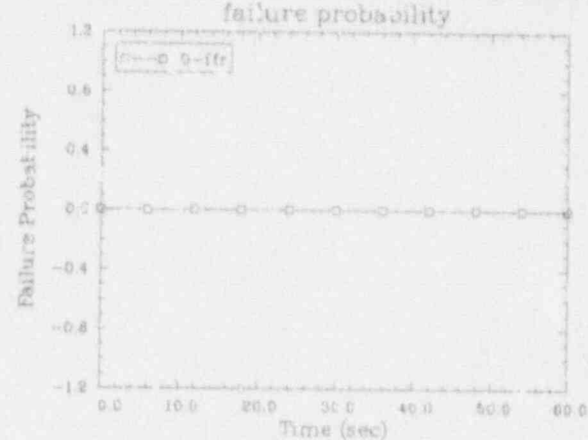
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/EMON

internal pin pressure



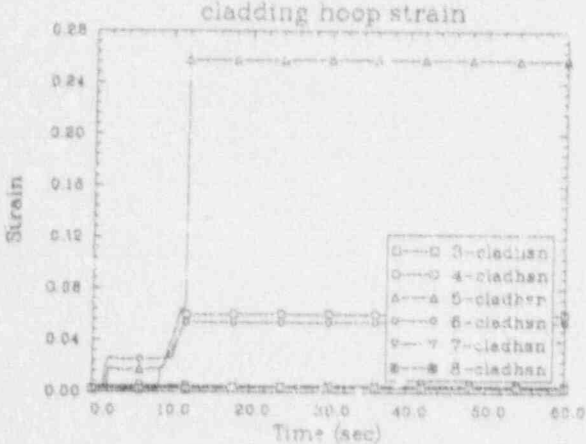
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/EMON

failure probability



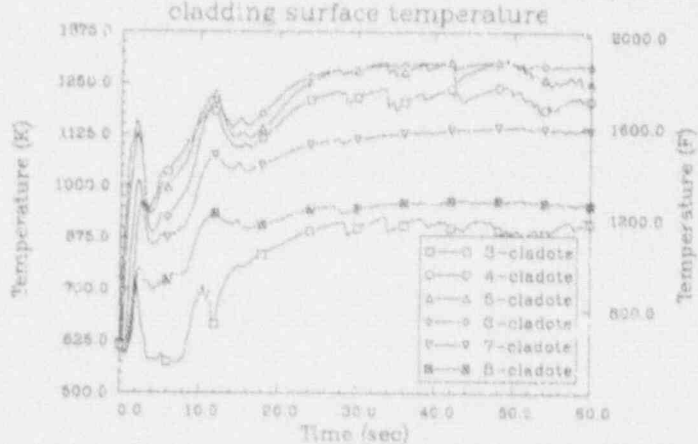
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/EMON

cladding hoop strain



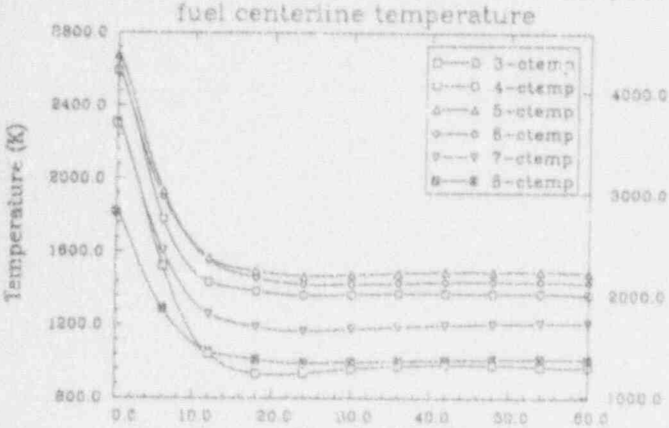
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/EMON

cladding surface temperature



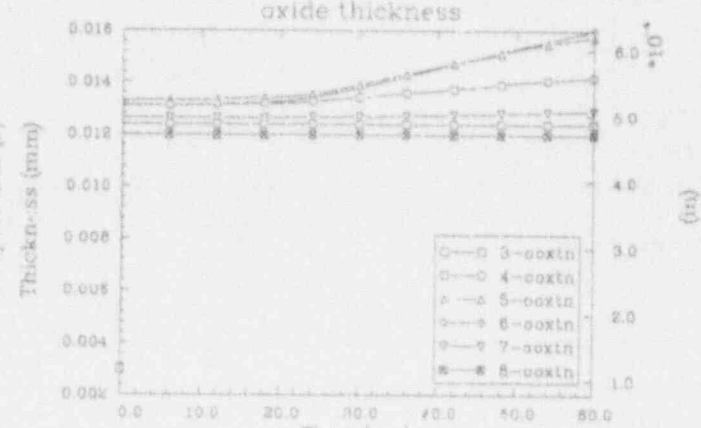
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/EMON

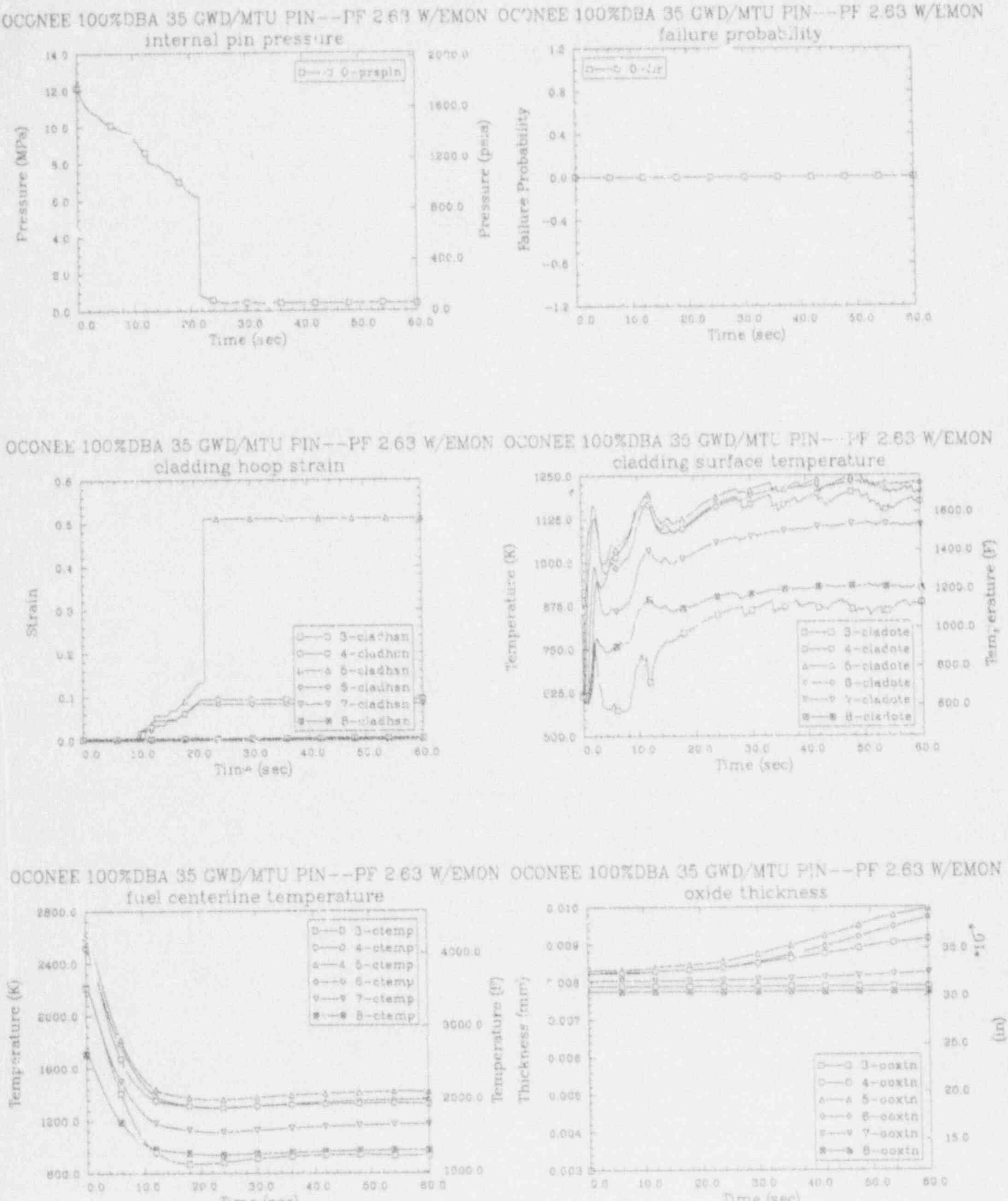
fuel centerline temperature



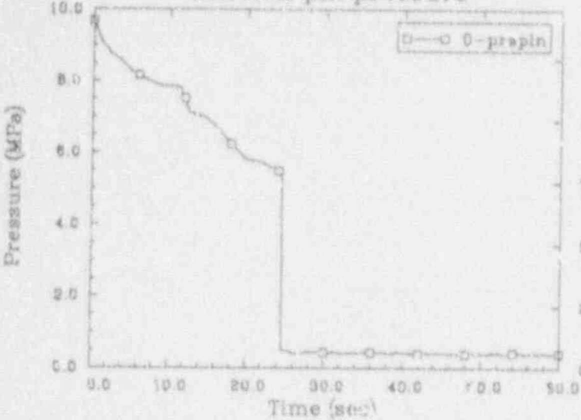
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.63 W/EMON

oxide thickness

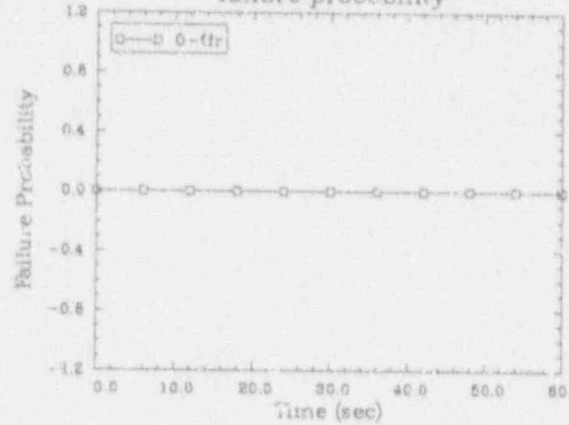



OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/EMON
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/EMON
failure probability
Failure Probability
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/EMON
cladding hoop strain
Strain
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/EMON
cladding surface temperature
Temperature (K)
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/EMON
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.63 W/EMON
oxide thickness
Time (sec)

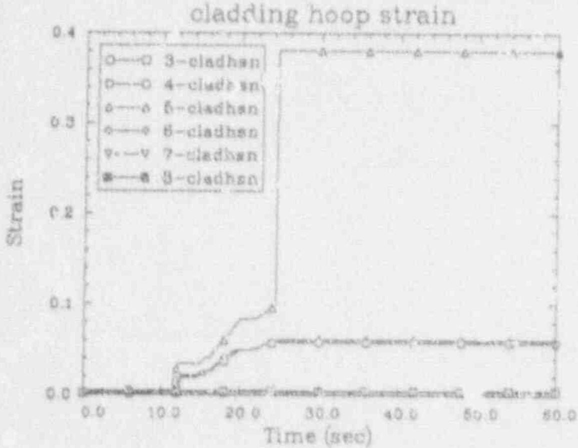
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/EMON
internal pin pressure



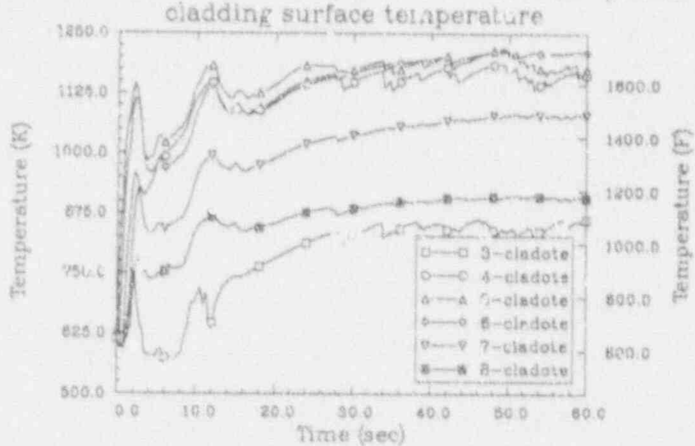
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/EMON
failure probability



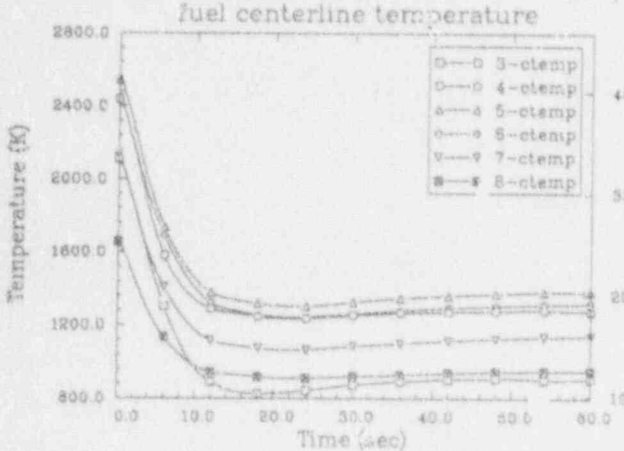
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/EMON
cladding hoop strain



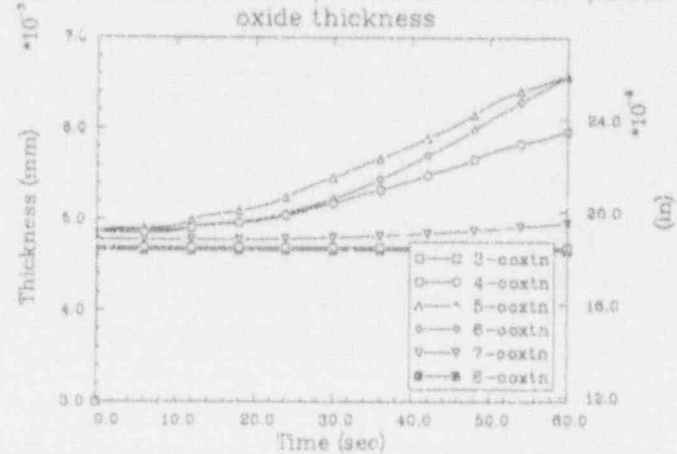
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/EMON
cladding surface temperature



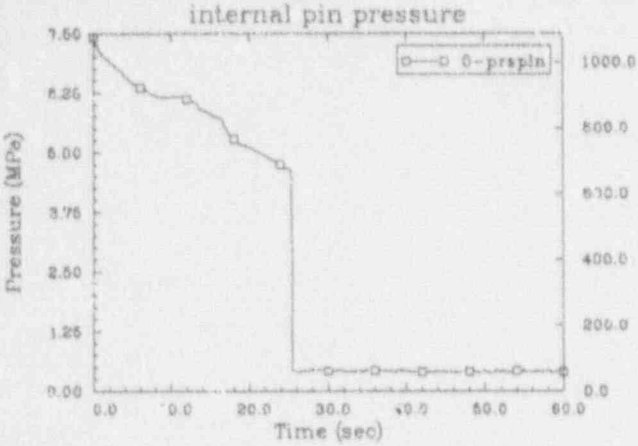
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/EMON
fuel centerline temperature



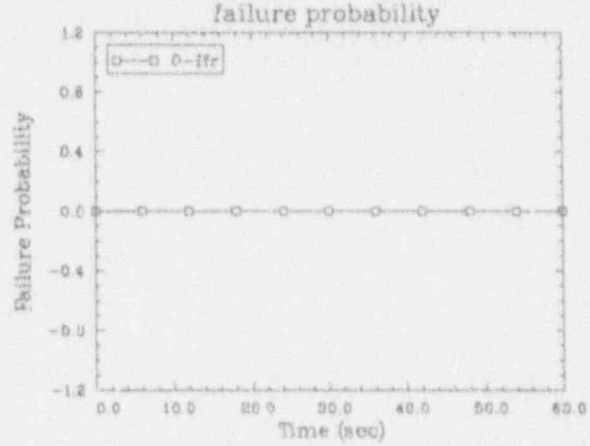
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.63 W/EMON
oxide thickness



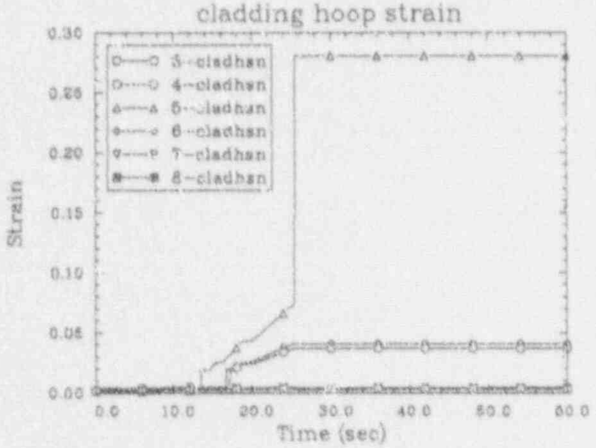
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/EMON
internal pin pressure



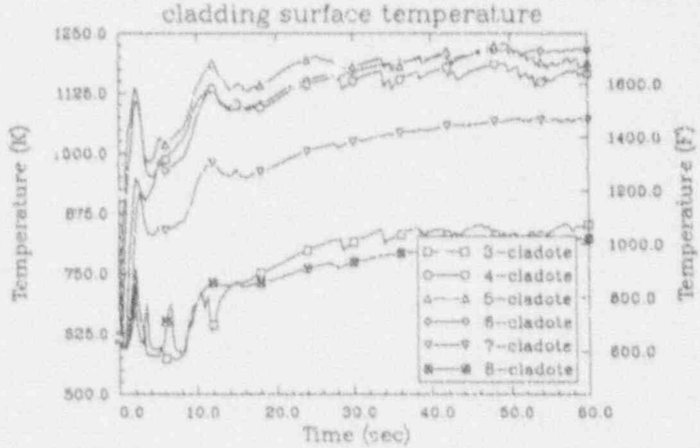
OCONEF 100%DBA 5 GWD/MTU PIN--PF 2.63 W/EMON
failure probability



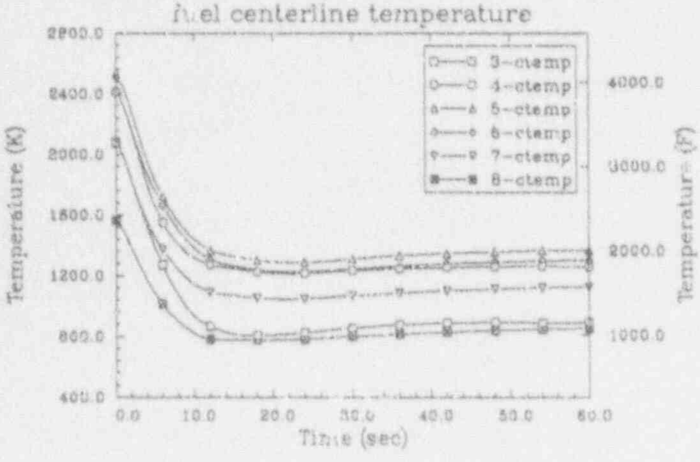
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/EMON
cladding hoop strain



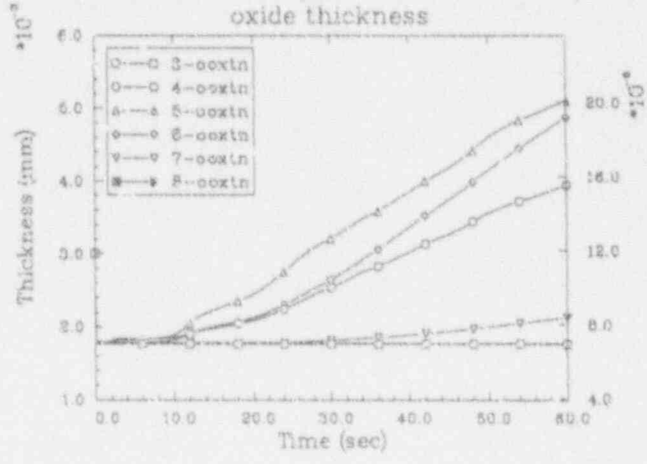
OCONEF 100%DBA 5 GWD/MTU PIN--PF 2.63 W/EMON
cladding surface temperature



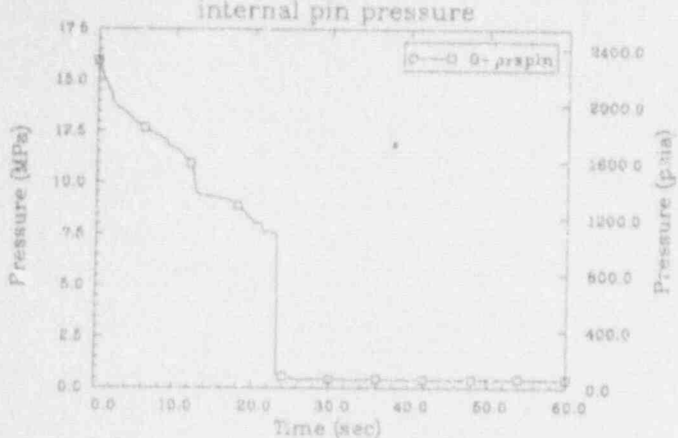
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/EMON
fuel centerline temperature



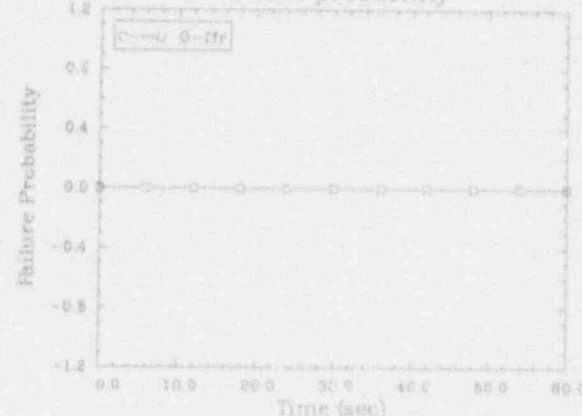
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.63 W/EMON
oxide thickness



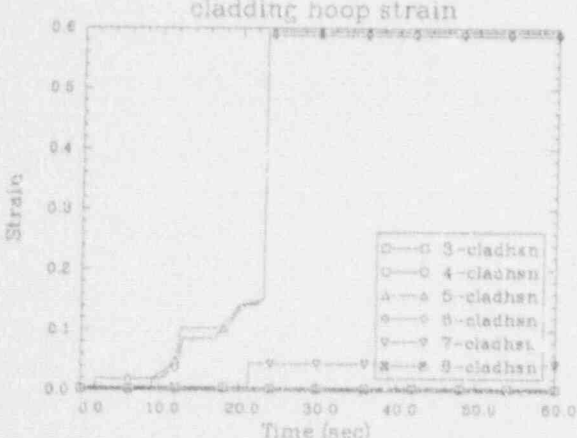
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/EMON
internal pin pressure



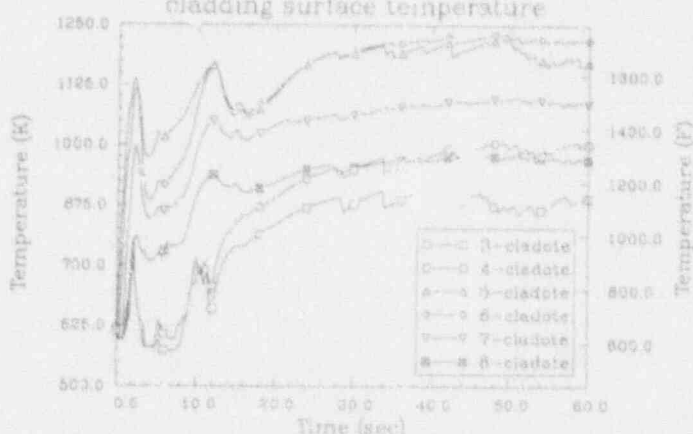
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/EMON
failure probability



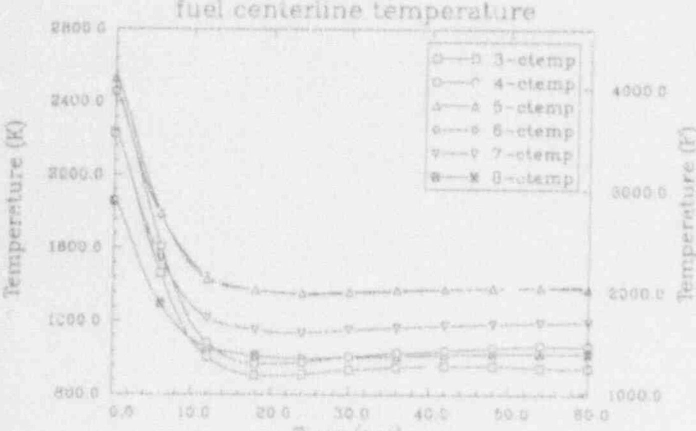
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/EMON
cladding hoop strain



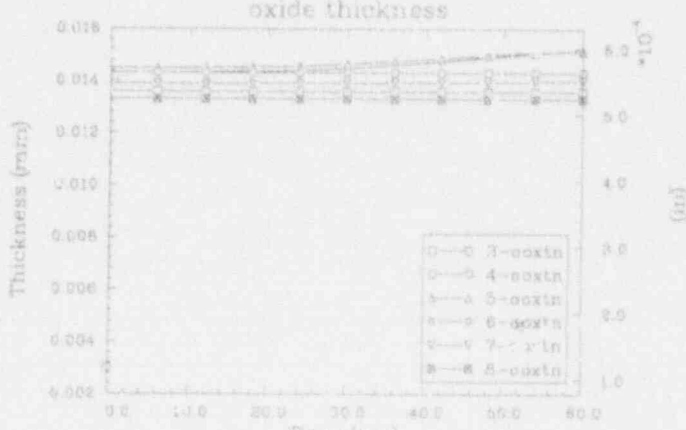
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/EMON
cladding surface temperature

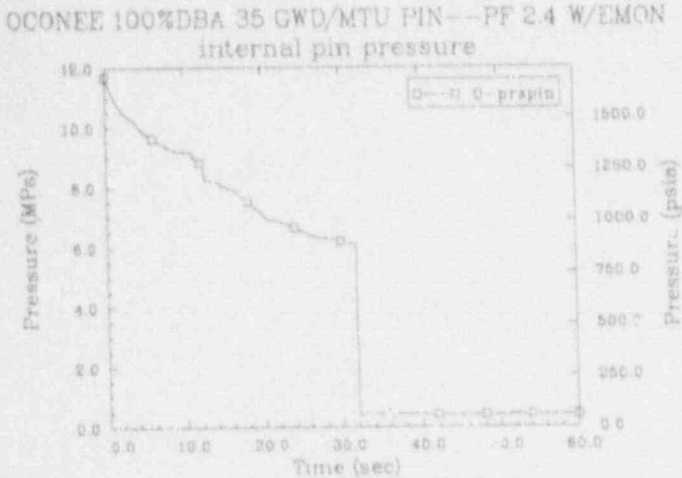


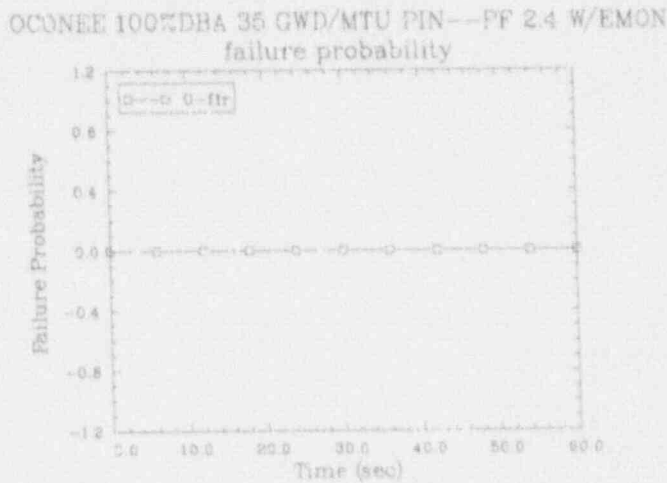
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/EMON
fuel centerline temperature

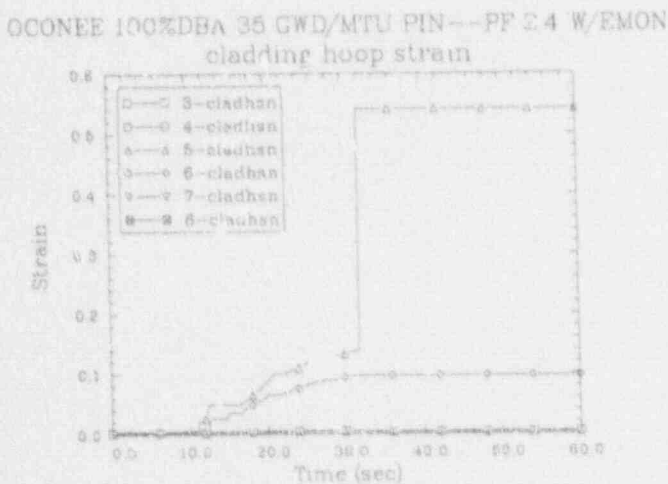


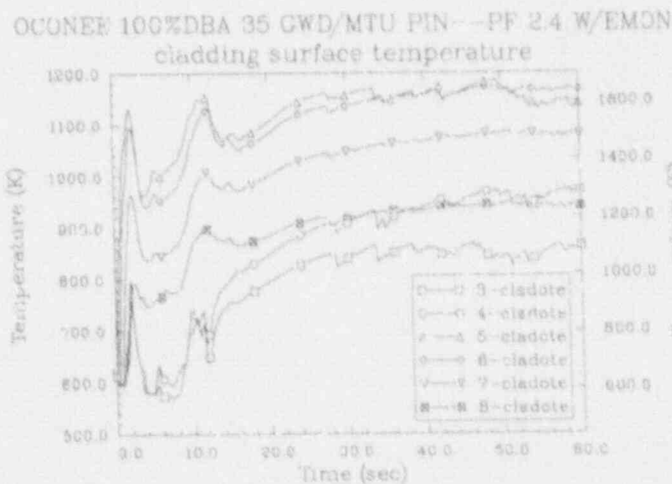
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.4 W/EMON
oxide thickness

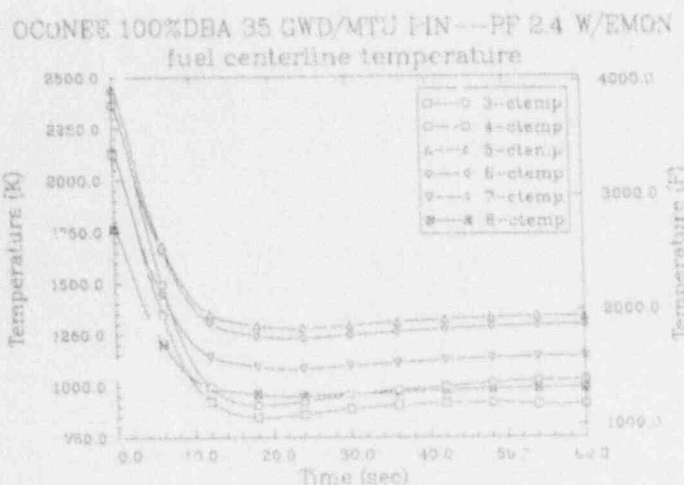


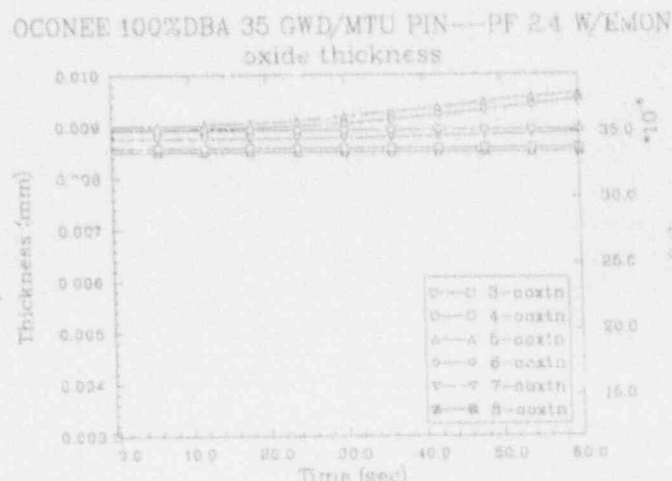

OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.4 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.4 W/EMON
failure probability
0-flr
Failure Probability
Time (sec)

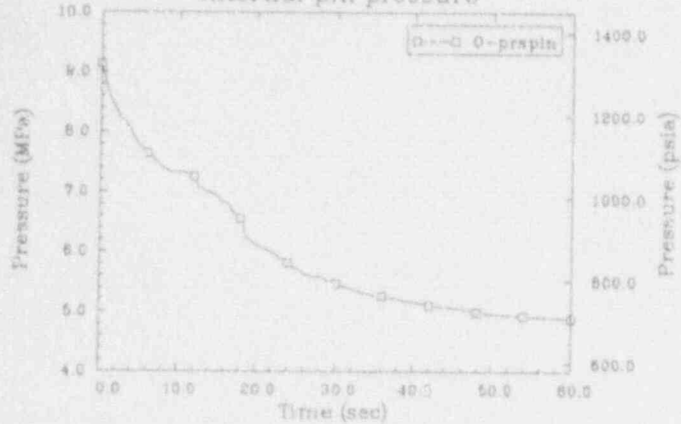

OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.4 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.4 W/EMON
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

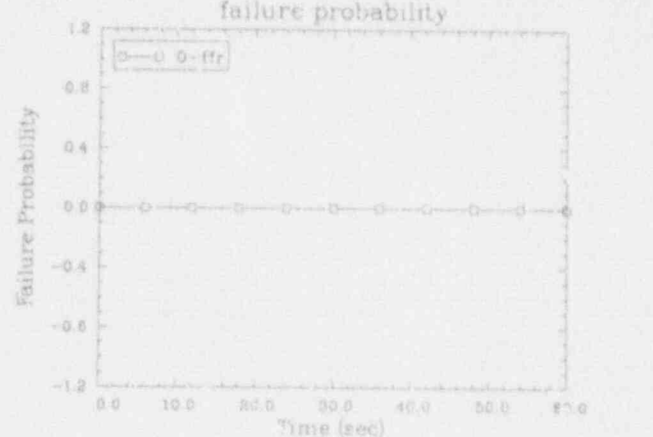

OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.4 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 35 GWD/MTU PIN---PF 2.4 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

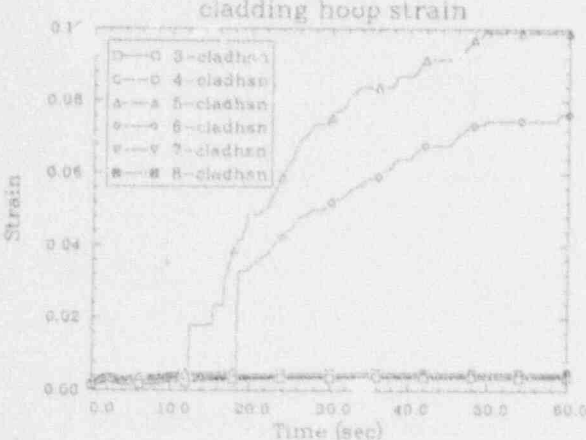
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/EMON
internal pin pressure



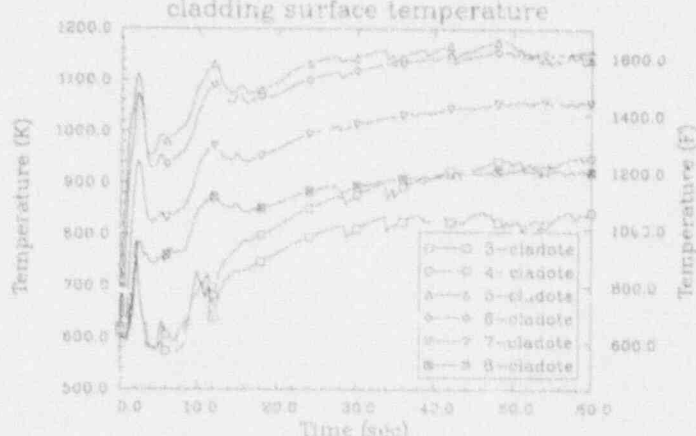
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/EMON
failure probability



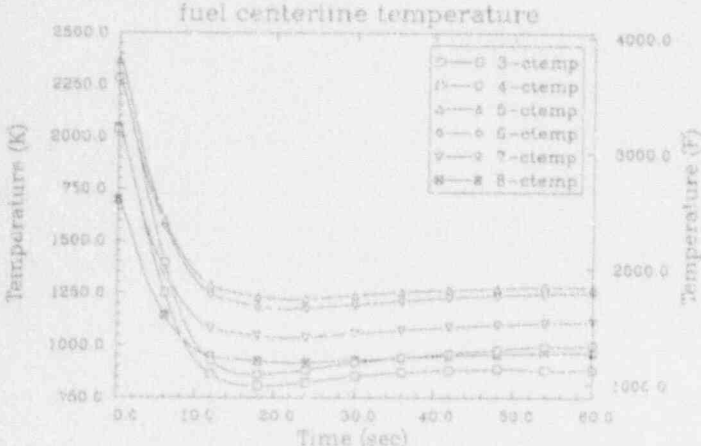
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/EMON
cladding hoop strain



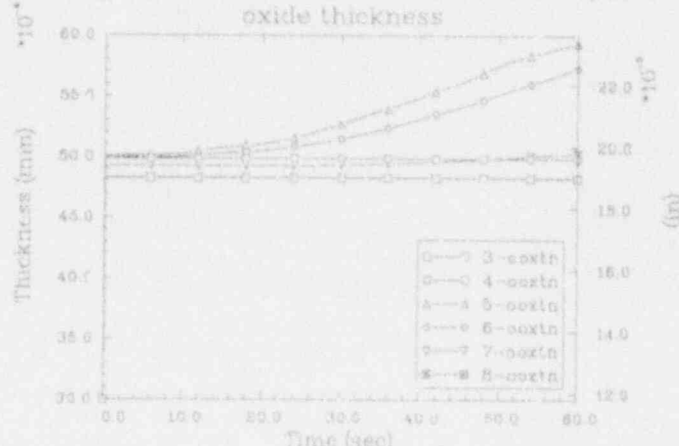
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/EMON
cladding surface temperature



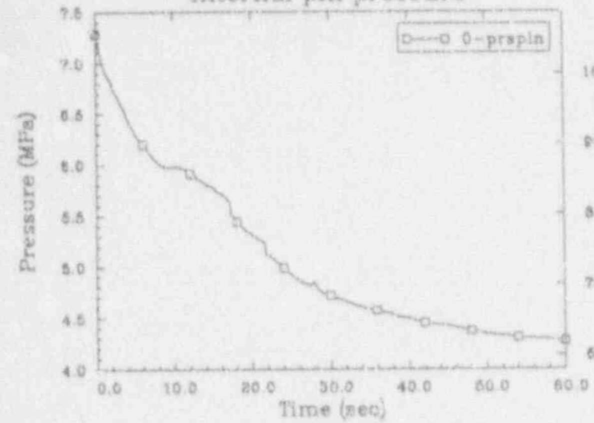
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/EMON
fuel centerline temperature



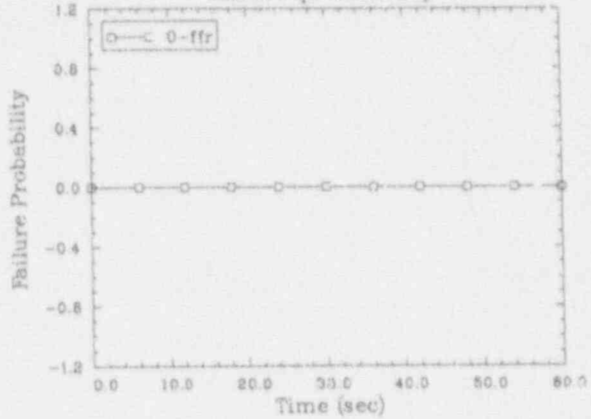
OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.4 W/EMON
oxide thickness



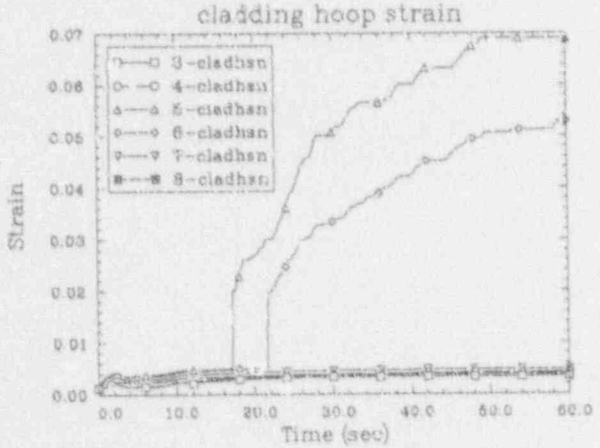
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/EMON
internal pin pressure



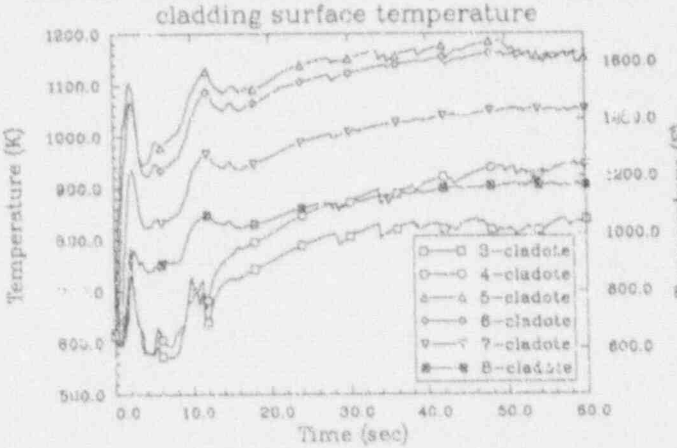
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/EMON
failure probability



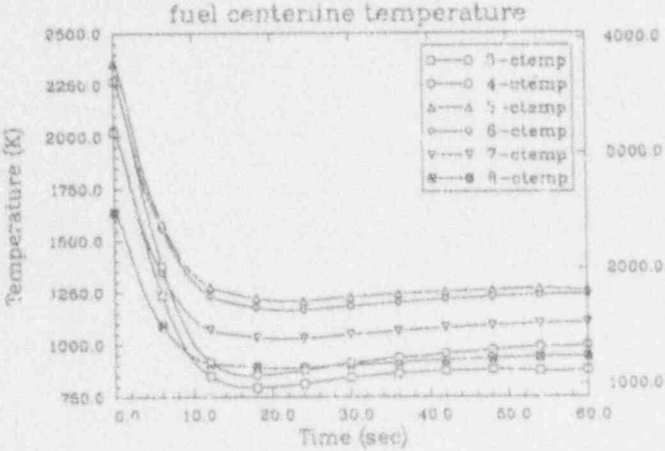
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/EMON
cladding hoop strain



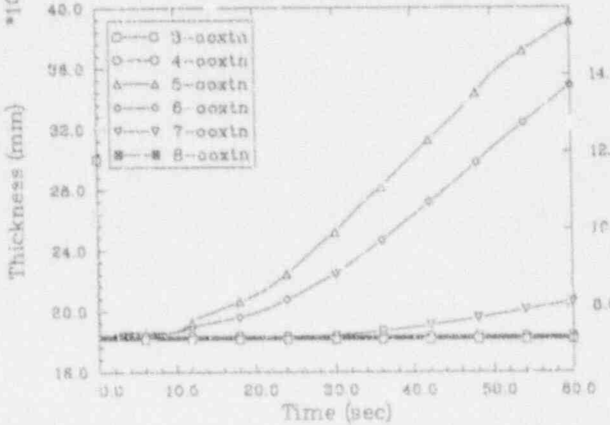
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/EMON
cladding surface temperature

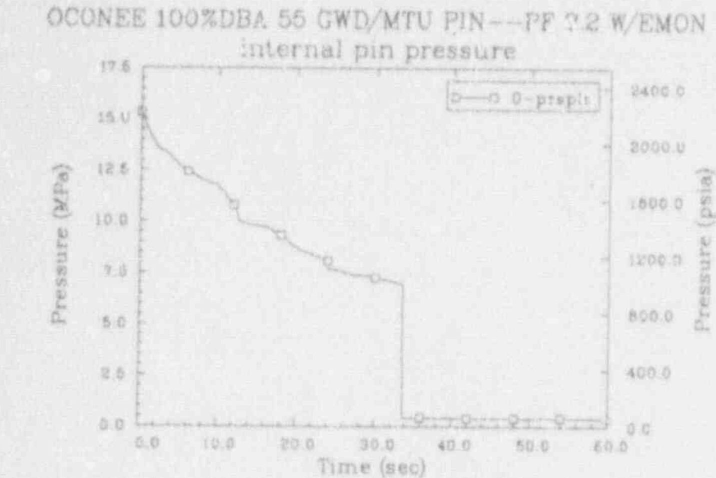


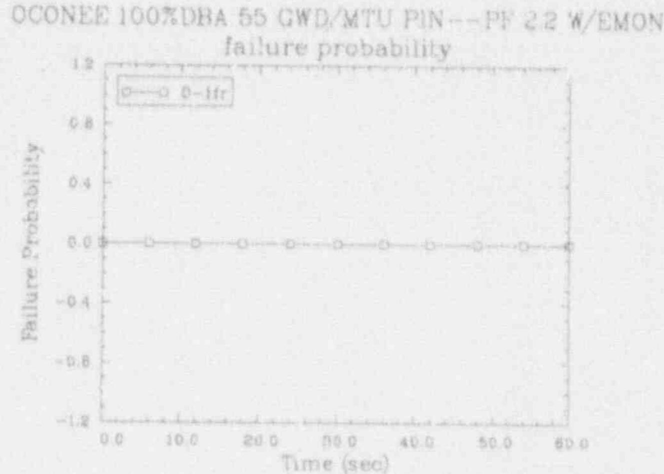
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/EMON
fuel centerline temperature

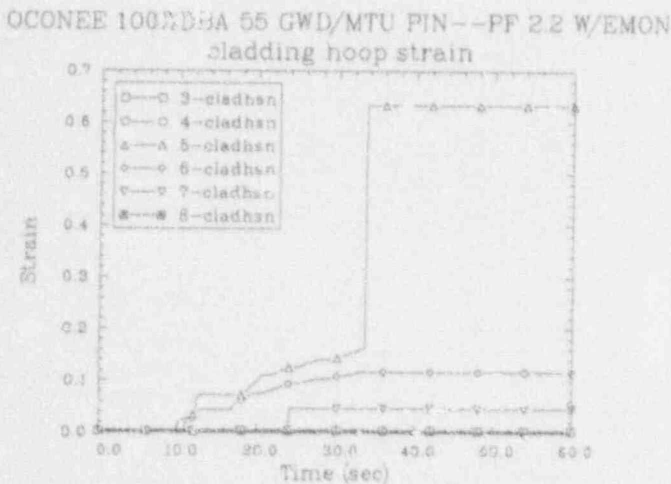


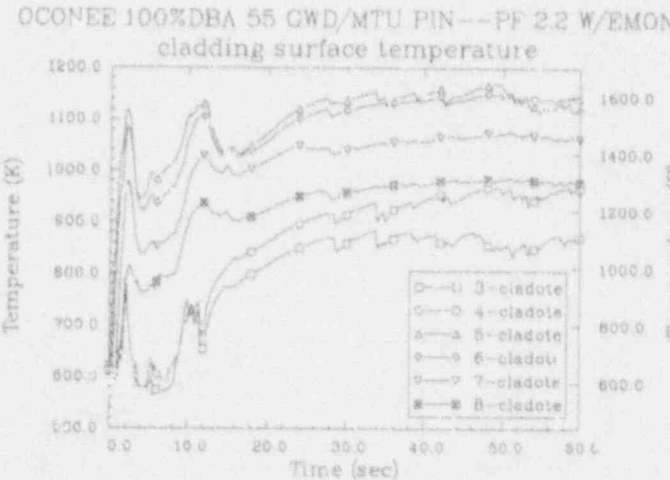
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.4 W/EMON
oxide thickness

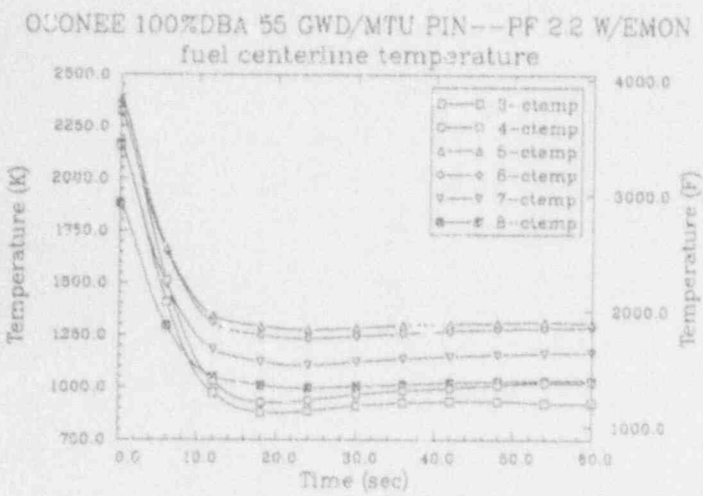


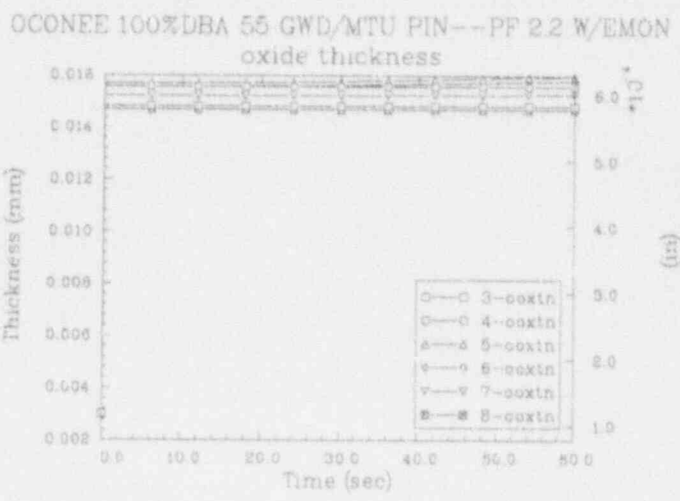

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/EMON
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

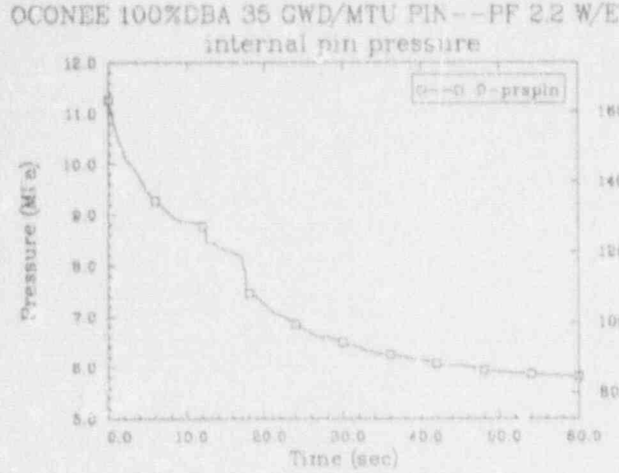

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/EMON
failure probability
Failure Probability
Time (sec)

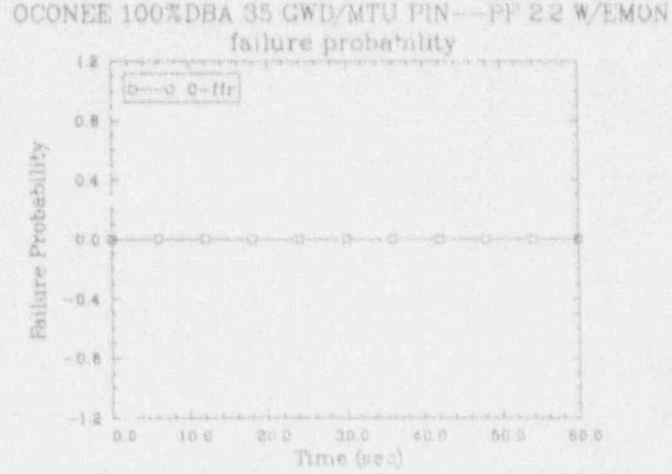

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/EMON
cladding hoop strain
Strain
Time (sec)

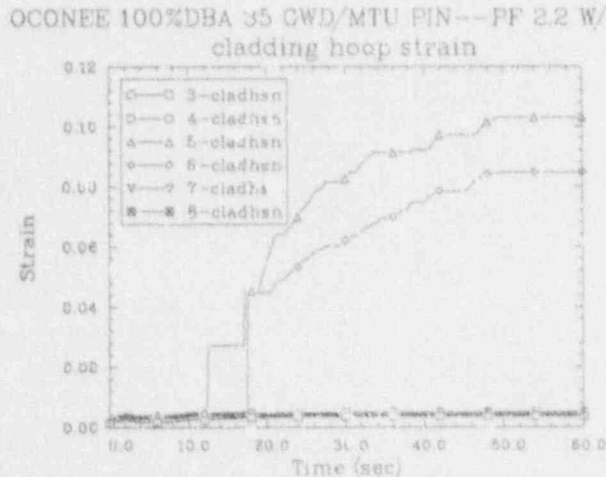

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/EMON
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)

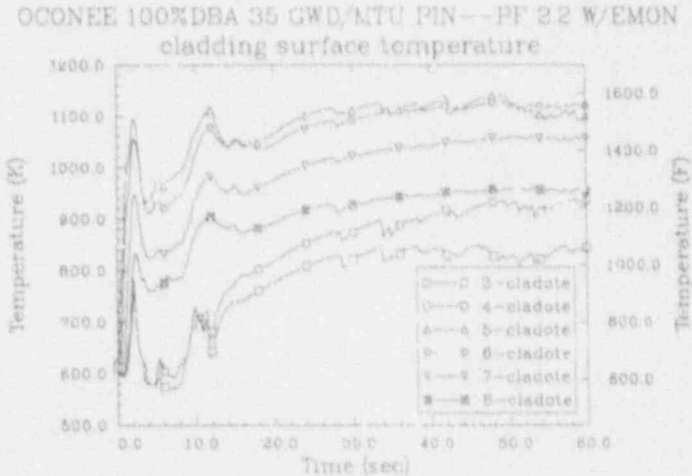

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/EMON
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)

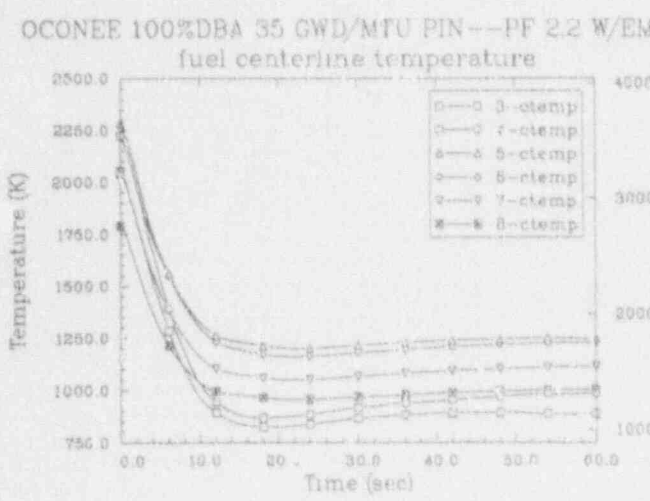

OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.2 W/EMON
oxide thickness
Thickness (mm)
Time (sec)

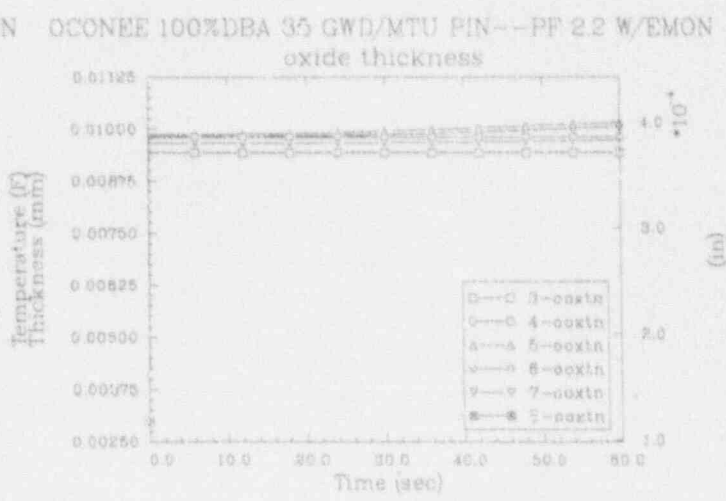

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/EMON
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin

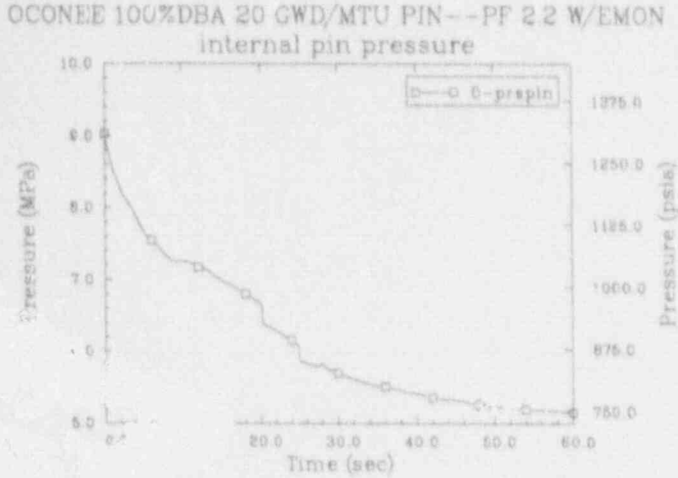

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/EMON
failure probability
Failure Probability
Time (sec)
0-ffr

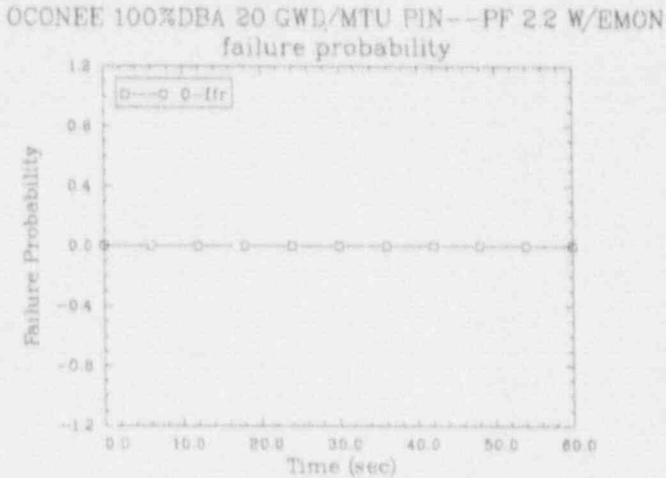

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/EMON
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhs
8-cladhsn

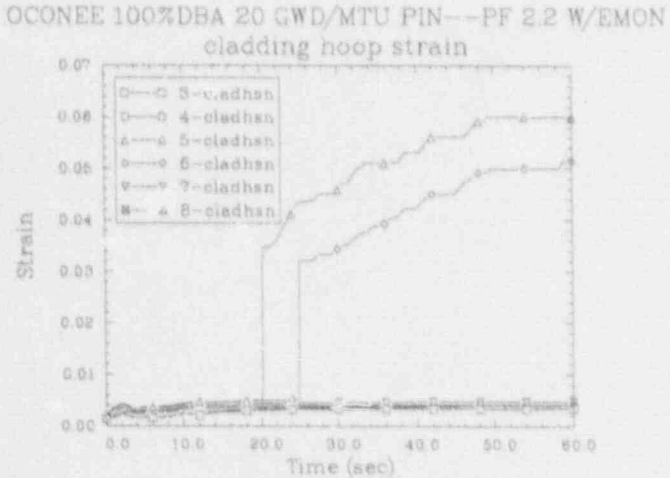

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/EMON
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

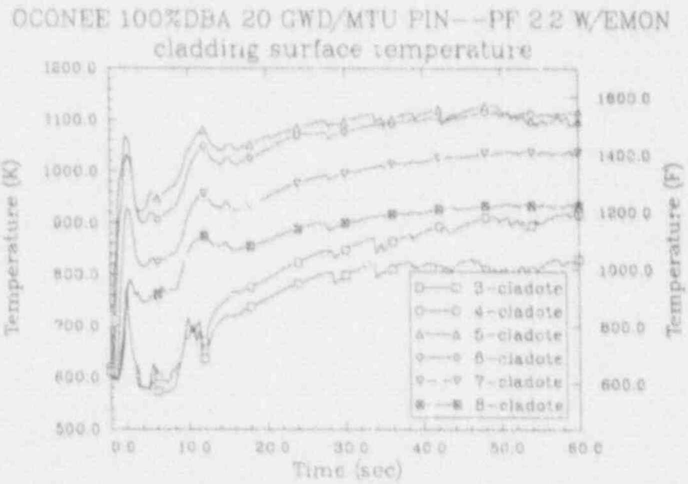

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/EMON
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp

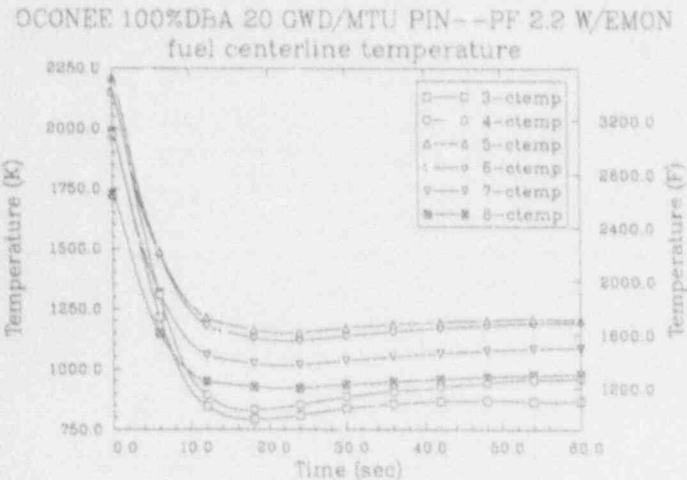

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.2 W/EMON
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

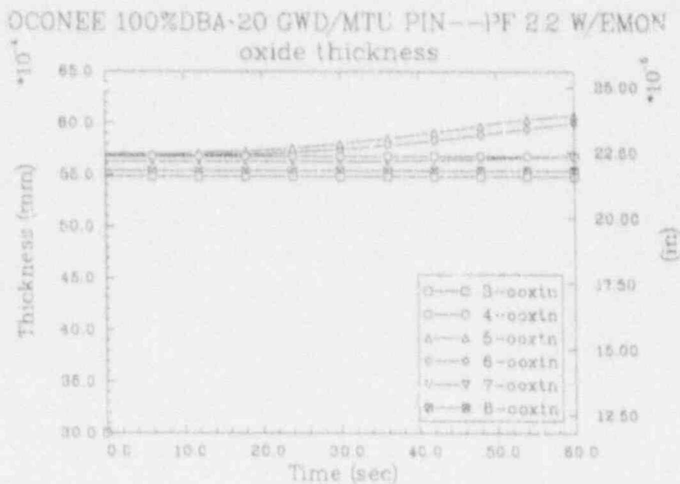

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)

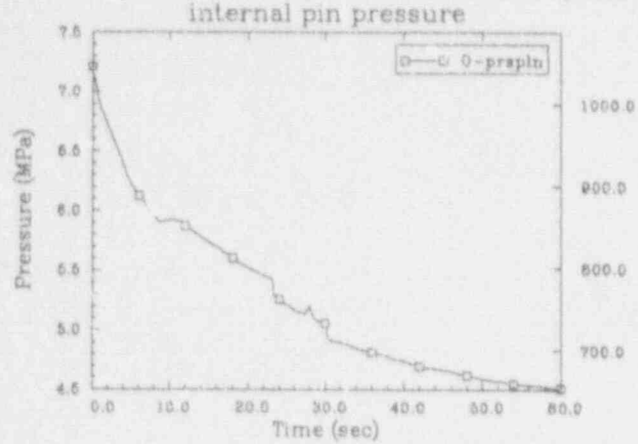

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/EMON
cladding hoop strain
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/EMON
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

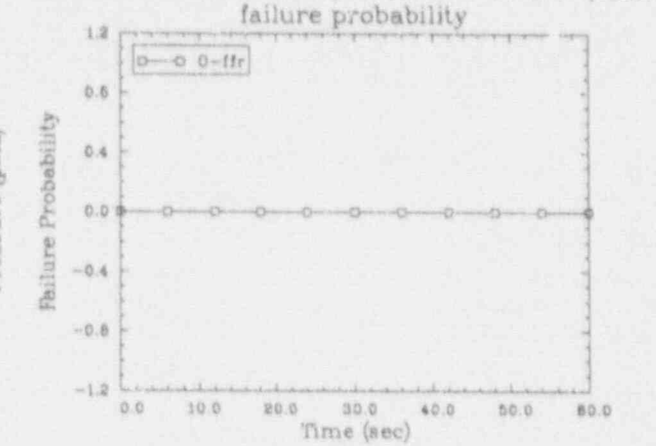

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.2 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

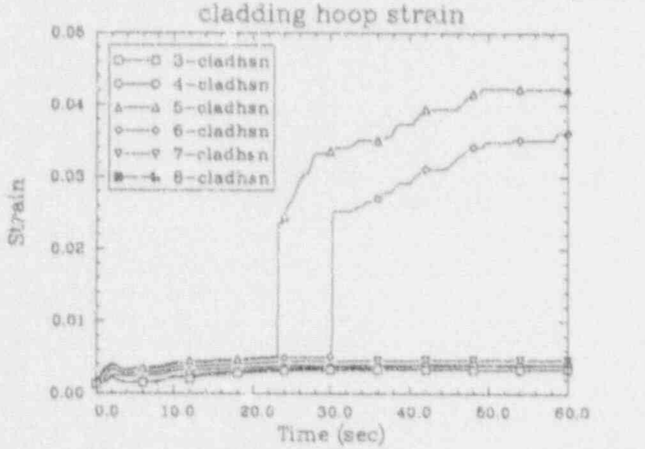
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/EMON
internal pin pressure



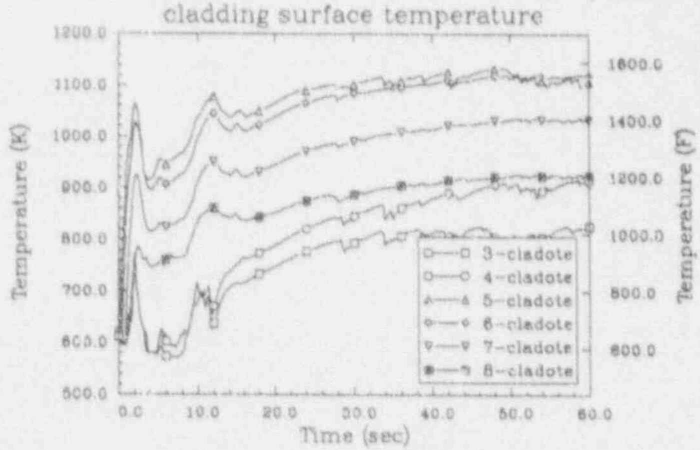
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/EMON
failure probability



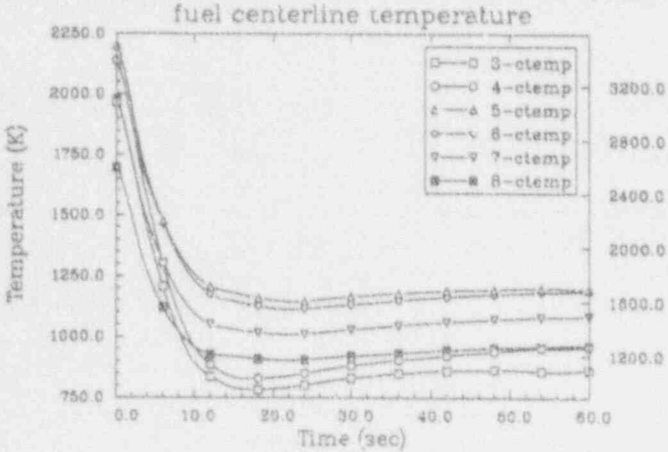
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/EMON
cladding hoop strain



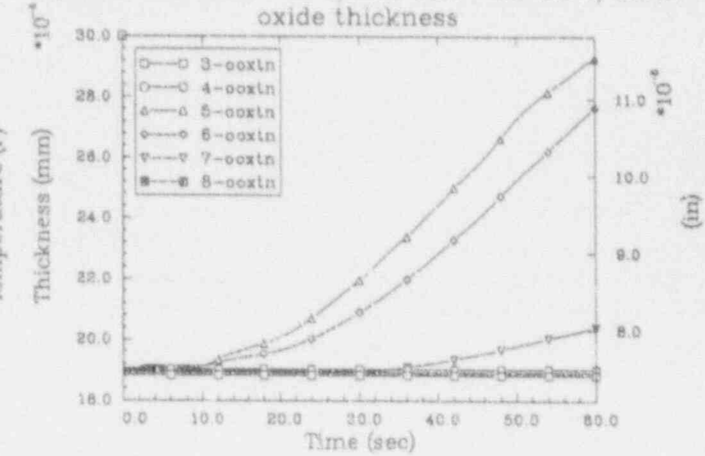
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/EMON
cladding surface temperature



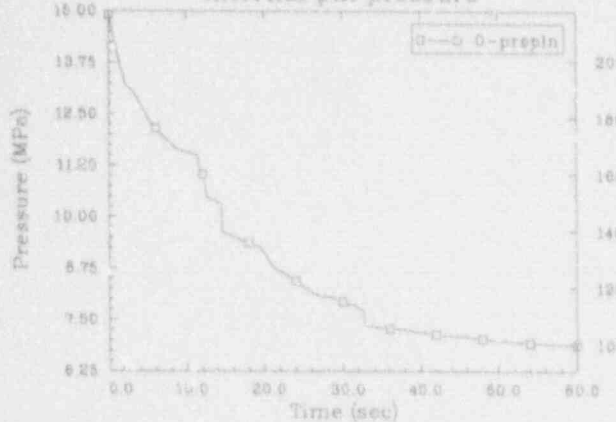
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/EMON
fuel centerline temperature



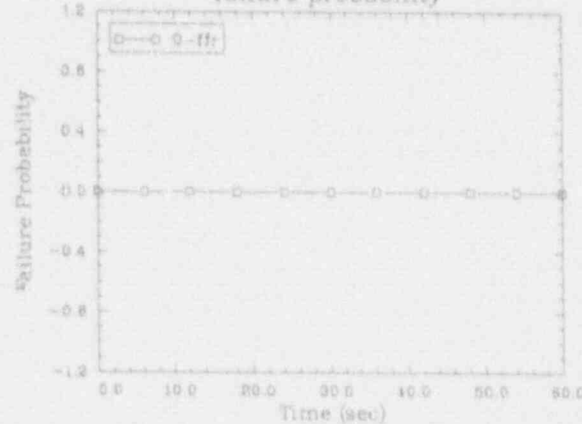
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.2 W/EMON
oxide thickness



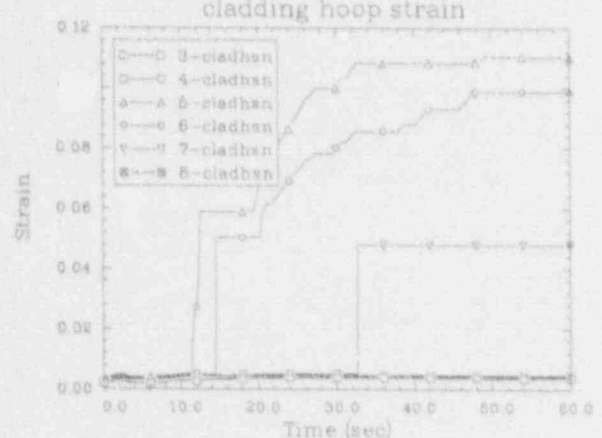
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/EMON
internal pin pressure



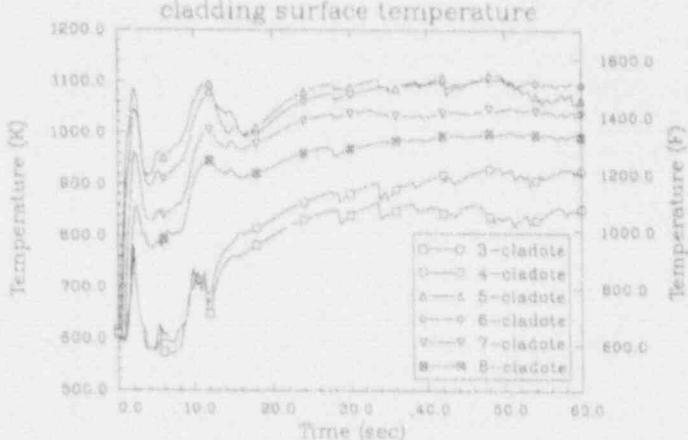
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/EMON
failure probability



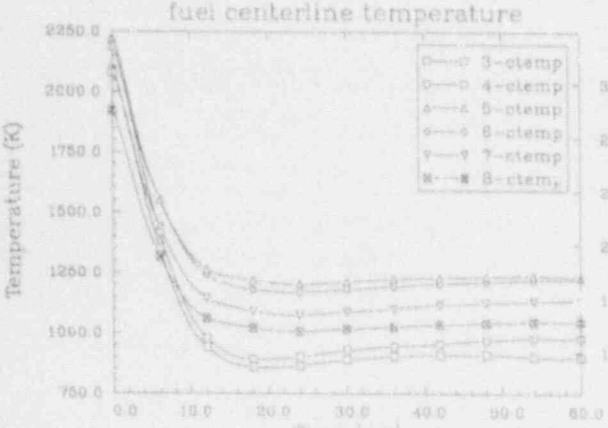
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/EMON
cladding hoop strain



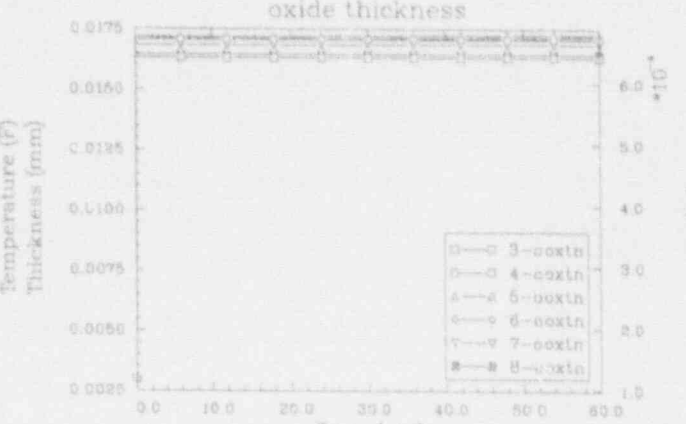
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/EMON
cladding surface temperature

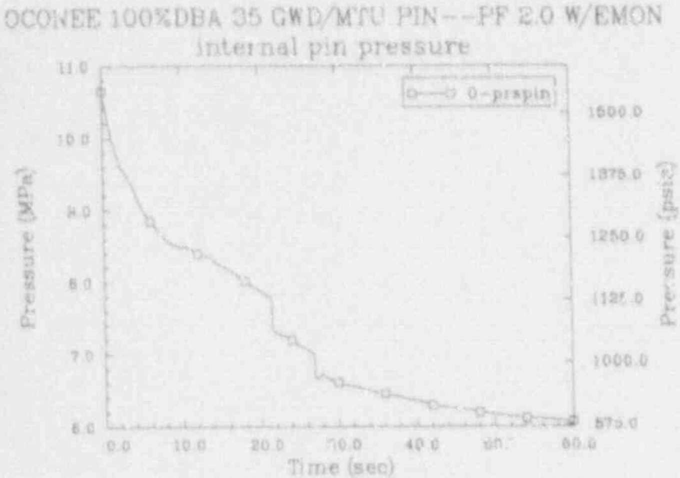


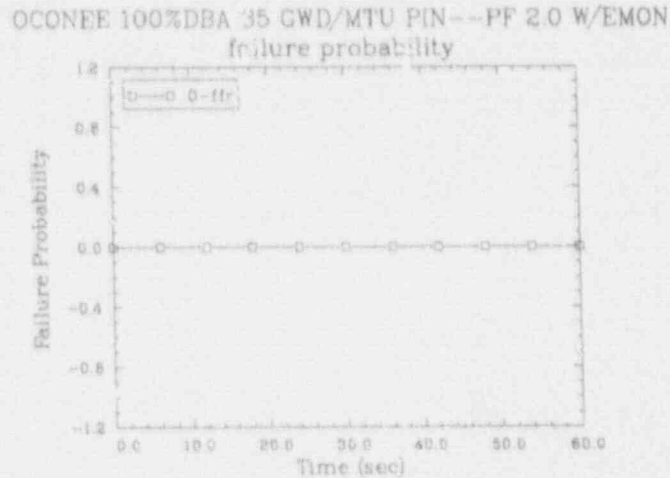
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/EMON
fuel centerline temperature

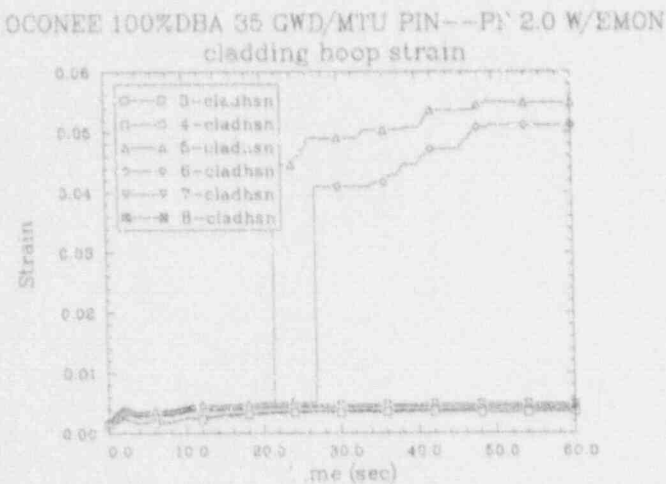


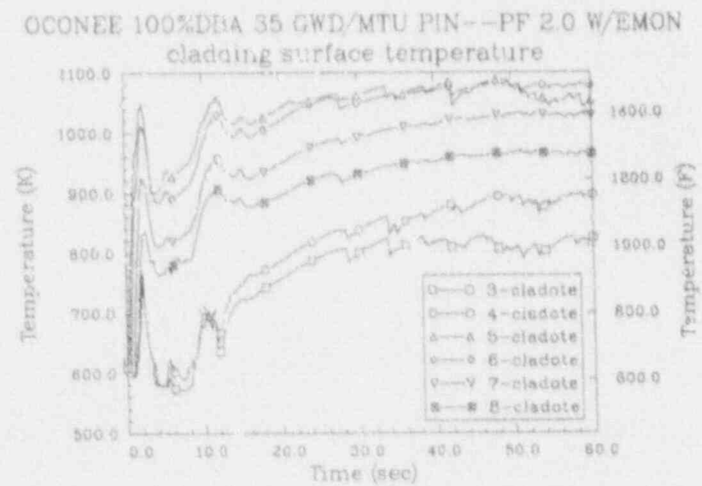
OCONEE 100%DBA 55 GWD/MTU PIN--PF 2.0 W/EMON
oxide thickness

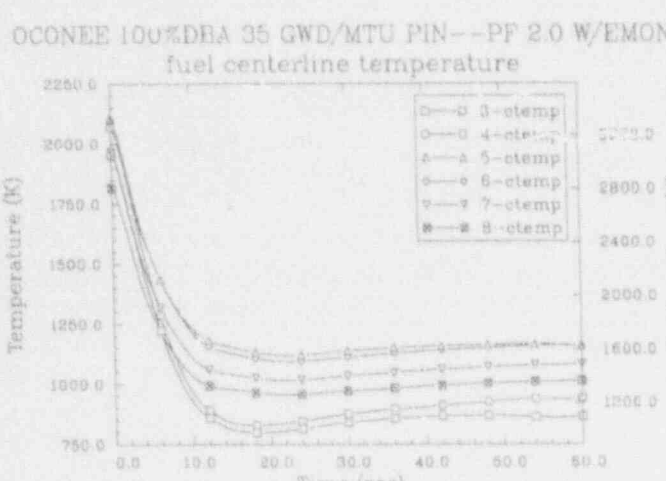


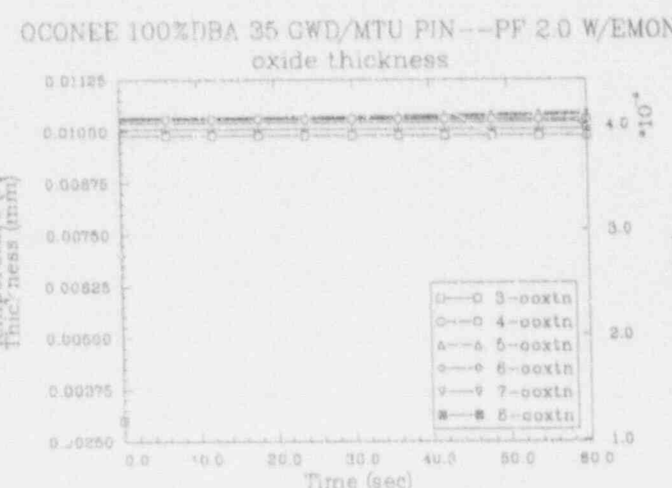

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

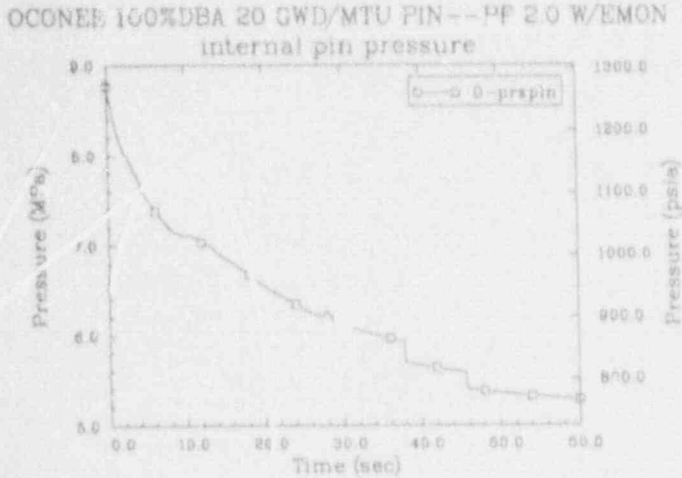

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)

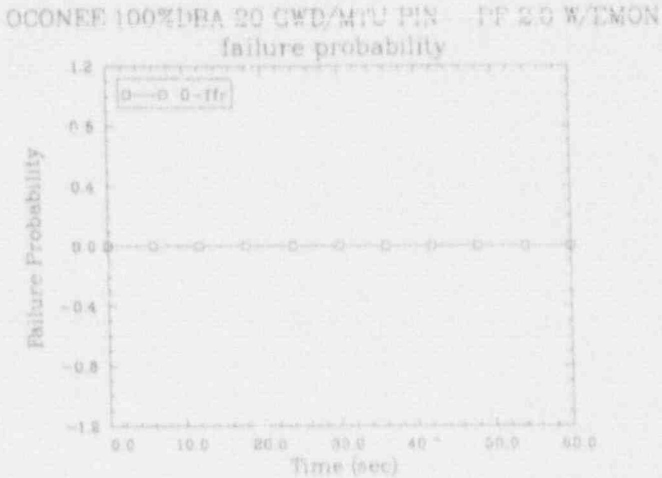

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain

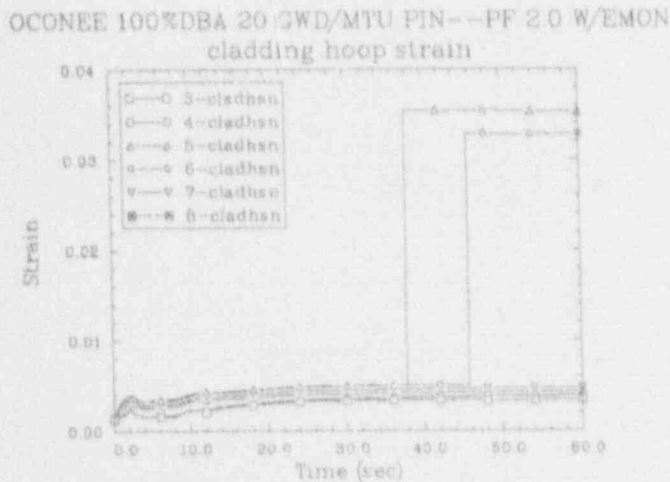

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/EMON
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

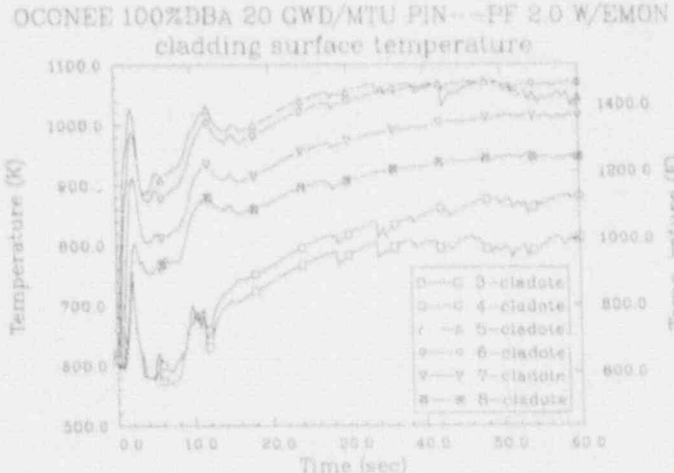

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

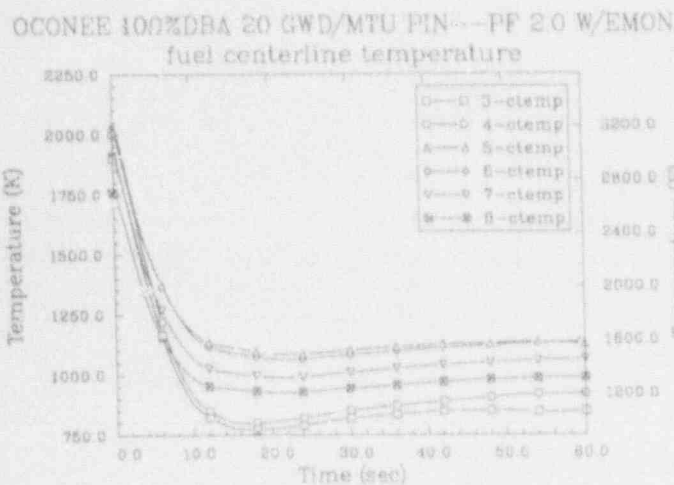

OCONEE 100%DBA 35 GWD/MTU PIN--PF 2.0 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

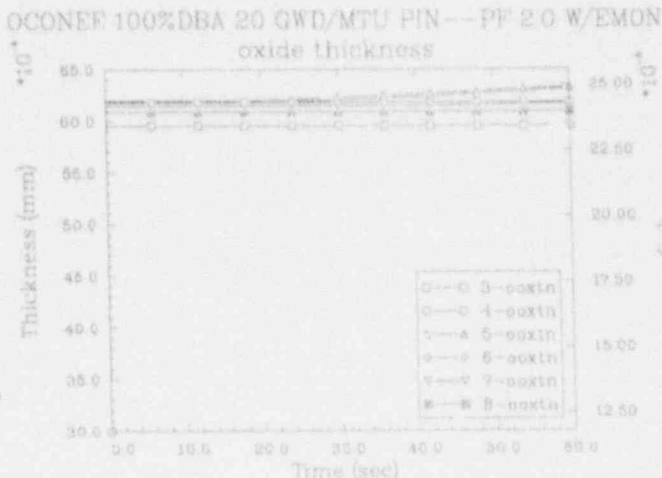

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)

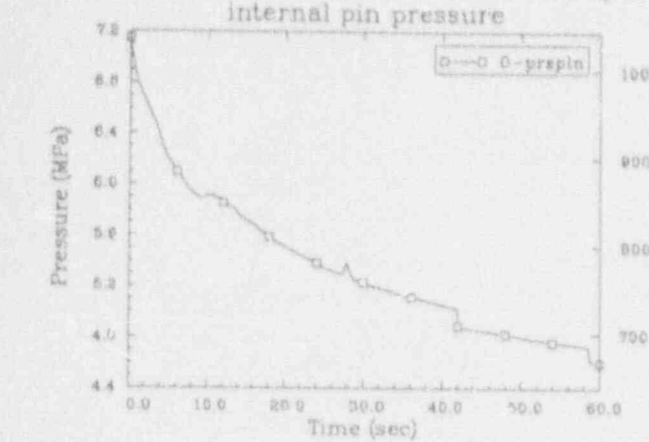

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/EMON
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Time (sec)

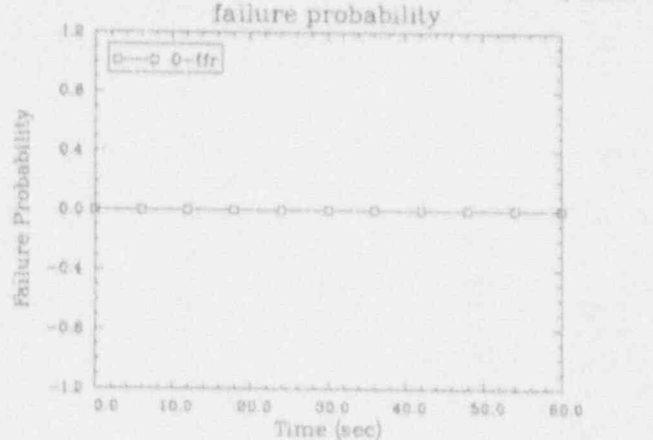

OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE 100%DBA 20 GWD/MTU PIN--PF 2.0 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

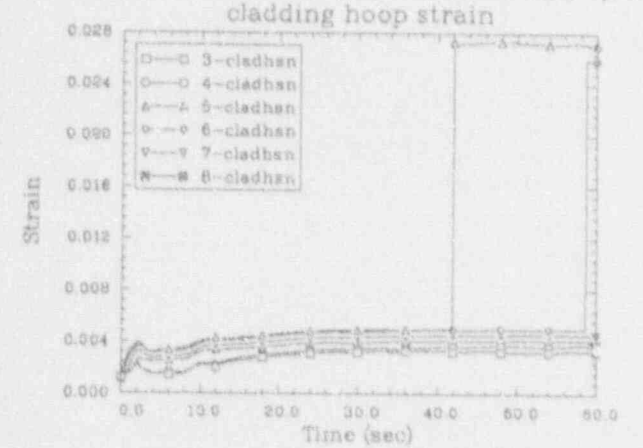
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/EMON
internal pin pressure



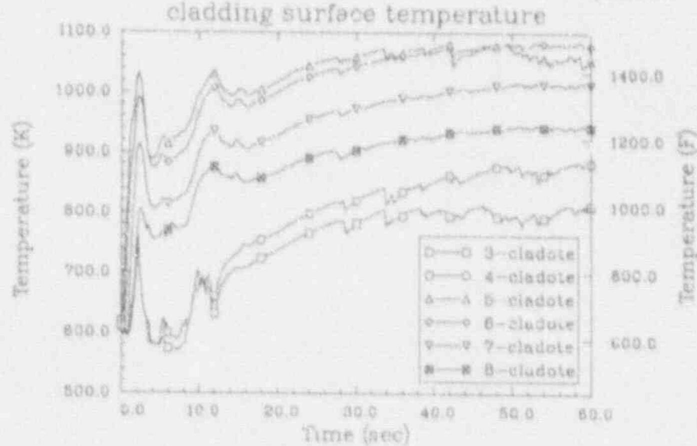
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/EMON
failure probability



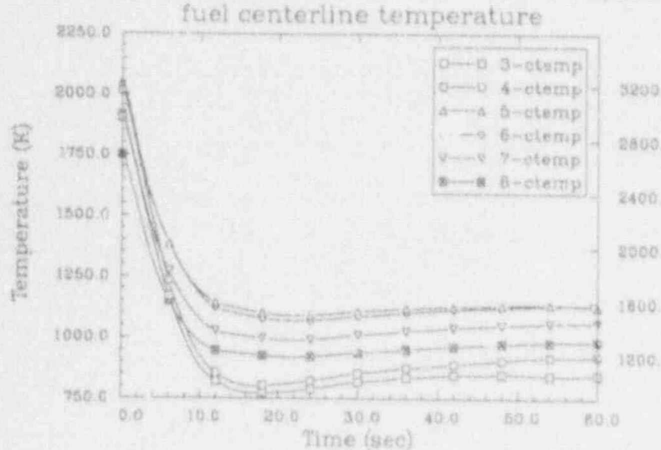
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/EMON
cladding hoop strain



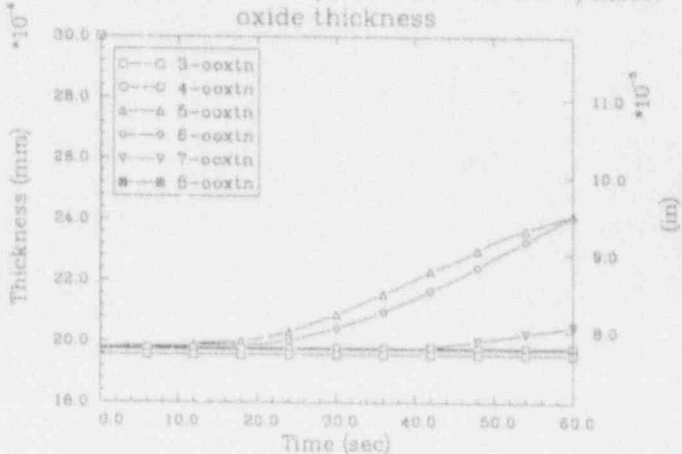
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/EMON
cladding surface temperature

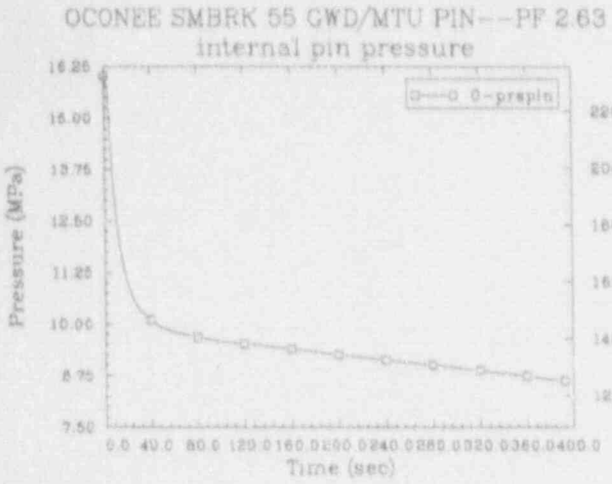


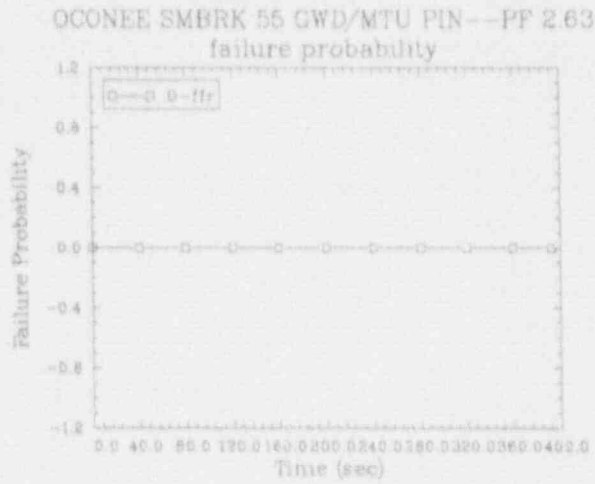
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/EMON
fuel centerline temperature

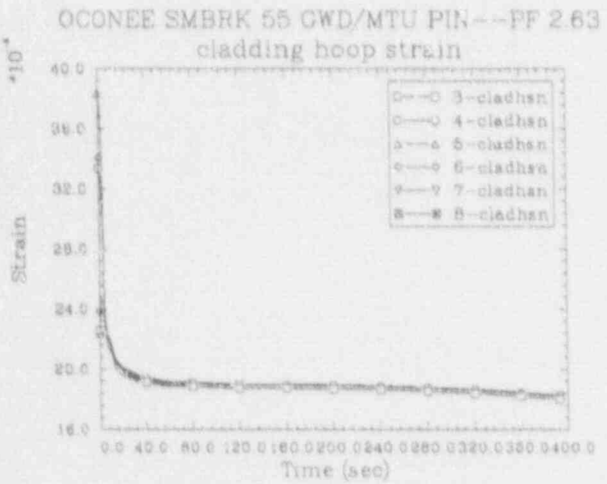


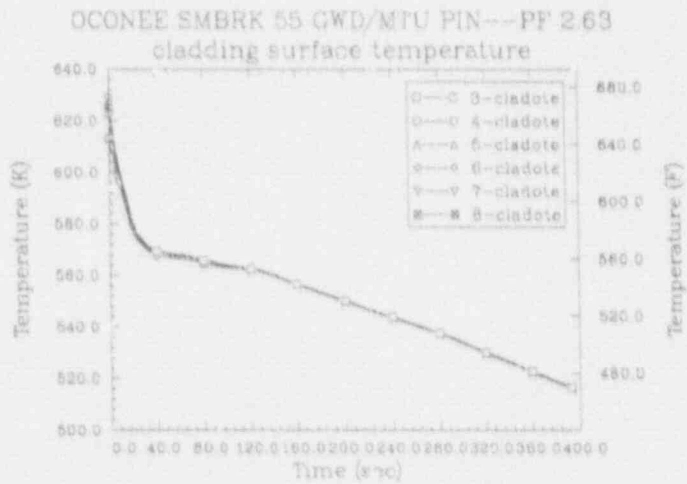
OCONEE 100%DBA 5 GWD/MTU PIN--PF 2.0 W/EMON
oxide thickness

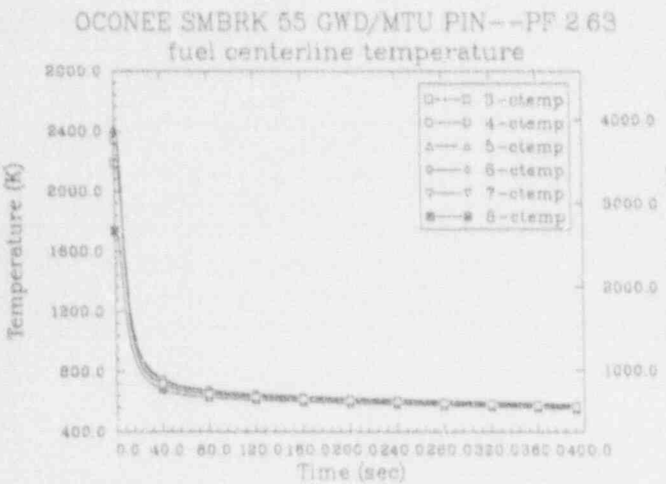


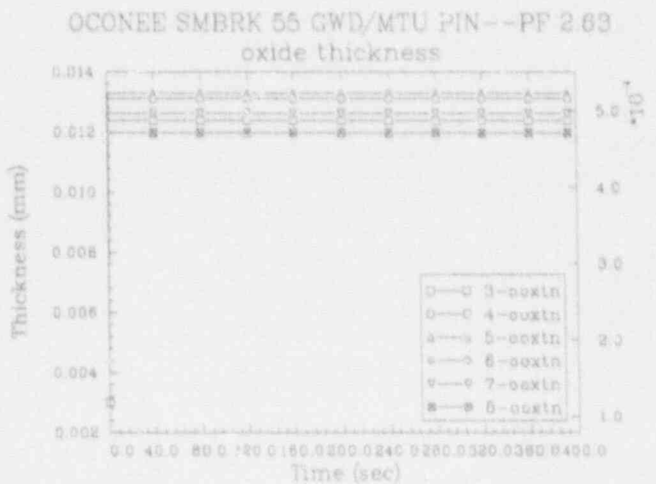

OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin

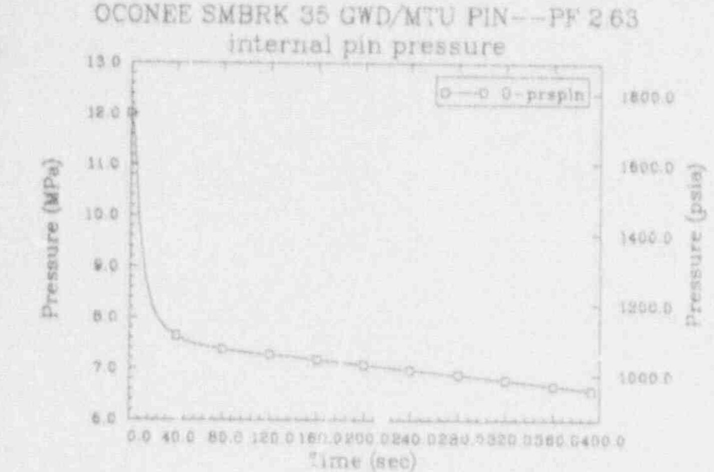

OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63
failure probability
Failure Probability
Time (sec)
0-ffr

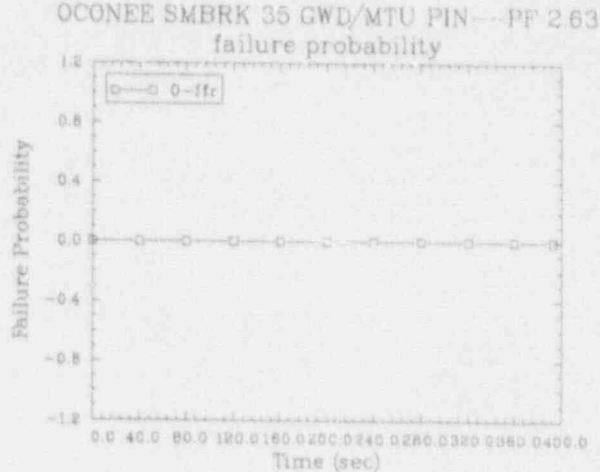

OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn

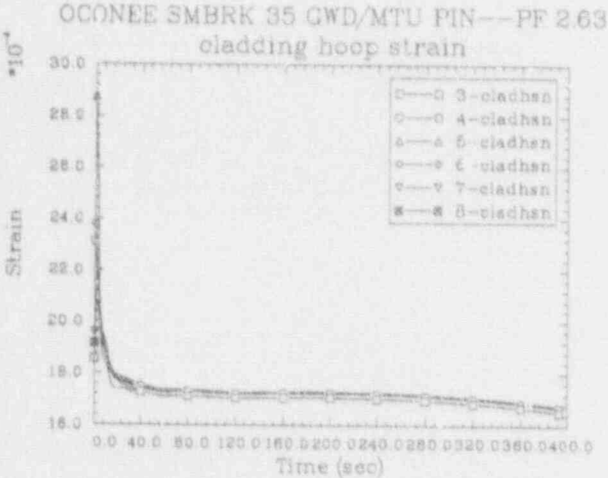

OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

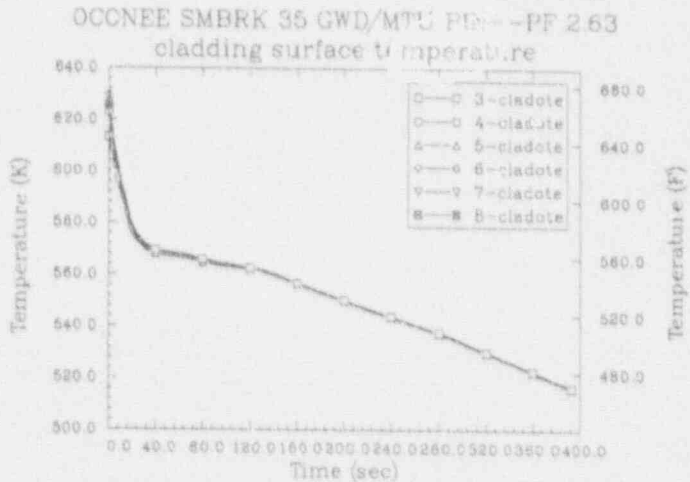

OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp

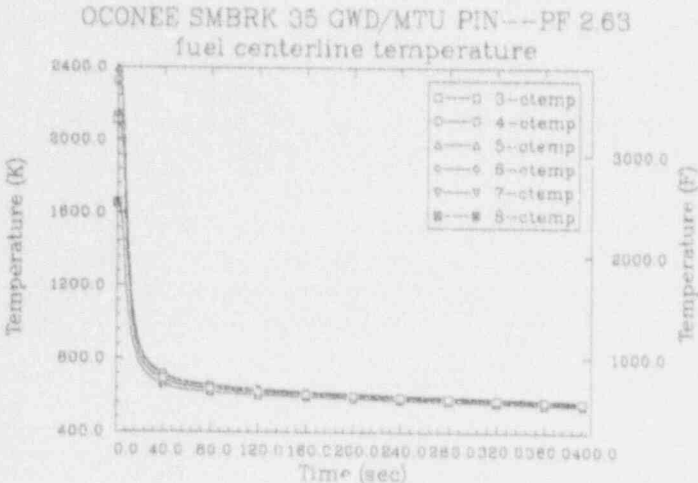

OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

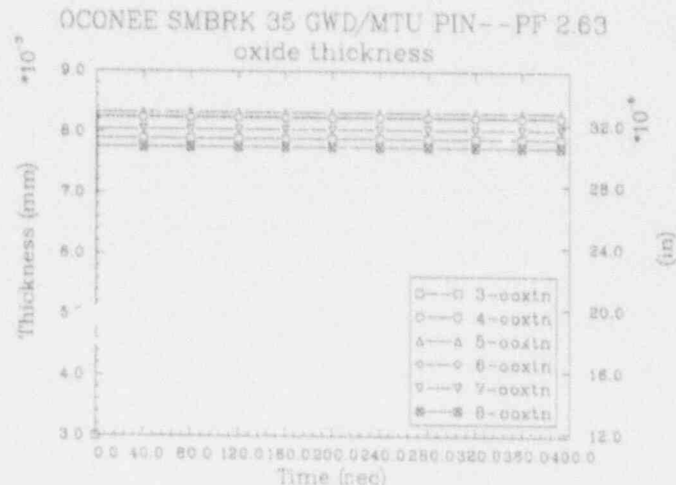

OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

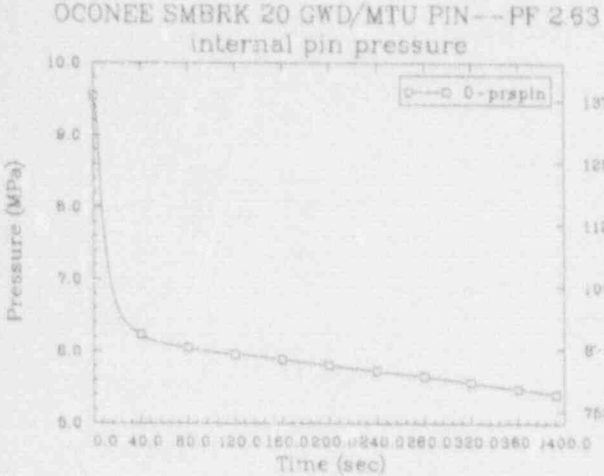

OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)

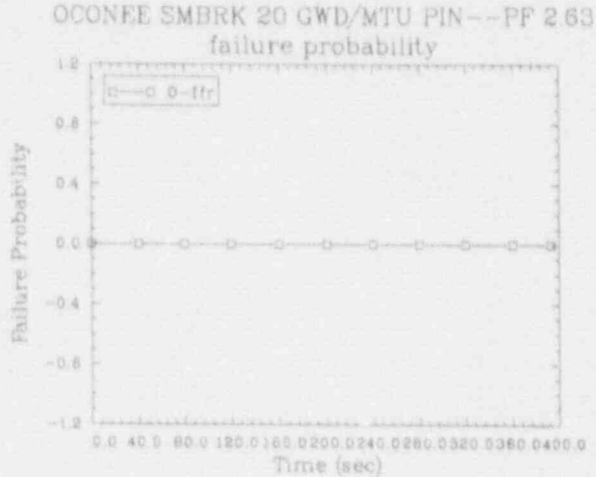

OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

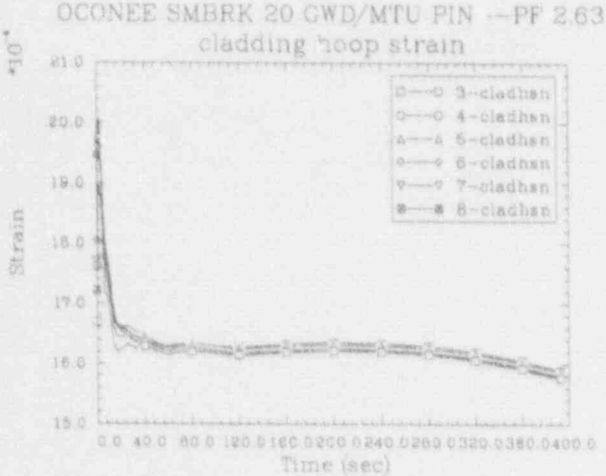

OCONEE SMBRK 35 GWD/MTU
cladding surface
3-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

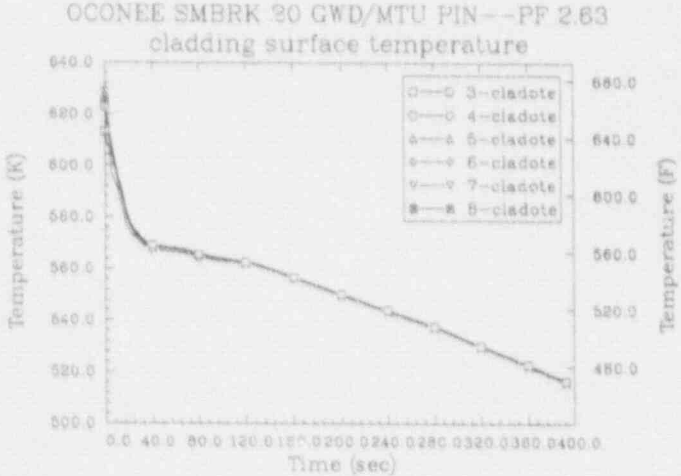

OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)

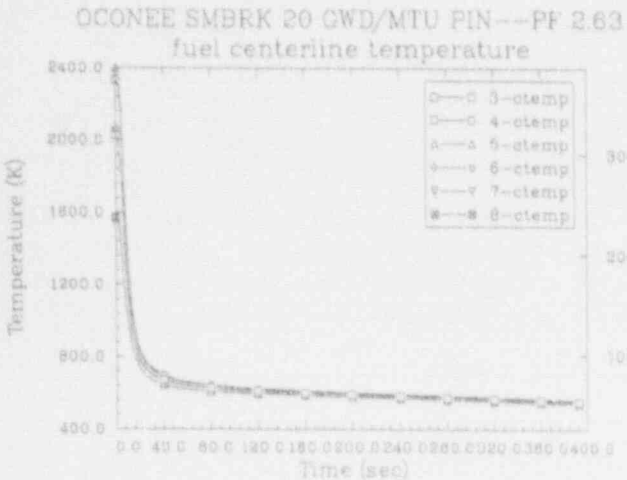

OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

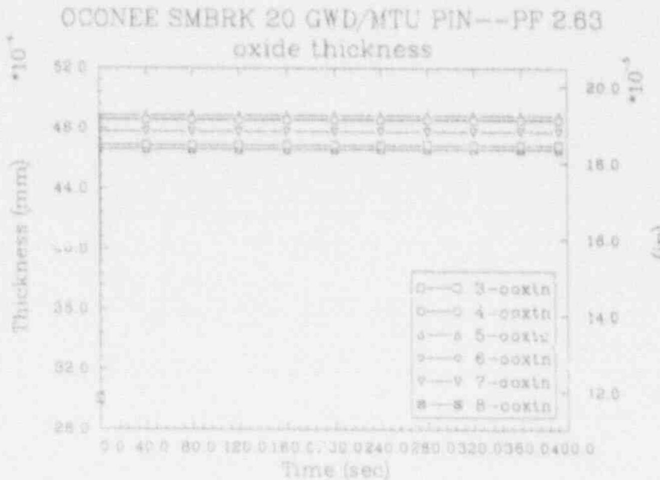

OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psi)
Time (sec)
10.0
9.0
8.0
7.0
6.0
5.0
1375.0
1250.0
1125.0
1000.0
750.0
0.0 40.0 80.0 120.0 160.0 200.0 240.0 280.0 320.0 360.0 400.0

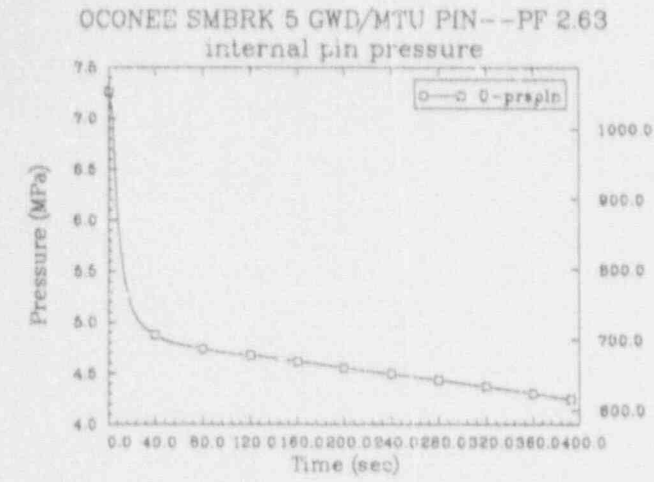

OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63
failure probability
0-ffr
Failure Probability
Time (sec)
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
0.0 40.0 80.0 120.0 160.0 200.0 240.0 280.0 320.0 360.0 400.0

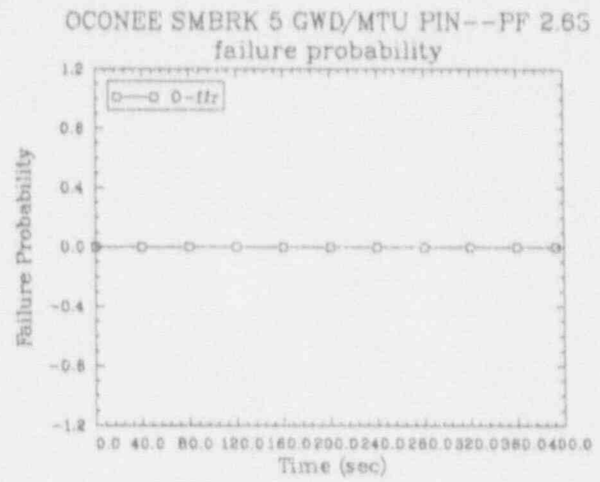

OCONEE SMBRK 20 GWD/MTU PIN --PF 2.63
cladding hoop strain
*10^-3
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)
21.0
20.0
19.0
18.0
17.0
16.0
15.0
0.0 40.0 80.0 120.0 160.0 200.0 240.0 280.0 320.0 360.0 400.0

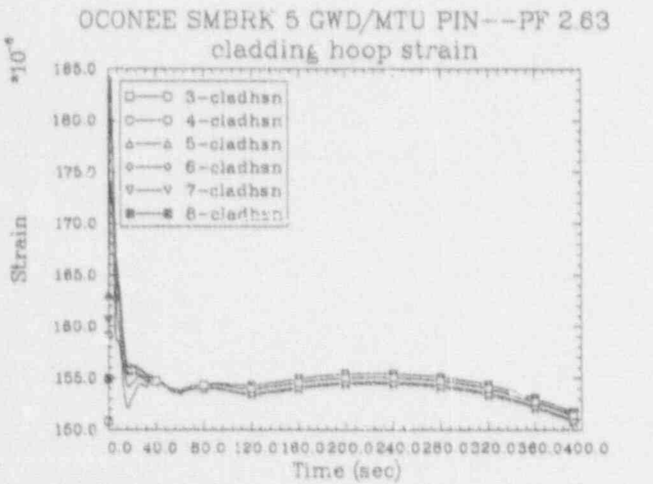

OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)
640.0
620.0
600.0
580.0
560.0
540.0
520.0
500.0
680.0
640.0
600.0
560.0
520.0
480.0
0.0 40.0 80.0 120.0 160.0 200.0 240.0 280.0 320.0 360.0 400.0

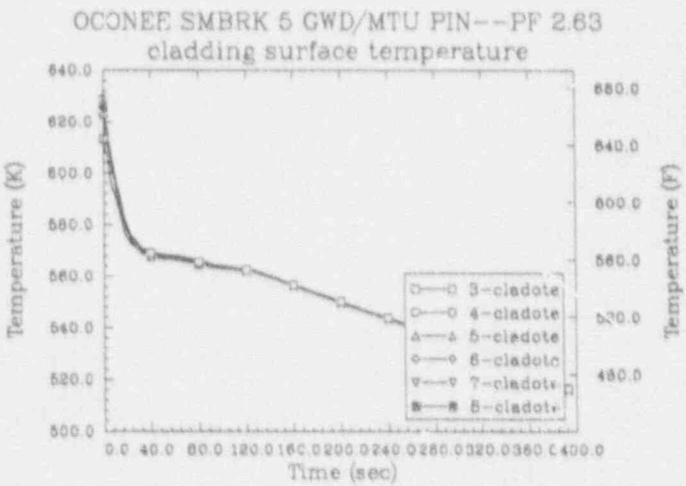

OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)
2400.0
2000.0
1600.0
1200.0
800.0
400.0
3000.0
2000.0
1000.0
0.0 40.0 80.0 120.0 160.0 200.0 240.0 280.0 320.0 360.0 400.0

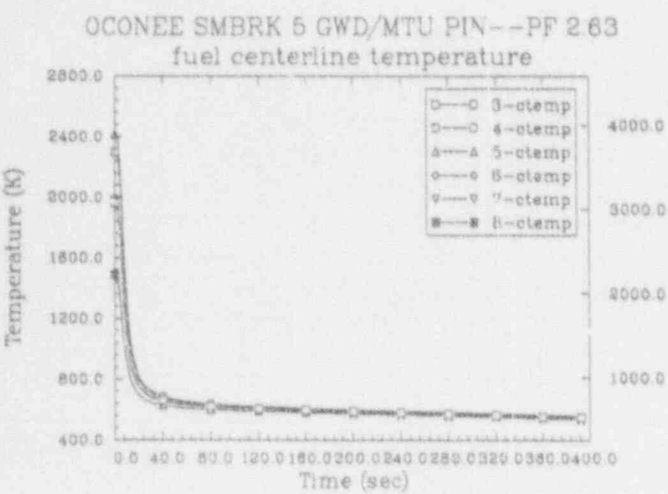

OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63
oxide thickness
*10^-3
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)
52.0
48.0
44.0
36.0
32.0
28.0
20.0
18.0
16.0
14.0
12.0

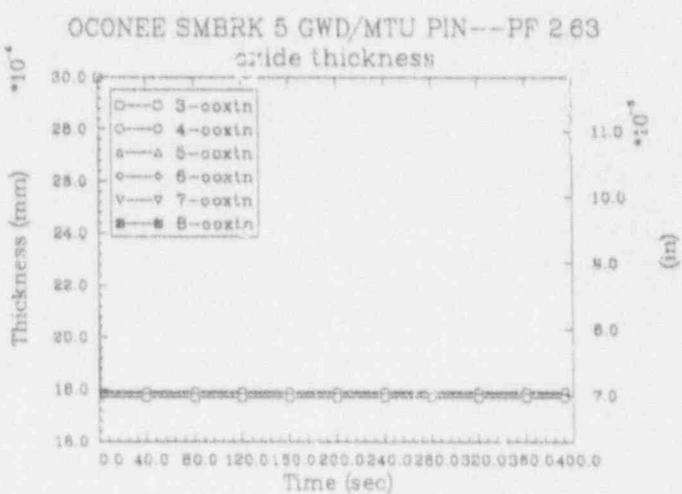

OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63
internal pin pressure
0-prspln
Pressure (MPa)
Pressure (psia)
Time (sec)

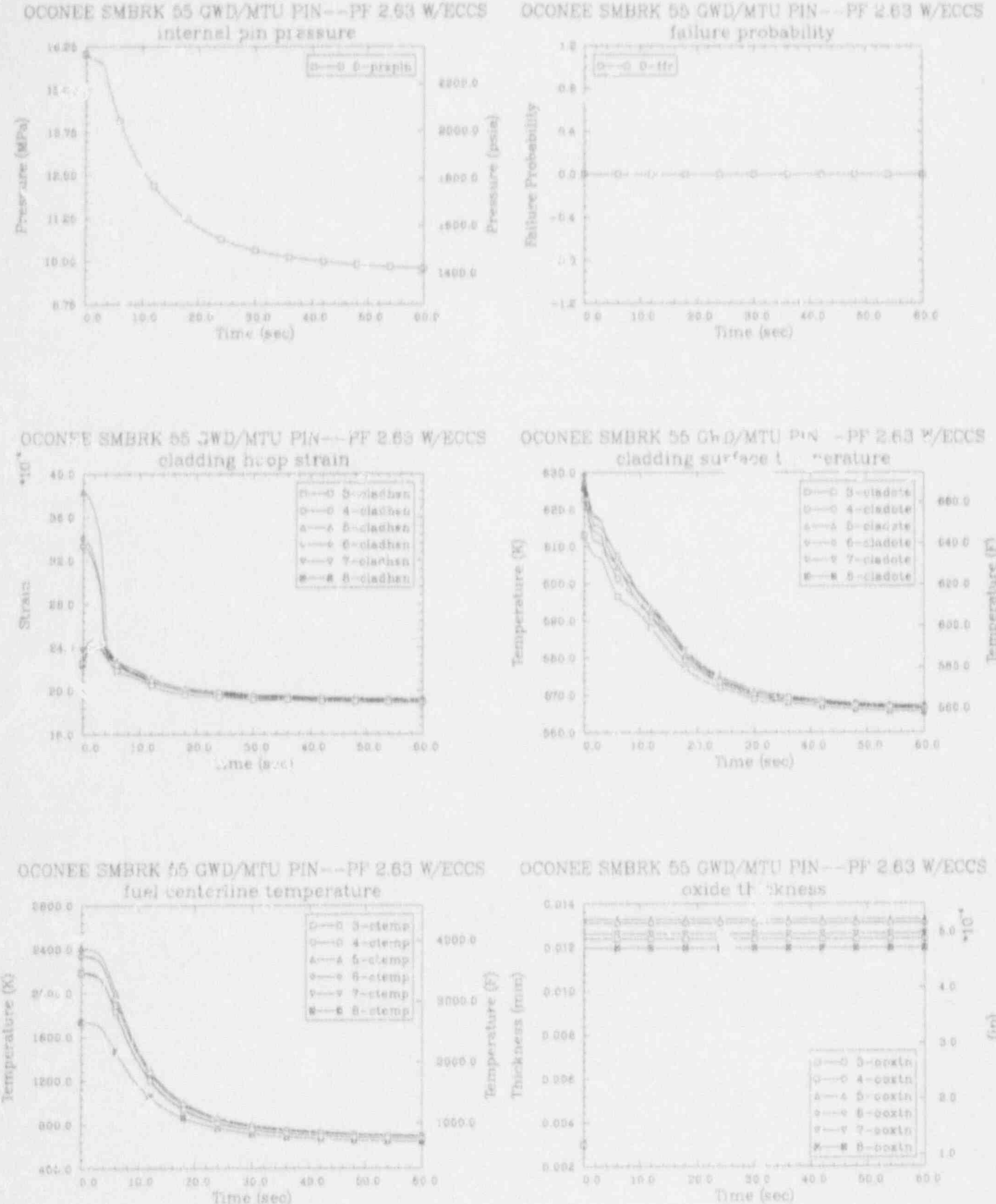

OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63
failure probability
0-flr
Failure Probability
Time (sec)


OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

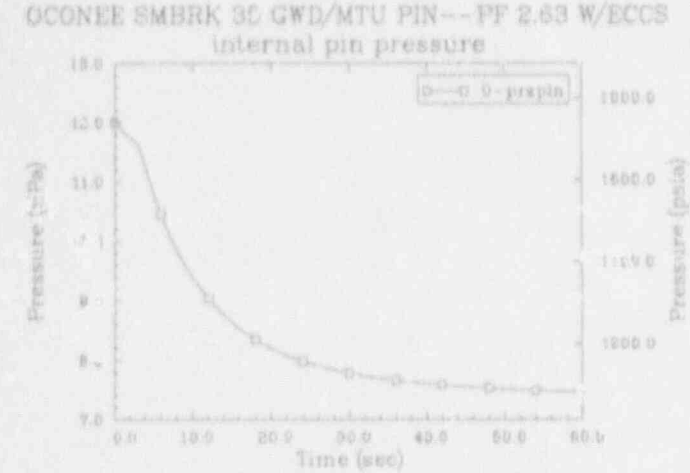

OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63
cladding surface temperature
3-cladote
4-cladote
5-cladote
Temperature (K)
Temperature (F)
Time (sec)

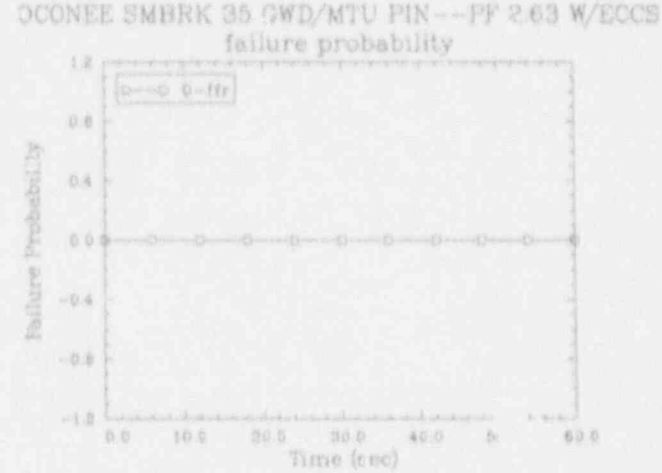

OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

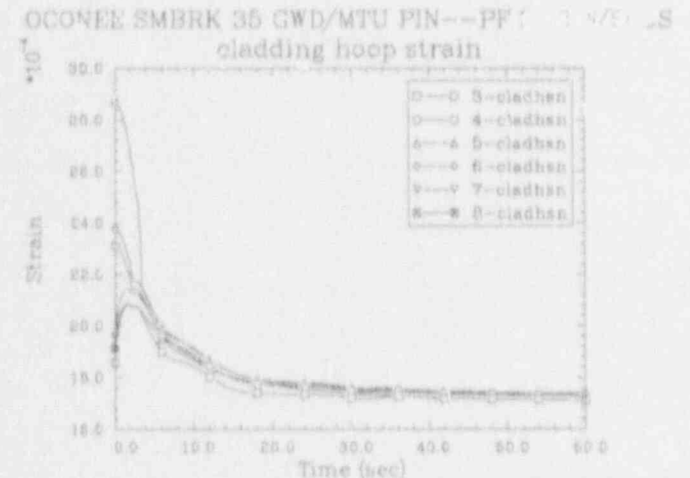

OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

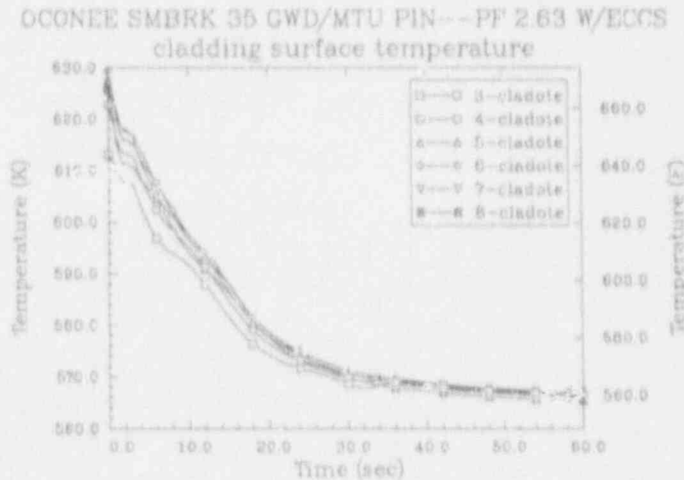


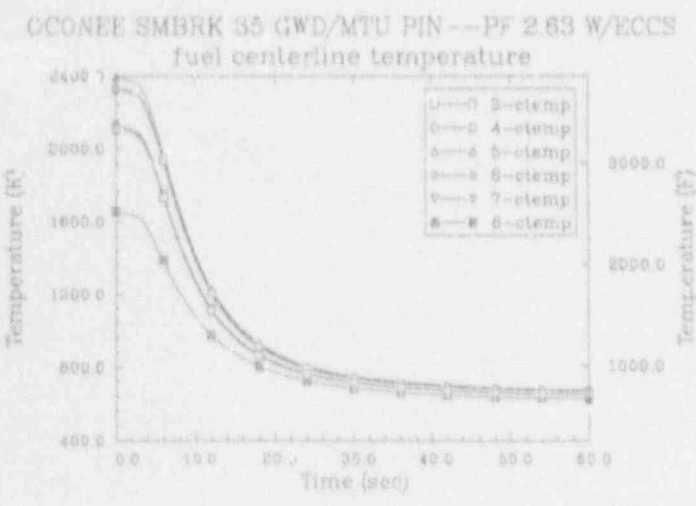
OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
OCONEE SMBRK 55 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability
Failure Probability
Time (sec)
cladding hoop strain
Strain
cladding surface temperature
Temperature (K)
Temperature (F)
fuel centerline temperature
oxide thickness
Thickness (mm)

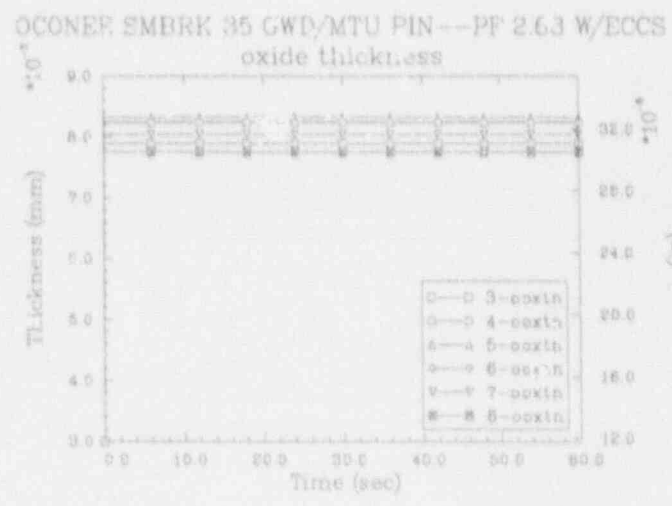

OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

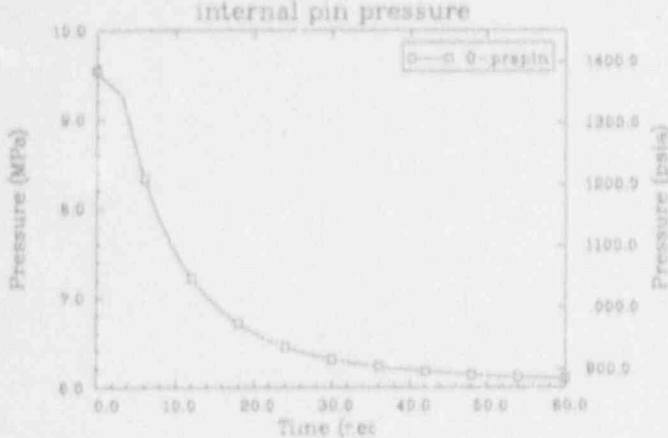

OCONEE SMBRK 35 GWD/MTU PIN--PF
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

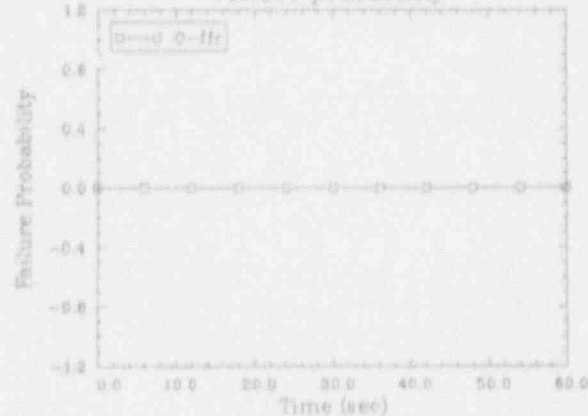

OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


OCONEE SMBRK 35 GWD/MTU PIN--PF 2.63 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

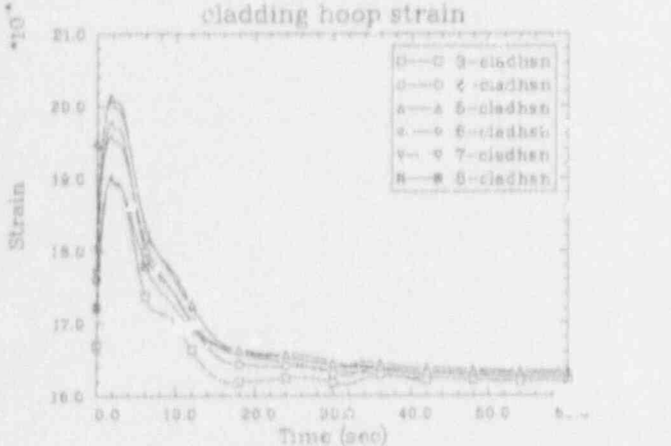
OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure



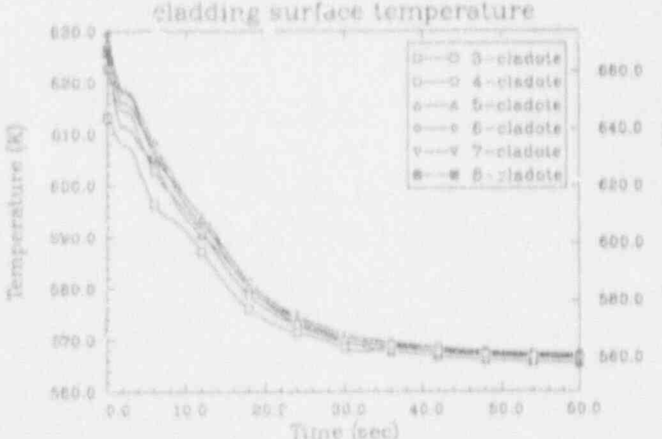
OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability



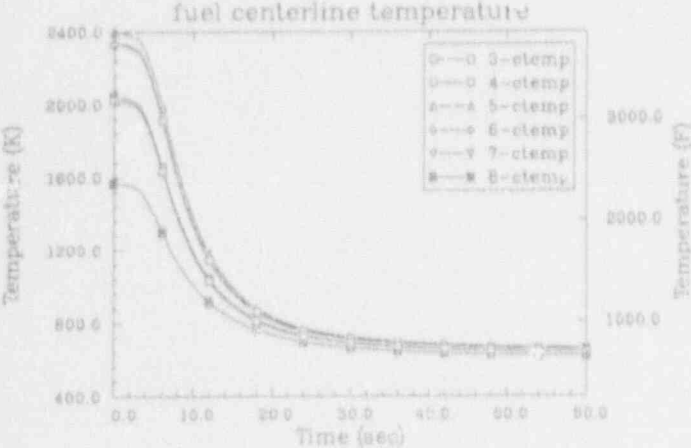
OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63 W/ECCS
cladding hoop strain



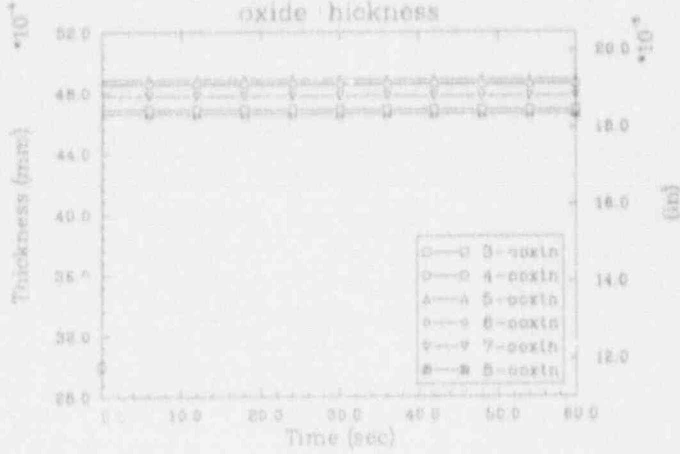
OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63 W/ECCS
cladding surface temperature

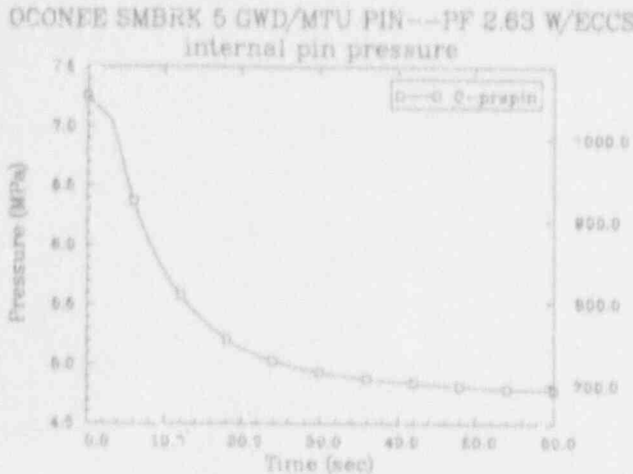


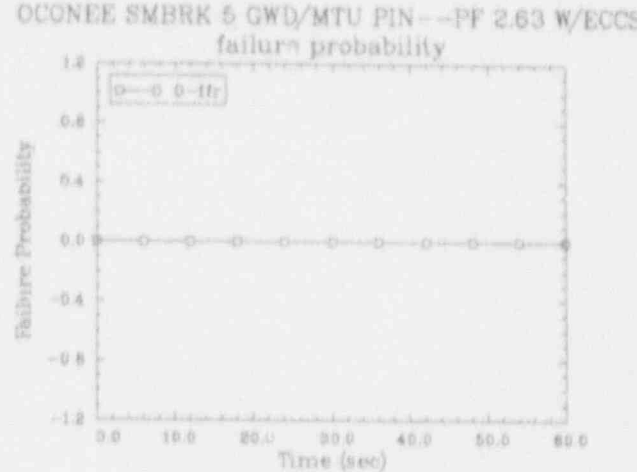
OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63 W/ECCS
fuel centerline temperature

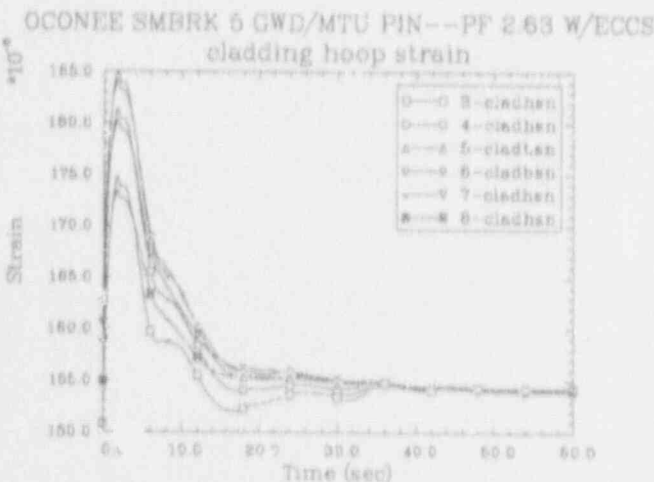


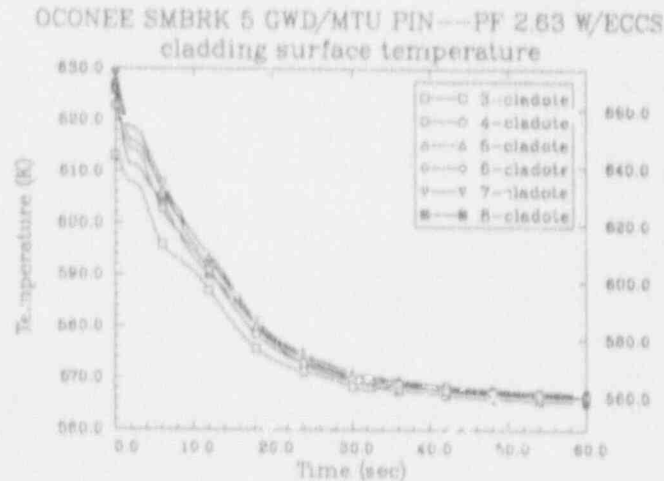
OCONEE SMBRK 20 GWD/MTU PIN--PF 2.63 W/ECCS
oxide thickness

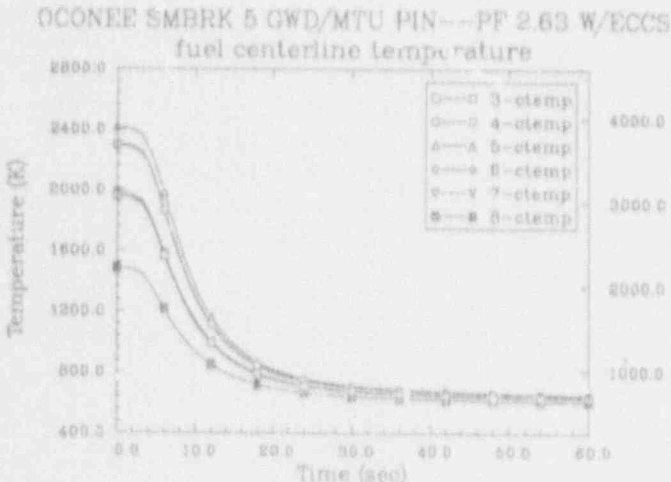


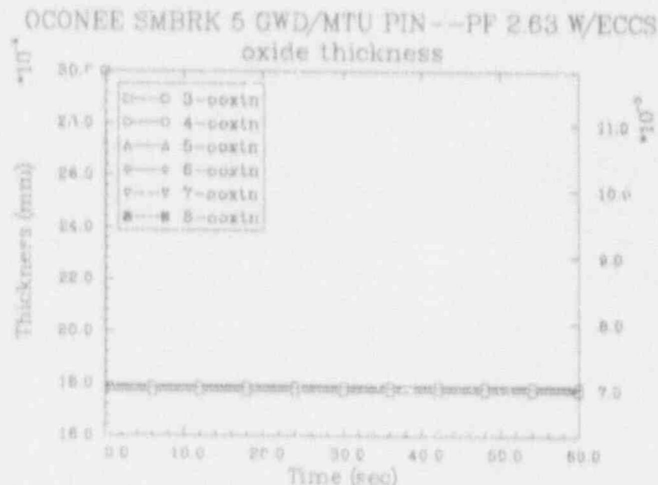

OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63 W/ECCS
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin


OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63 W/ECCS
failure probability
Failure Probability
Time (sec)
0-ffr


OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63 W/ECCS
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn


OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63 W/ECCS
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote


OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63 W/ECCS
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp


OCONEE SMBRK 5 GWD/MTU PIN--PF 2.63 W/ECCS
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

Appendix L

Plots for the Timing Analysis of PWR Fuel Pin Failures for Seabrook

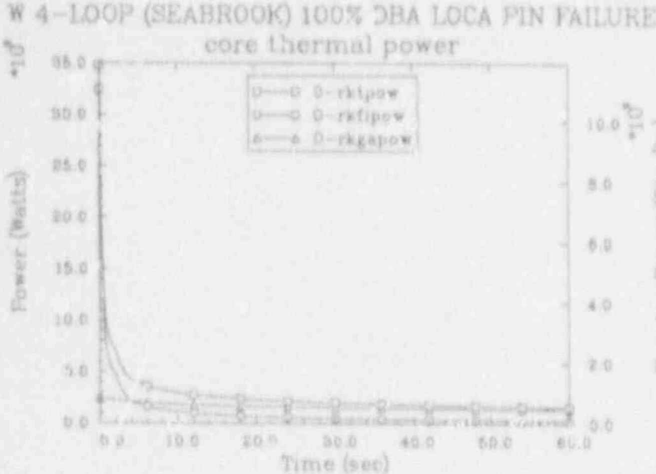
Appendix L
Plots for the Timing Analysis of PWR Fuel Pin Failures for Seabrook

Appendix L contains the plotted results for the timing analysis of PWR fuel pin failures for the Seabrook reactor. Section L-1.1 contains the SCDAP/RELAP5/MOD3 plots of total core power, collapsed reactor water level, reactor upper head and pressurizer dome pressures, containment pressure, fission product release, internal pin pressures, fuel centerline temperatures, cladding surface temperatures, hoop strains, total break flow, accumulator flow, accumulator liquid volume, hot leg flows, cold leg flows, hot channel core flow, downcomer void fractions, mass error, time step size, and cpu time for the nine accident scenarios. Section L-1.2 contains the FRAP-T6 plots of failure probability, internal pin pressure, cladding hoop strain, cladding surface temperature, fuel centerline temperature, and oxide thickness for the nine accident scenarios with peaking factors of 2.232, 2.2, 2.0, and 1.8 and burnups of 50, 35, 20, and 5 GWd/MTU and using SCDAP/RELAP5/MOD3 thermal-hydraulic boundary condition data. For the 100% design basis accident (DBA) case, plots of results obtained using TRAC-PF1/MOD1 thermal-hydraulic boundary condition data are also included. Section L-1.3 contains plots comparing TRAC-PF1/MOD1 and SCDAP/RELAP5/MOD3 results for the 100% DBA case for the following variables: core thermal power, collapsed reactor water level, presurizer dome and reactor upper head pressures, total break flow, accumulator flow, accumulator liquid volume, hot leg flow, cold leg flow, hot channel core flow, downcomer void fractions, and time step size. Tables L-1, L-2, and L-3 provide a listing of the plot variables.

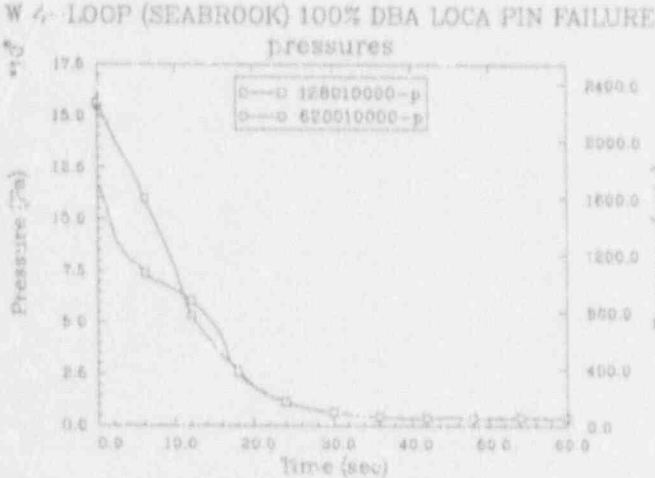
L-1.1 SCDAP/RELAP5/MOD3 Plotted Results for Seabrook

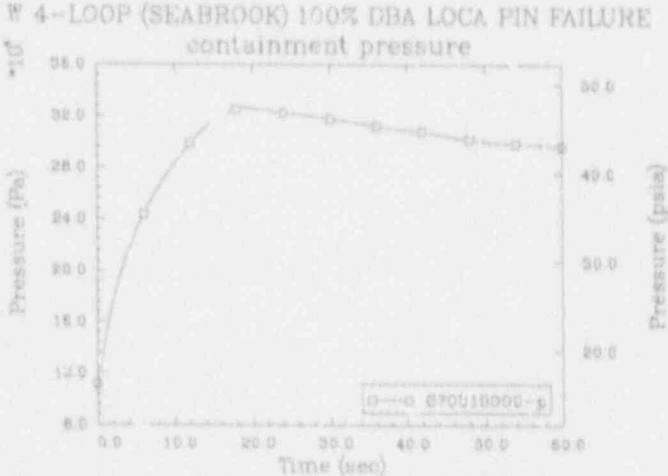
Table L-1. Description of SCDAP/RELAP5/MOD3 plot variables for Seabrook.

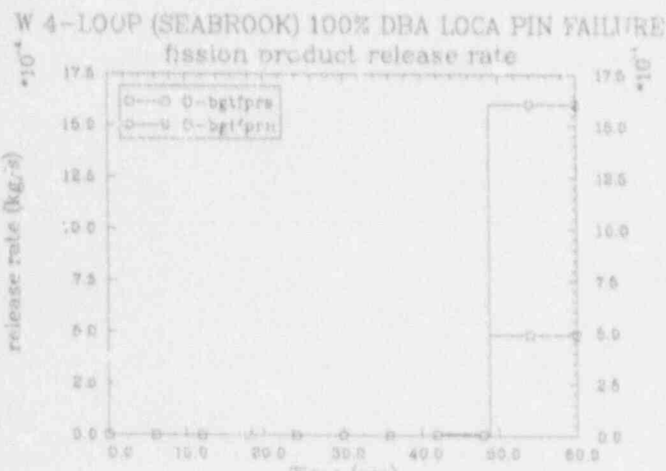
Variable	Description
0-rktpow	Total core thermal power (W)
0-rkfipow	Total core fission power (W)
0-rkgapow	Total core decay heat (W)
400-cntrlvar	Hot channel collapsed reactor water level for Seabrook (m)
403-cntrlvar	Core average collapsed reactor water level for Seabrook (m)
128010000-p	Reactor upper head pressure for Seabrook (Pa)
620010000-p	Pressurizer dome pressure for Seabrook (Pa)
670010000-p	Containment pressure for Seabrook (Pa)
0-bgtfprs	Soluble fission product release rate (kg/s)
0-bgtfprn	Insoluble fission product release rate (kg/s)
1-pgas	Average-burnup fuel pin internal pressure (Pa)
2-pgas	Low-burnup fuel pin internal pressure (Pa)
3-pgas	High-burnup fuel pin internal pressure (Pa)
1nn02-cadct	Low-burnup fuel pin centerline temperature for node nn (K)
1nn03-cadct	High-burnup fuel pin centerline temperature for node nn (K)
14nn02-cadct	Low-burnup fuel pin cladding temperature for node nn (K)
14nn03-cadct	High-burnup fuel pin cladding temperature for node nn (K)
n02-hoop	Low-burnup fuel pin cladding hoop strain for node n (dimensionless)
n03-hoop	High-burnup fuel pin cladding hoop strain for node n (dimensionless)
410-cntrlvar	Total break flow (kg/s)
704010000-mflowj	Accumulator flow for the Seabrook broken loop (kg/s)
702010000-mflowj	Accumulator flow for the Seabrook intact loop (kg/s)
704-acvliq	Accumulator liquid volume for the Seabrook broken loop (m^3)
702-acvliq	Accumulator liquid volume for the Seabrook intact loop (m^3)
400010000-mflowj	Hot leg flow for the Seabrook broken loop (kg/s)
200010000-mflowj	Hot leg flow for the Seabrook intact loop (kg/s)
453010000-mflowj	Cold leg flow for the Seabrook broken loop (kg/s)
253010000-mflowj	Cold leg flow for the Seabrook intact loop (kg/s)
15n010000-mflowj	Hot channel flows for n = 1, 3, 5, 7, and 9 for Seabrook (kg/s)

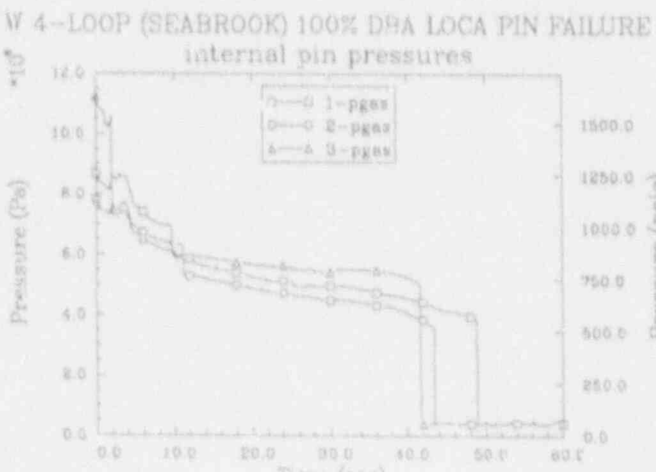

W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
collapsed reactor water level
400-cntrlvar
403-cntrlvar
Level (ft)
Time (sec)

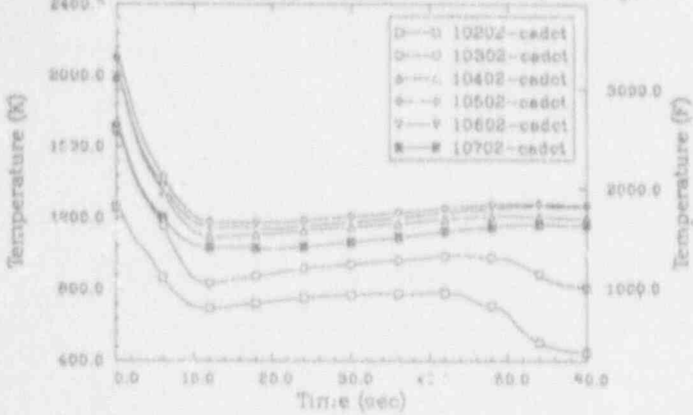

W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
pressures
128010000-p
620010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
containment pressure
670010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)

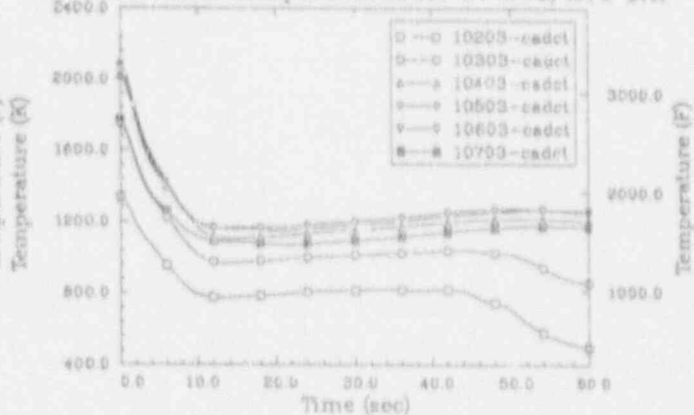

W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
fission product release rate
0-bgtfprs
0-bgtfprn
release rate (kg/s)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

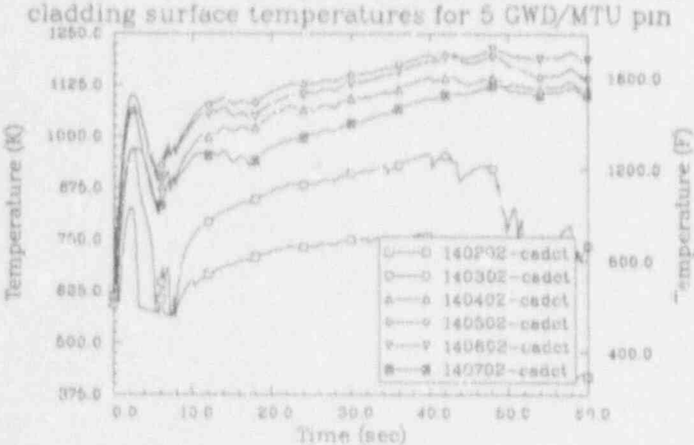
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



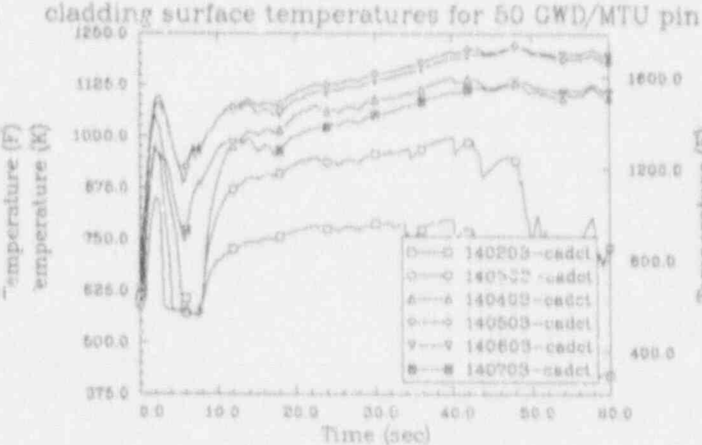
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
fuel centerline temperatures for 50 GWD/MTU pin



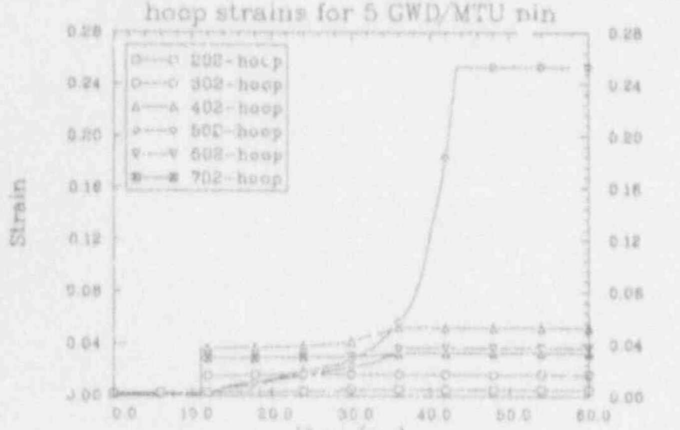
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



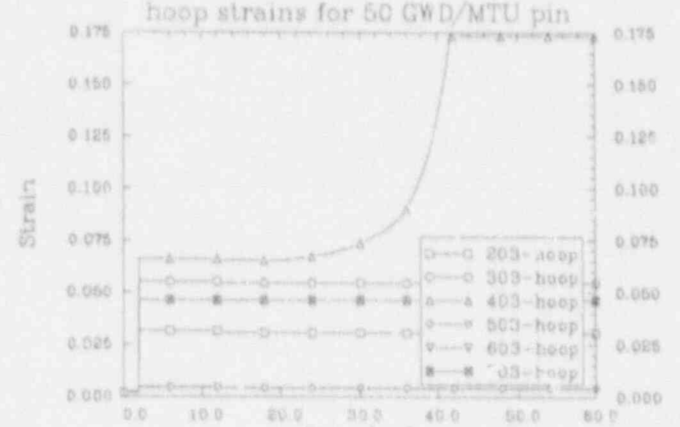
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
cladding surface temperatures for 50 GWD/MTU pin



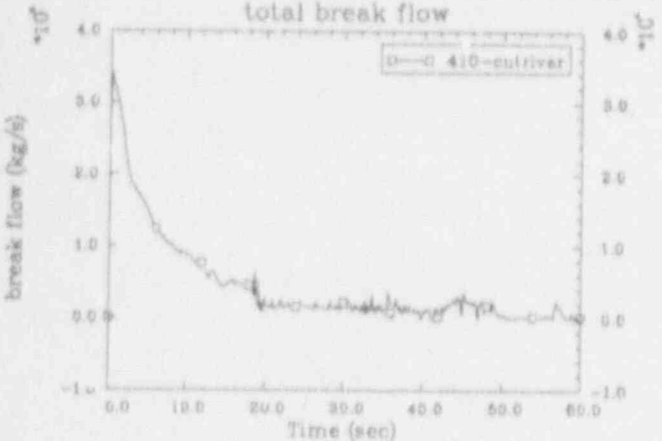
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin



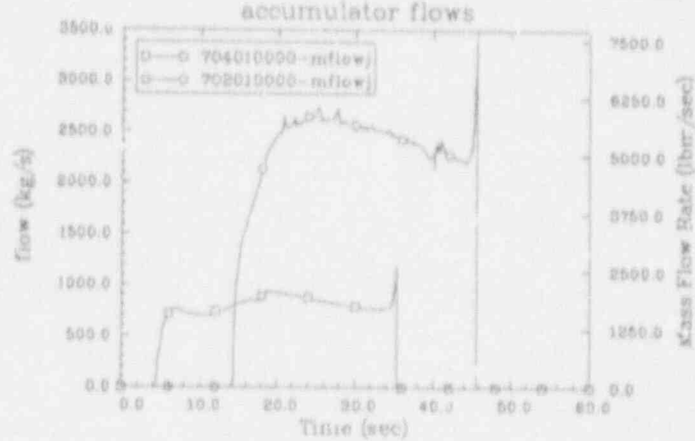
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
hoop strains for 50 GWD/MTU pin



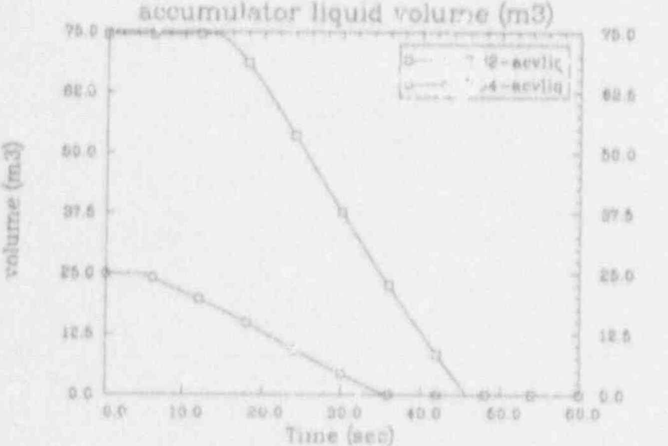
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
total break flow



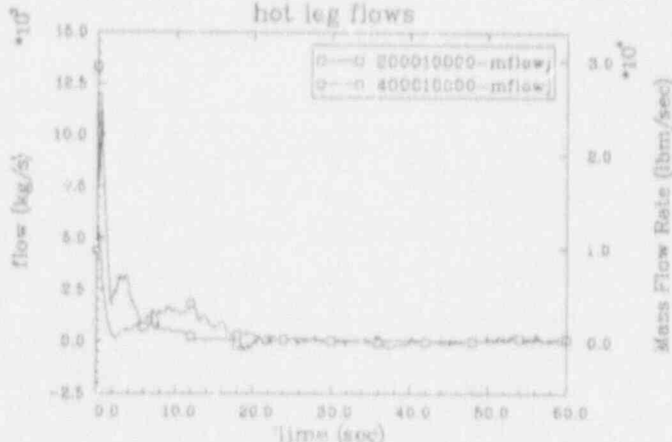
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
accumulator flows



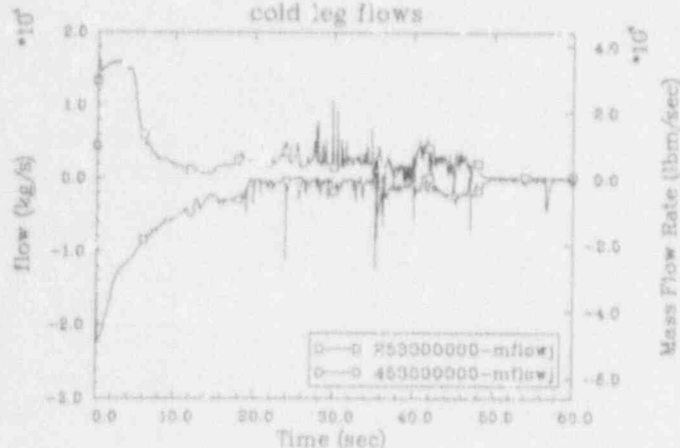
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)



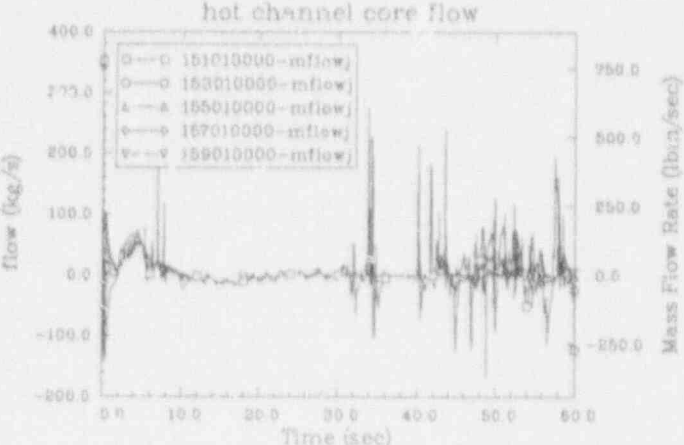
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
hot leg flows

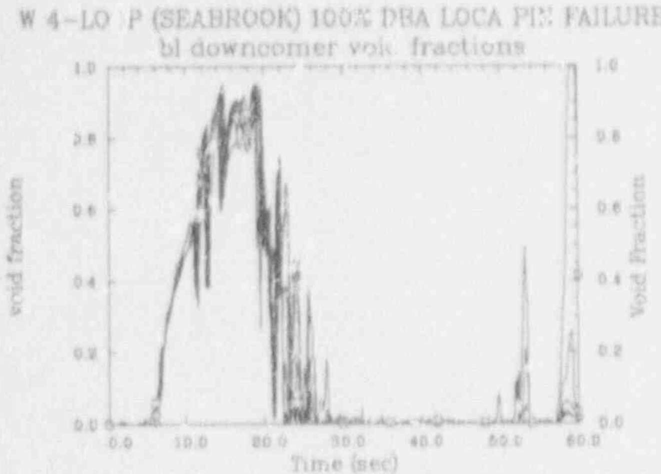


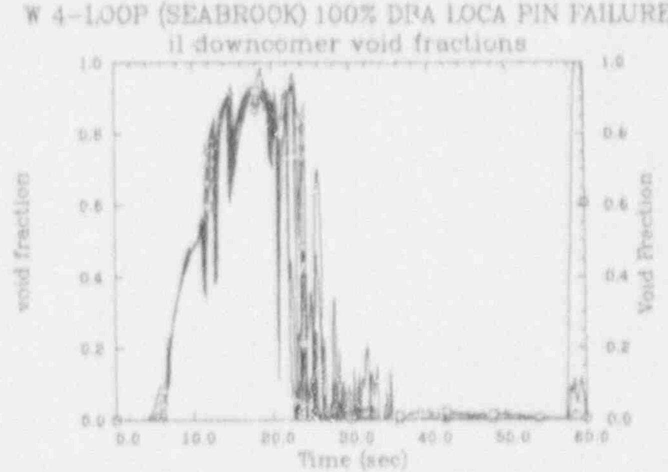
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
cold leg flows

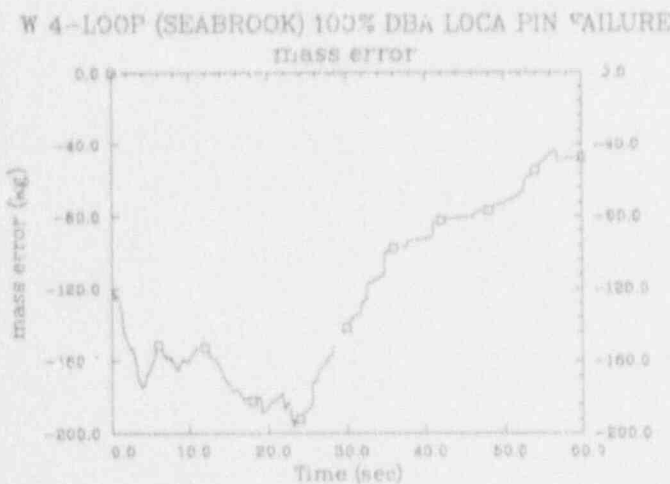


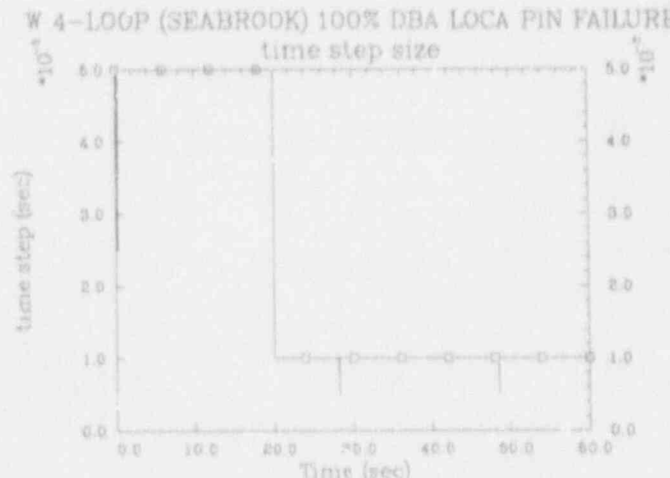
W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
hot channel core flow

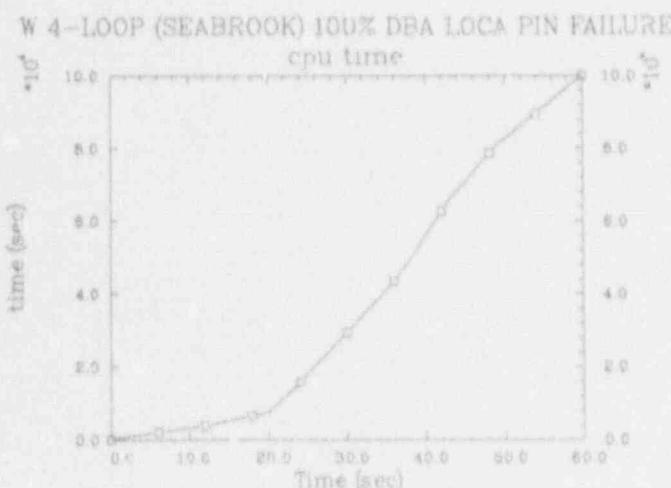


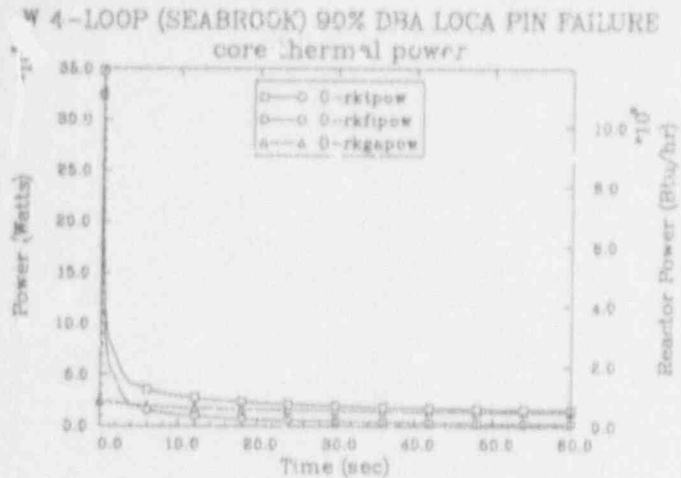

W 4-LO P (SEABROOK) 100% DBA LOCA PIN FAILURE
bl downcomer voi fractions
void fraction
Void Fraction
Time (sec)

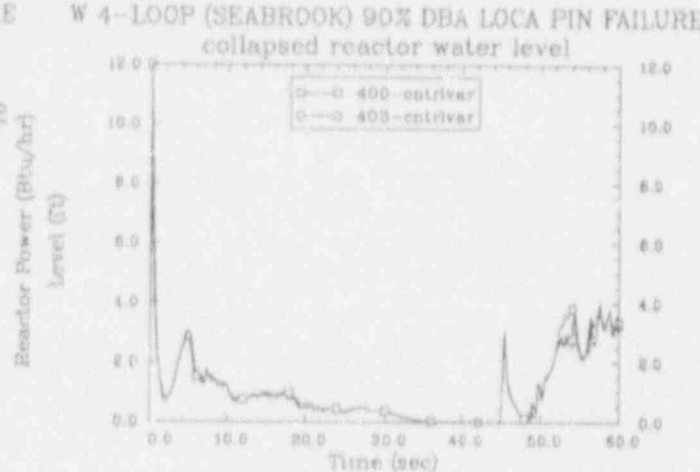

W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
il downcomer void fractions
void fraction
Void Fraction
Time (sec)

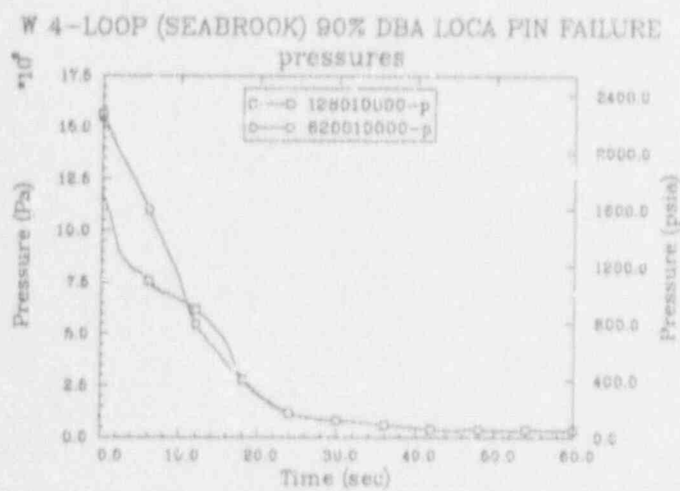

W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

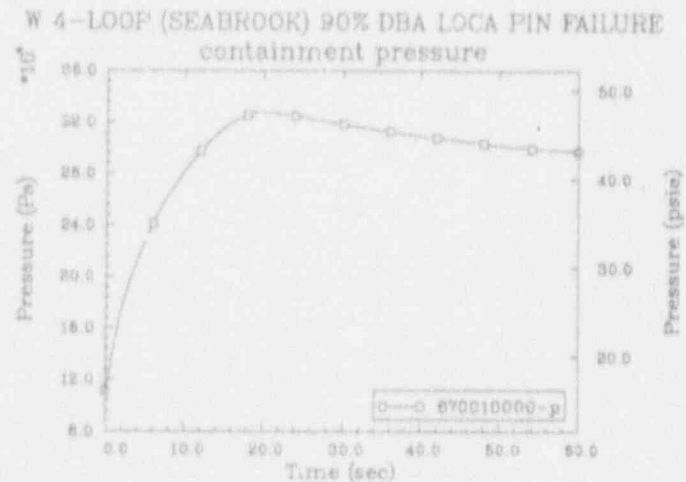

W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)

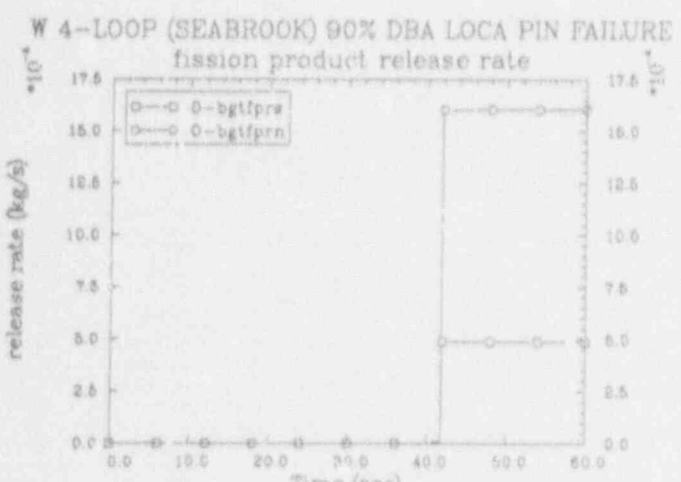

W 4-LOOP (SEABROOK) 100% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

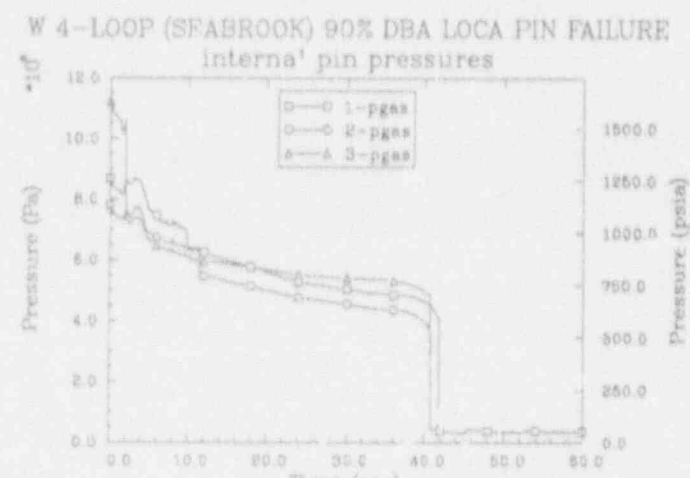

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
collapsed reactor water level
400-cntrlvar
403-cntrlvar
Level (ft)
Time (sec)

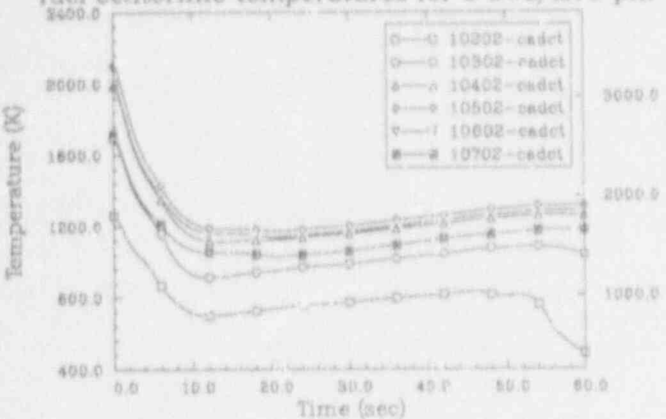

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
pressures
128010000-p
620010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)


W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
containment pressure
670010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)

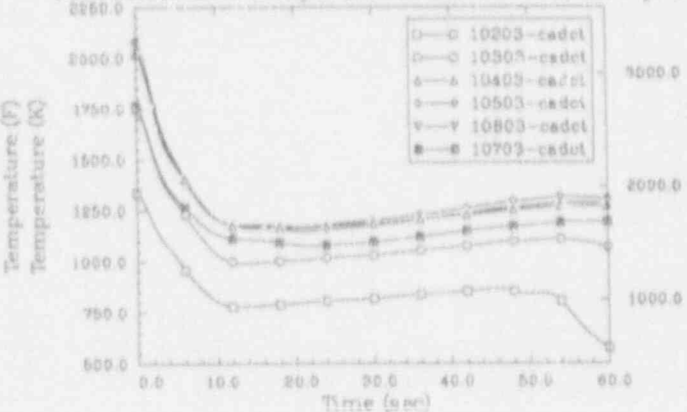

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
fission product release rate
0-bgtfprs
0-bgtfprn
release rate (kg/s)
Time (sec)


W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

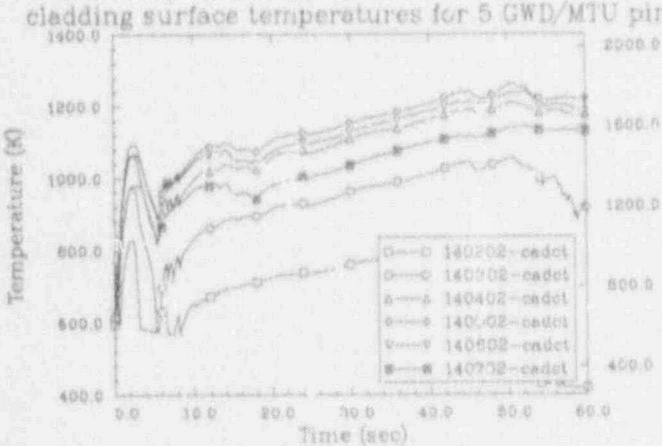
W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



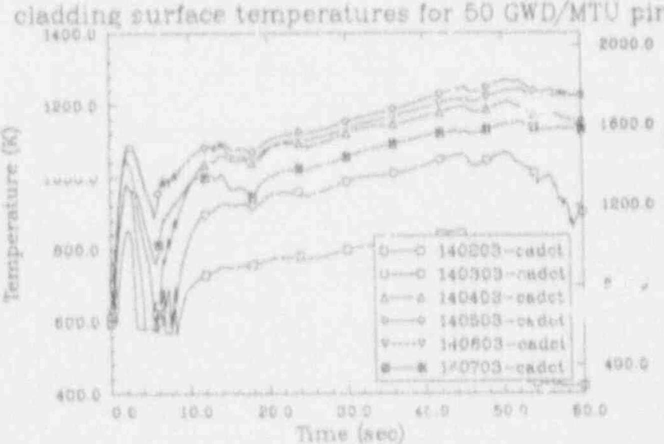
W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
fuel centerline temperatures for 50 GWD/MTU pin



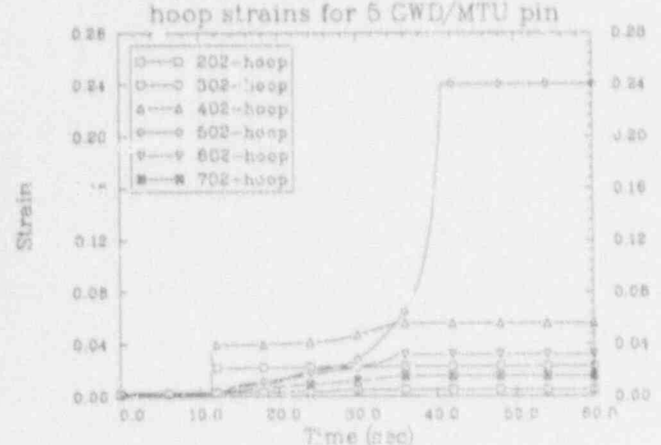
W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



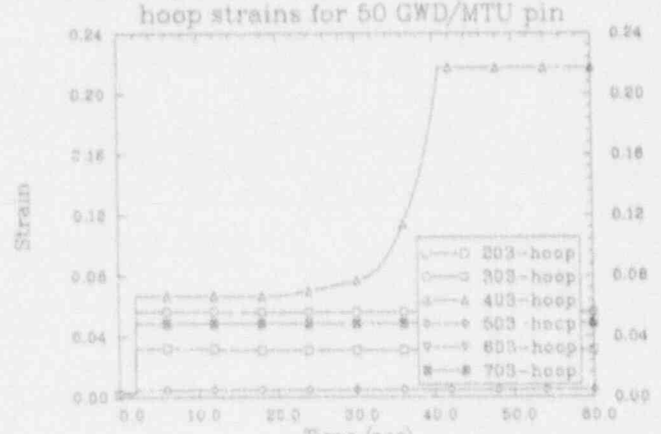
W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
cladding surface temperatures for 50 GWD/MTU pin

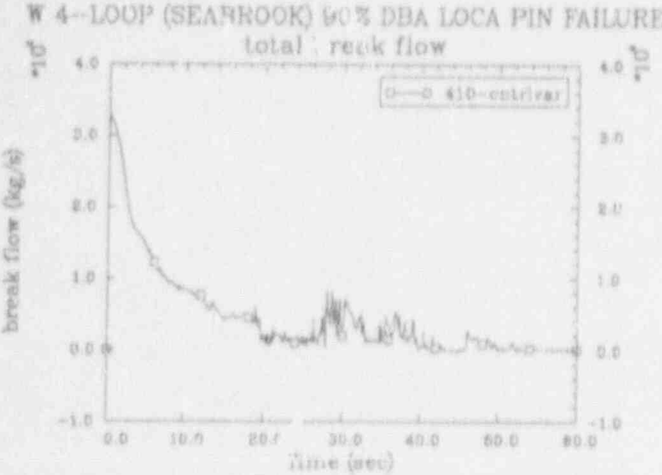


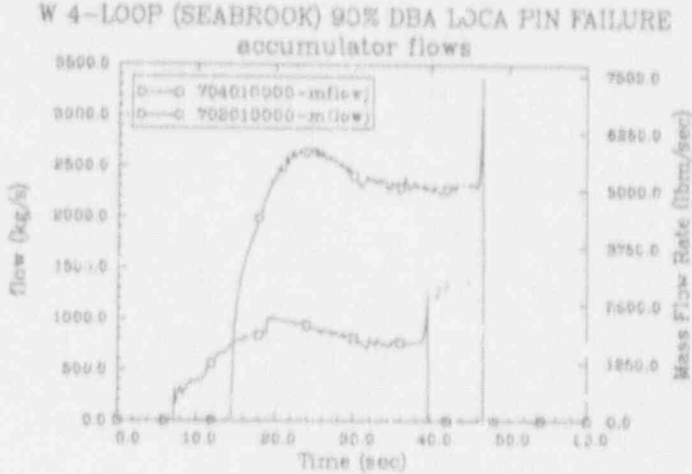
W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin

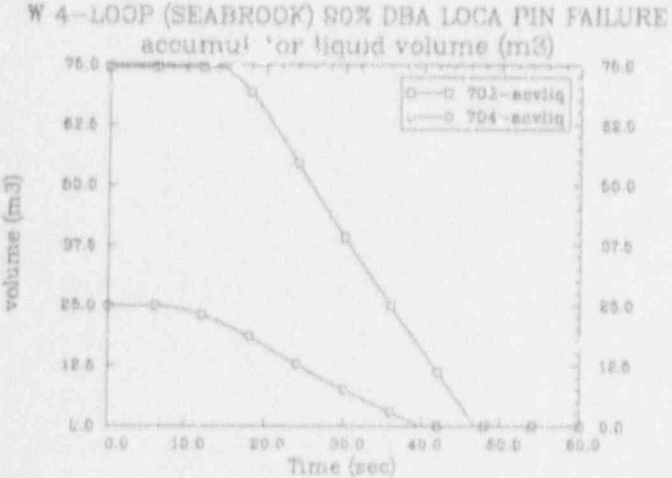


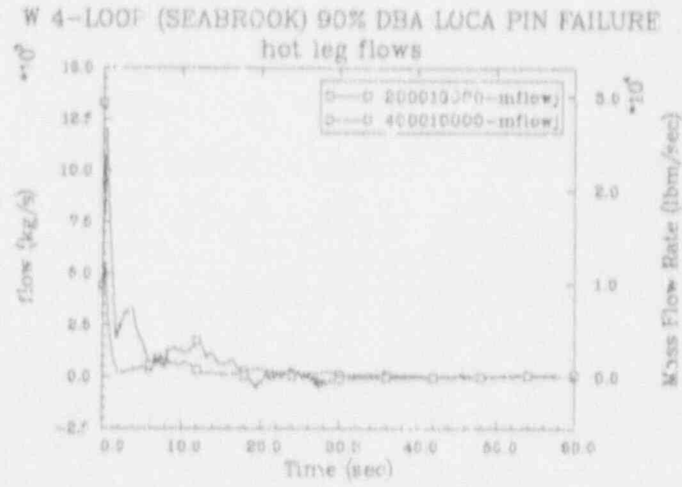
W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
hoop strains for 50 GWD/MTU pin

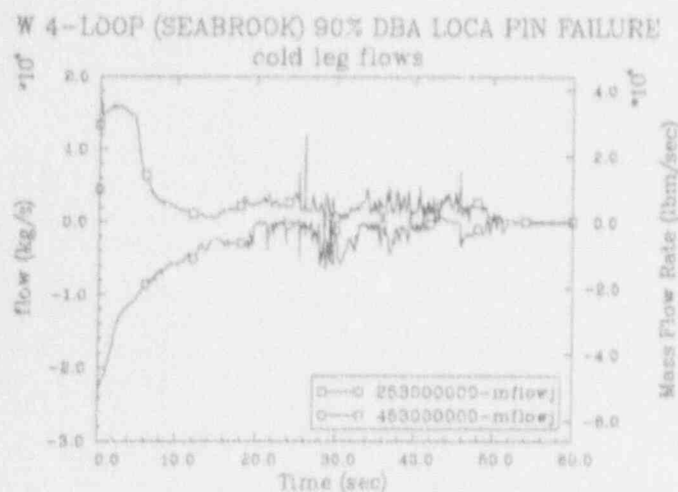


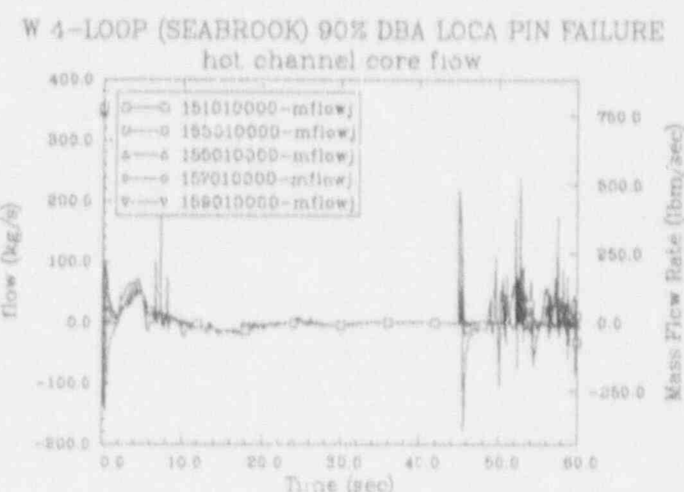

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
total break flow
410-cntrlvar
break flow (kg/s)
*10^3
Time (sec)

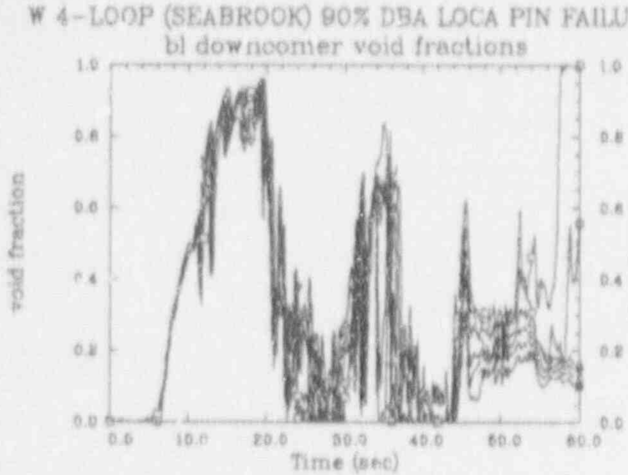

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
accumulator flows
704010000-mflowj
702010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

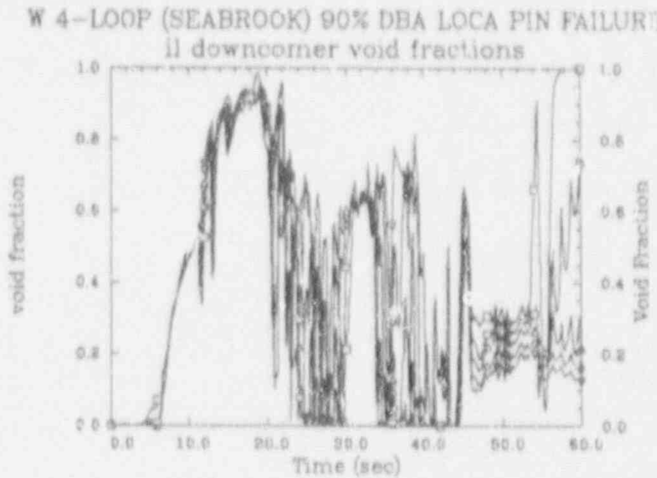

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)
702-acvliq
704-acvliq
volume (m3)
Time (sec)

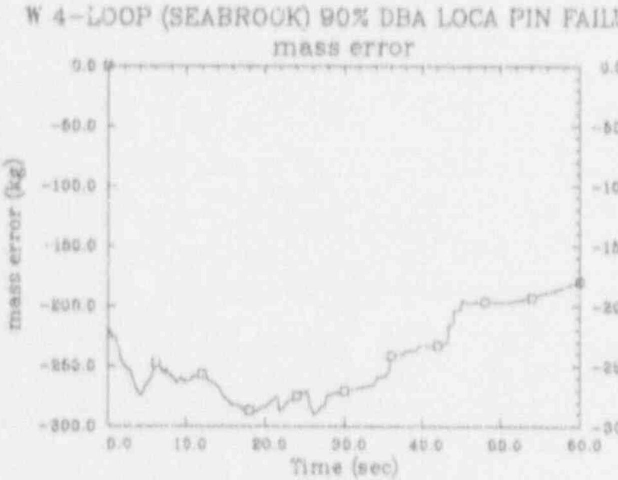

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
hot leg flows
200010000-mflowj
400010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
*10^3
Time (sec)

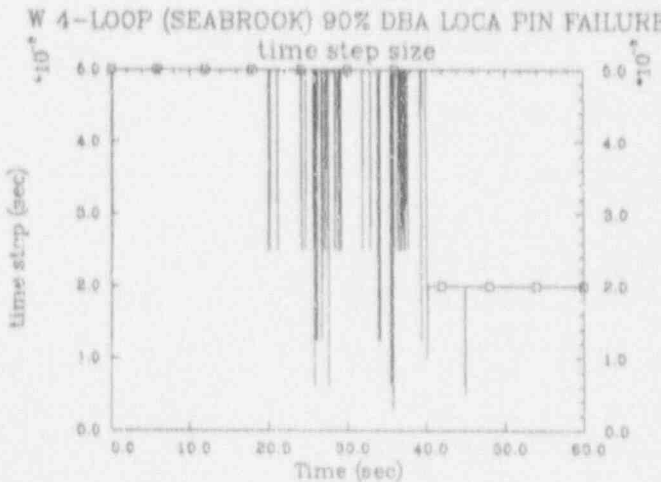

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
cold leg flows
253000000-mflowj
453000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
*10^3
Time (sec)

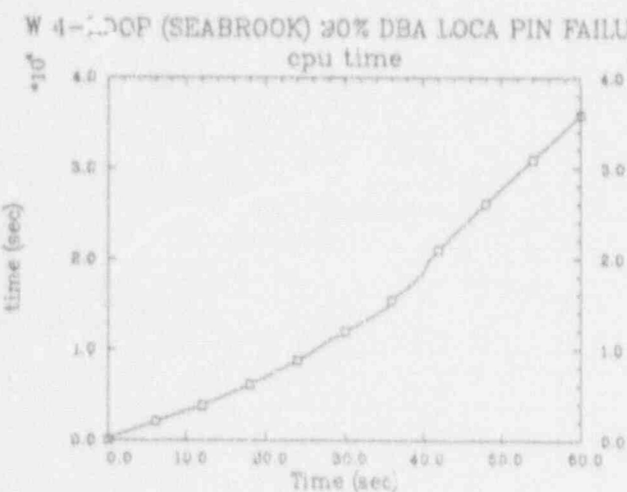

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
hot channel core flow
151010000-mflowj
155010000-mflowj
156010000-mflowj
157010000-mflowj
158010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)


W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

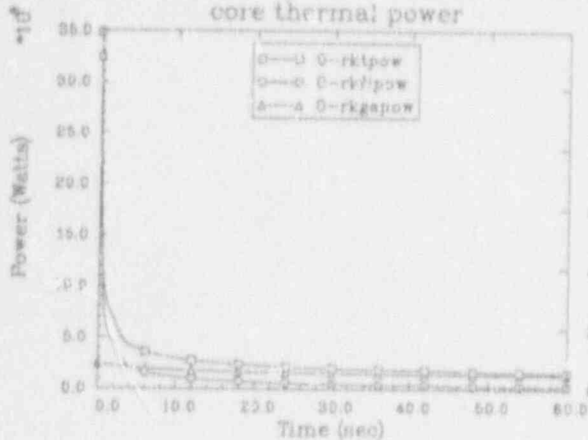

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
il downcomer void fractions
void fraction
Void Fraction
Time (sec)


W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

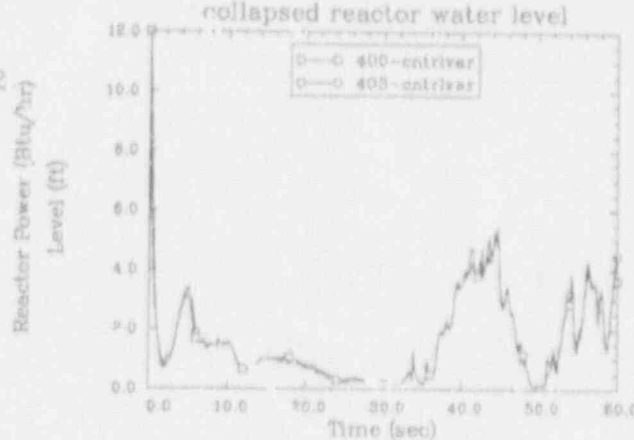

W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)


W 4-LOOP (SEABROOK) 90% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

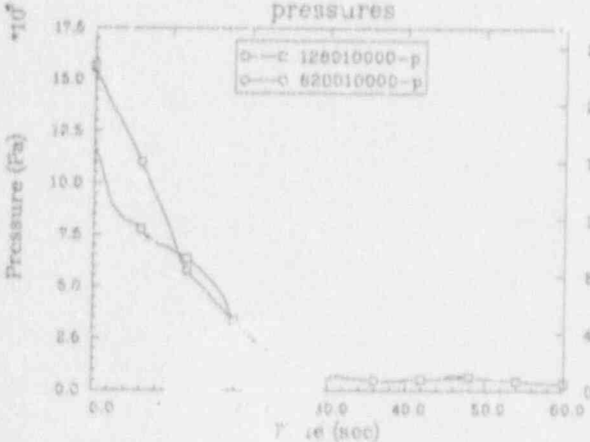
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
core thermal power



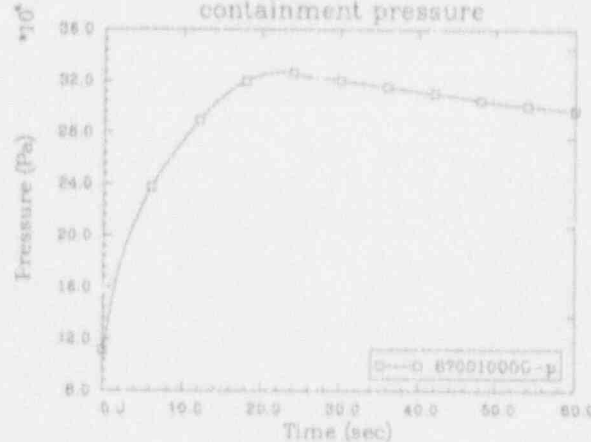
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
collapsed reactor water level



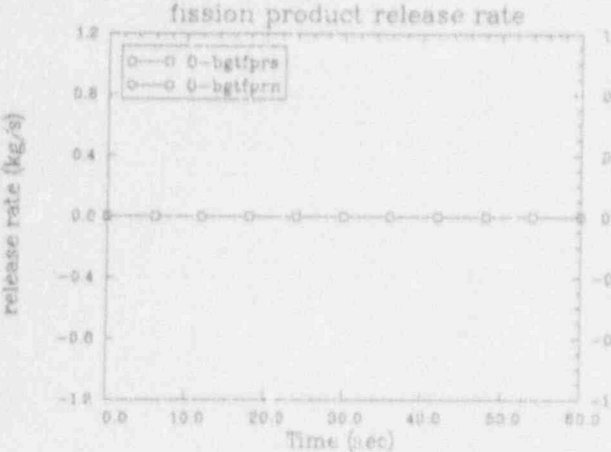
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
pressures



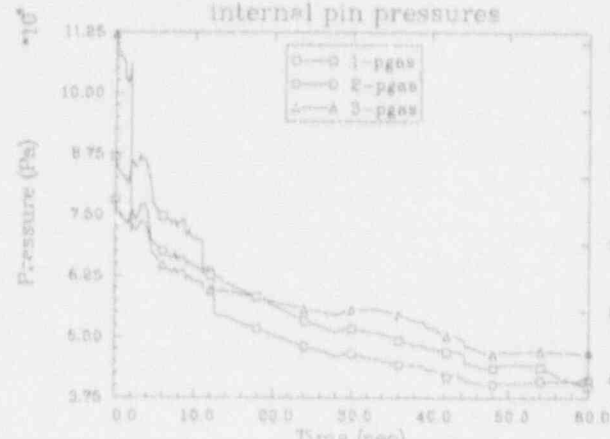
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
containment pressure



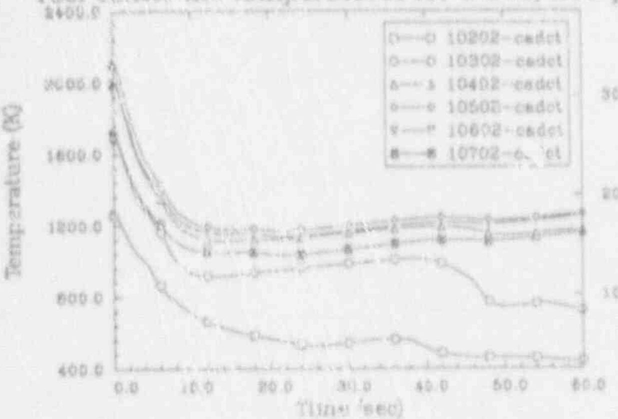
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
fission product release rate



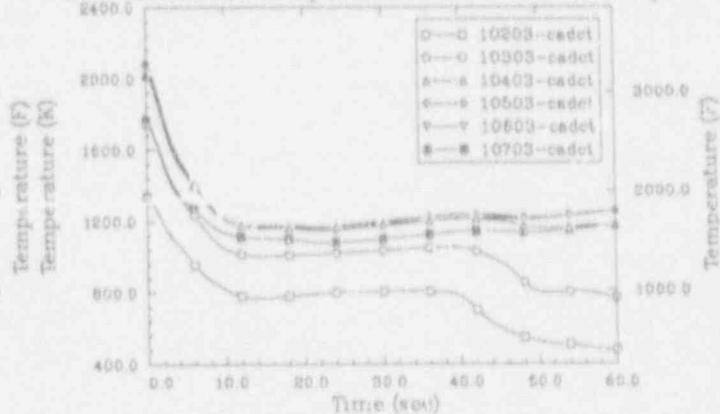
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
internal pin pressures



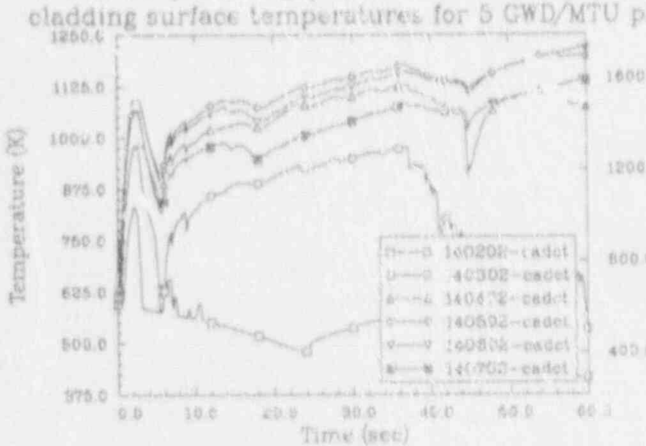
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



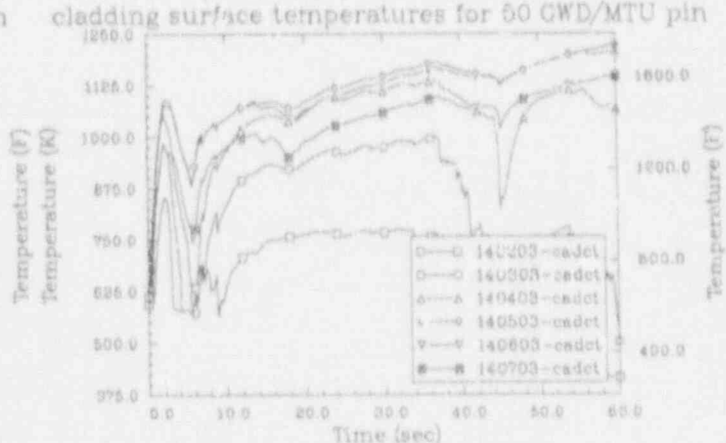
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
fuel centerline temperatures for 50 GWD/MTU pin



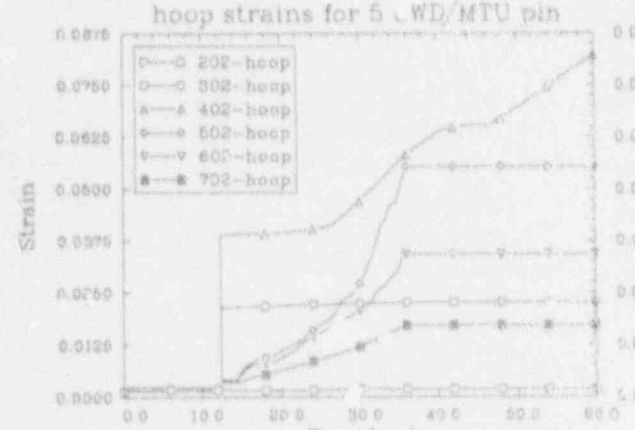
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



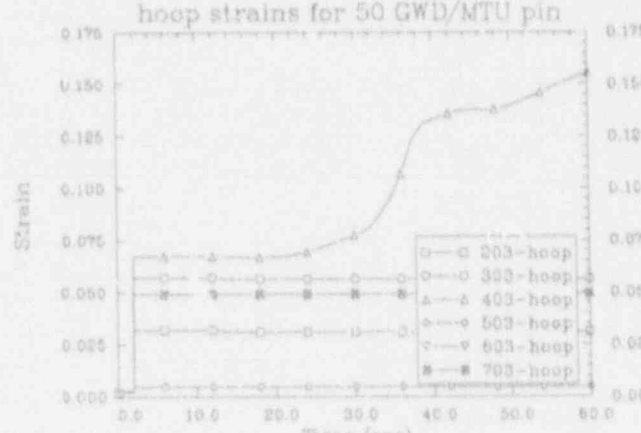
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
cladding surface temperatures for 50 GWD/MTU pin



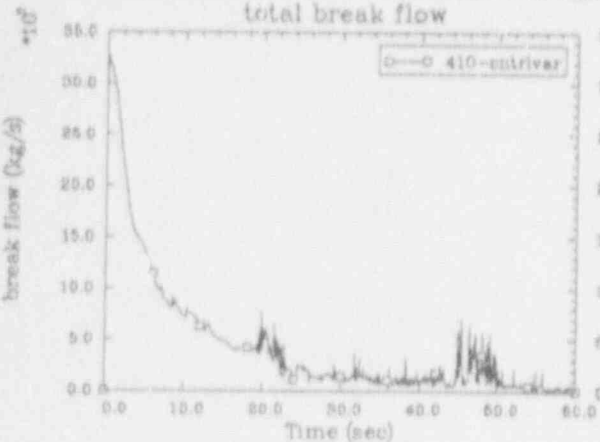
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin



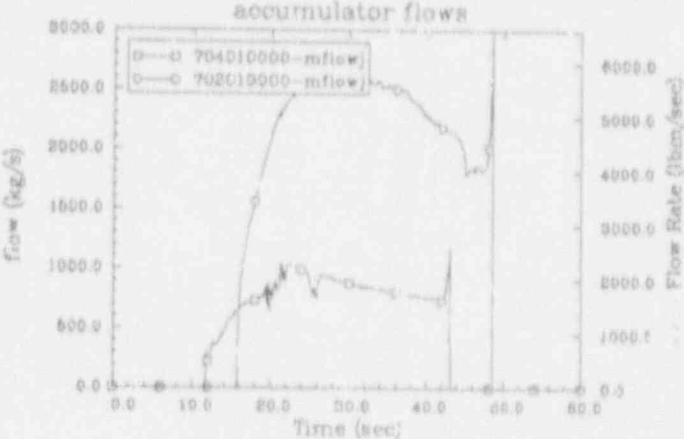
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
hoop strains for 50 GWD/MTU pin



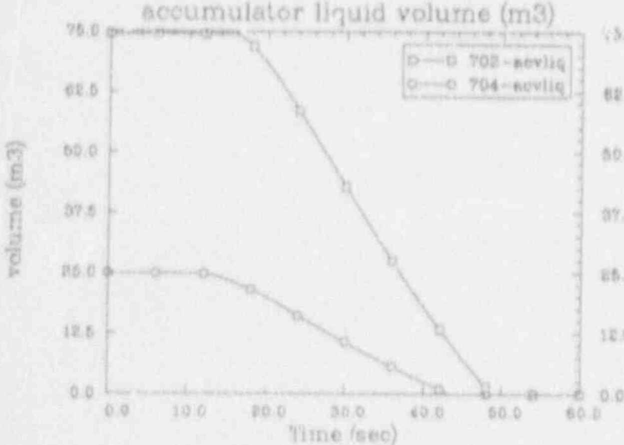
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
total break flow



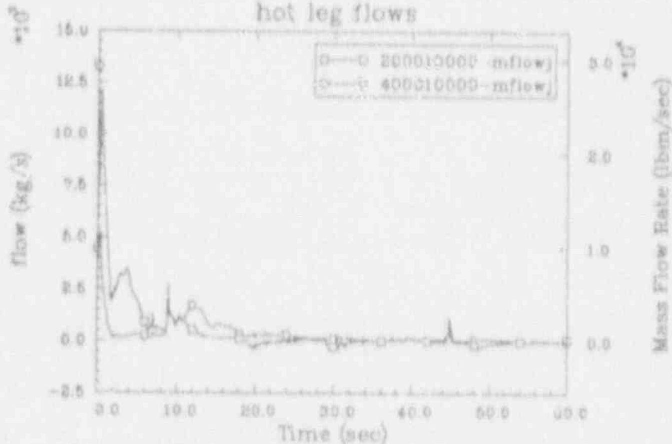
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
accumulator flows



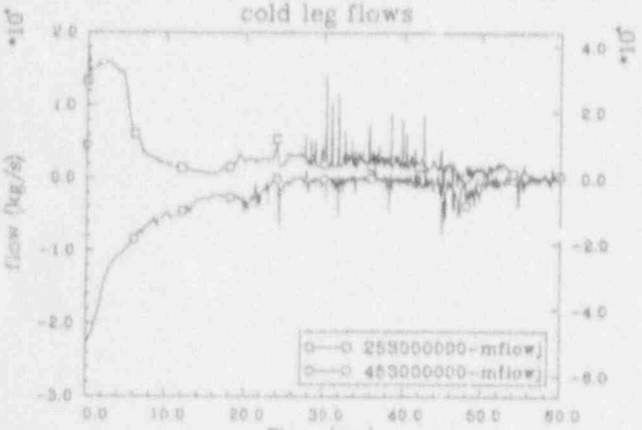
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)



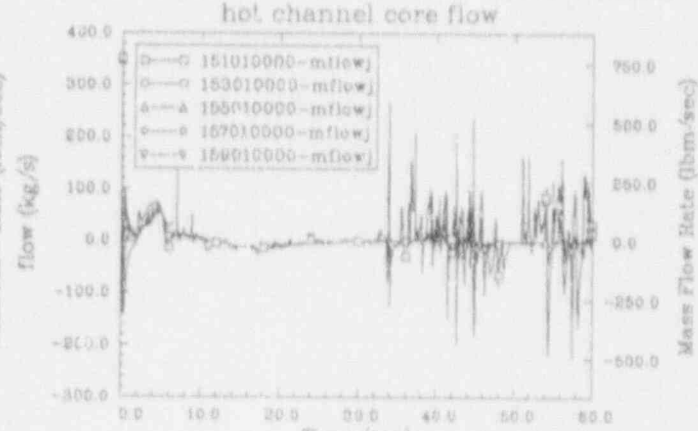
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
hot leg flows

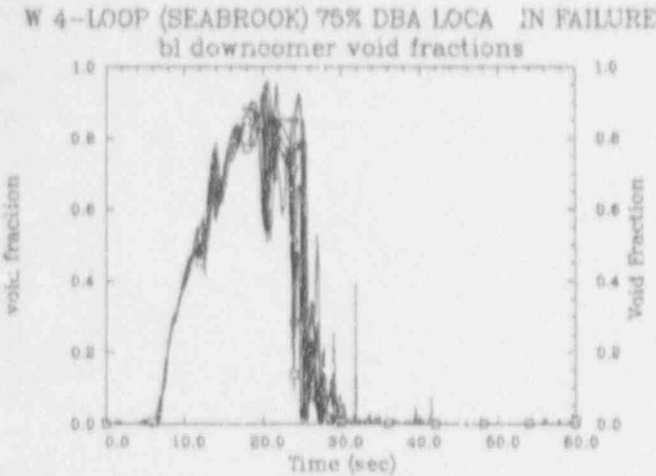


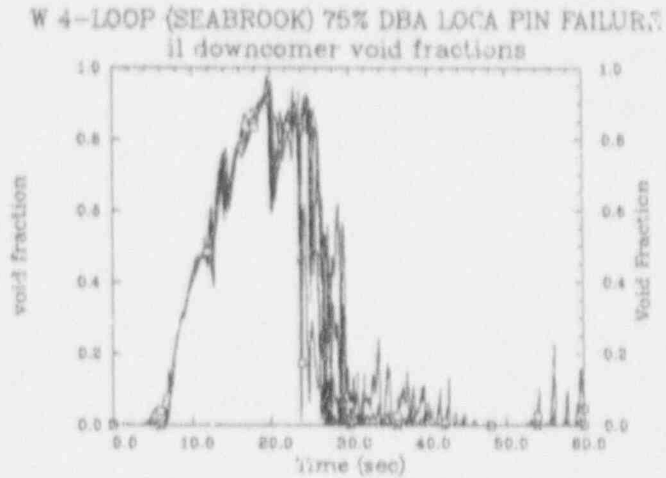
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
cold leg flows

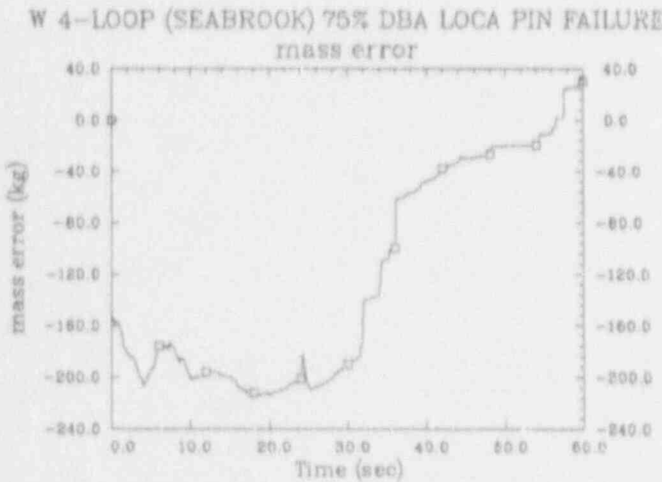


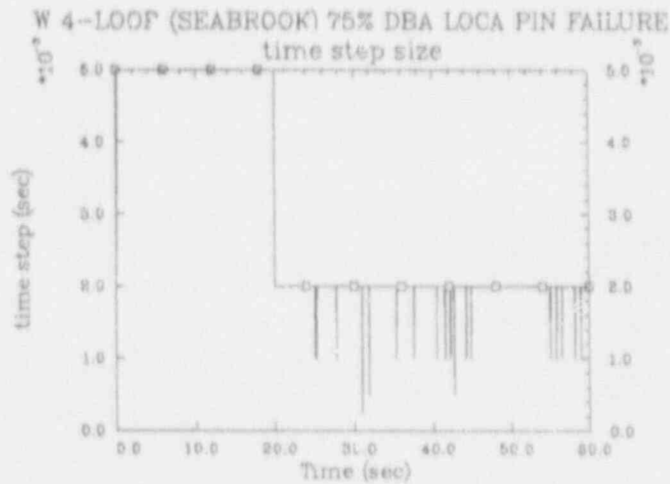
W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
hot channel core flow

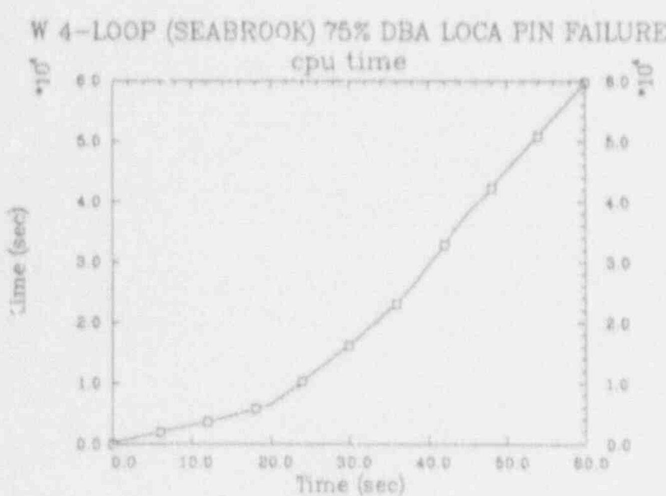



W 4-LOOP (SEABROOK) 75% DBA LOCA IN FAILURE
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

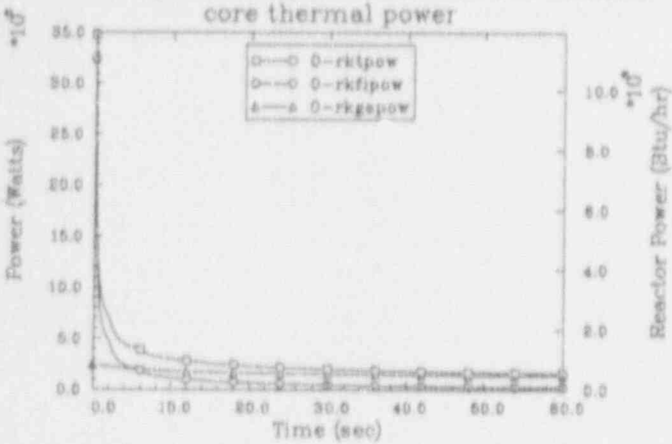

W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILUR
il downcomer void fractions
void fraction
Void Fraction
Time (sec)


W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

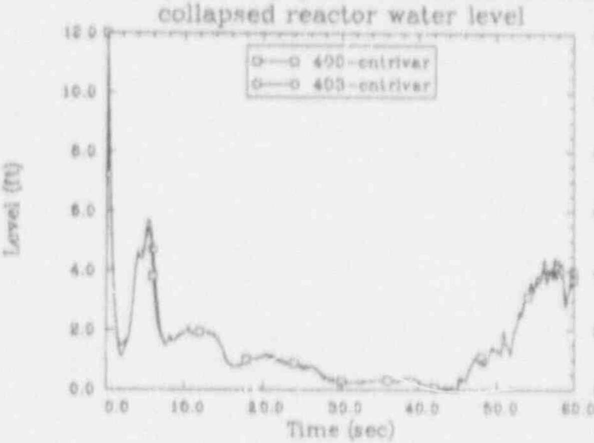

W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)


W 4-LOOP (SEABROOK) 75% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

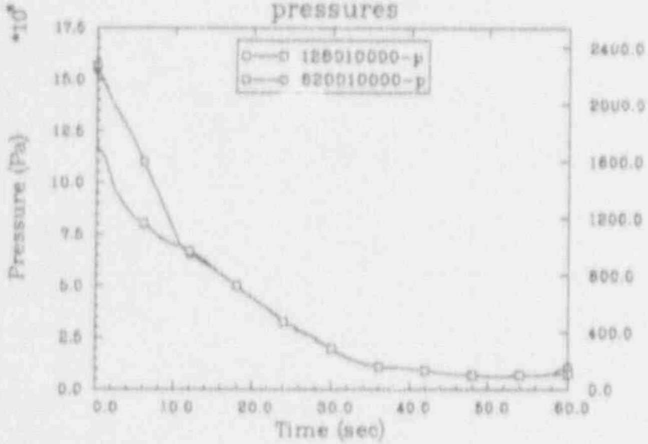
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
core thermal power



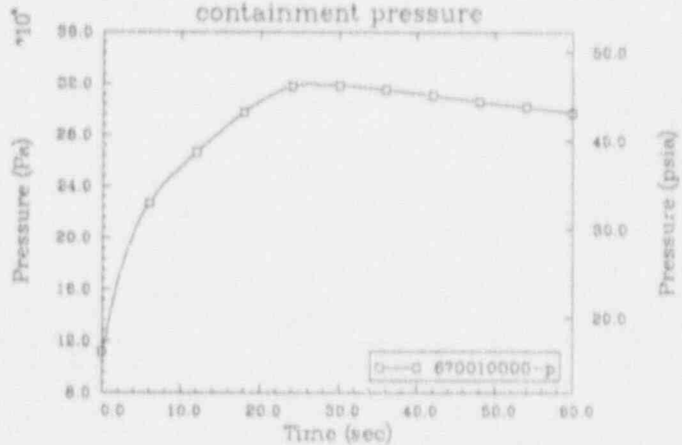
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
collapsed reactor water level



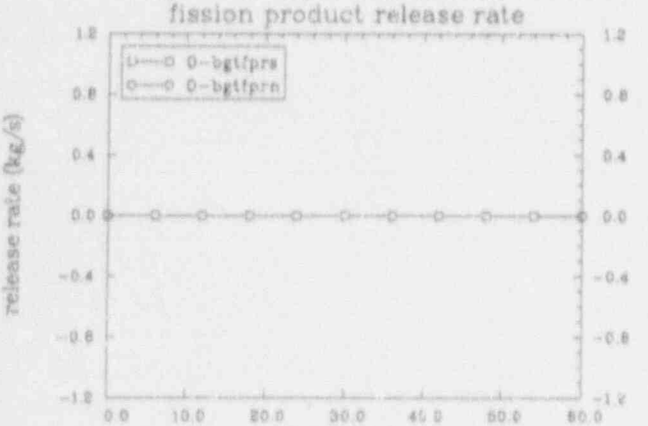
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
pressures



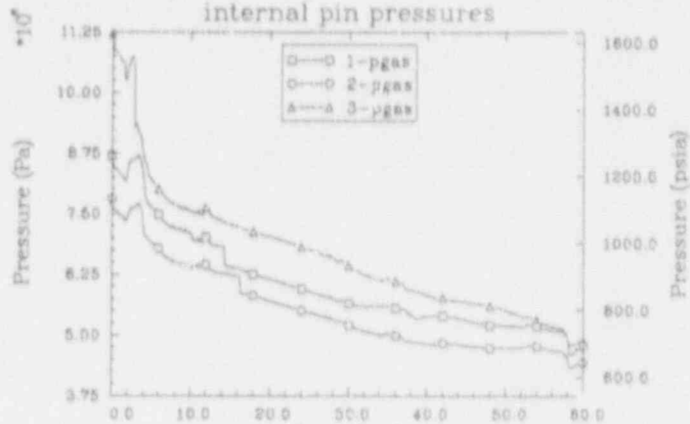
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
containment pressure



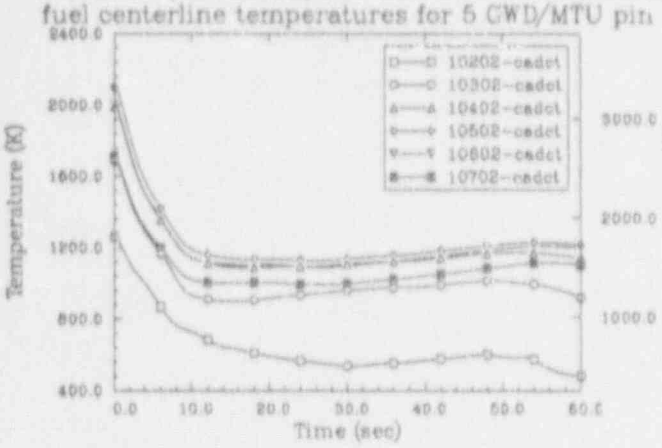
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
fission product release rate



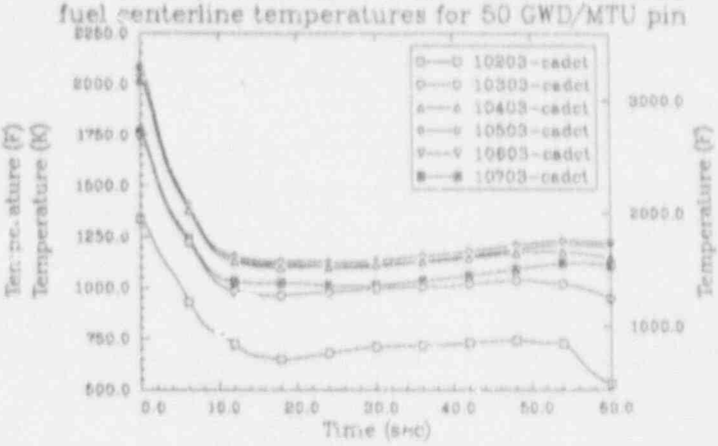
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
internal pin pressures



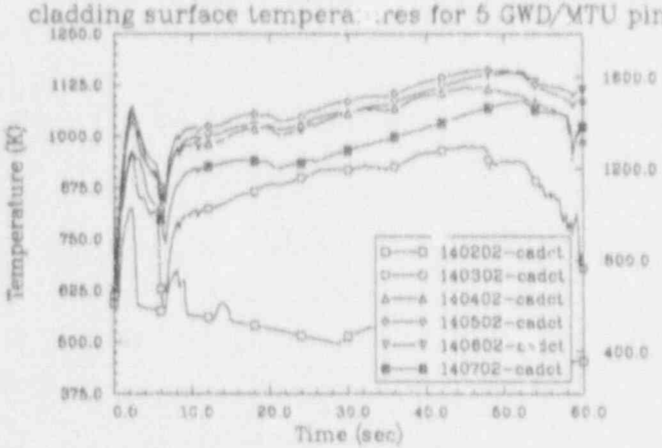
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
fuel centerline temperatures for 5 GWD/MTU pin



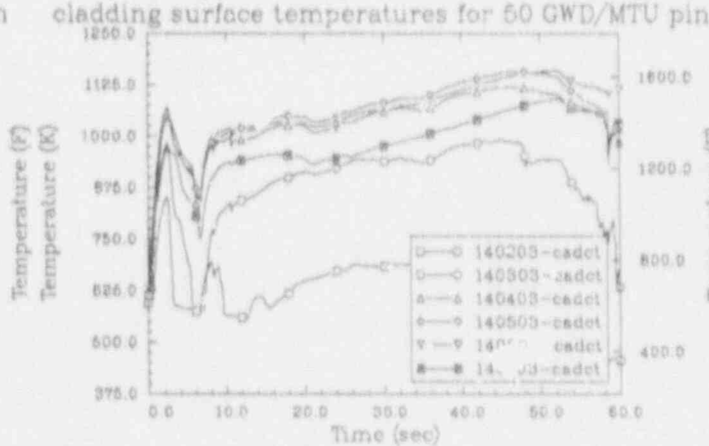
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
fuel centerline temperatures for 50 GWD/MTU pin



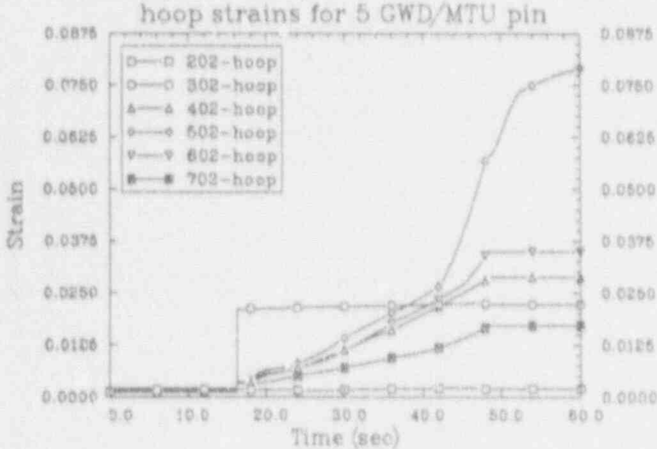
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
cladding surface temperatures for 5 GWD/MTU pin



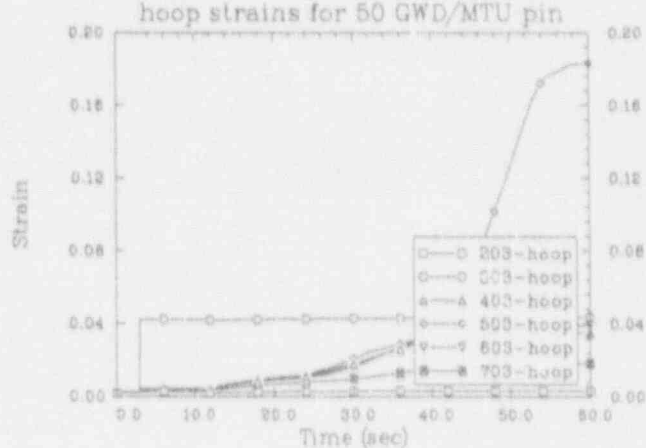
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
cladding surface temperatures for 50 GWD/MTU pin



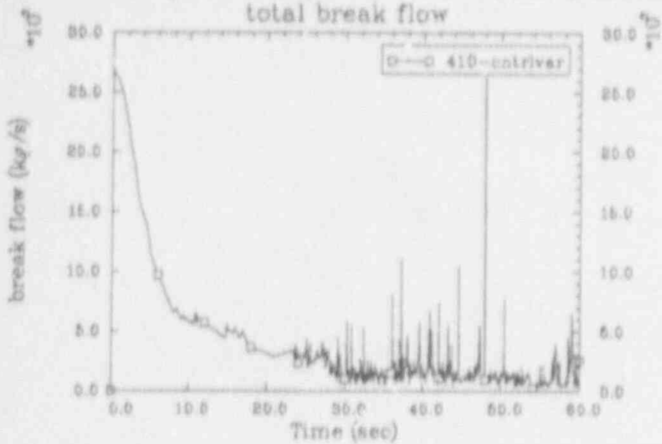
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin



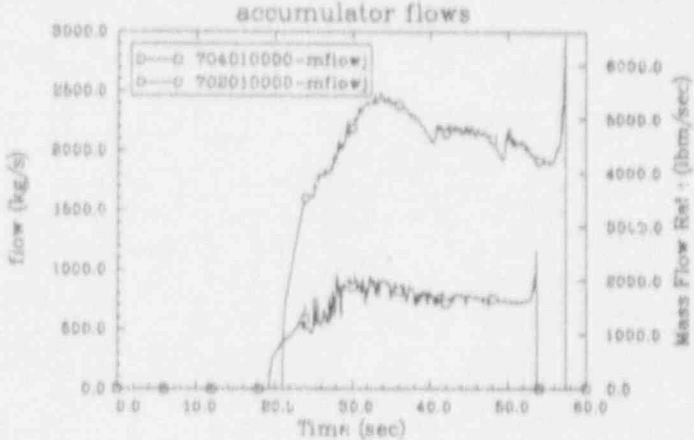
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
hoop strains for 50 GWD/MTU pin



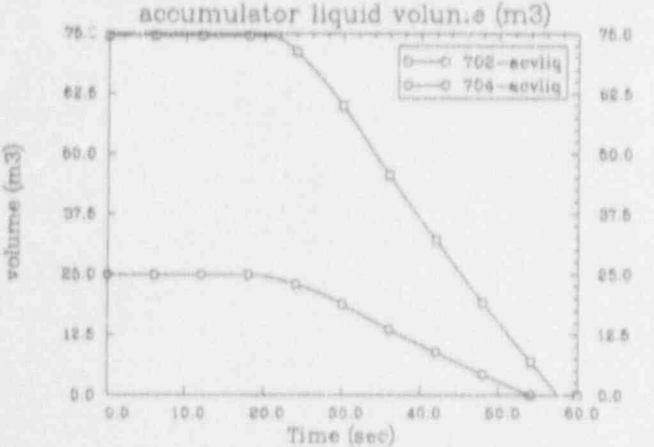
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
total break flow



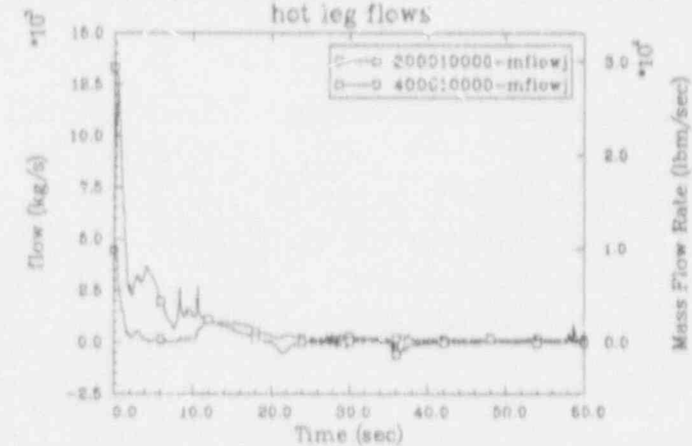
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
accumulator flows



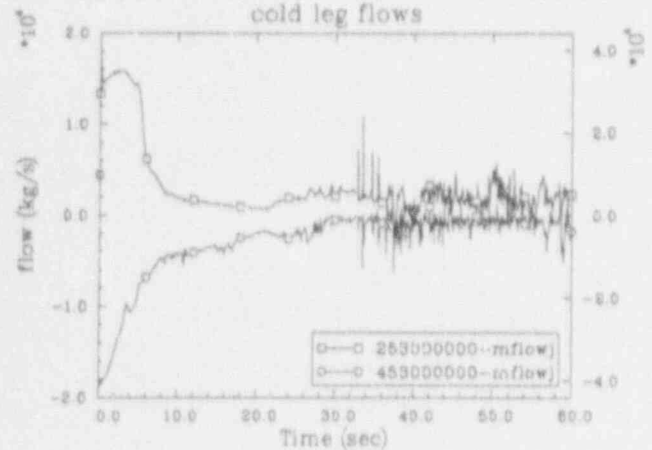
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
accumulator liquid volume (m3)



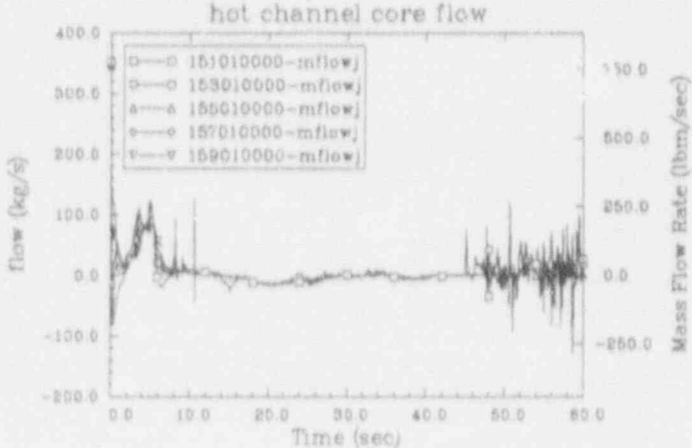
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
hot leg flows

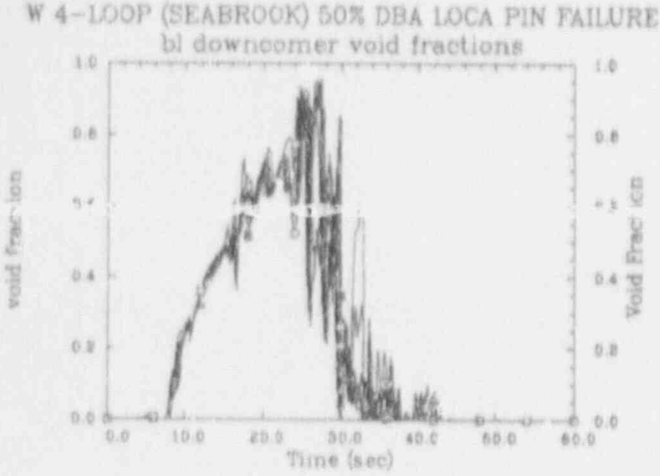


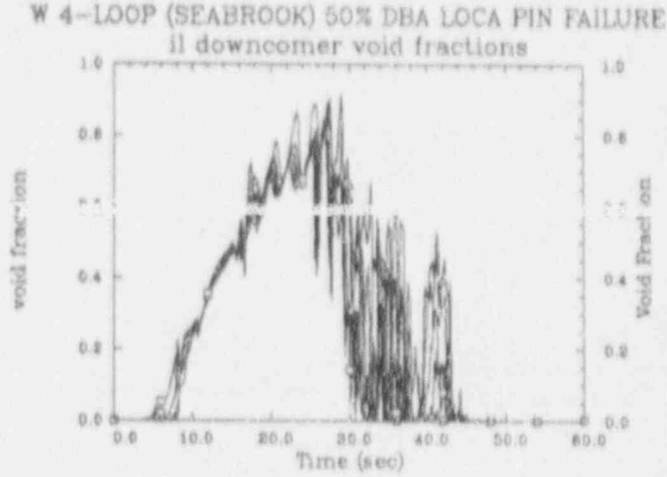
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
cold leg flows

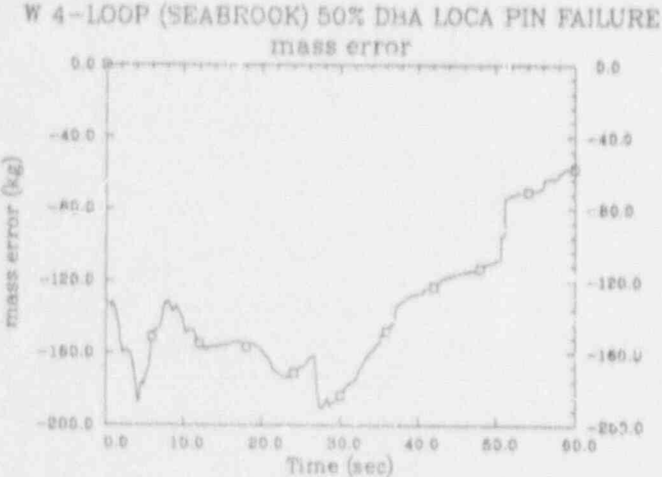


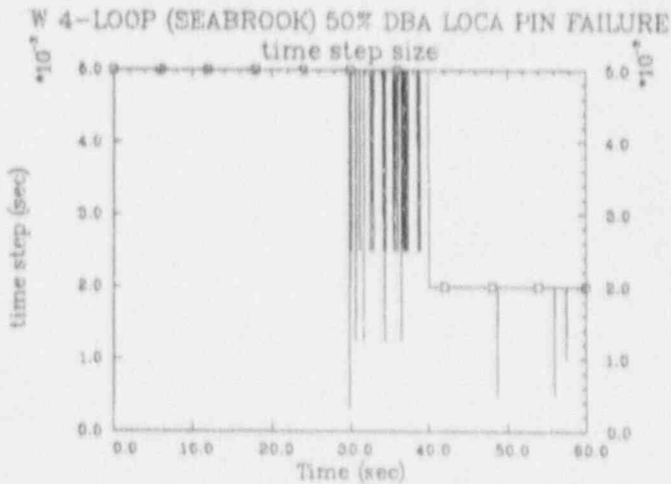
W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
hot channel core flow

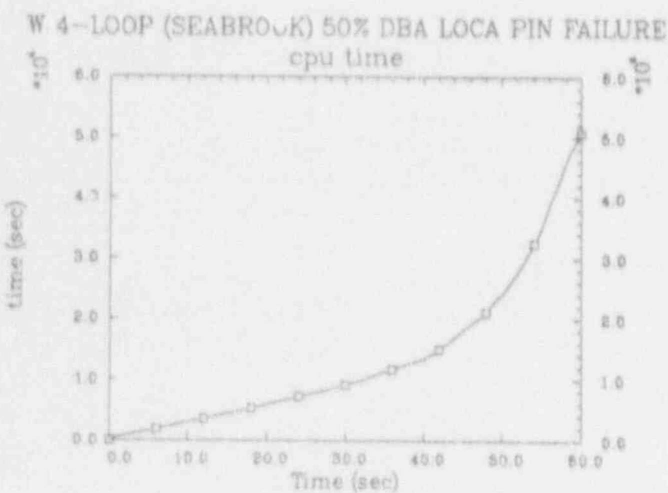


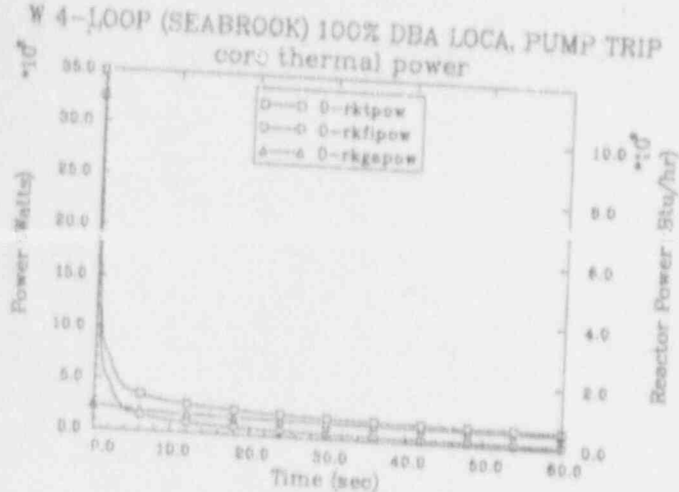

W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

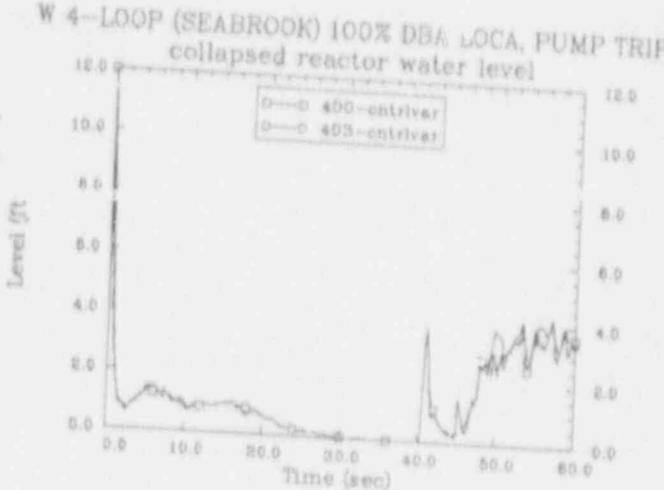

W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
il downcomer void fractions
void fraction
Void Fraction
Time (sec)

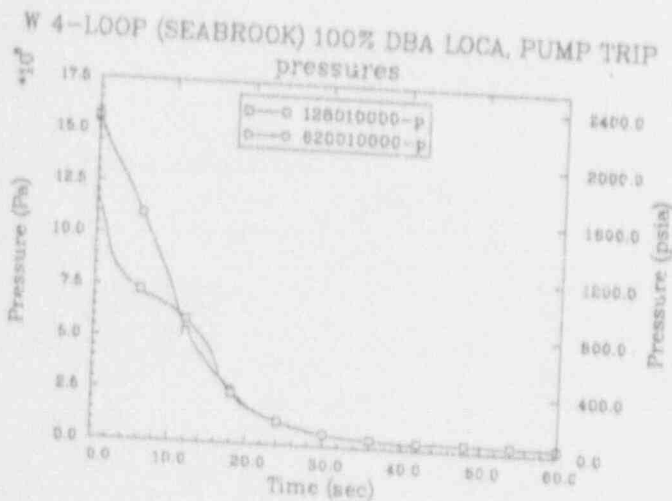

W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

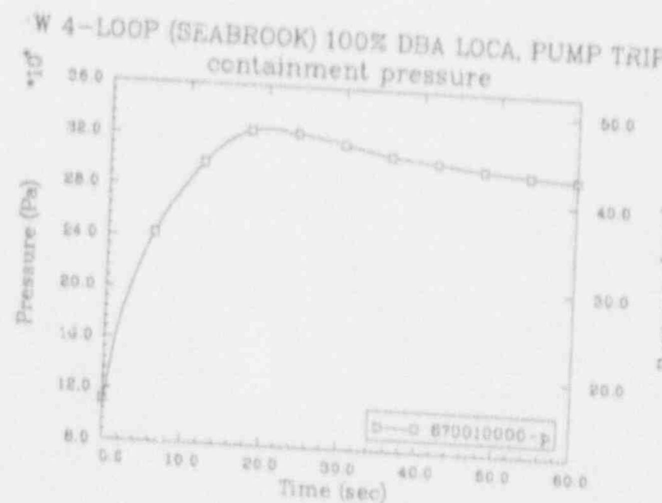

W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
time step size
time step (sec)
Time (sec)

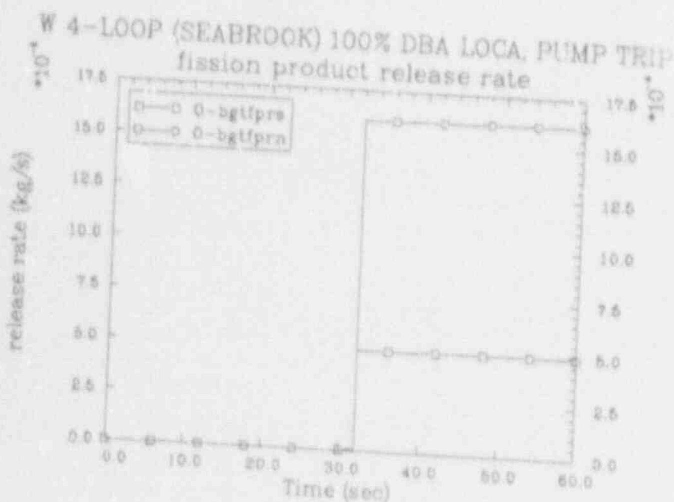

W 4-LOOP (SEABROOK) 50% DBA LOCA PIN FAILURE
cpu time
time (sec)
Time (sec)

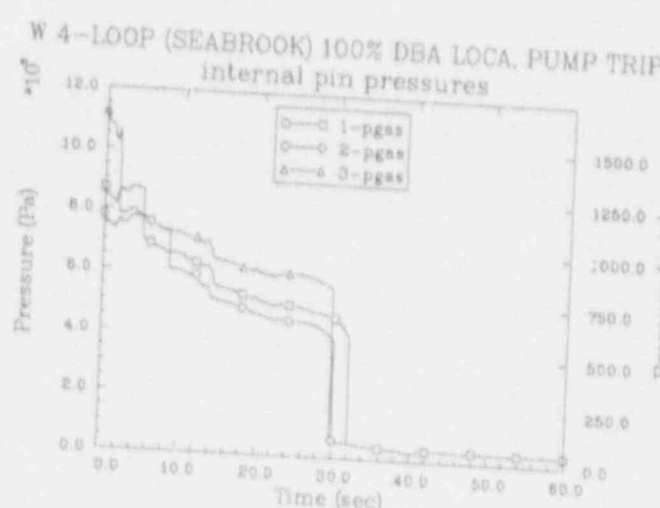

W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
collapsed reactor water level
400-cntrlvar
403-cntrlvar
Level (ft)
Time (sec)

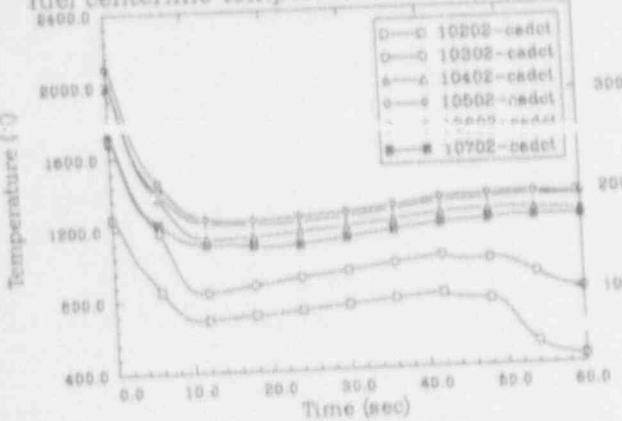

W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
pressures
128010000-p
620010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
containment pressure
670010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)

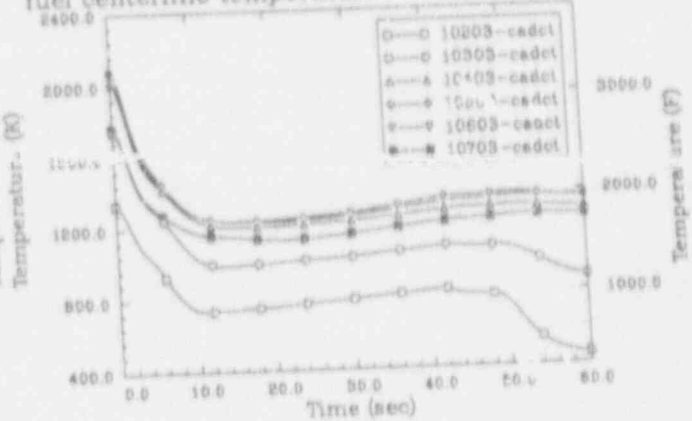

W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
fission product release rate
0-bgtfprs
0-bgtfprn
release rate (kg/s)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

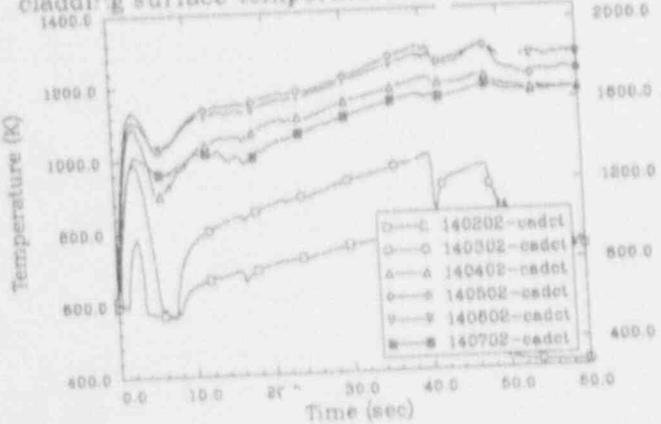
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
fuel centerline temperatures for 5 GWD/MTU pin



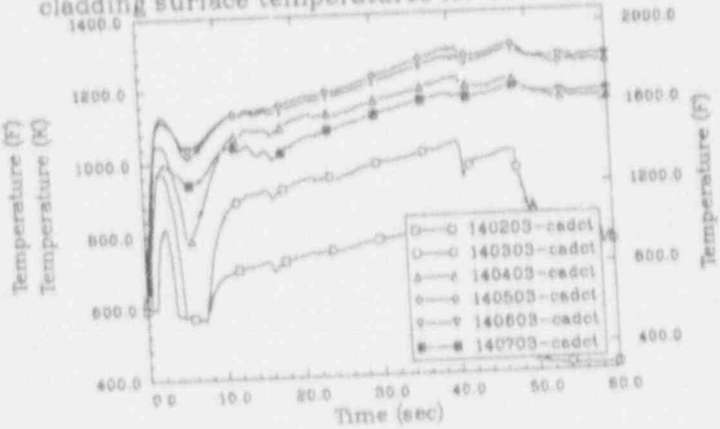
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
fuel centerline temperatures for 50 GWD/MTU pin



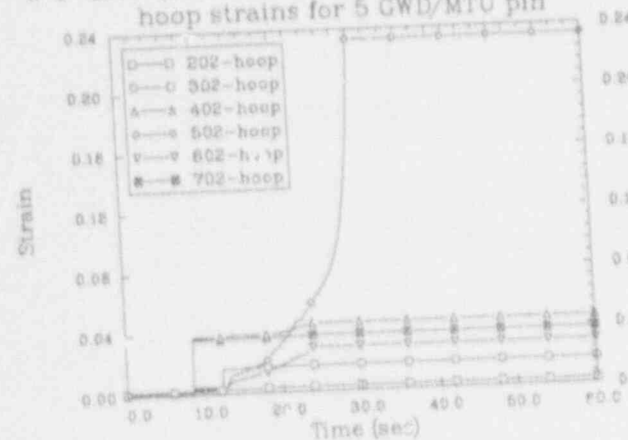
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
cladding surface temperatures for 5 GWD/MTU pin



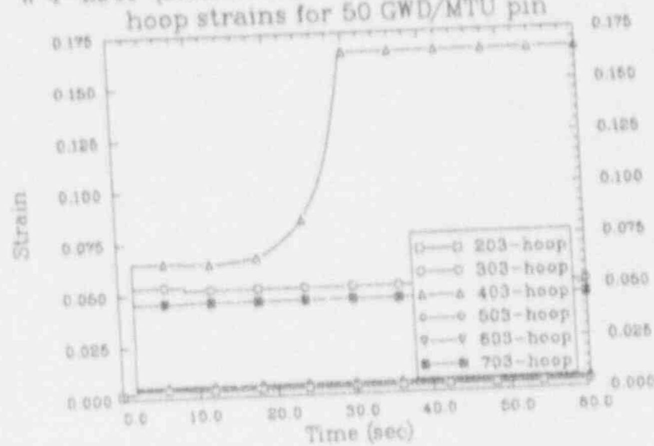
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
cladding surface temperatures for 50 GWD/MTU pin

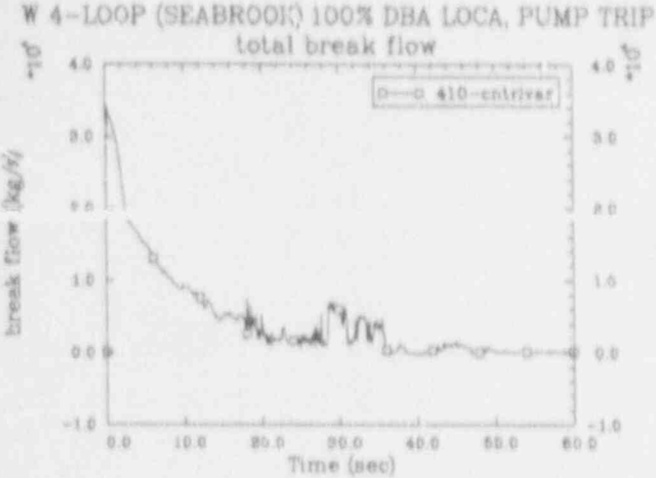


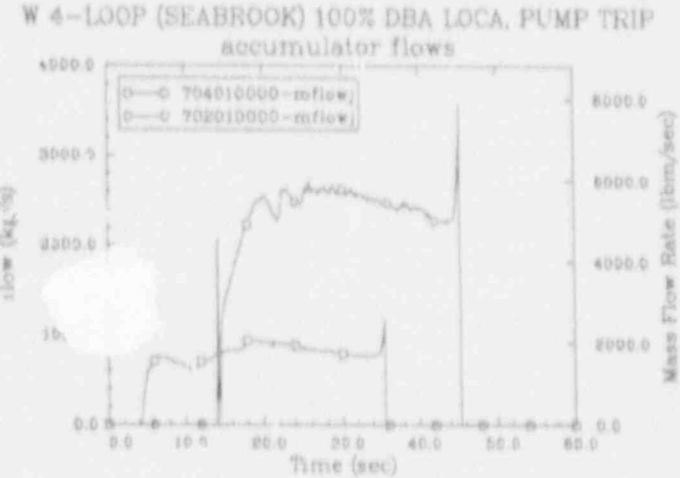
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
hoop strains for 5 GWD/MTU pin

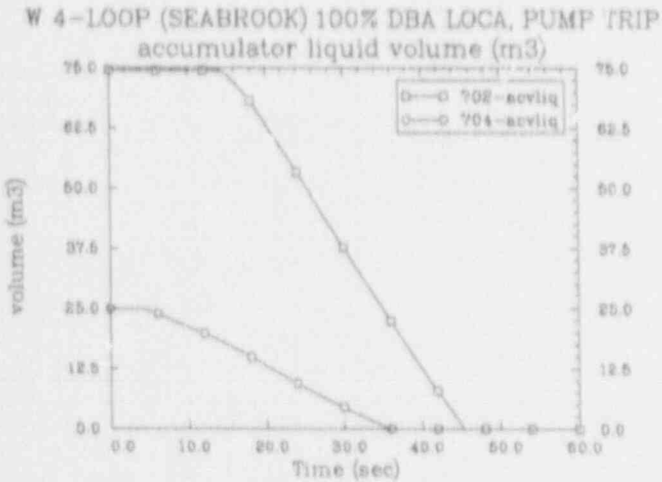


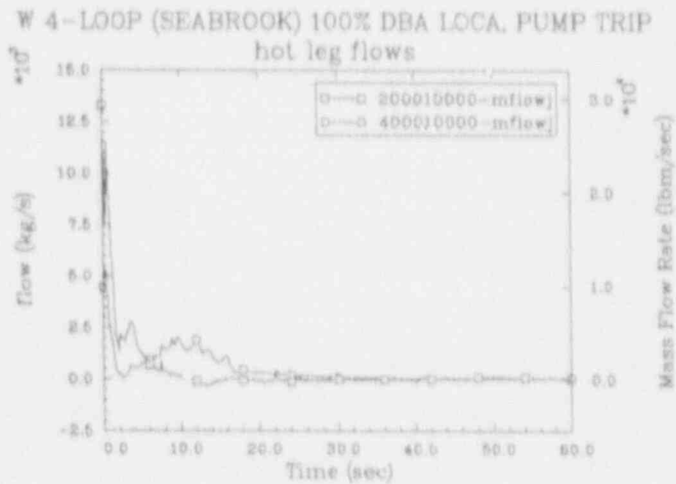
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
hoop strains for 50 GWD/MTU pin

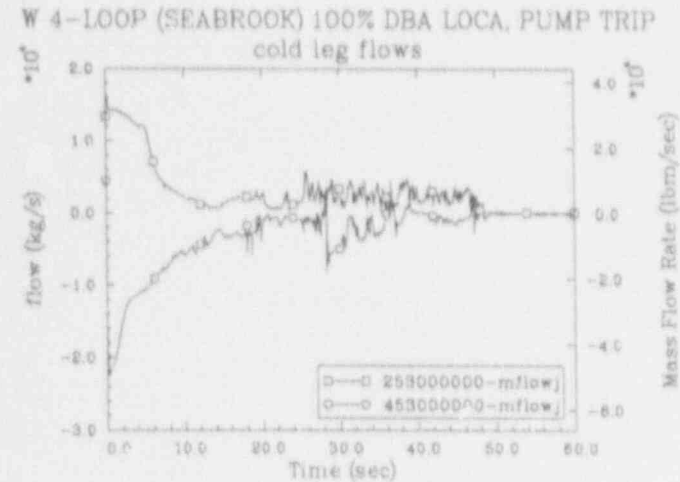


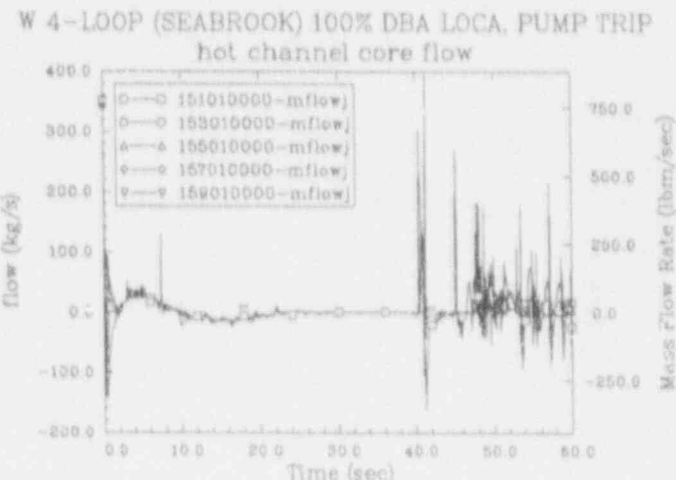

W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
total break flow
410-cntrlvar
break flow (kg/s)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
accumulator flows
704010000-mflowj
702010000-mflowj
Mass Flow Rate (lbm/sec)
Time (sec)

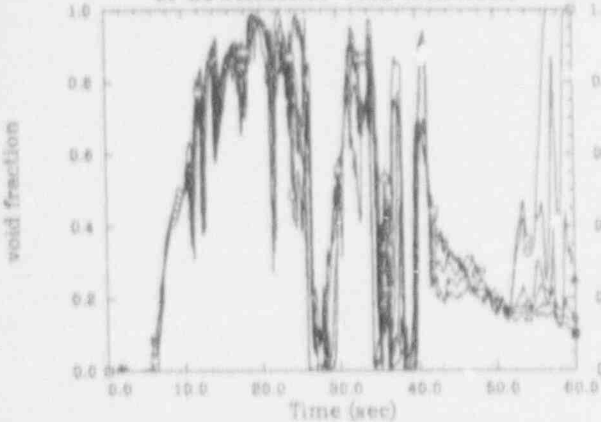

W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
accumulator liquid volume (m3)
702-acvliq
704-acvliq
volume (m3)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
hot leg flows
200010000-mflowj
400010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

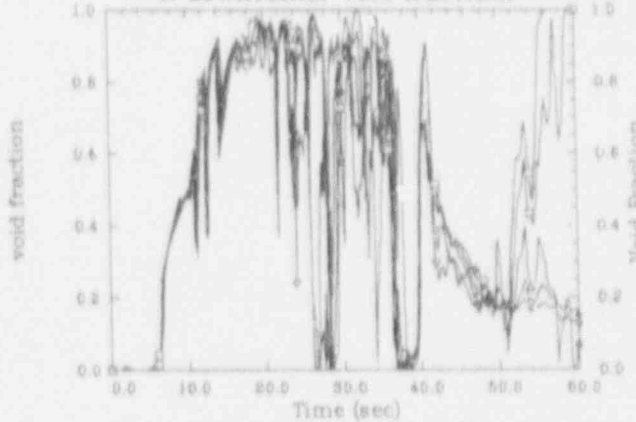

W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
cold leg flows
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
hot channel core flow
151010000-mflowj
153010000-mflowj
155010000-mflowj
157010000-mflowj
159010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

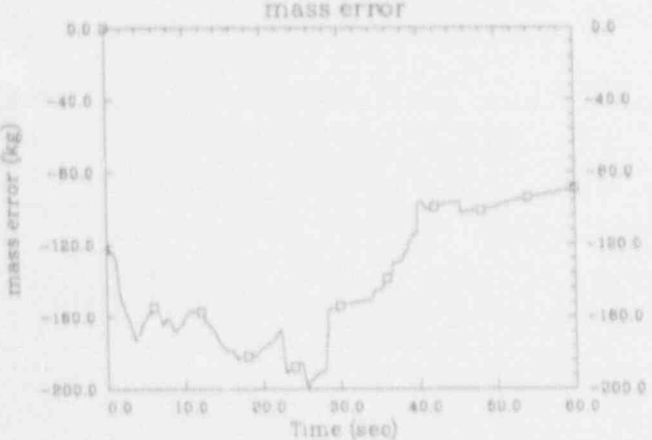
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
bl downcomer void fractions



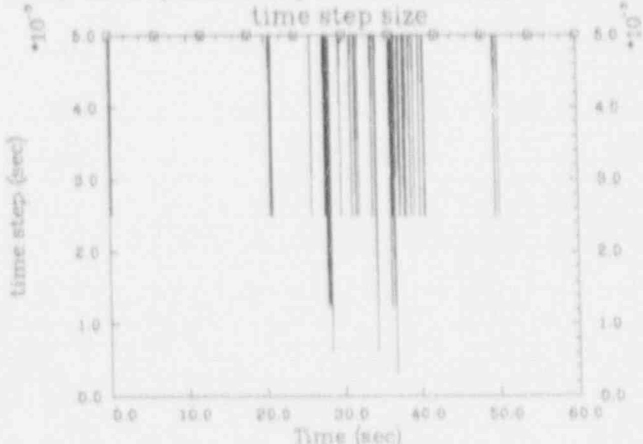
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
il downcomer void fractions



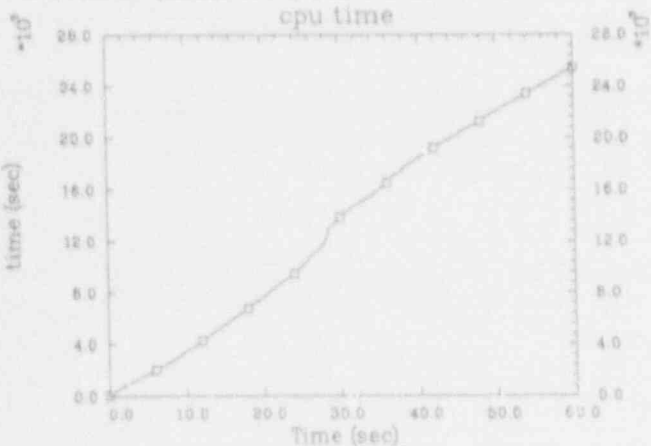
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
mass error



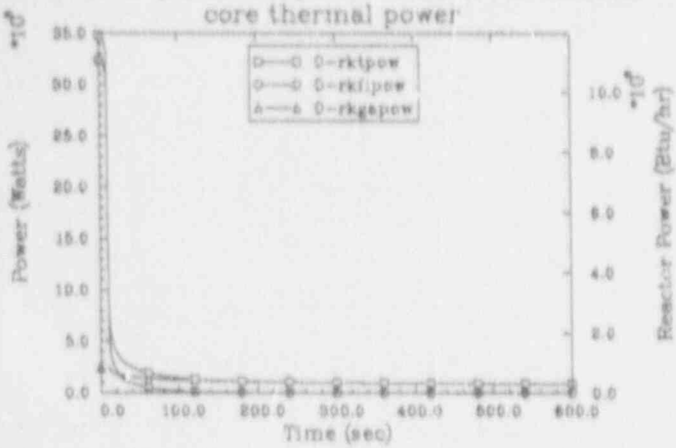
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
time step size



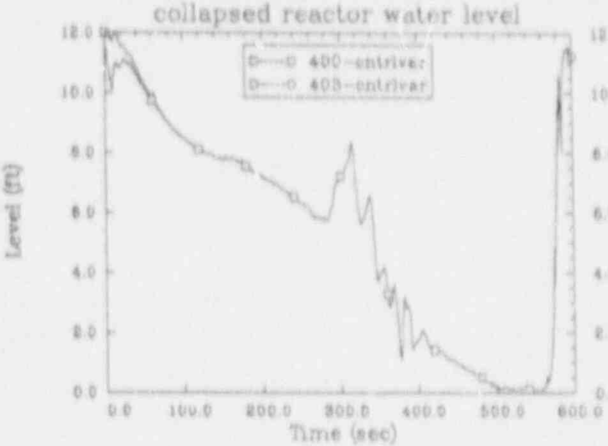
W 4-LOOP (SEABROOK) 100% DBA LOCA, PUMP TRIP
cpu time



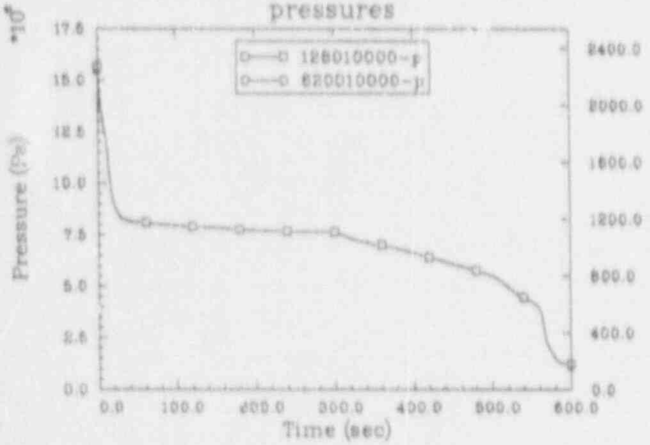
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
core thermal power



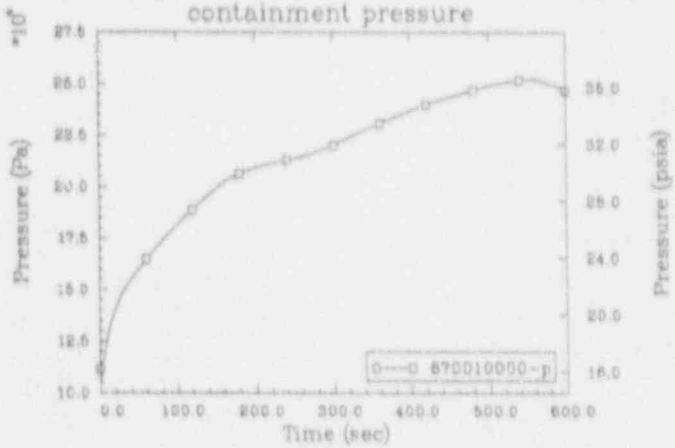
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
collapsed reactor water level



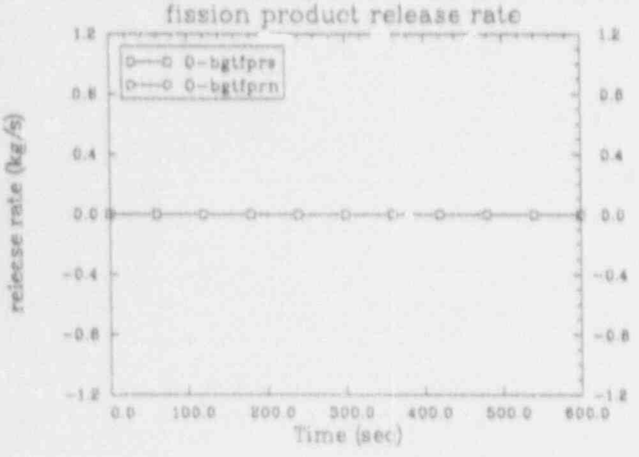
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
pressures



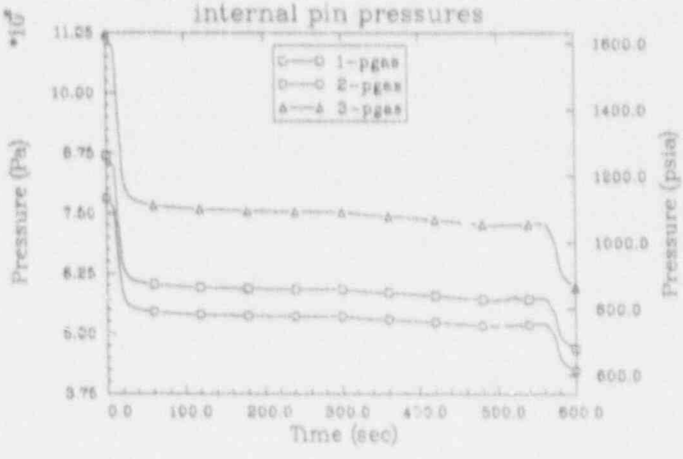
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
containment pressure

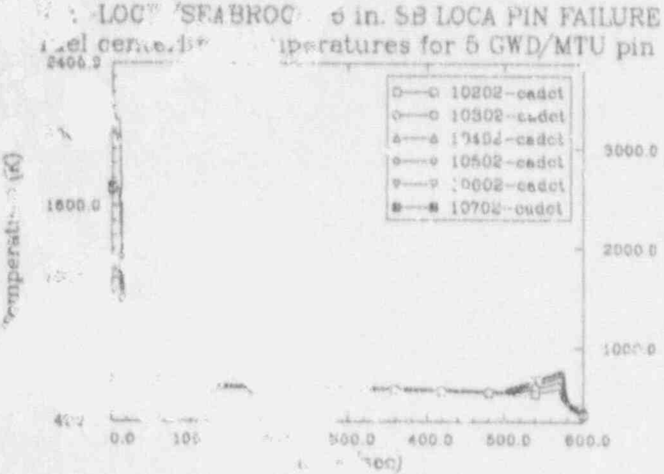


W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
fission product release rate

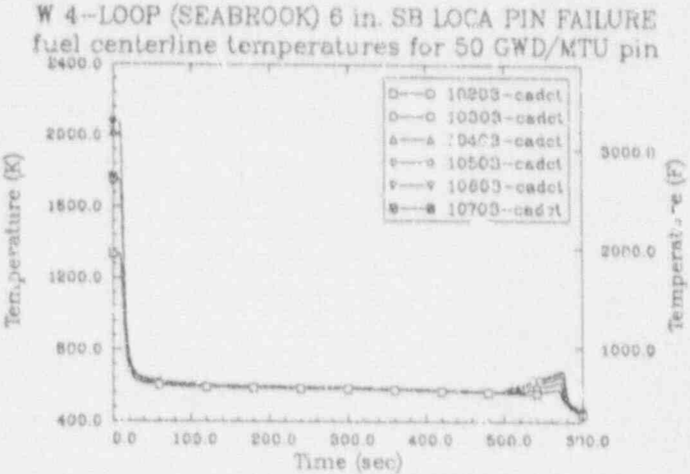


W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
internal pin pressures

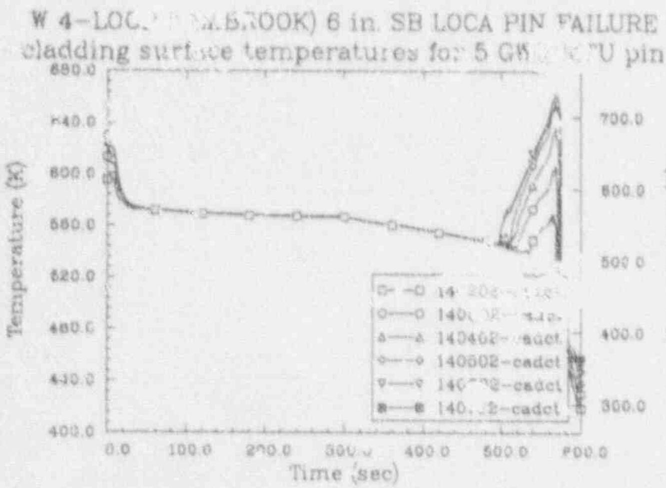




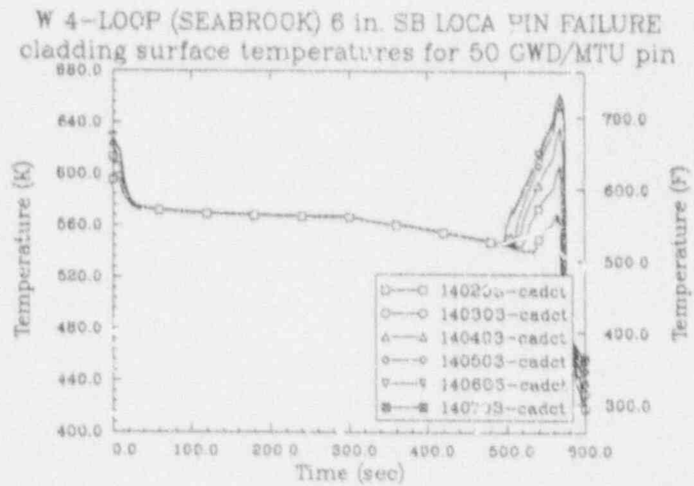
SB LOCA PIN FAILURE
10202-cadct
10302-cadct
10502-cadct
10702-cadct
Temperature (K)
Temperature (F)



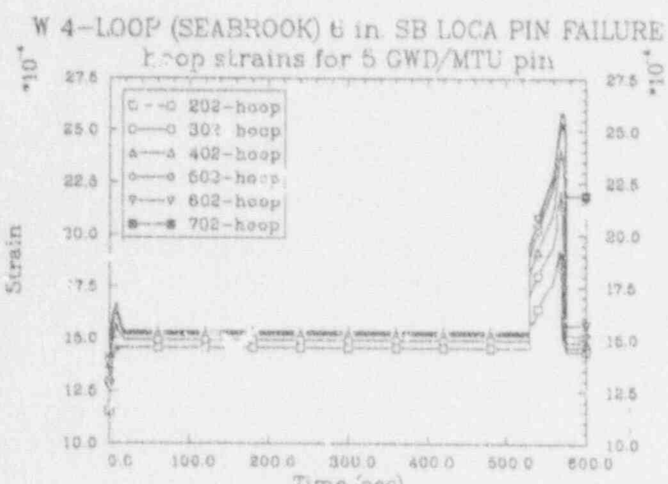
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
fuel centerline temperatures for 50 GWD/MTU pin
10203-cadct
10303-cadct
10503-cadct
10603-cadct
Temperature (K)
Time (sec)



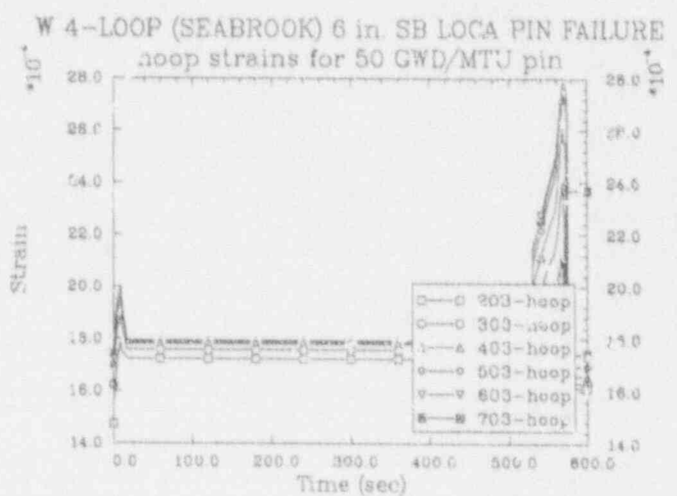
W 4-LOO
6 in. SB LOCA PIN FAILURE
140402-cadct
140502-cadct
Temperature (K)
Temperature (F)
Time (sec)



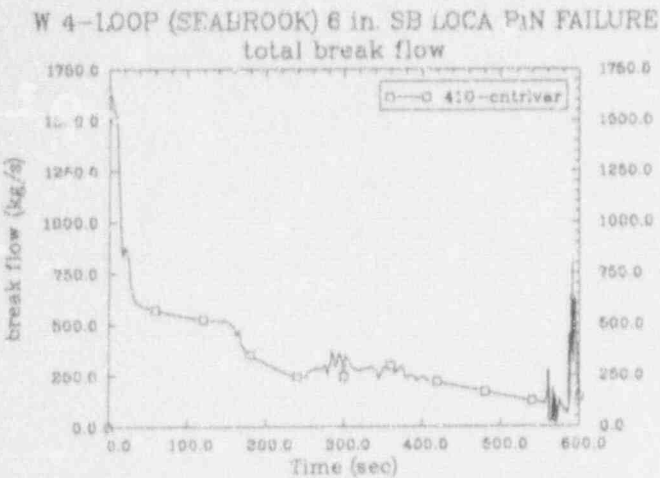
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
cladding surface temperatures for 50 GWD/MTU pin
140303-cadct
140403-cadct
140503-cadct
Temperature (K)
Temperature (F)
Time (sec)

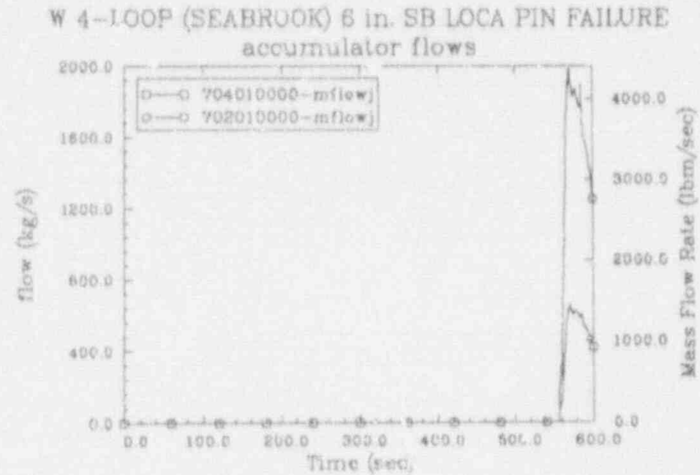


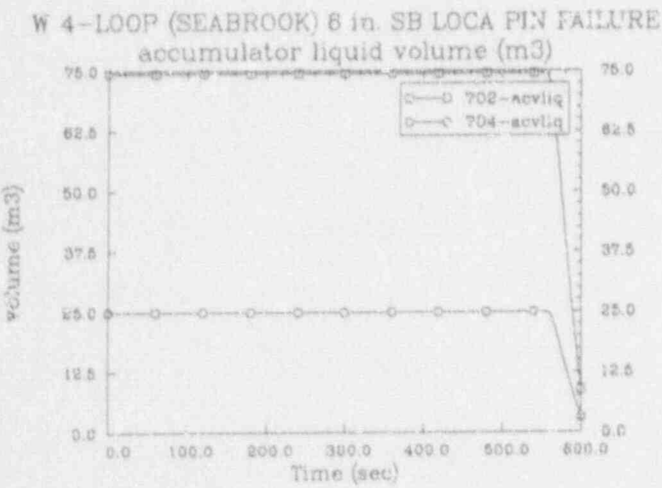
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
hoop strains for 5 GWD/MTU pin
202-hoop
402-hoop
602-hoop
702-hoop
Strain
Time (sec)

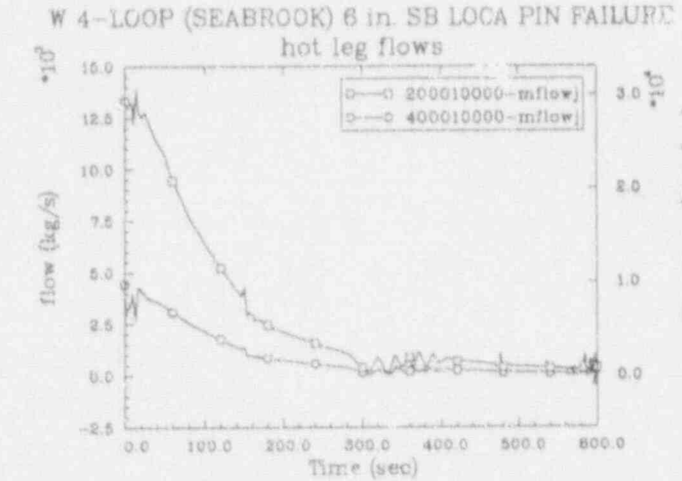


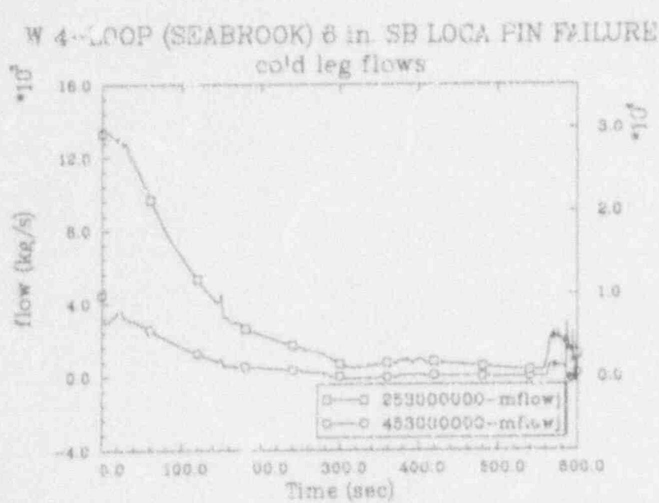
W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
hoop strains for 50 GWD/MTU pin
203-hoop
403-hoop
503-hoop
603-hoop
Strain
Time (sec)

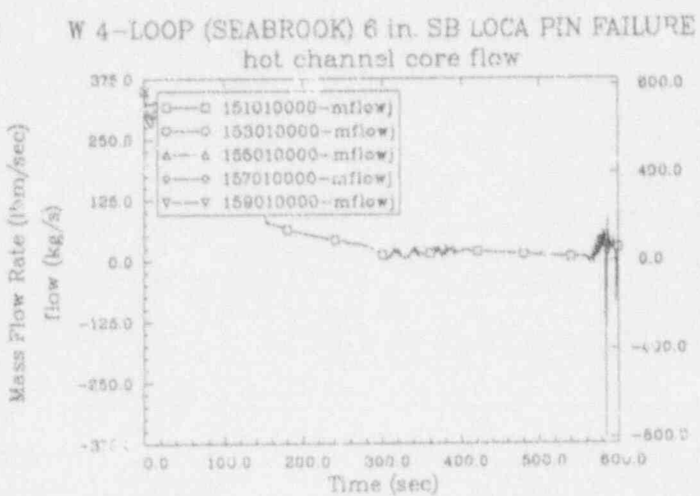

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
total break flow
410-cntrlvar
break flow (kg/s)
Time (sec)

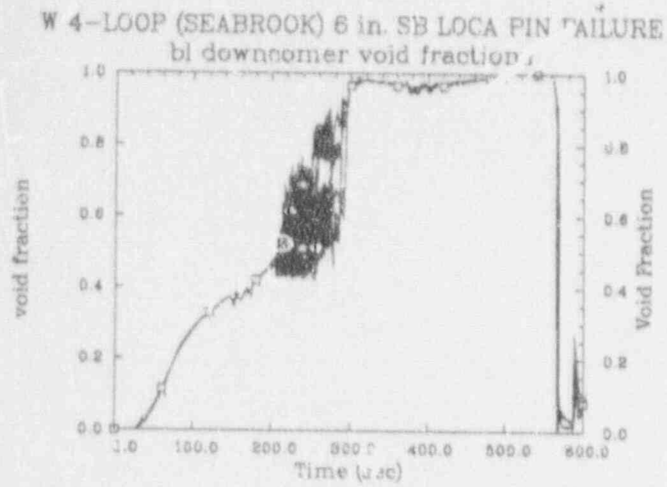

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
accumulator flows
704010000-mflowj
702010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

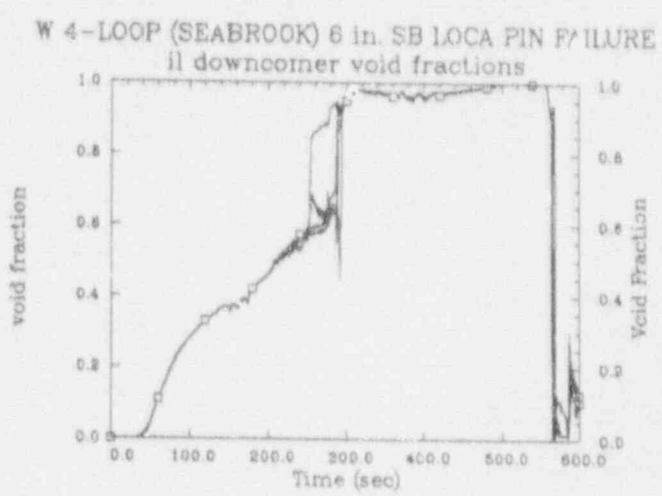

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
accumulator liquid volume (m3)
702-acvliq
704-acvliq
volume (m3)
Time (sec)

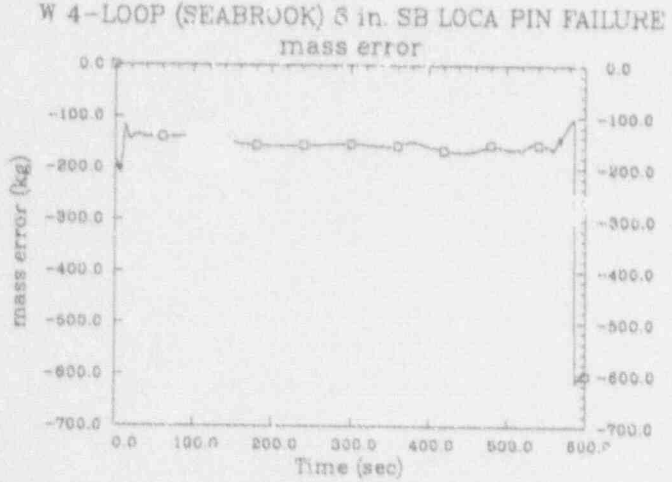

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
hot leg flows
200010000-mflowj
400010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

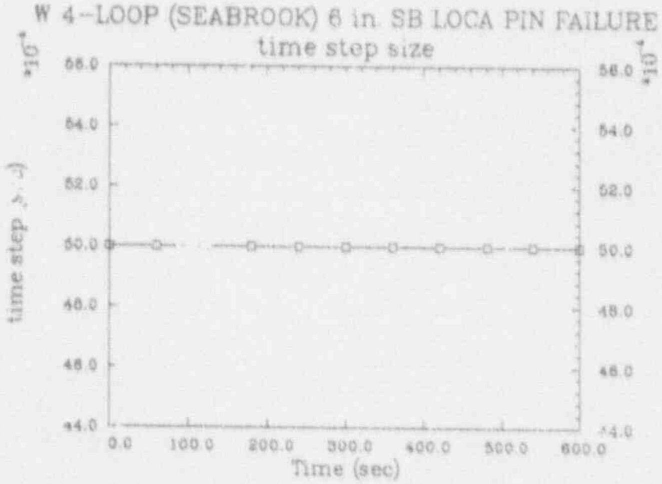

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
cold leg flows
253000000-mflowj
453000000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

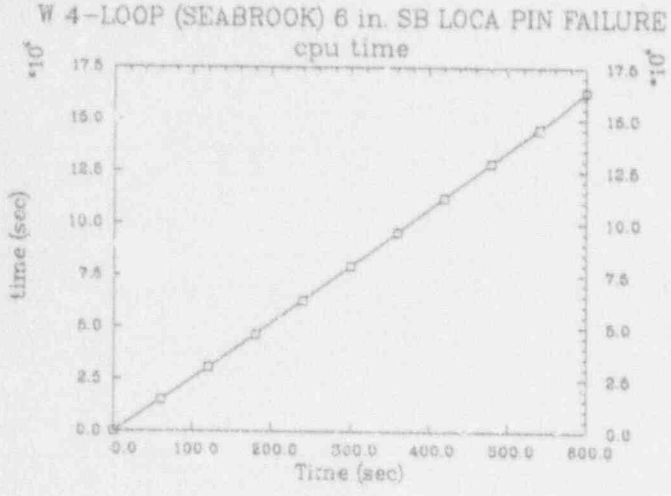

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
hot channel core flow
151010000-mflowj
153010000-mflowj
155010000-mflowj
157010000-mflowj
159010000-mflowj
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

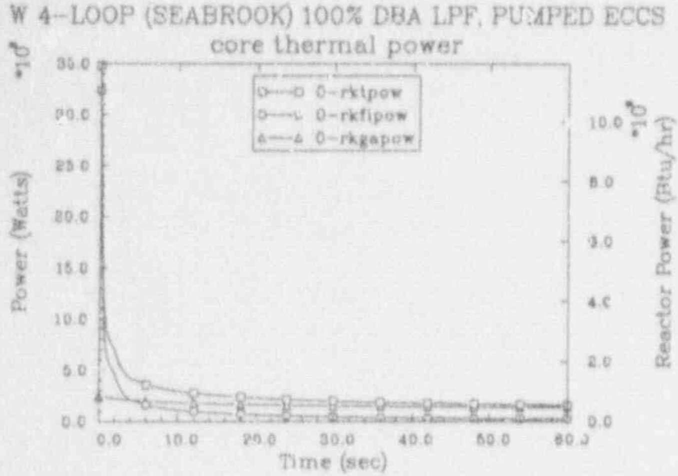

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

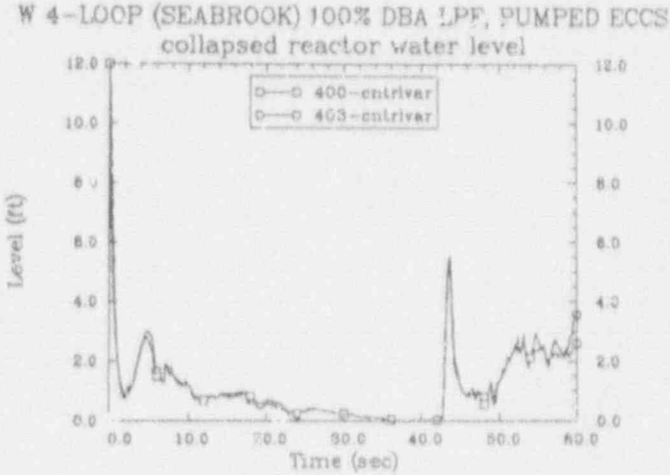

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
il downcomer void fractions
void fraction
Void Fraction
Time (sec)

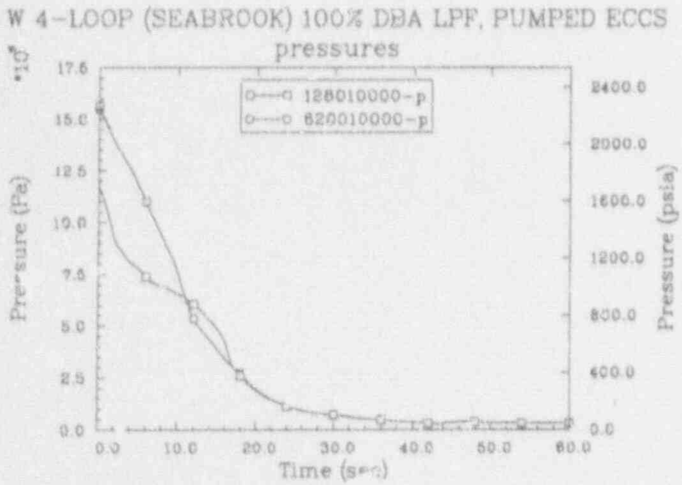

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
mass error
mass error (kg)
Time (sec)

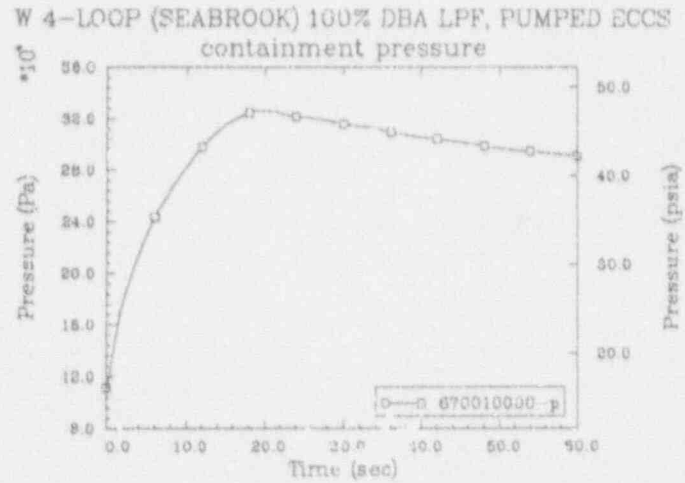

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
time step size
*10^-4
Time (sec)

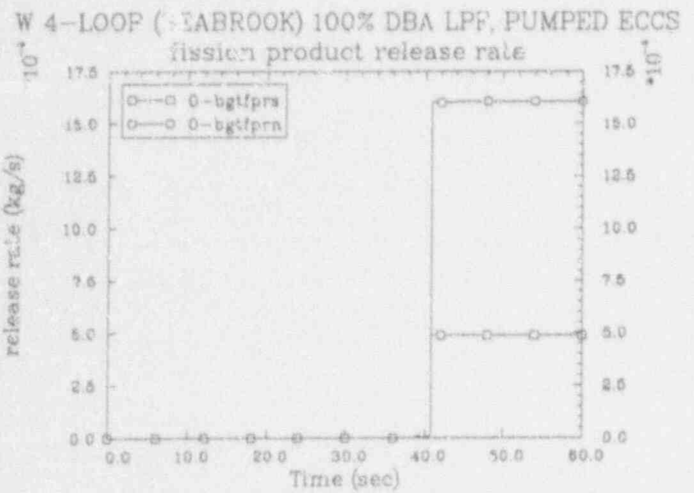

W 4-LOOP (SEABROOK) 6 in. SB LOCA PIN FAILURE
cpu time
*10^4
time (sec)
Time (sec)

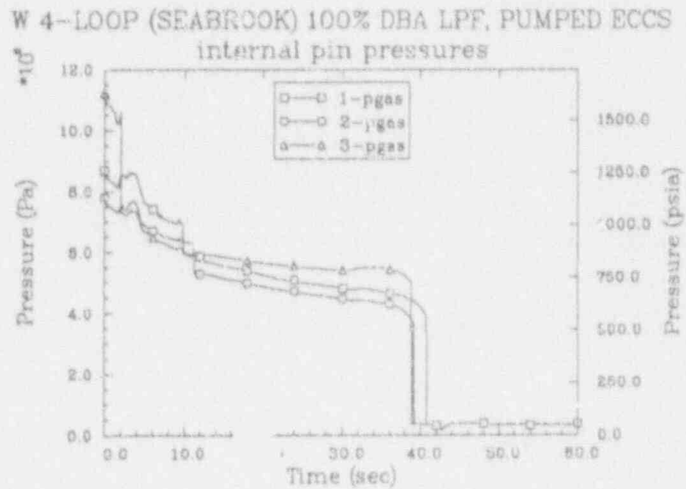

W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
collapsed reactor water level
400-cntrlvar
403-cntrlvar
Level (ft)
Time (sec)

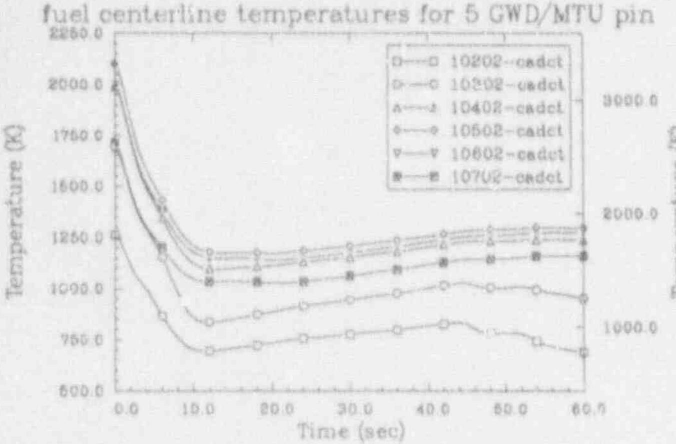

W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
pressures
128010000-p
620010000-p
Pressure (Pa)
Pressure (psia)


W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
containment pressure
670010000-p
Pressure (Pa)
Pressure (psia)

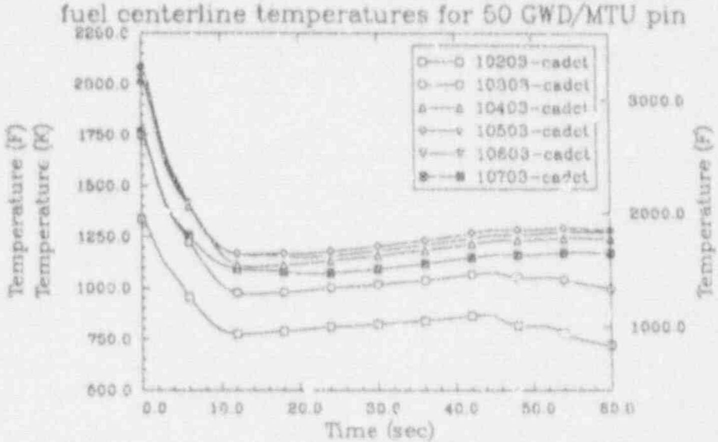

fission product release rate
0-bgtfprs
0-bgtfprn
release rate (kg/s)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
internal pin pressures
1-pgas
2-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

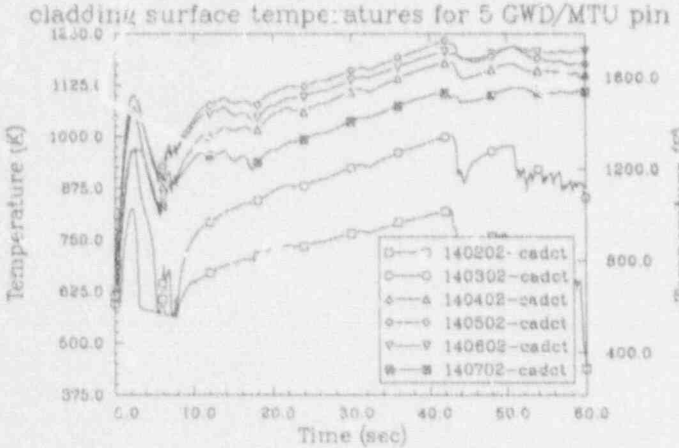
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
fuel centerline temperatures for 5 GWD/MTU pin



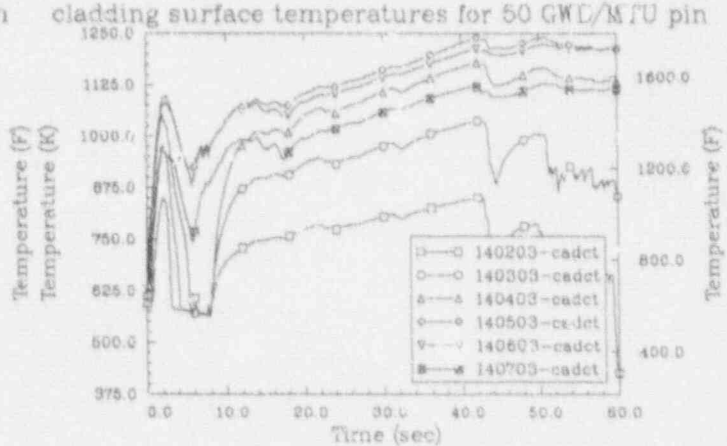
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
fuel centerline temperatures for 50 GWD/MTU pin



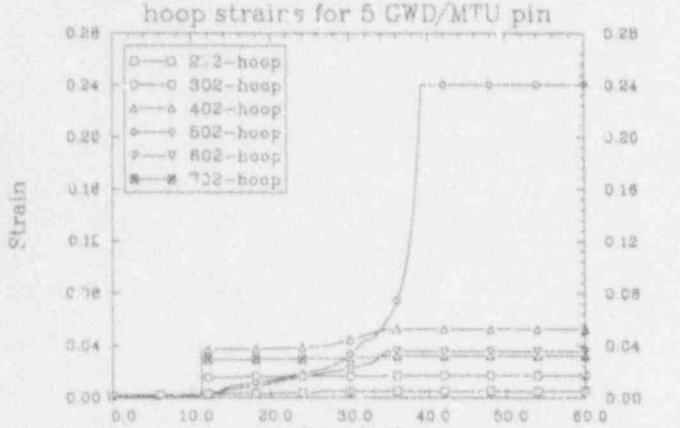
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
cladding surface temperatures for 5 GWD/MTU pin



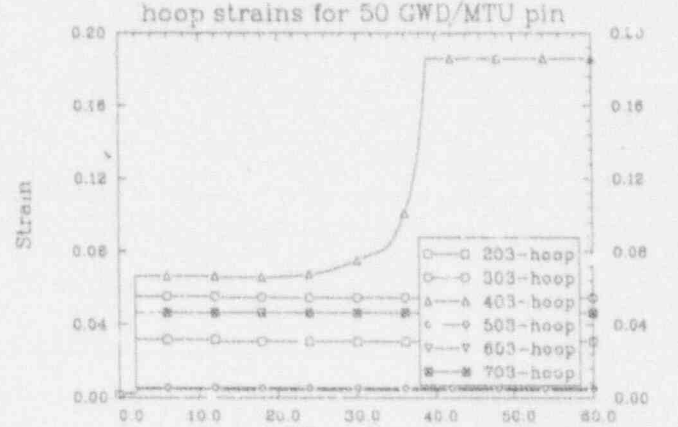
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
cladding surface temperatures for 50 GWD/MTU pin



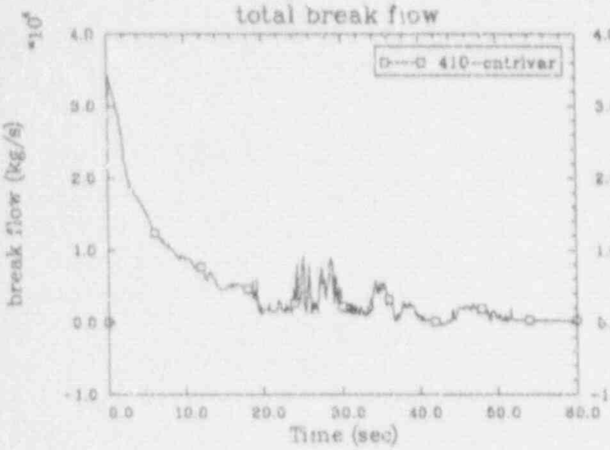
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
hoop strains for 5 GWD/MTU pin



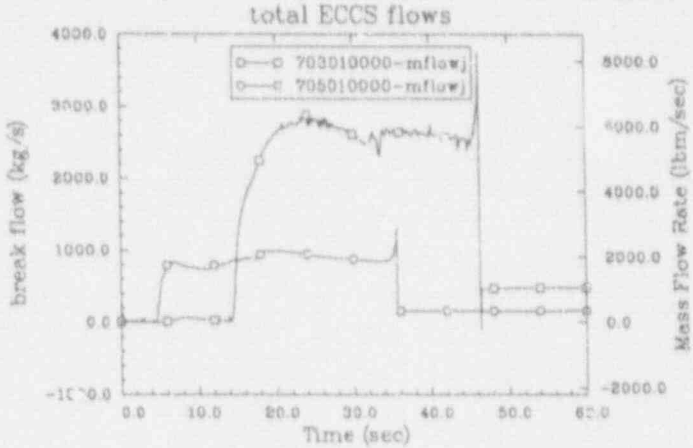
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
hoop strains for 50 GWD/MTU pin



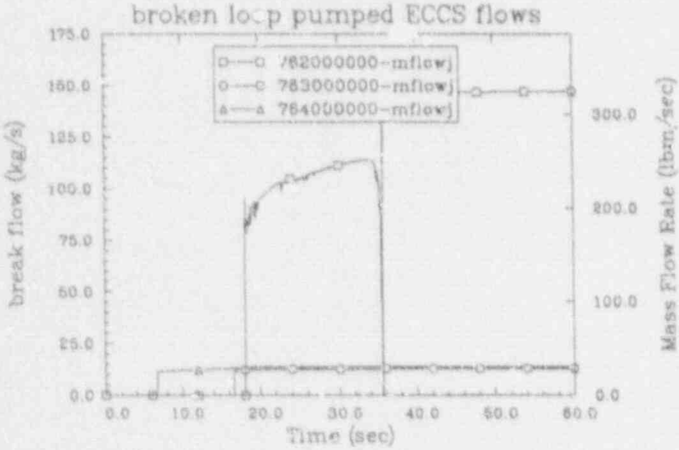
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
total break flow



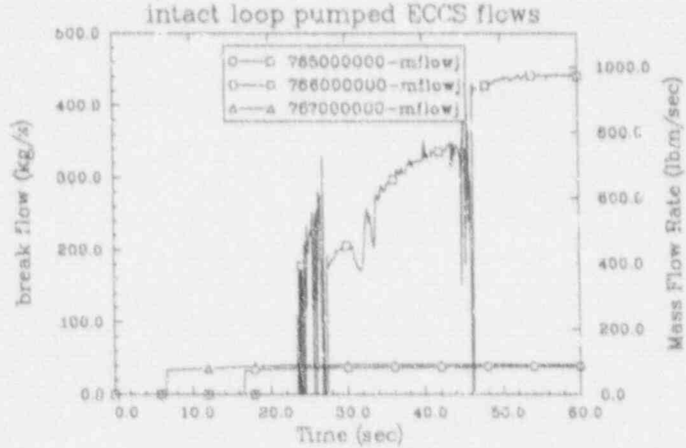
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
total ECCS flows



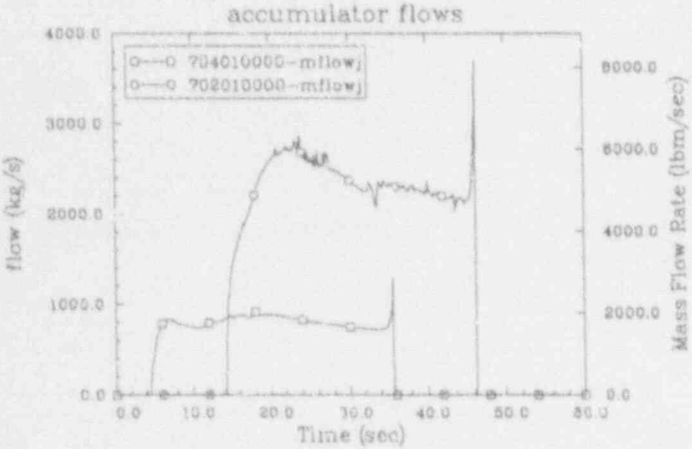
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
broken loop pumped ECCS flows



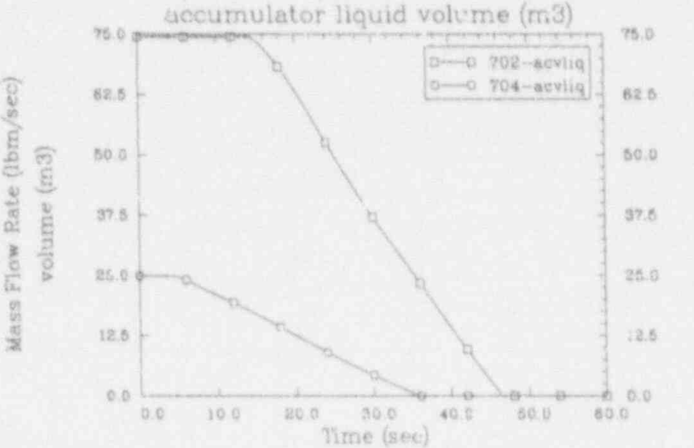
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
intact loop pumped ECCS flows



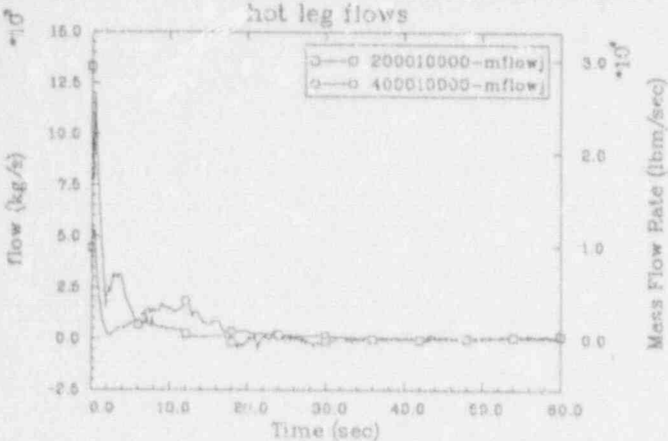
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
accumulator flows



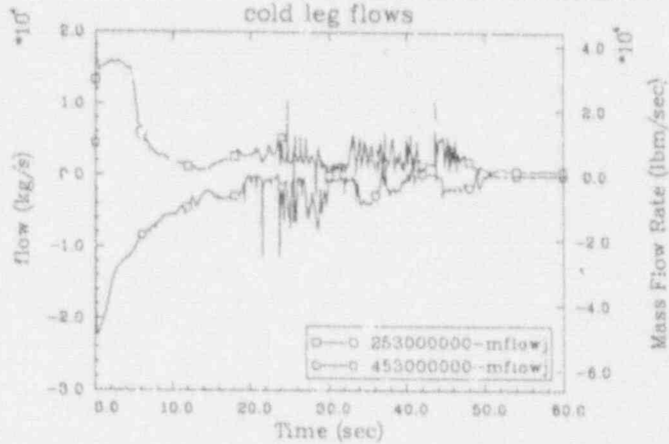
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
accumulator liquid volume (m3)



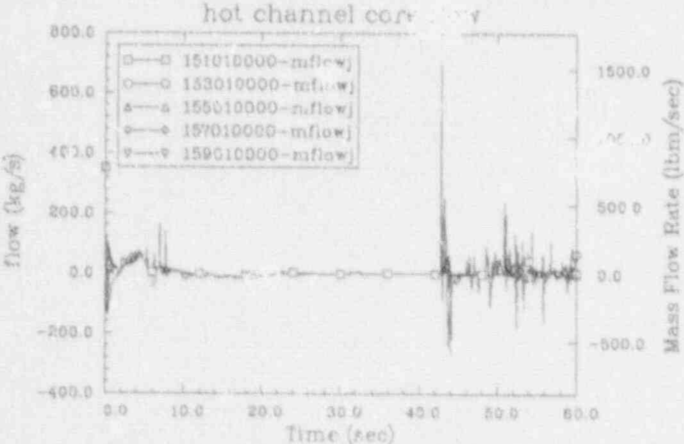
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
hot leg flows



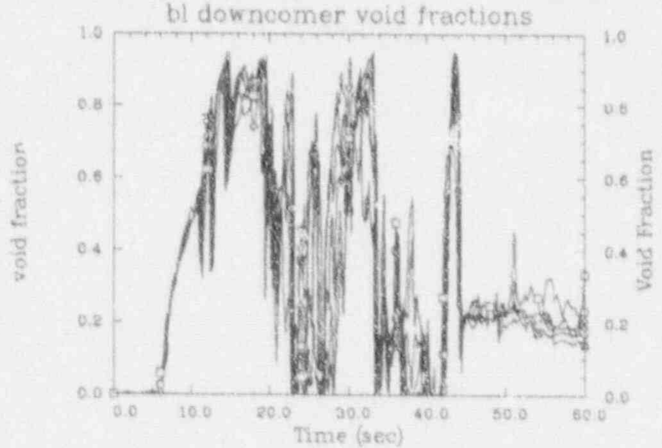
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
cold leg flows



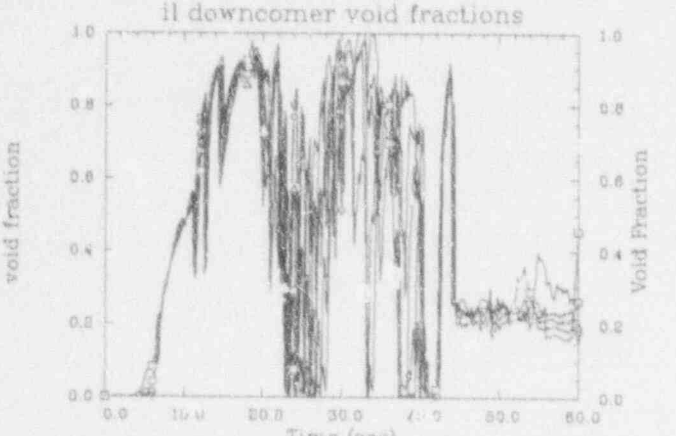
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
hot channel core flow



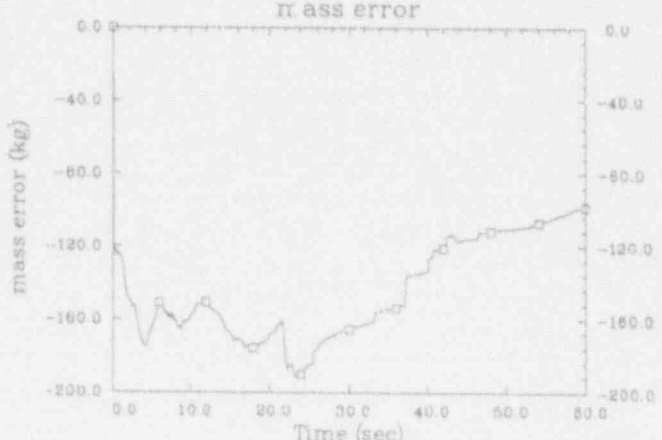
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
bl downcomer void fractions

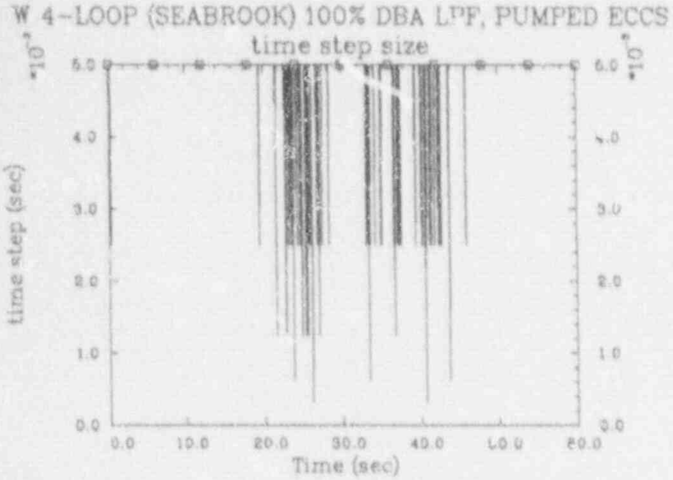


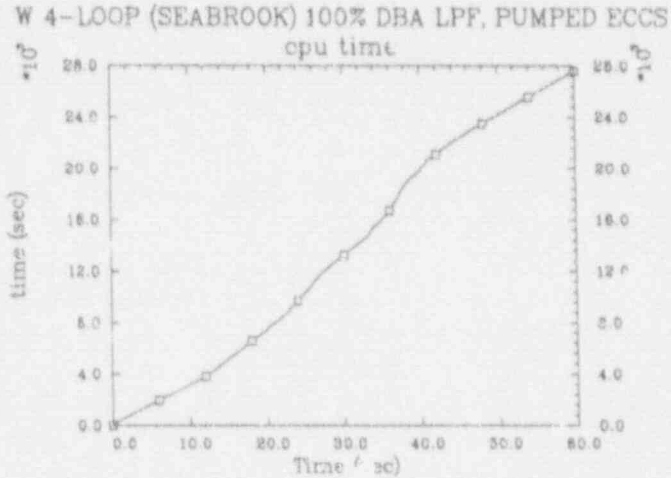
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
il downcomer void fractions



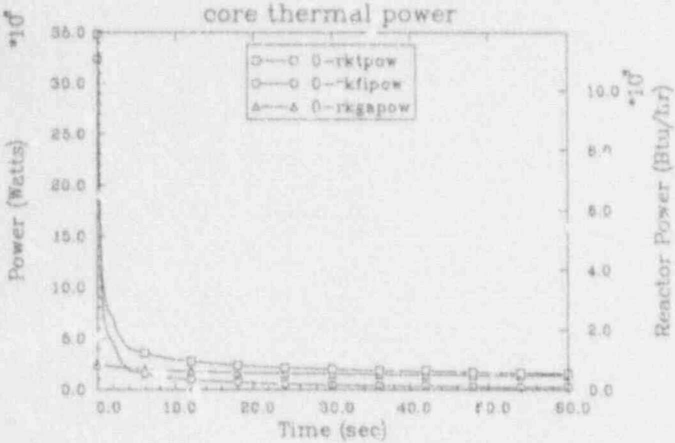
W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
mass error



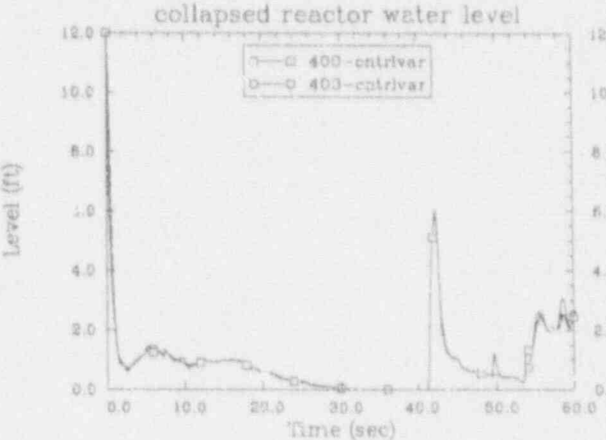

W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
time step size
time step (sec)
Time (sec)


W 4-LOOP (SEABROOK) 100% DBA LPF, PUMPED ECCS
cpu time
time (sec)
Time (sec)

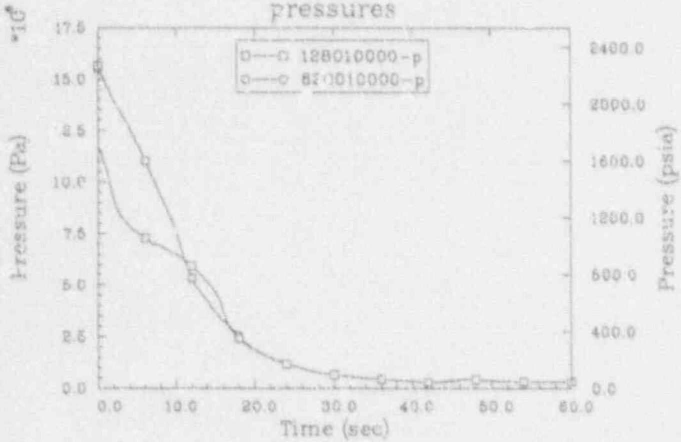
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
core thermal power



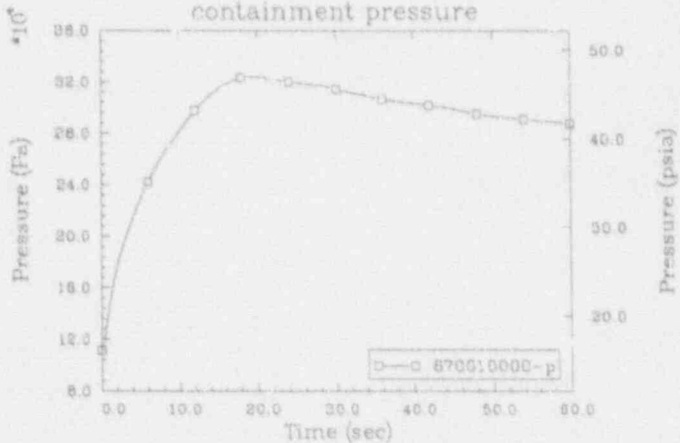
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
collapsed reactor water level



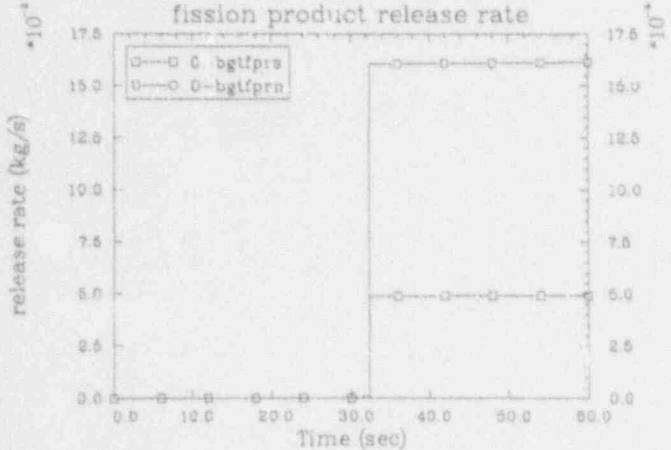
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
pressures



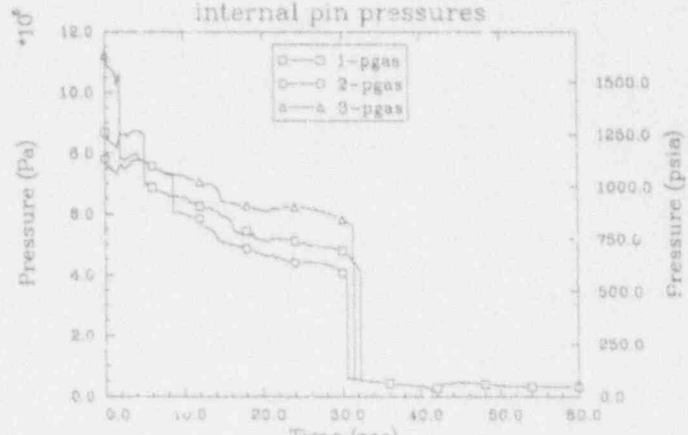
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
containment pressure



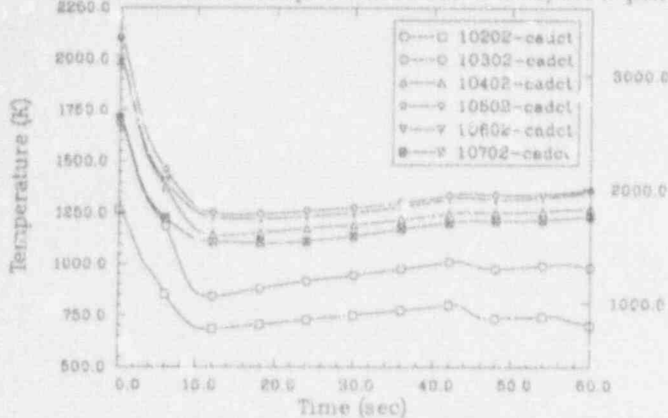
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
fission product release rate



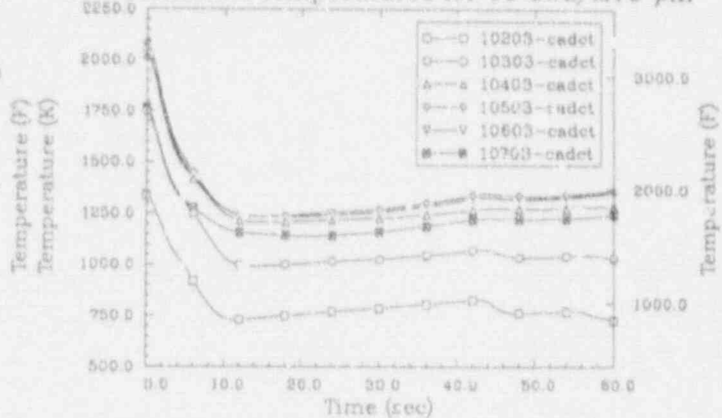
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
internal pin pressures



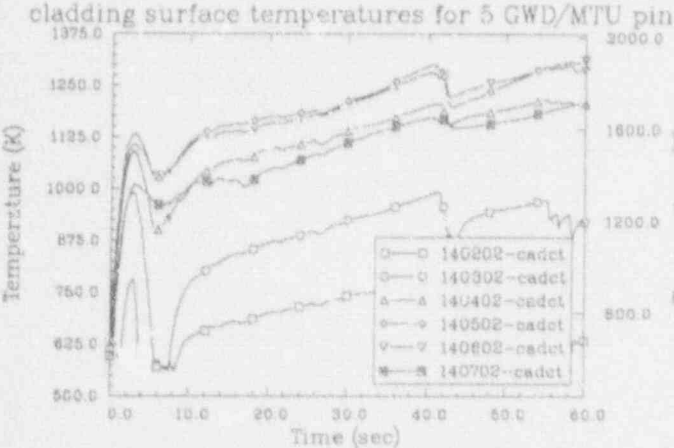
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
fuel centerline temperatures for 5 GWD/MTU pin



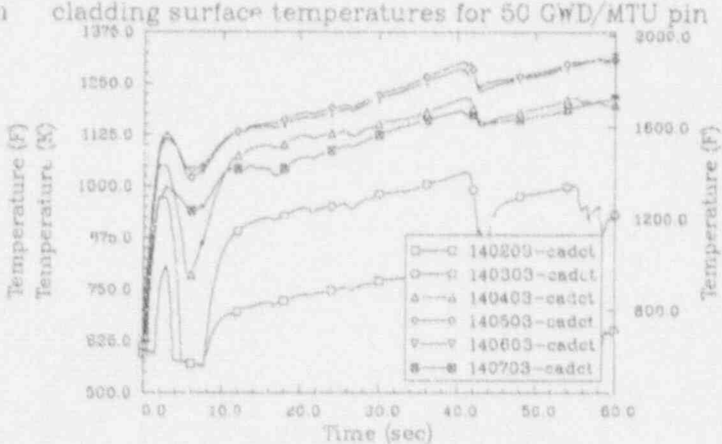
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
fuel centerline temperatures for 50 GWD/MTU pin



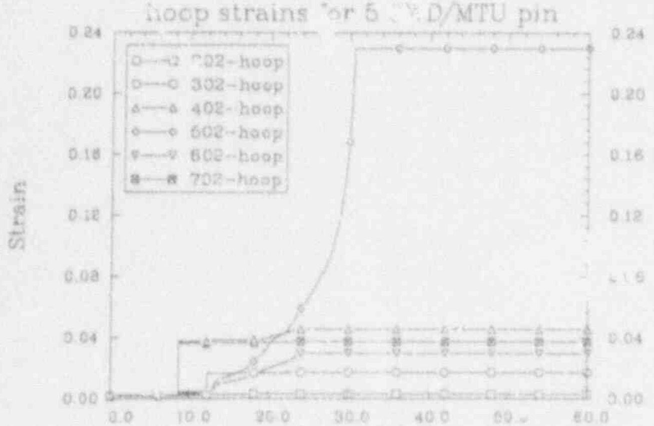
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
cladding surface temperatures for 5 GWD/MTU pin



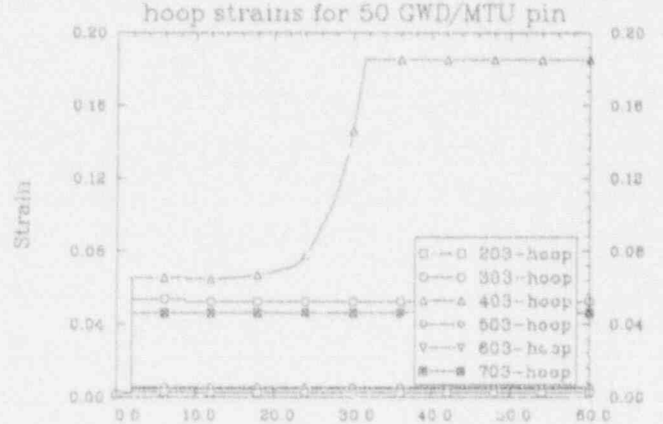
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
cladding surface temperatures for 50 GWD/MTU pin



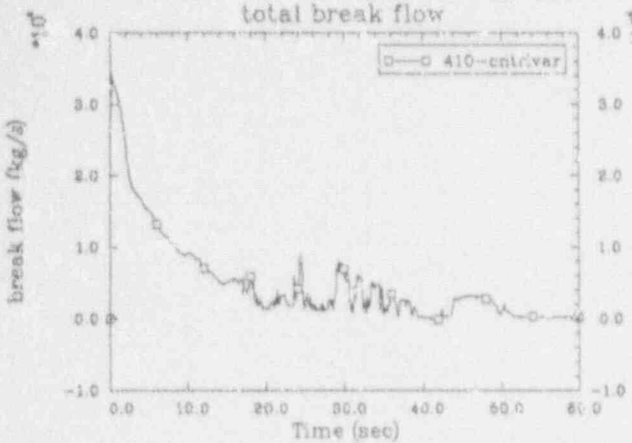
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
hoop strains for 5 GWD/MTU pin



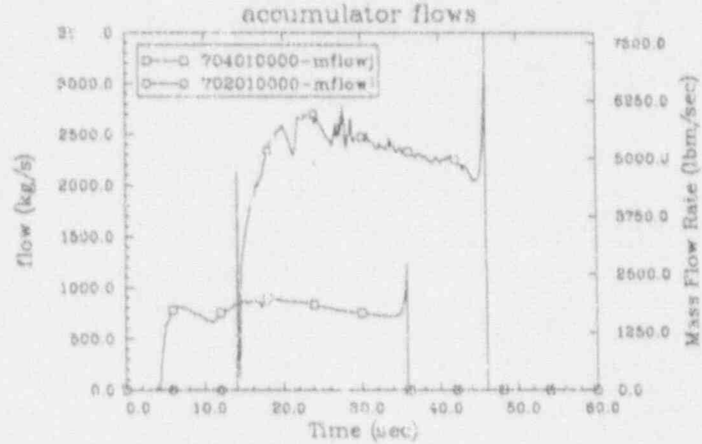
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
hoop strains for 50 GWD/MTU pin



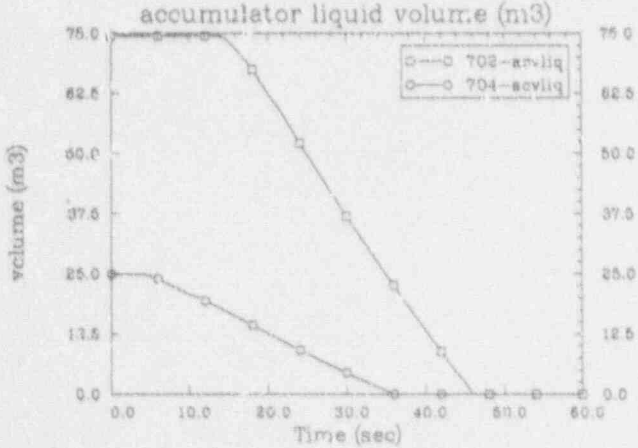
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
total break flow



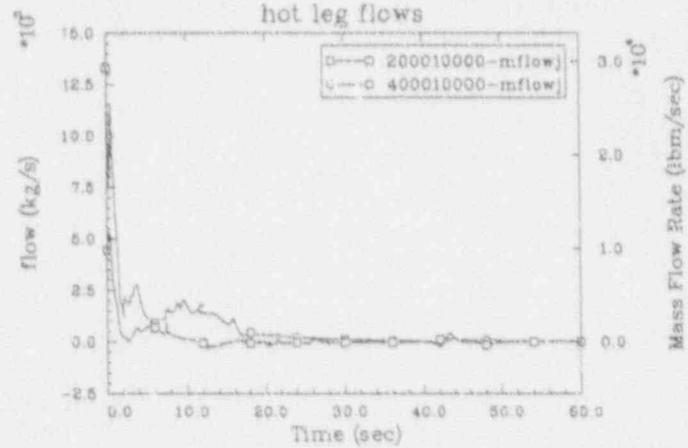
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
accumulator flows



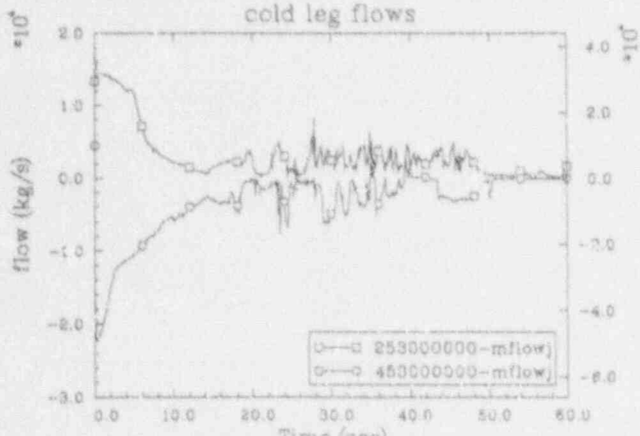
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
accumulator liquid volume (m3)



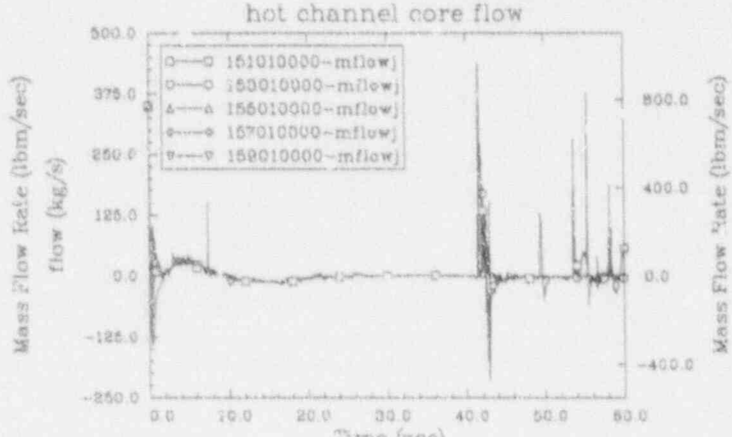
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
hot leg flows

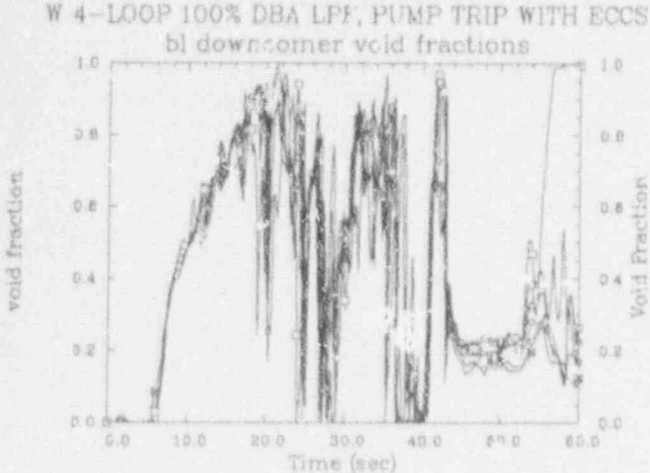


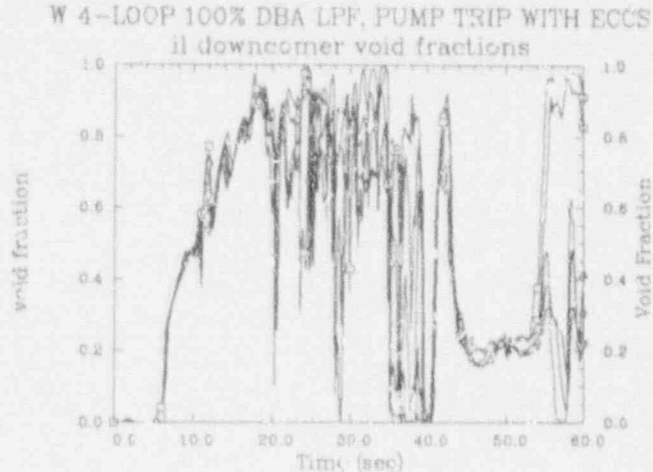
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
cold leg flows

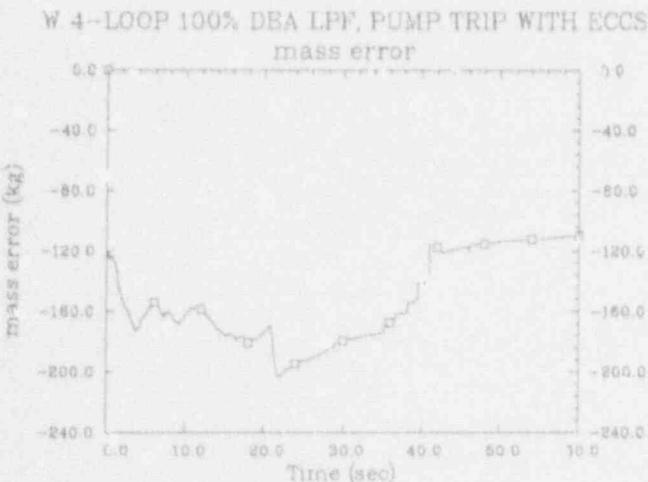


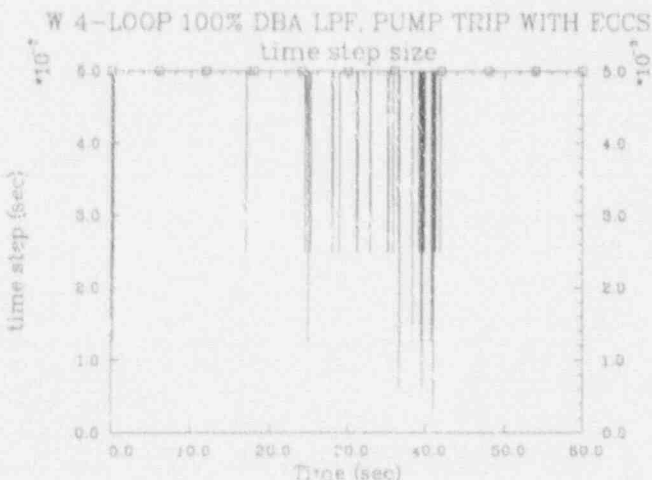
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
hot channel core flow

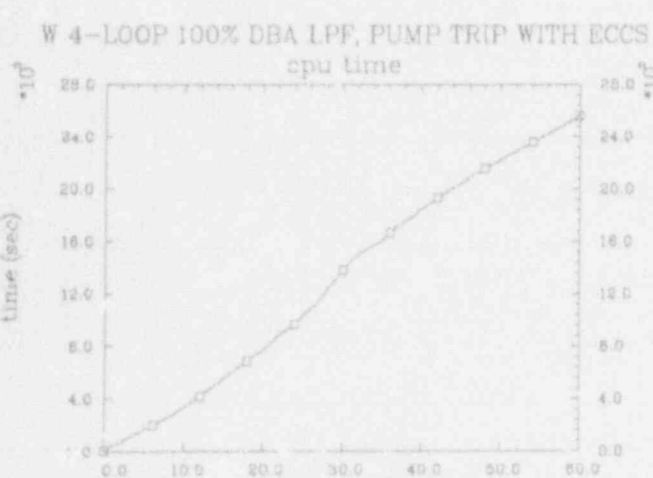


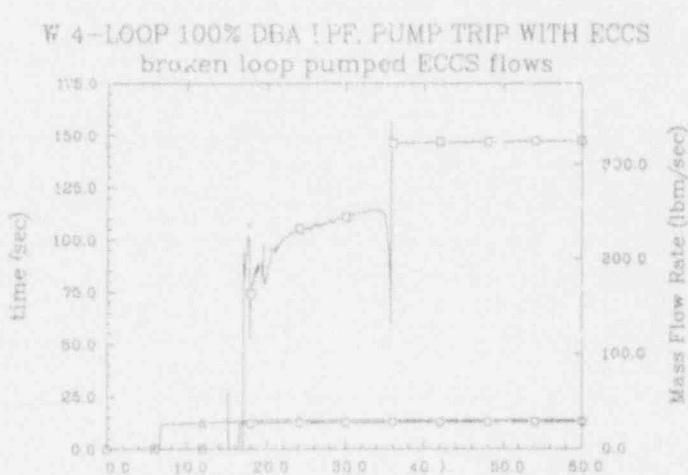

W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

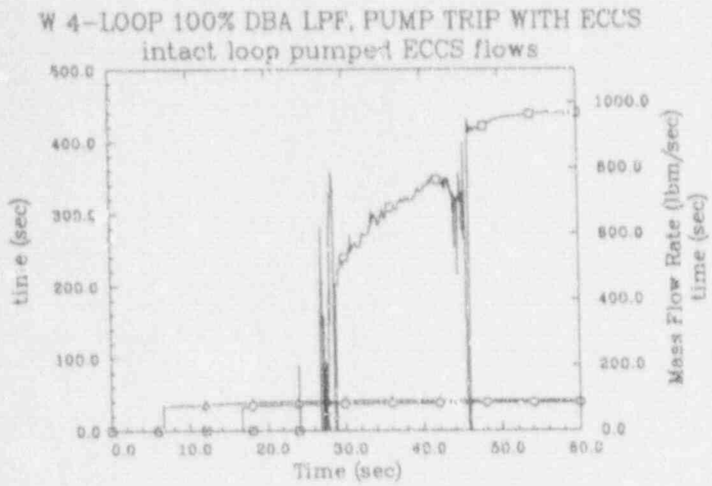

W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
il downcomer void fractions
void fraction
Void Fraction
Time (sec)


W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
mass error
mass error (kg)
Time (sec)

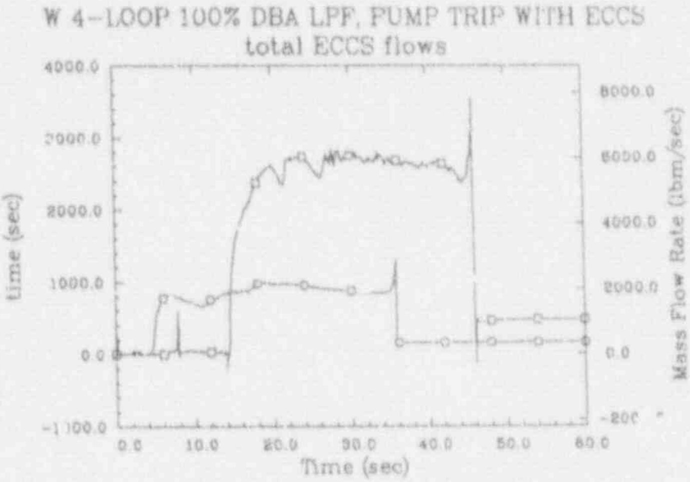

W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
time step size
time step (sec)
Time (sec)


W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
cpu time
time (sec)
Time (sec)

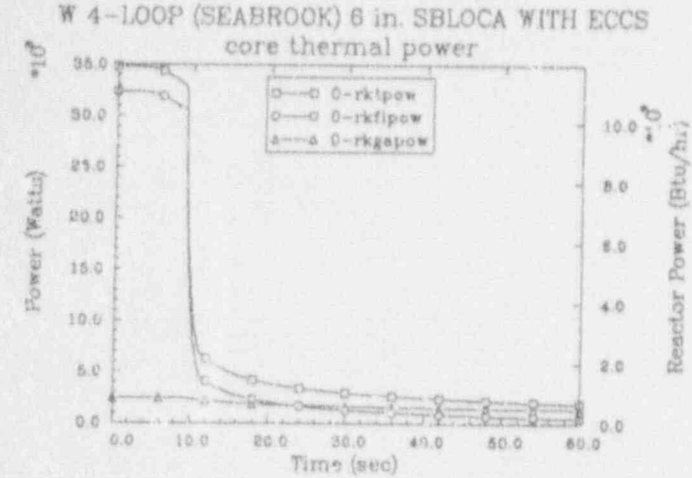

W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
broken loop pumped ECCS flows
time (sec)
Mass Flow Rate (lbm/sec)
Time (sec)

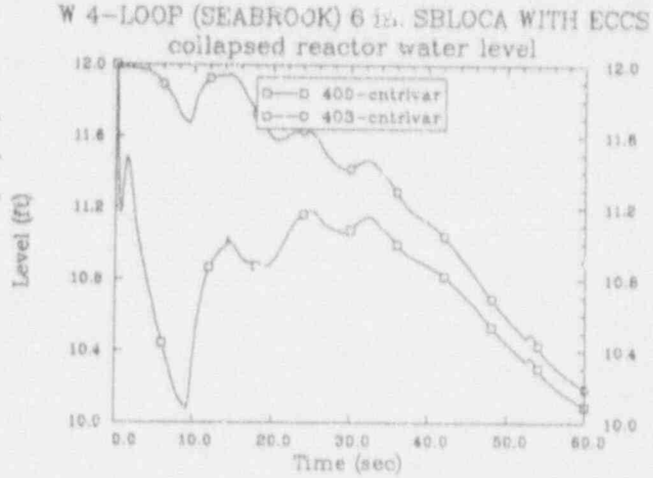


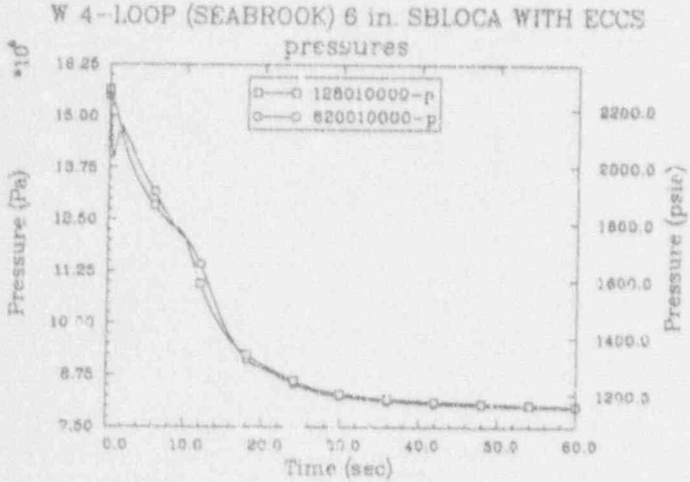
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
intact loop pumped ECCS flows
time (sec)
Mass Flow Rate (lbm/sec)
Time (sec)

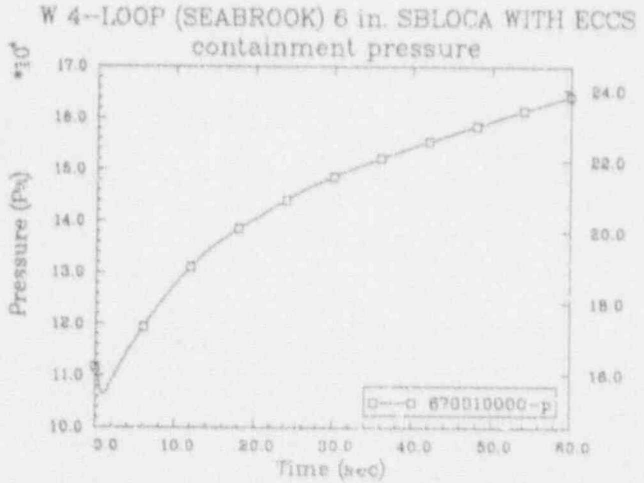


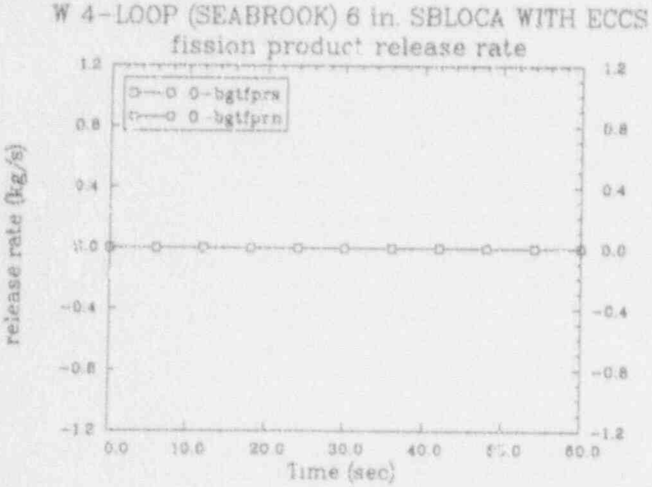
W 4-LOOP 100% DBA LPF, PUMP TRIP WITH ECCS
total ECCS flows
time (sec)
Mass Flow Rate (lbm/sec)
Time (sec)

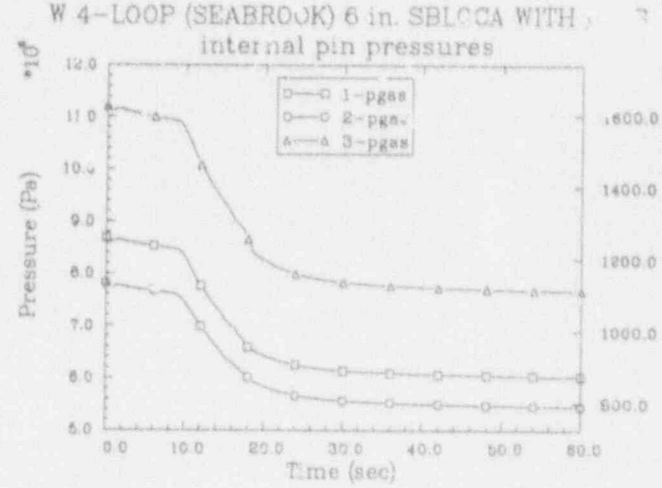

W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
core thermal power
0-rktpow
0-rkfipow
0-rkgapow
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)


W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
collapsed reactor water level
400-cntrlvar
403-cntrlvar
Level (ft)
Time (sec)

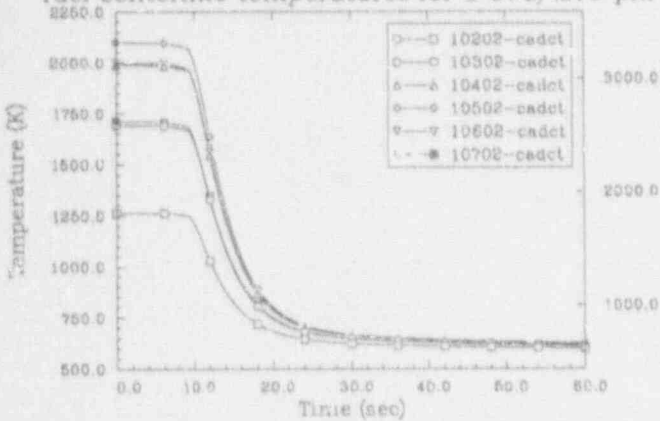

W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
pressures
128010000-p
620010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)


W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
containment pressure
670010000-p
Pressure (Pa)
Pressure (psia)
Time (sec)

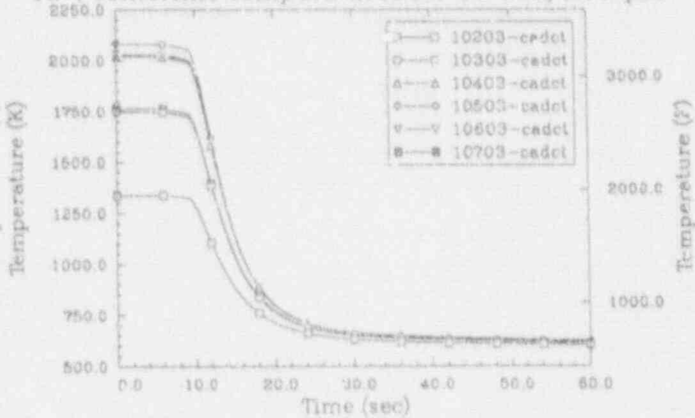

W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
fission product release rate
0-bgtfprs
0-bgtfprn
release rate (kg/s)
Time (sec)


W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH
internal pin pressures
1-pgas
3-pgas
Pressure (Pa)
Pressure (psia)
Time (sec)

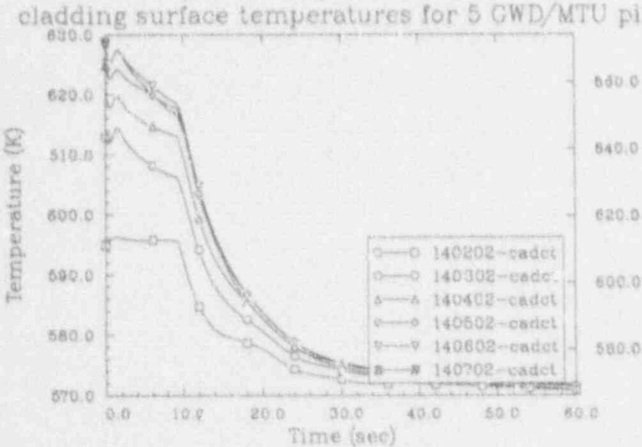
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
fuel centerline temperatures for 5 GWD/MTU pin



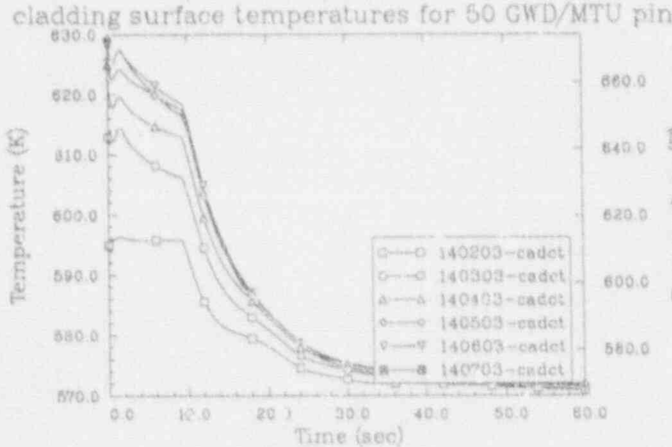
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
fuel centerline temperatures for 50 GWD/MTU pin



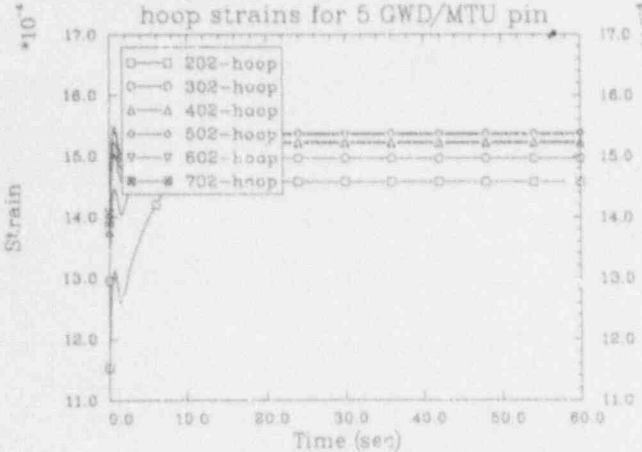
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
cladding surface temperatures for 5 GWD/MTU pin



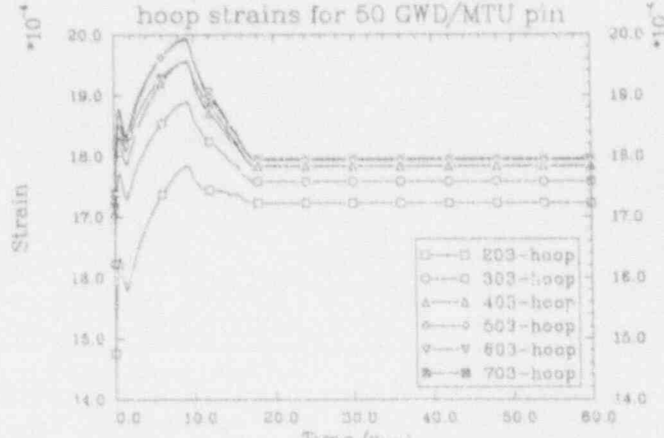
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
cladding surface temperatures for 50 GWD/MTU pin



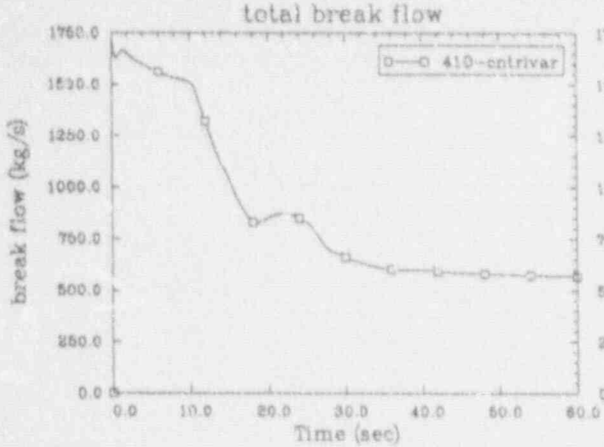
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
hoop strains for 5 GWD/MTU pin



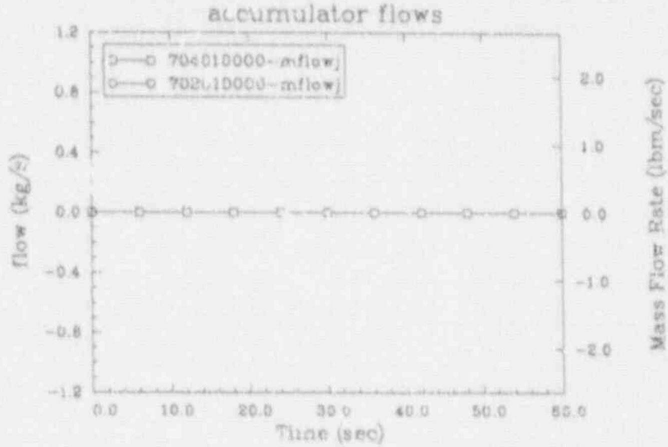
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
hoop strains for 50 GWD/MTU pin



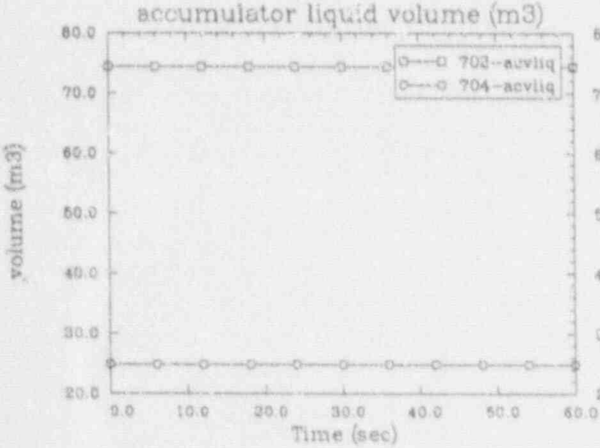
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
total break flow



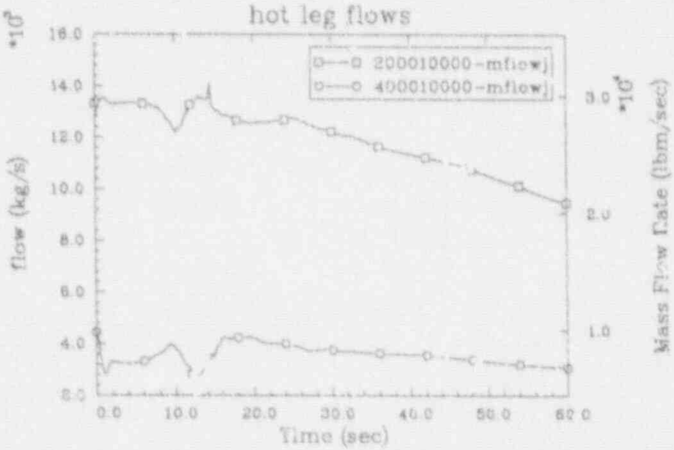
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
accumulator flows



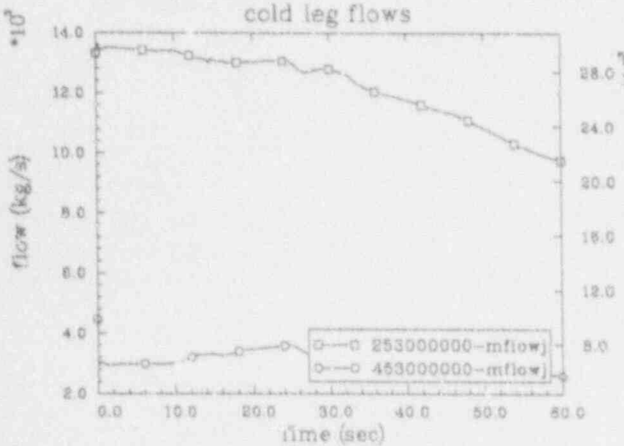
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
accumulator liquid volume (m3)



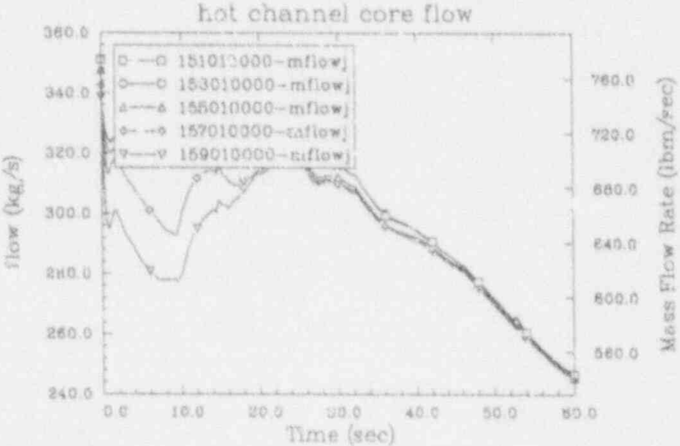
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
hot leg flows

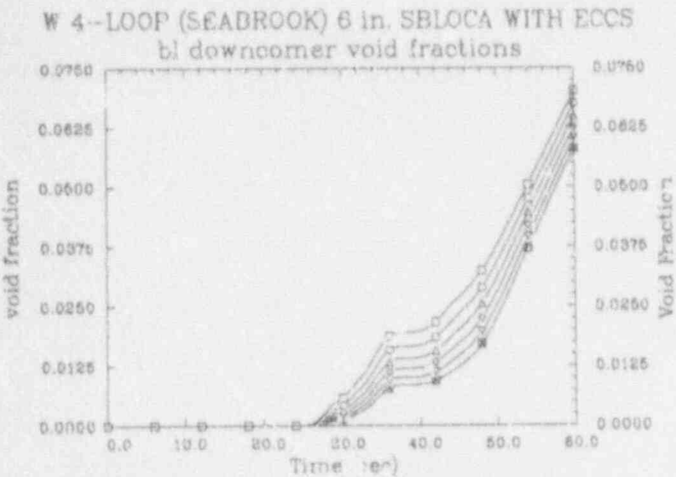


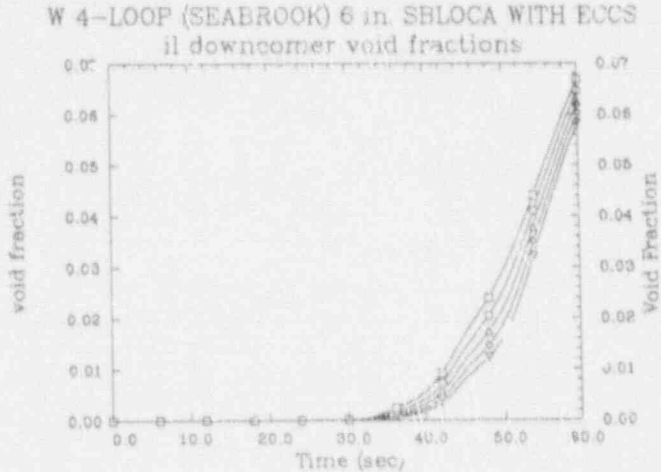
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
cold leg flows

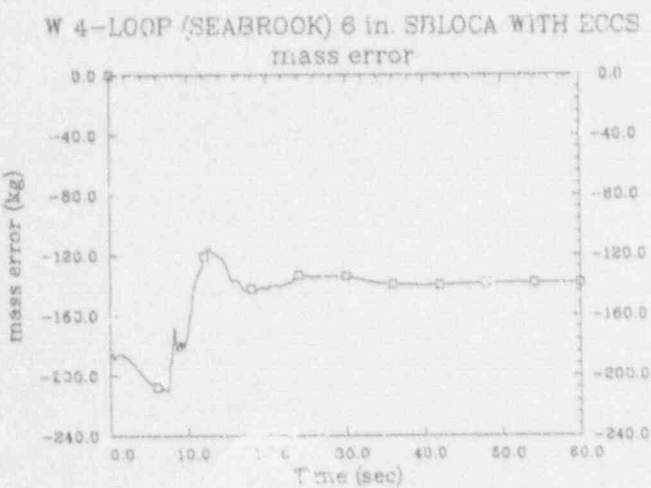


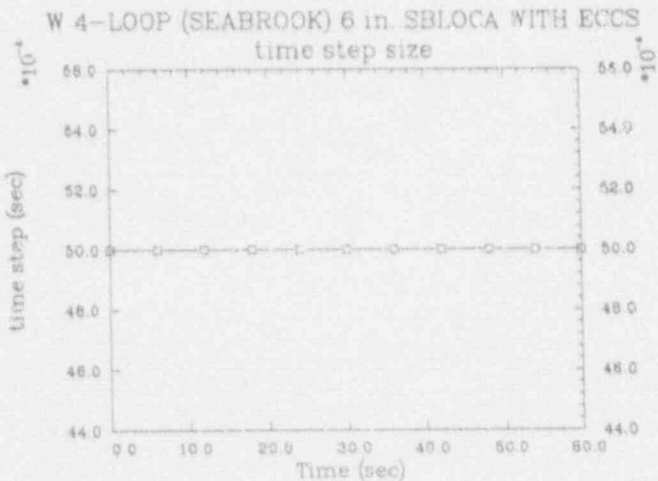
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
hot channel core flow

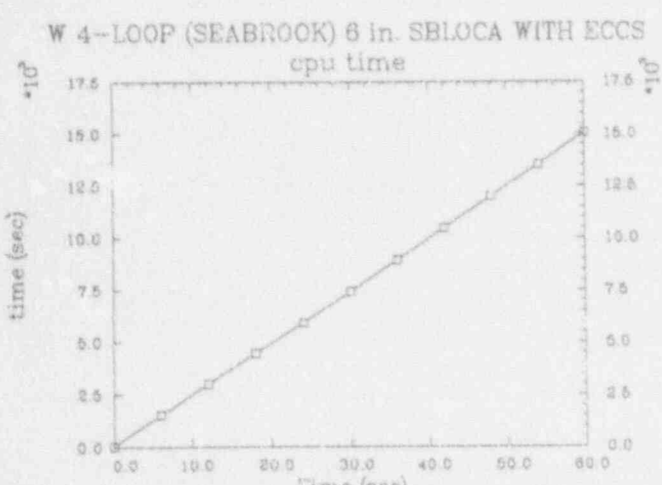


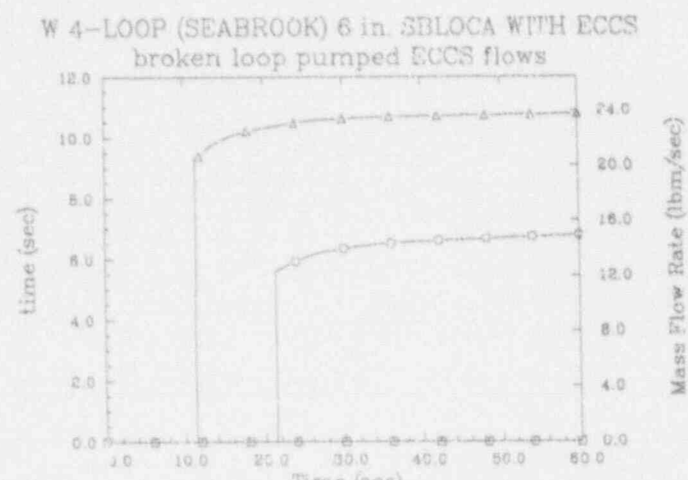

W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)

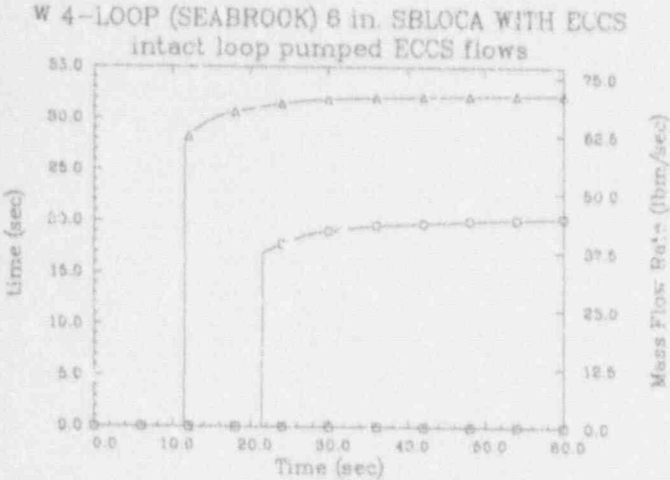

W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
il downcomer void fractions
void fraction
Void Fraction
Time (sec)


W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
mass error
mass error (kg)
Time (sec)

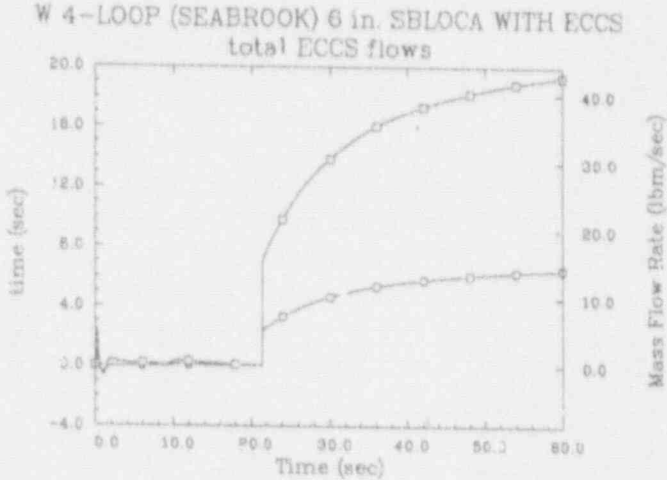

W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
time step size
time step (sec)
Time (sec)


W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
cpu time
time (sec)
Time (sec)


W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
broken loop pumped ECCS flows
time (sec)
Mass Flow Rate (lbm/sec)
Time (sec)



W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
intact loop pumped ECCS flows
time (sec)
Mass Flow Rate (lbm/sec)
Time (sec)

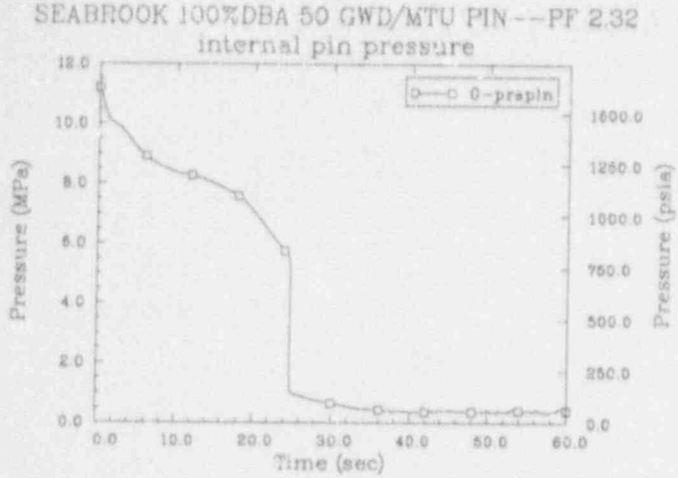


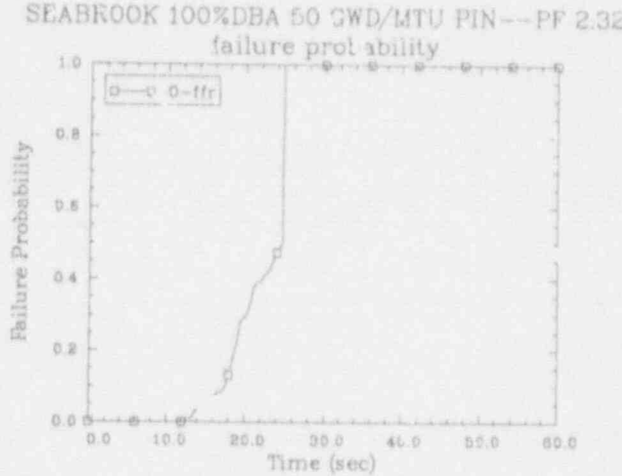
W 4-LOOP (SEABROOK) 6 in. SBLOCA WITH ECCS
total ECCS flows
time (sec)
Mass Flow Rate (lbm/sec)
Time (sec)

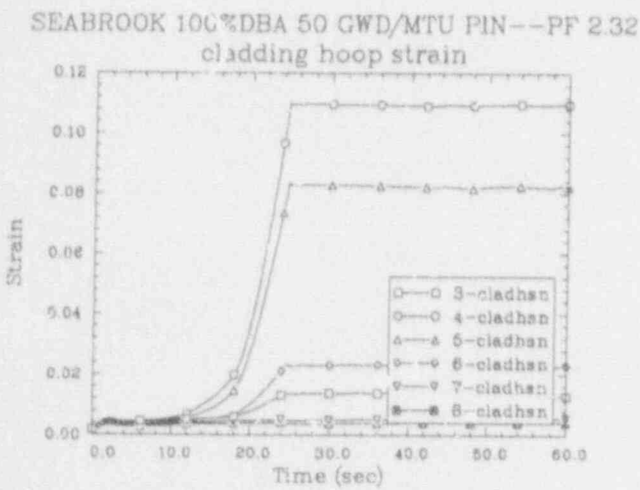
L-1.2 FRAP-T6 PLOTTED RESULTS FOR SEABROOK

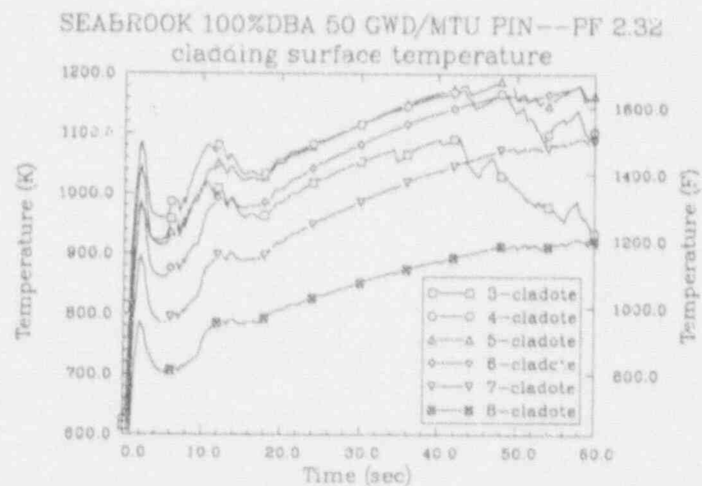
Table L-2. Description of FRAP-T6 plot variables for Seabrook.

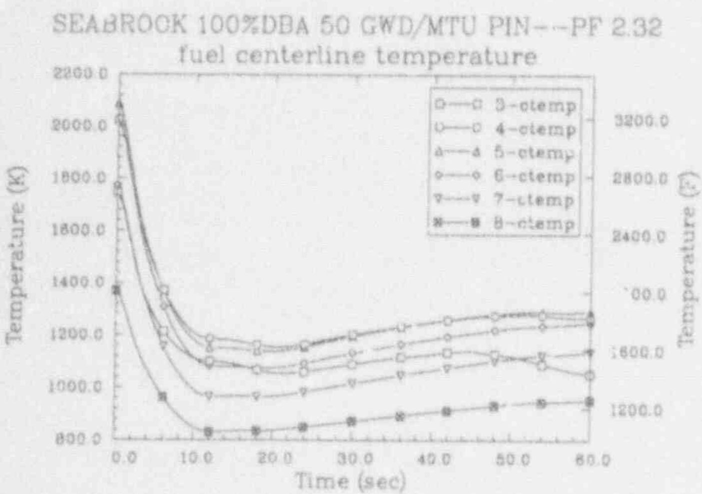
Variable	Description
0-ffr	Failure probability
0-prspln	Internal pin pressure (psia, Pa)
n-cladhsn	Cladding hoop strain at axial node n
n-cladote	Cladding surface temperature at axial node n (°F, K)
n-ctemp	Fuel centerline temperature at axial node n (°F, K)
n-ooxtn	Oxide thickness at axial node n (in., mm)

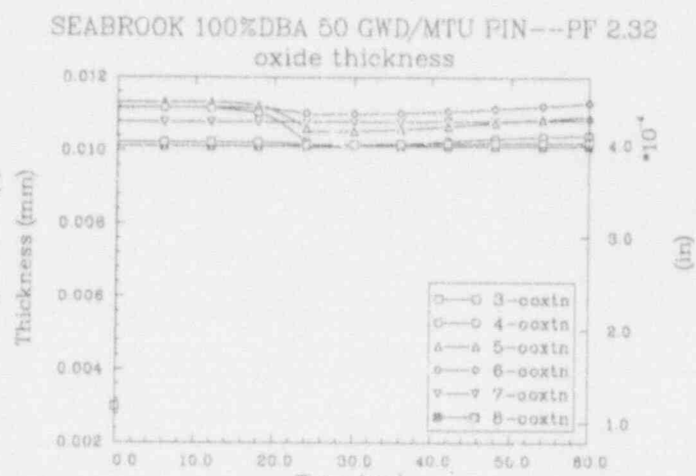

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32
internal pin pressure
0-prspln
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32
failure probability
0-ffr
Failure Probability
Time (sec)

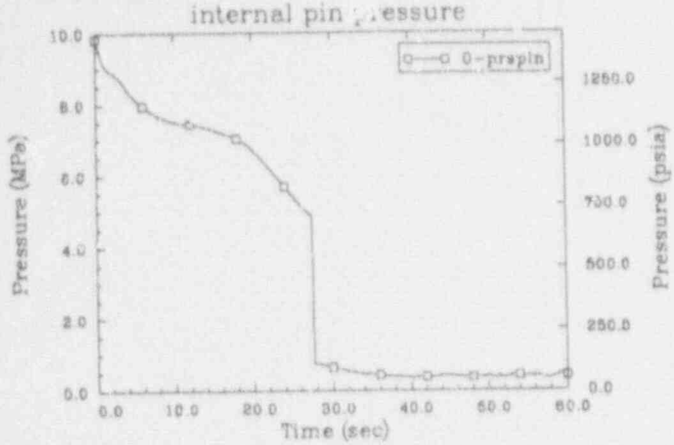

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

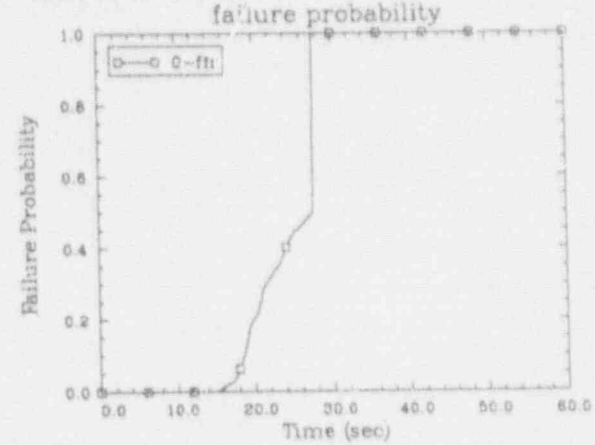

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

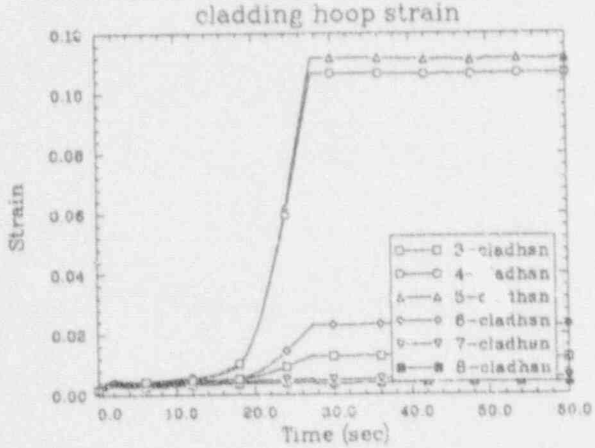
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32
internal pin pressure



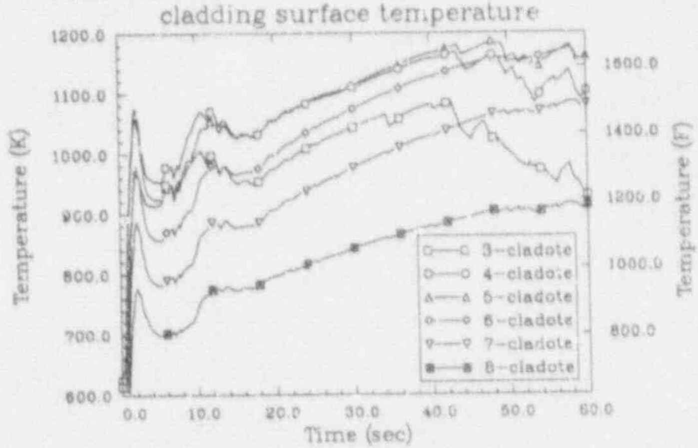
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32
failure probability



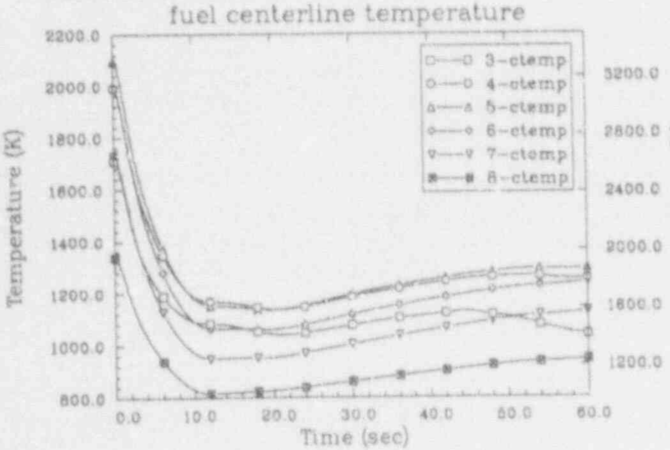
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32
cladding hoop strain



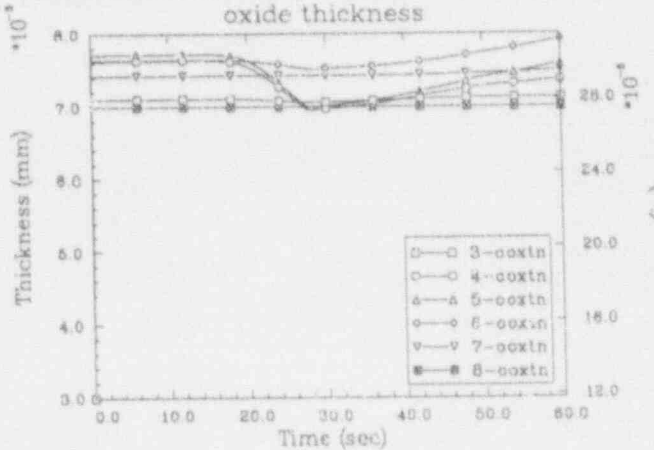
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32
cladding surface temperature



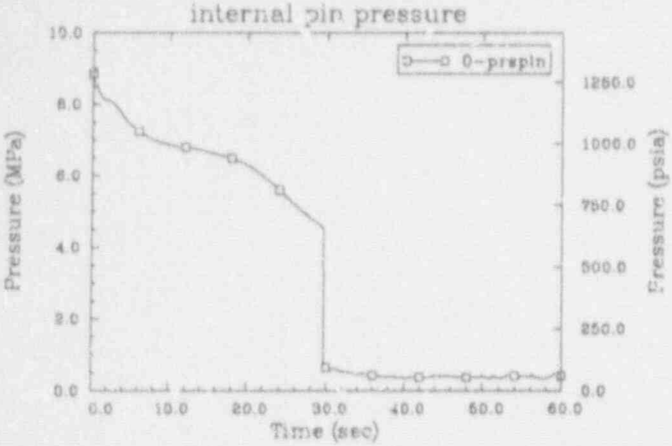
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32
fuel centerline temperature



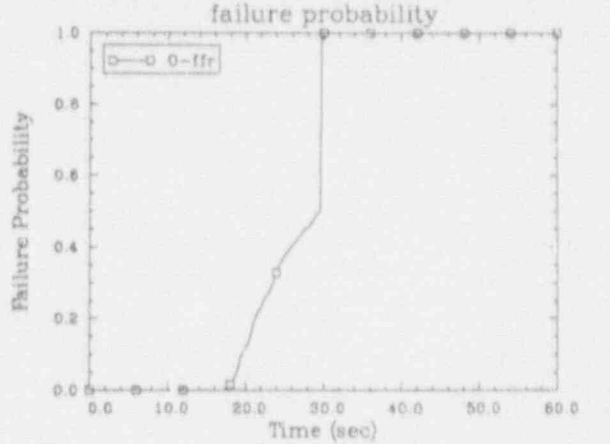
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32
oxide thickness



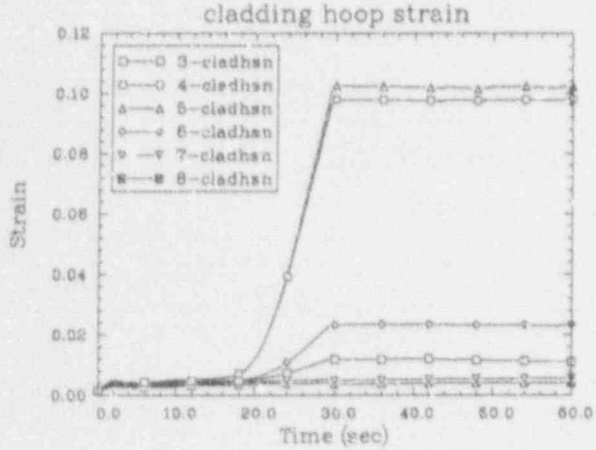
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32
internal pin pressure



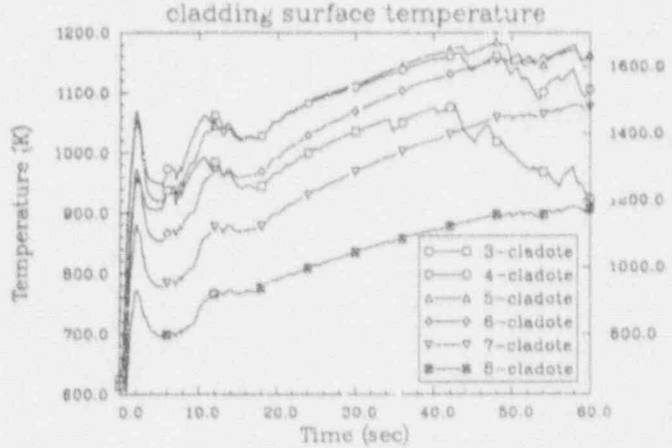
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32
failure probability



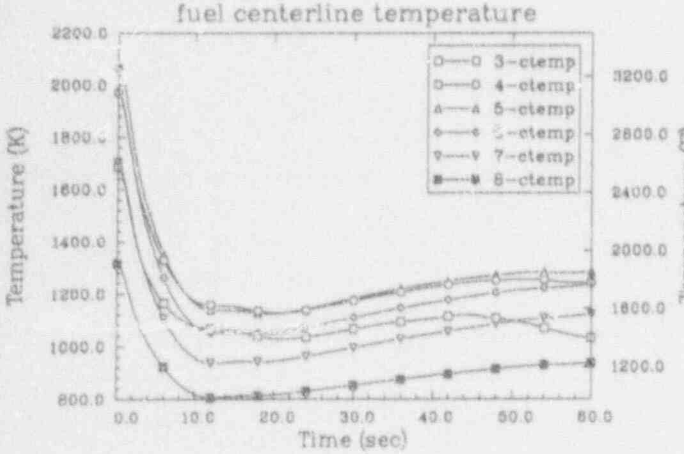
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32
cladding hoop strain



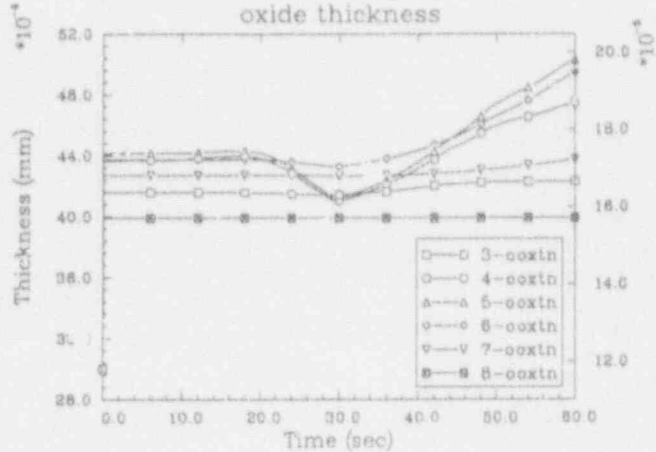
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32
cladding surface temperature



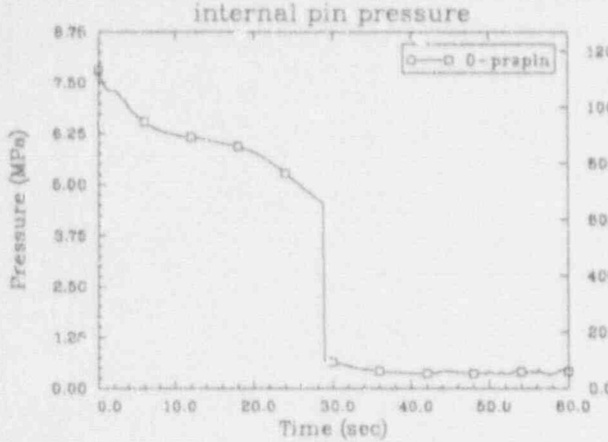
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32
fuel centerline temperature



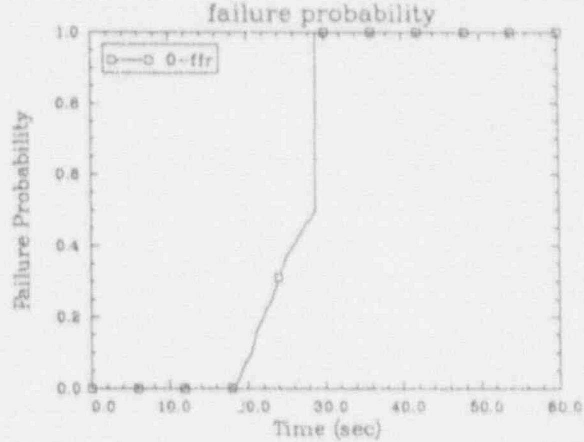
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32
oxide thickness



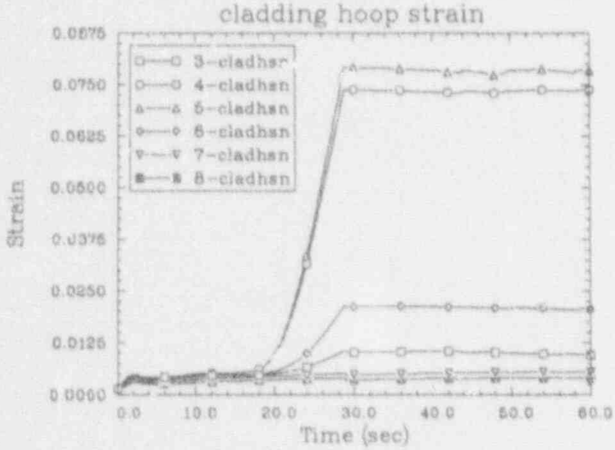
SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32
internal pin pressure



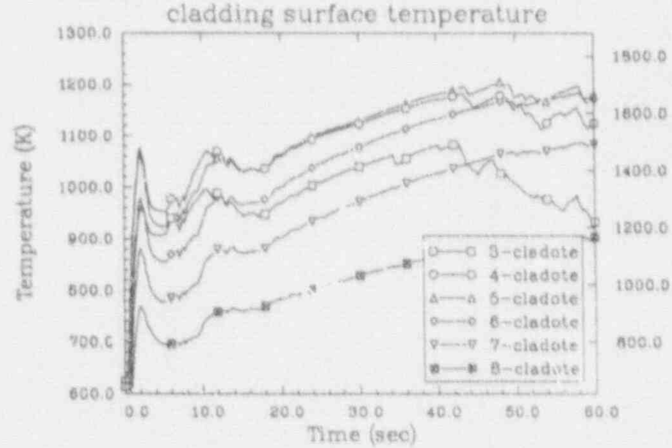
SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32
failure probability



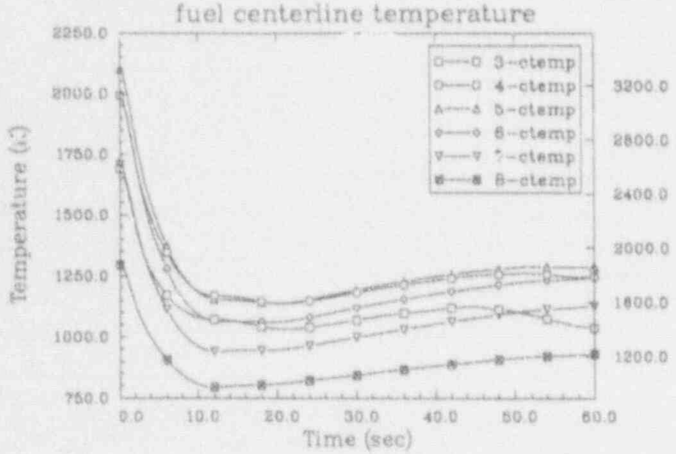
SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32
cladding hoop strain



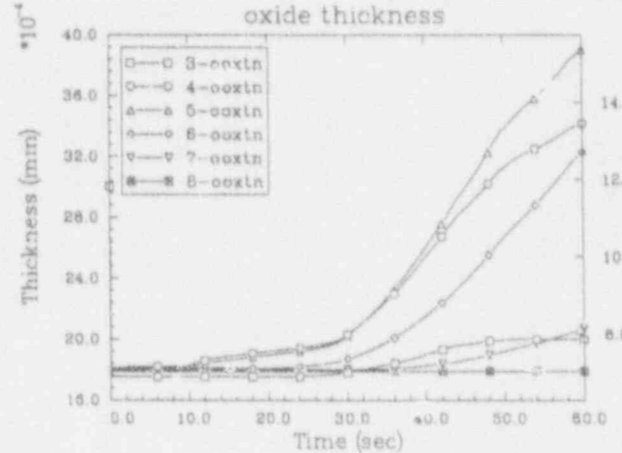
SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32
cladding surface temperature

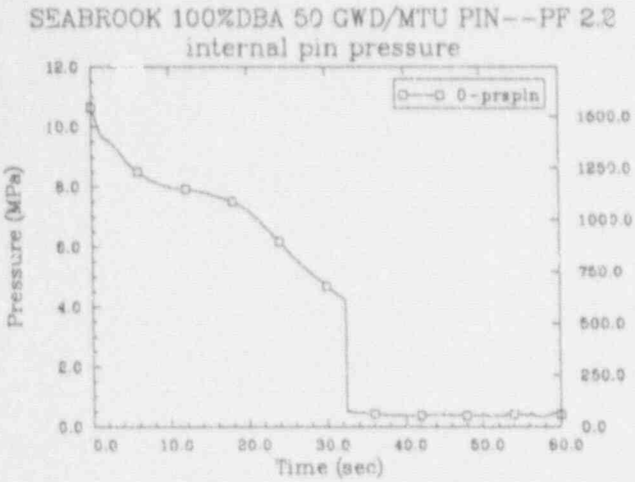


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32
fuel centerline temperature

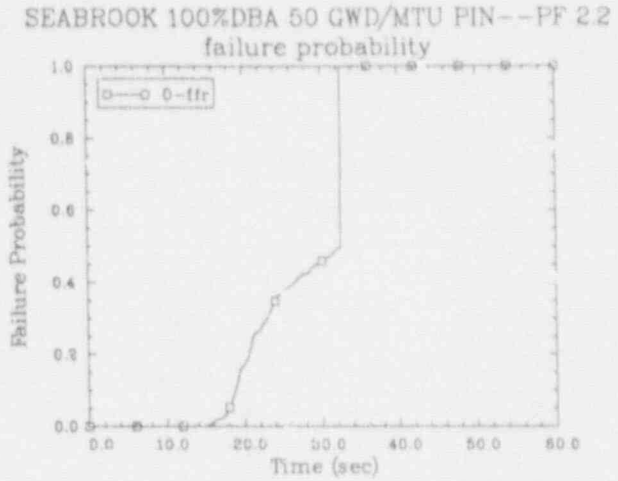


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32
oxide thickness

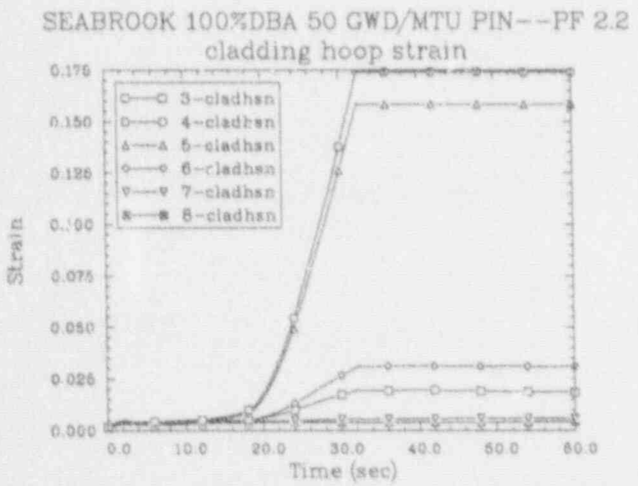




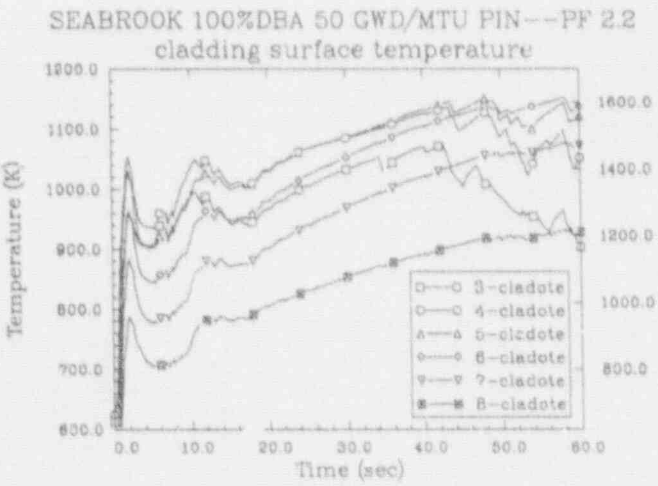
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)



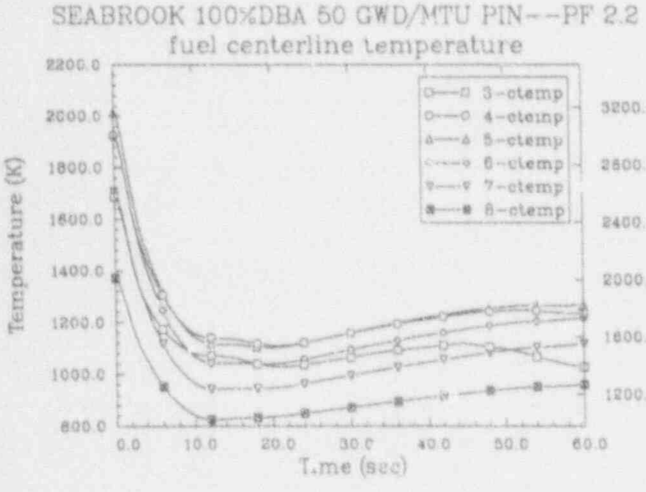
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)



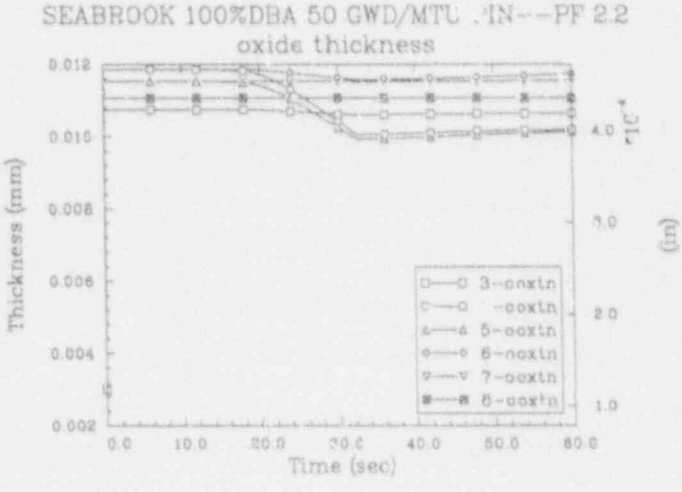
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)



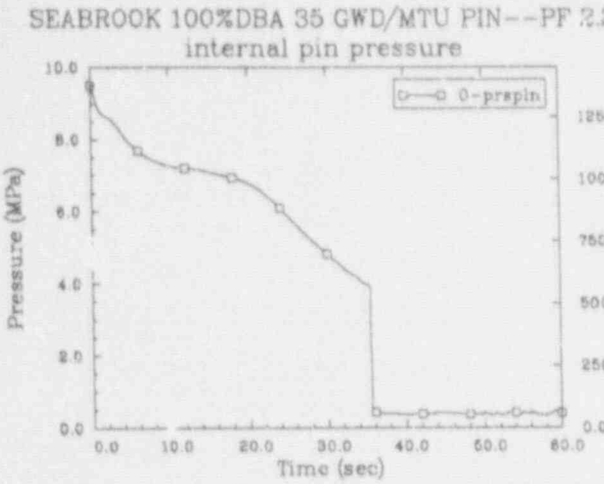
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

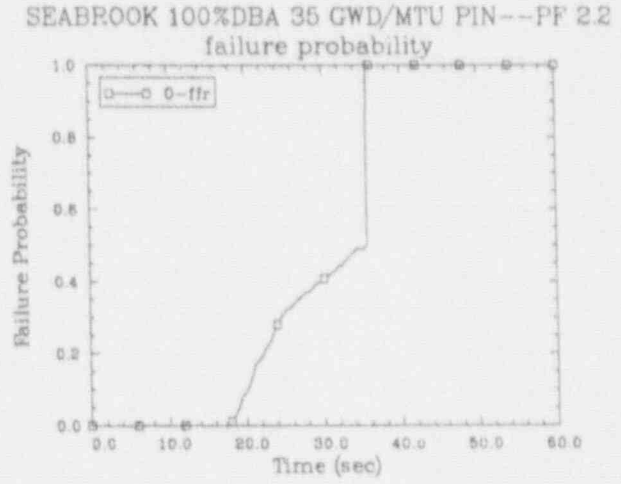


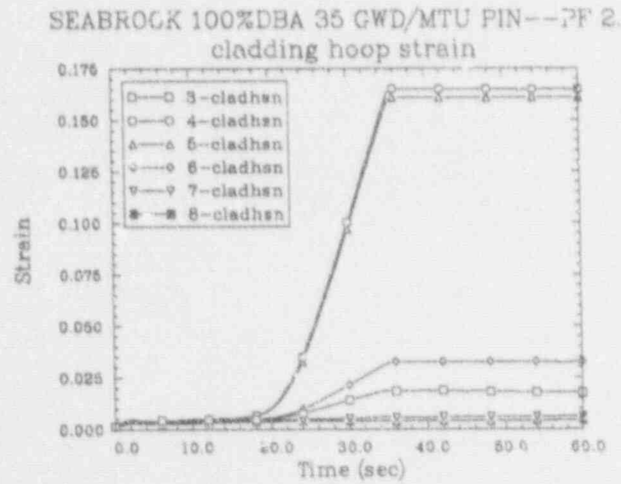
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)

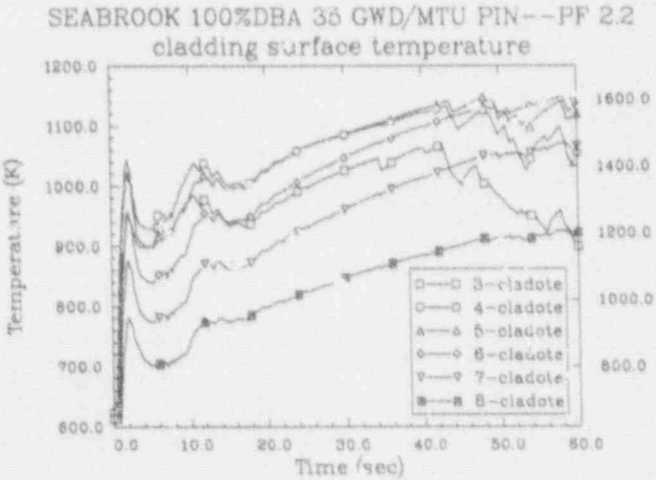


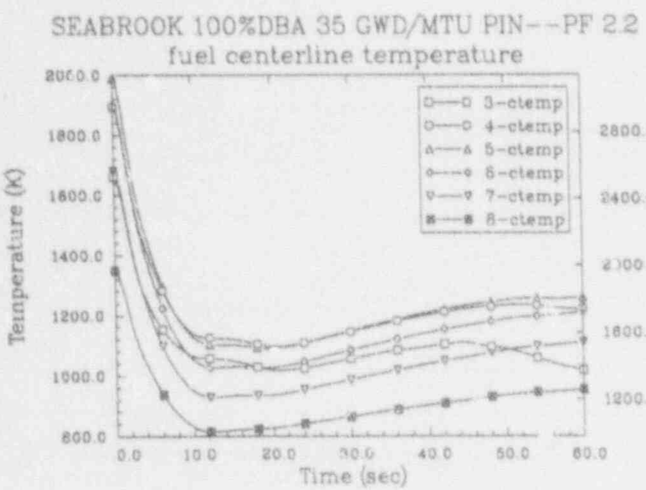
oxide thickness
Thickness (mm)
(in)
7-ooxtn
Time (sec)

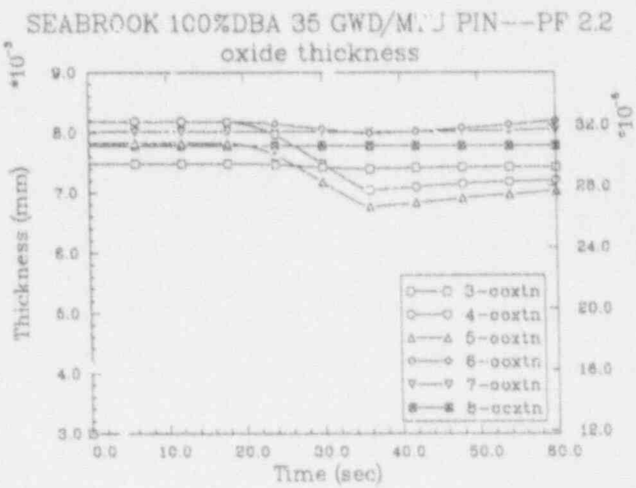

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.2
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.2
failure probability
Failure Probability
Time (sec)
0-ffr


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.2
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.2
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.2
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.2
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

1

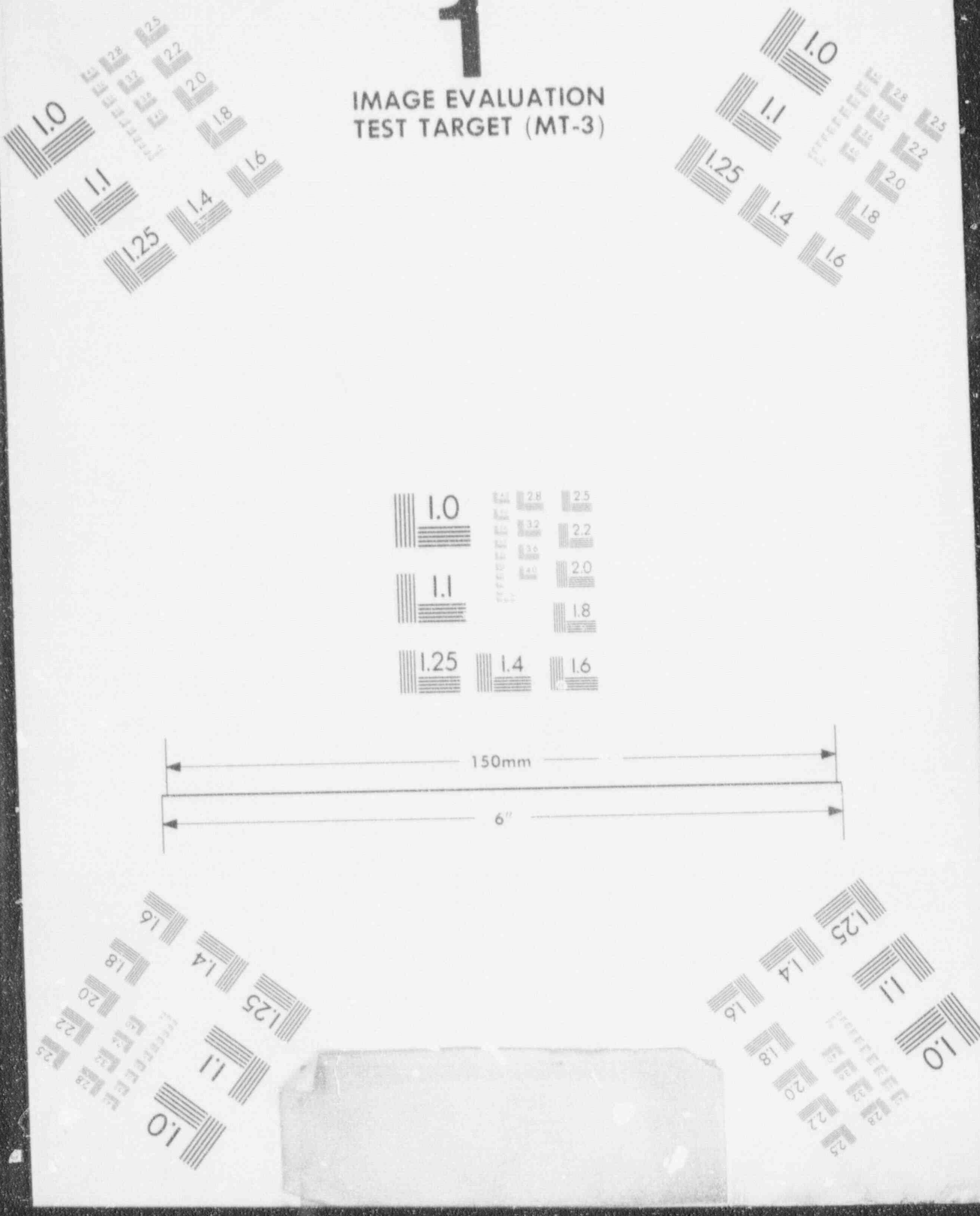
IMAGE EVALUATION TEST TARGET (MT-3)

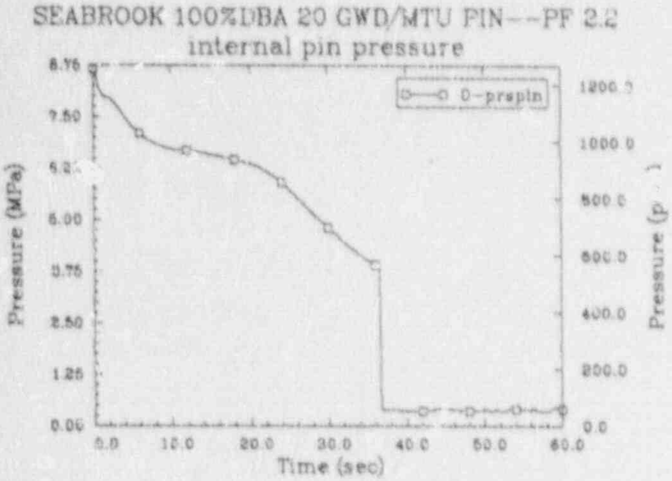
150mm

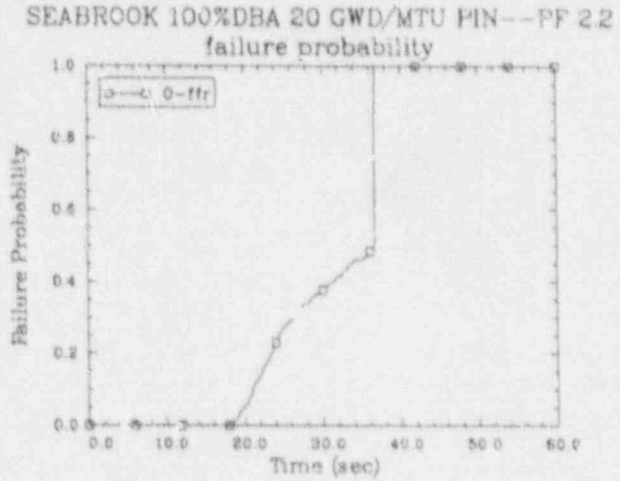
6″

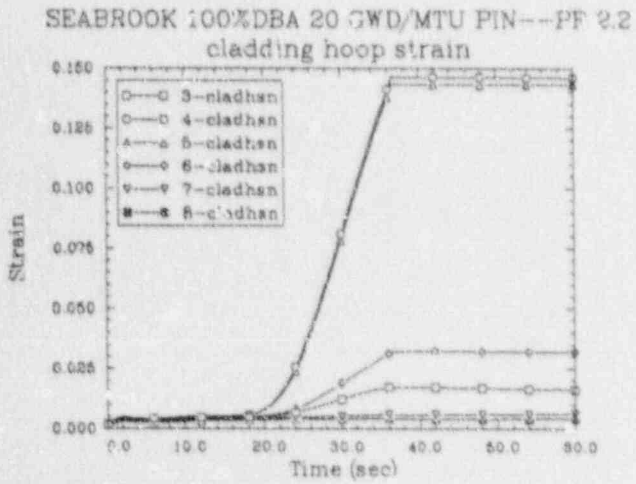
1

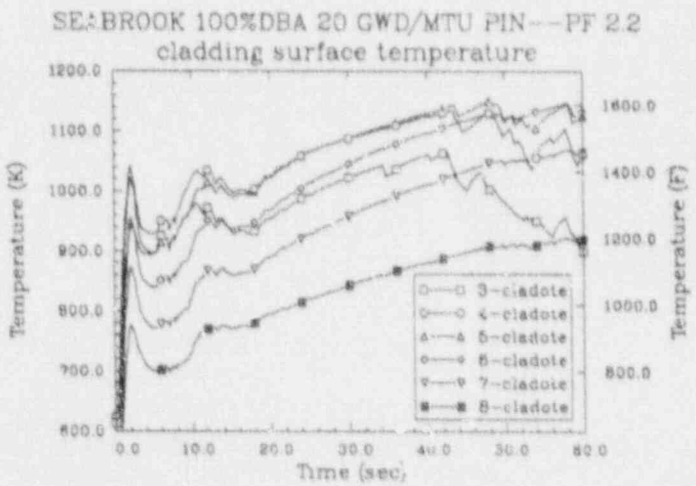
IMAGE EVALUATION
TEST TARGET (MT-3)

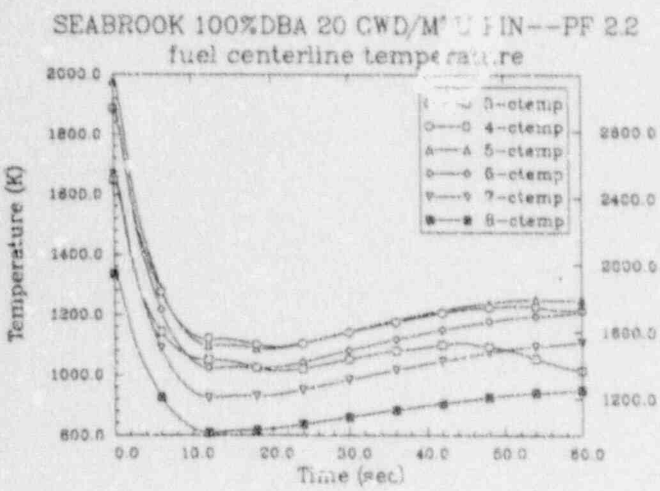


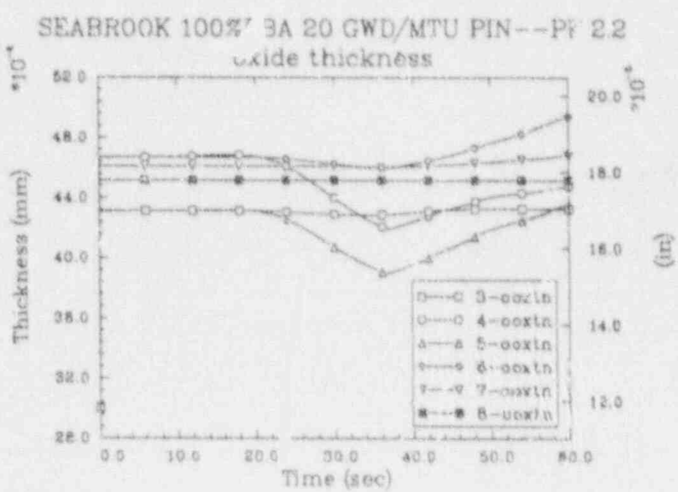

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Time (sec)

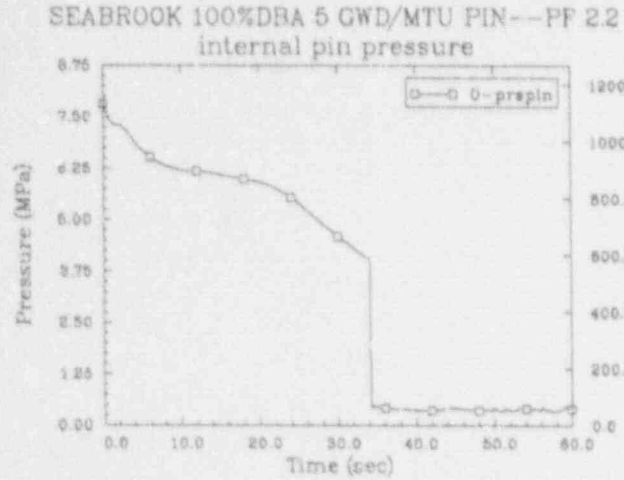

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

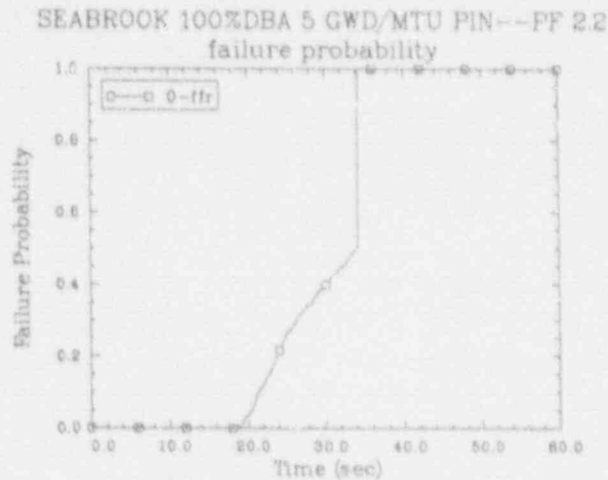

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
Strain
Time (sec)

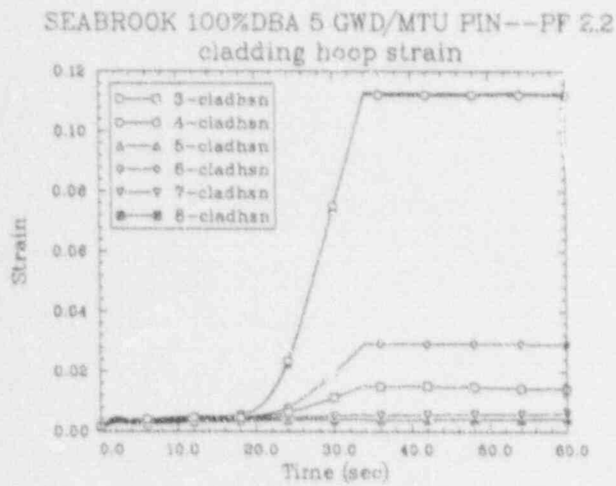

cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)

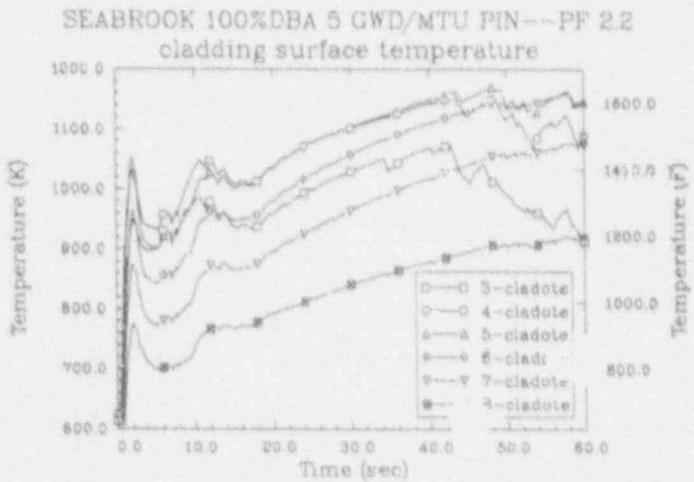

4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)

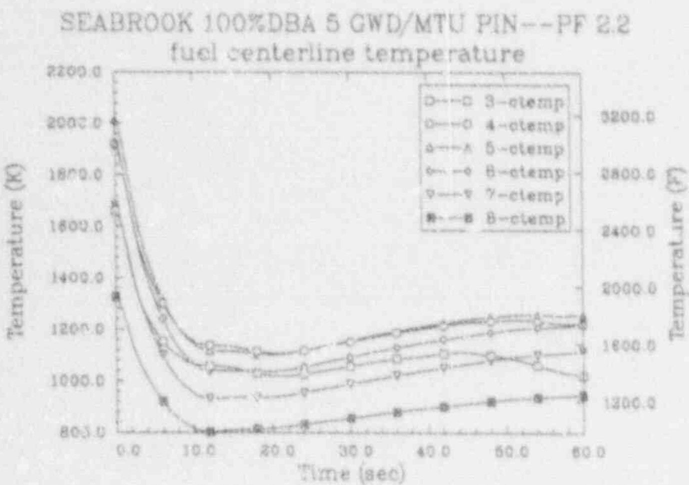

3-ooxtn
4-ooxtn
5-ooxtn
Thickness (mm)
(in)
Time (sec)

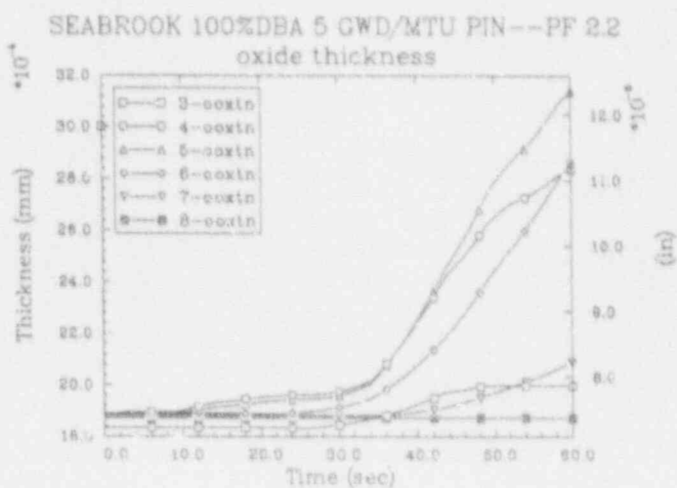

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

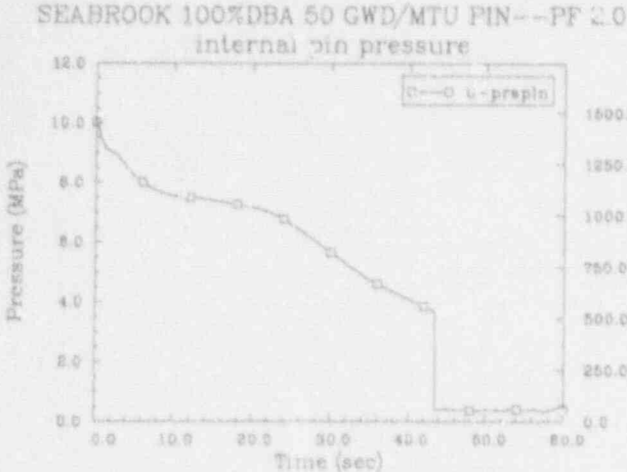

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

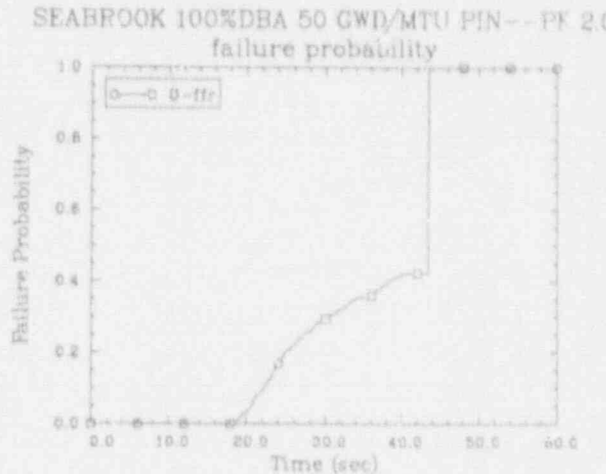

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

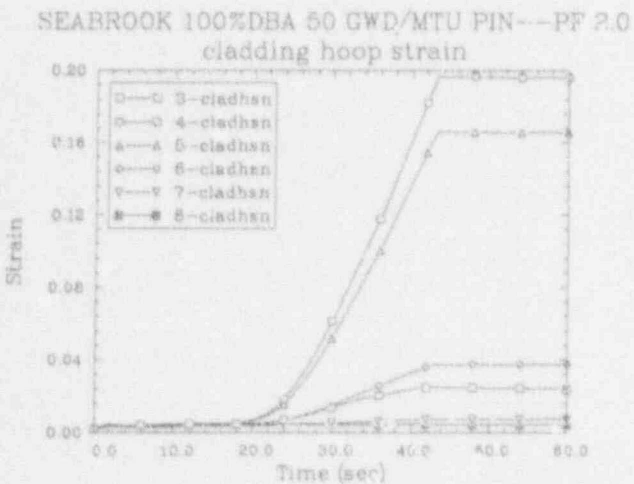

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
7-cladote
Temperature (K)
Temperature (F)
Time (sec)

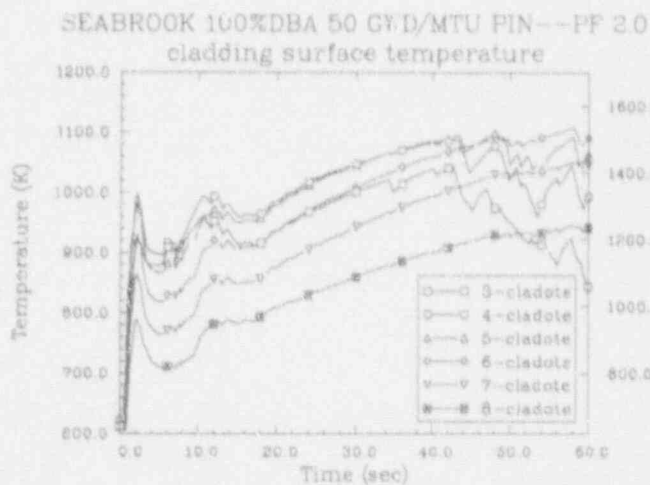

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

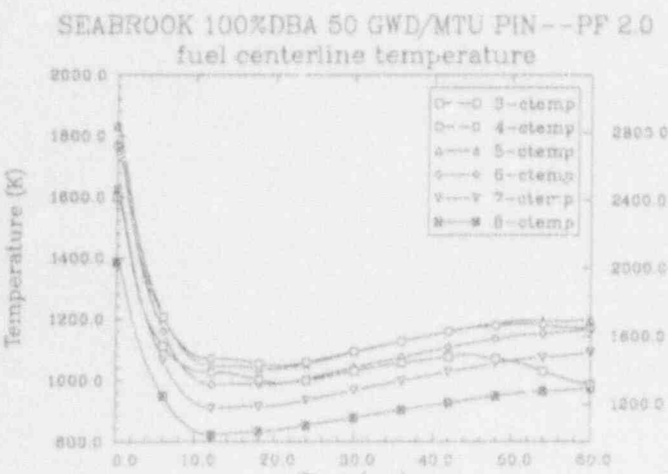

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
Thickness (mm)
(in)
Time (sec)

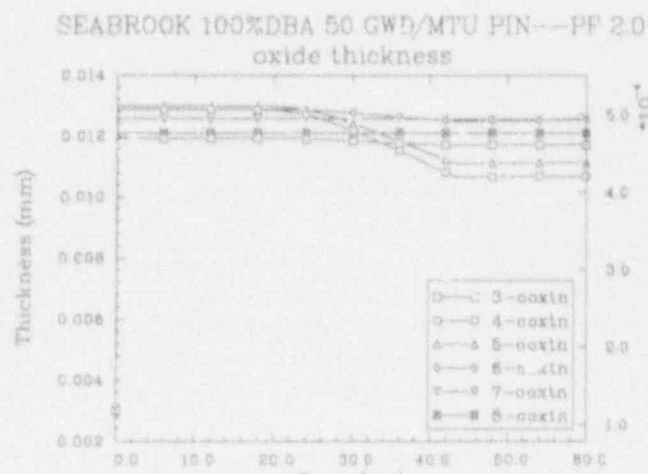

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0
internal pin pressure
6-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

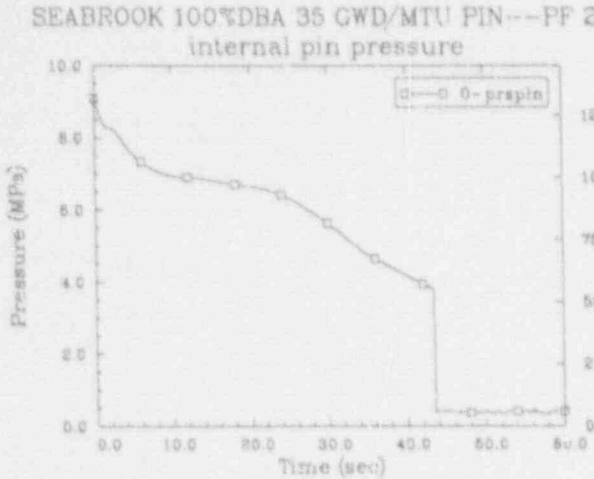

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

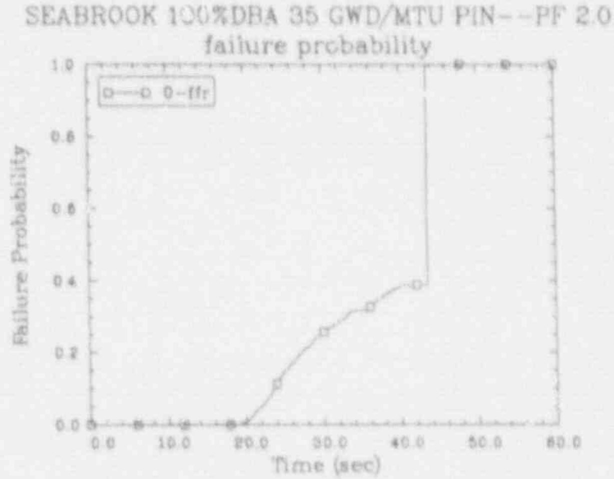

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

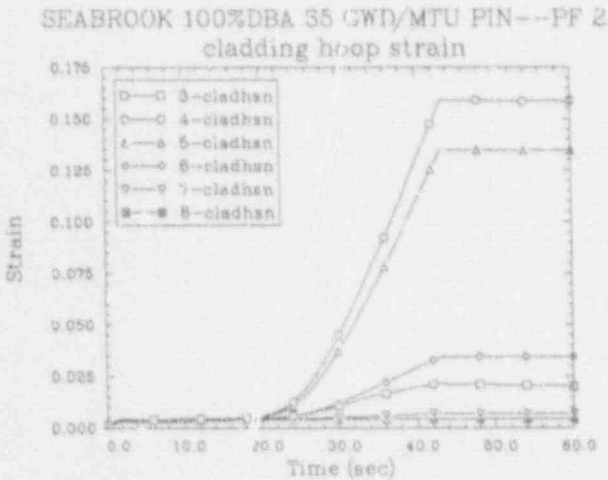

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

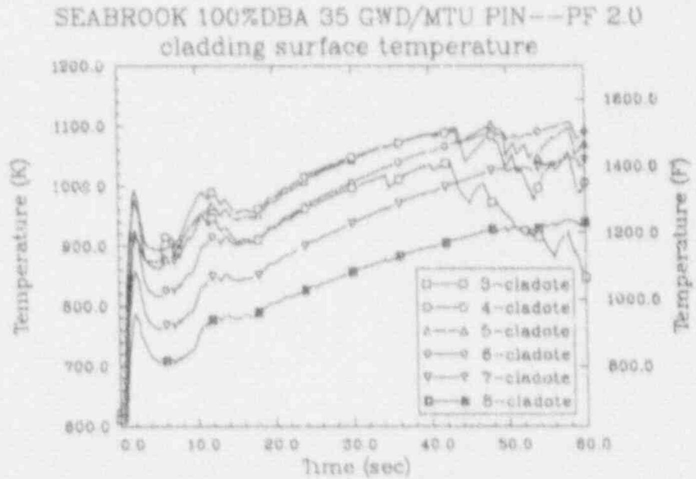

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

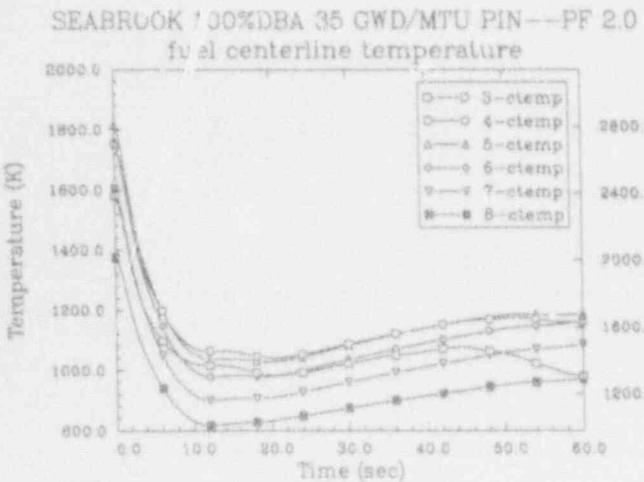

SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

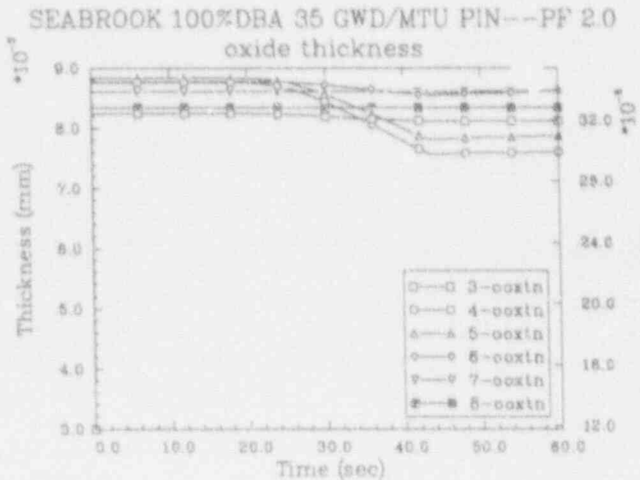

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

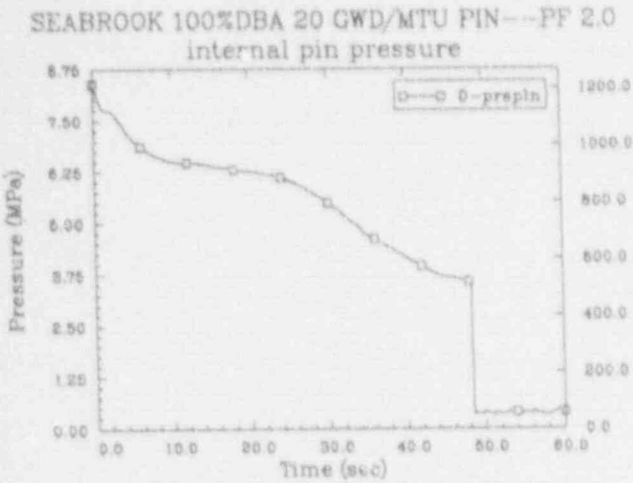

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

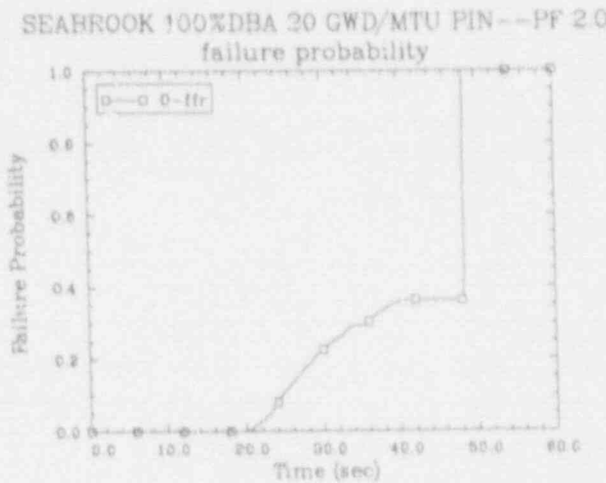

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

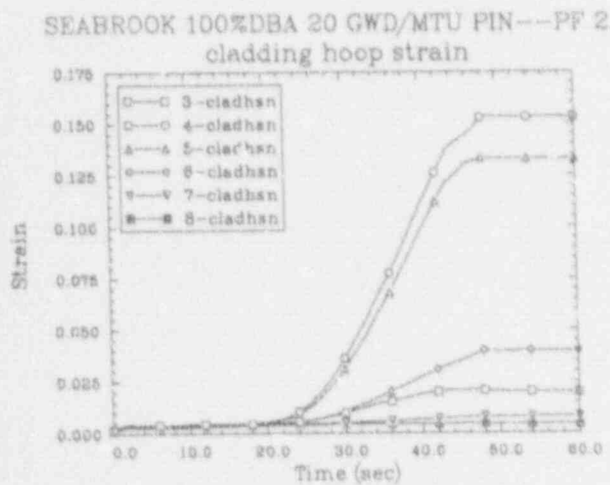

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

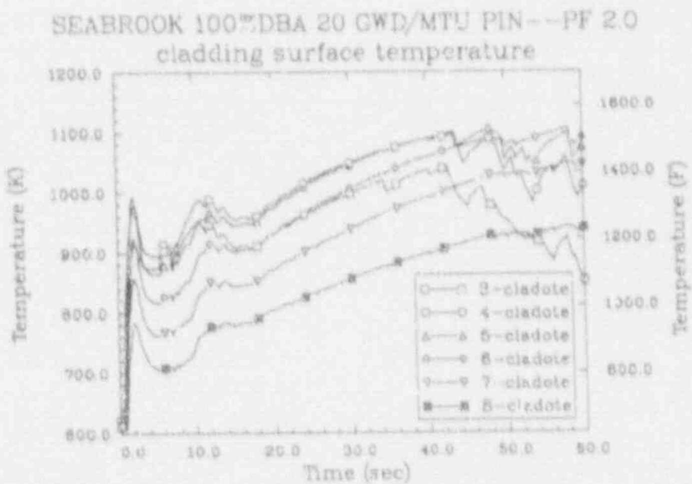

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

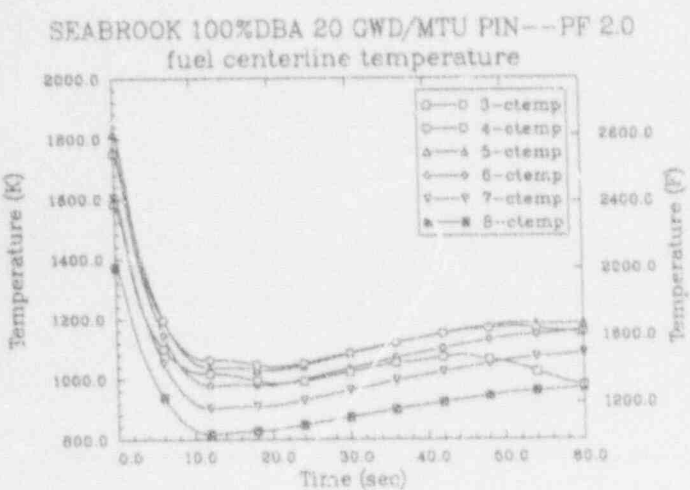

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

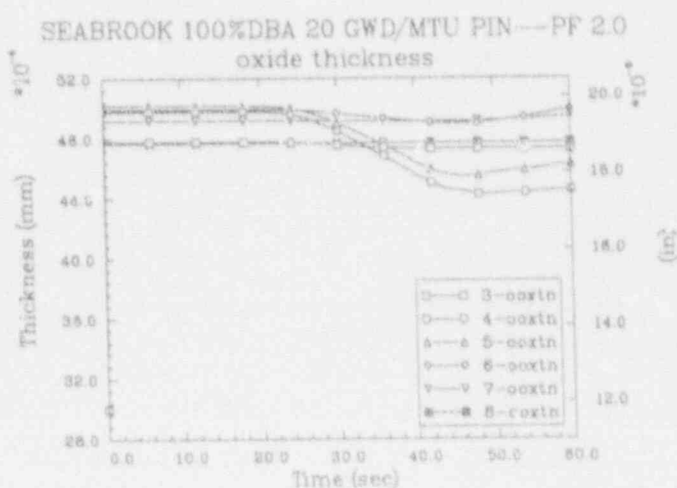

SEABROOK 100%DBA 20 GWD/MTU PIN---PF 2.0
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

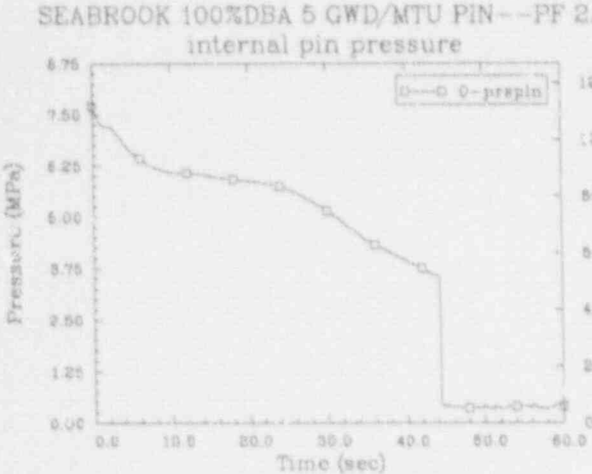

SEABROOK 100%DBA 20 GWD/MTU PIN---PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

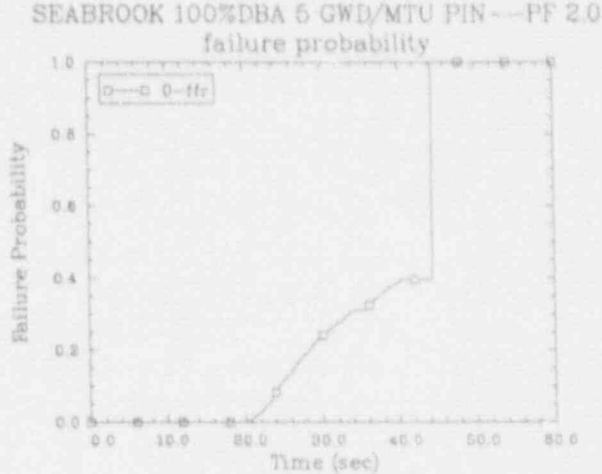

SEABROOK 100%DBA 20 GWD/MTU PIN---PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

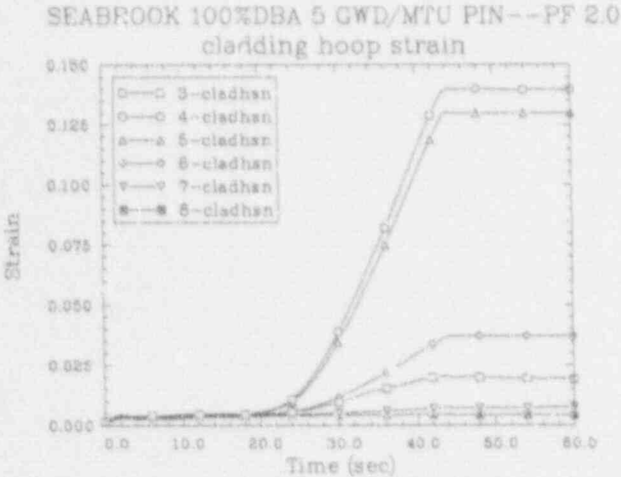

SEABROOK 100%DBA 20 GWD/MTU PIN---PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

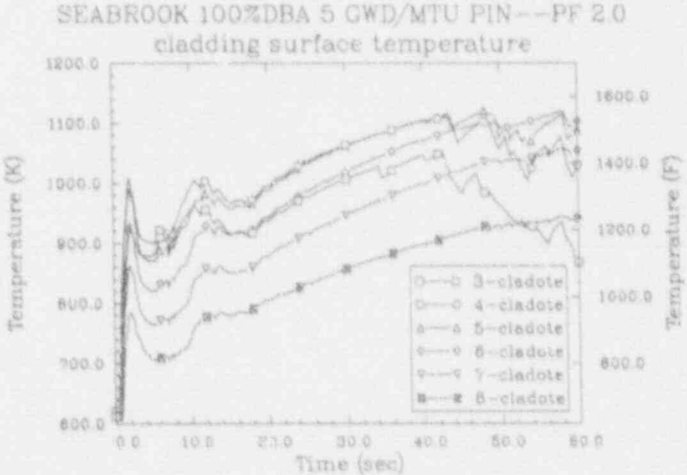

SEABROOK 100%DBA 20 GWD/MTU PIN---PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

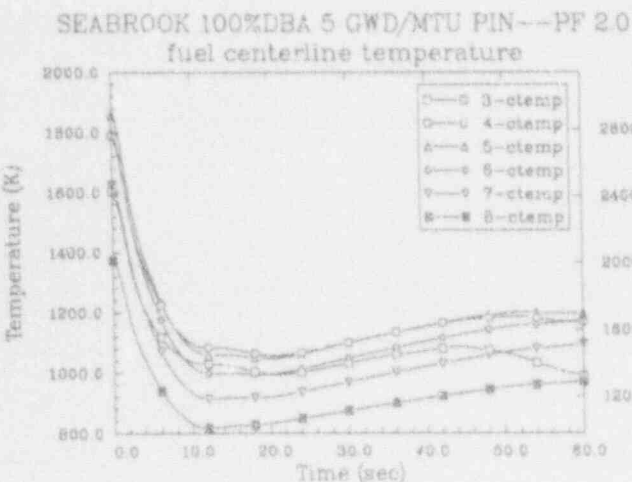

SEABROOK 100%DBA 20 GWD/MTU PIN---PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

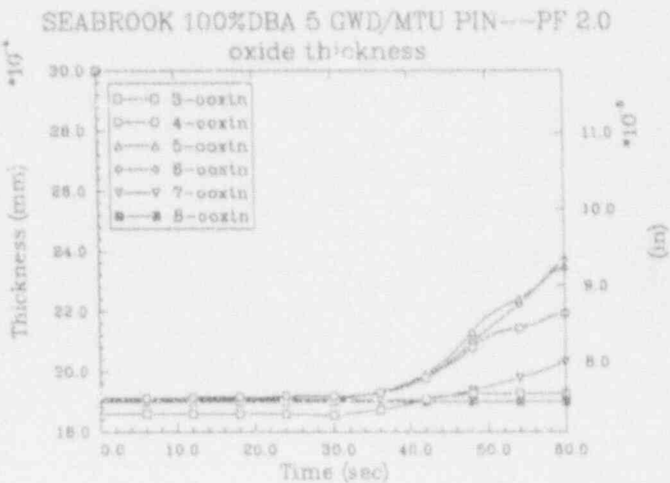

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

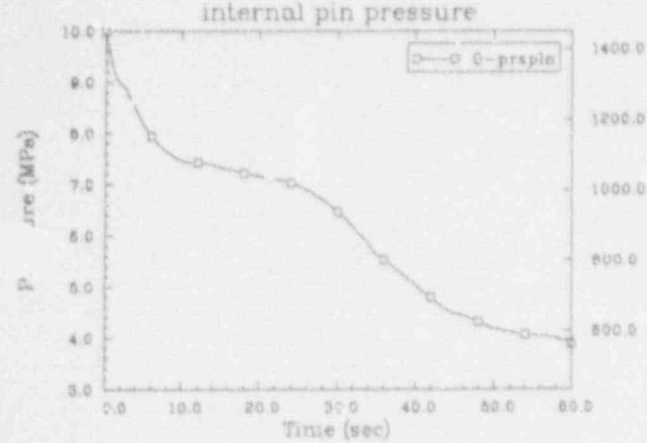

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

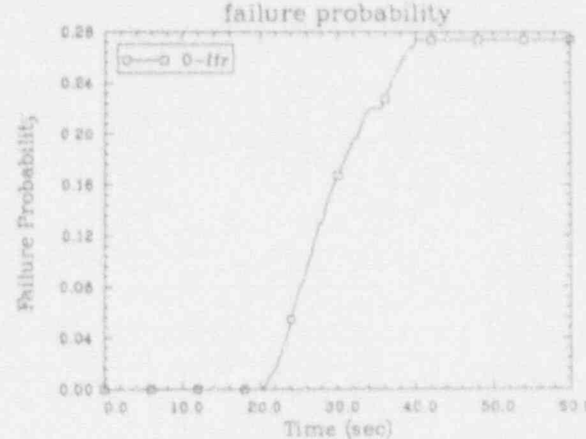

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

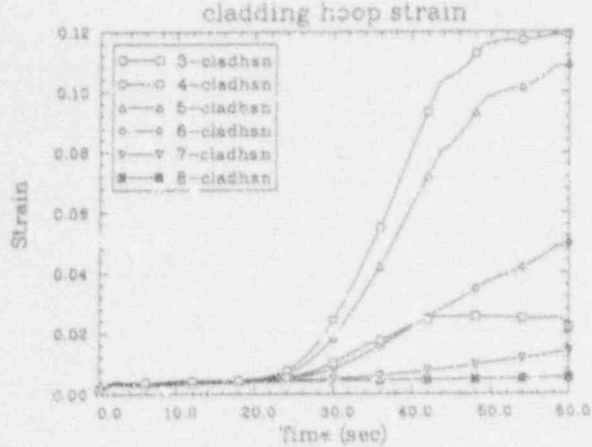
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8
internal pin pressure



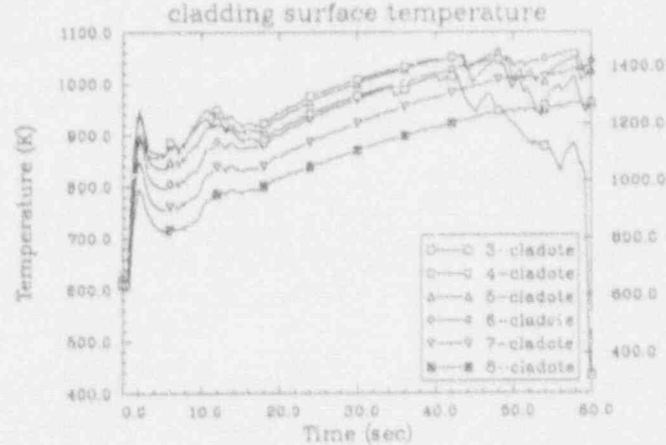
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8
failure probability



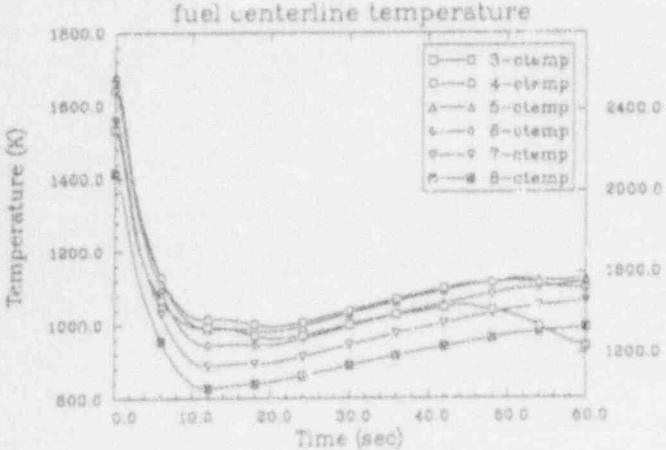
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8
cladding hoop strain



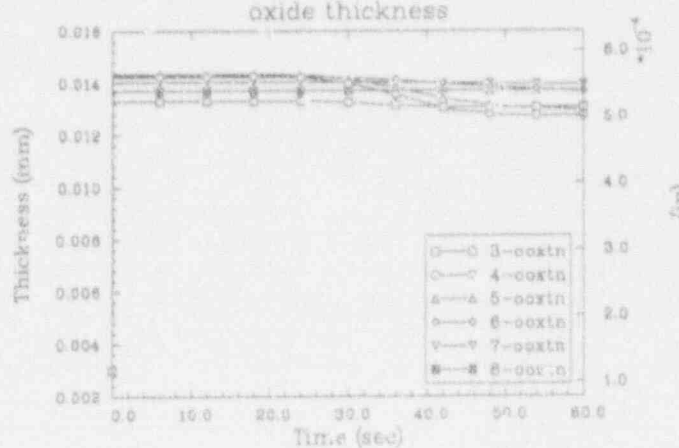
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8
cladding surface temperature



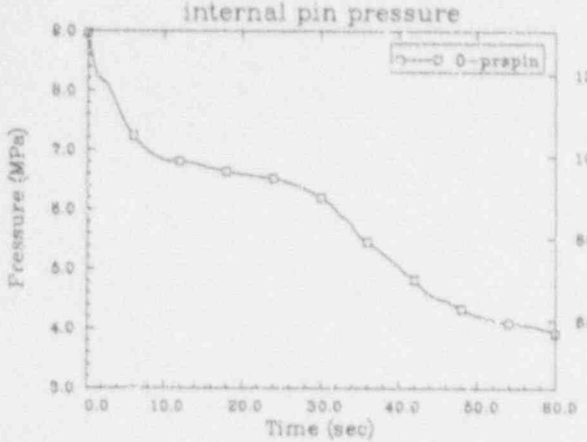
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8
fuel centerline temperature



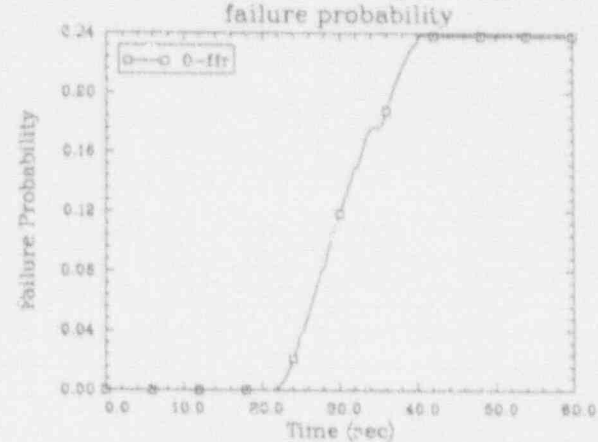
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8
oxide thickness



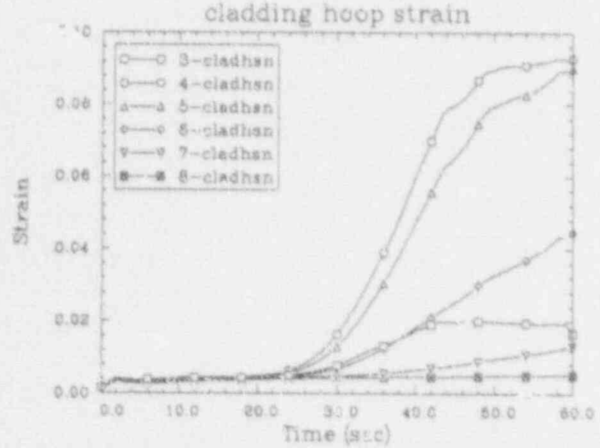
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8
internal pin pressure



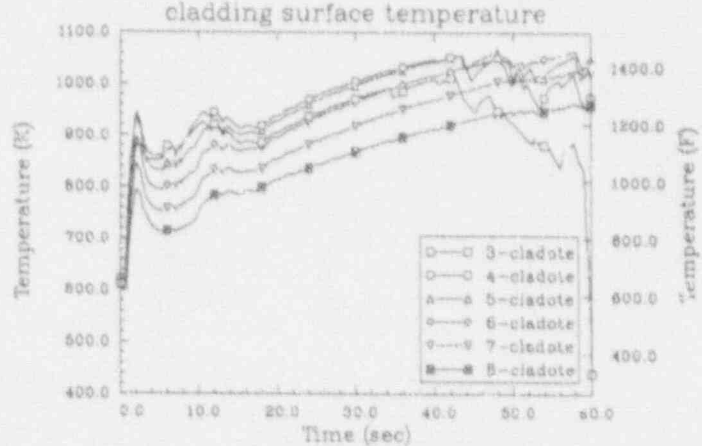
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8
failure probability



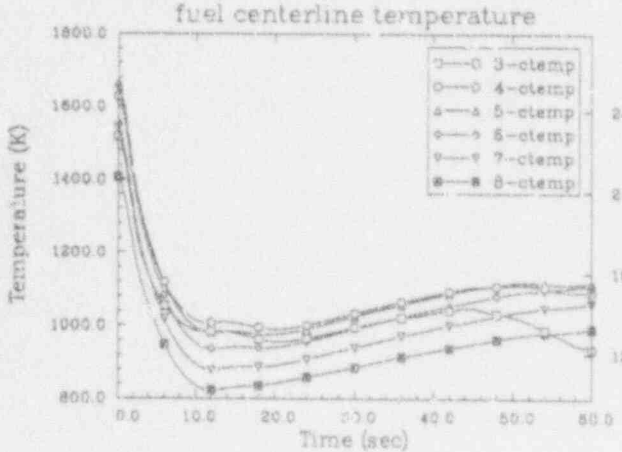
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8
cladding hoop strain



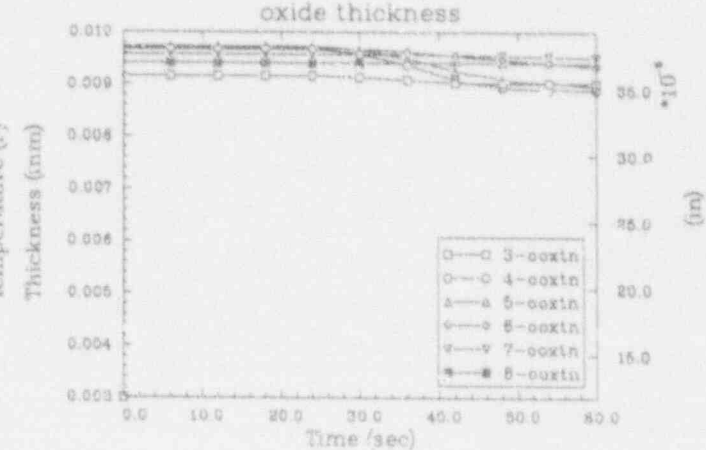
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8
cladding surface temperature

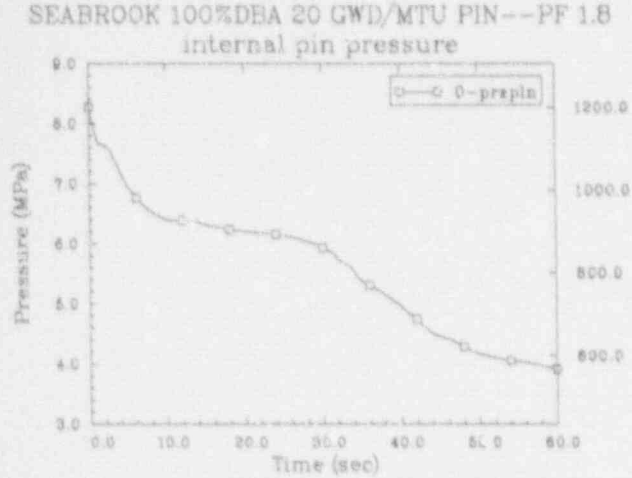


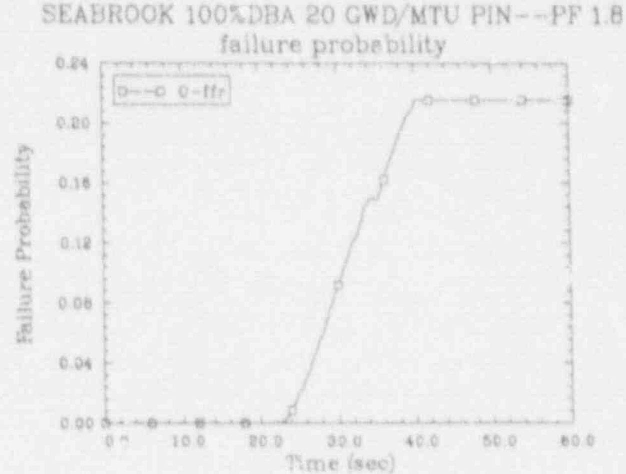
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8
fuel centerline temperature

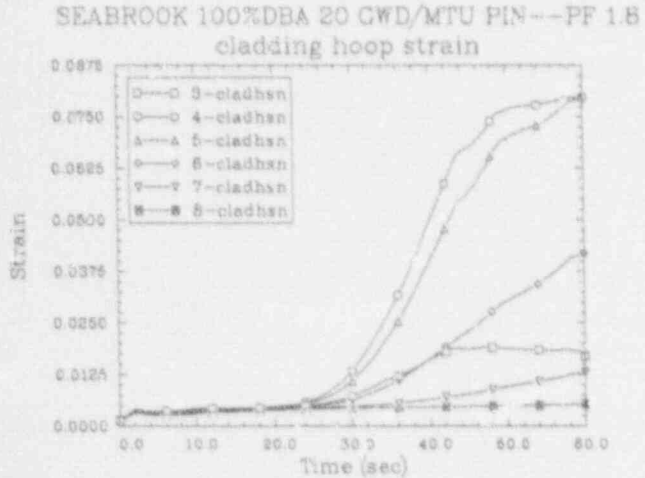


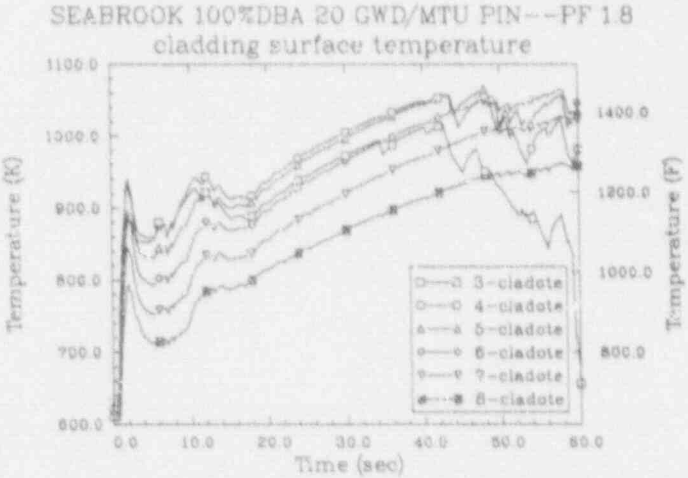
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8
oxide thickness

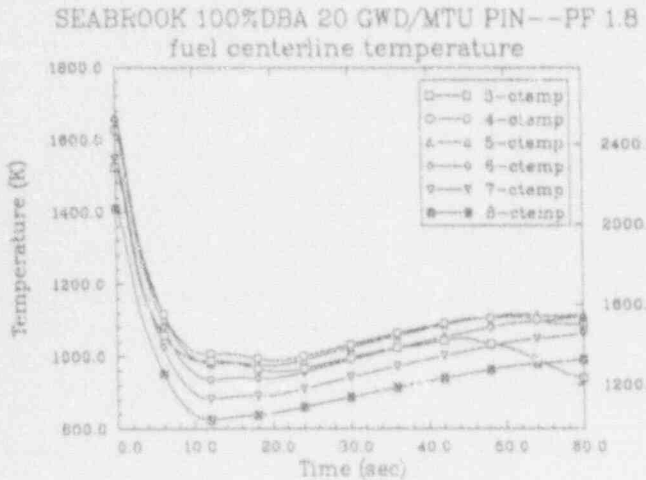


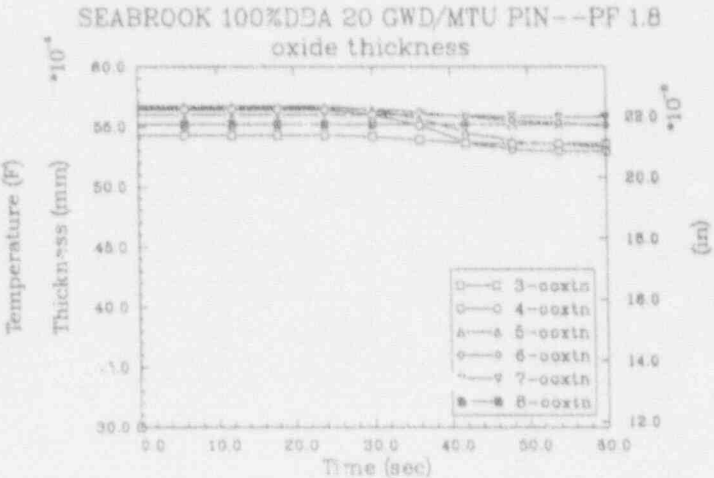

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

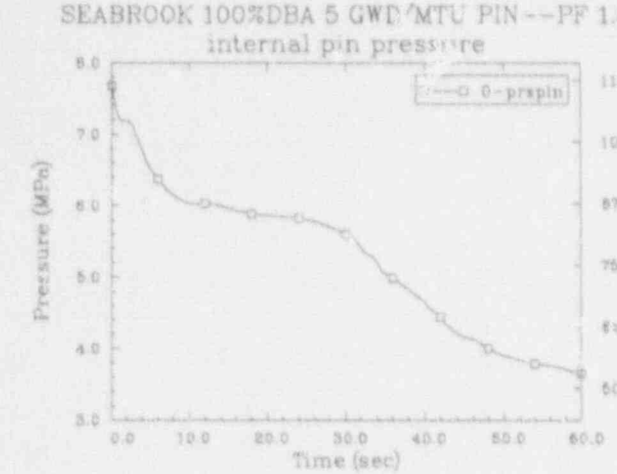

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

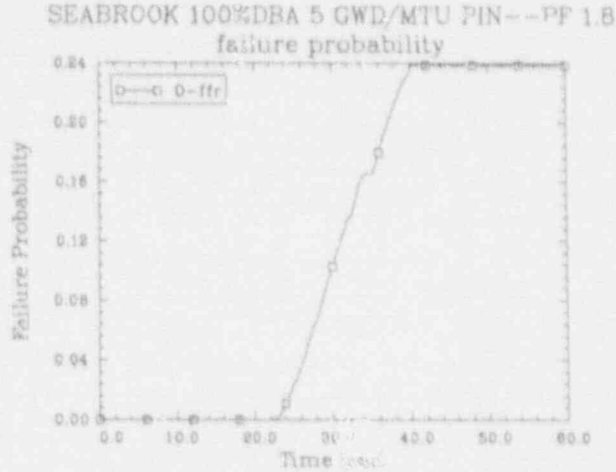

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

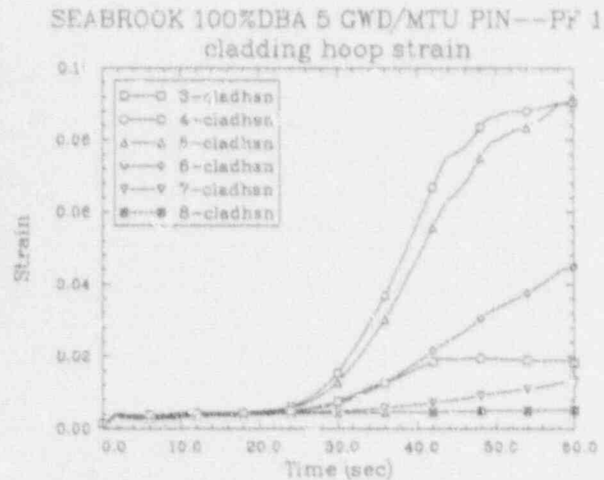

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

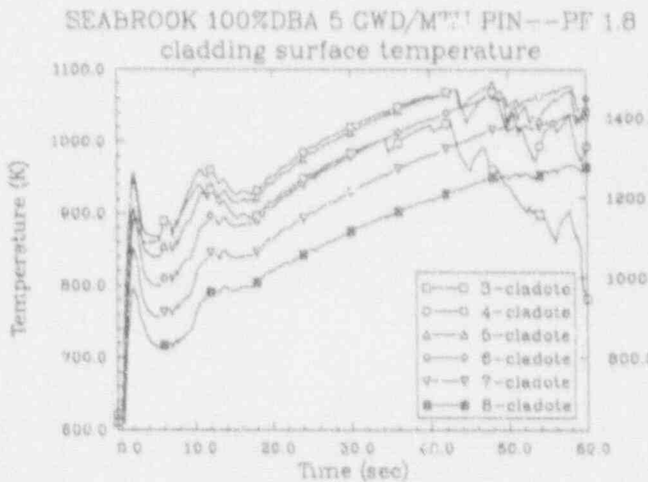

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

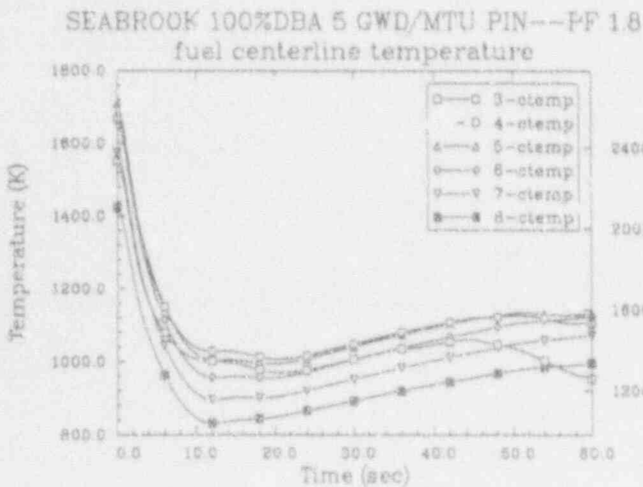

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

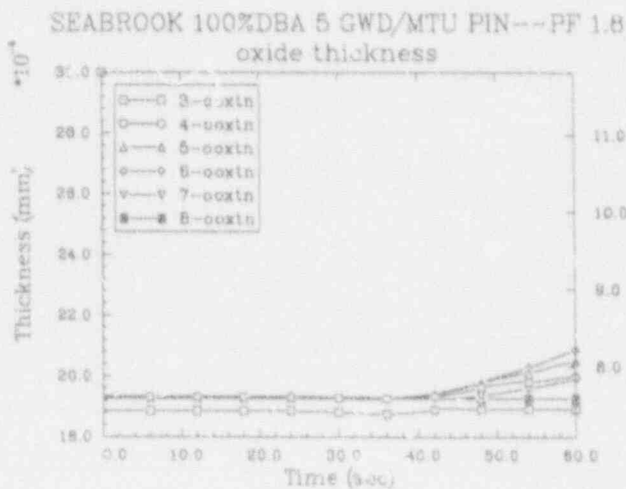

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability

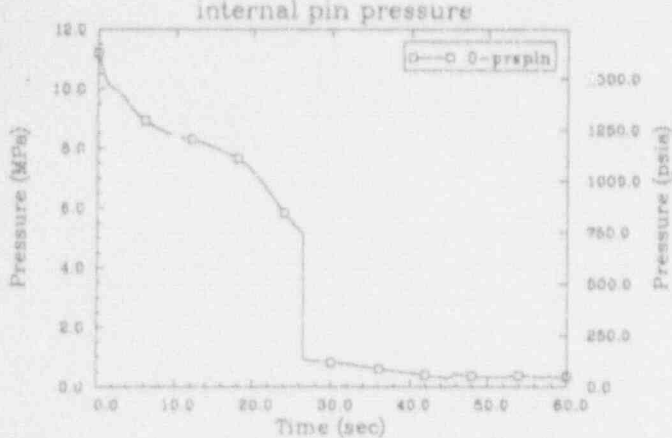

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 1.8
cladding hoop strain
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Time (sec)

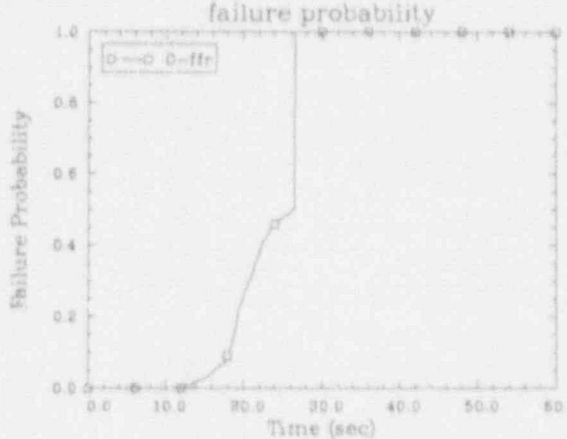

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 1.8
oxide thickness
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
(in)

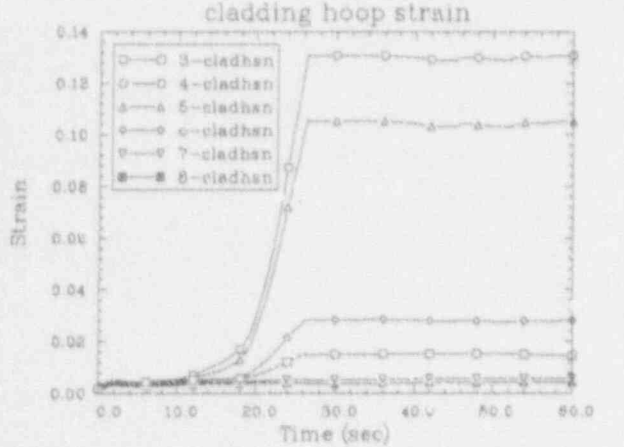
SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.32
internal pin pressure



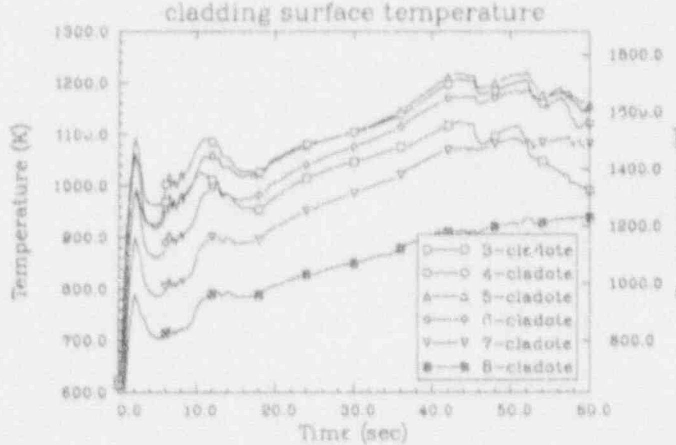
SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.32
failure probability



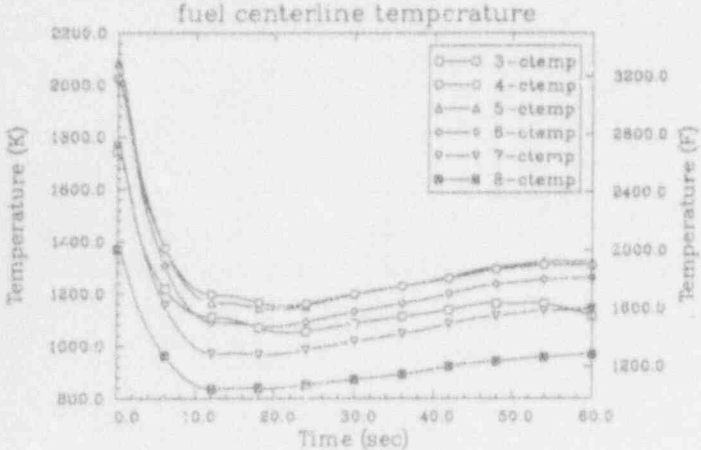
SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.32
cladding hoop strain



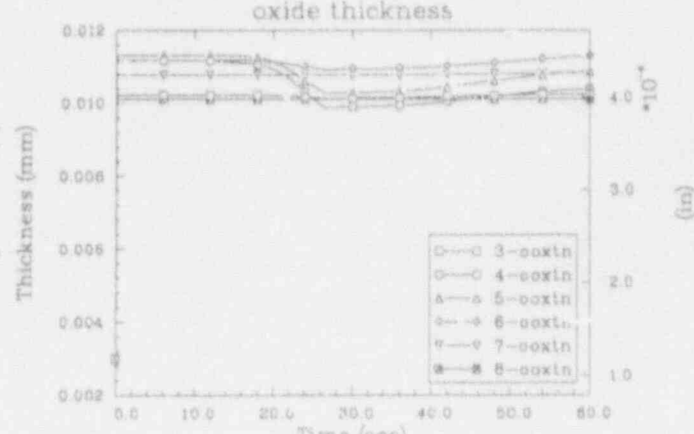
SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.32
cladding surface temperature

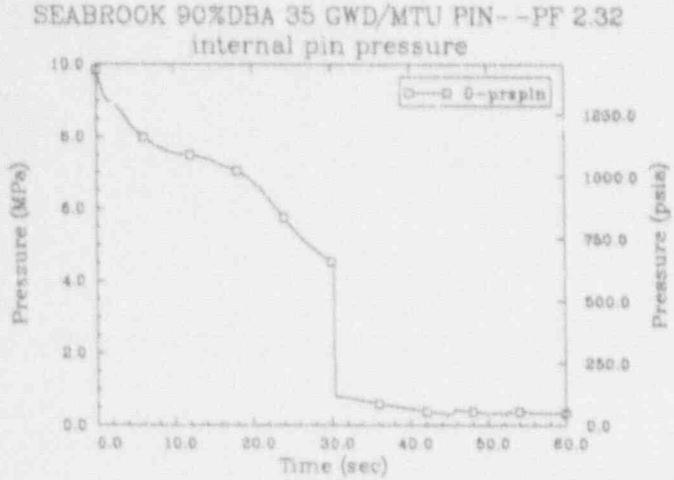


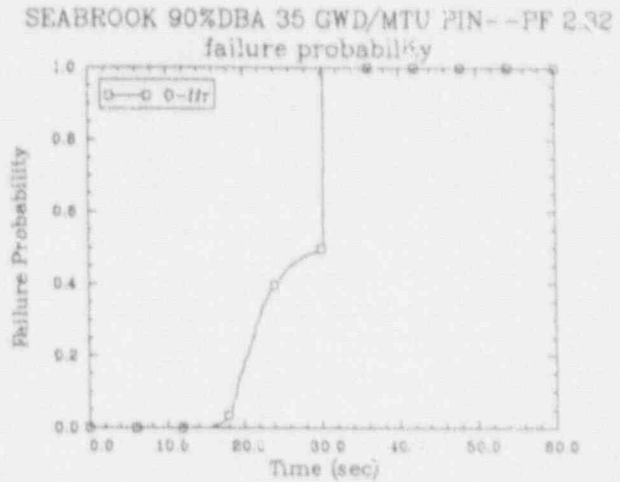
SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.32
fuel centerline temperature

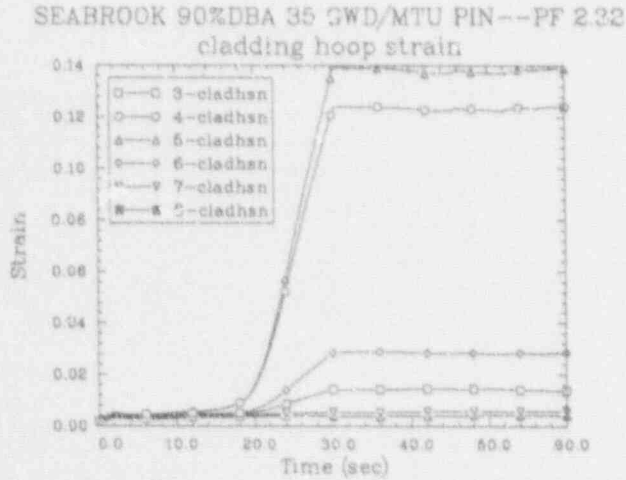


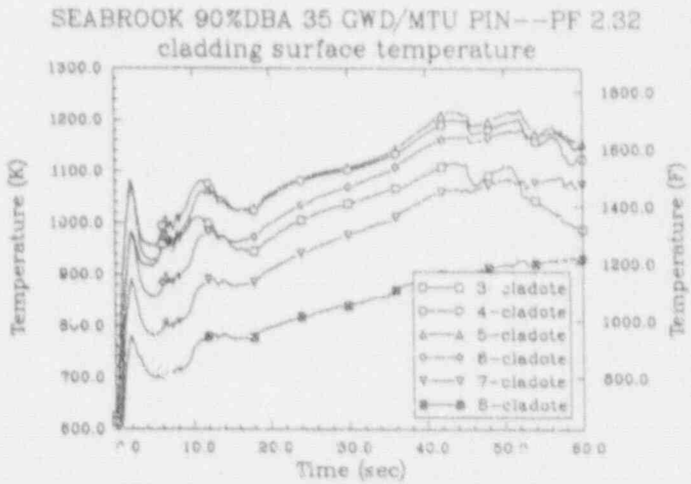
SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.32
oxide thickness

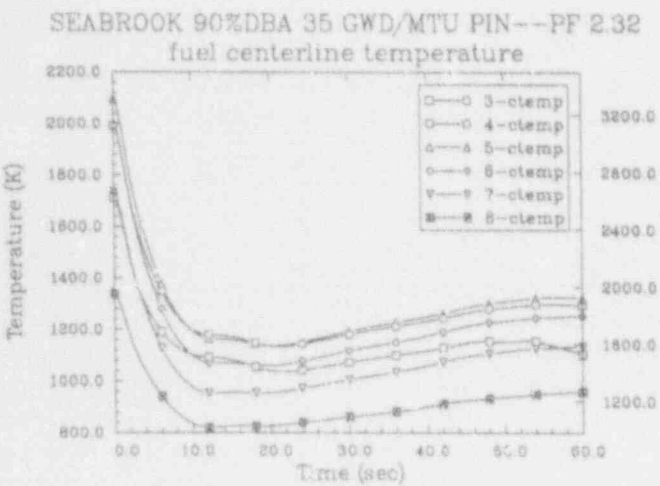


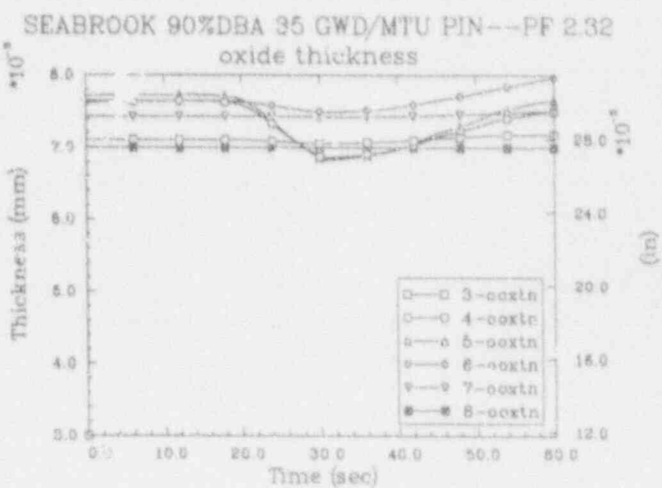

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.32
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

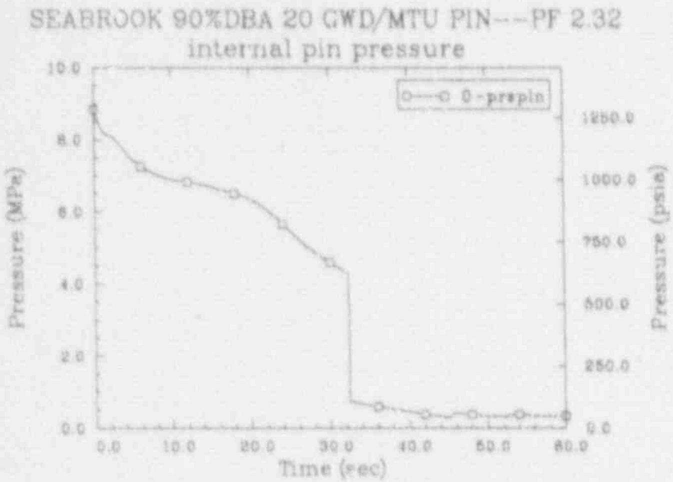

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.32
failure probability
Failure Probability
Time (sec)

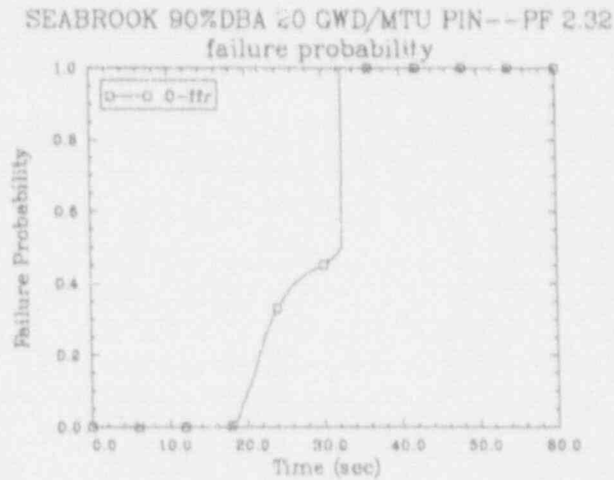

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
Strain
Time (sec)

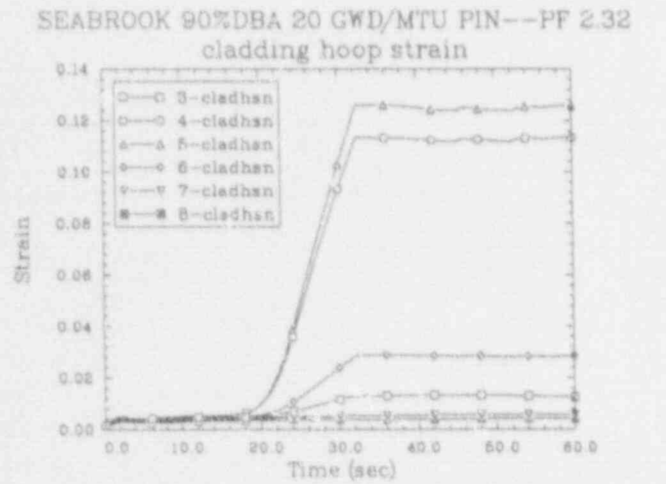

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.32
cladding surface temperature
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

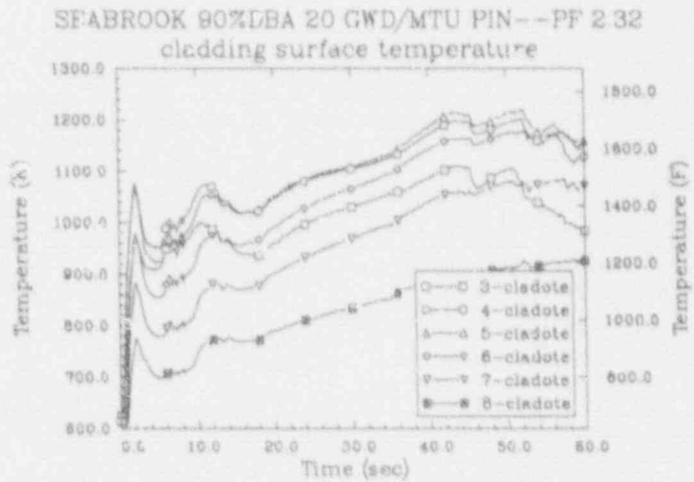

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

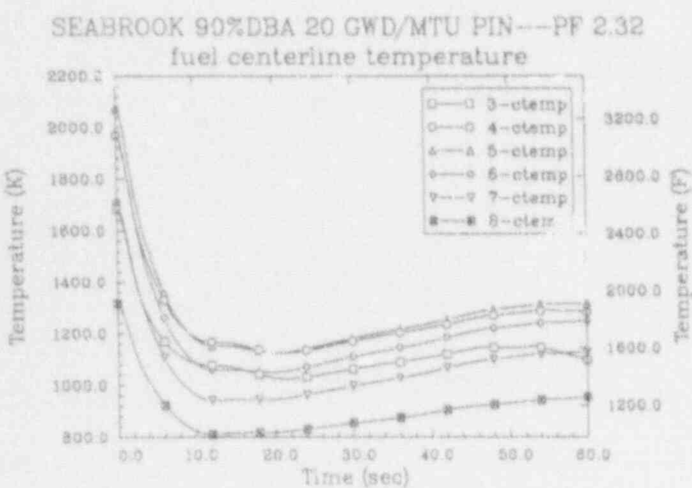

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.32
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

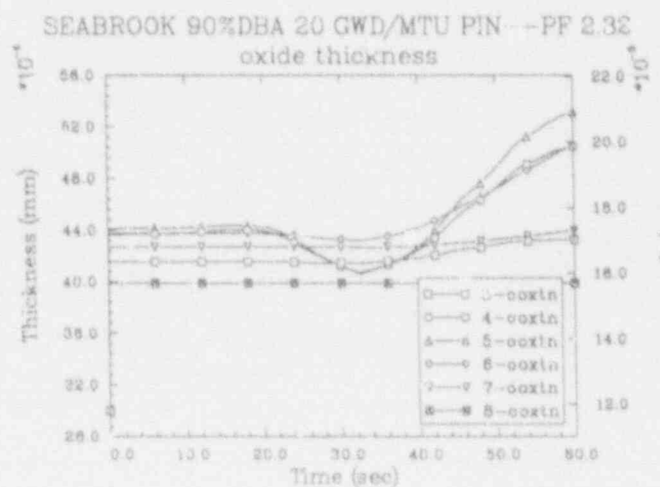

SEABROOK 90%DBA 20 GWD/MTU PIN---PF 2.32
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

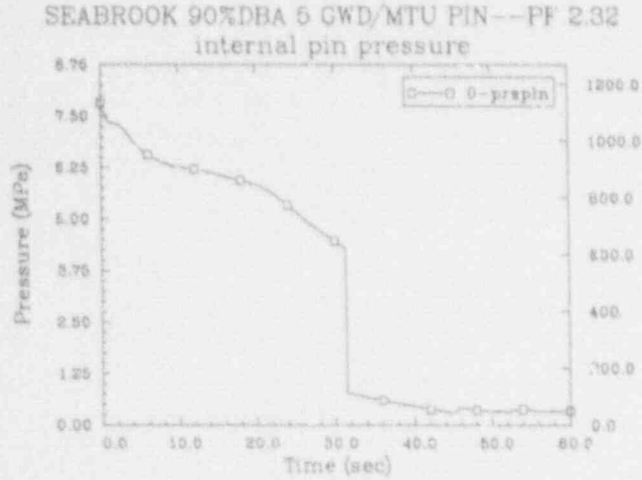

SEABROOK 90%DBA 20 GWD/MTU PIN---PF 2.32
failure probability
0-ffr
Failure Probability
Time (sec)

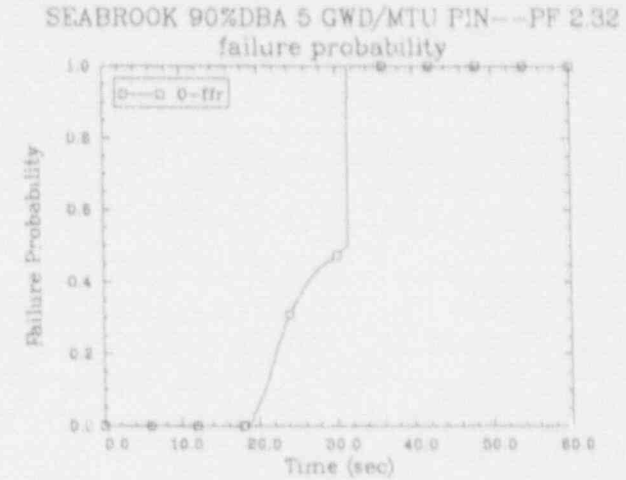

SEABROOK 90%DBA 20 GWD/MTU PIN---PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

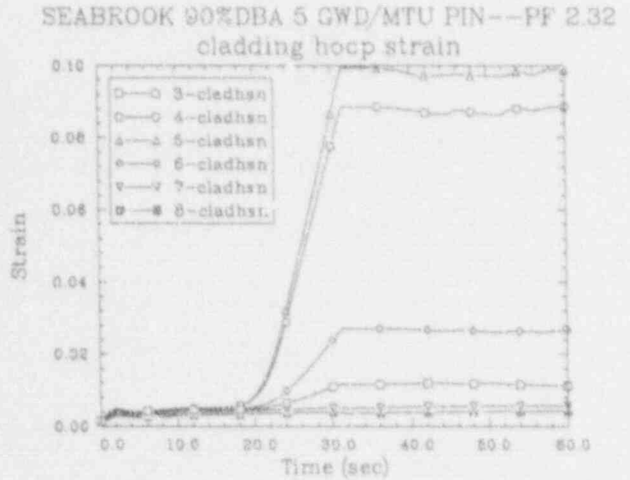

SEABROOK 90%DBA 20 GWD/MTU PIN---PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

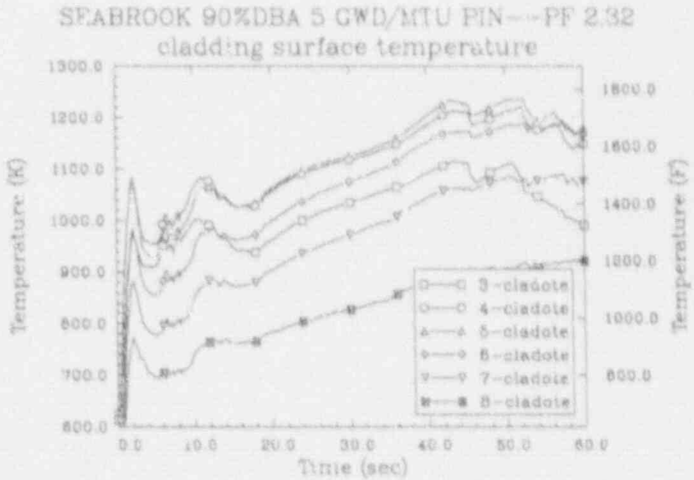

SEABROOK 90%DBA 20 GWD/MTU PIN---PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-cteir
Temperature (K)
Temperature (F)
Time (sec)

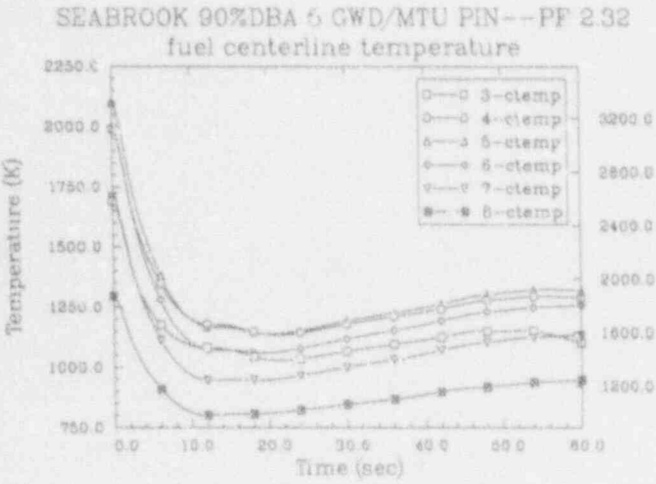

SEABROOK 90%DBA 20 GWD/MTU PIN---PF 2.32
oxide thickness
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

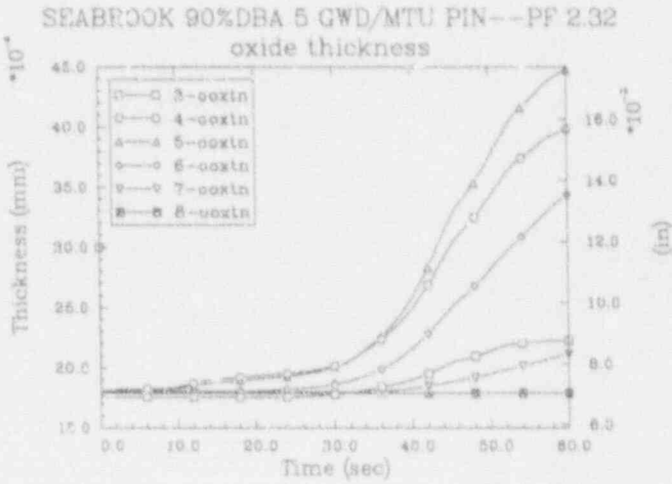

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.32
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

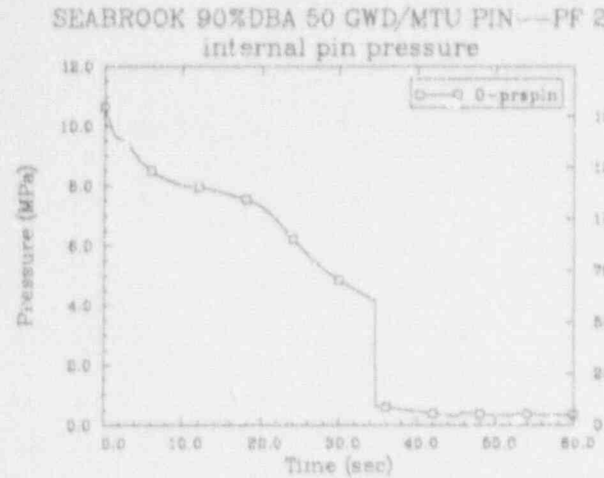

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.32
failure probability
0-ffr
Failure Probability
Time (sec)

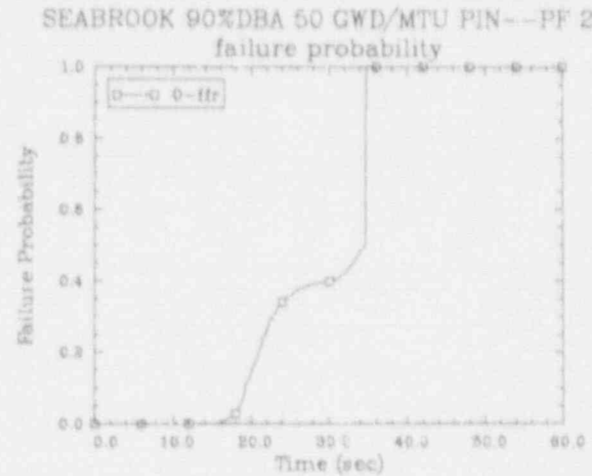

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

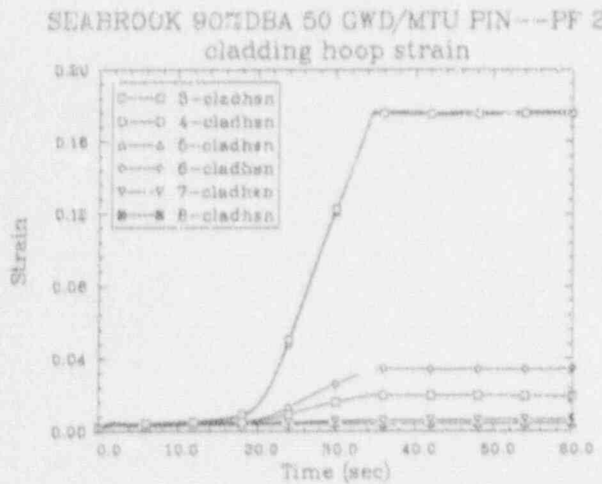

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

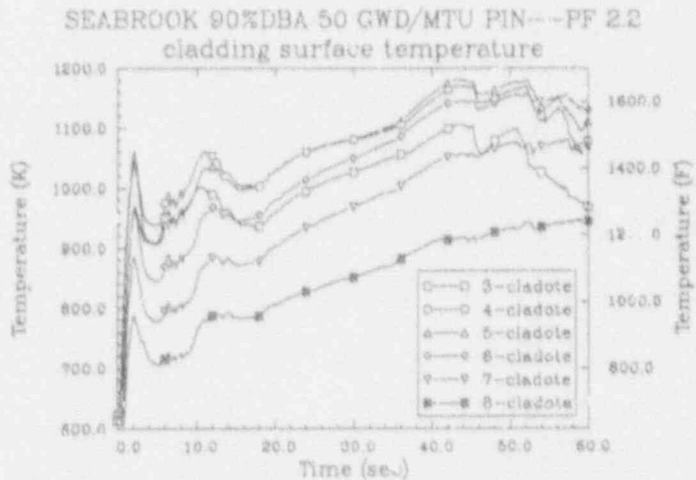

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

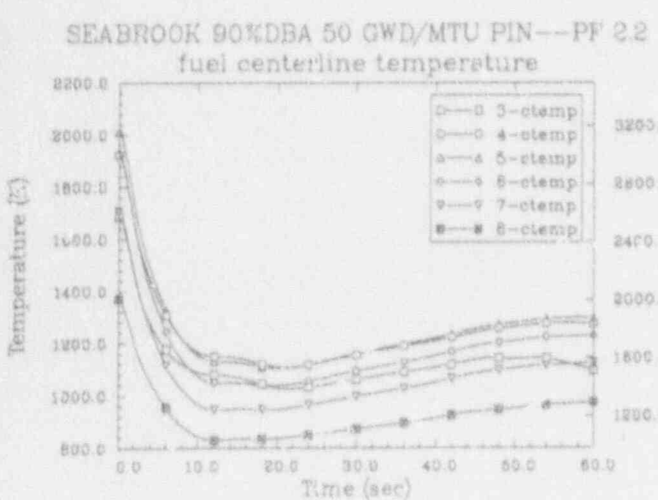

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.32
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

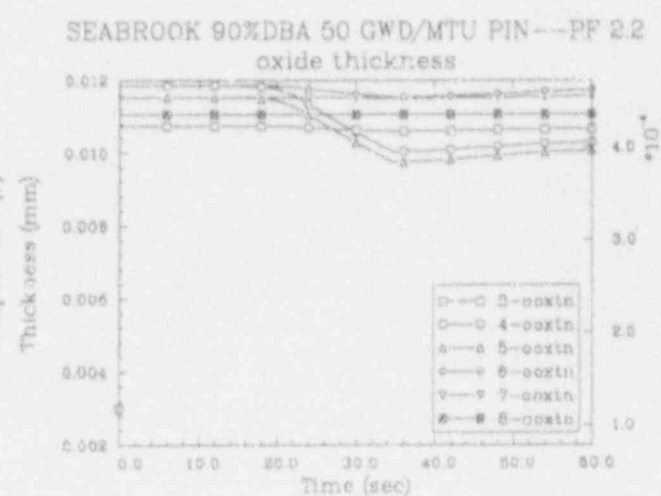

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

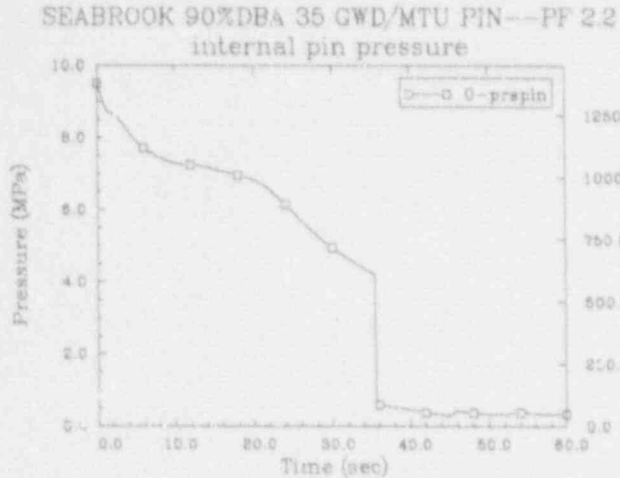

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

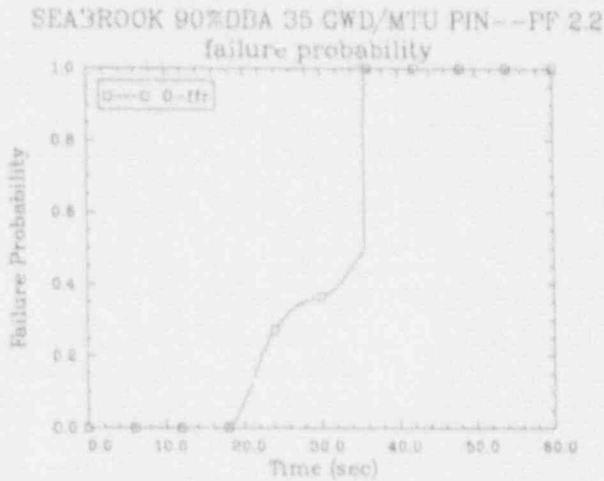

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

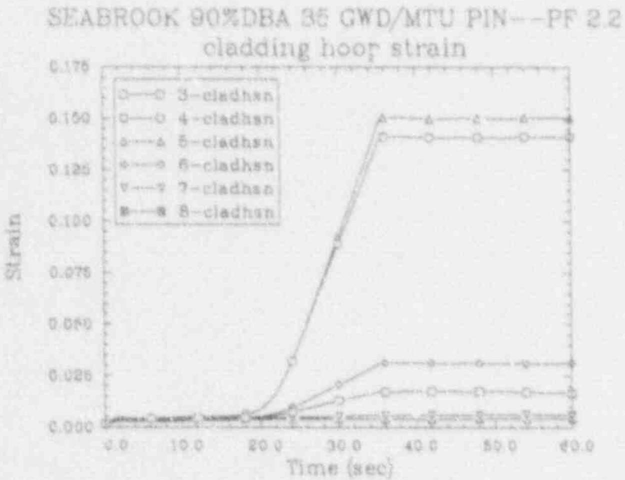

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)

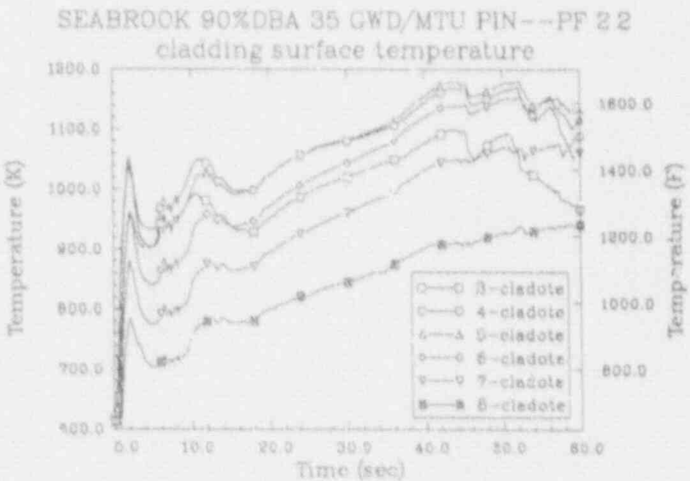

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

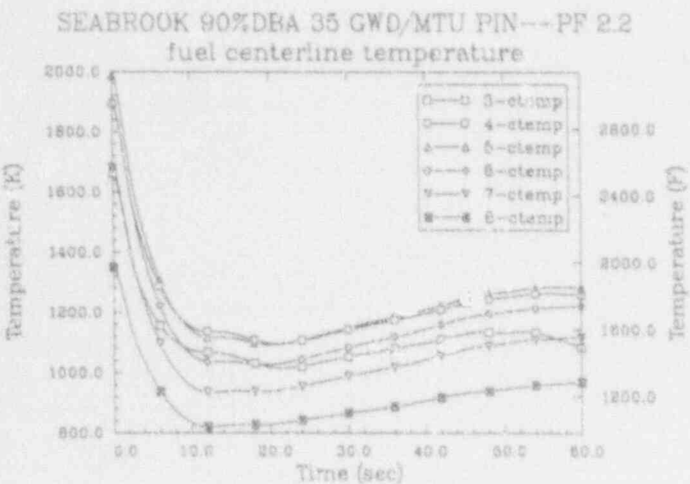

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
(in)
Time (sec)

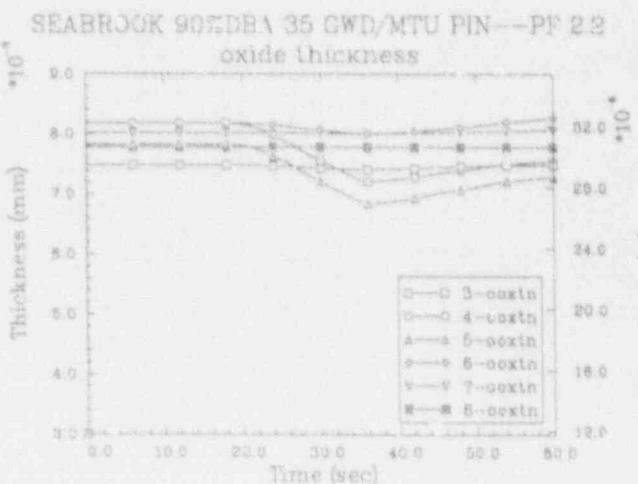

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

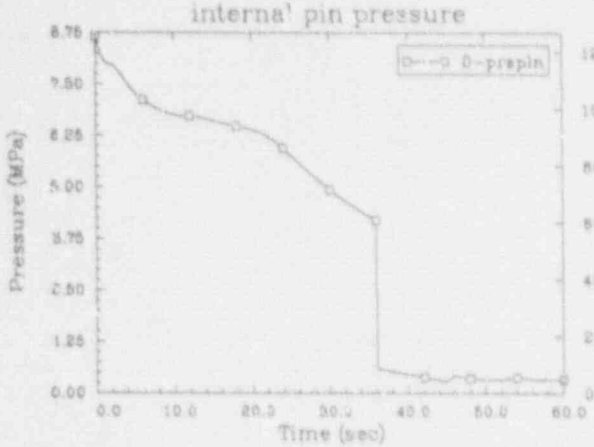

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

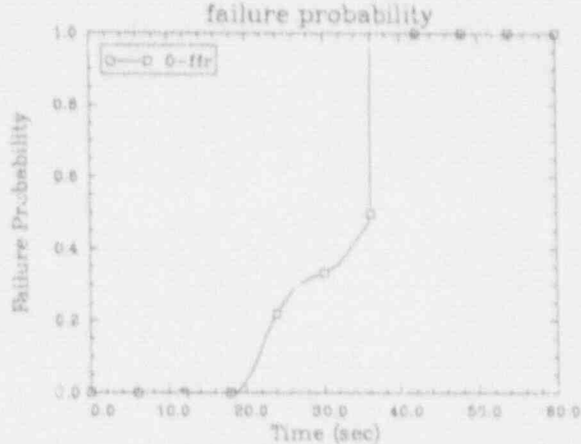

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

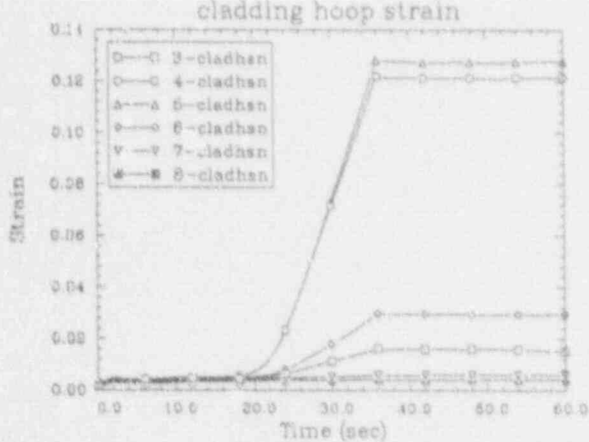
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure



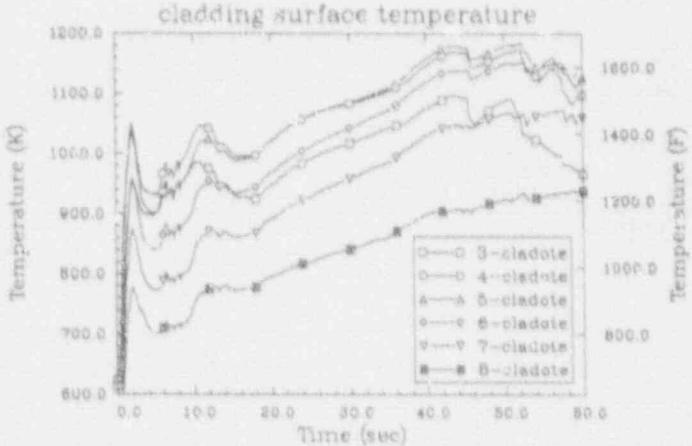
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.2
failure probability



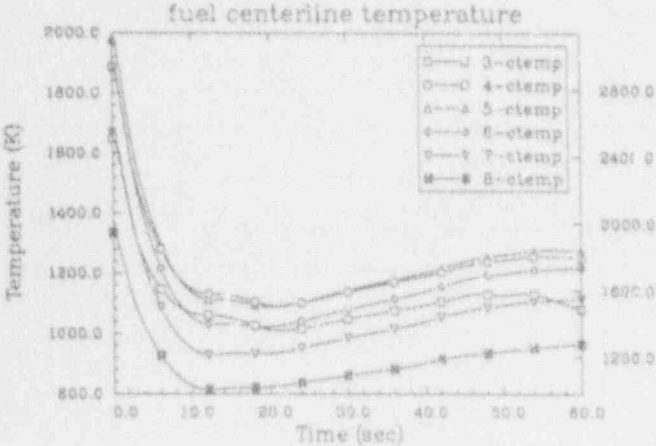
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain



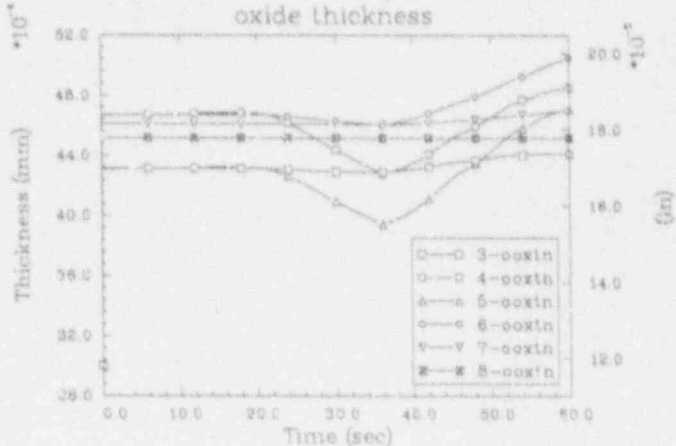
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.2
cladding surface temperature

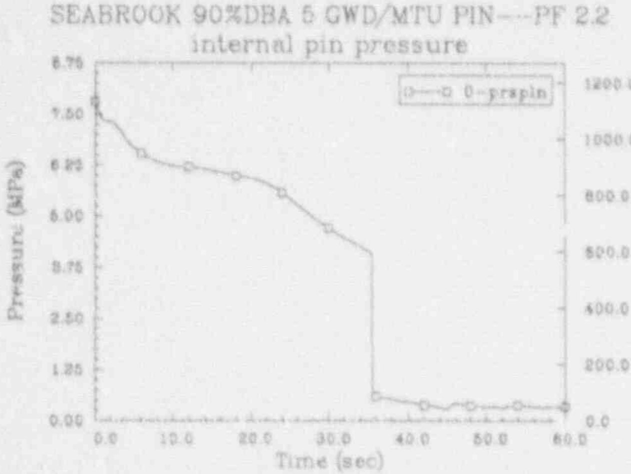


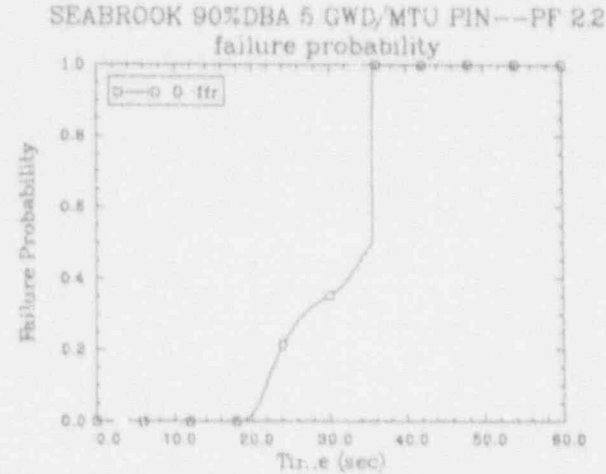
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.2
fuel centerline temperature

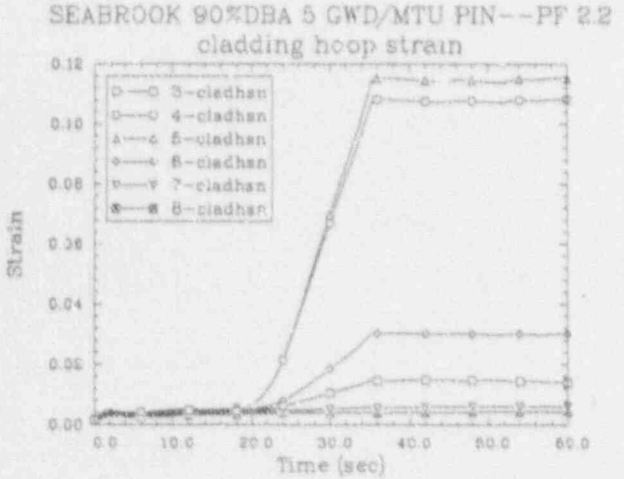


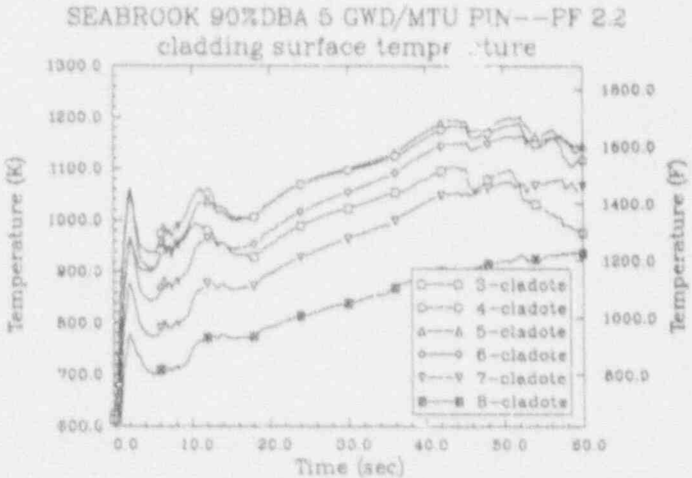
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.2
oxide thickness

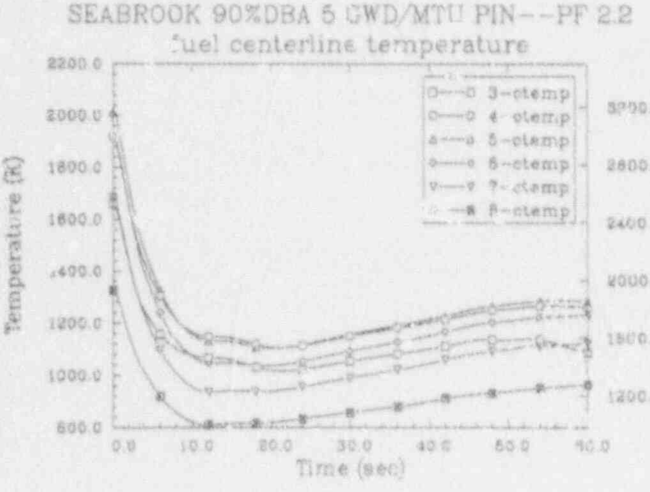


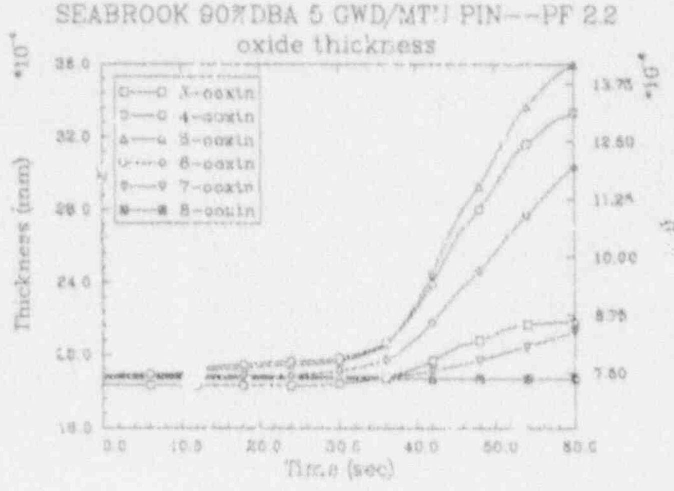

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

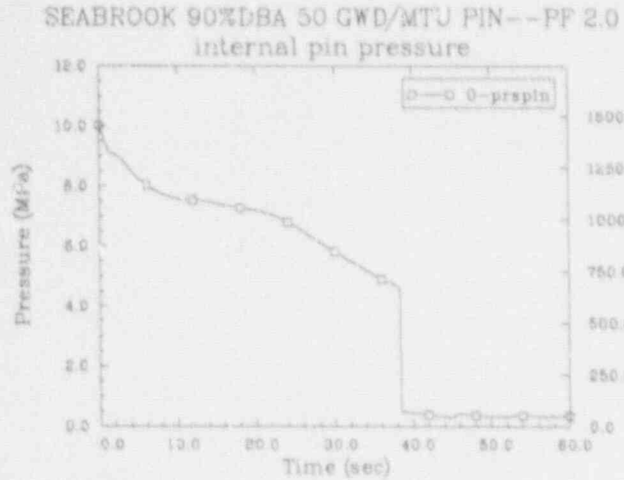

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

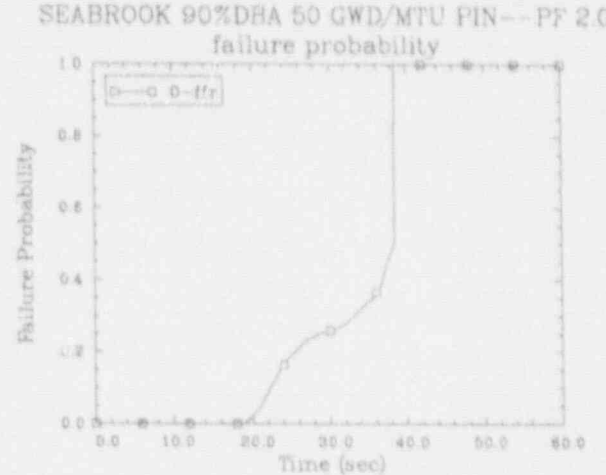

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

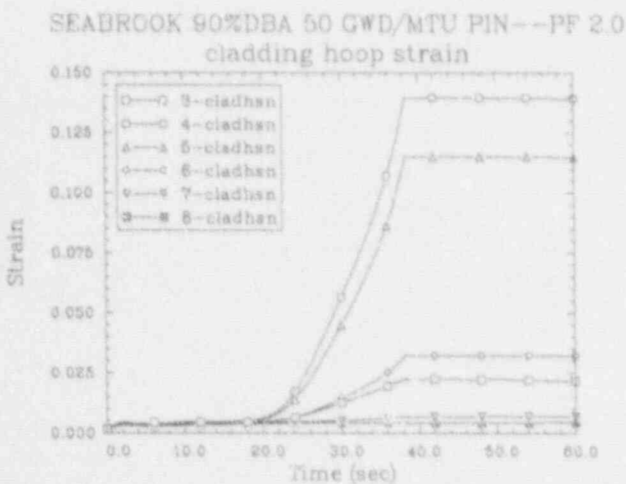

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.2
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

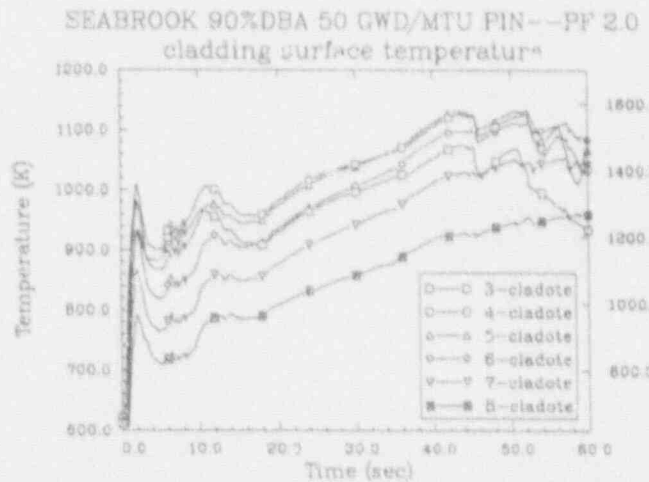

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.2
3-ctemp
5-ctemp
Temperature (K)
Temperature (F)
Time (sec)

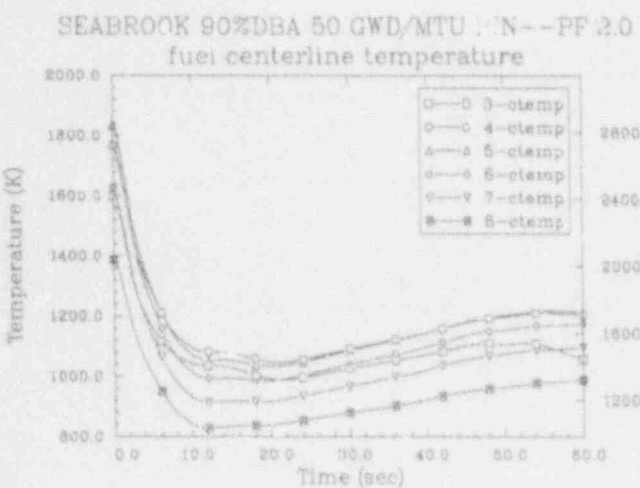

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.2
oxide thickness
4-ooxin
6-ooxin
7-ooxin
8-ooxin
Time (sec)

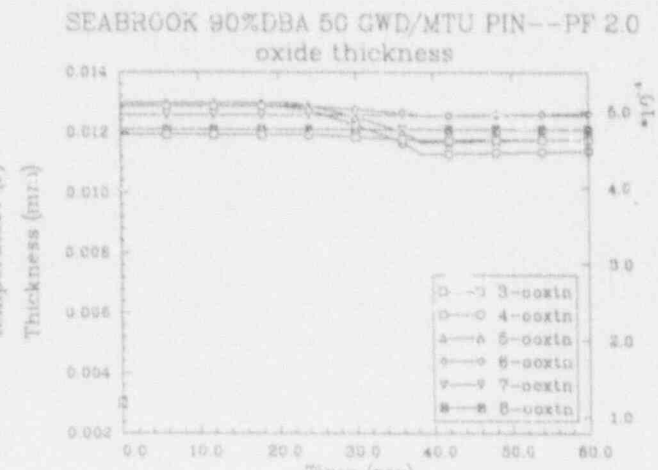

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

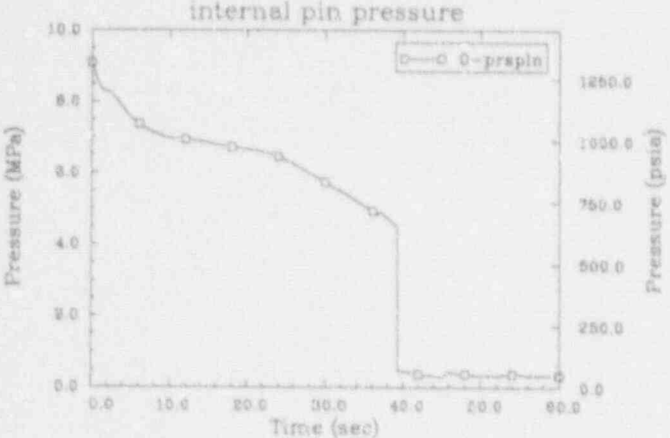

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

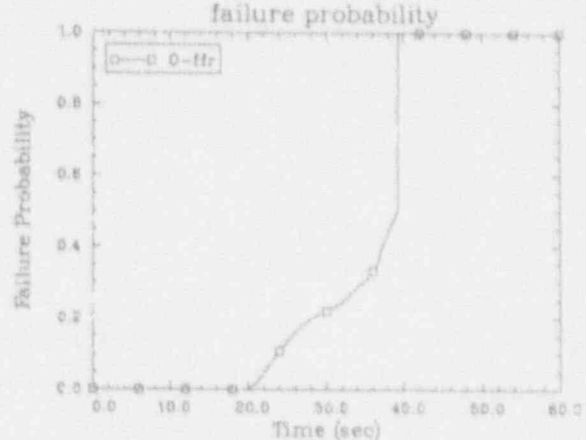

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 90%DBA 50 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

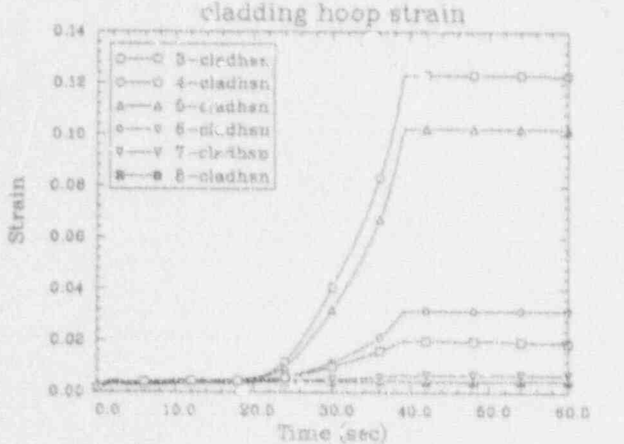
SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure



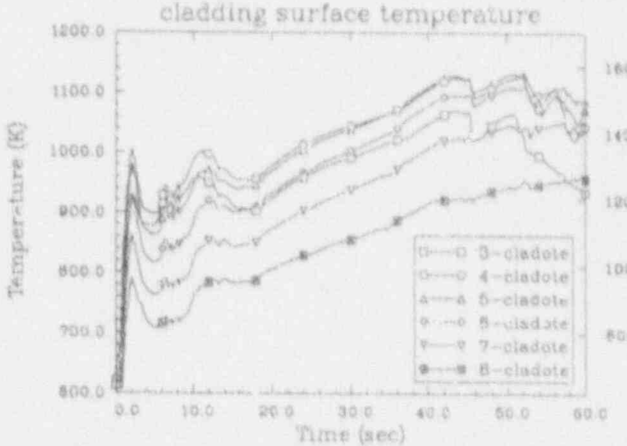
SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.0
failure probability



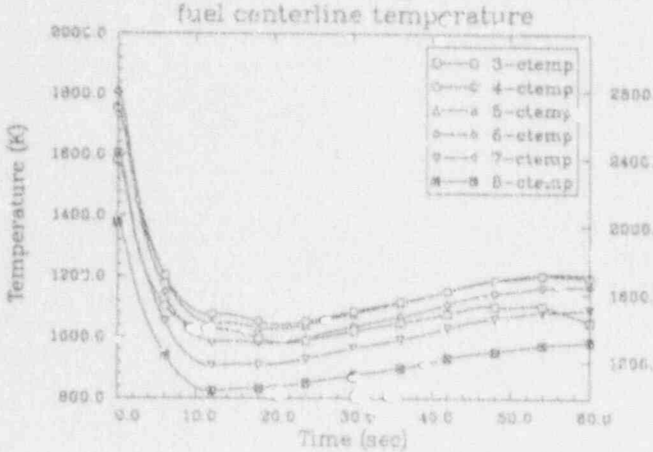
SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain



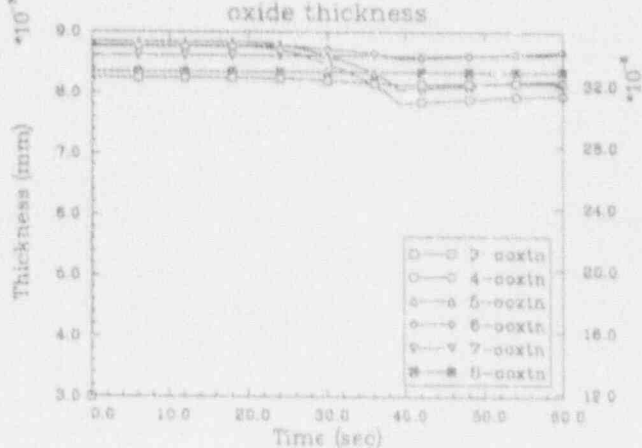
SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature



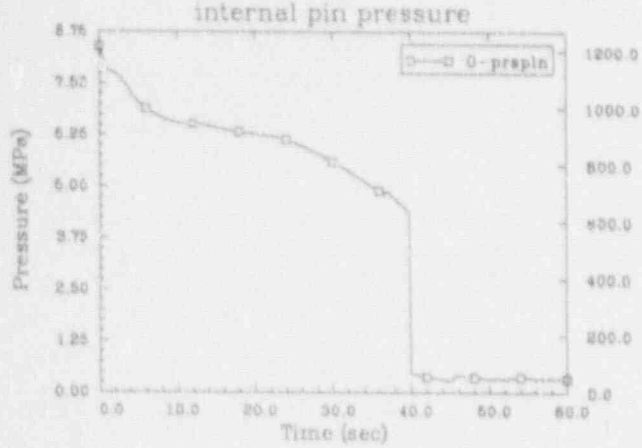
SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature



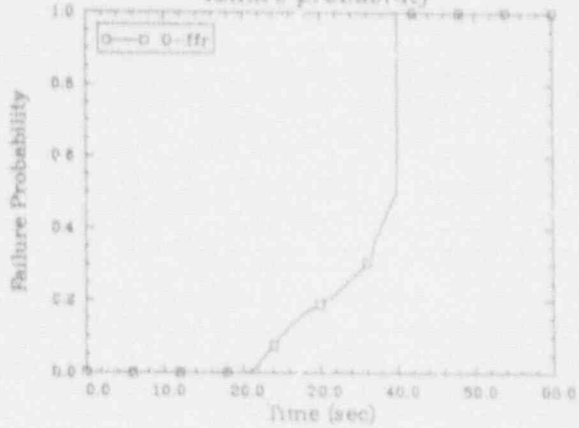
SEABROOK 90%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness



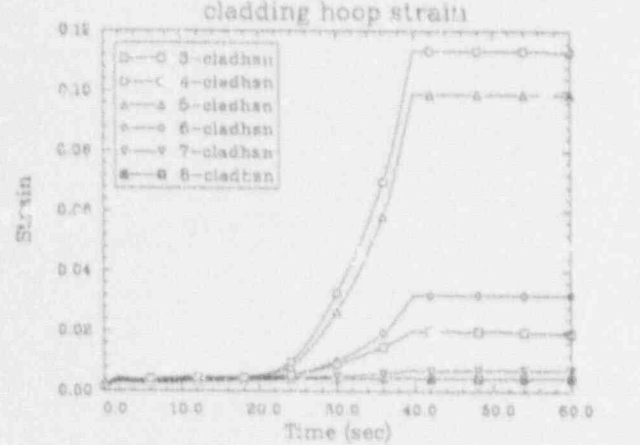
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.0
internal pin pressure



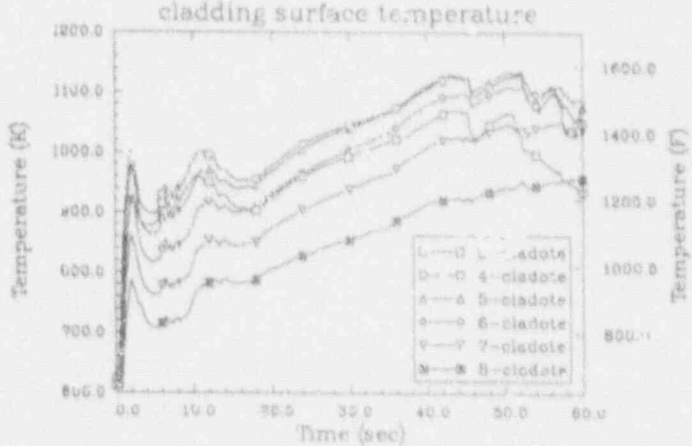
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.0
failure probability



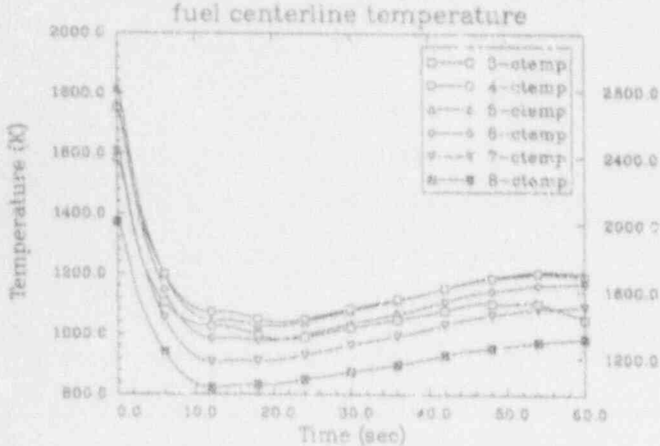
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.0
cladding hoop strain



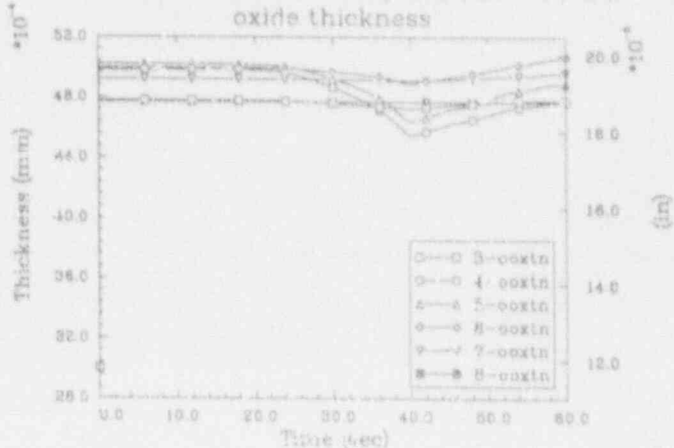
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.0
cladding surface temperature

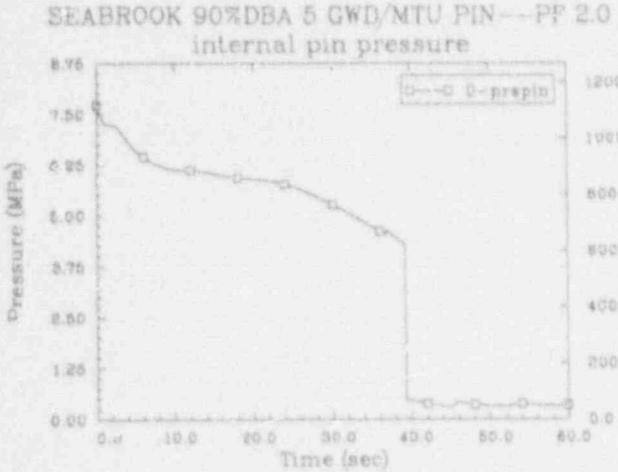


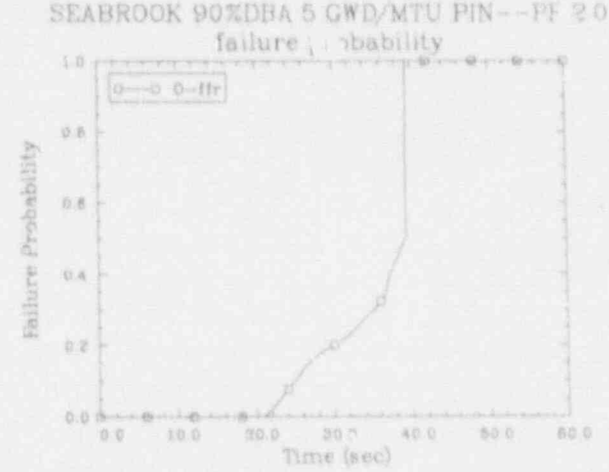
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.0
fuel centerline temperature

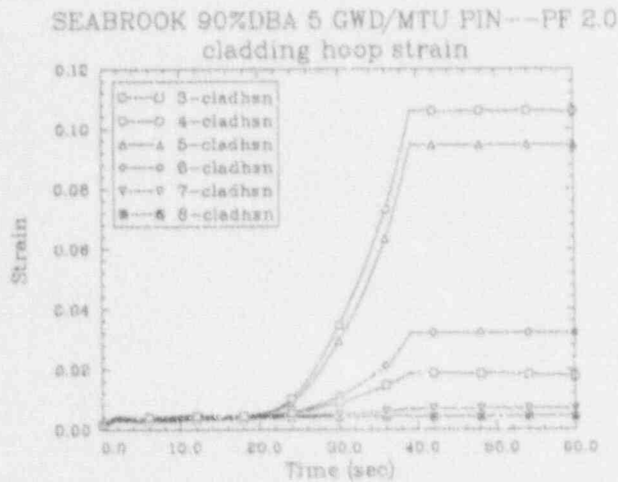


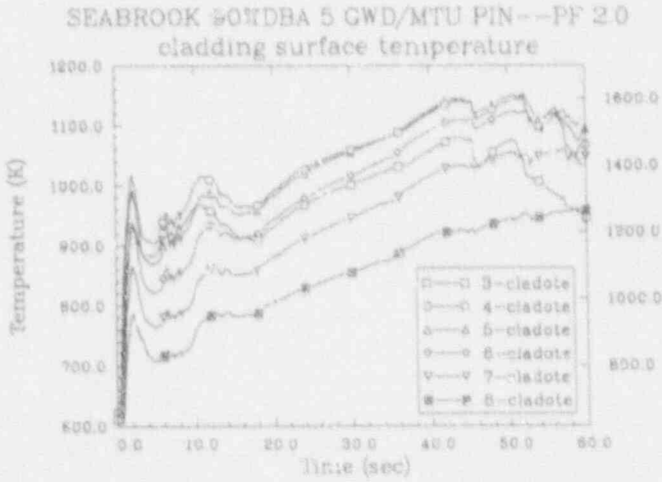
SEABROOK 90%DBA 20 GWD/MTU PIN--PF 2.0
oxide thickness

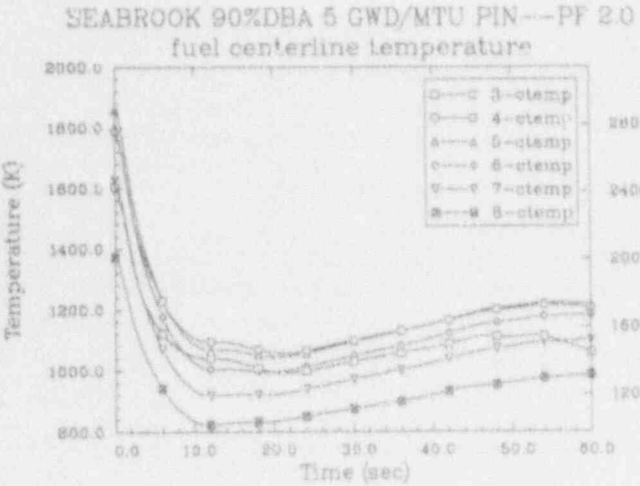


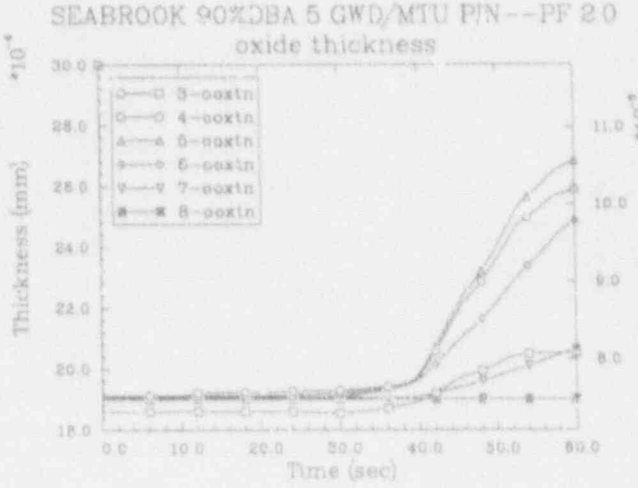

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

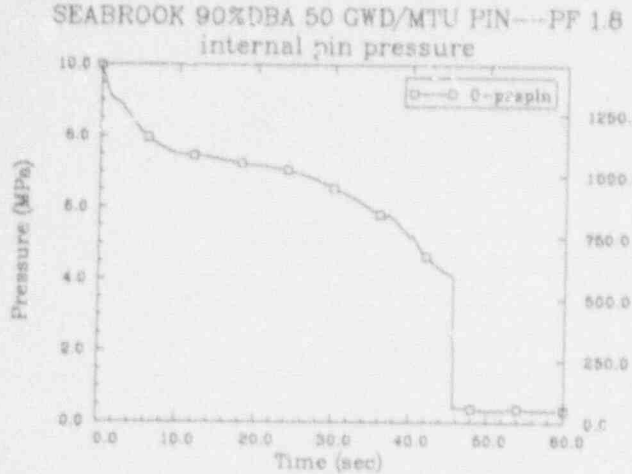

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.0
0-ffr
Failure Probability
Time (sec)

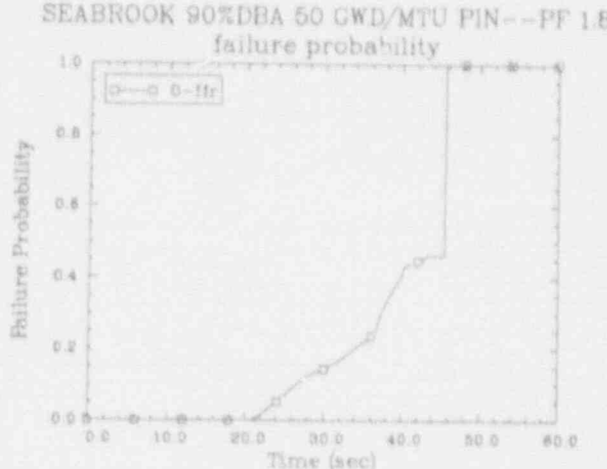

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

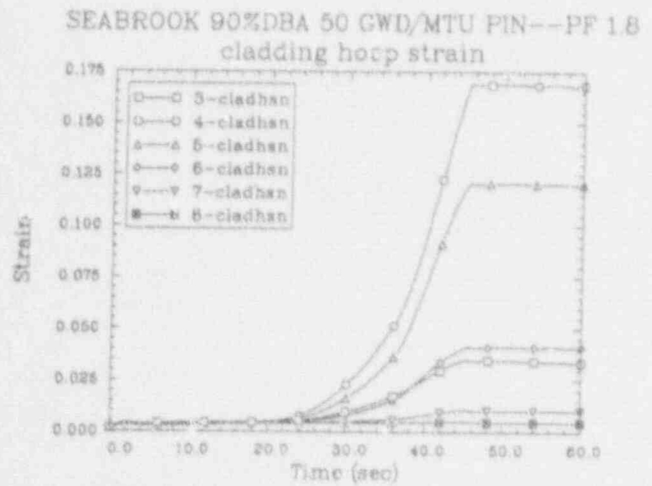

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Temperature (F)

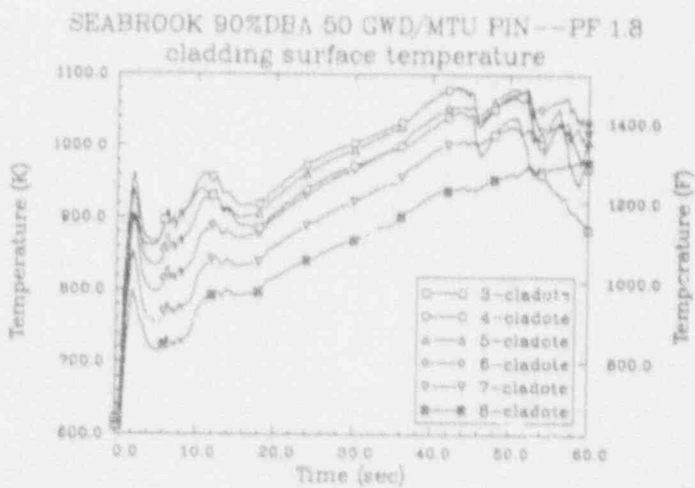

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

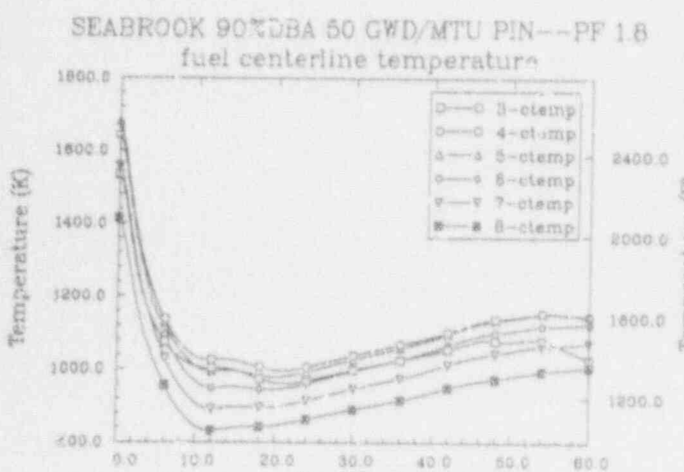

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

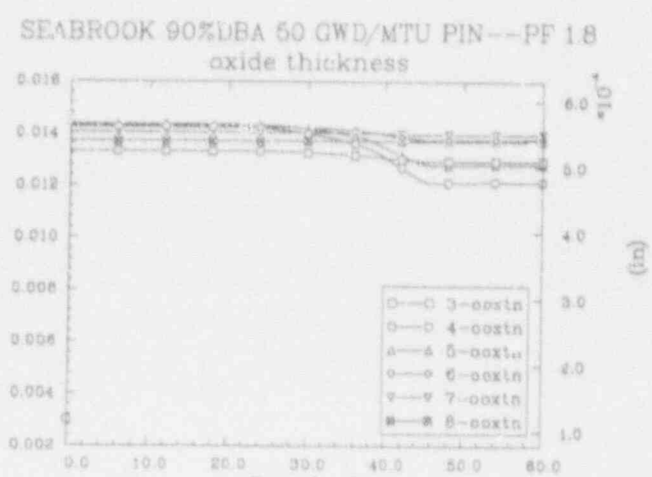

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

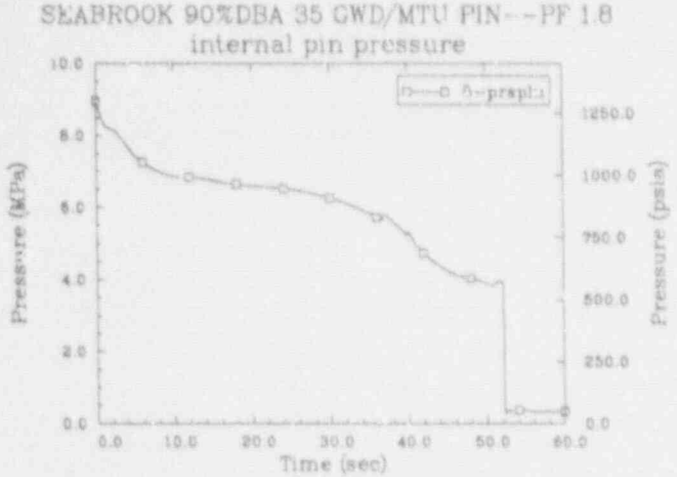

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

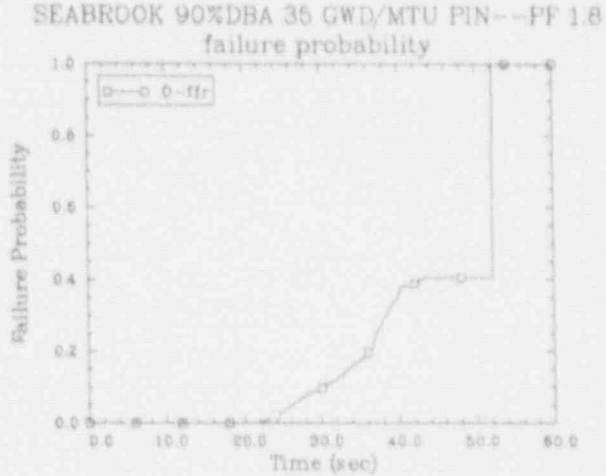

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

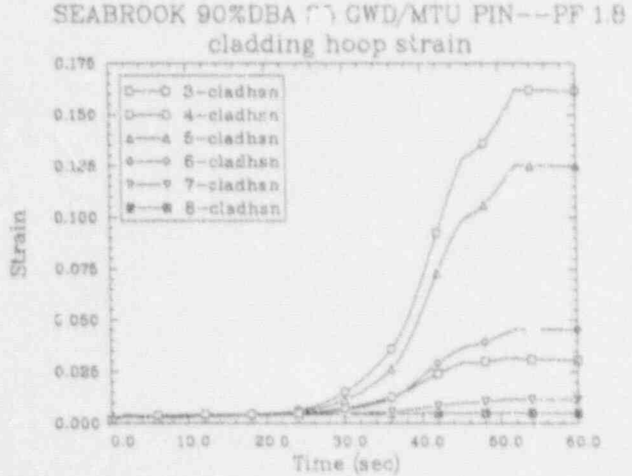

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

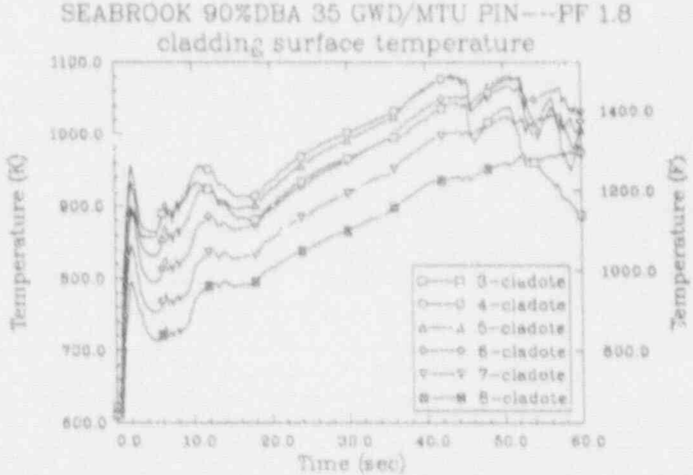

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

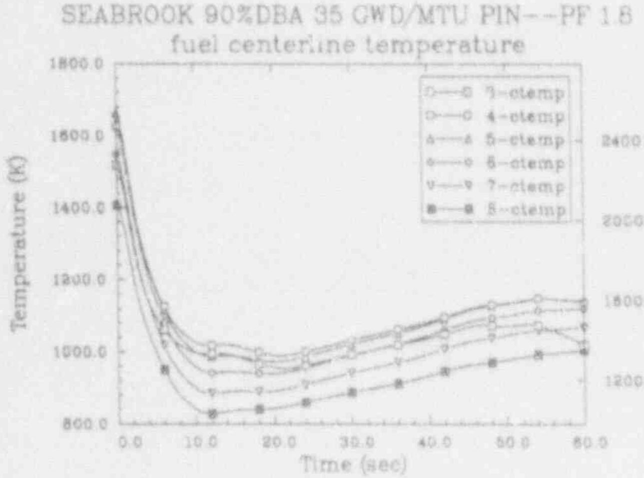

SEABROOK 90%DBA 50 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

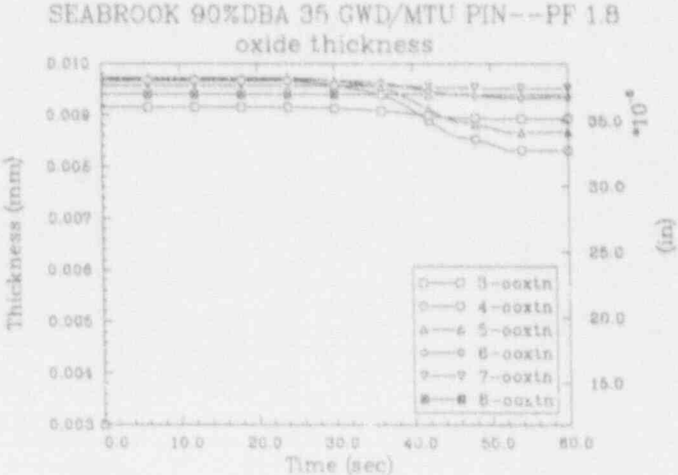

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 1.8
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

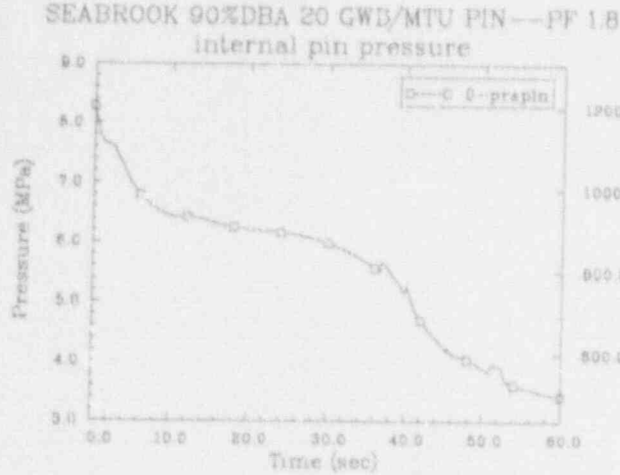

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 1.8
failure probability
Failure Probability
Time (sec)

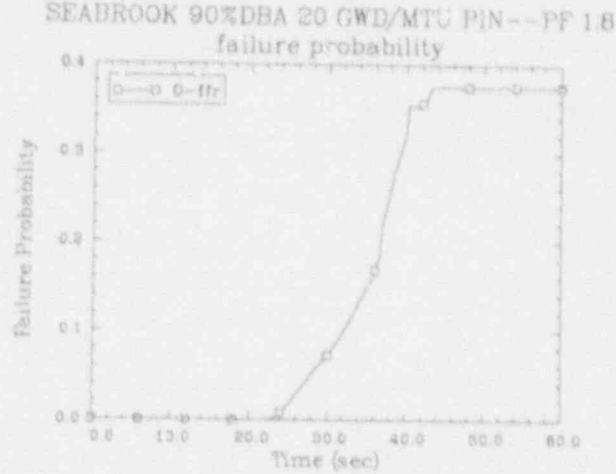

cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

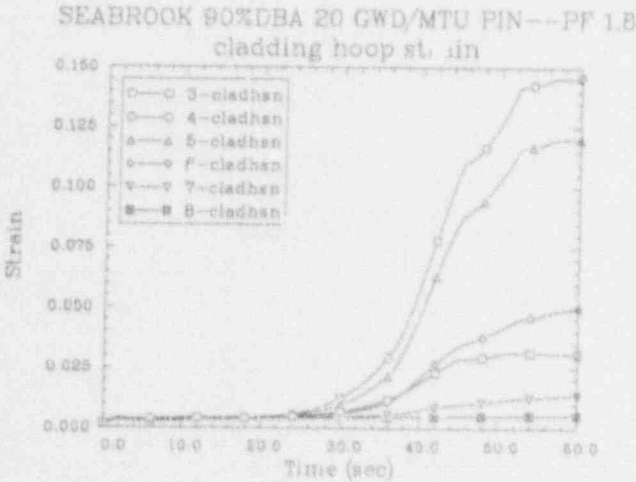

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 1.8
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Time (sec)

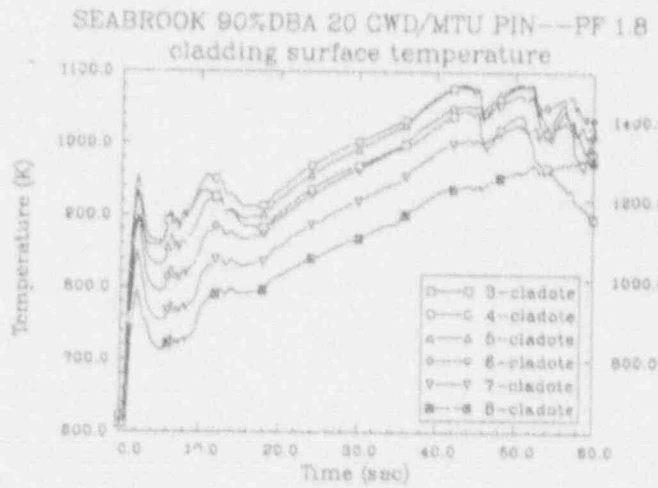

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 1.8
fuel centerline temperature
4-ctemp
5-ctemp
6-ctemp
7-ctemp
Temperature (K)
Temperature (F)
Time (sec)

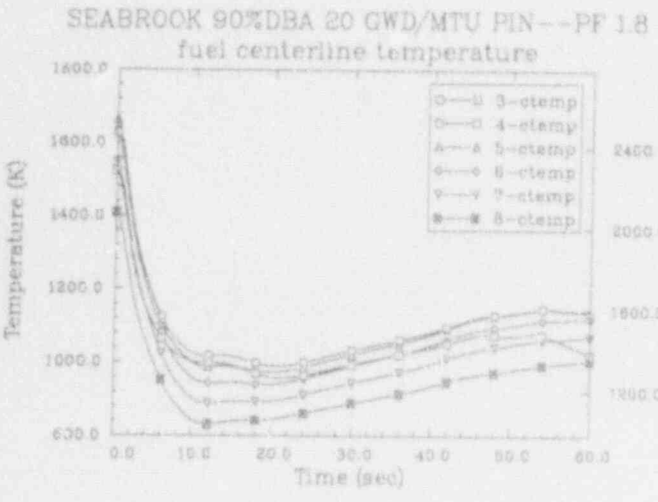

SEABROOK 90%DBA 35 GWD/MTU PIN--PF 1.8
oxide thickness
Thickness (mm)
(in)
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Time (sec)

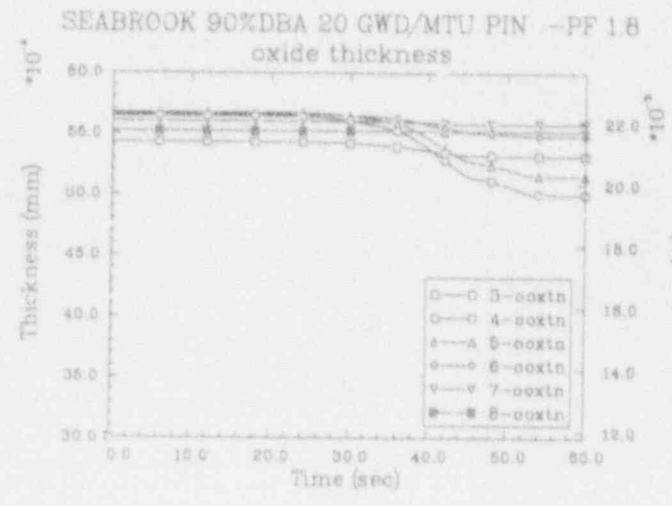

SEABROOK 90%DBA 20 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

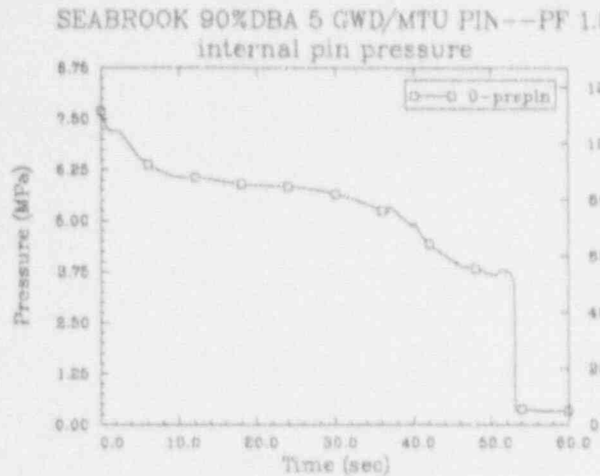

SEABROOK 90%DBA 20 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

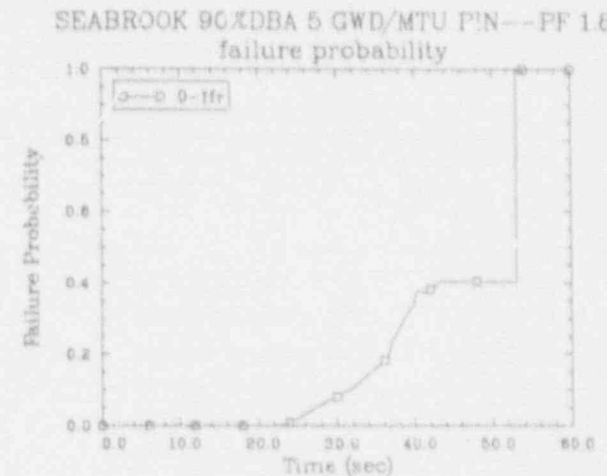

SEABROOK 90%DBA 20 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

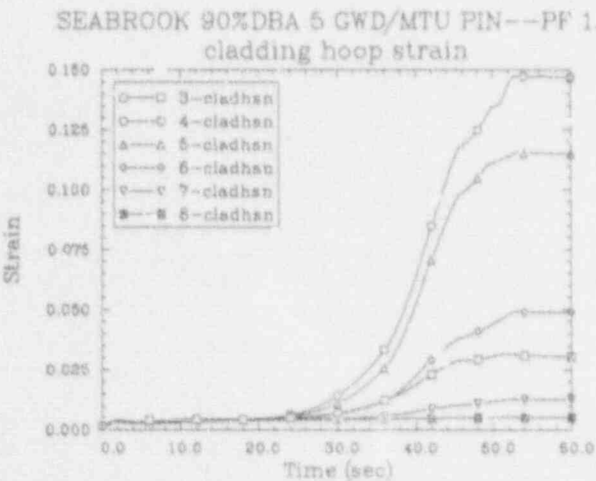

SEABROOK 90%DBA 20 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

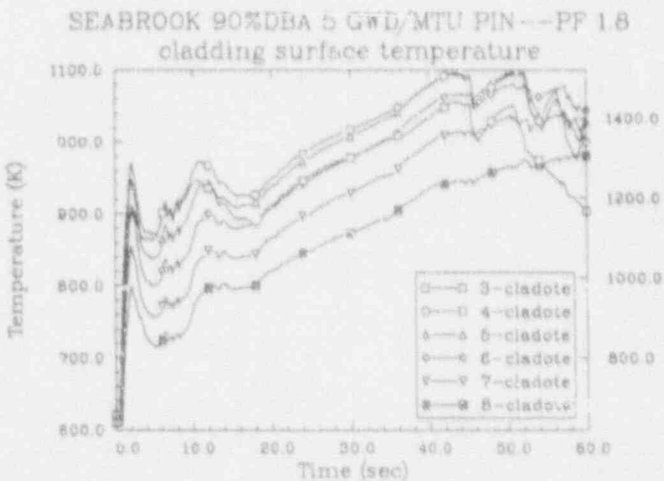

SEABROOK 90%DBA 20 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

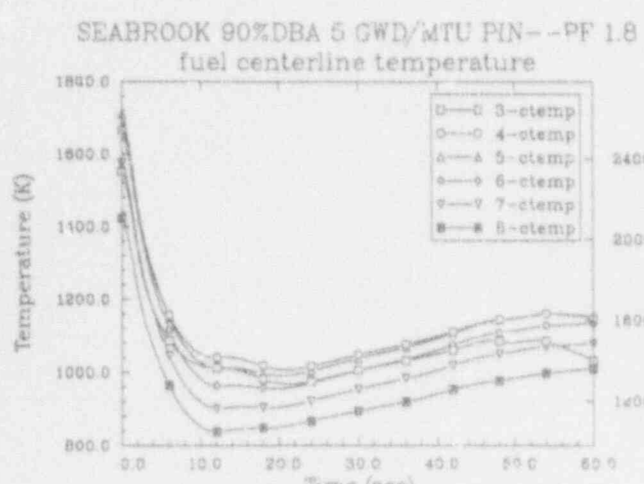

SEABROOK 90%DBA 20 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

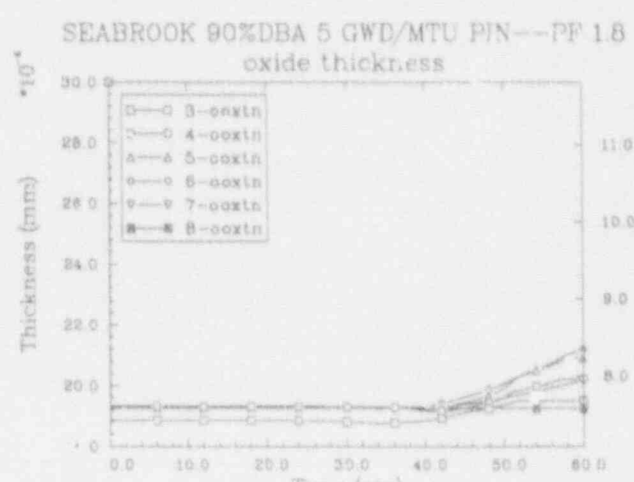

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

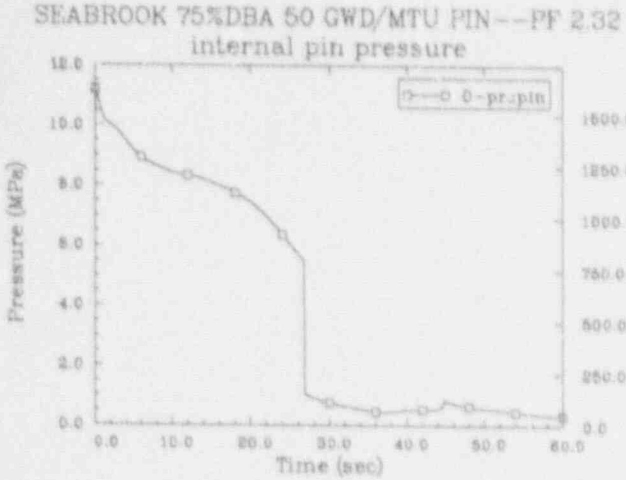

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

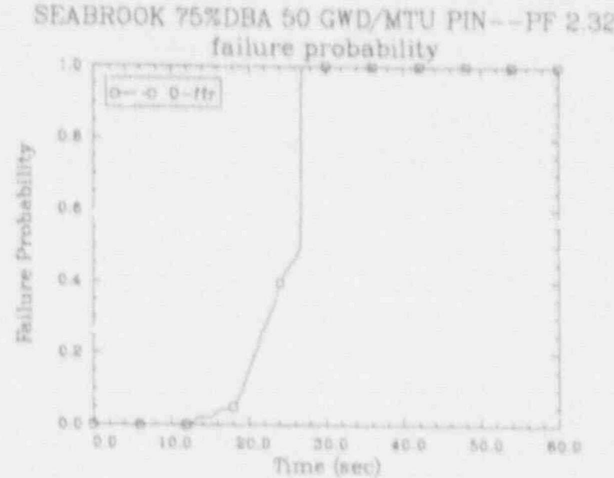

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

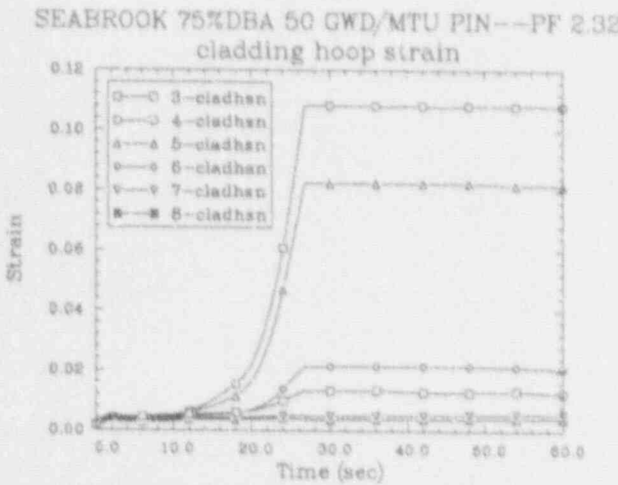

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

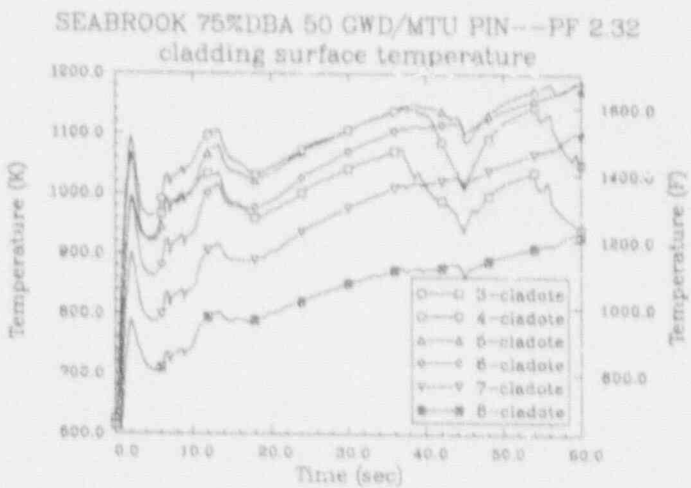

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

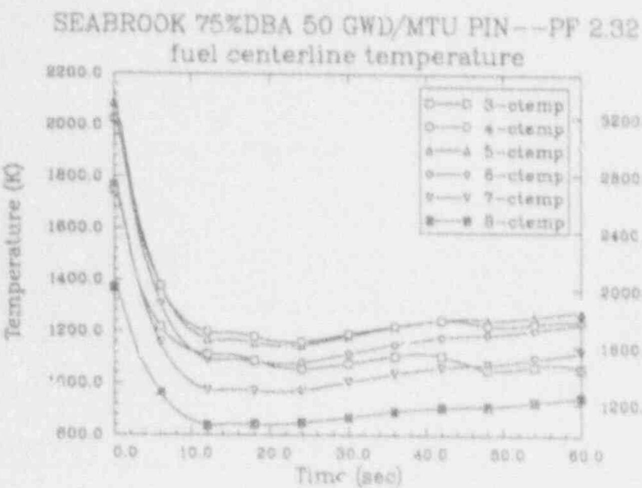

SEABROOK 90%DBA 5 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
Time (sec)

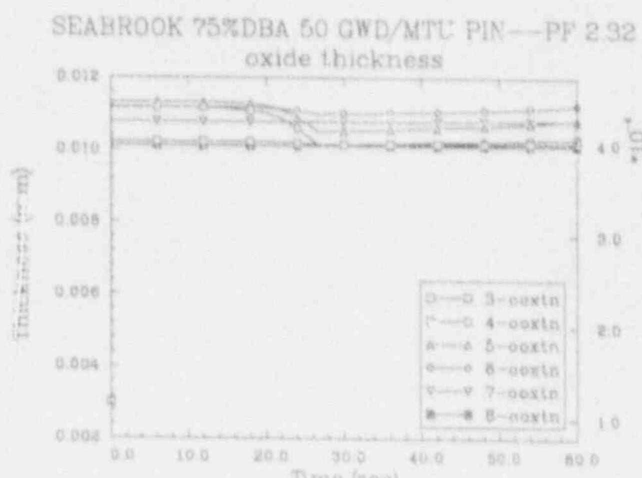

SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.32
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin


SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.32
failure probability
Failure Probability
Time (sec)

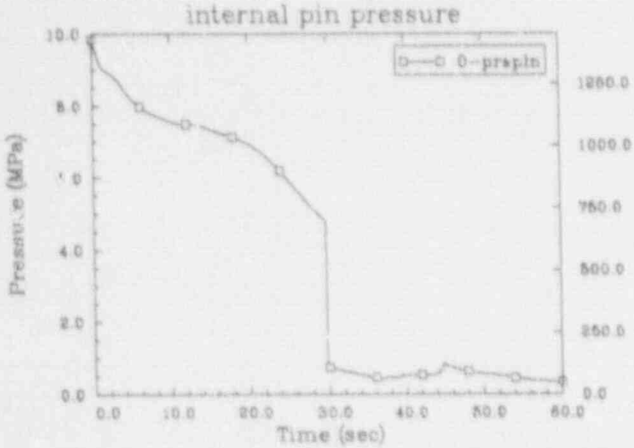

SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.32
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn


SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.32
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

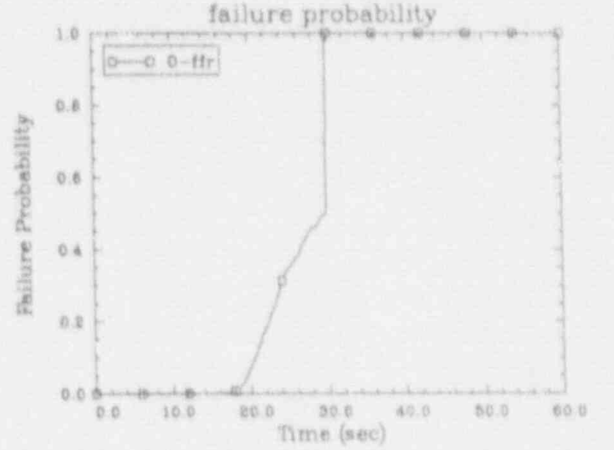

SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.32
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp


SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.32
oxide thickness
Time (sec)
(in)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

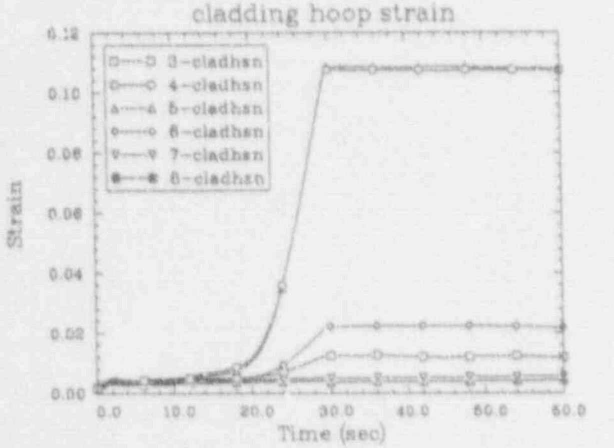
SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.32
internal pin pressure



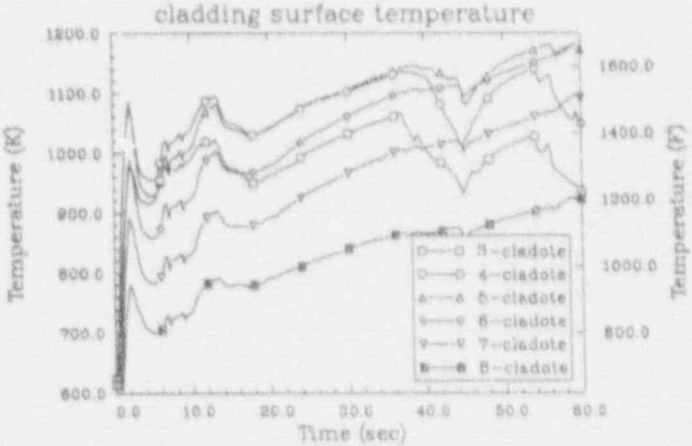
SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.32
failure probability



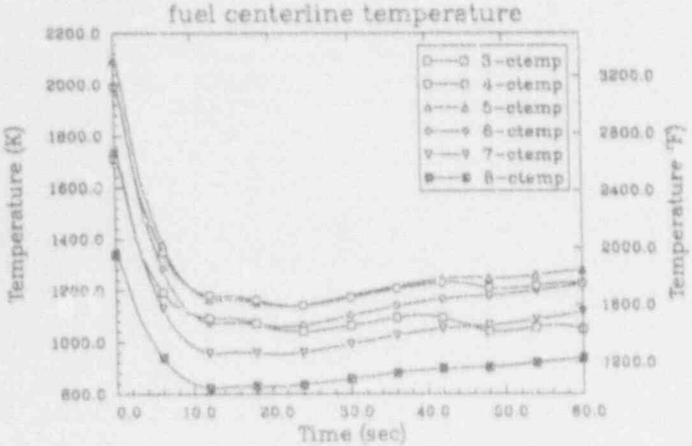
SEABROOK 7.%DBA 35 GWD/MTU PIN--PF 2.32
cladding hoop strain



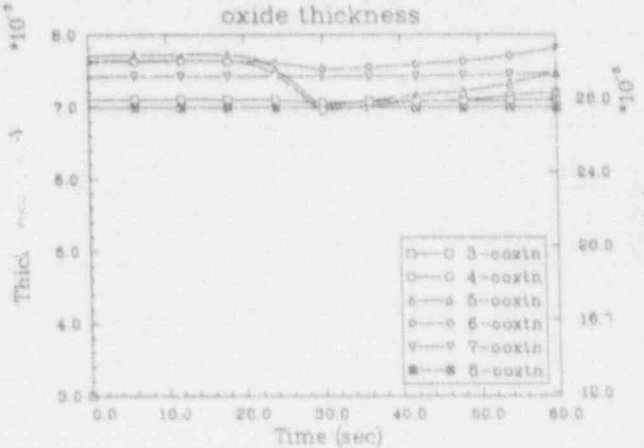
SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.32
cladding surface temperature



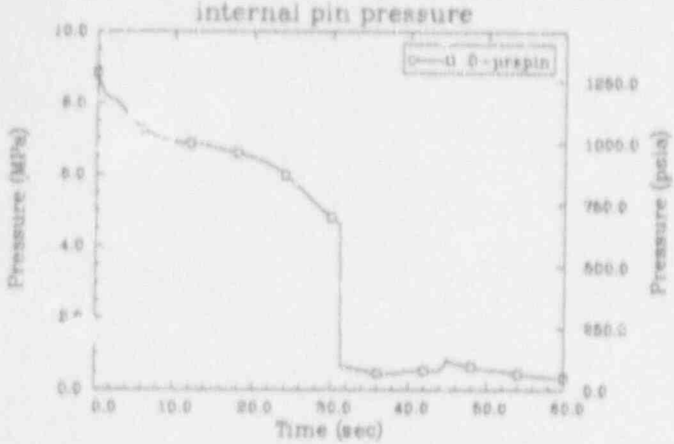
SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.32
fuel centerline temperature



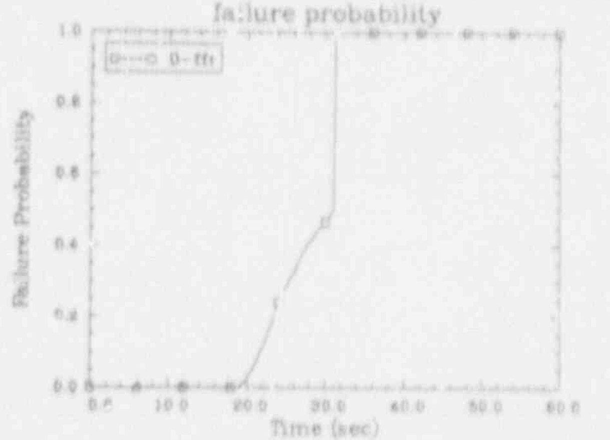
SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.32
oxide thickness



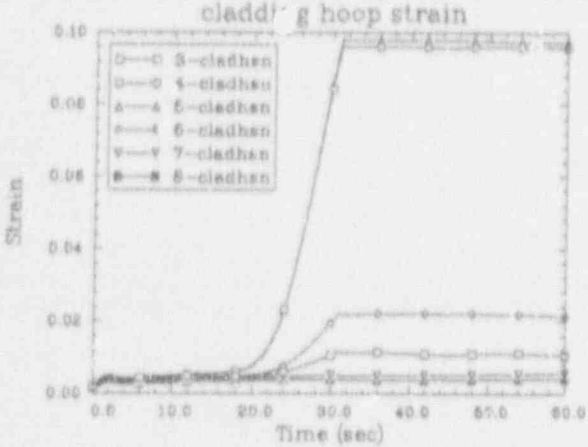
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.32
internal pin pressure



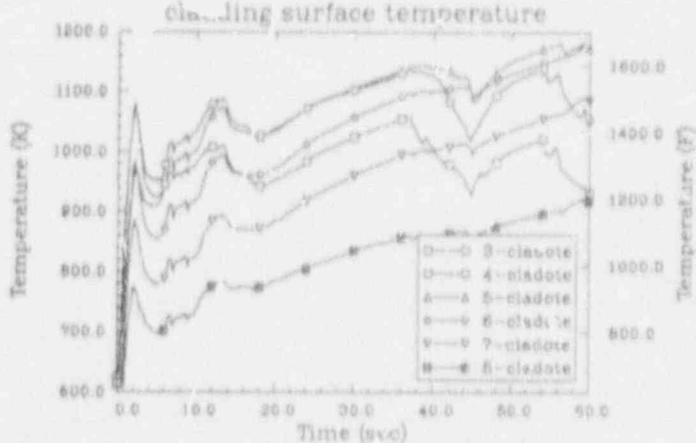
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.32
failure probability



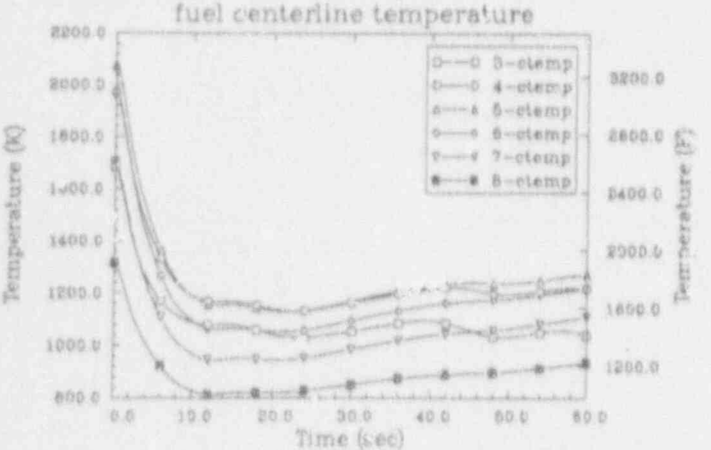
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.32
cladding hoop strain



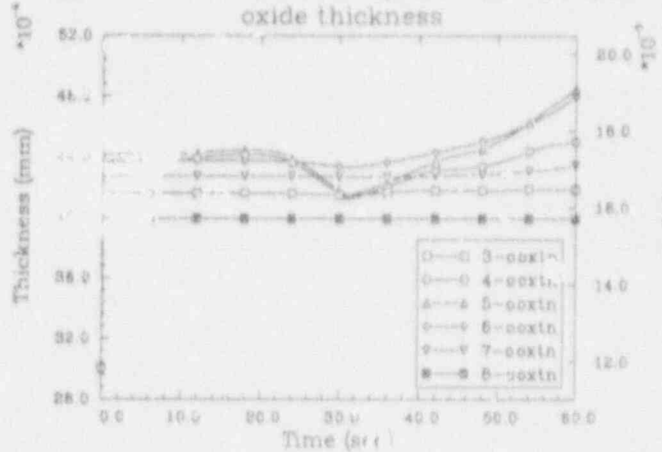
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.32
cladding surface temperature



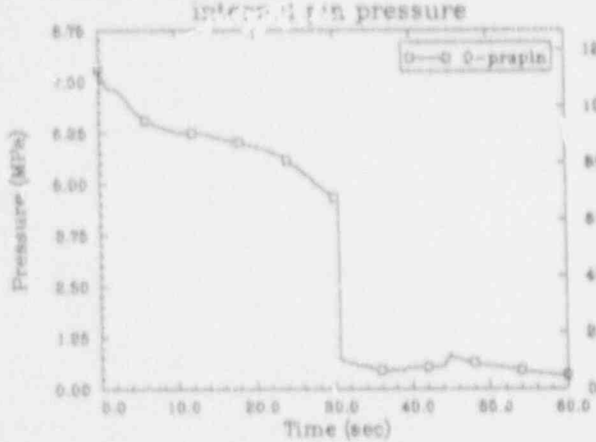
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.32
fuel centerline temperature



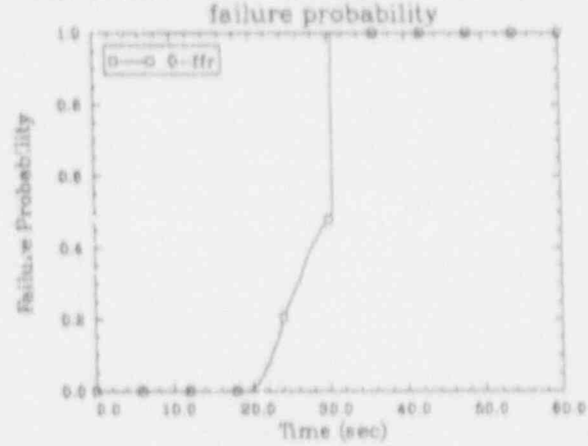
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.32
oxide thickness



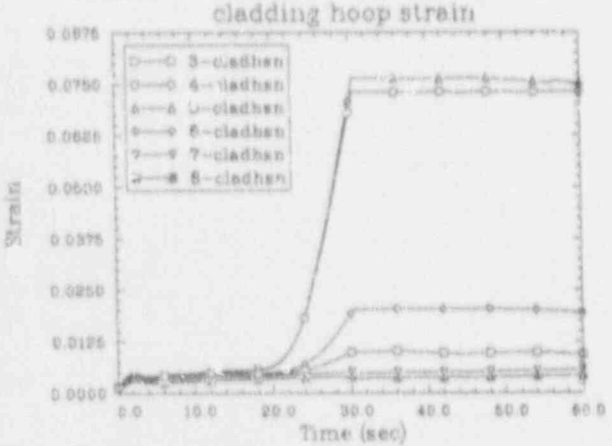
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.32
internal pin pressure



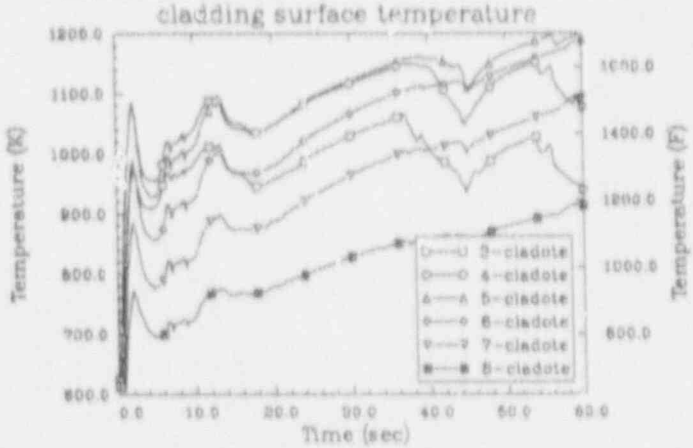
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.32
failure probability



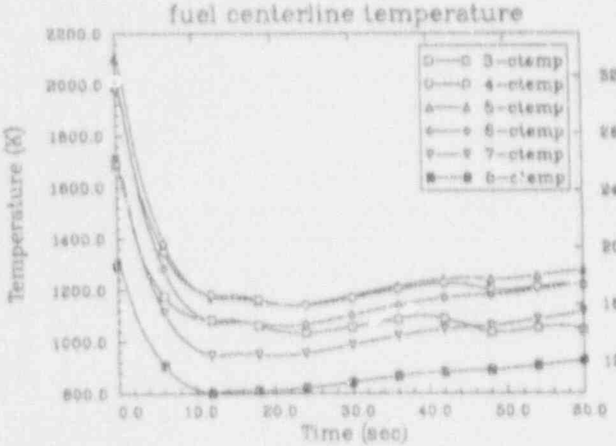
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.32
cladding hoop strain



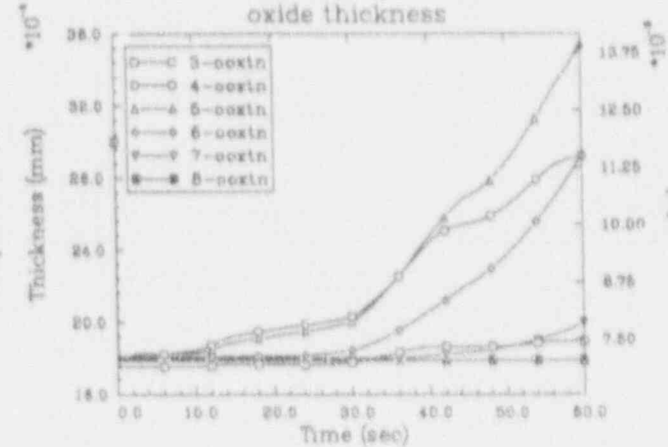
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.32
cladding surface temperature



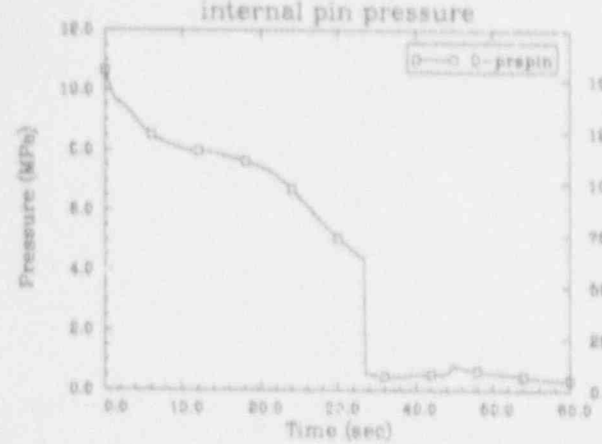
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.32
fuel centerline temperature



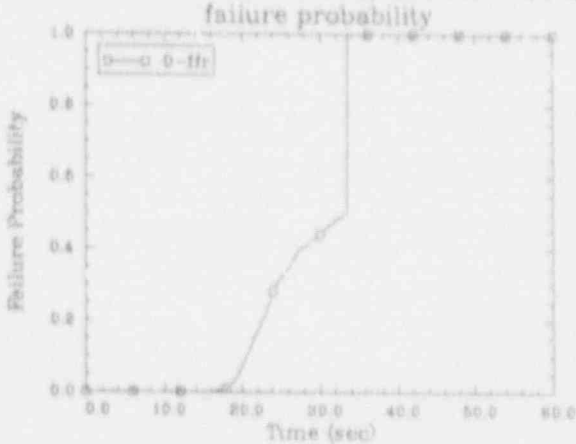
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.32
oxide thickness



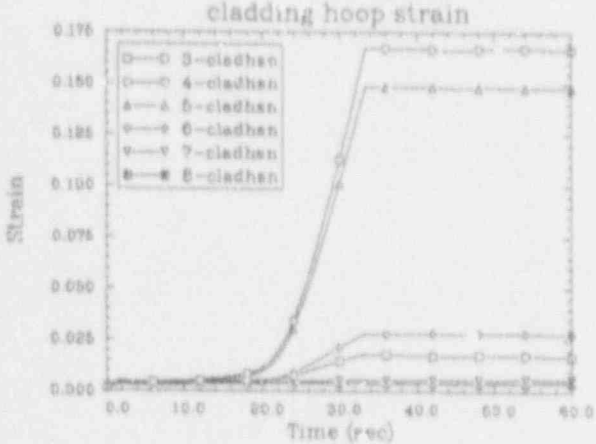
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.2
internal pin pressure



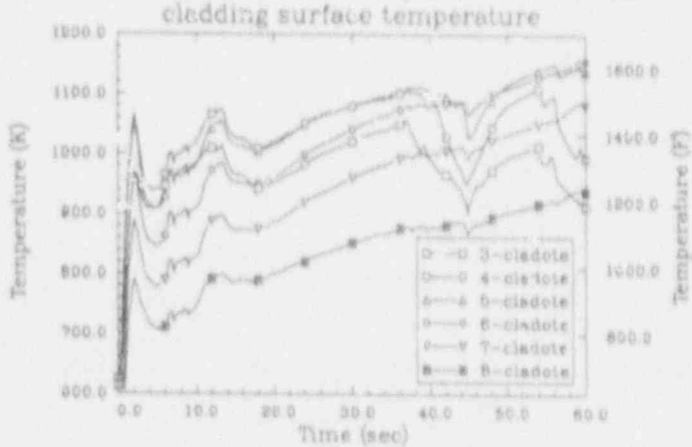
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.2
failure probability



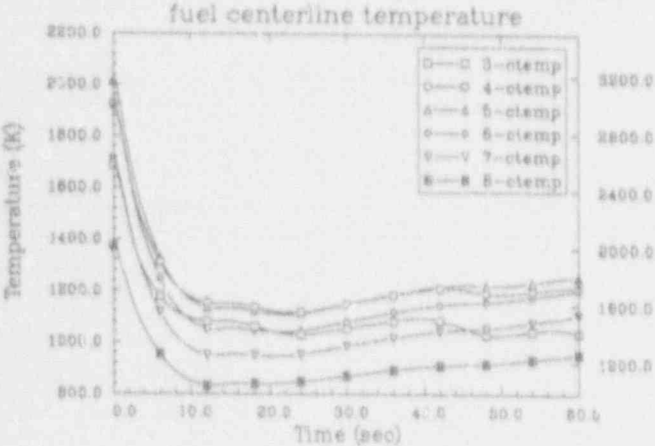
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.2
cladding hoop strain



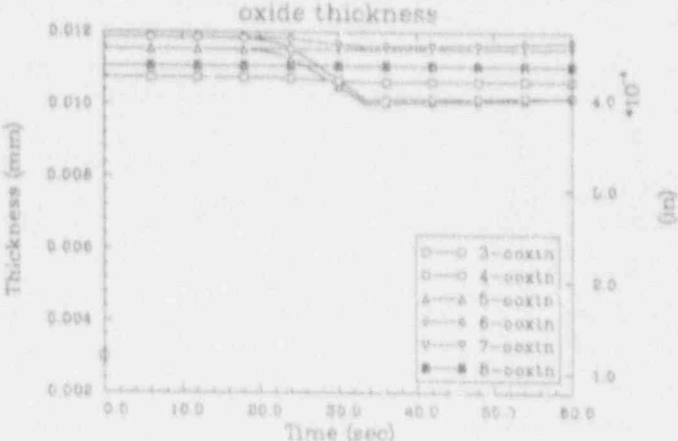
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.2
cladding surface temperature

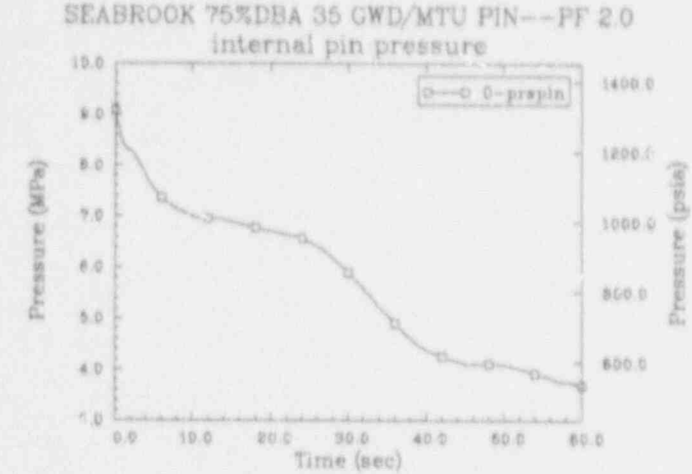


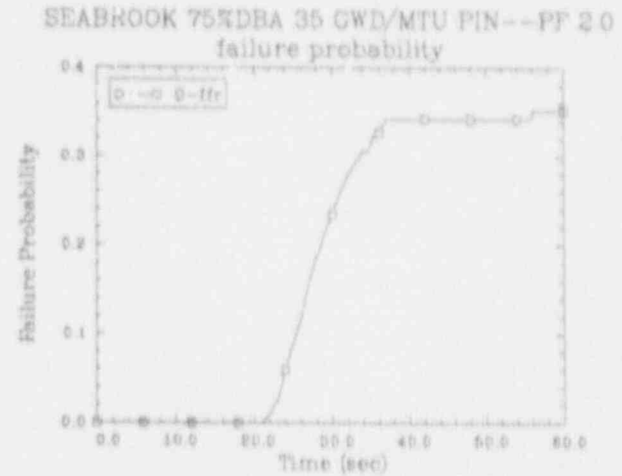
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.2
fuel centerline temperature

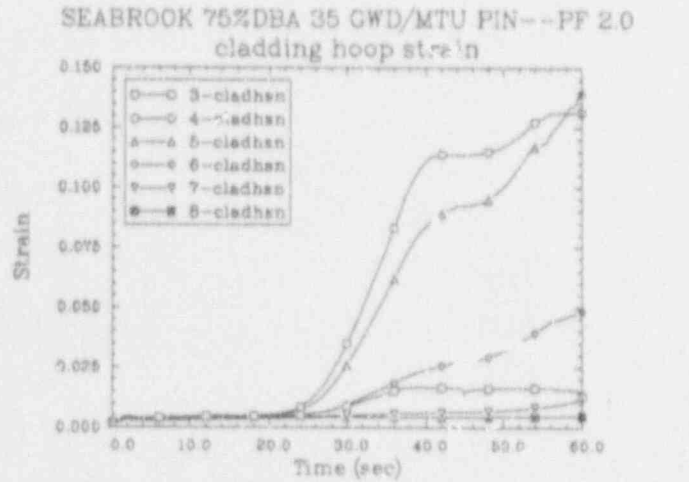


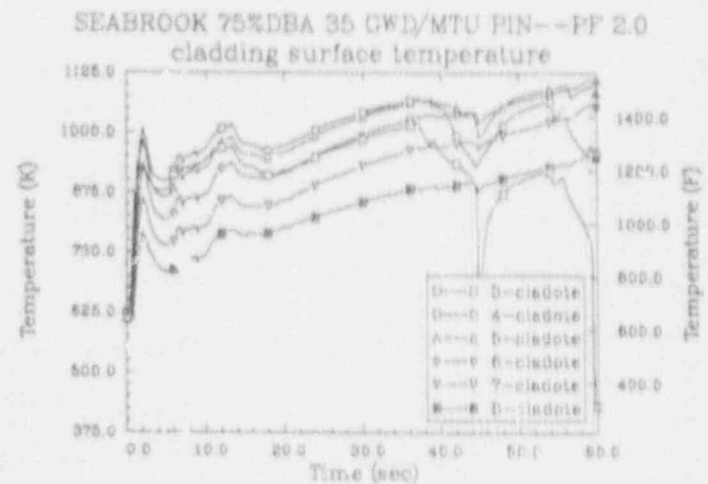
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.2
oxide thickness

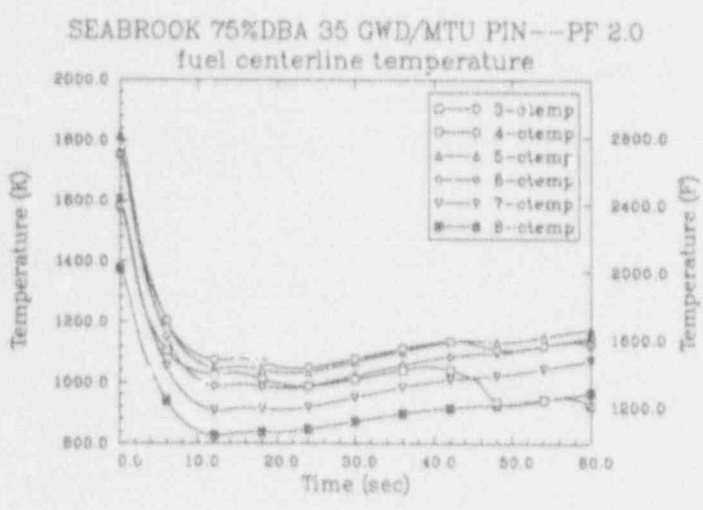


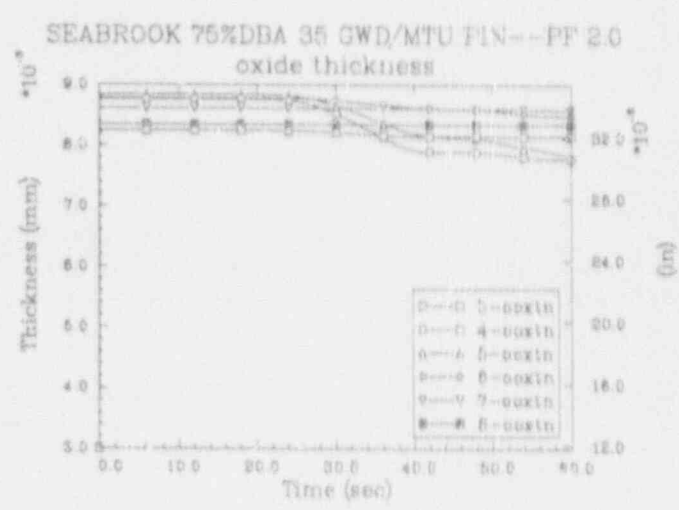

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

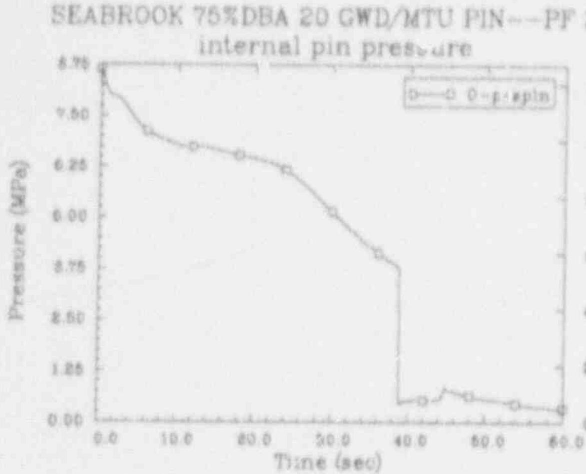

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

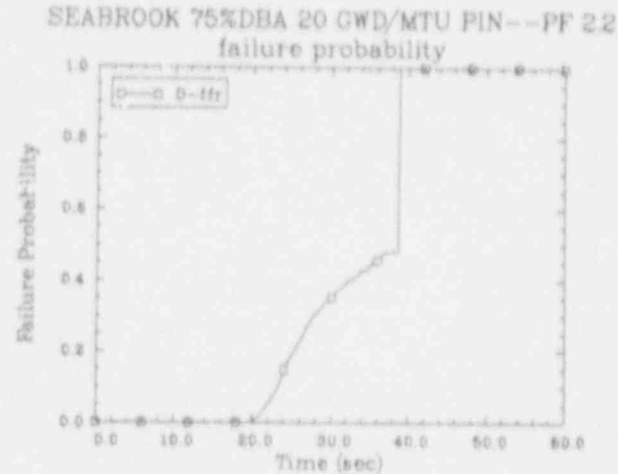

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

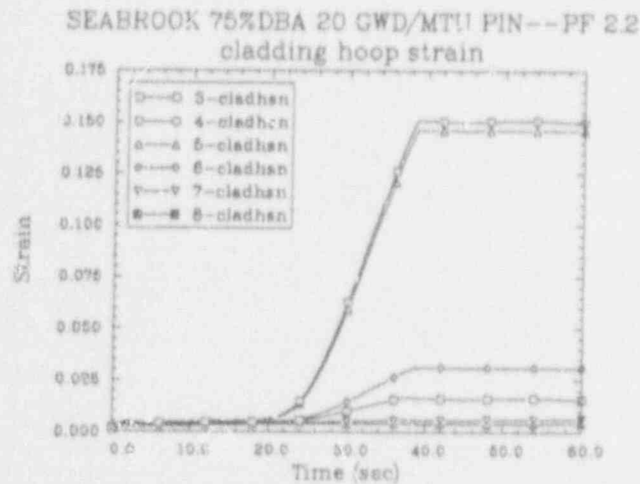

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)

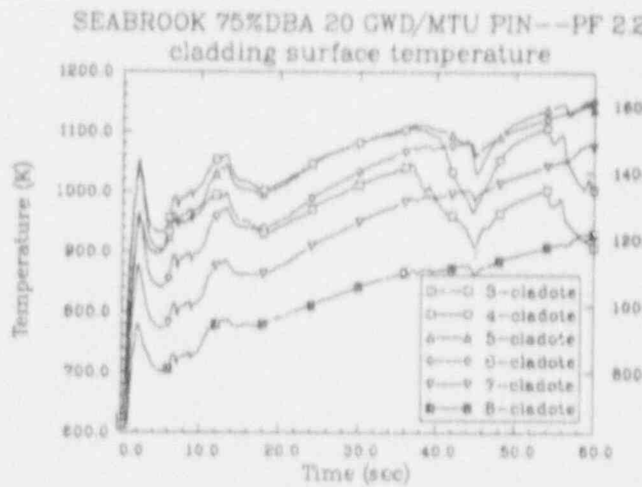

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature
4-ctemp
5-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

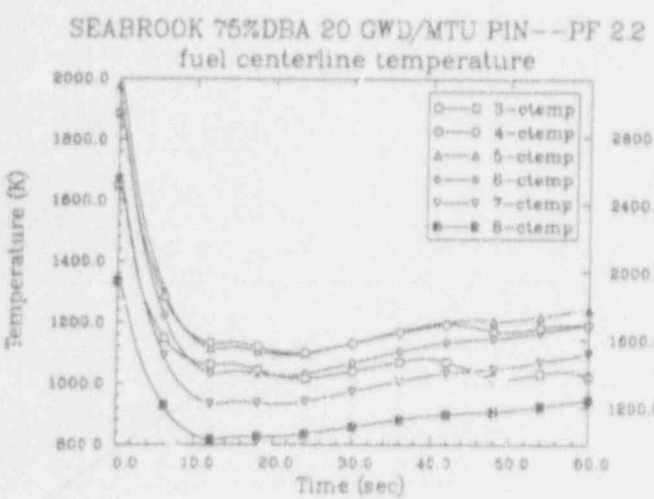

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness
Thickness (mm)
Time (sec)

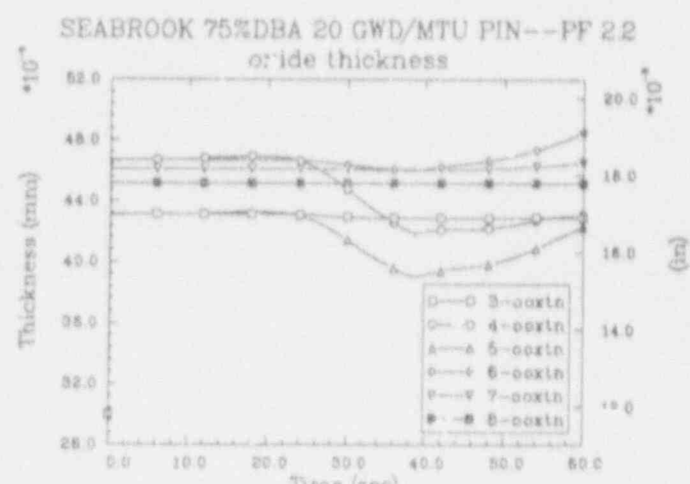

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure
0-p-spin
Pressure (MPa)
Pressure (psia)
Time (sec)

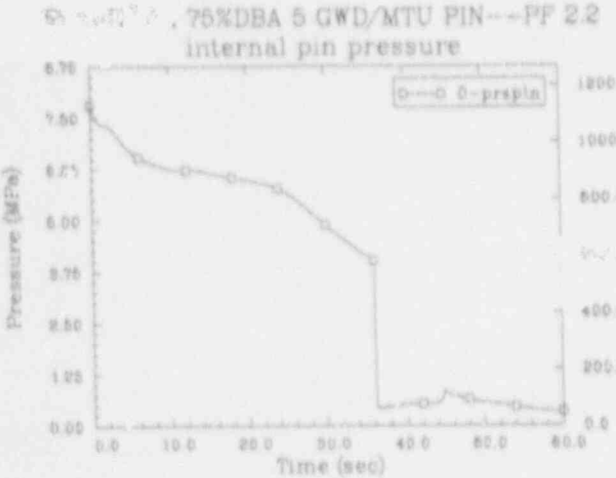

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

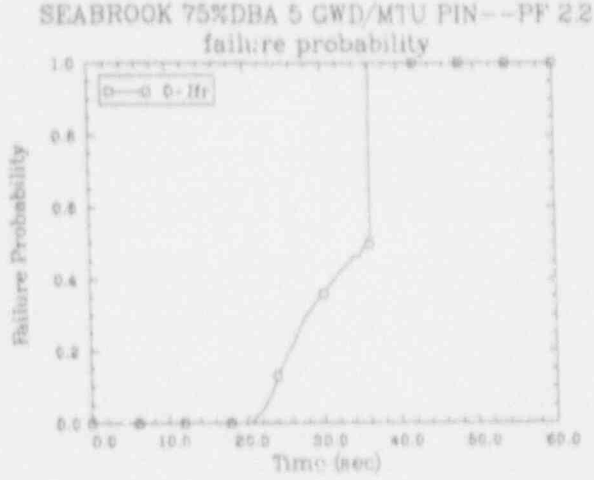

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

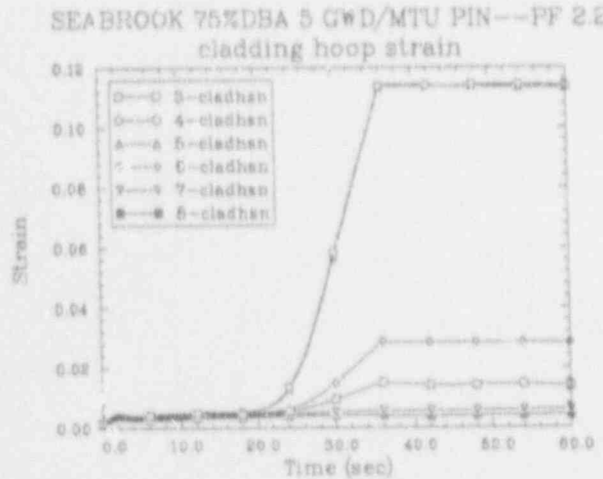

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

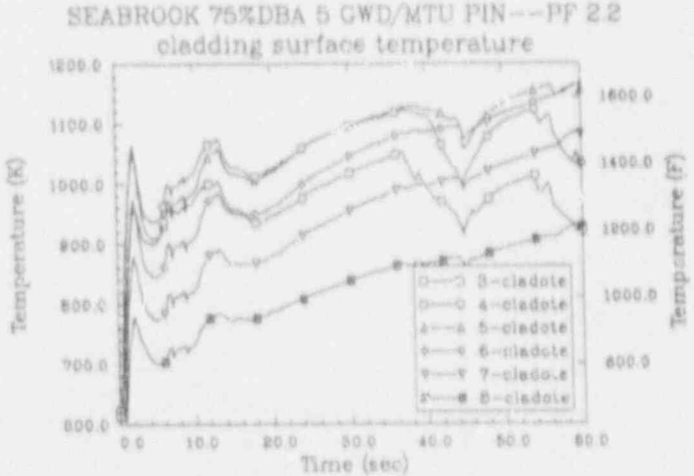

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

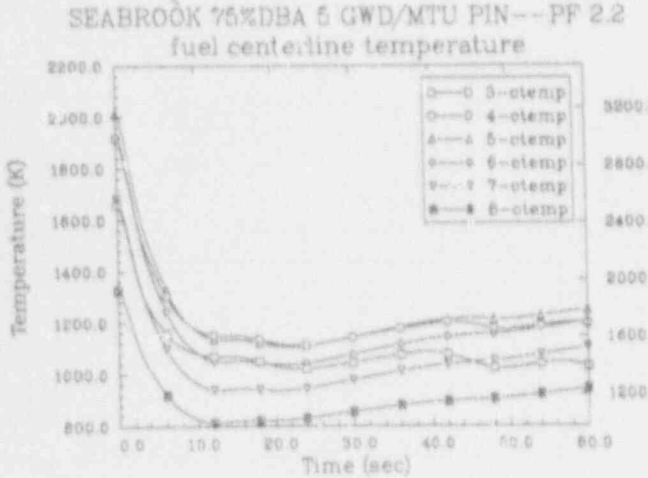

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

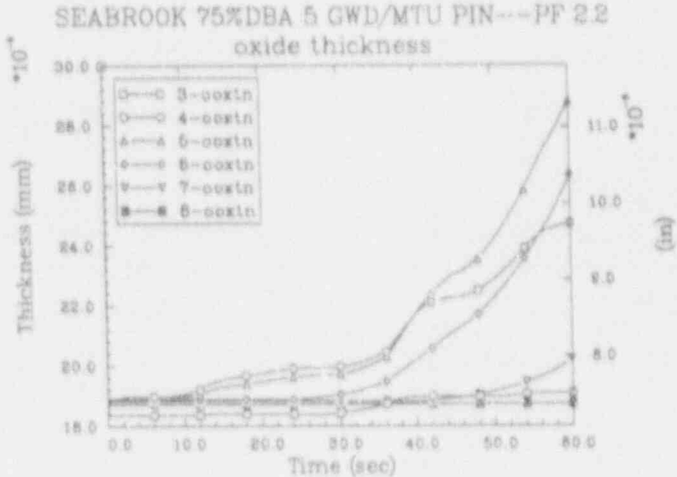

75%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.2
failure probability
Failure Probability
Time (sec)

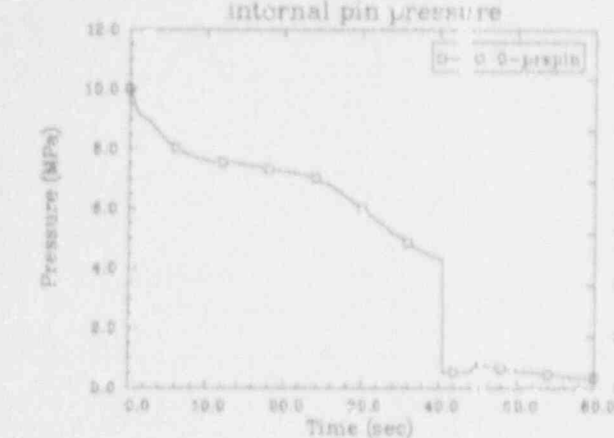

SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

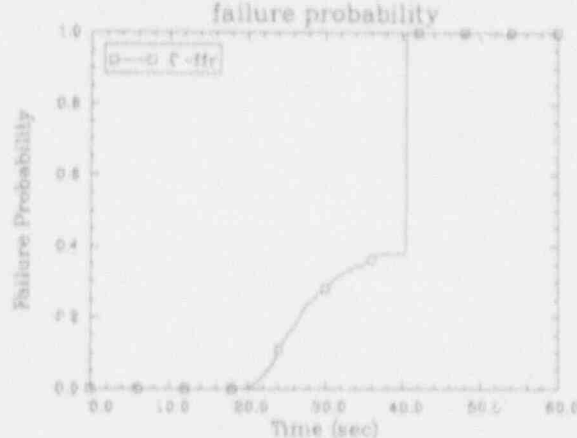

SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

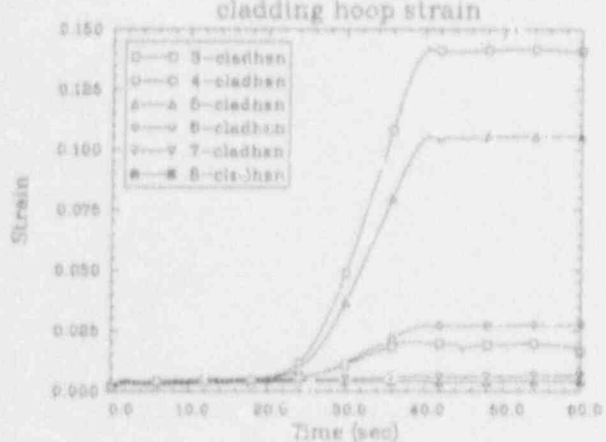
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.0
internal pin pressure



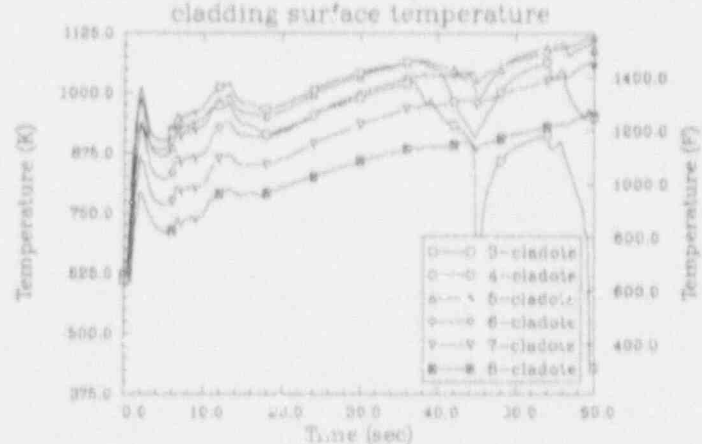
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.0
failure probability



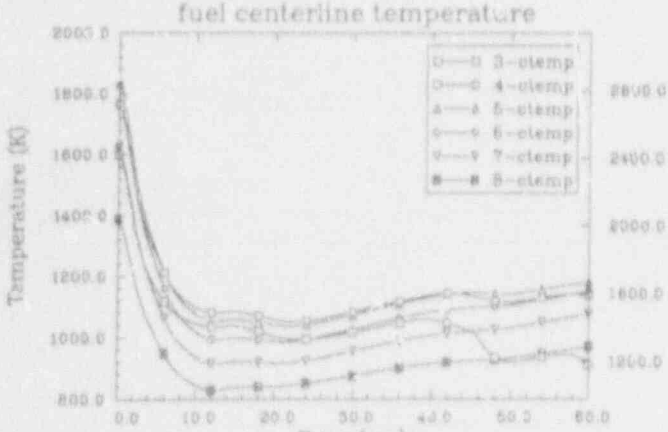
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.0
cladding hoop strain



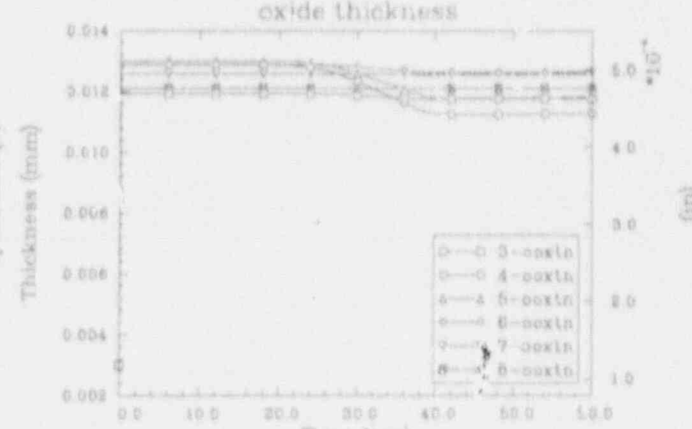
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.0
cladding surface temperature

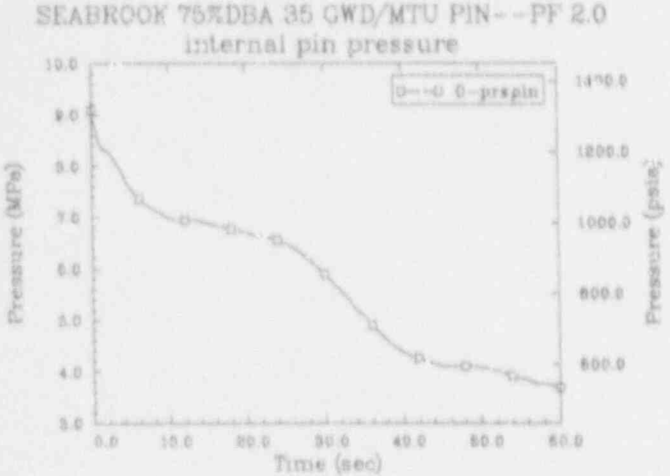


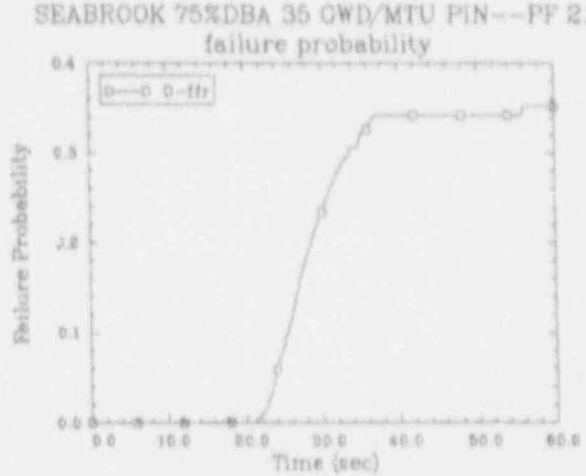
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.0
fuel centerline temperature

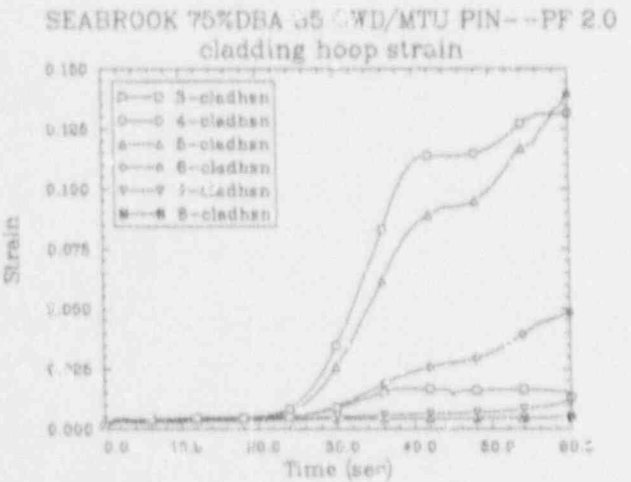


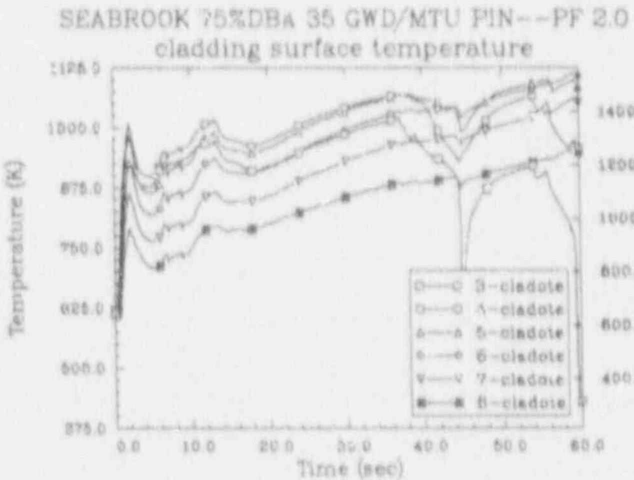
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 2.0
oxide thickness

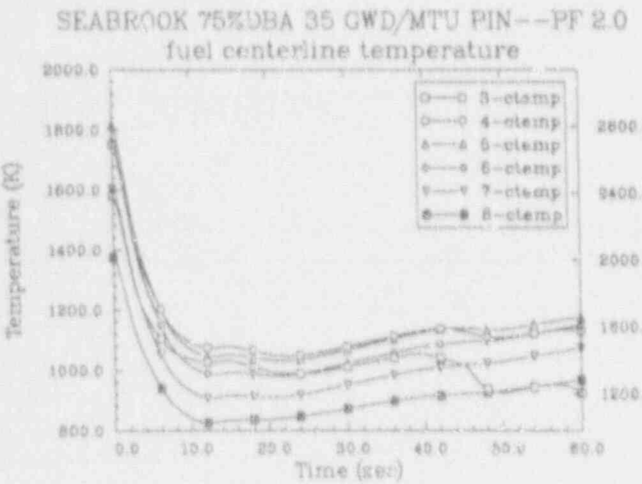


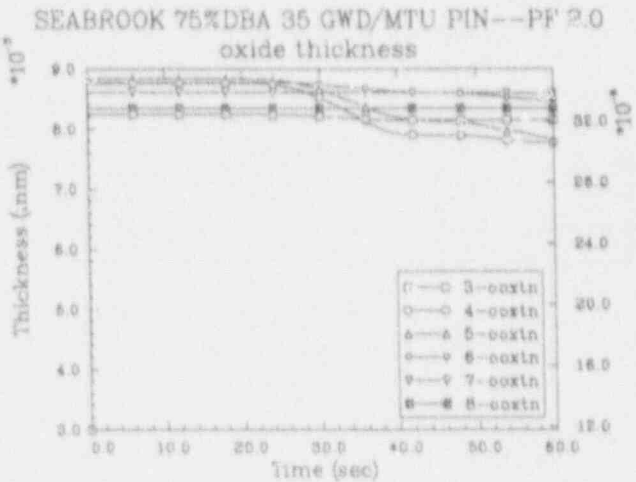

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

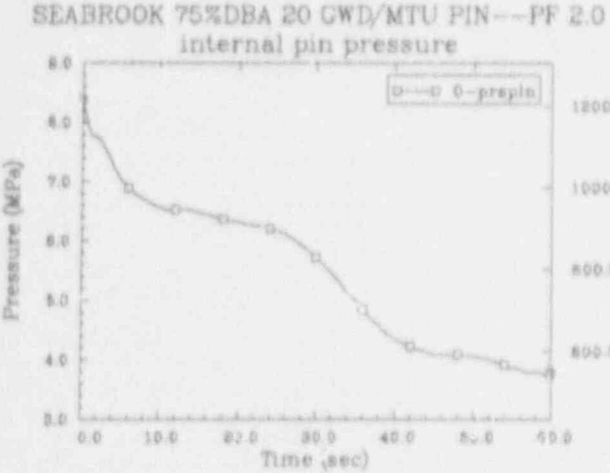

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

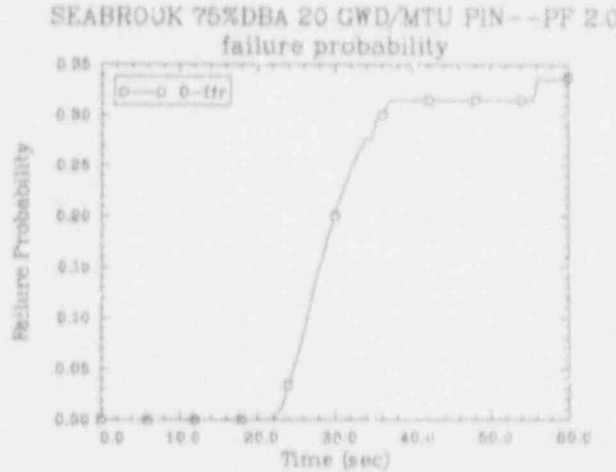

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

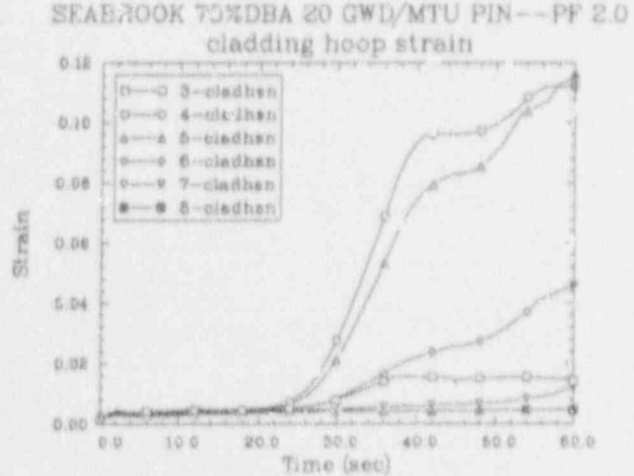

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

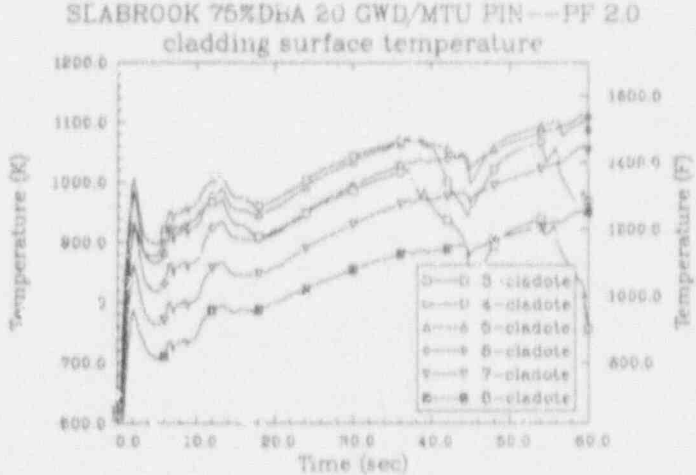

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

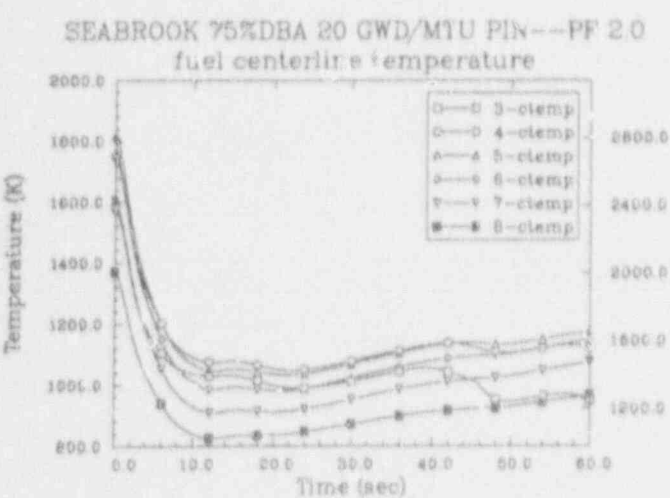

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

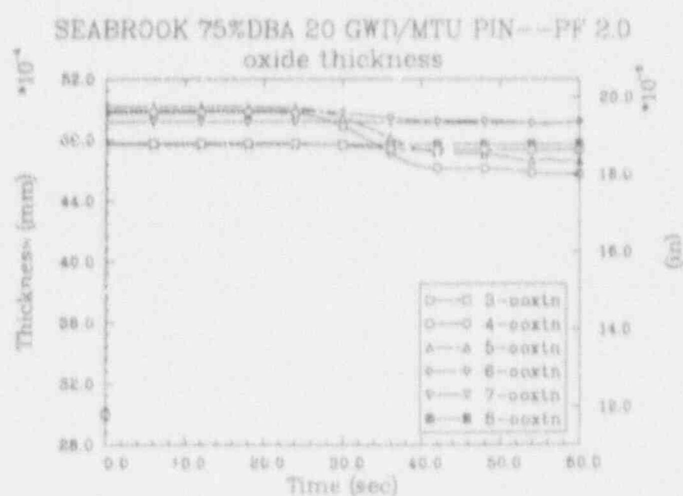

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

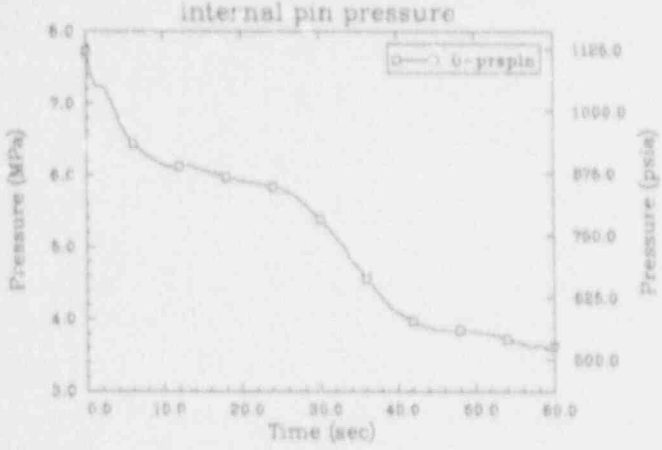

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

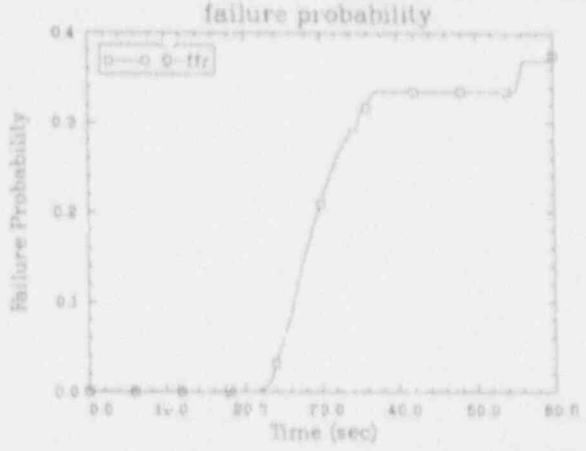

SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 75%DBA 20 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

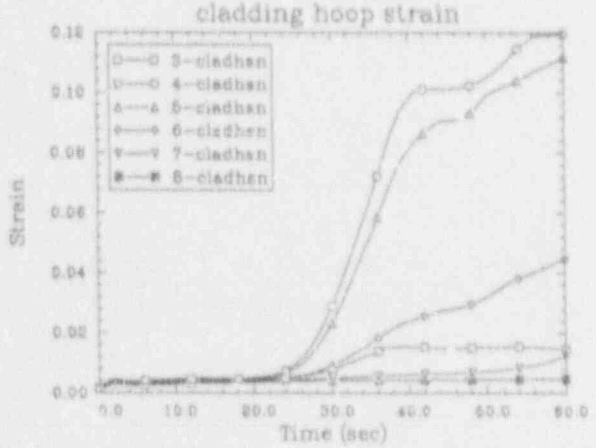
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure



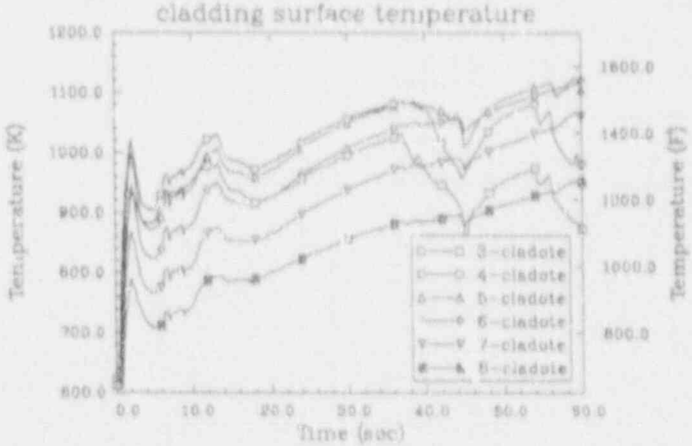
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.0
failure probability



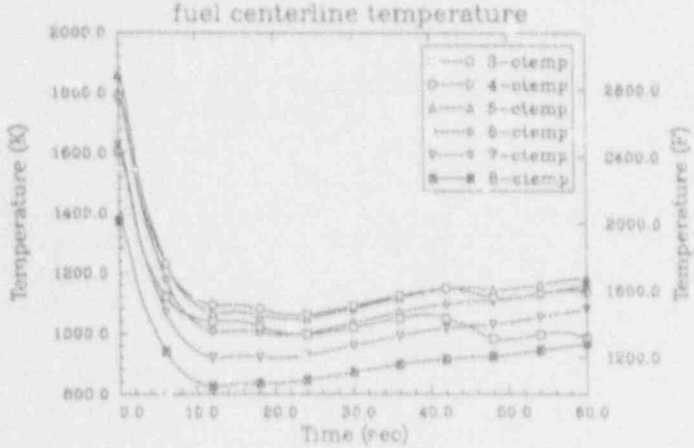
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain



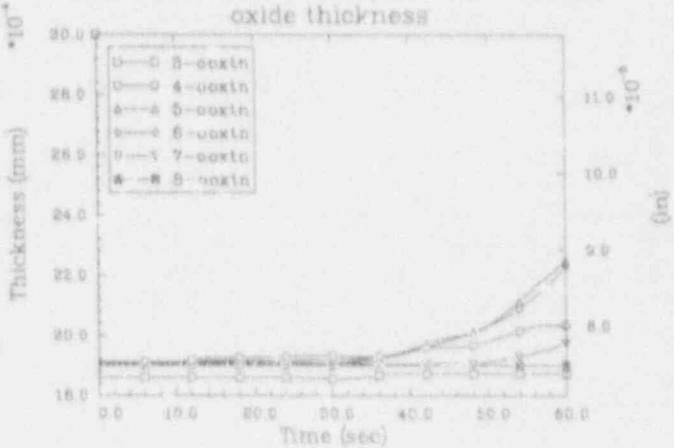
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature



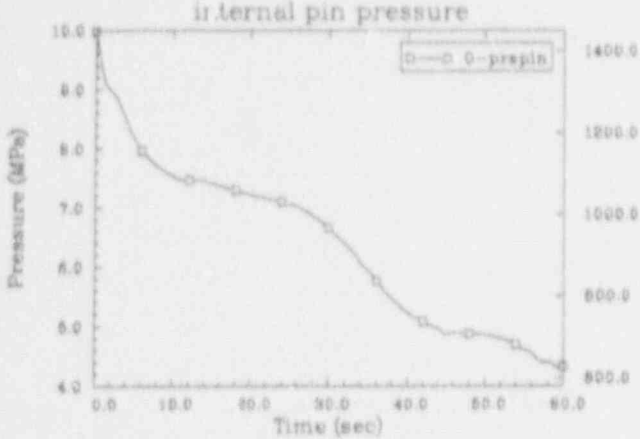
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.0
fuel centerline temperature



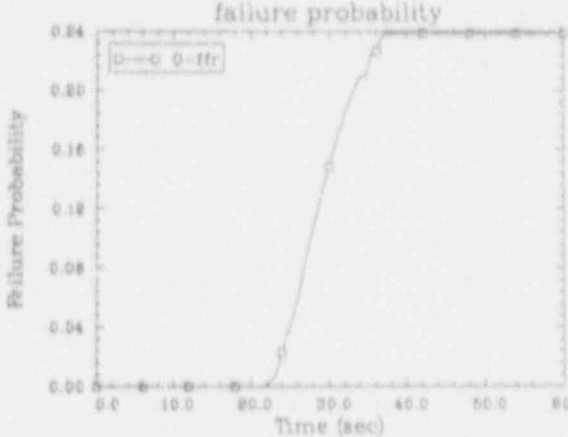
SEABROOK 75%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness



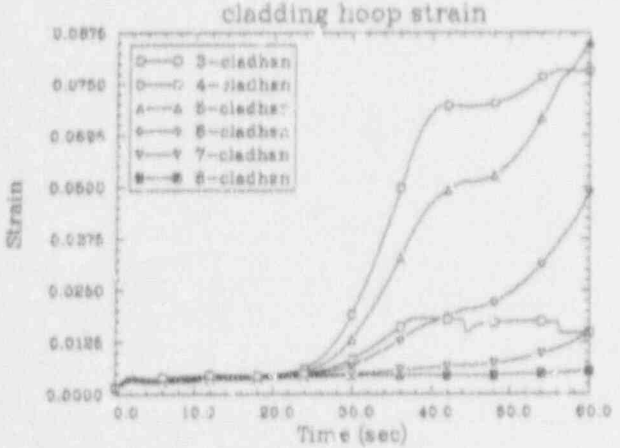
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 1.8
internal pin pressure



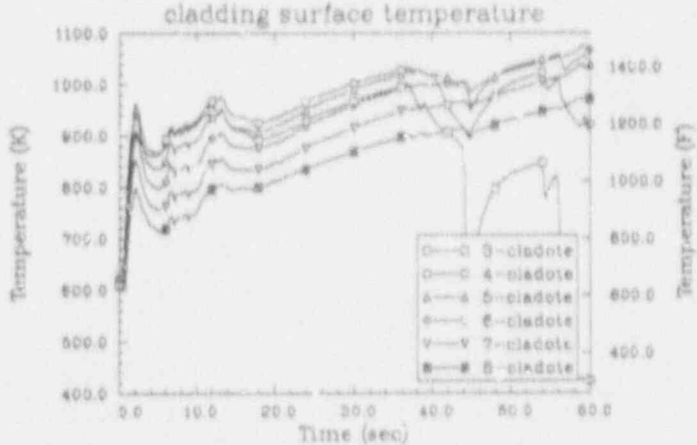
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 1.8
failure probability



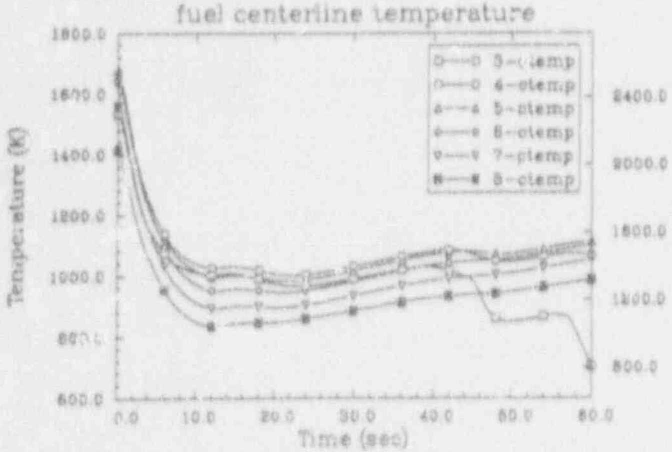
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 1.8
cladding hoop strain



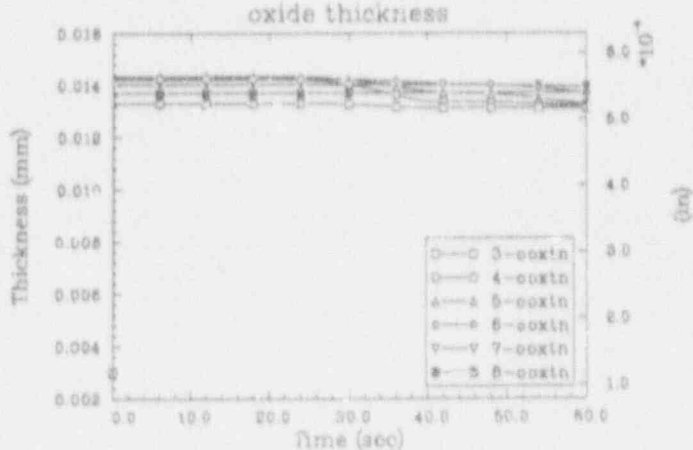
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 1.8
cladding surface temperature

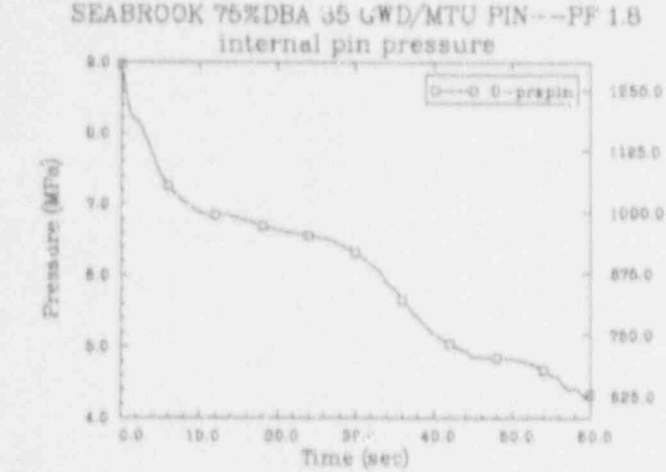


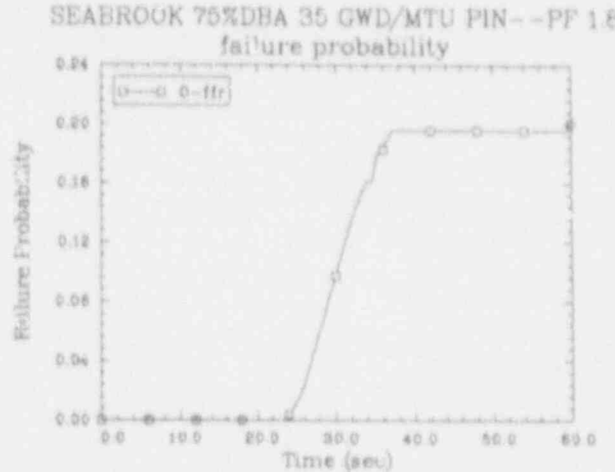
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 1.8
fuel centerline temperature

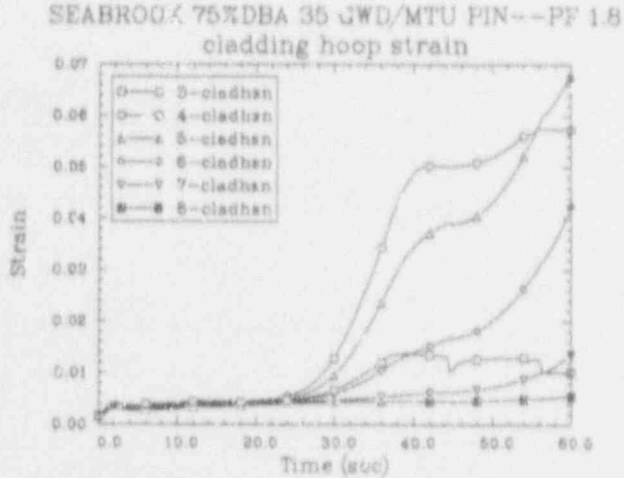


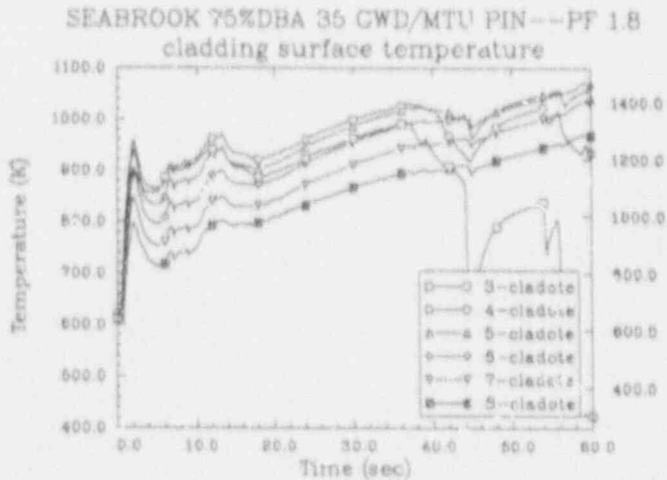
SEABROOK 75%DBA 50 GWD/MTU PIN--PF 1.8
oxide thickness

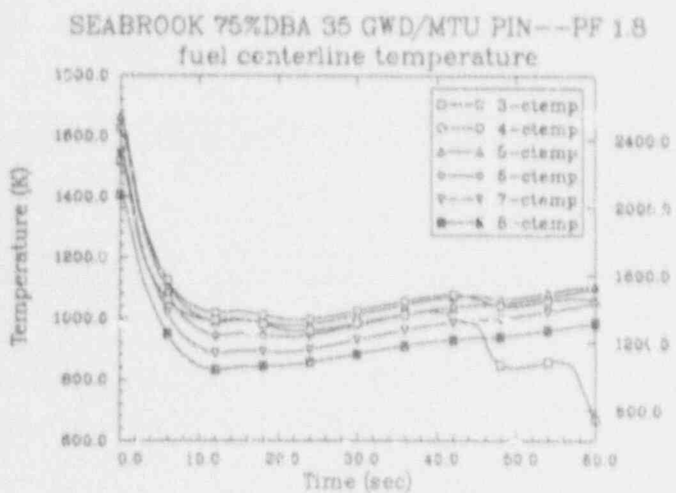


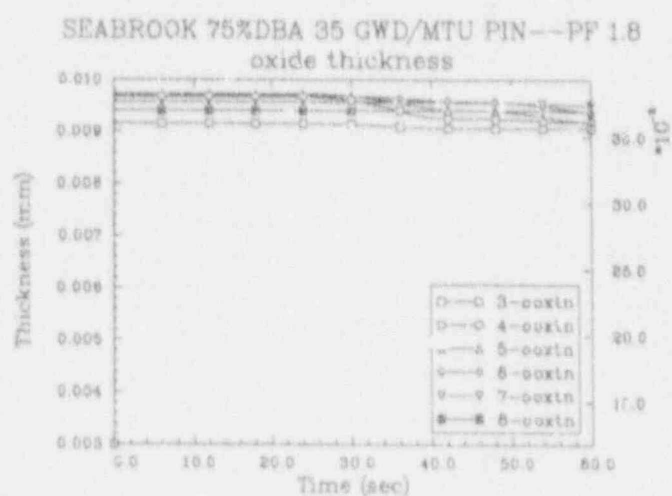

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

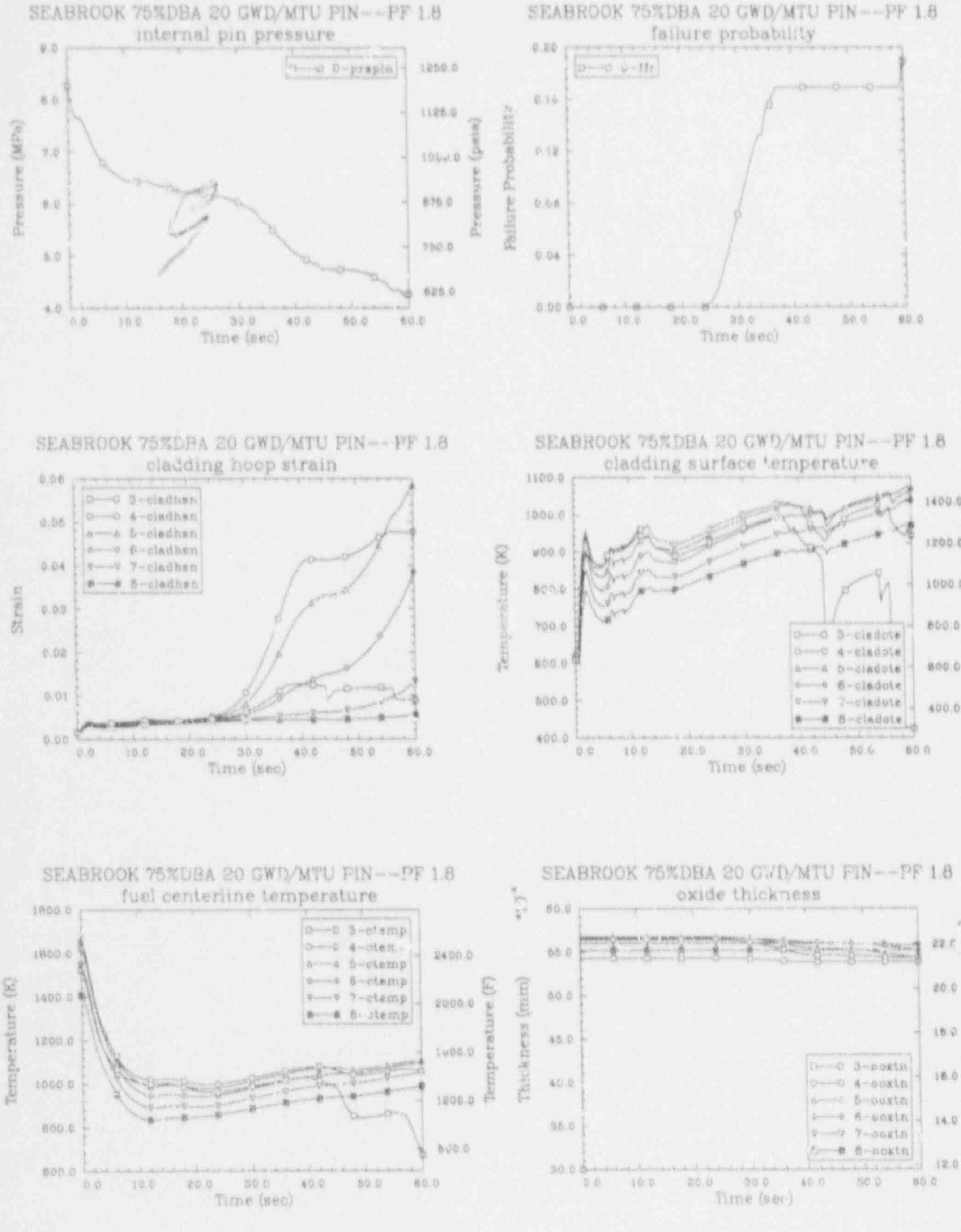

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)


SEABROOK 75%DBA 35 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

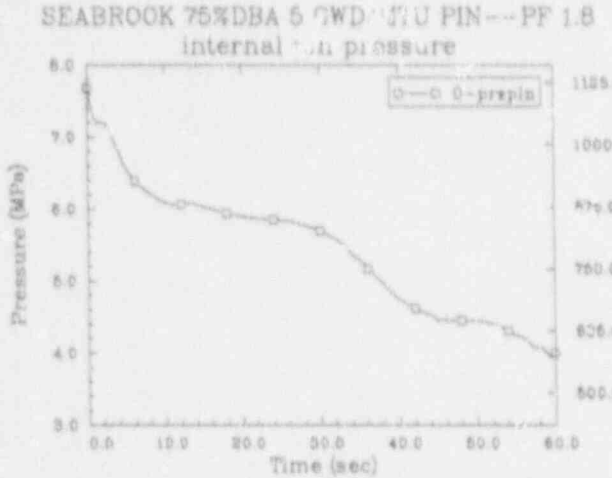

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
5-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

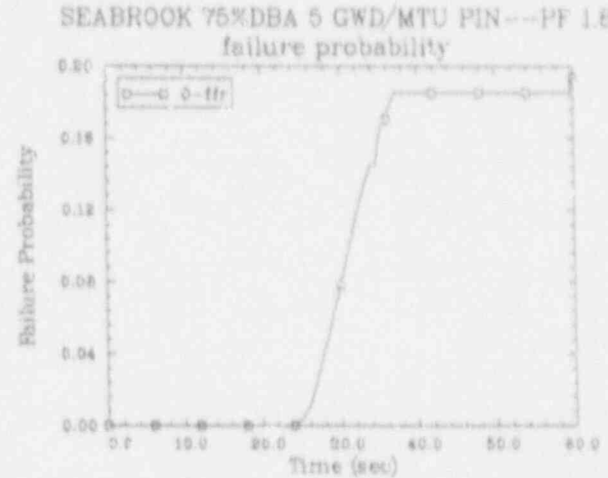

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

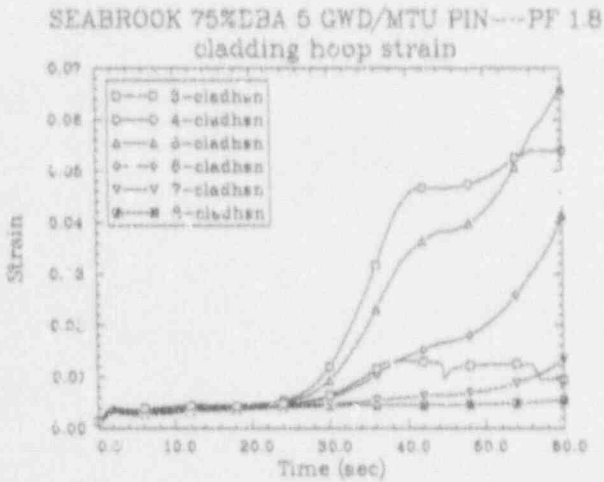

SEABROOK 75%DBA 35 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

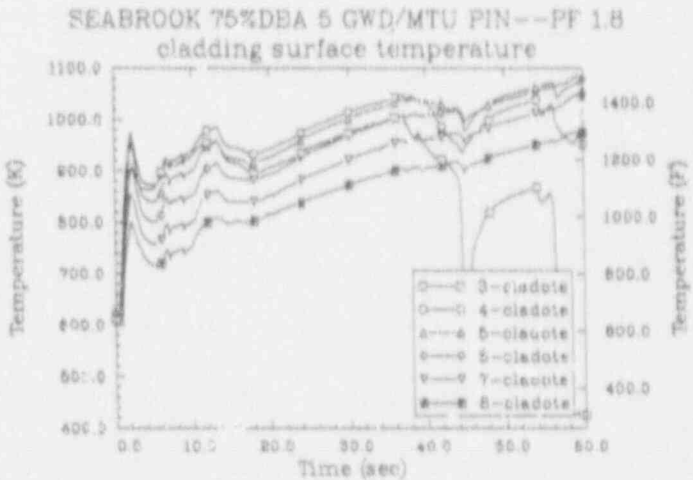


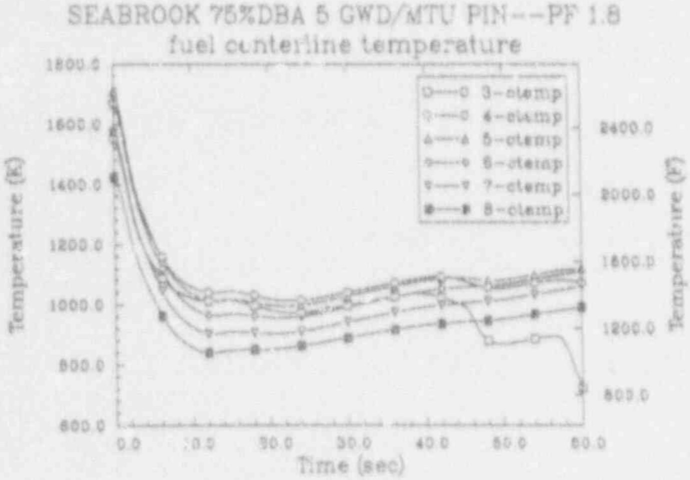
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 1.8
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 1.8
failure probability
Failure Probability
Time (sec)
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 1.8
cladding hoop strain
Strain
Time (sec)
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 1.8
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 1.8
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
SEABROOK 75%DBA 20 GWD/MTU PIN--PF 1.8
oxide thickness
Thickness (mm)
(in)
Time (sec)

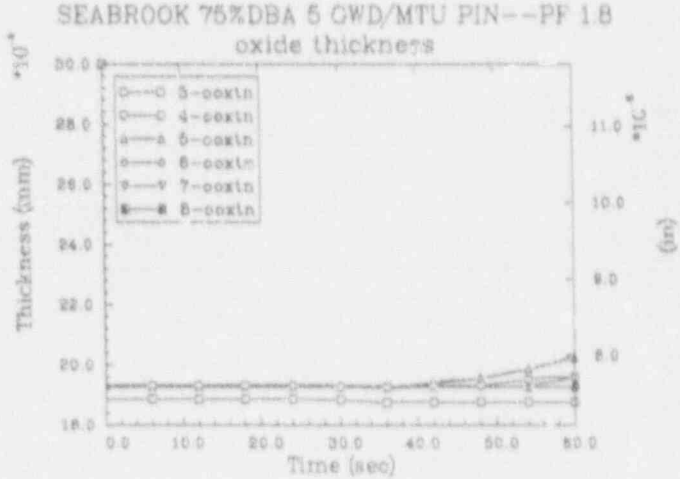

SEABROOK 75%DBA 5 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 75%DBA 5 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

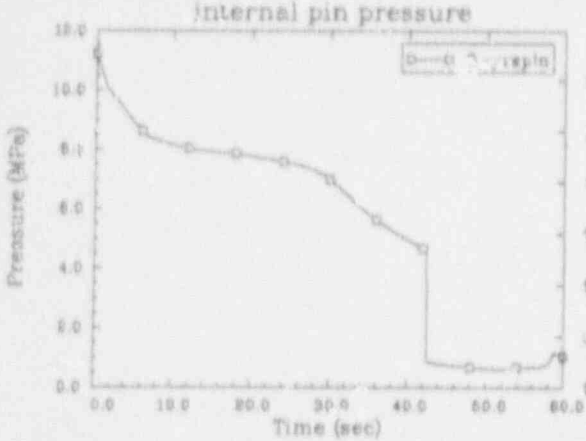

SEABROOK 75%DBA 5 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 75%DBA 5 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

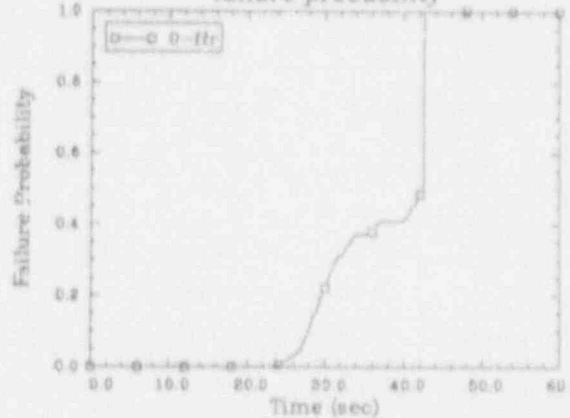

SEABROOK 75%DBA 5 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 75%DBA 5 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
Thickness (mm)
(in)
Time (sec)

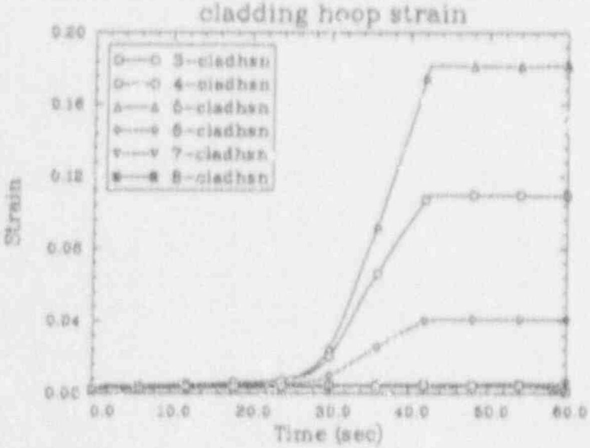
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.32
internal pin pressure



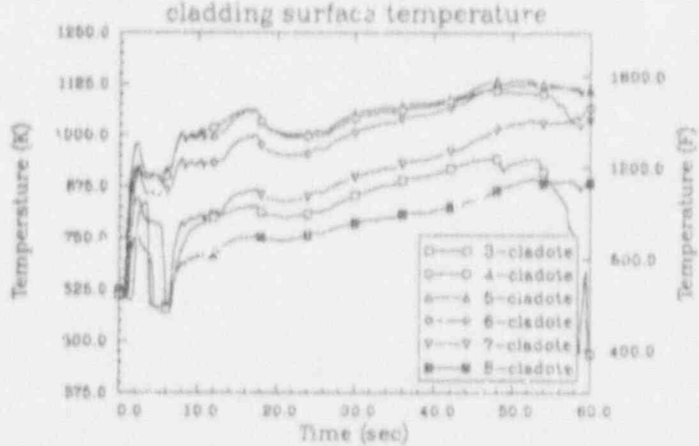
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.32
failure probability



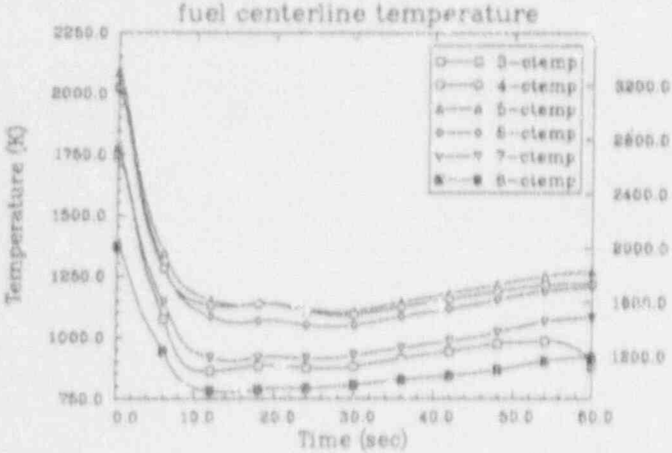
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.32
cladding hoop strain



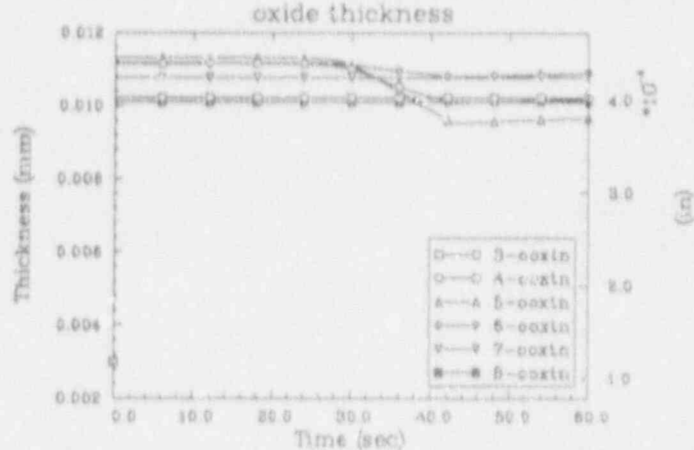
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.32
cladding surface temperature

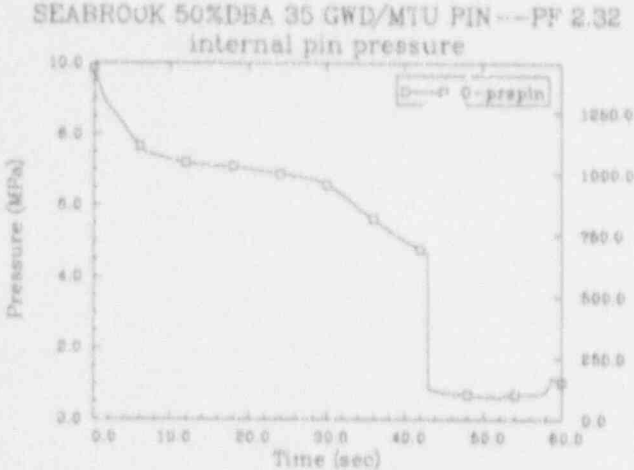


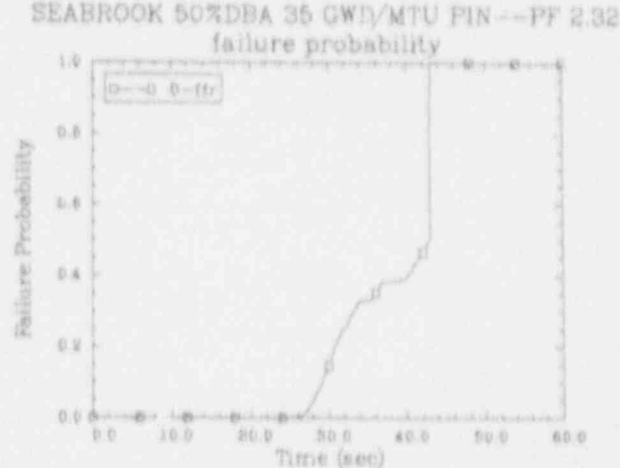
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.32
fuel centerline temperature

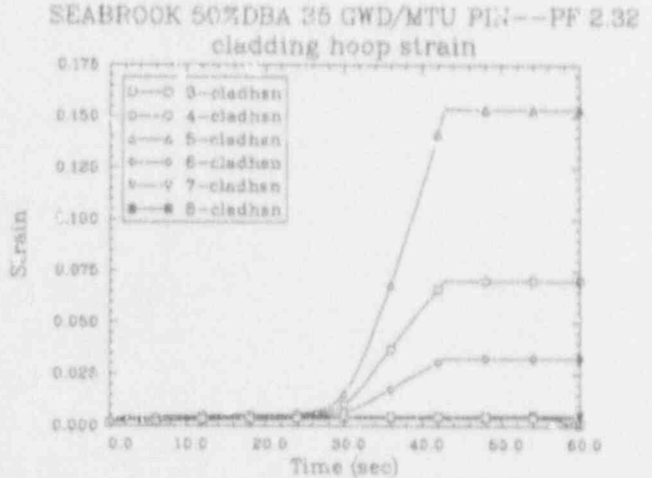


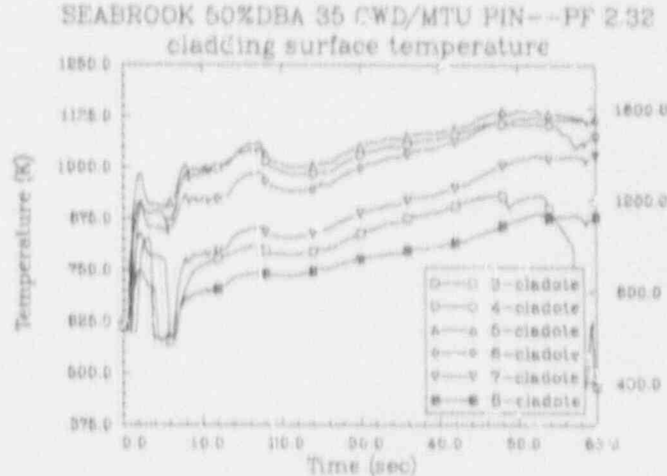
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.32
oxide thickness

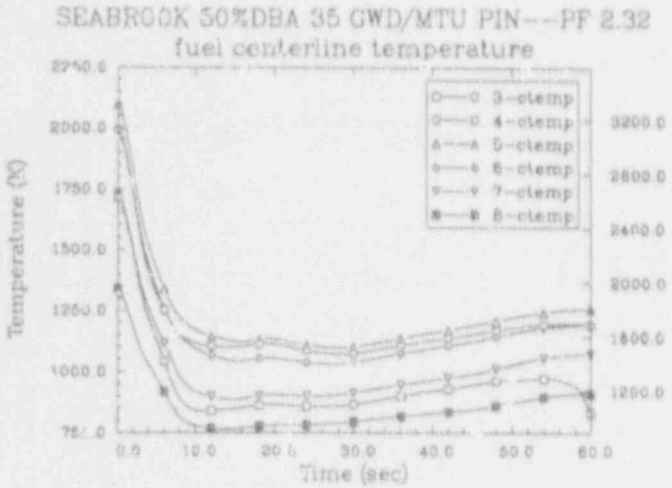


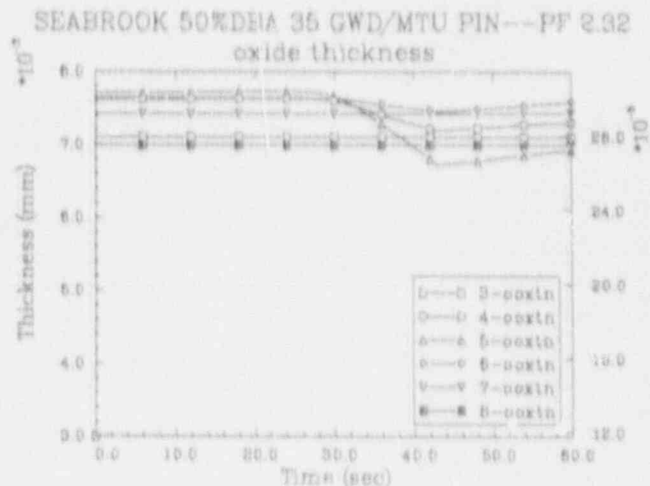

SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.32
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.32
failure probability
0-ffr
Failure Probability
Time (sec)

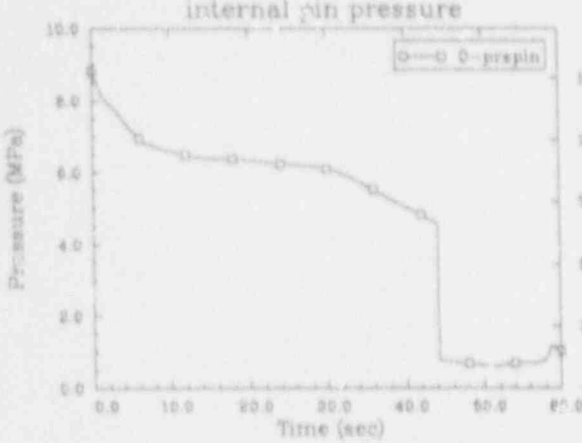

SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

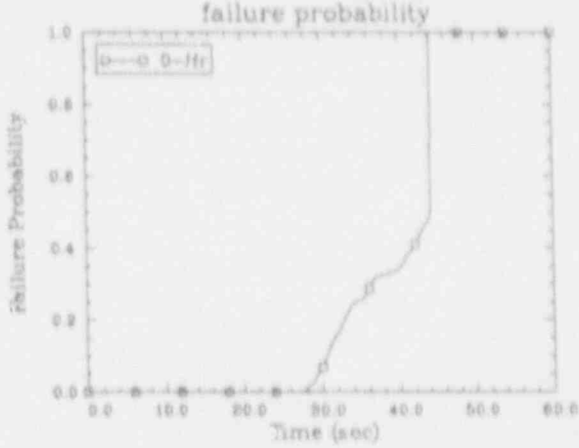

SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.32
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

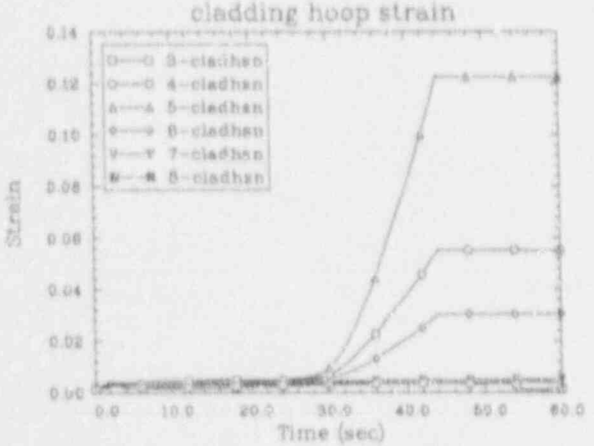
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.32
internal pin pressure



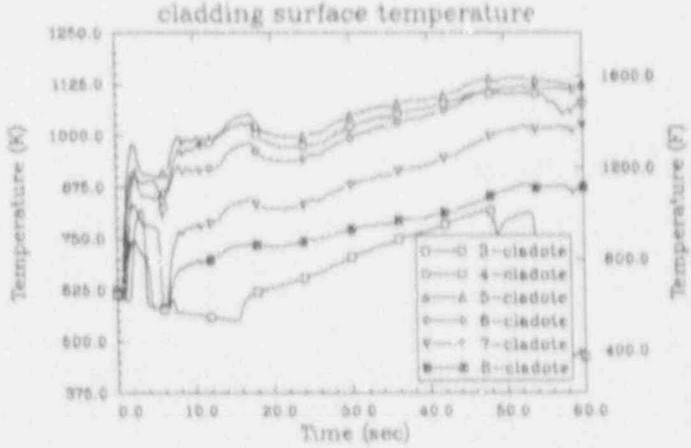
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.32
failure probability



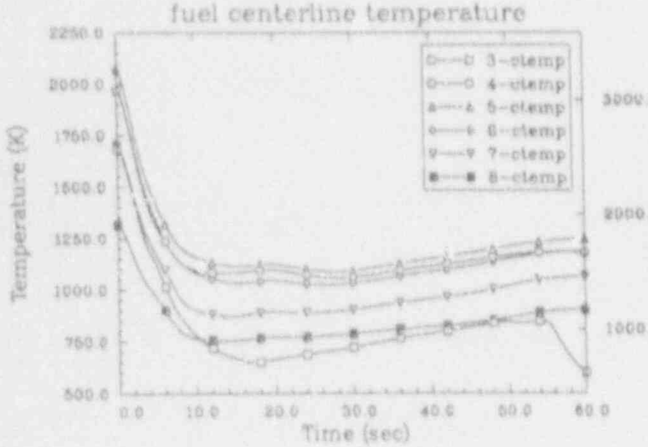
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.32
cladding hoop strain



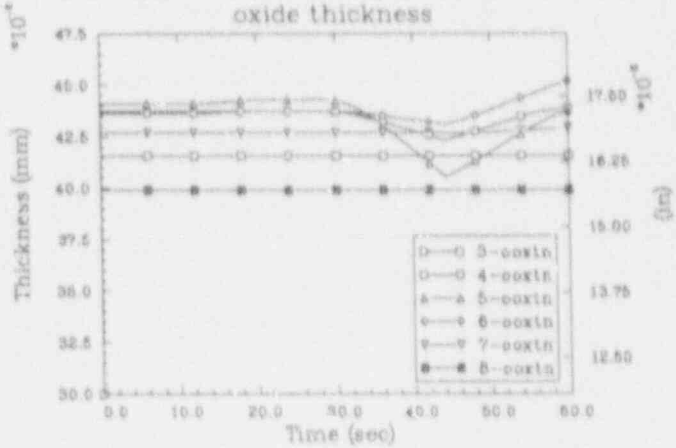
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.32
cladding surface temperature

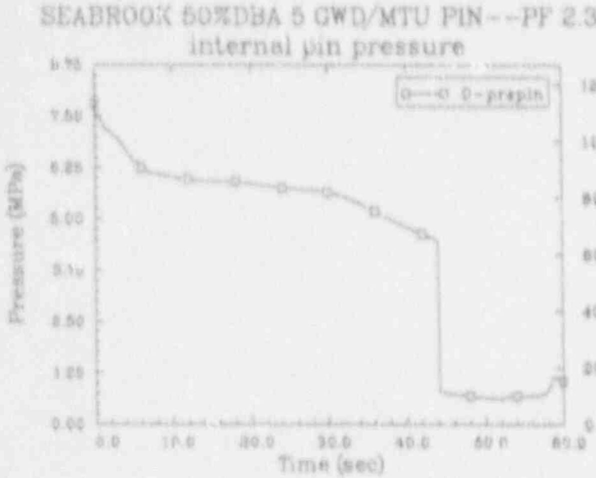


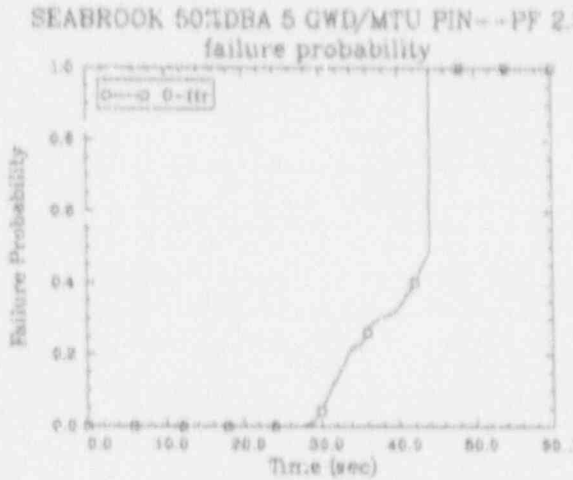
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.32
fuel centerline temperature

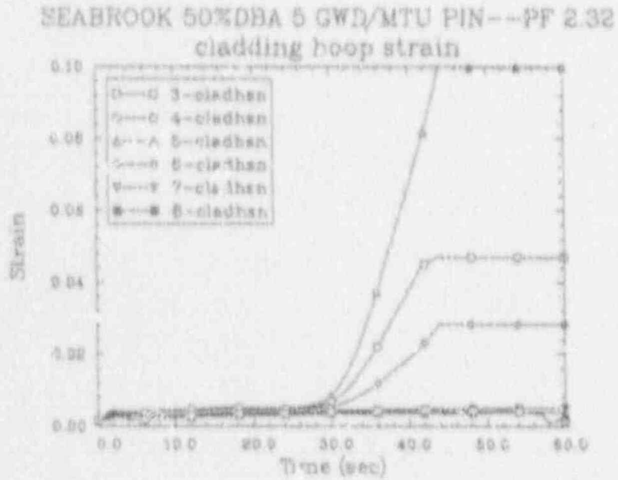


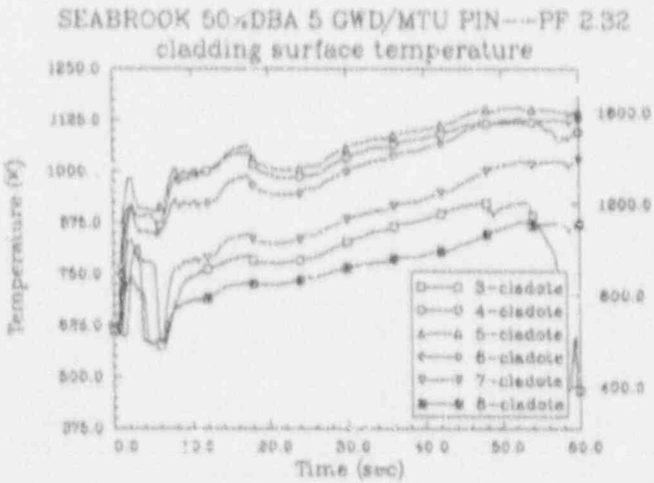
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.32
oxide thickness

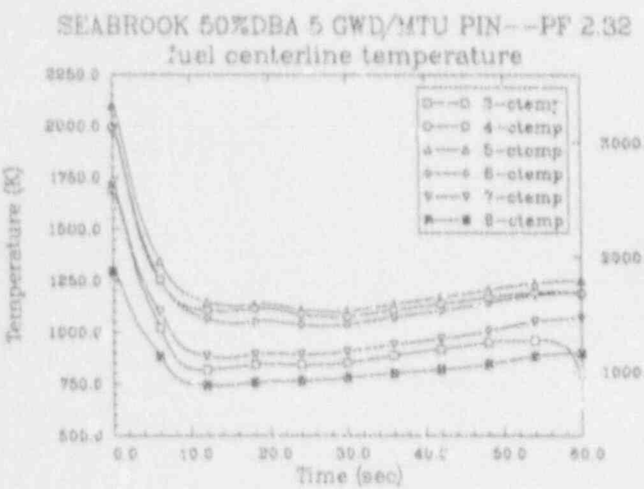


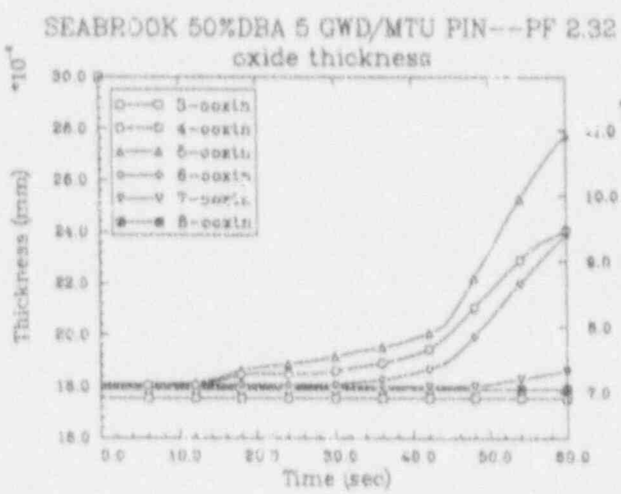

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.32
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.32
failure probability
Failure Probability
Time (sec)

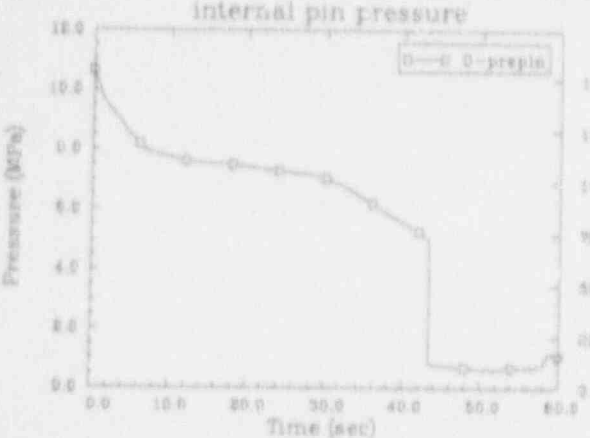

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

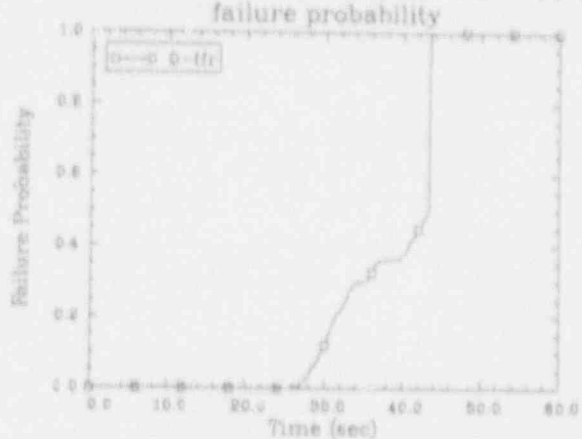

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.32
fuel centerline temperature
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.32
oxide thickness
5-ooxin
4-ooxin
8-ooxin
Thickness (mm)
(in)
Time (sec)

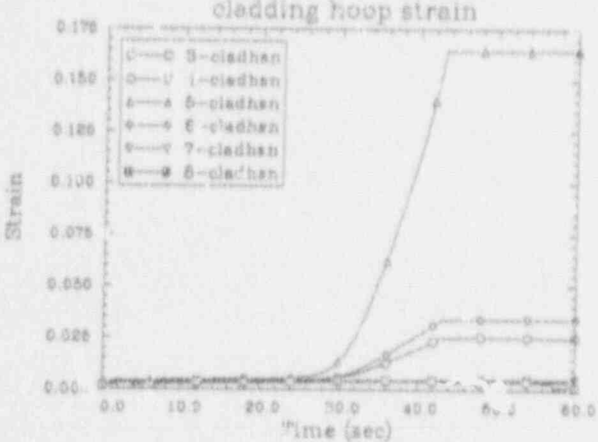
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.2
internal pin pressure



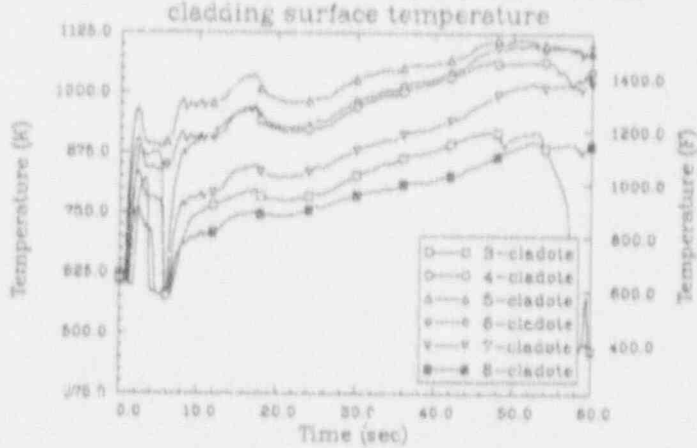
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.2
failure probability



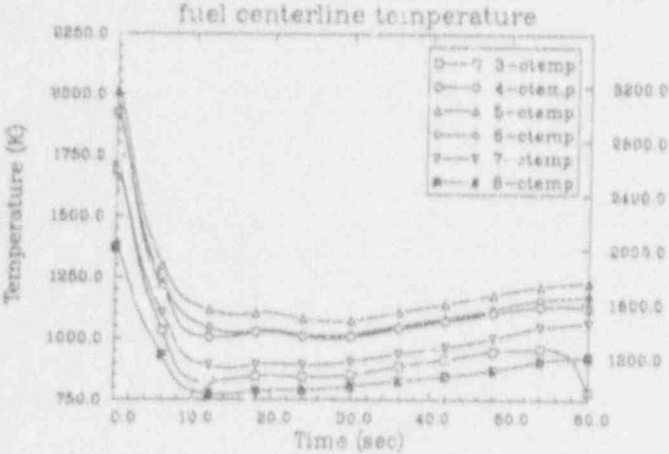
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.2
cladding hoop strain



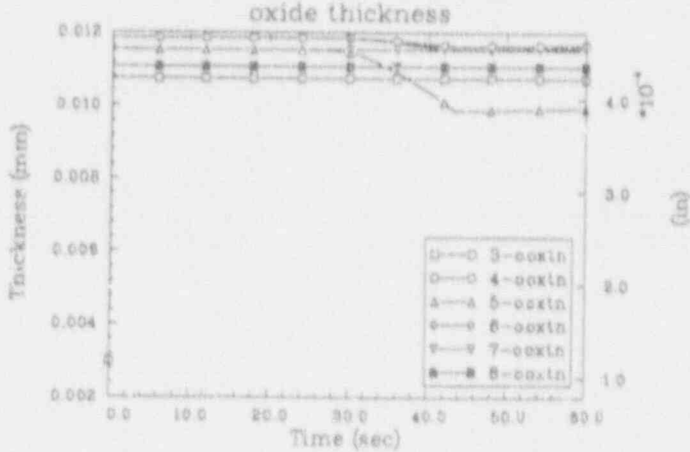
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.2
cladding surface temperature



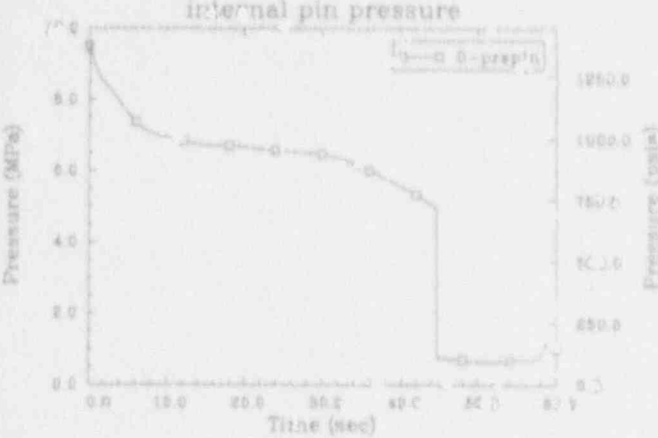
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.2
fuel centerline temperature



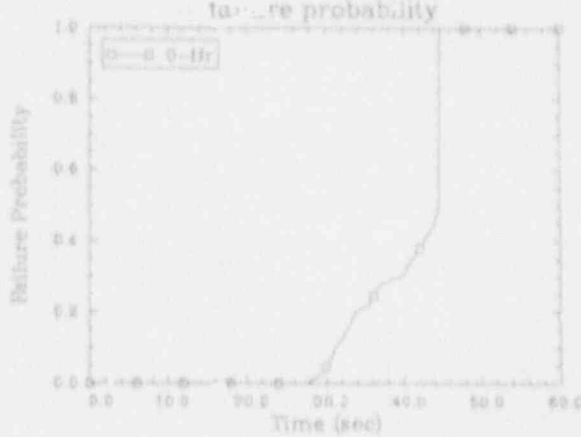
SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.2
oxide thickness



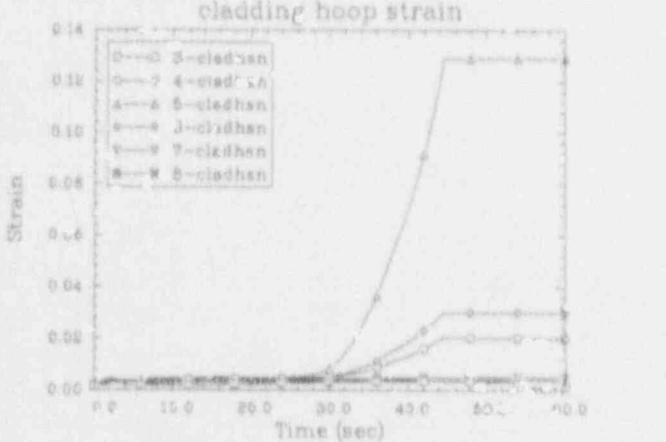
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.2
internal pin pressure



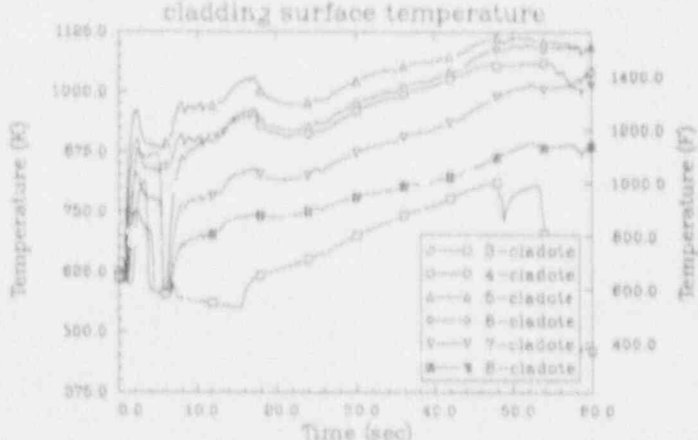
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.2
failure probability



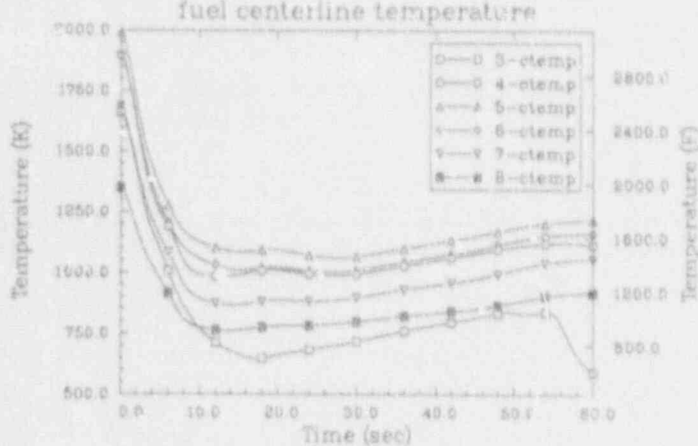
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.2
cladding hoop strain



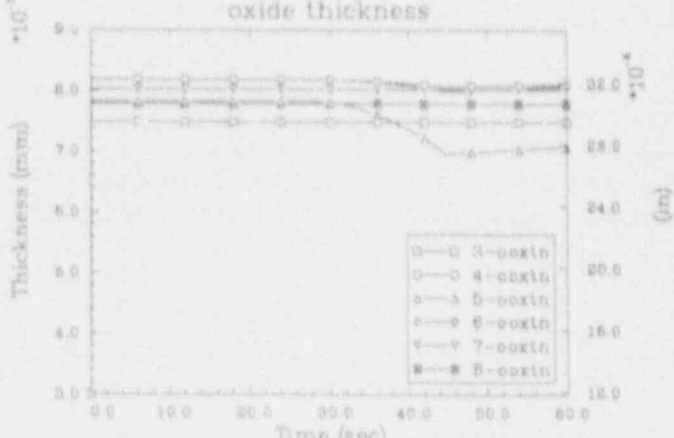
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.2
cladding surface temperature

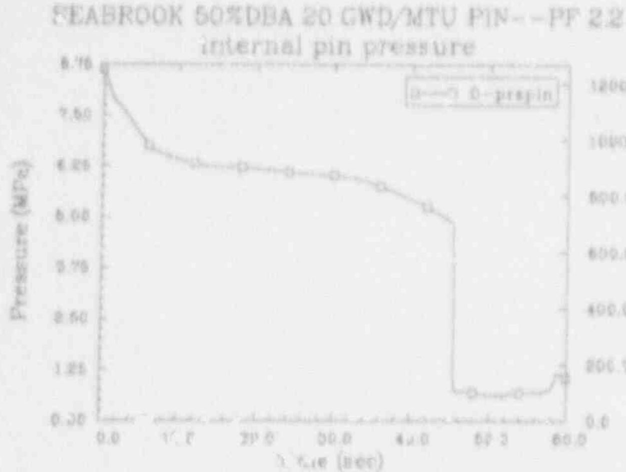


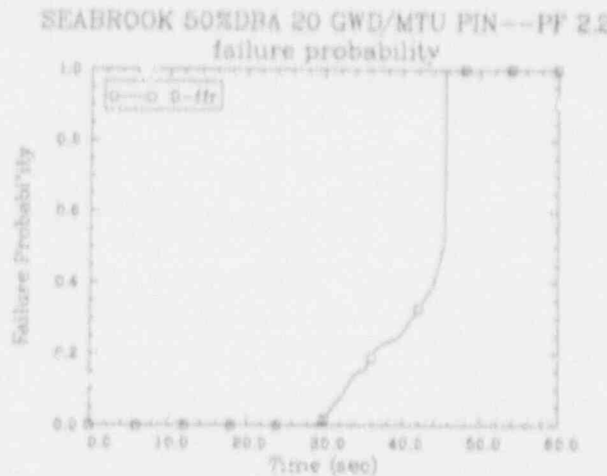
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.2
fuel centerline temperature

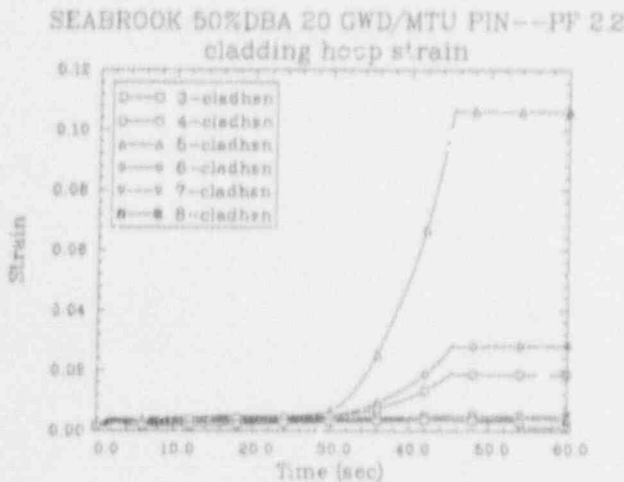


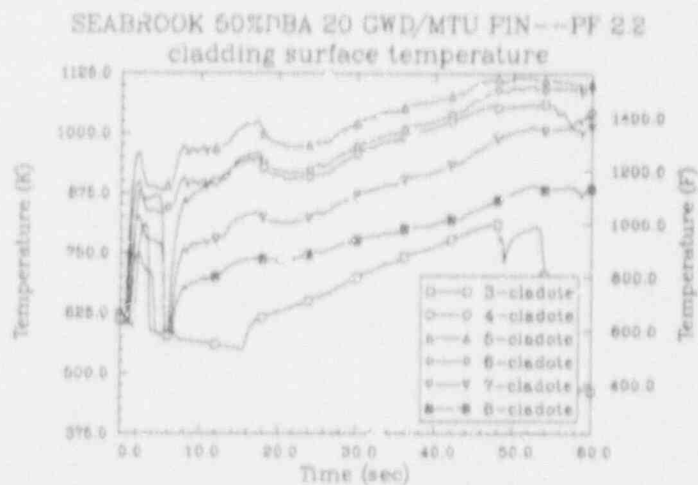
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.2
oxide thickness

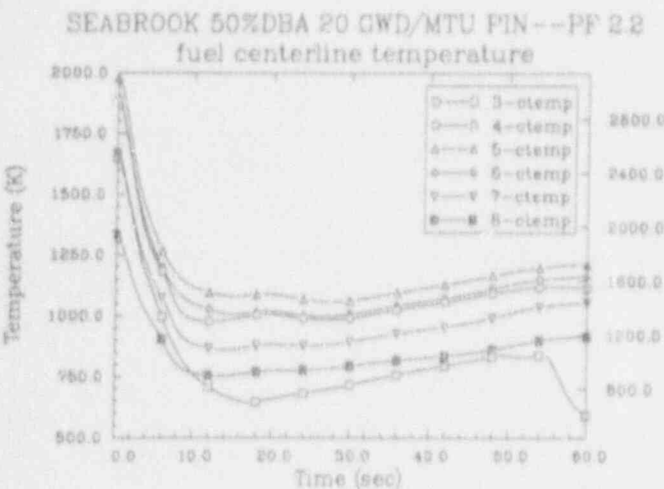


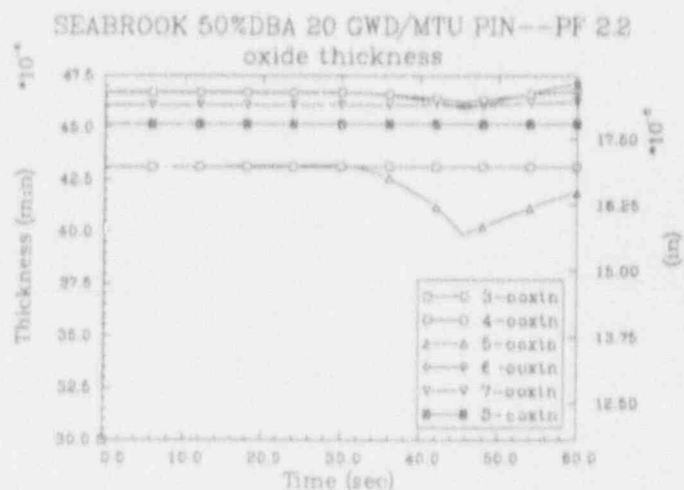

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.2
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

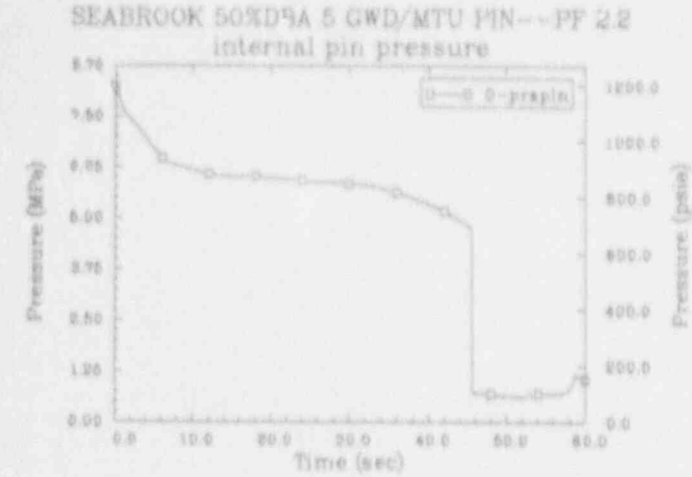

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.2
failure probability
0-ffr
Failure Probability
Time (sec)

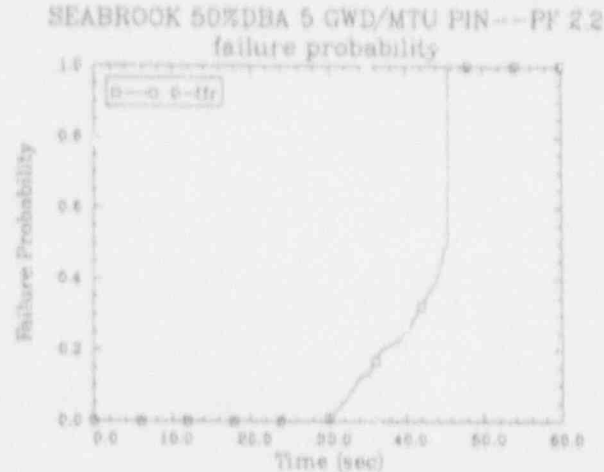

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.2
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

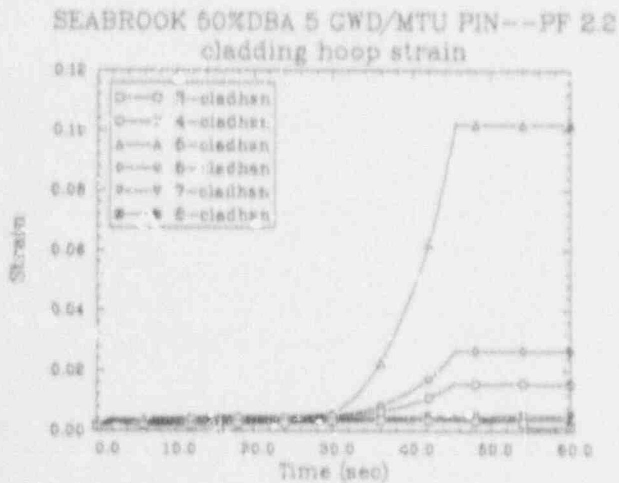

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.2
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

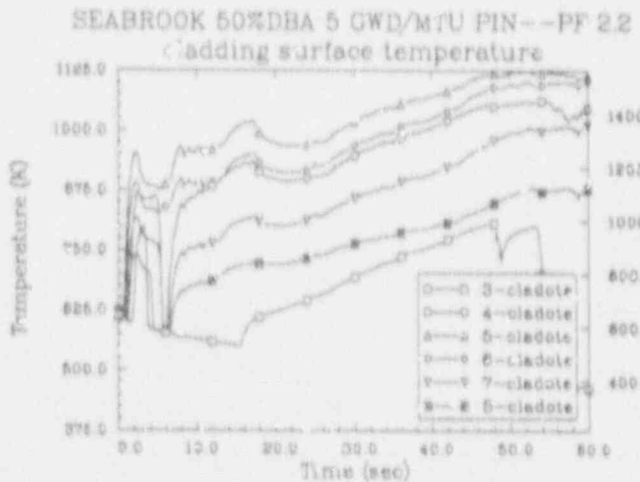

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.2
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

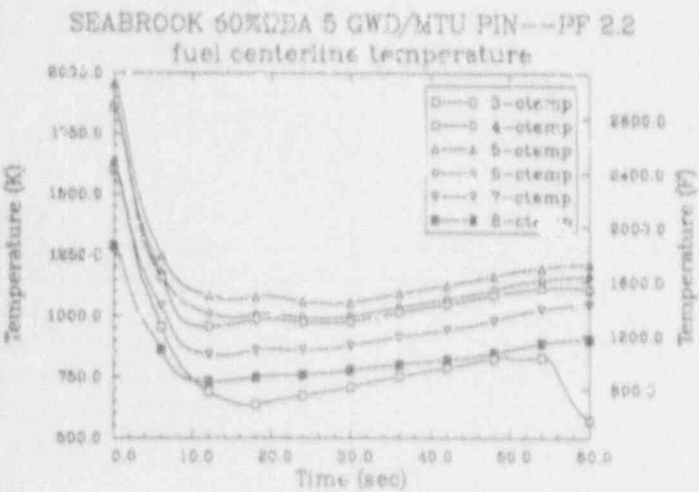

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.2
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
7-ooxtn
Thickness (mm)
(in)
Time (sec)

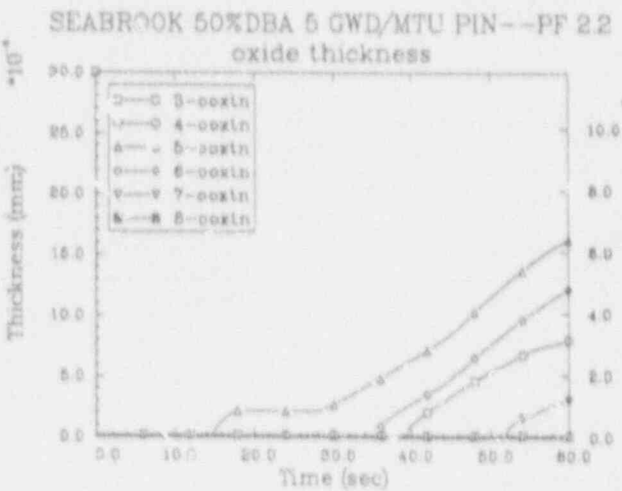

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.2
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

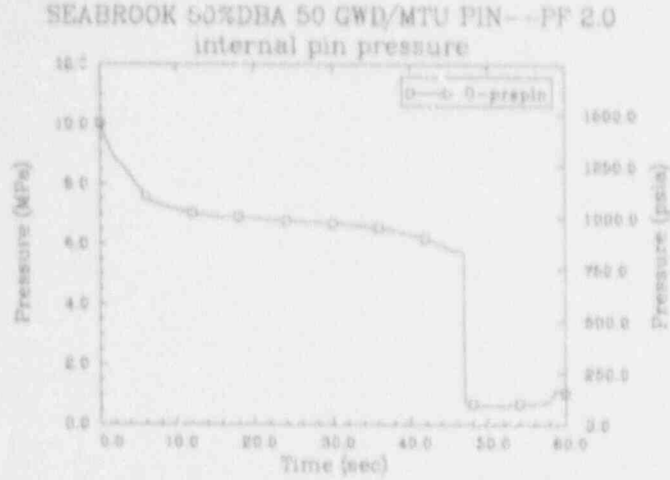

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.2
failure probability
Failure Probability
Time (sec)

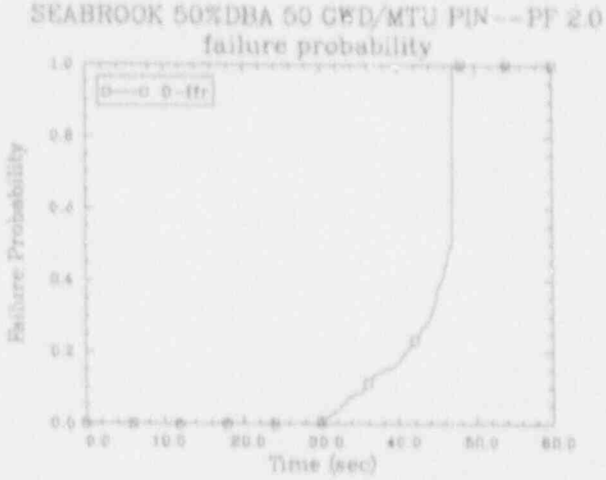

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.2
cladding hoop strain
Strain
Time (sec)

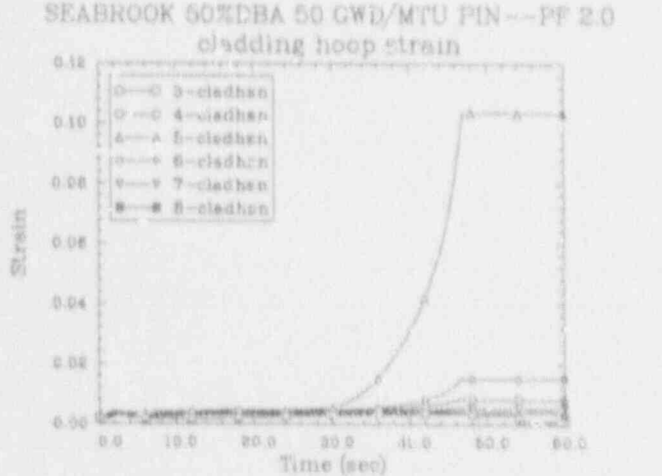

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.2
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)

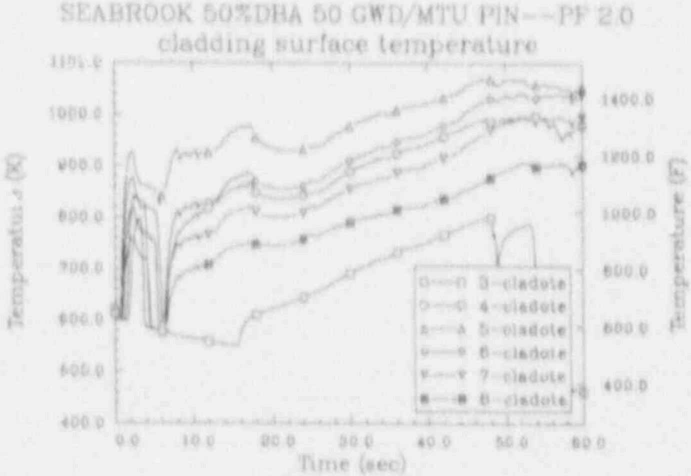

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.2
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)

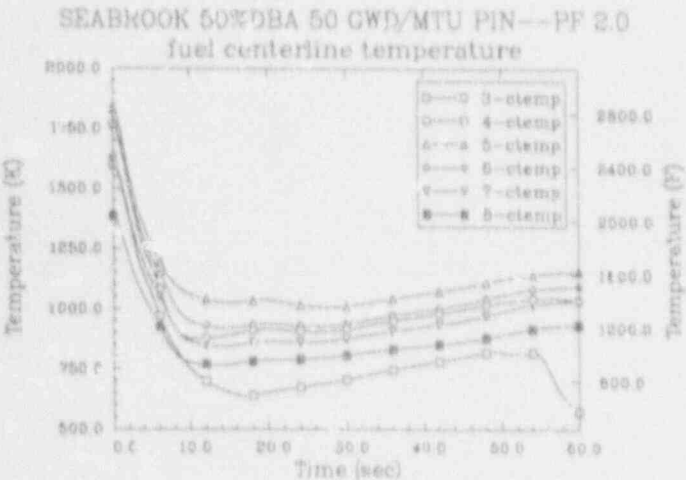

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.2
oxide thickness
Thickness (mm)
(in)
Time (sec)

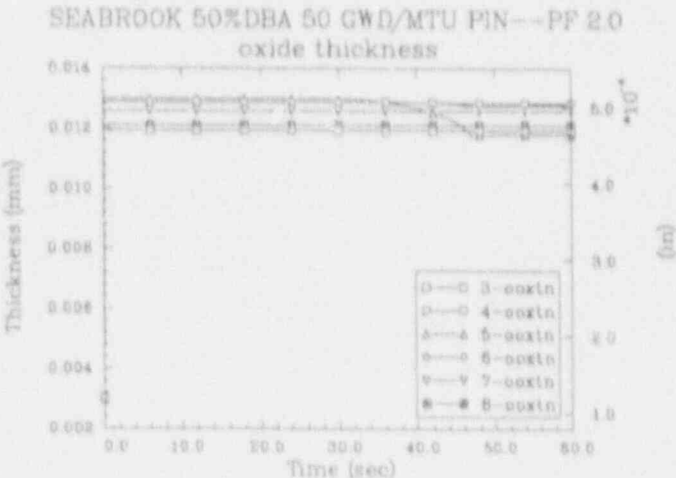

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

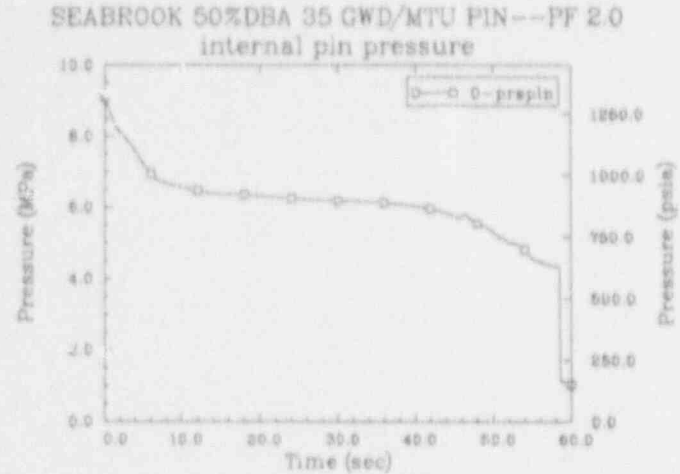

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

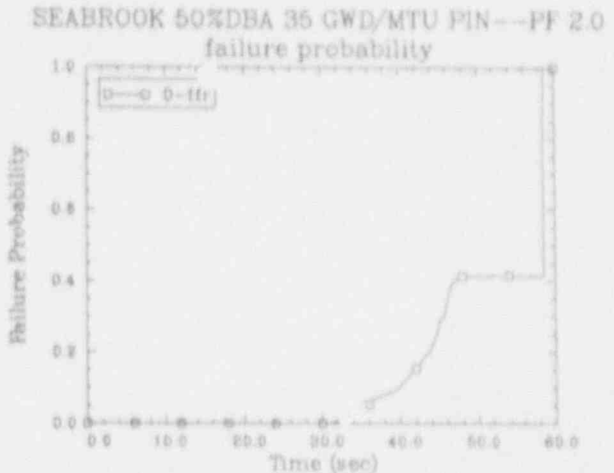

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

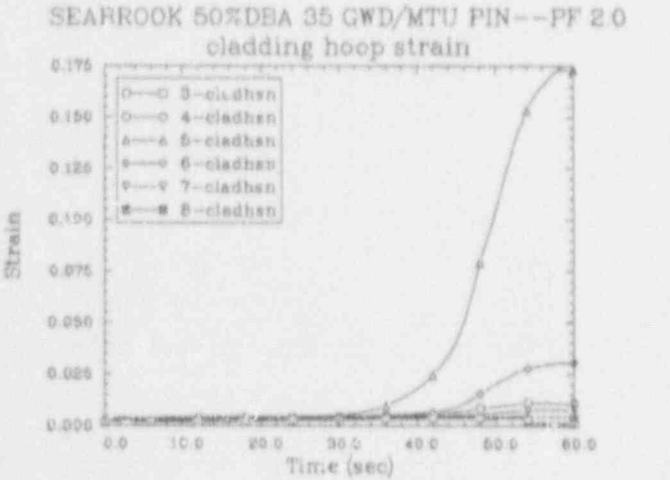

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (F)
Time (sec)

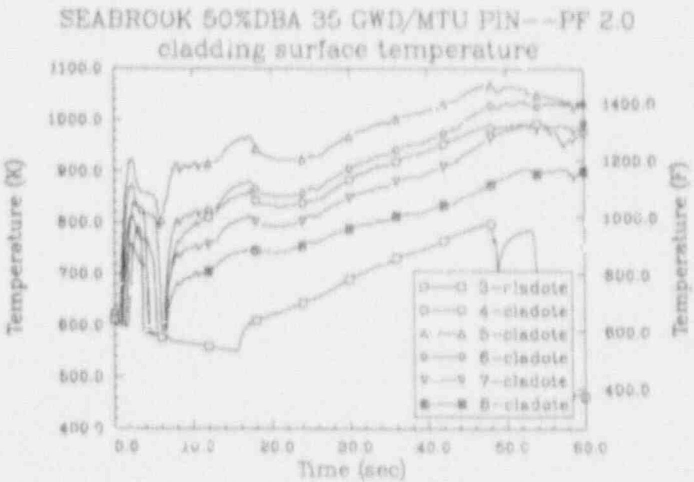

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

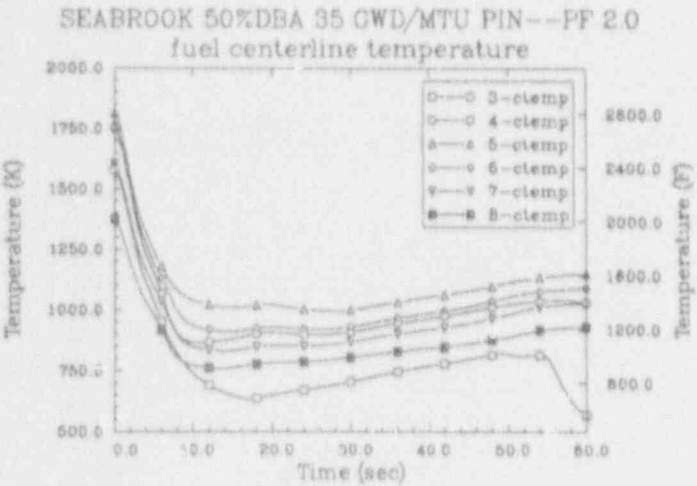

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

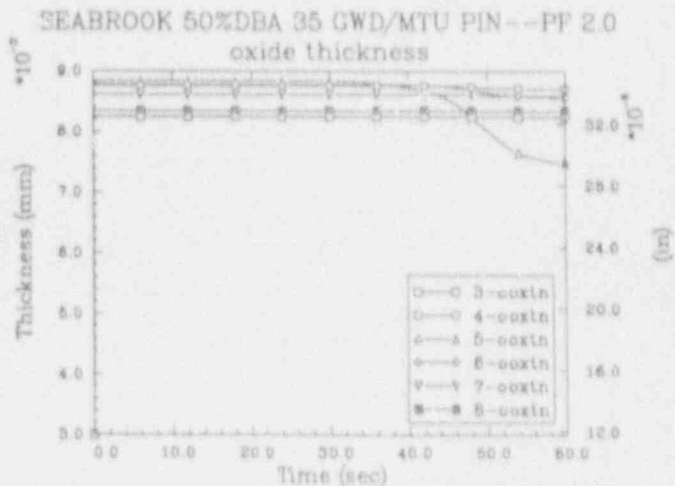

SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.0
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.0
failure probability
0-ffr
Failure Probability
Time (sec)

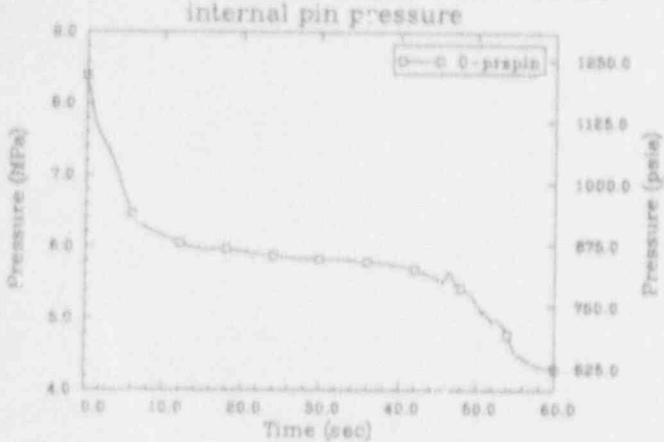

SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.0
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.0
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

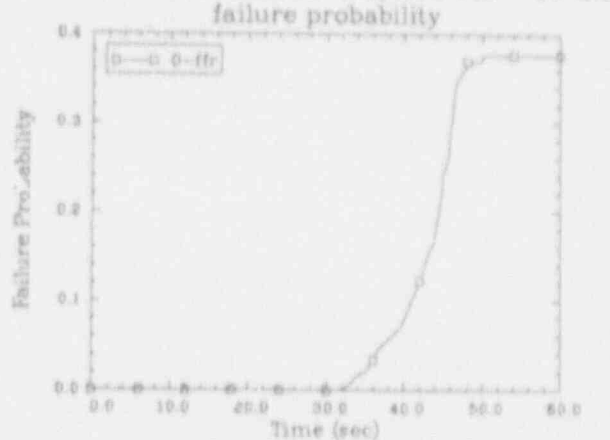

SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.0
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 50%DBA 35 GWD/MTU PIN--PF 2.0
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

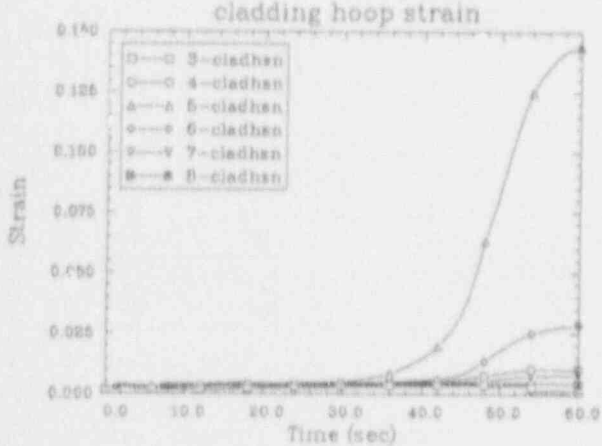
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.0
internal pin pressure



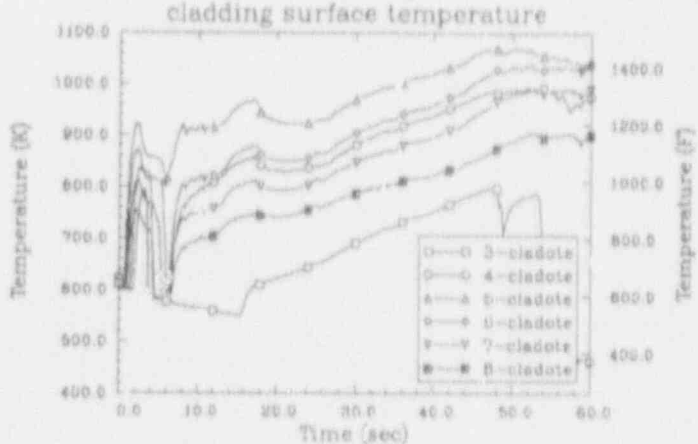
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.0
failure probability



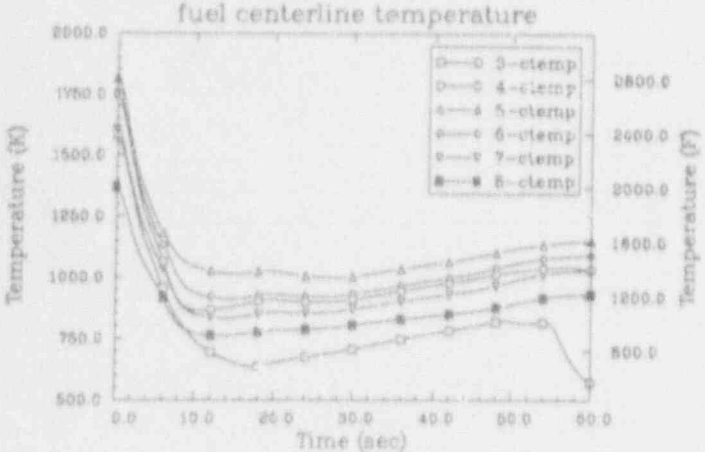
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.0
cladding hoop strain



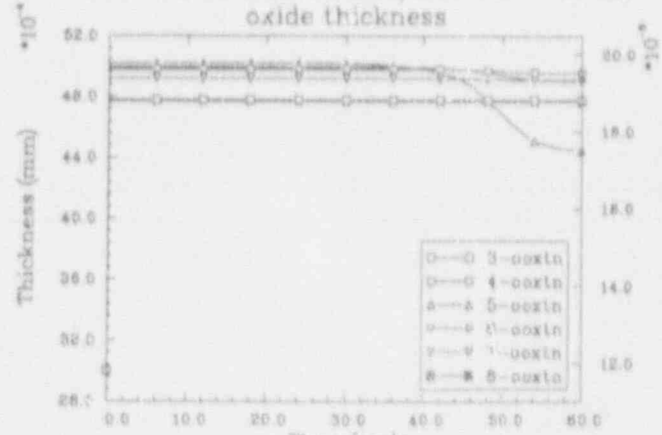
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.0
cladding surface temperature

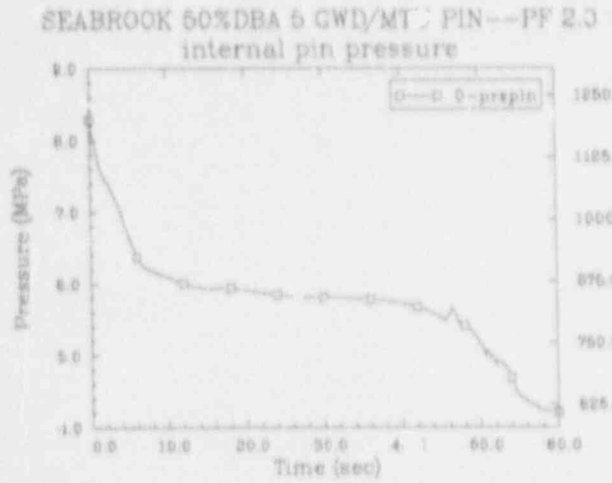


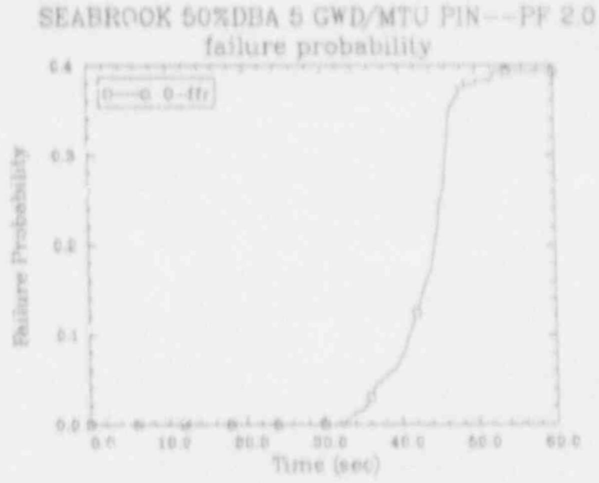
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.0
fuel centerline temperature

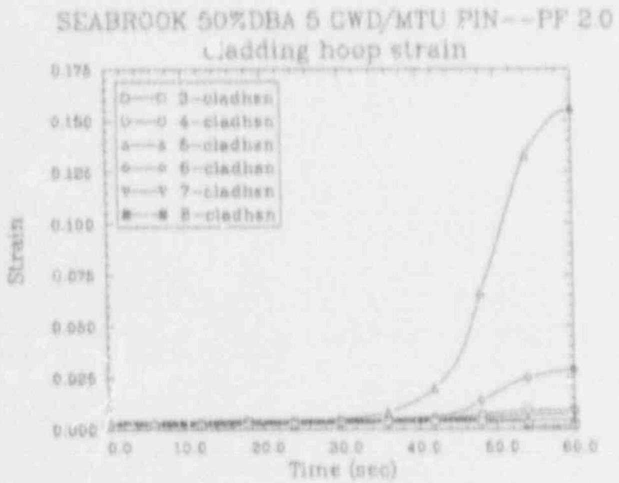


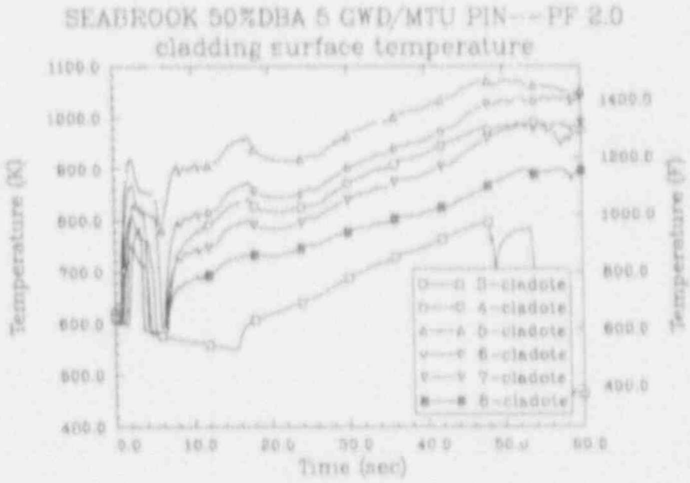
SEABROOK 50%DBA 20 GWD/MTU PIN--PF 2.0
oxide thickness

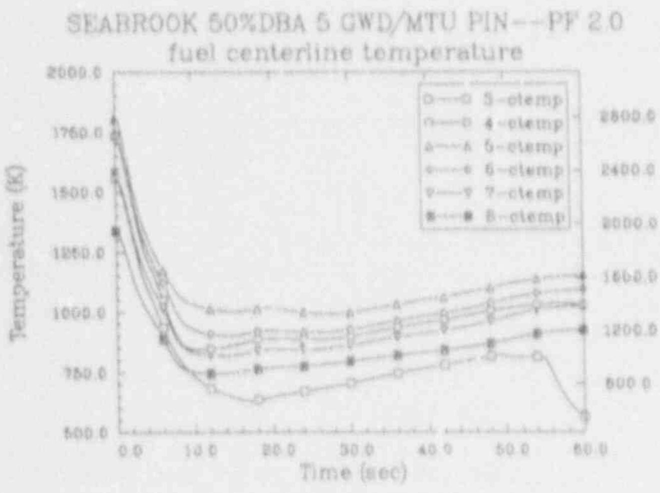


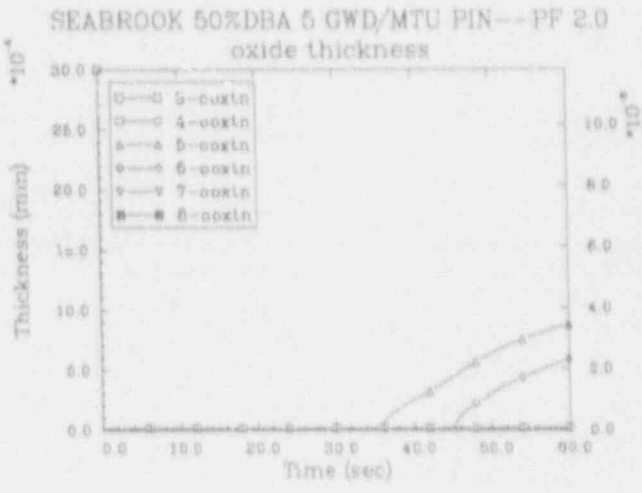

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.0
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

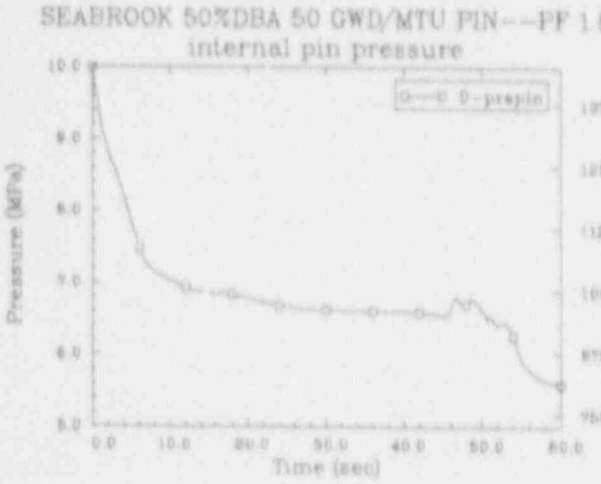

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.0
failure probability
Failure Probability
Time (sec)

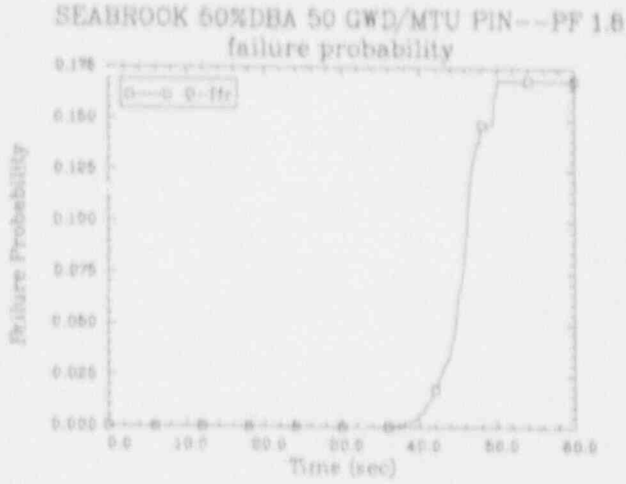

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.0
cladding hoop strain
Strain
Time (sec)

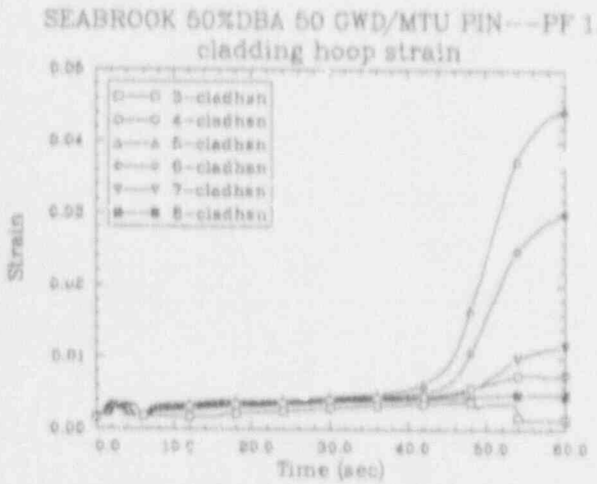

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.0
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)

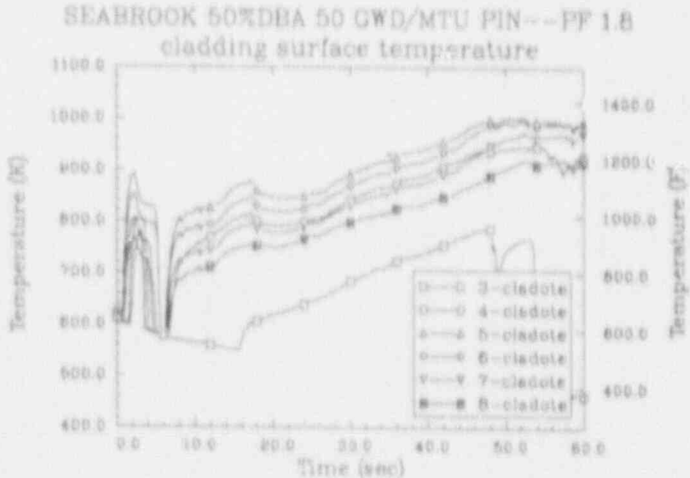

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.0
fuel centerline temperature
Temperature (K)
Time (sec)

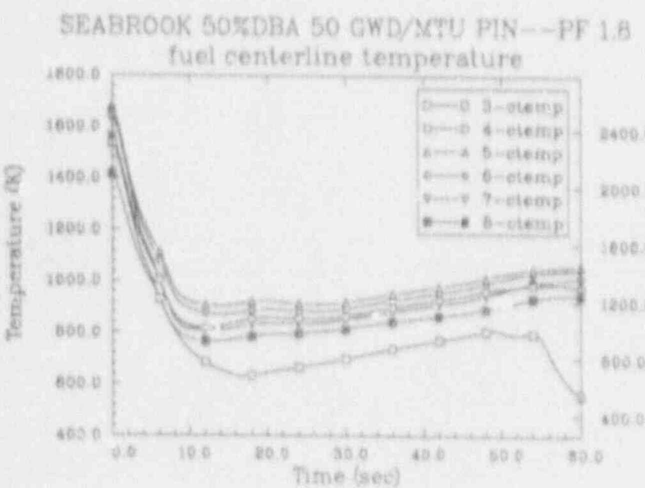

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 2.0
oxide thickness
Thickness (mm)
(in)
Time (sec)

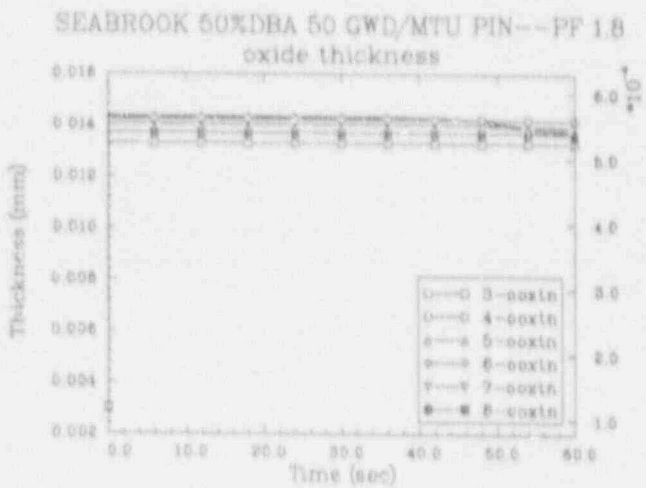

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 50%DBA 50 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

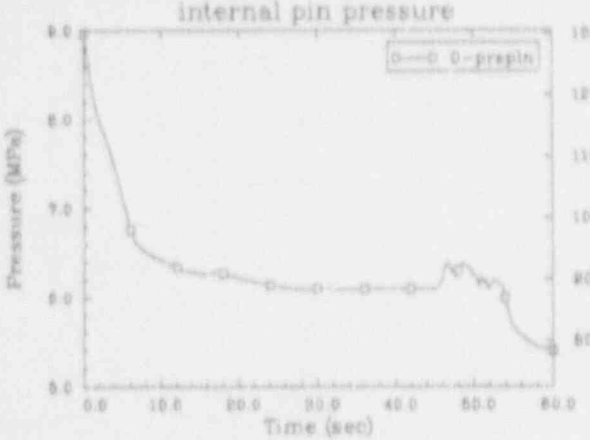

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 50%DBA 50 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

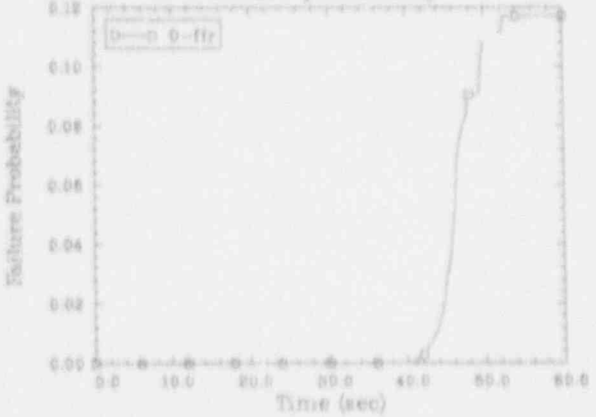

SEABROOK 50%DBA 50 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 50%DBA 50 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
Thickness (mm)
(in)
Time (sec)

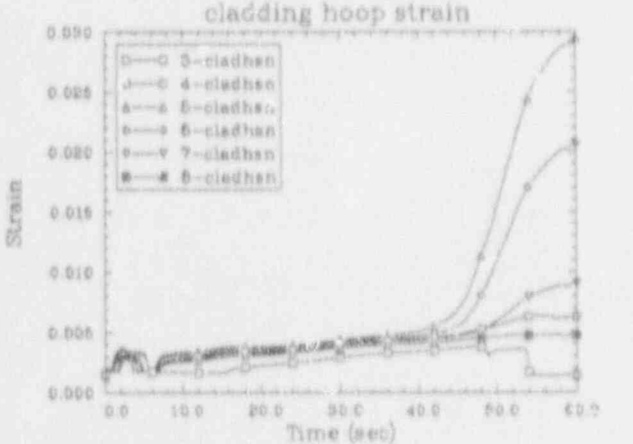
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 1.8
internal pin pressure



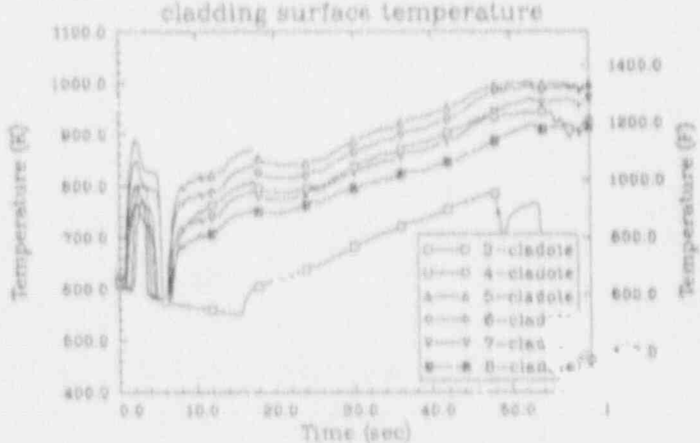
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 1.8
failure probability



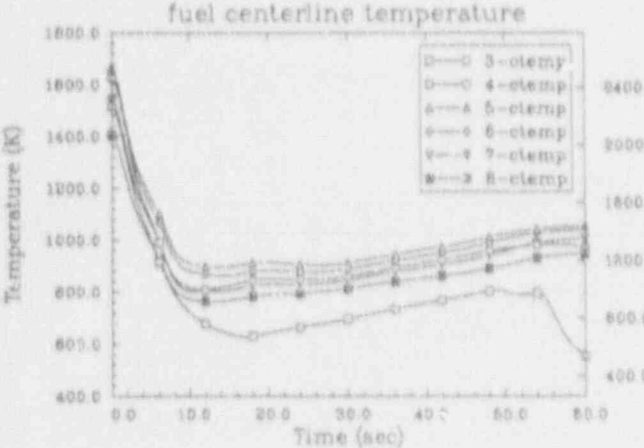
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 1.8
cladding hoop strain



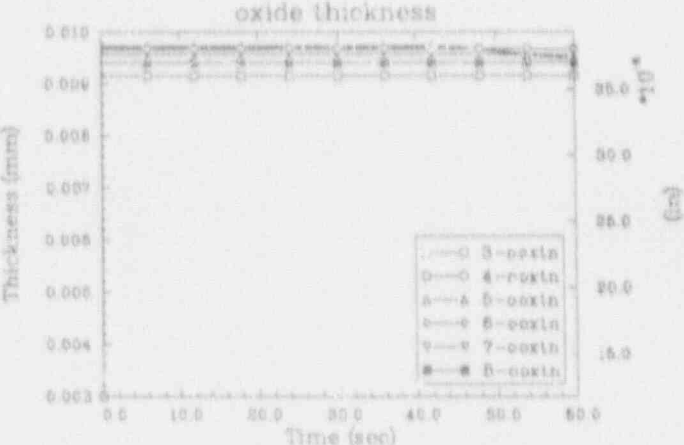
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 1.8
cladding surface temperature

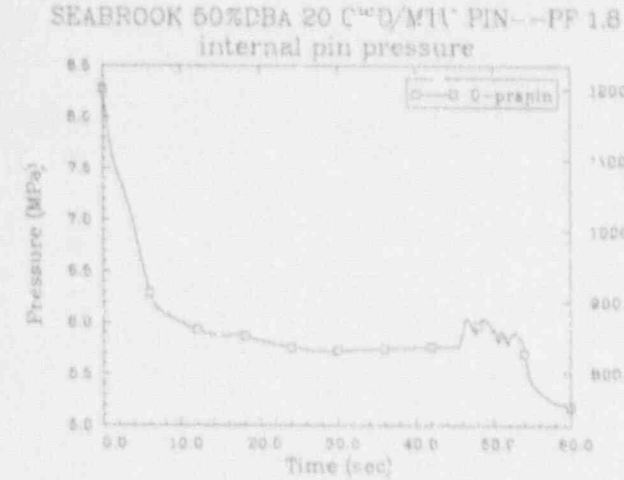


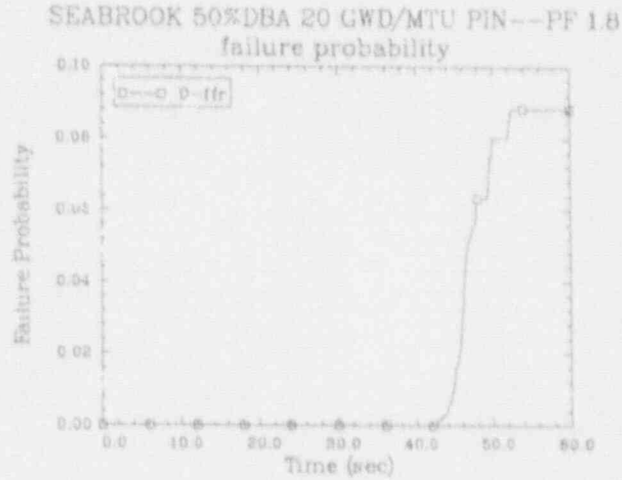
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 1.8
fuel centerline temperature

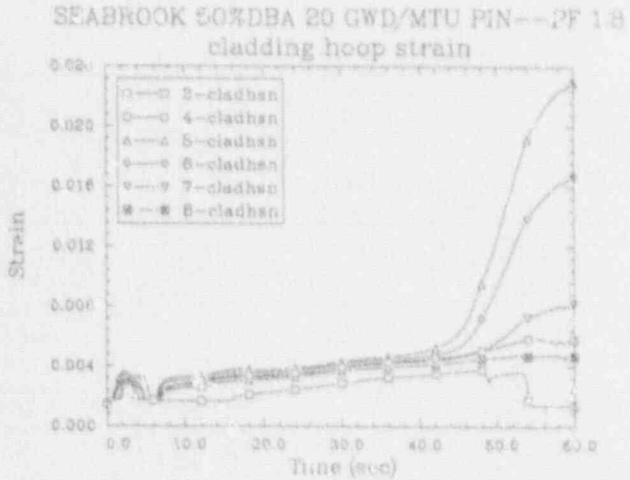


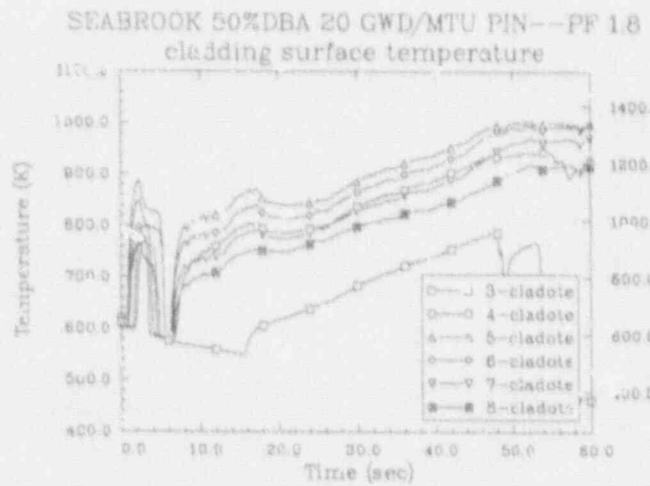
SEABROOK 50%DBA 35 GWD/MTU PIN--PF 1.8
oxide thickness

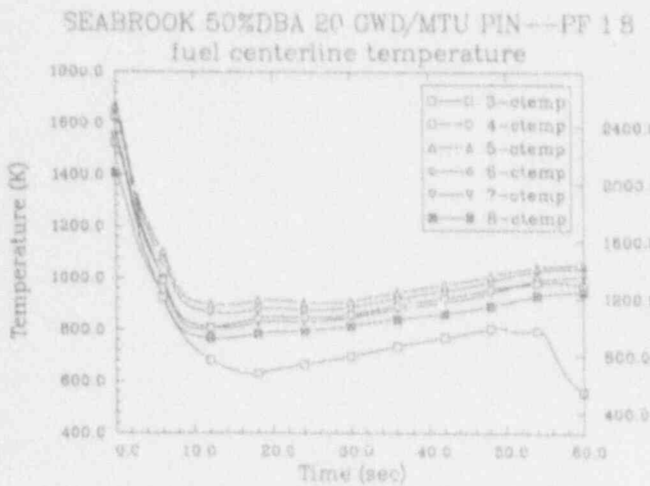


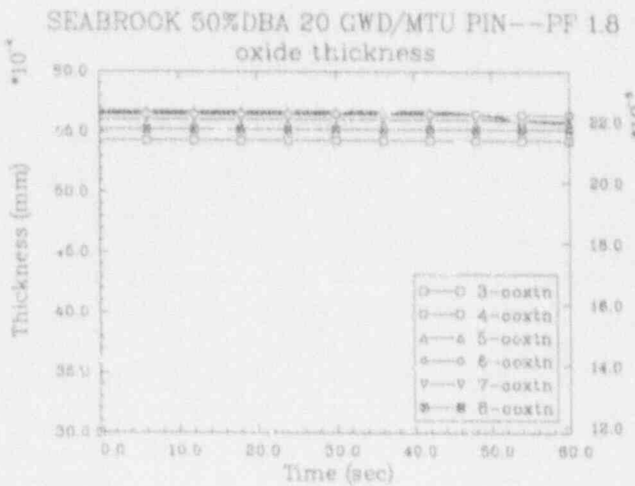

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

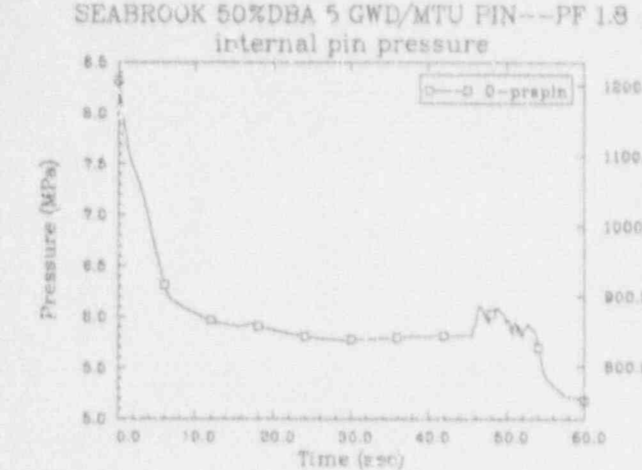

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

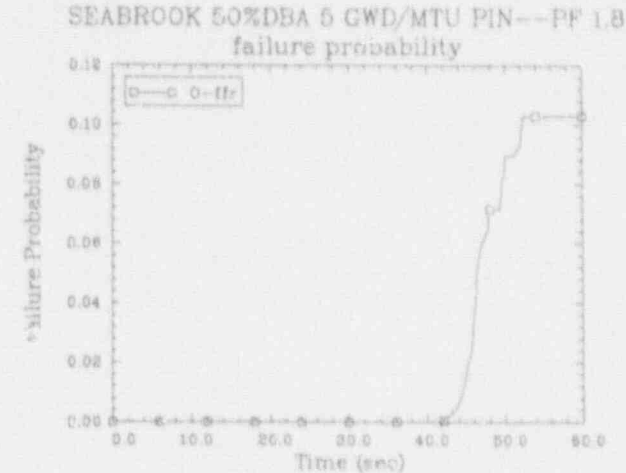

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 1.8
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

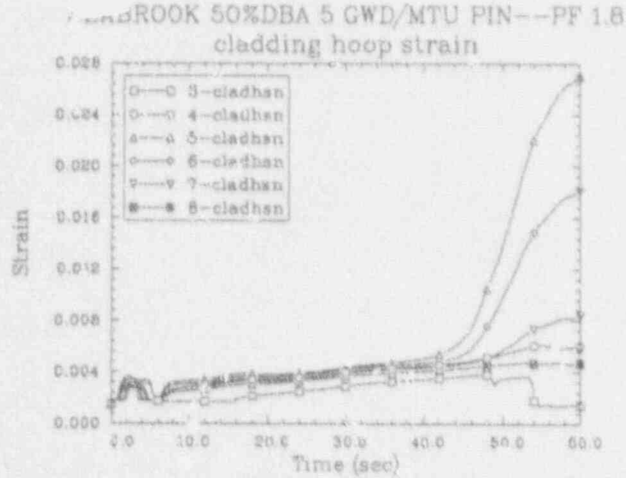

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

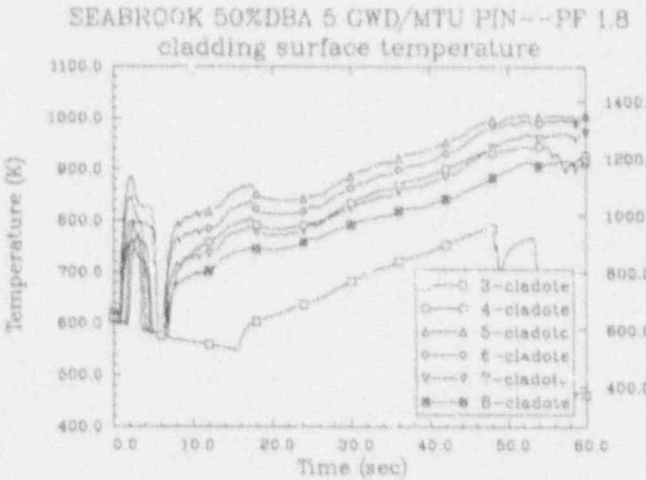

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

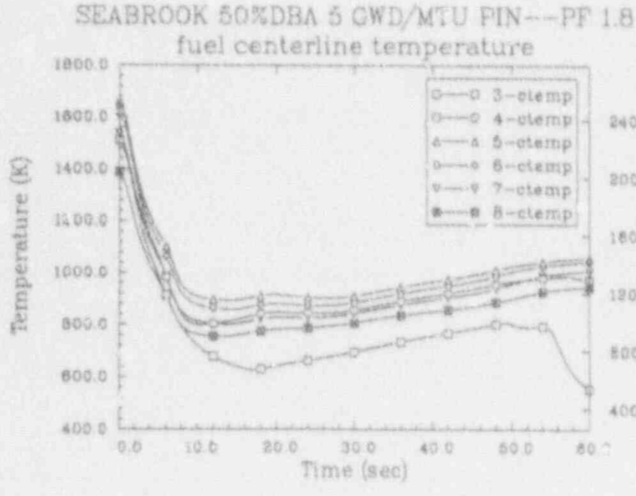

SEABROOK 50%DBA 20 GWD/MTU PIN--PF 1.8
oxide thickness
3-coxtn
4-coxtn
5-coxtn
6-coxtn
7-coxtn
8-coxtn
Thickness (mm)
(in)
Time (sec)

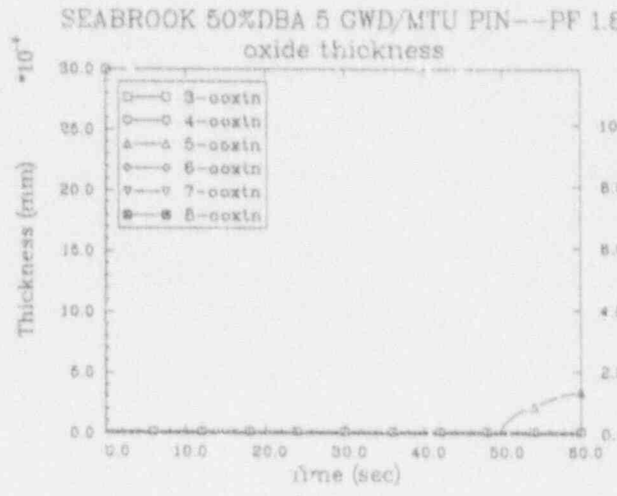

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 1.8
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 50%DBA 5 GWD/MTU PIN--PF 1.8
failure probability
0-ffr
Failure Probability
Time (sec)

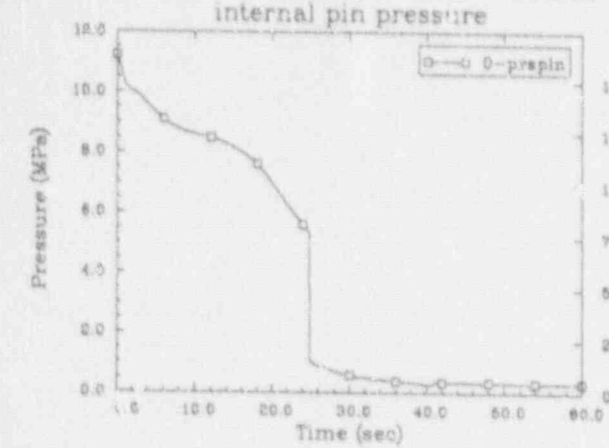

cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 50%DBA 5 GWD/MTU PIN--PF 1.8
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Temperature (F)
Time (sec)

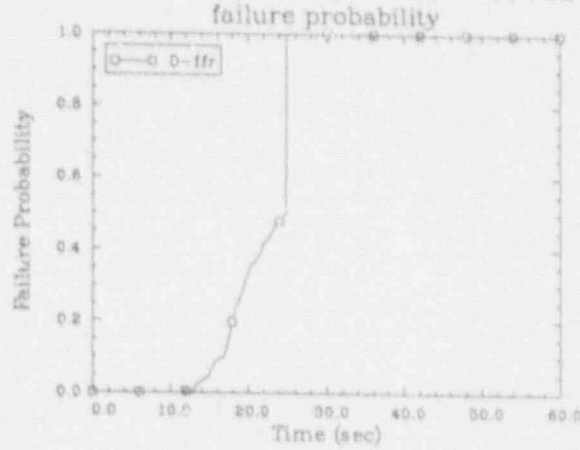

SEABROOK 50%DBA 5 GWD/MTU PIN--PF 1.8
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 50%DBA 5 GWD/MTU PIN--PF 1.8
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)

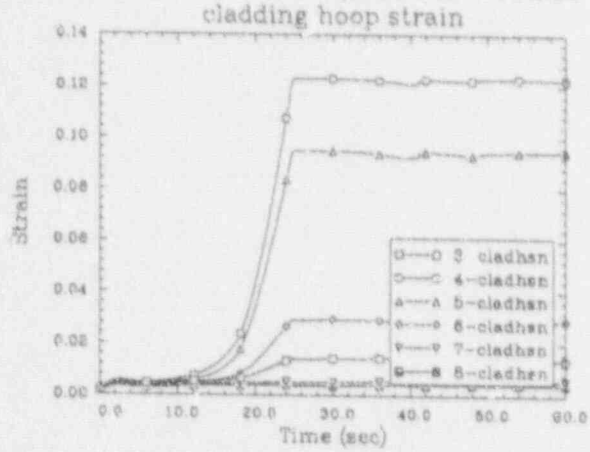
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/TRIP



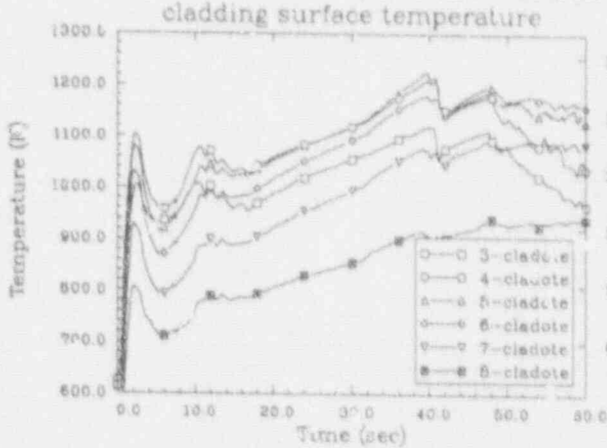
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/TRIP



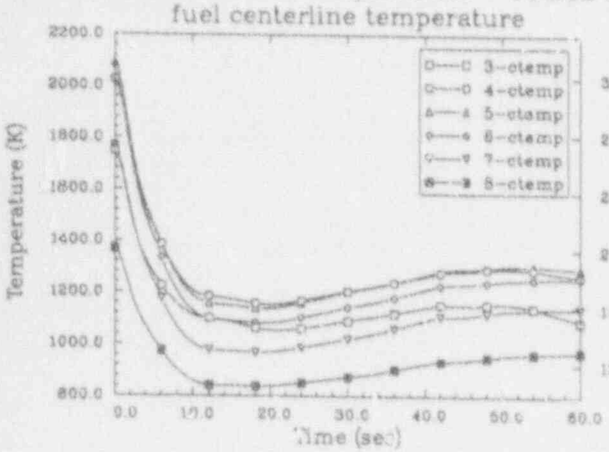
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/TRIP



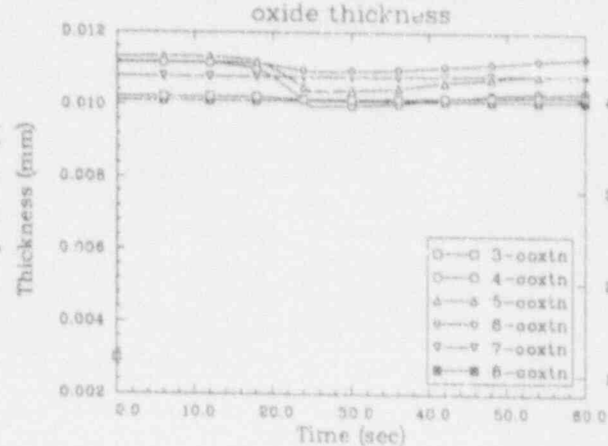
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/TRIP

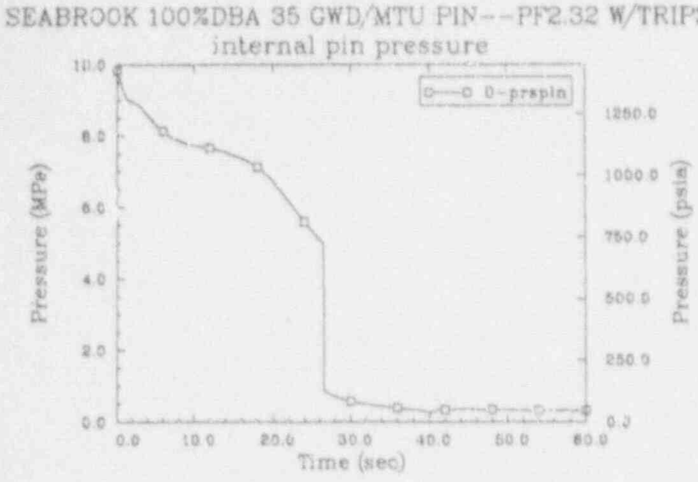


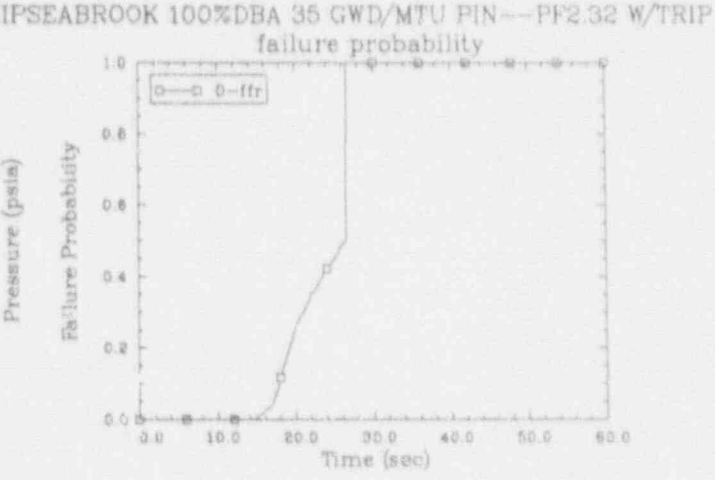
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/TRIP

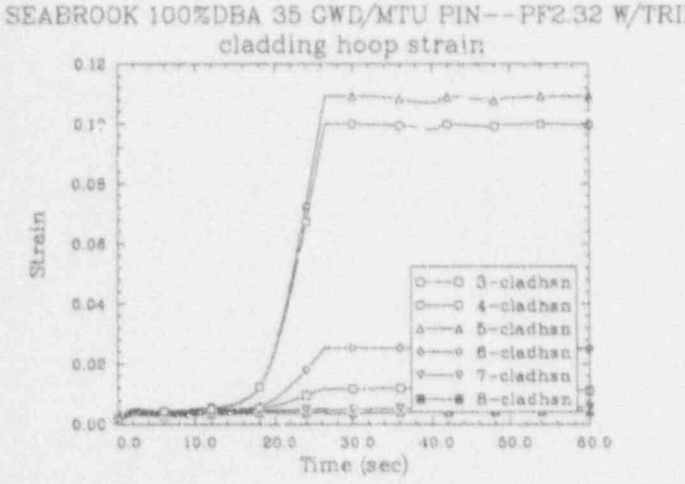


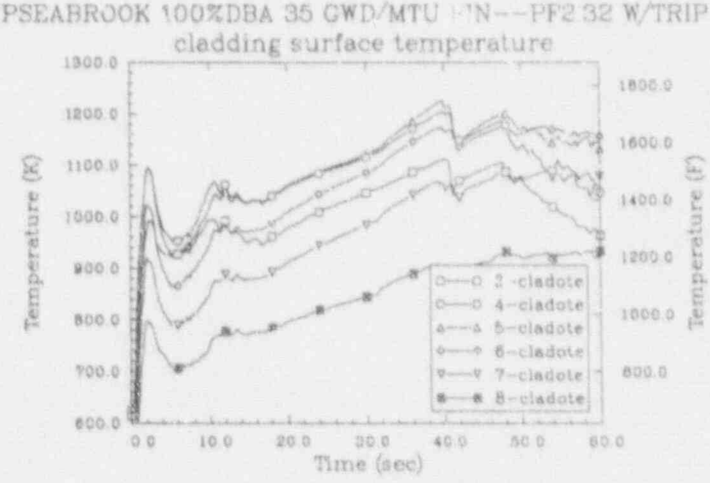
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/TRIP

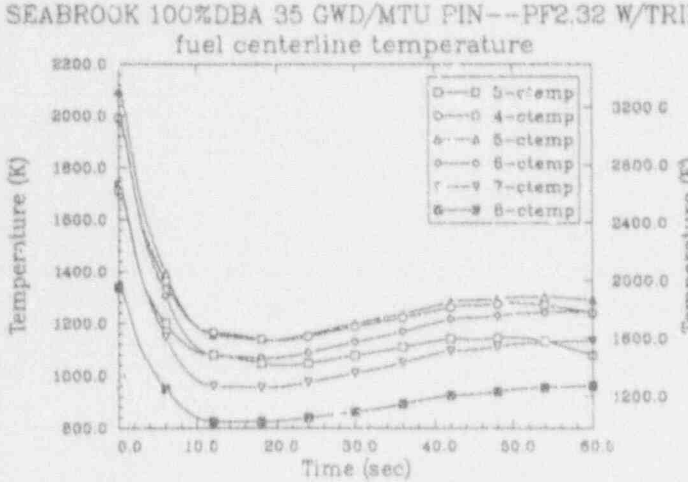


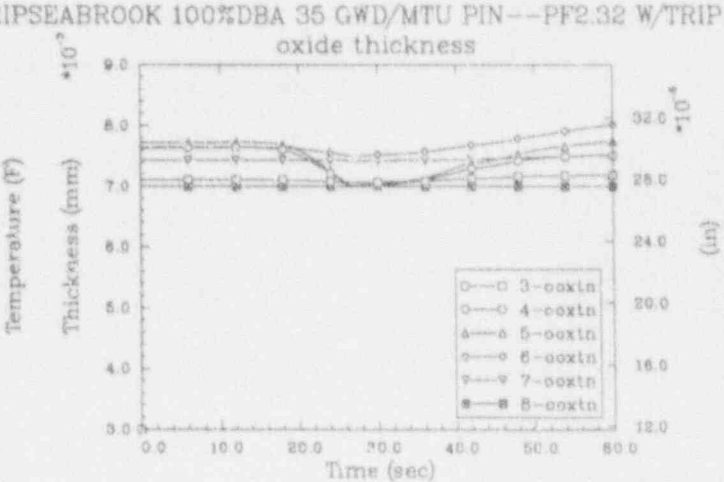

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

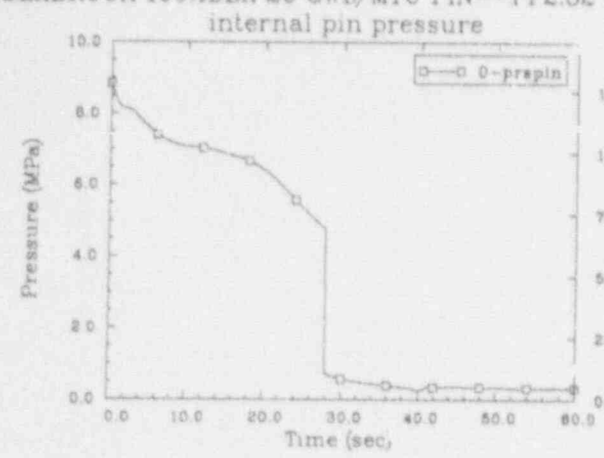

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

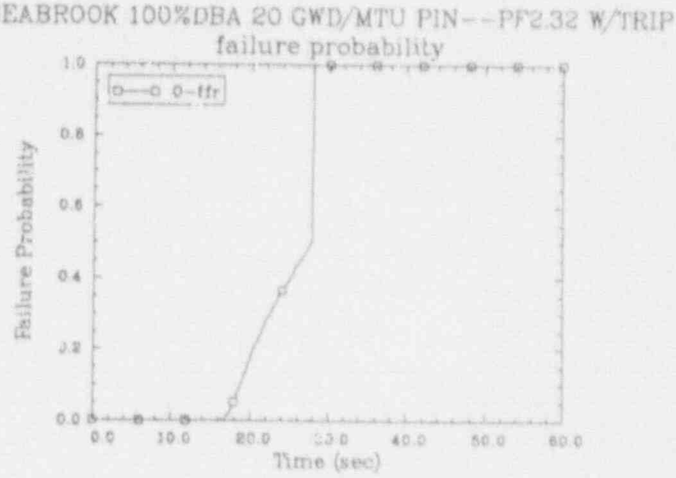

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

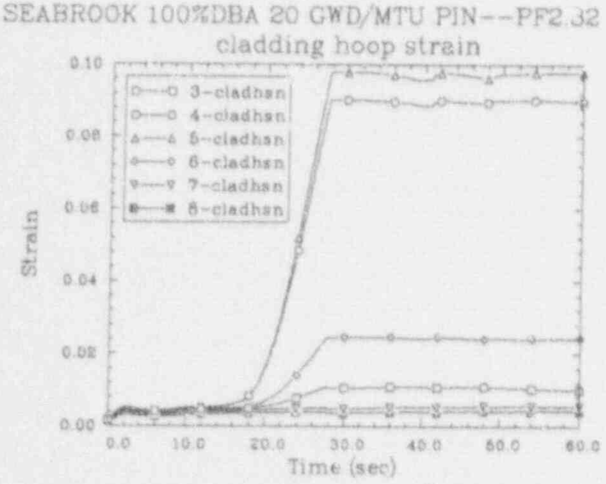

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

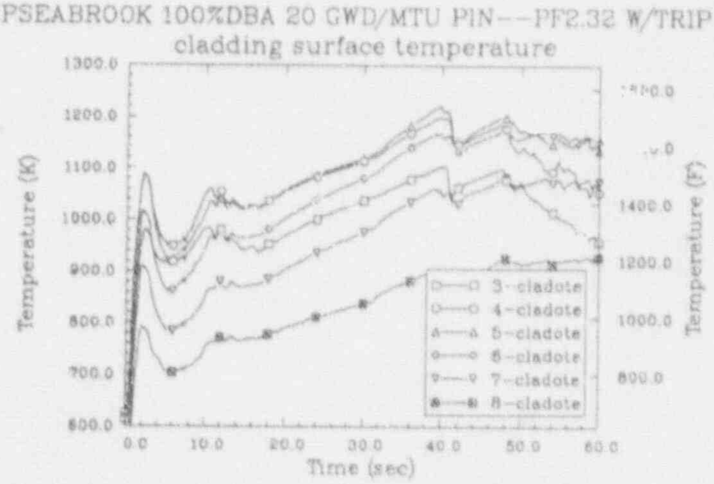

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

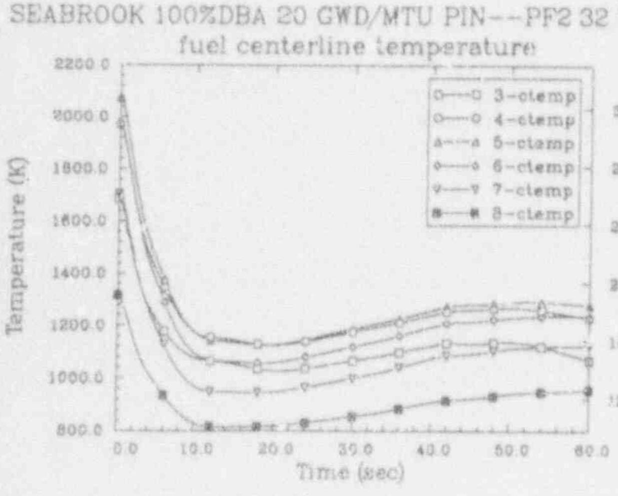

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

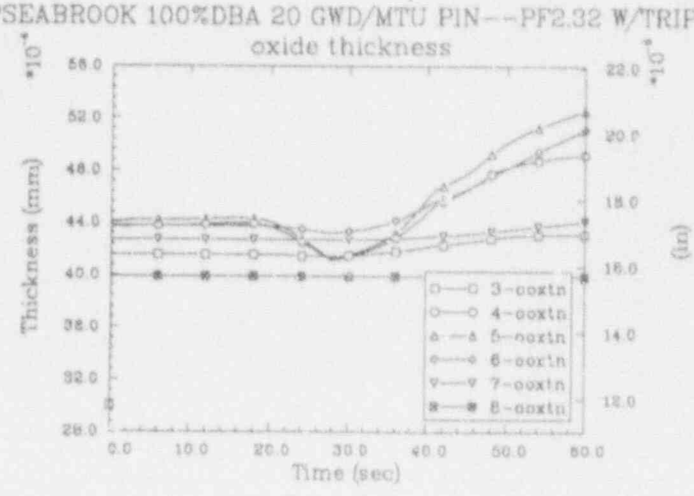

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

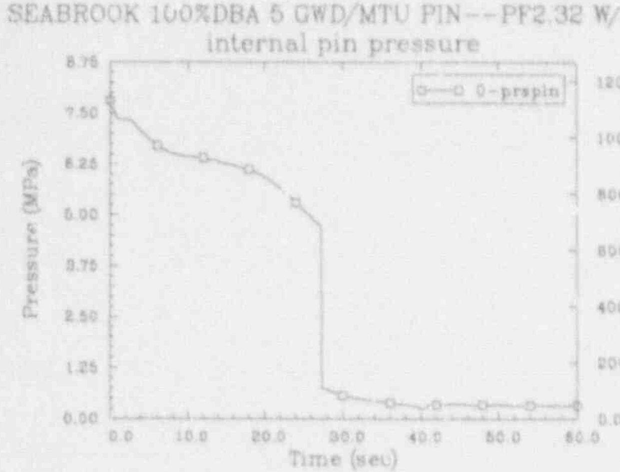

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

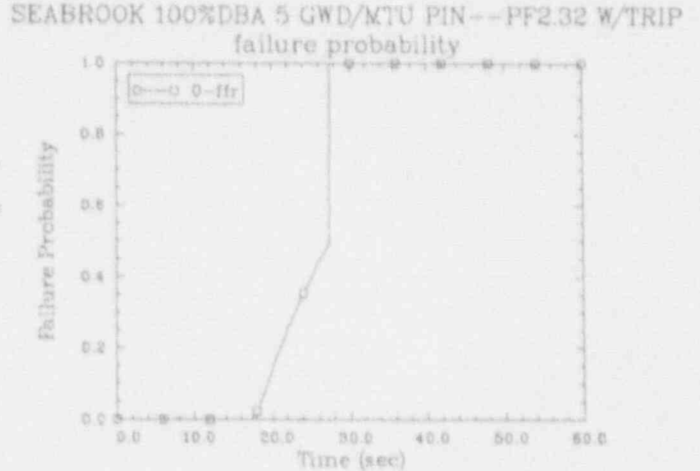

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

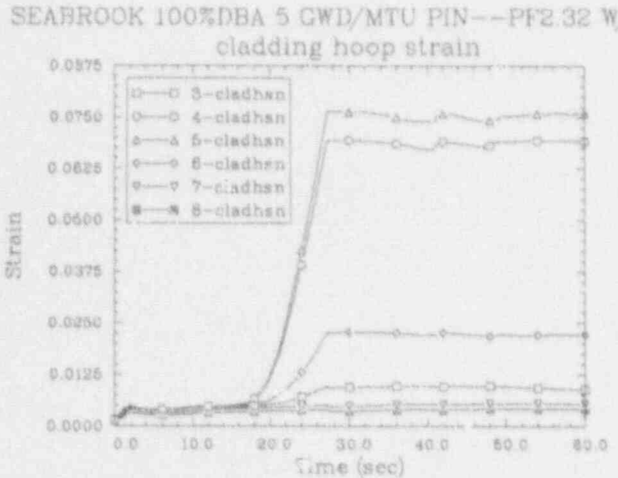

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

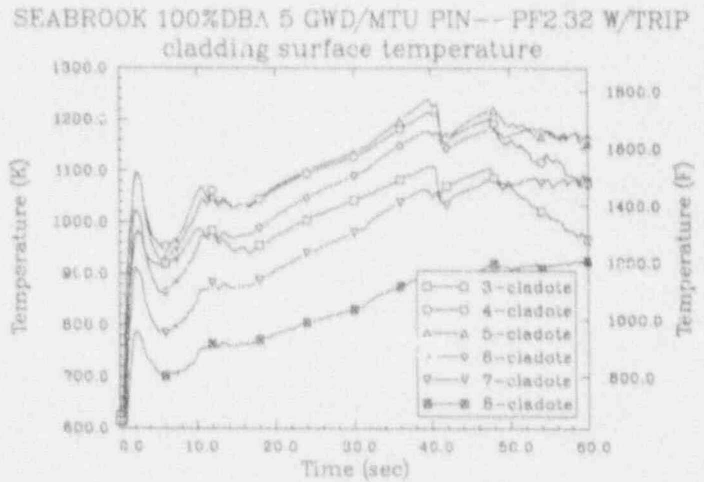

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

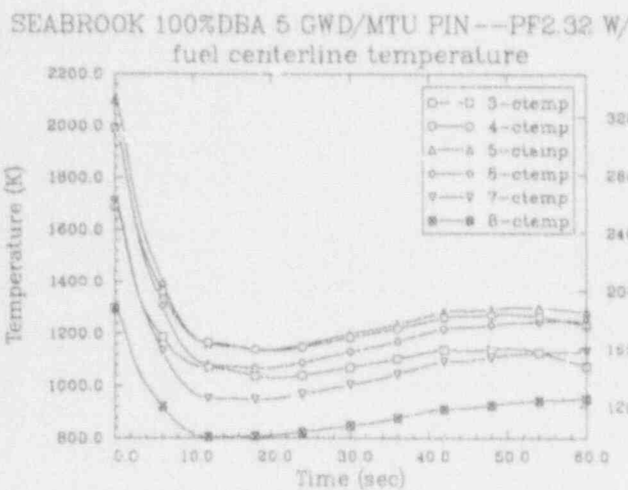

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

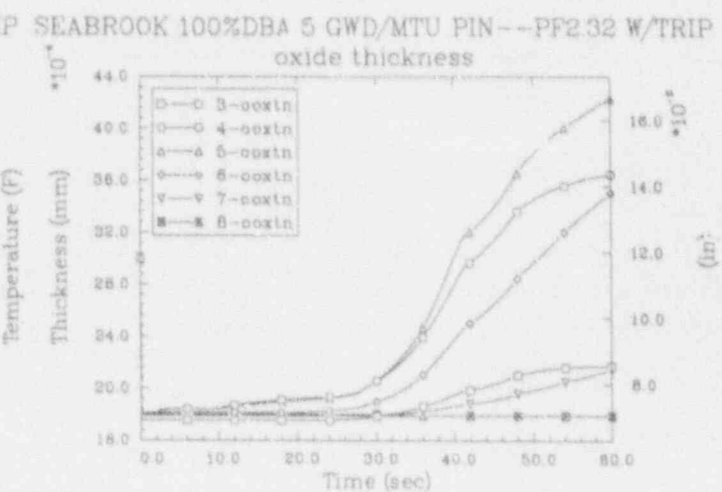

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

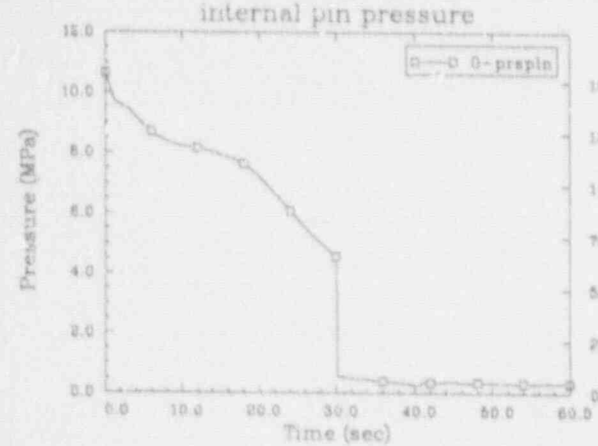

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

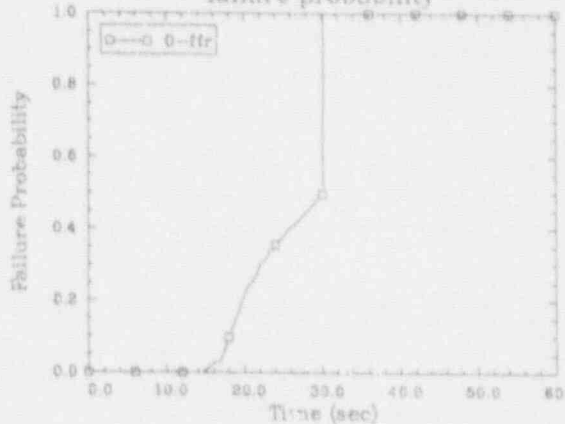

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

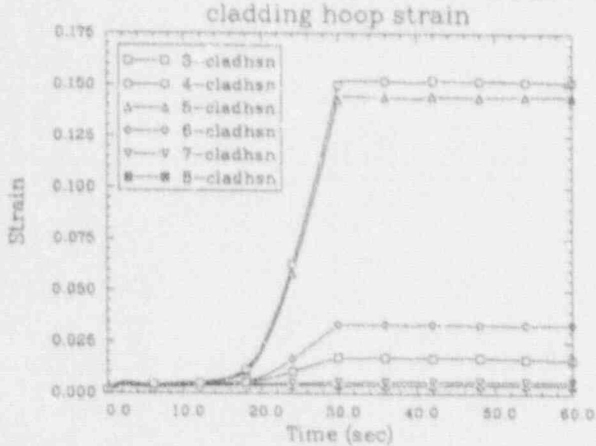
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/TRIP
internal pin pressure



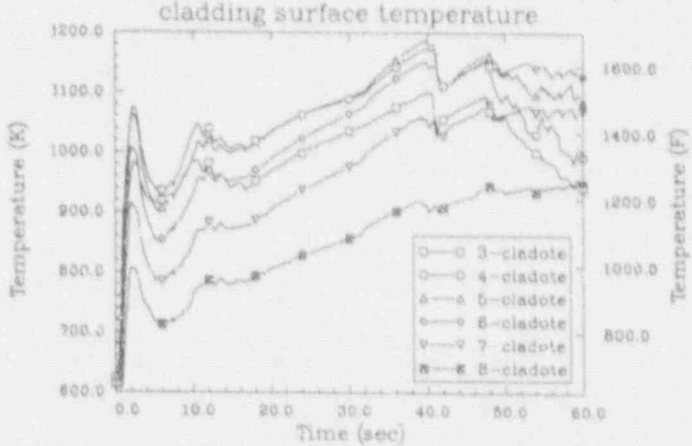
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/TRIP
failure probability



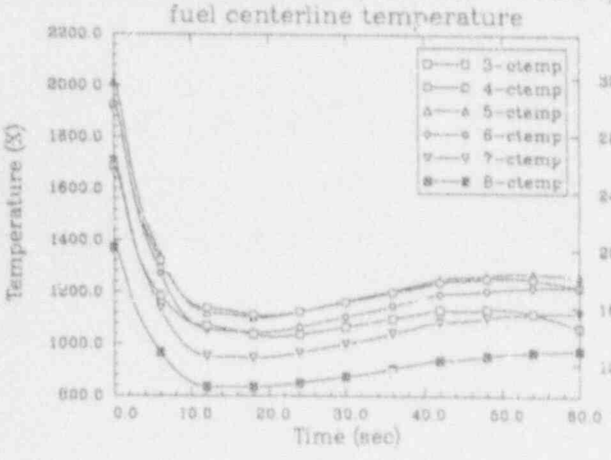
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/TRIP
cladding hoop strain



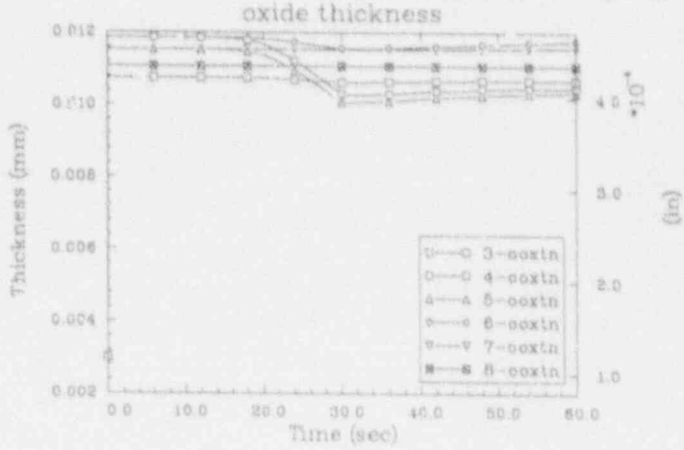
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/TRIP
cladding surface temperature



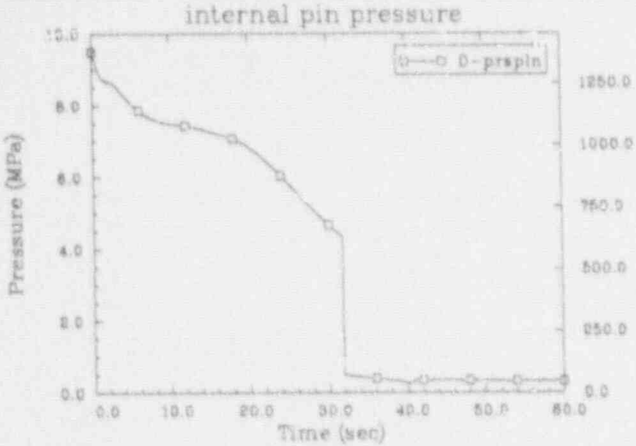
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/TRIP
fuel centerline temperature



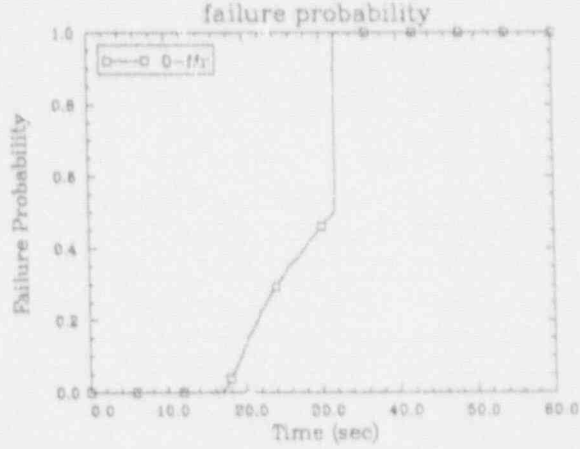
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/TRIP
oxide thickness



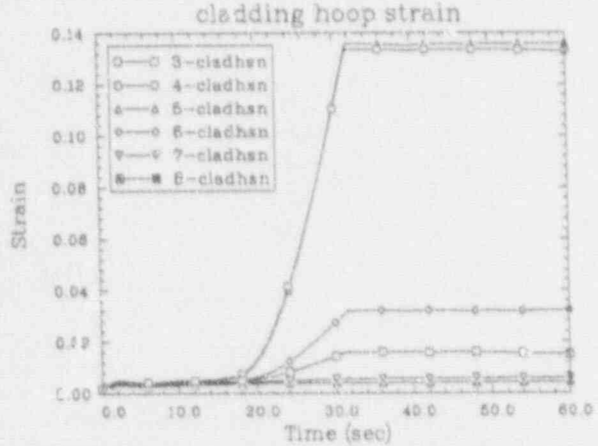
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/TRIP
internal pin pressure



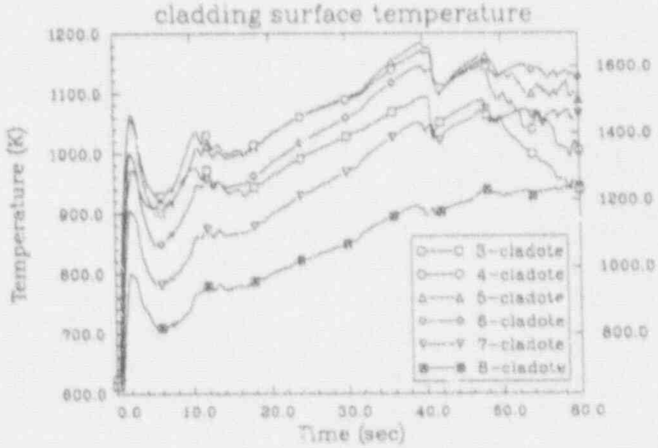
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/TRIP
failure probability



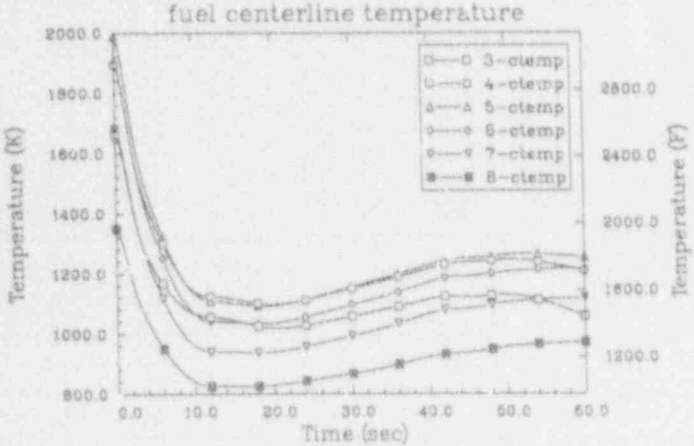
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/TRIP
cladding hoop strain



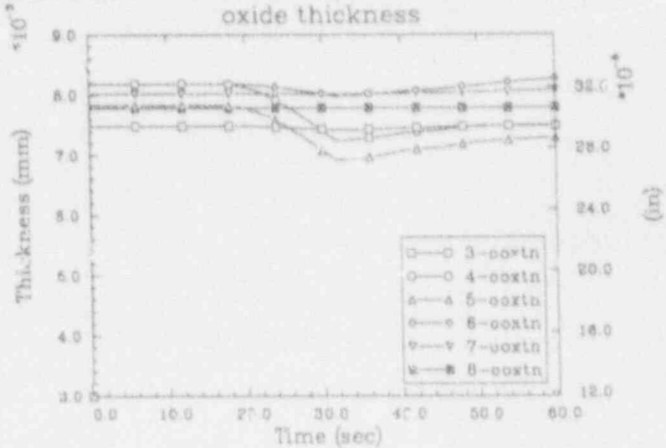
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/TRIP
cladding surface temperature



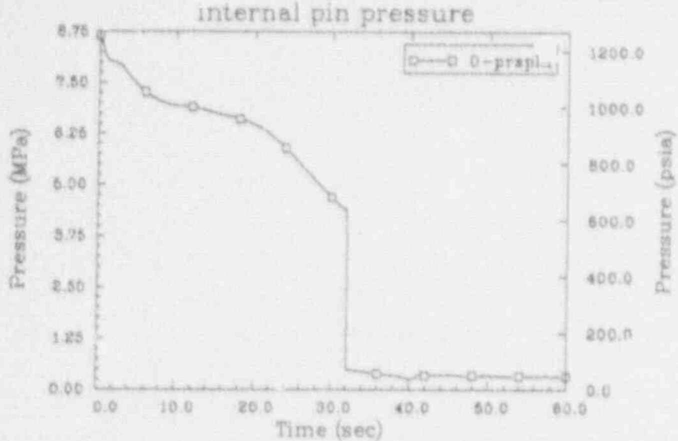
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/TRIP
fuel centerline temperature



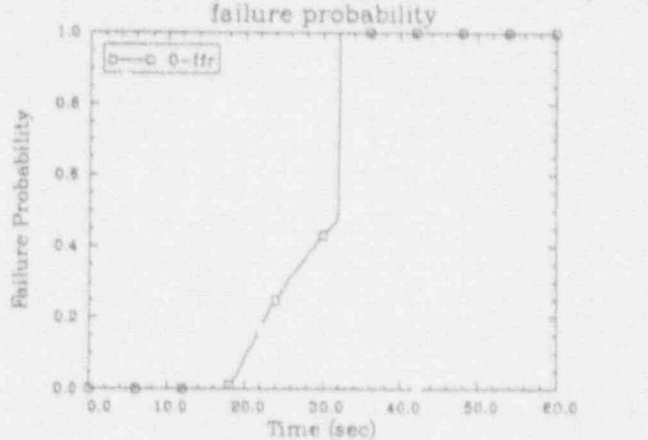
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/TRIP
oxide thickness



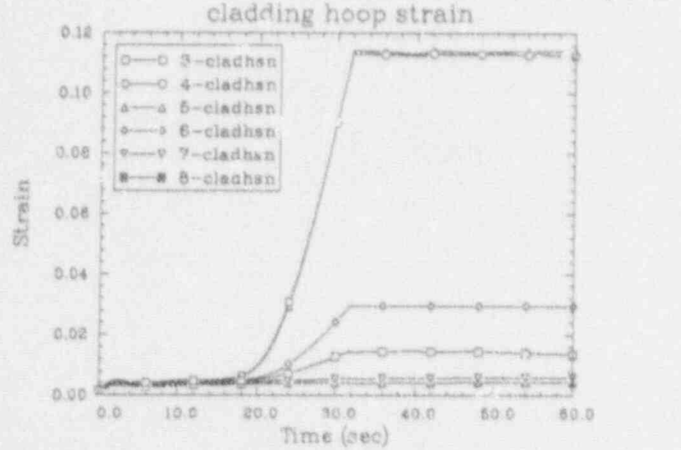
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/TRIP
internal pin pressure



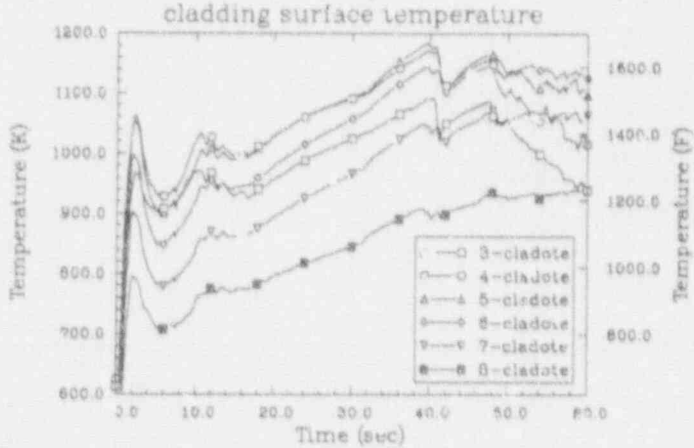
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/TRIP
failure probability



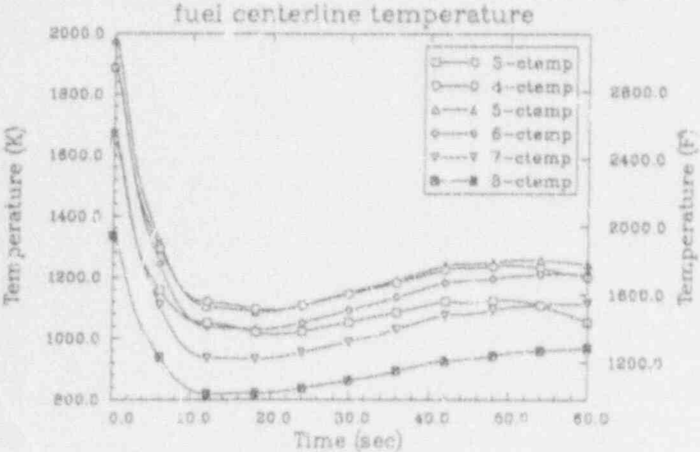
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/TRIP
cladding hoop strain



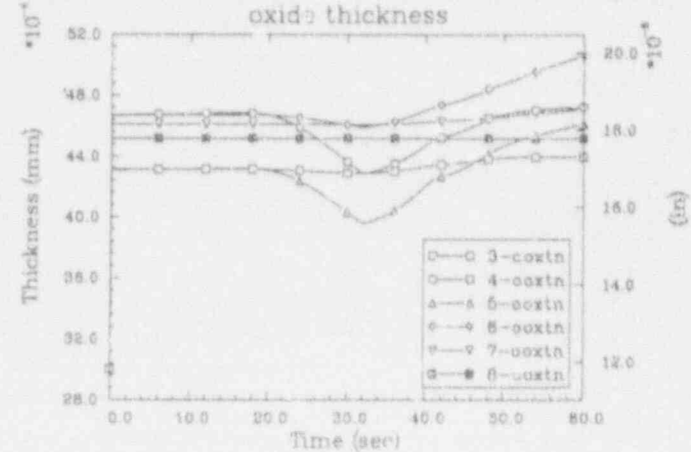
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/TRIP
cladding surface temperature



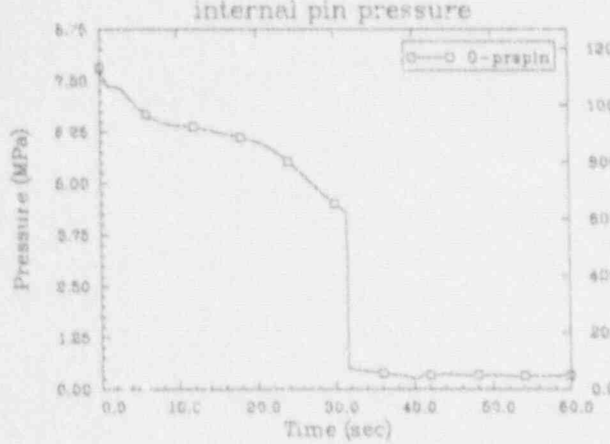
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/TRIP
fuel centerline temperature



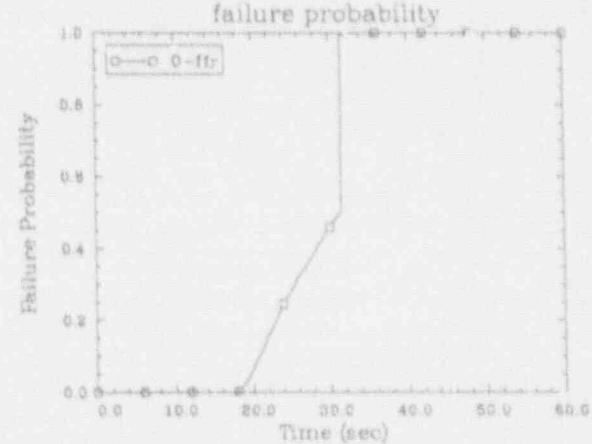
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/TRIP
oxide thickness



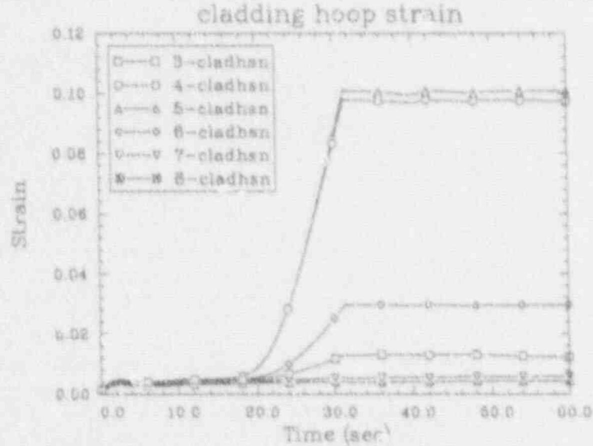
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/TRIP
internal pin pressure



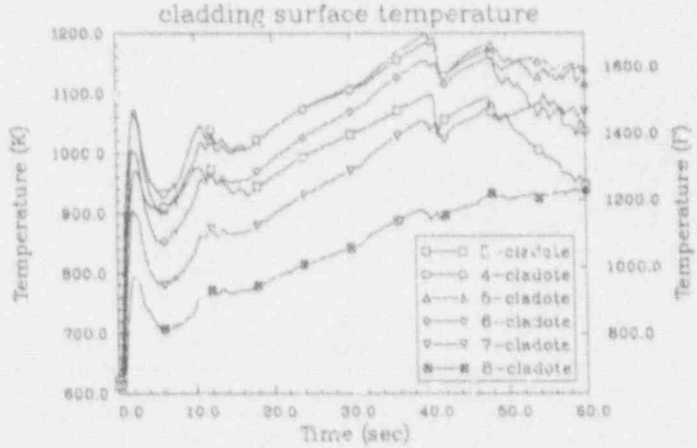
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/TRIP
failure probability



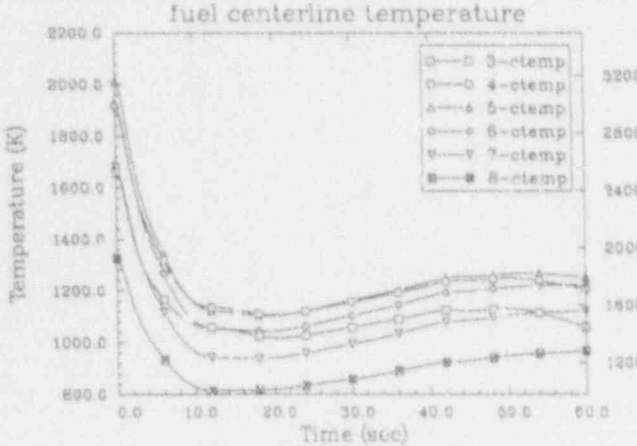
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/TRIP
cladding hoop strain



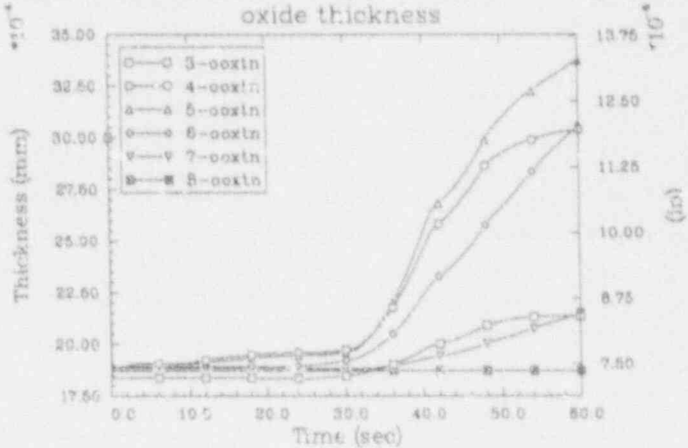
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/TRIP
cladding surface temperature



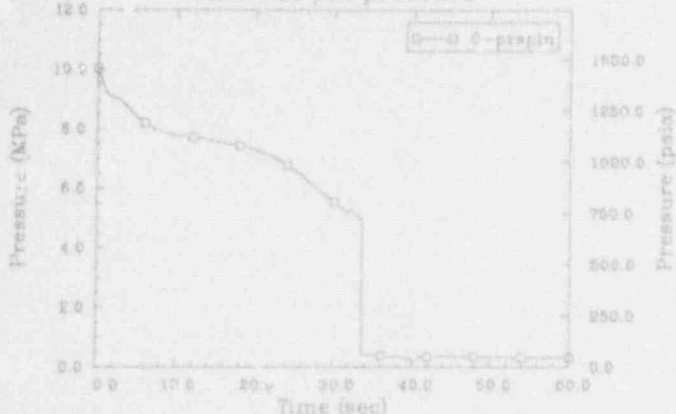
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/TRIP
fuel centerline temperature



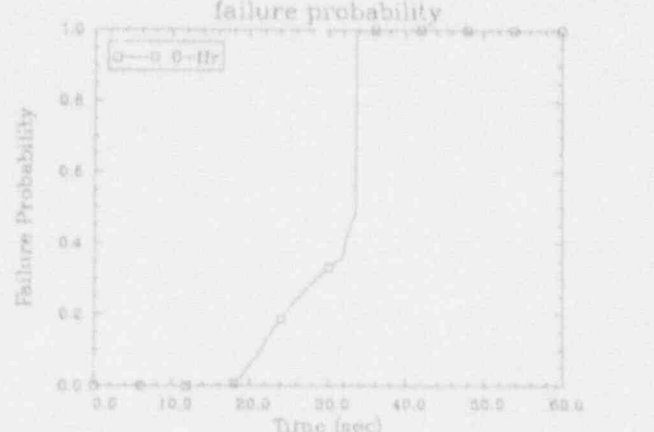
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/TRIP
oxide thickness



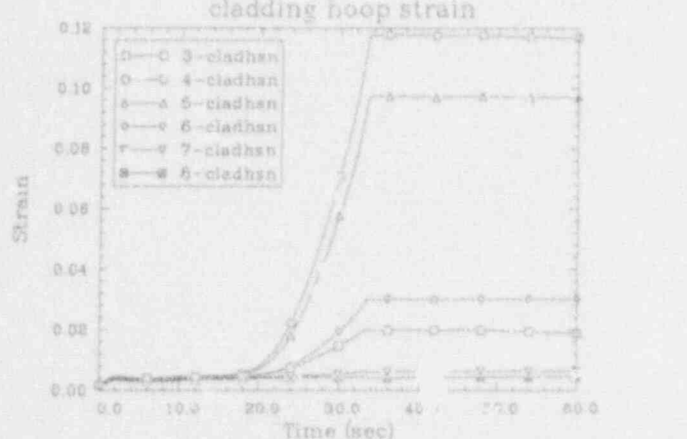
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/TRIP
internal pin pressure



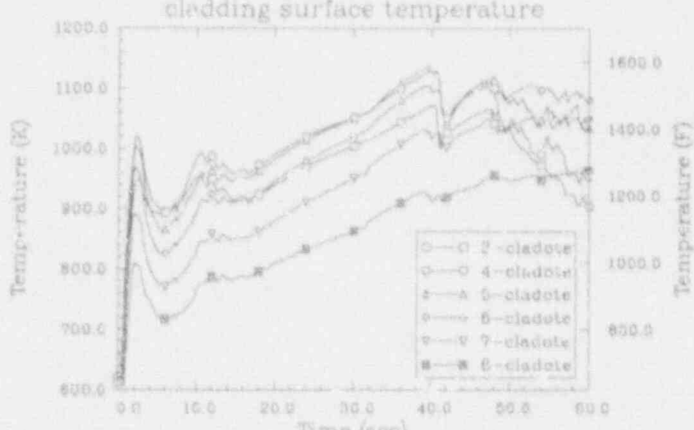
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/TRIP
failure probability



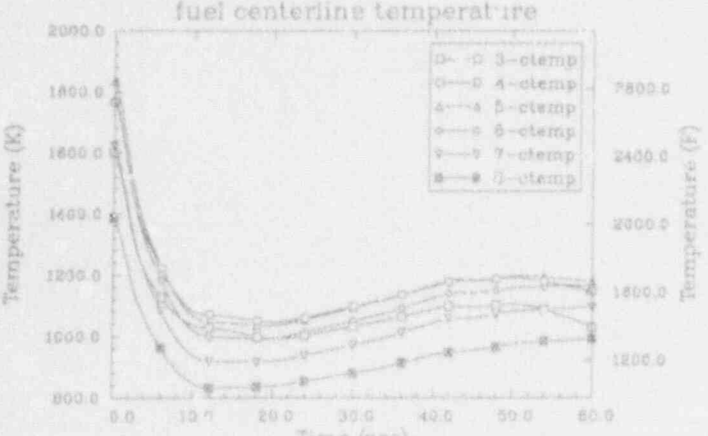
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/TRIP
cladding hoop strain



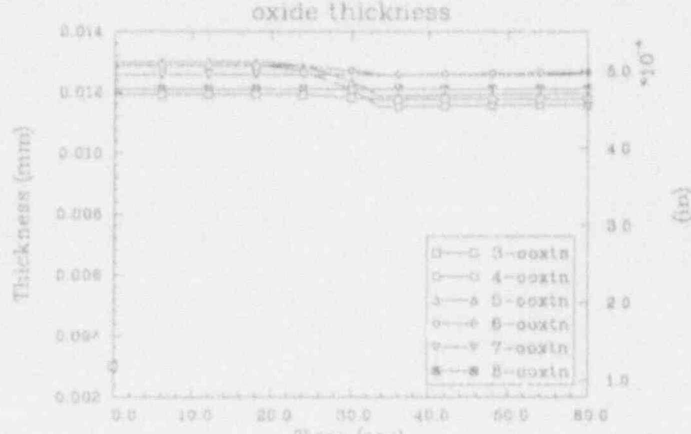
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/TRIP
cladding surface temperature

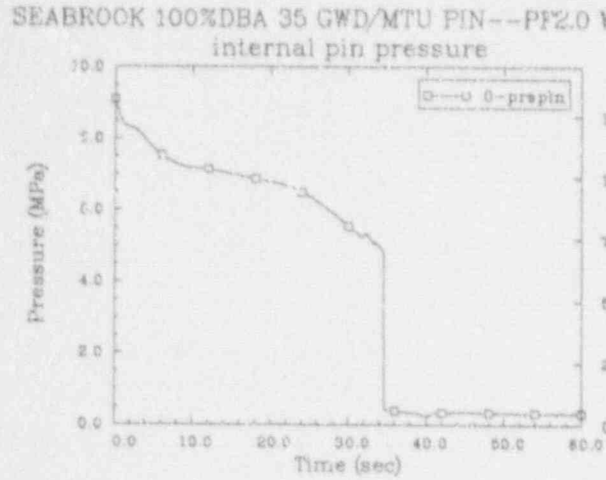


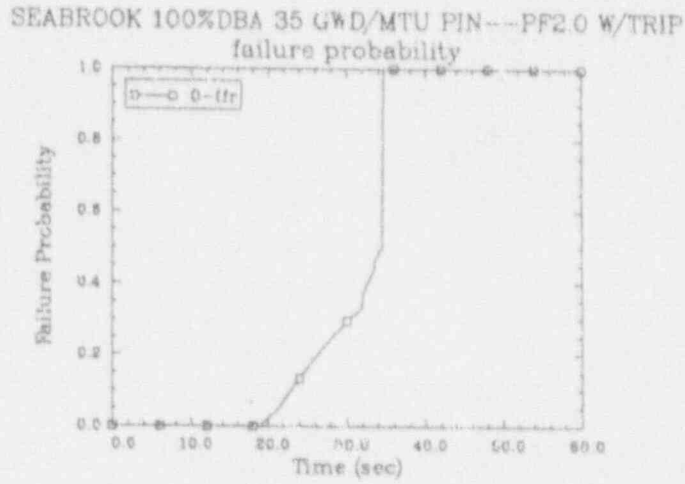
SEABROOK 100%DBA 50 GWD/MTU PIN-- PF2.0 W/TRIP
fuel centerline temperature

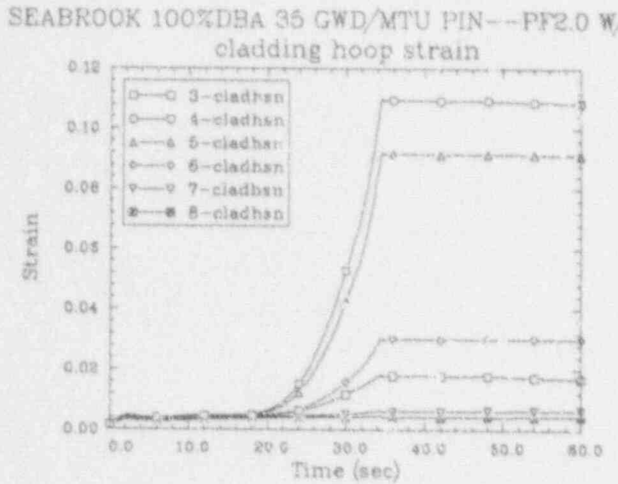


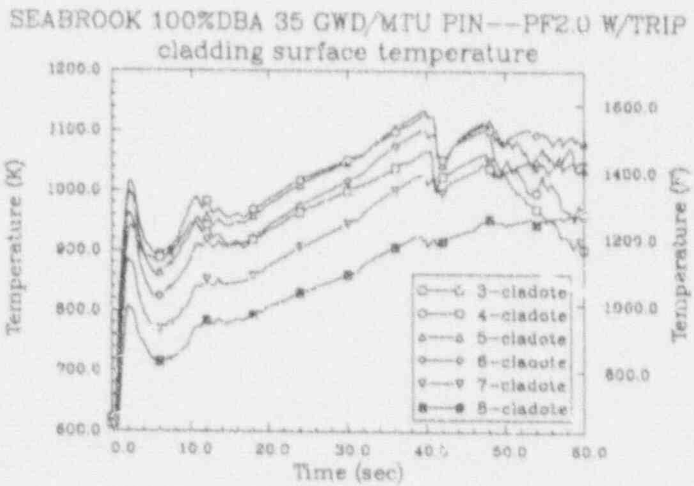
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/TRIP
oxide thickness

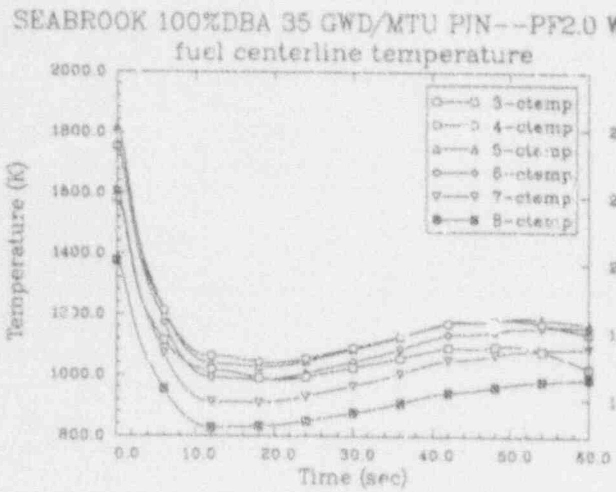


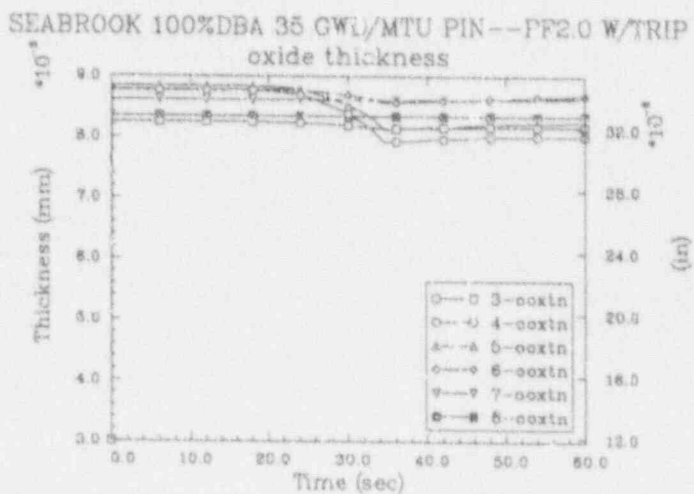

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

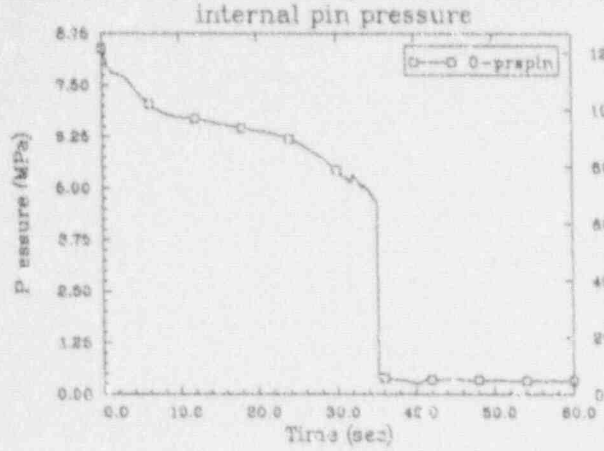

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

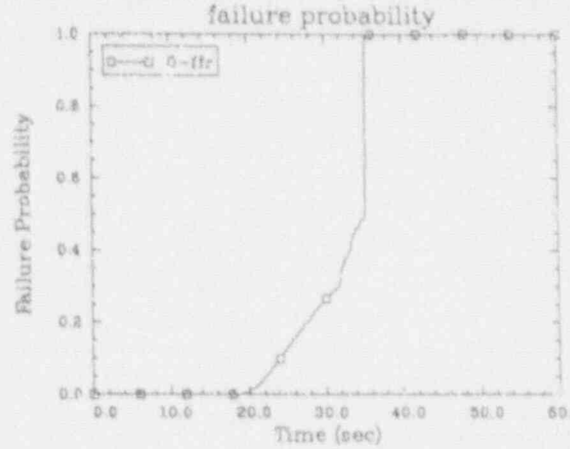

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

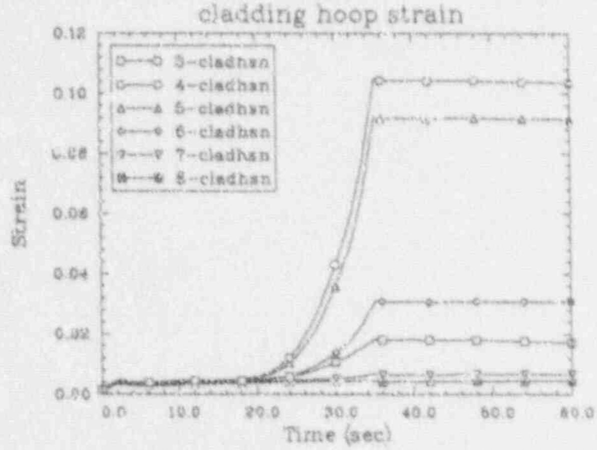
SEABROOK 100%DBA 20 GWD/MTU PIN---PF2.0 W/TRIP
internal pin pressure



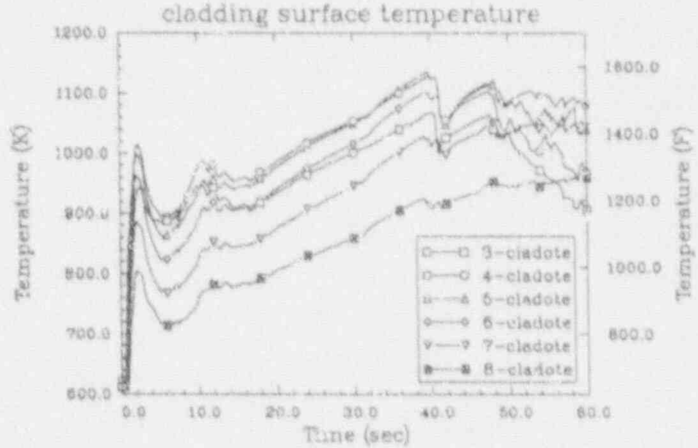
SEABROOK 100%DBA 20 GWD/MTU PIN---PF2.0 W/TRIP
failure probability



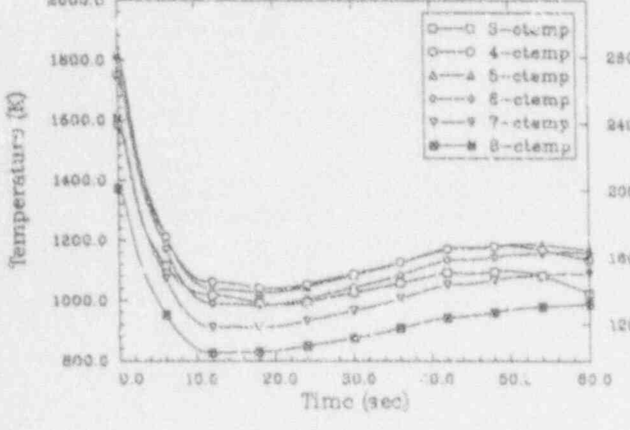
SEABROOK 100%DBA 20 GWD/MTU PIN---PF2.0 W/TRIP
cladding hoop strain



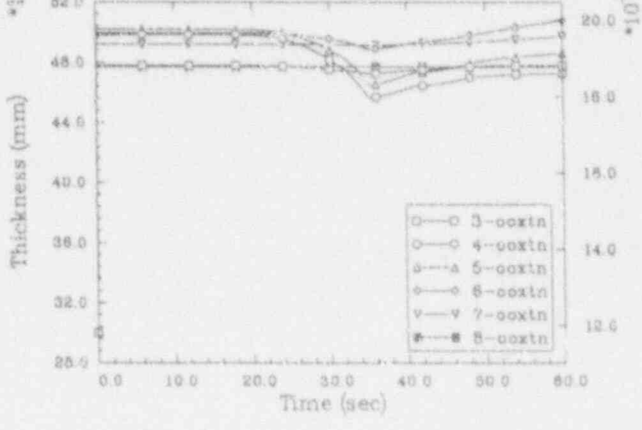
SEABROOK 100%DBA 20 GWD/MTU PIN---PF2.0 W/TRIP
cladding surface temperature

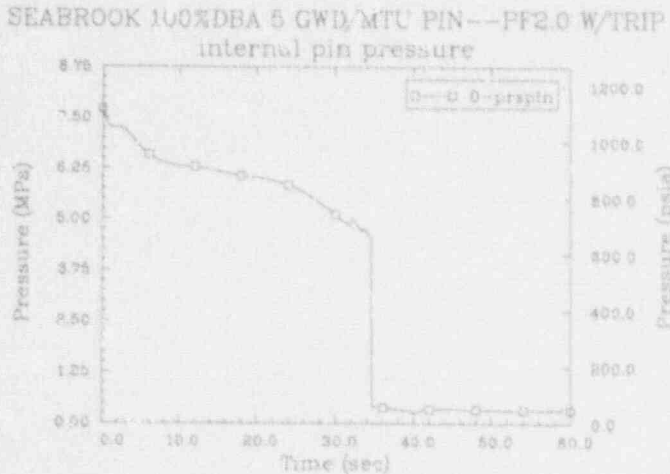


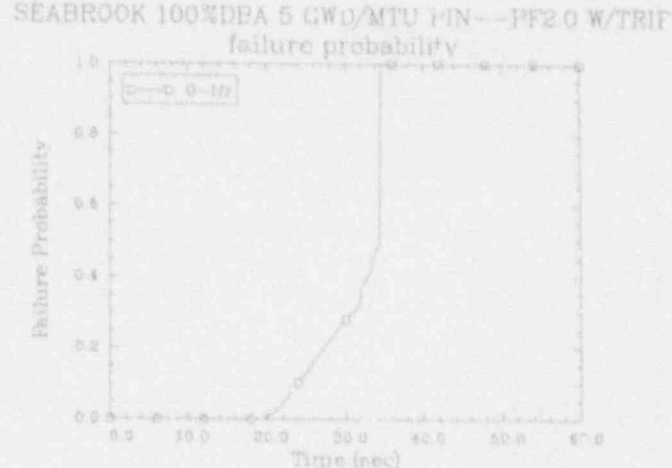
SEABROOK 100%DBA 20 GWD/MTU PIN---PF2.0 W/TRIP
fuel centerline temperature

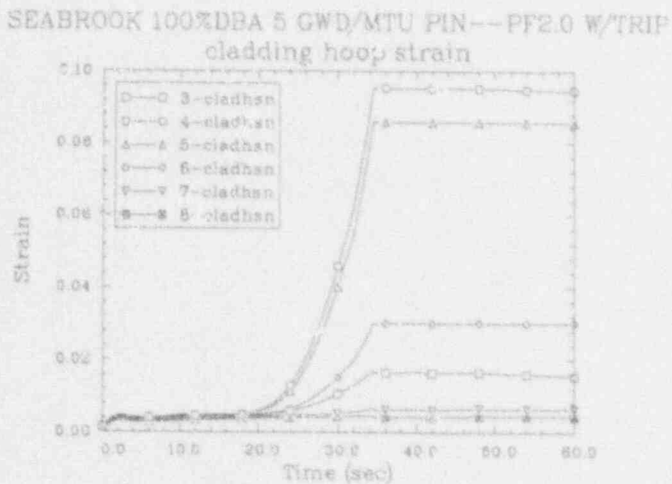


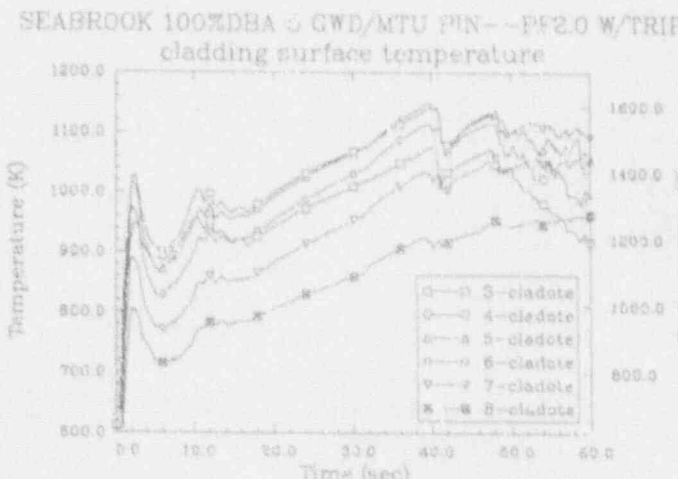
SEABROOK 100%DBA 20 GWD/MTU PIN---PF2.0 W/TRIP
oxide thickness

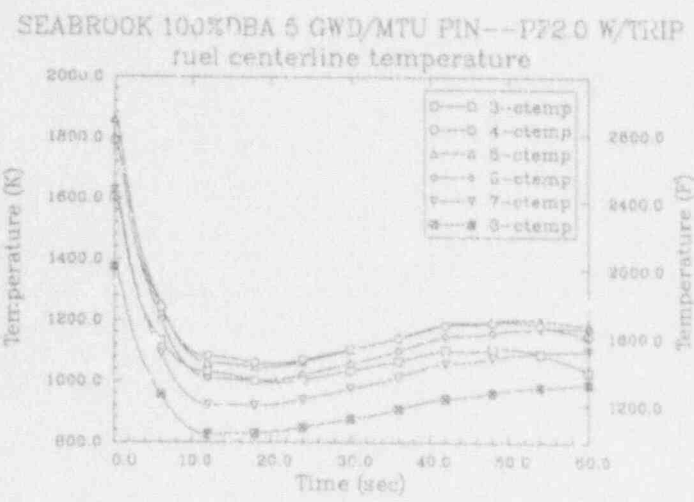


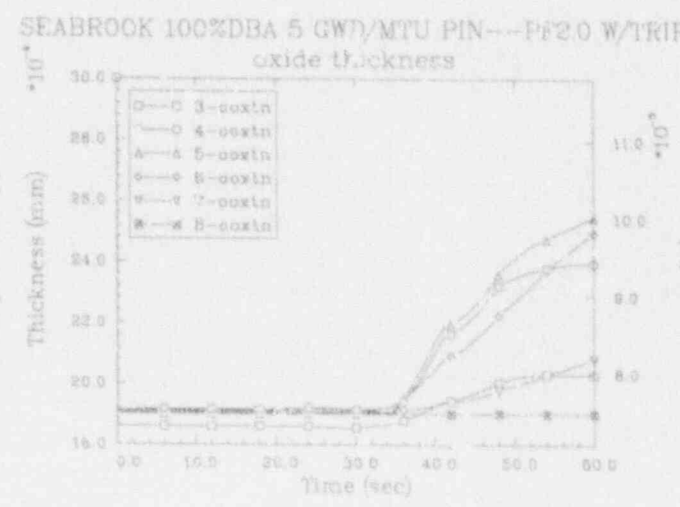

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/TRIP
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/TRIP
failure probability
0-ffr
Failure Probability
Time (sec)

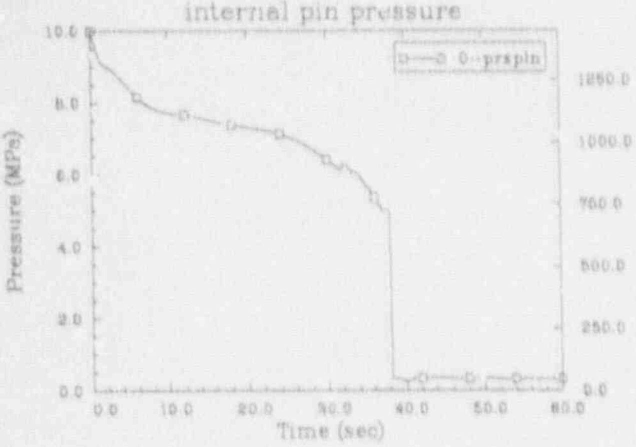

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/TRIP
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/TRIP
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

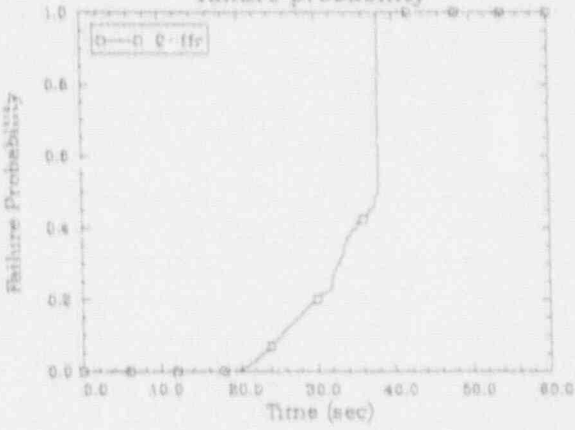

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/TRIP
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/TRIP
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

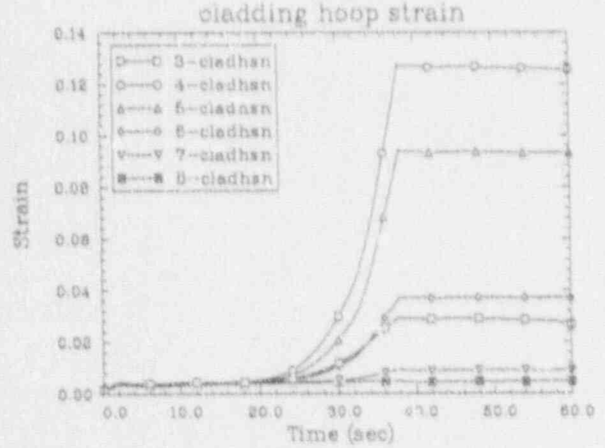
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/TRIP
internal pin pressure



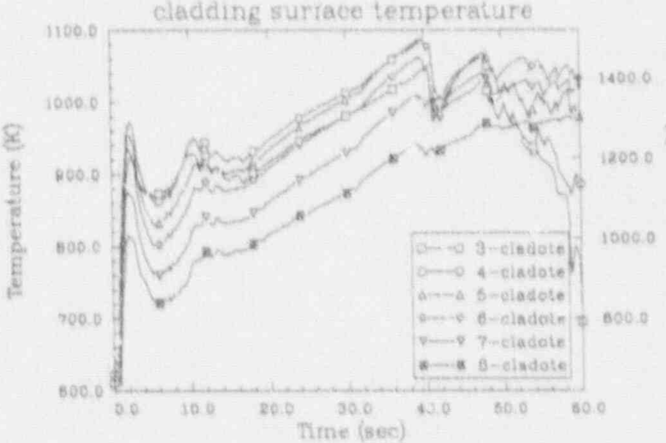
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/TRIP
failure probability



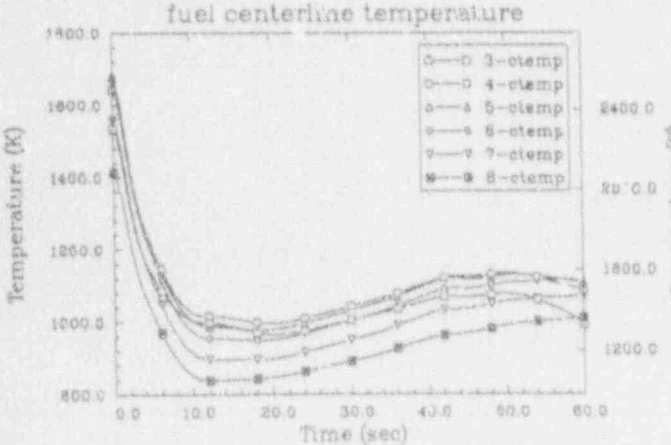
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/TRIP
cladding hoop strain



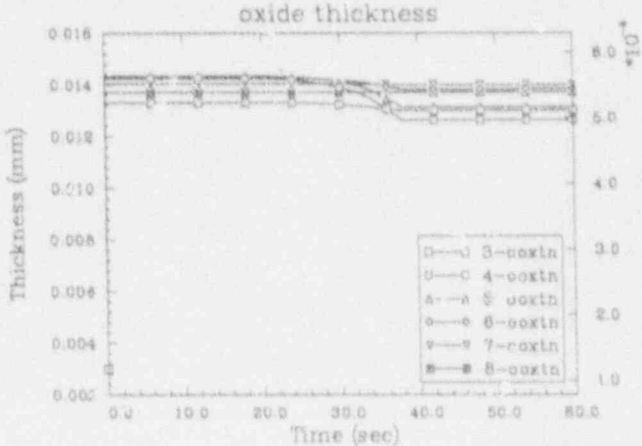
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/TRIP
cladding surface temperature



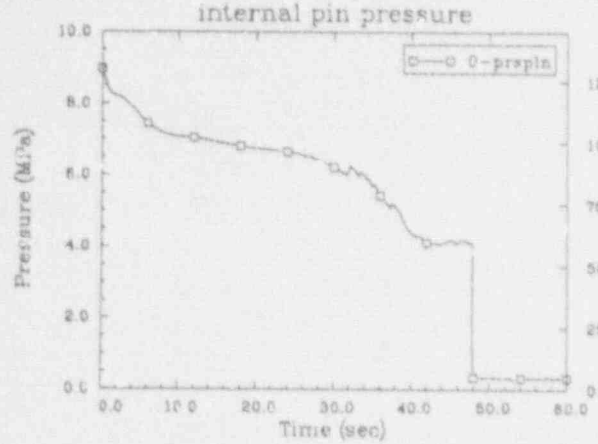
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/TRIP
fuel centerline temperature



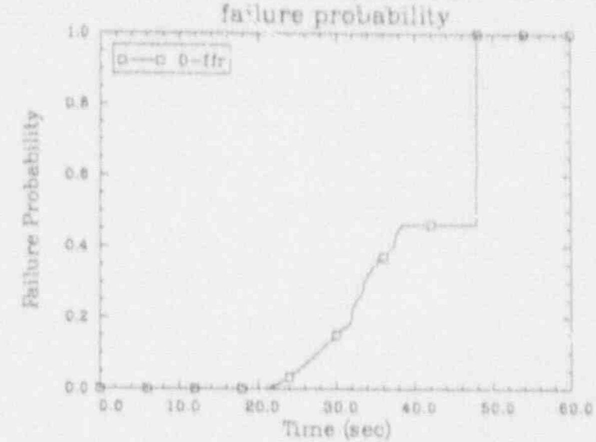
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/TRIP
oxide thickness



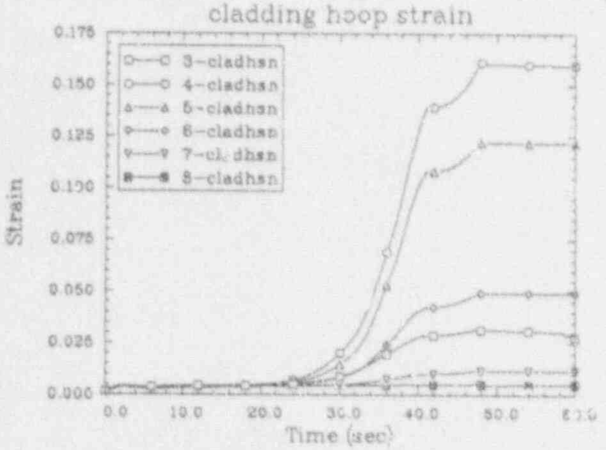
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/TRIP
internal pin pressure



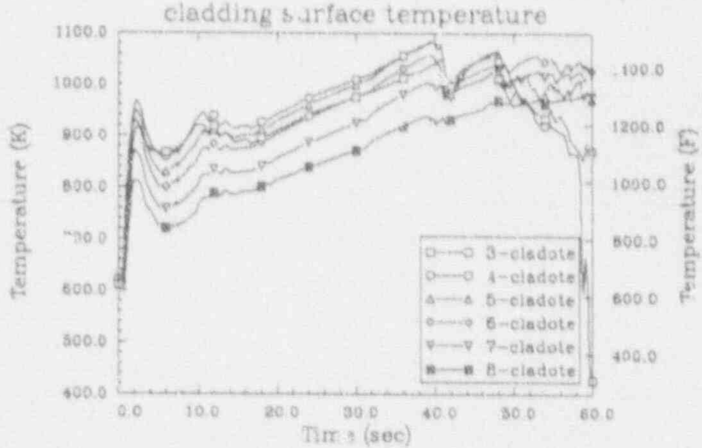
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/TRIP
failure probability



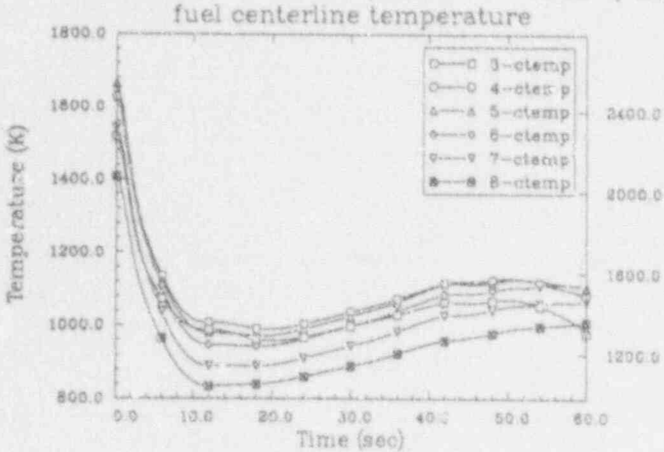
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/TRIP
cladding hoop strain



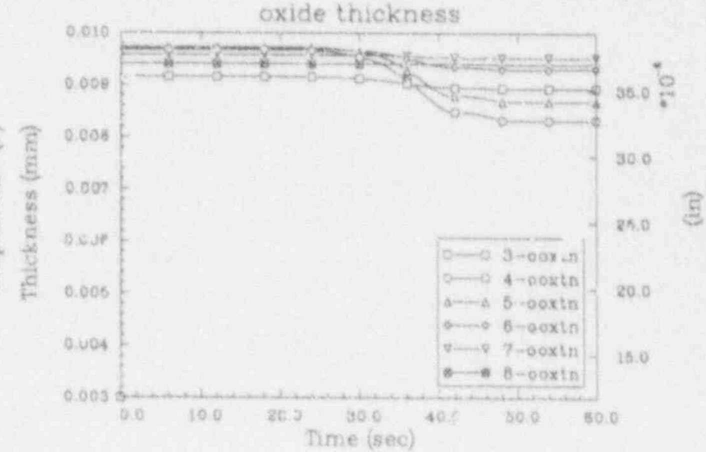
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/TRIP
cladding surface temperature



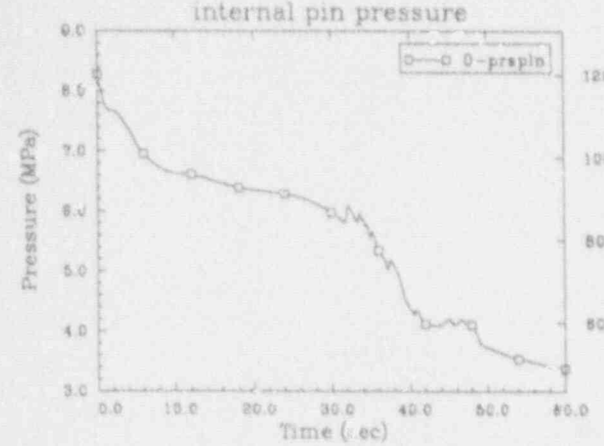
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/TRIP
fuel centerline temperature



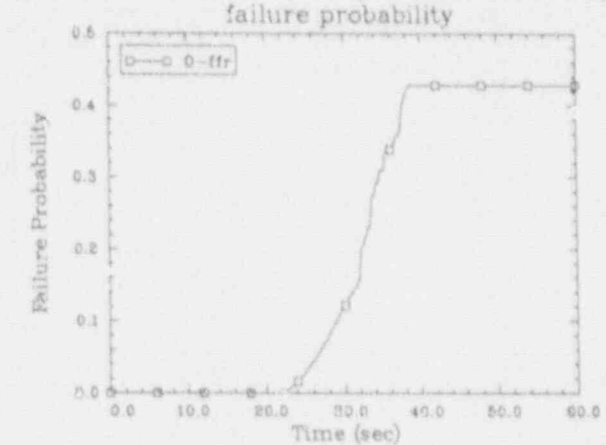
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/TRIP
oxide thickness



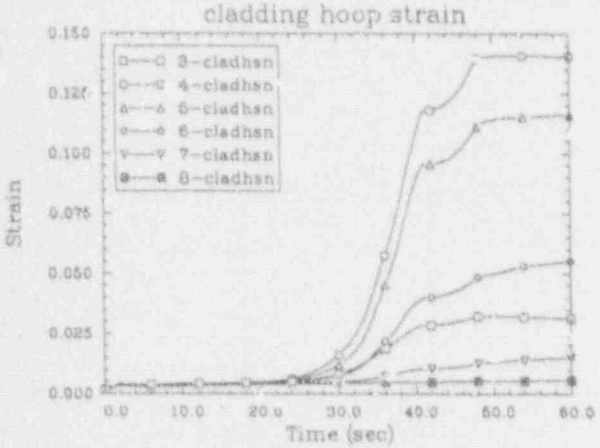
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/TRIP
internal pin pressure



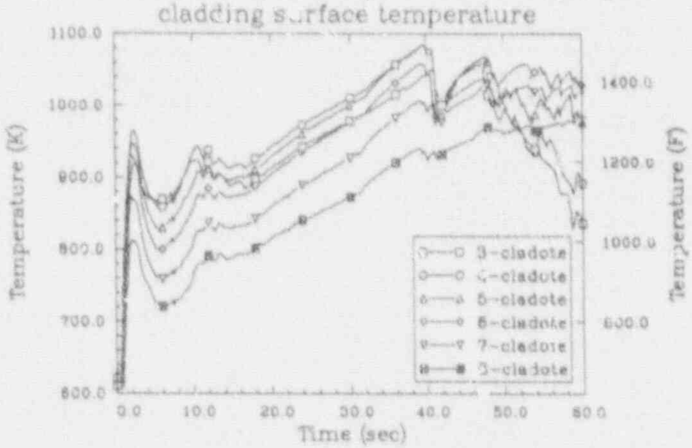
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/TRIP
failure probability



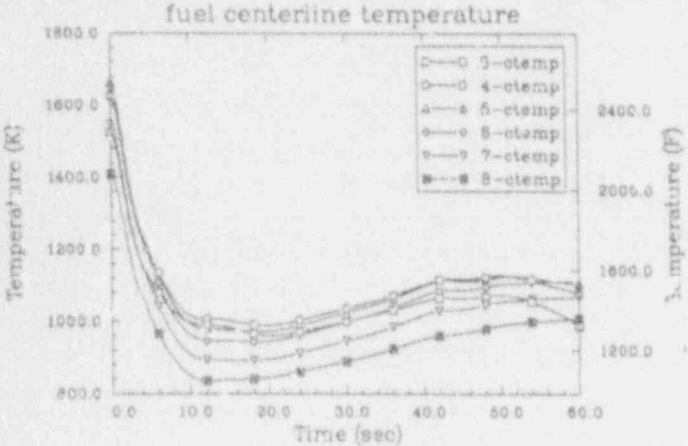
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/TRIP
cladding hoop strain



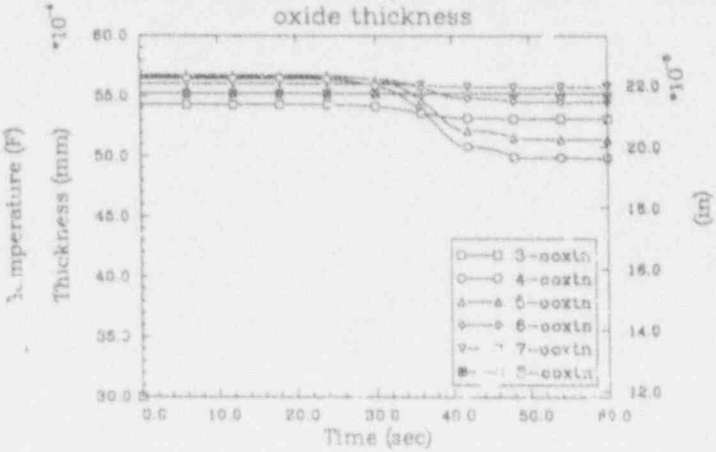
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/TRIP
cladding surface temperature

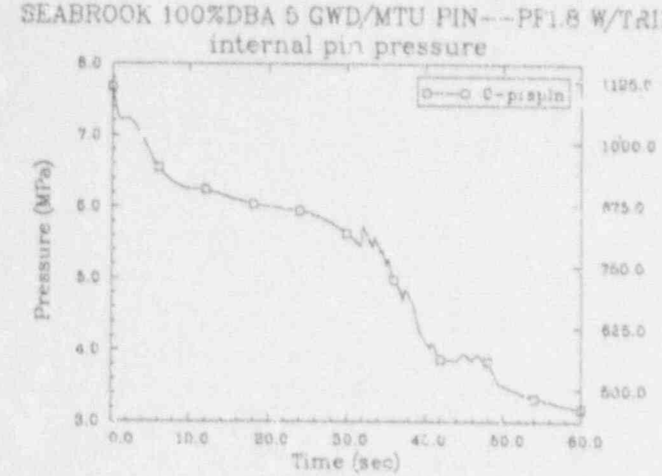


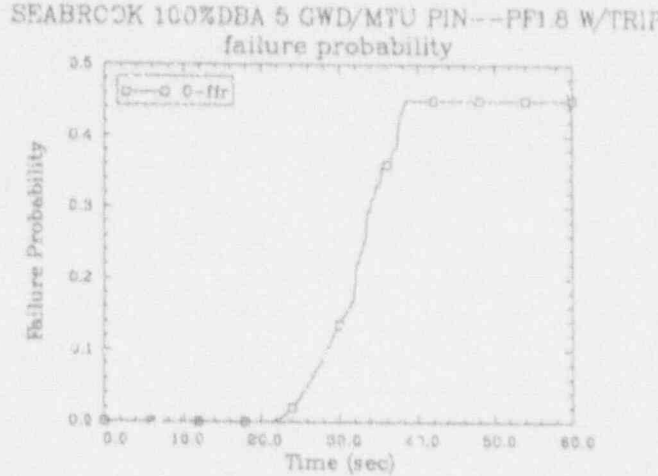
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/TRIP
fuel centerline temperature

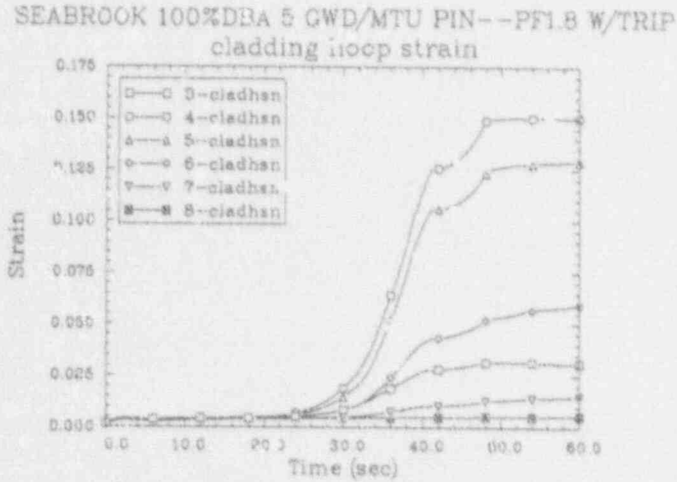


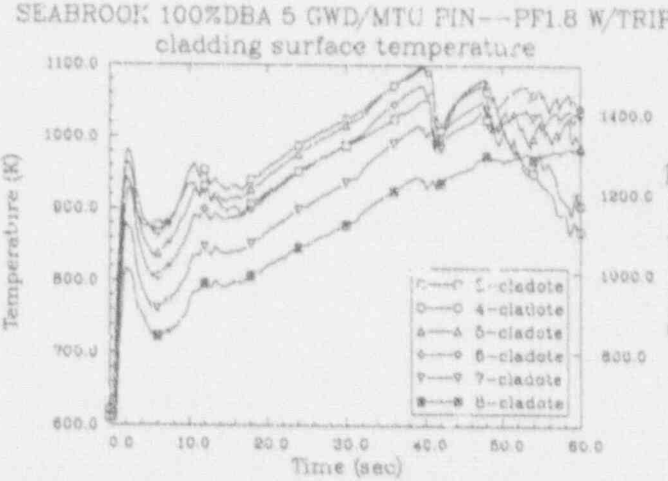
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/TRIP
oxide thickness

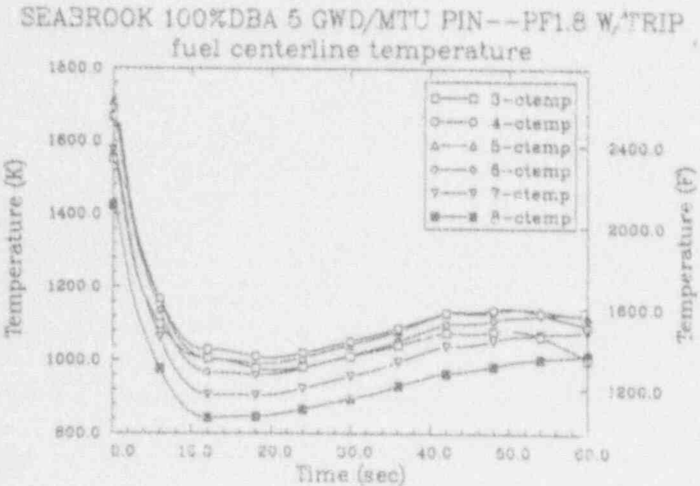


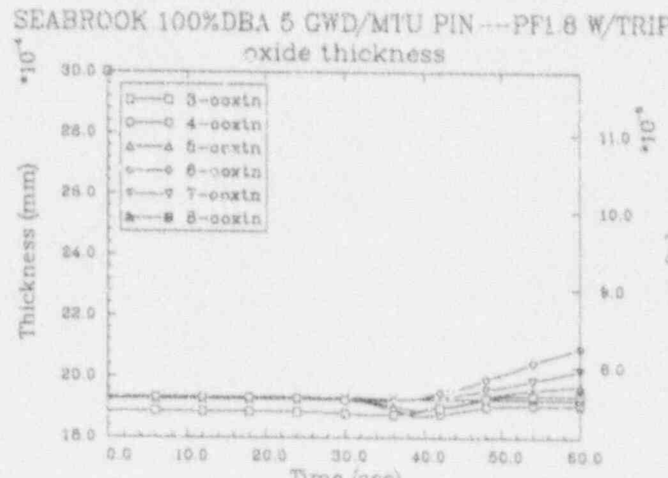

SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/TRIP
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin

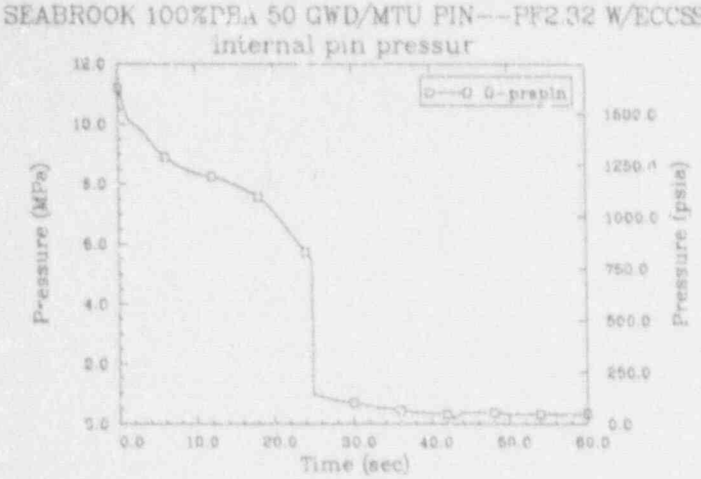

SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/TRIP
failure probability
Failure Probability
Time (sec)
0-ffr

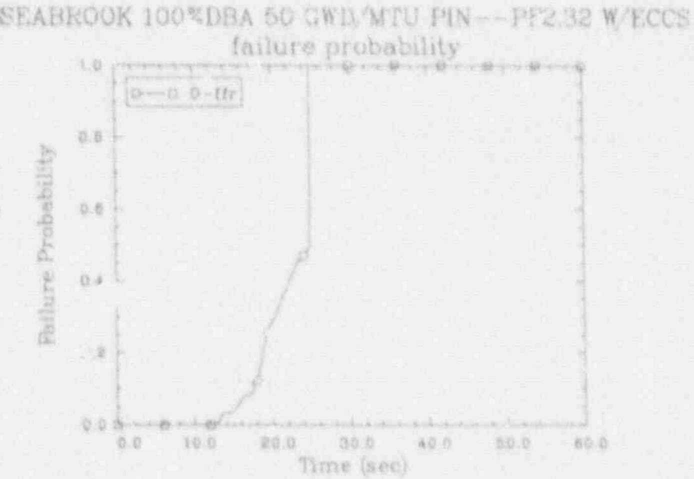

SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/TRIP
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn

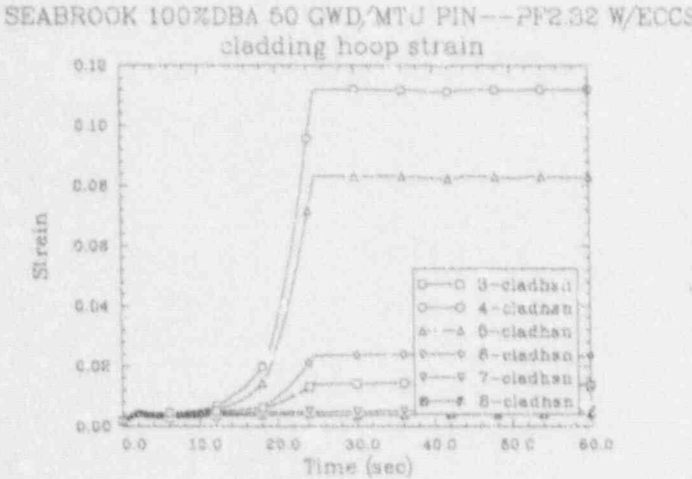

SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/TRIP
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote

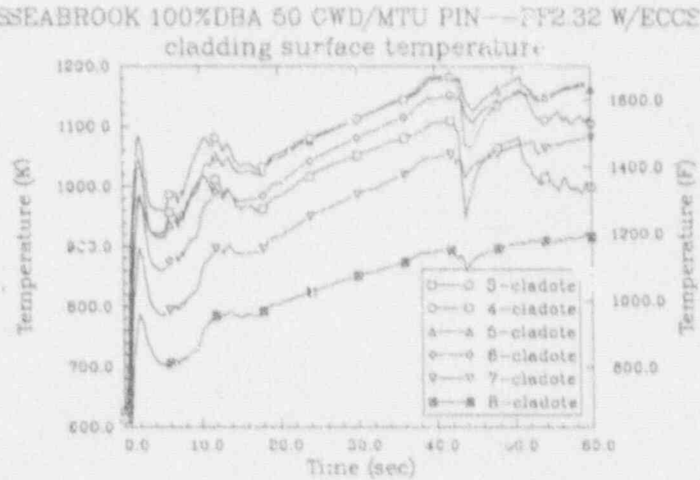

SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/TRIP
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp

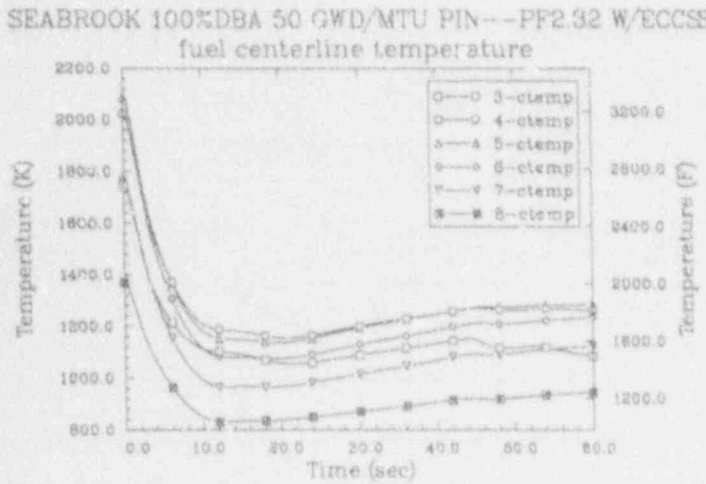

SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/TRIP
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

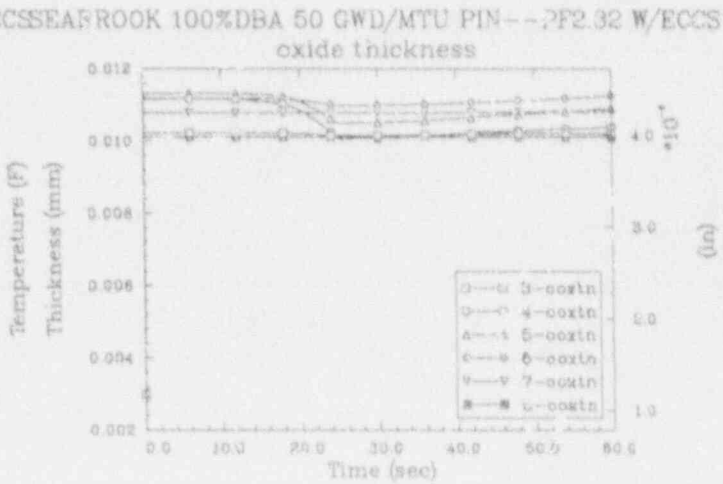

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/ECCS
internal pin pressur
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

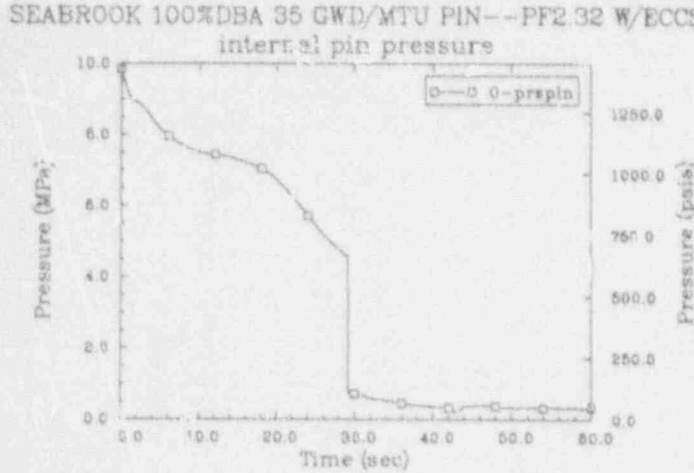

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

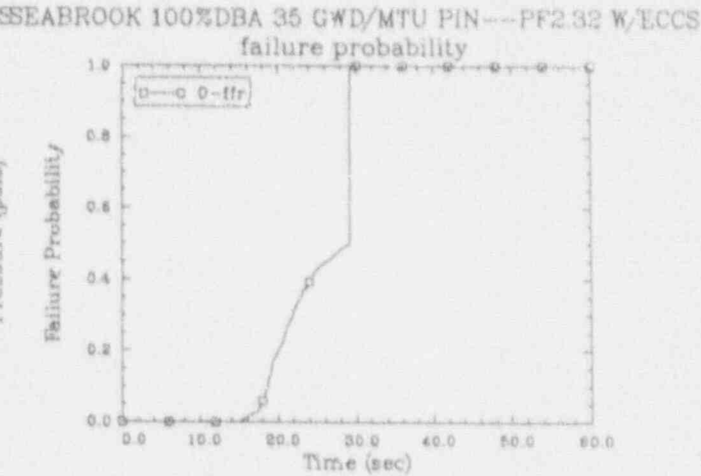

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/ECCS
cladding hoop strain
Strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Time (sec)

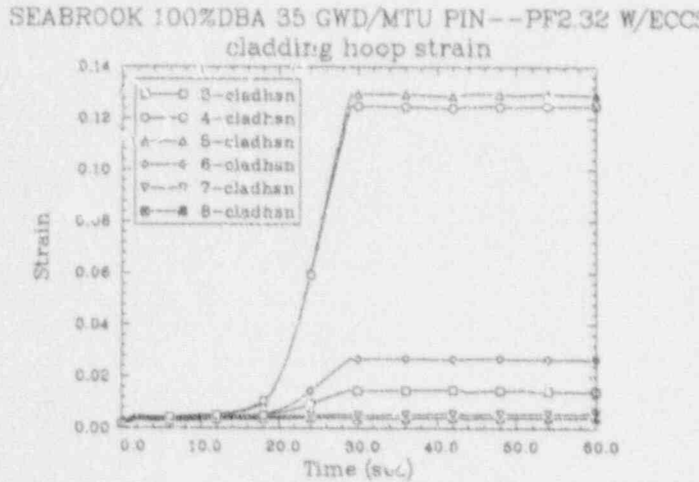

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/ECCS
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Time (sec)

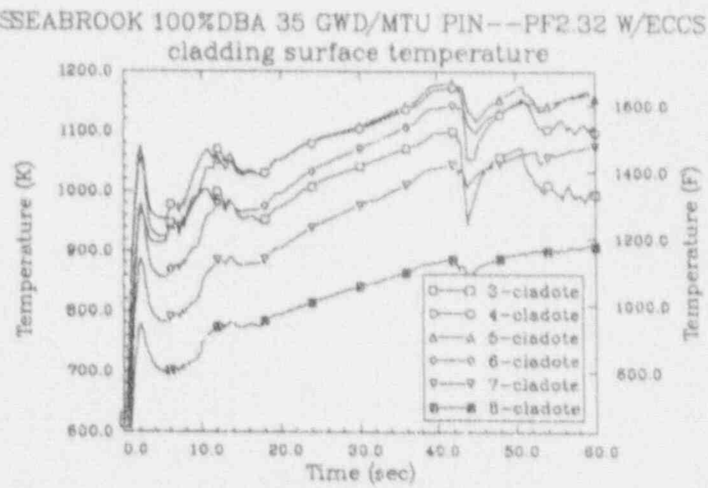

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/ECCS
fuel centerline temperature
Temperature (K)
Temperature (F)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Time (sec)

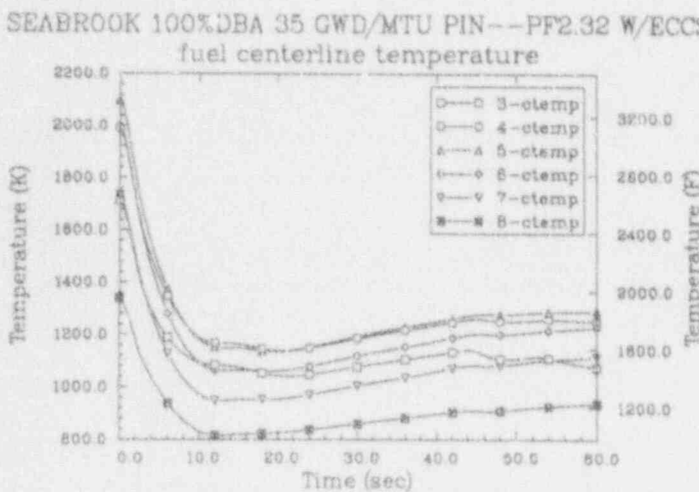

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/ECCS
oxide thickness
Thickness (mm)
(in)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Time (sec)

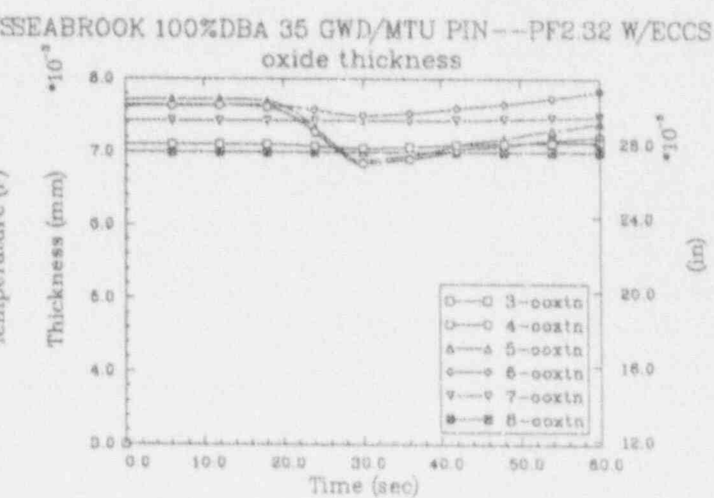

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

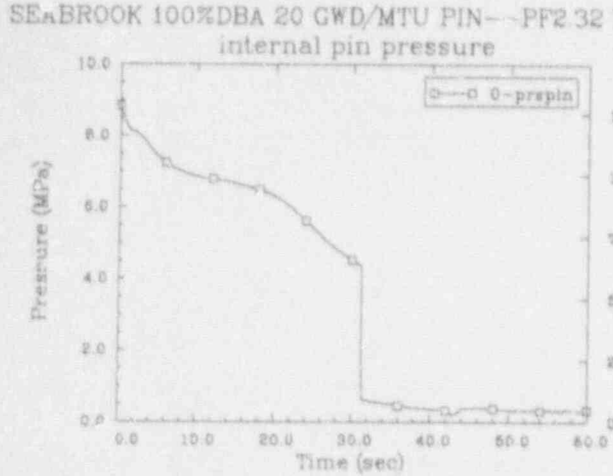

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

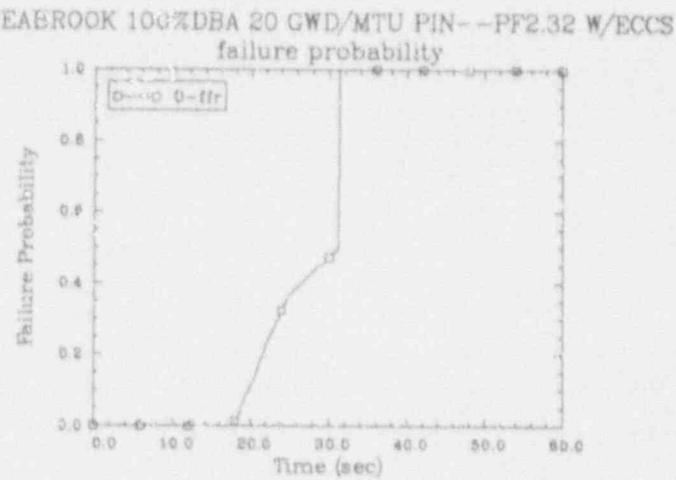

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain

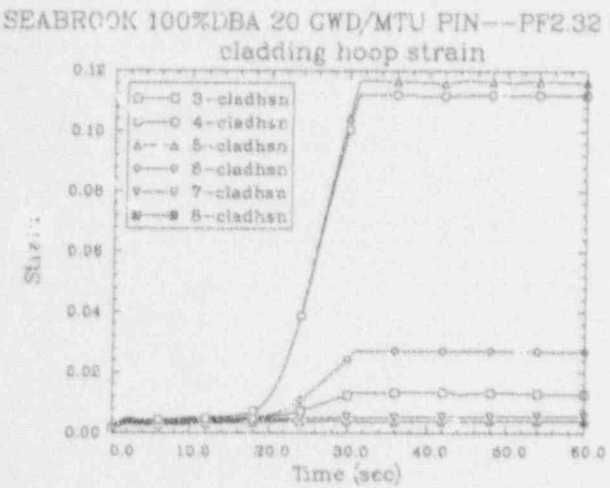

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

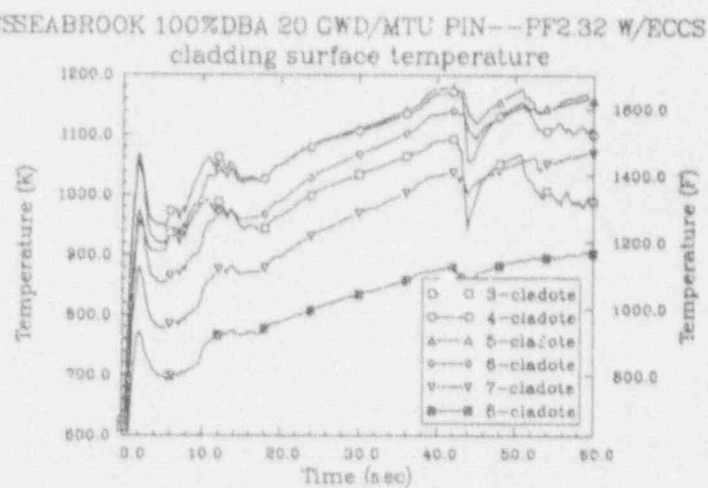

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

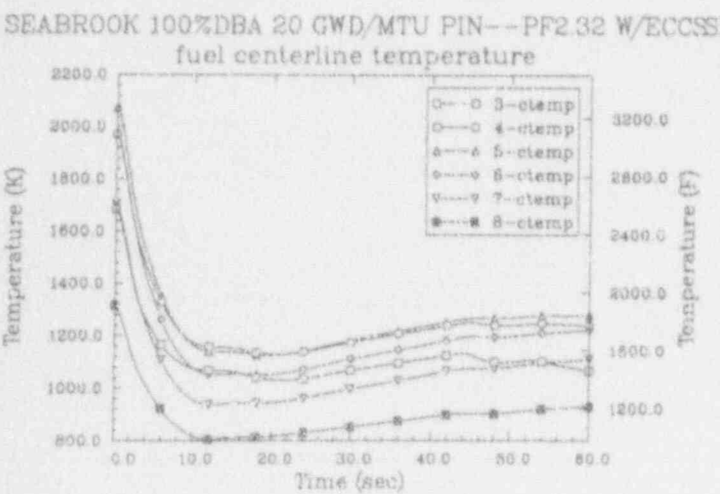

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

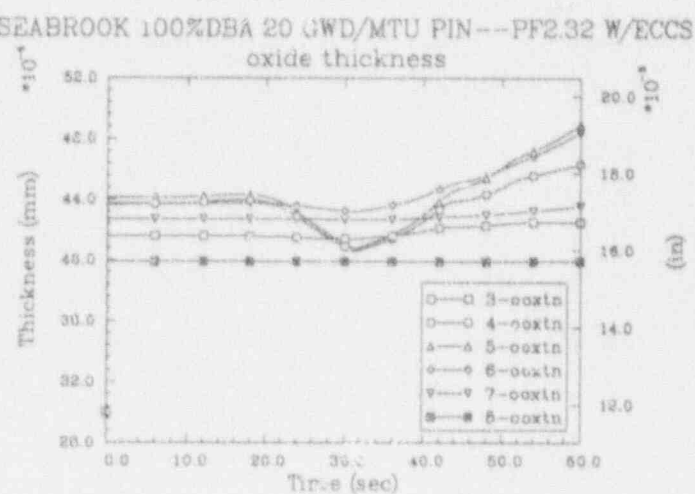

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

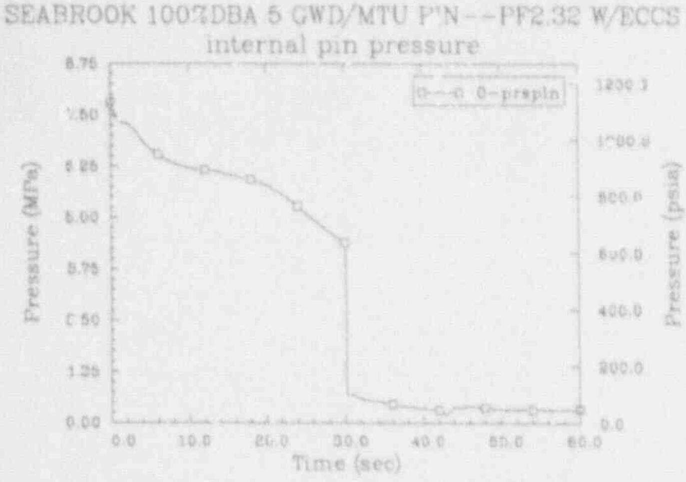

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

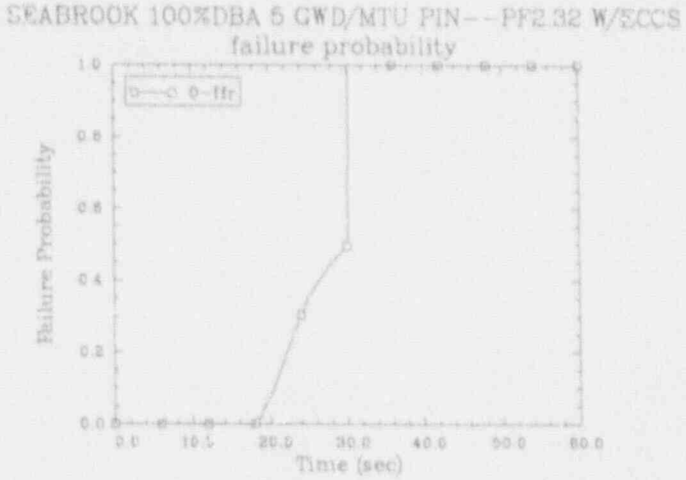

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Time (sec)

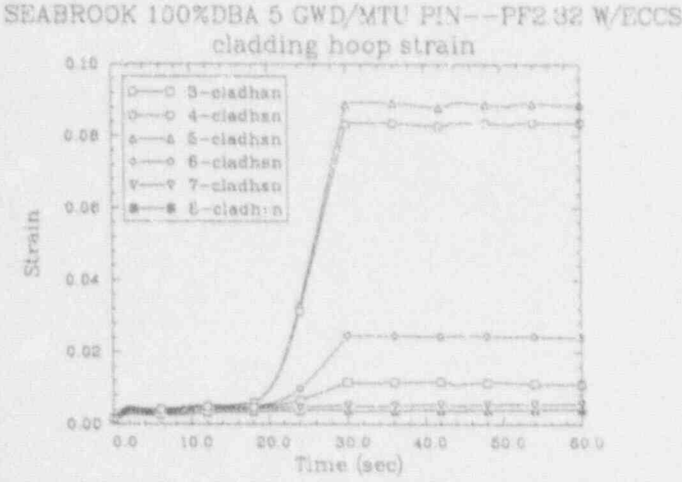

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/ECCS
cladding surface temperature
3-cladote
4-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

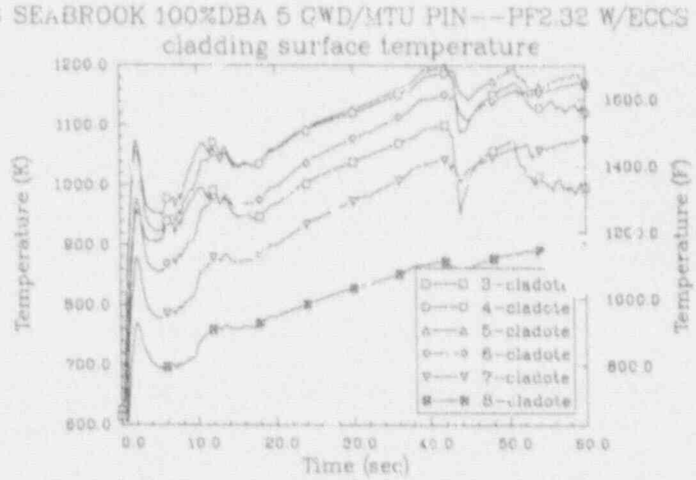

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

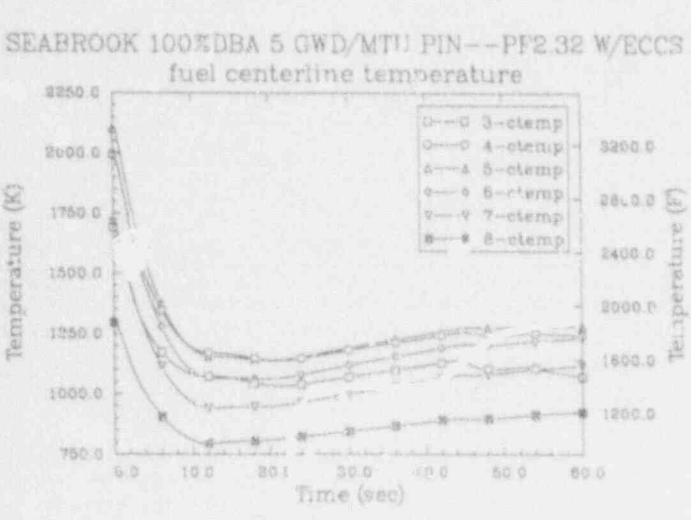

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)

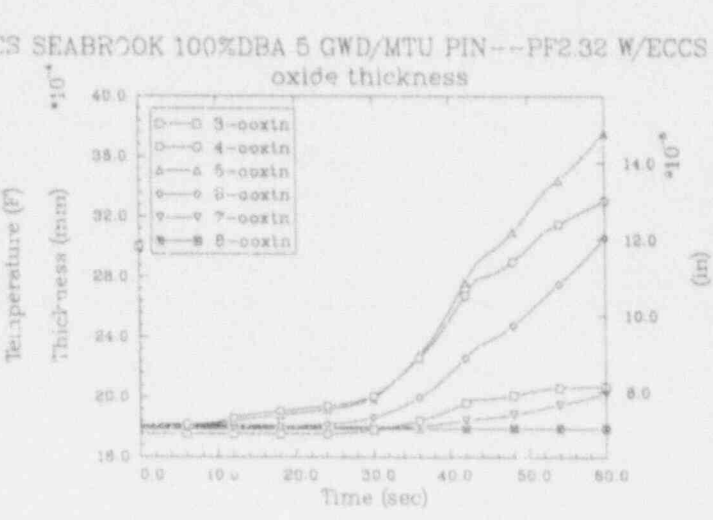

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/ECCS
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

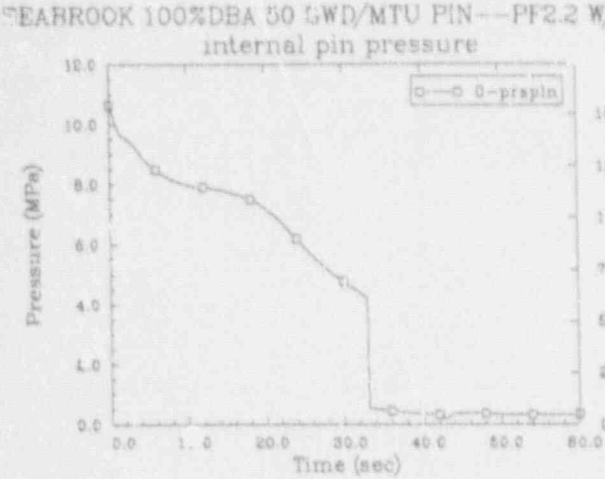

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

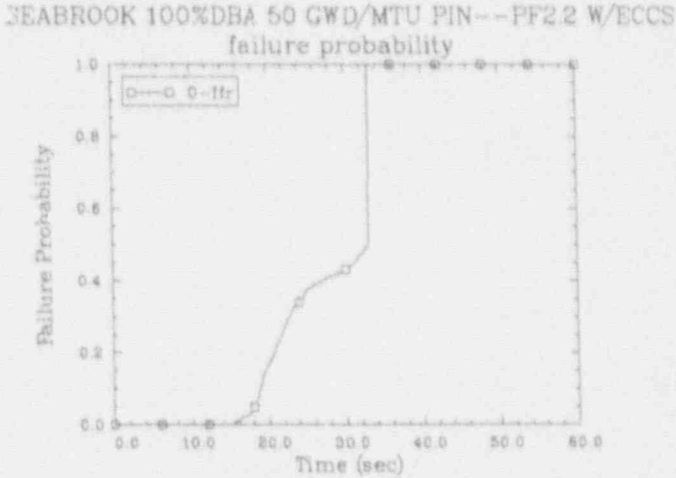

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
Strain
Time (sec)

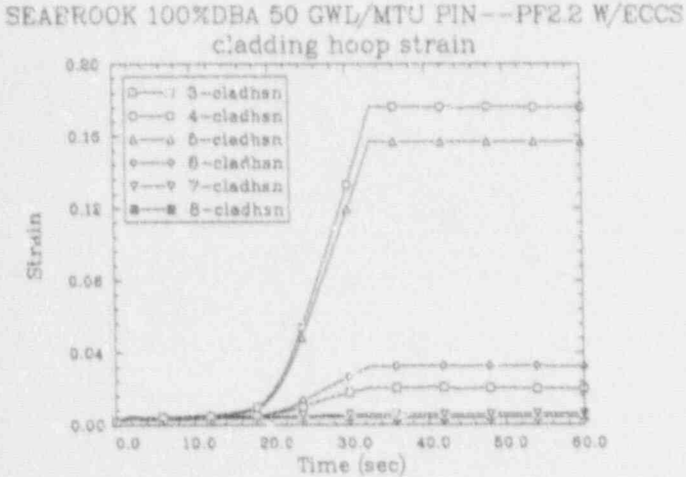

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/ECCS
cladding surface temperature
4-cladote
5-cladote
6-cladote
7-cladote
Temperature (K)
Temperature (F)
Time (sec)

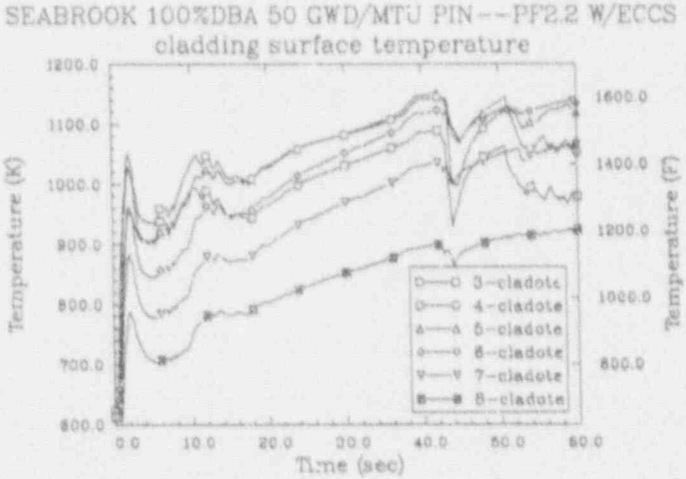

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
7-ctemp
8-ctemp
Temperature (K)
Time (sec)

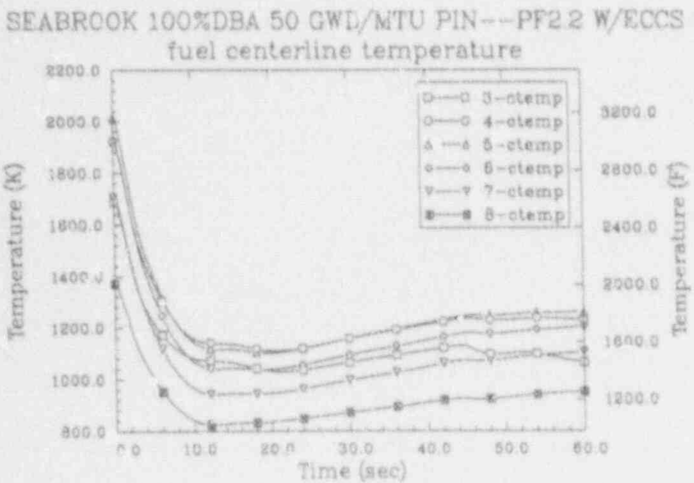

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/ECCS
oxide thickness
3-ooxin
4-ooxin
5-ooxin
6-ooxin
7-ooxin
8-ooxin
(in)
Time (sec)

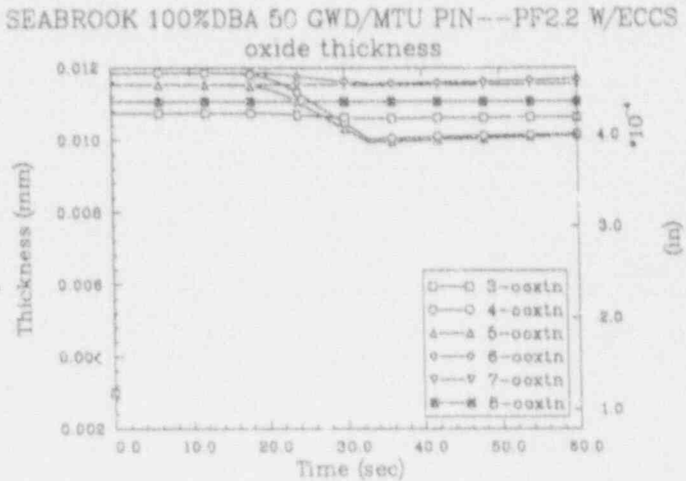

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

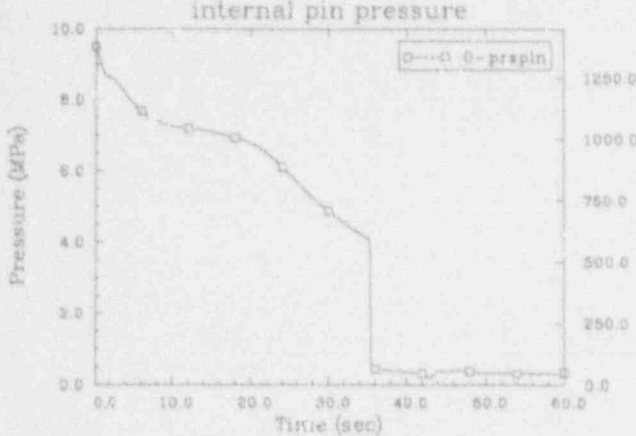

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/ECCS
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Temperature (F)
Time (sec)

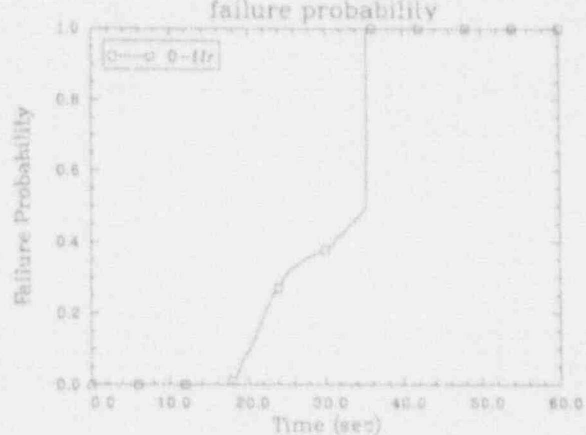

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

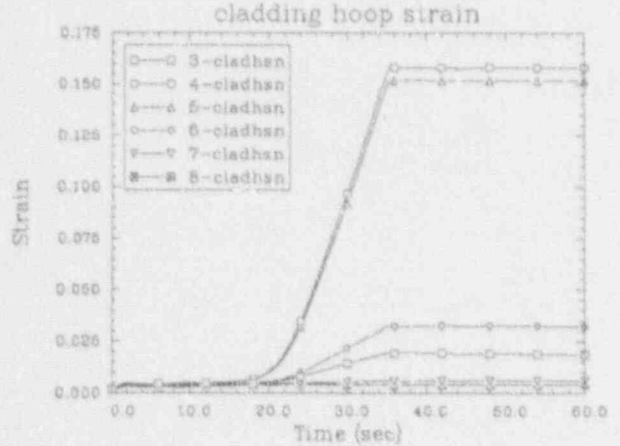
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/ECCS
internal pin pressure



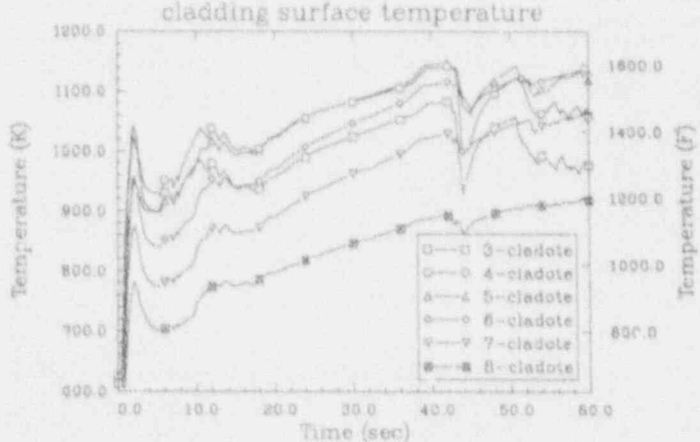
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/ECCS
failure probability



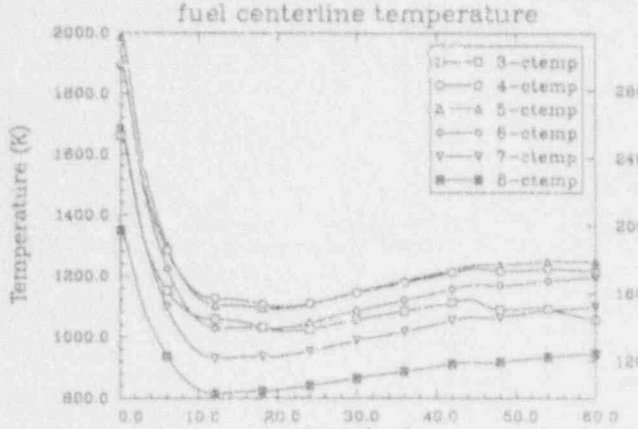
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/ECCS
cladding hoop strain



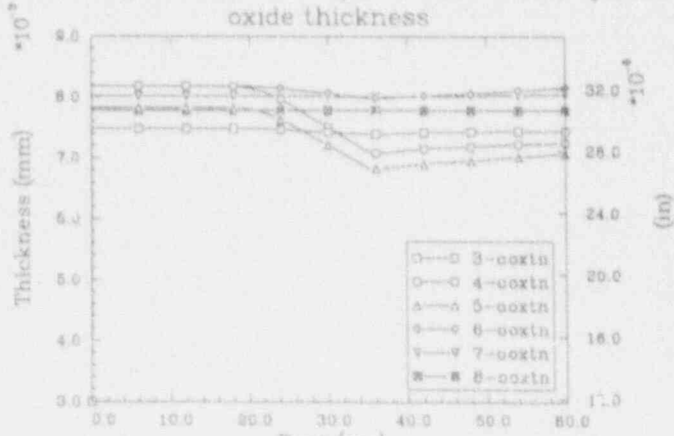
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/ECCS
cladding surface temperature



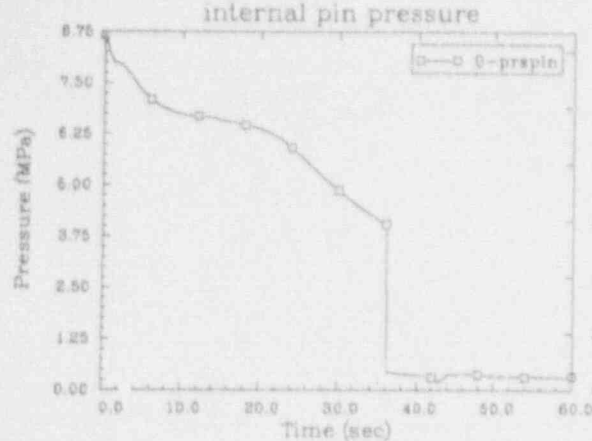
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/ECCS
fuel centerline temperature



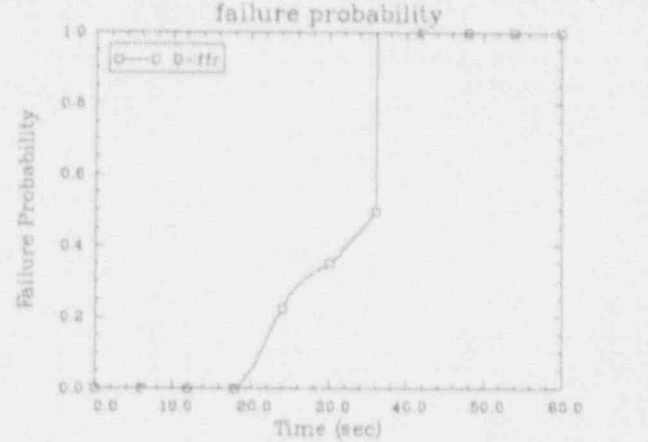
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/ECCS
oxide thickness



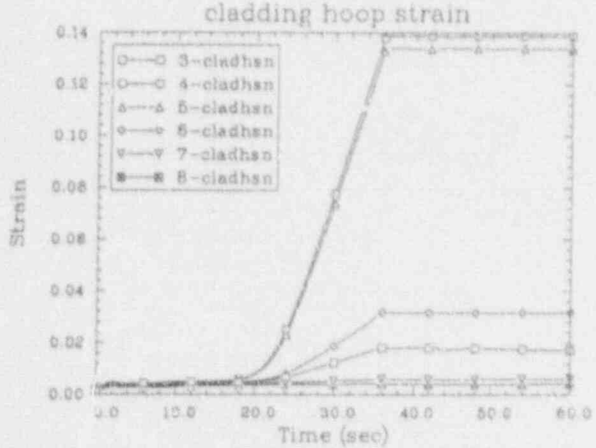
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/ECCS
internal pin pressure



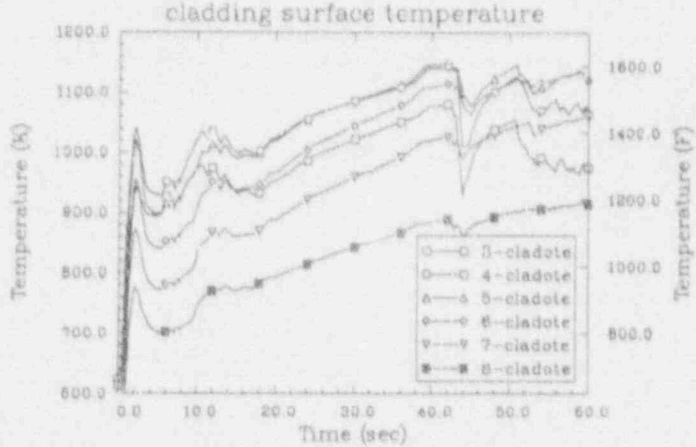
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/ECCS
failure probability



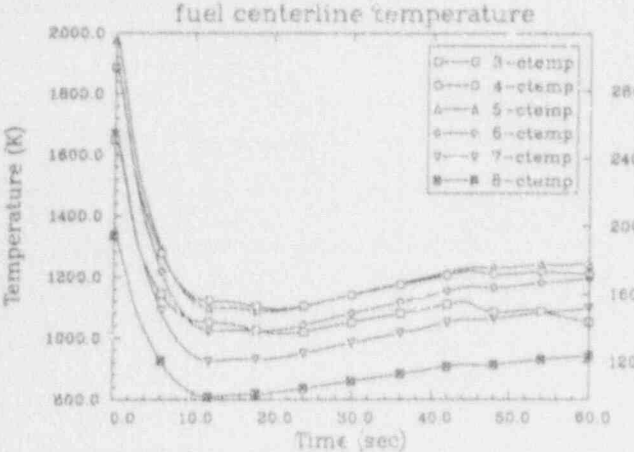
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/ECCS
cladding hoop strain



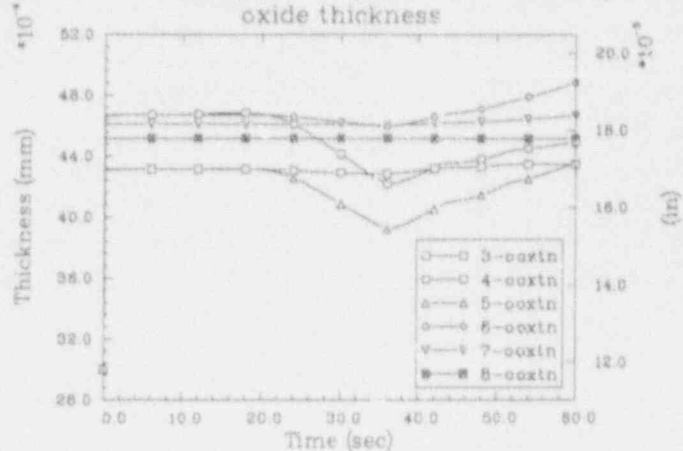
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/ECCS
cladding surface temperature



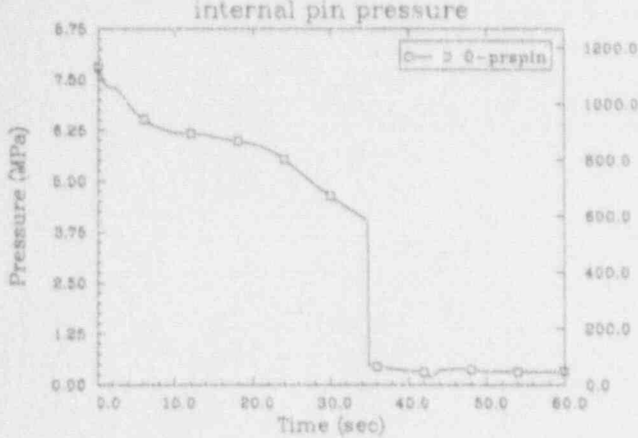
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/ECCS
fuel centerline temperature



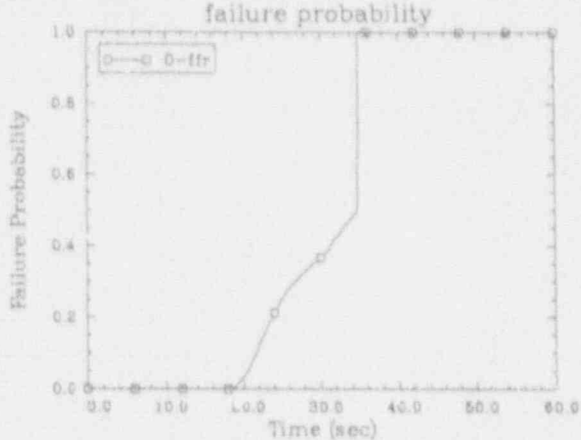
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/ECCS
oxide thickness



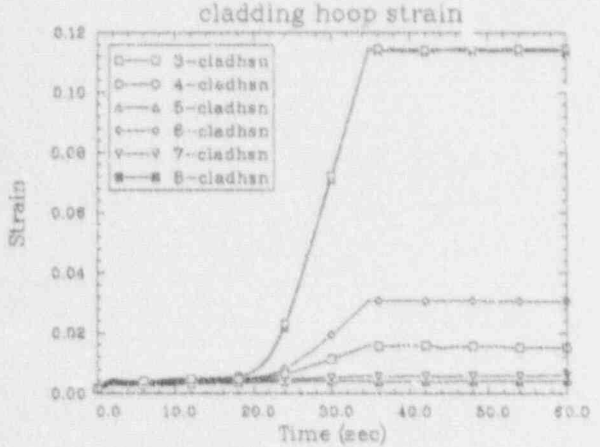
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/ECCS
internal pin pressure



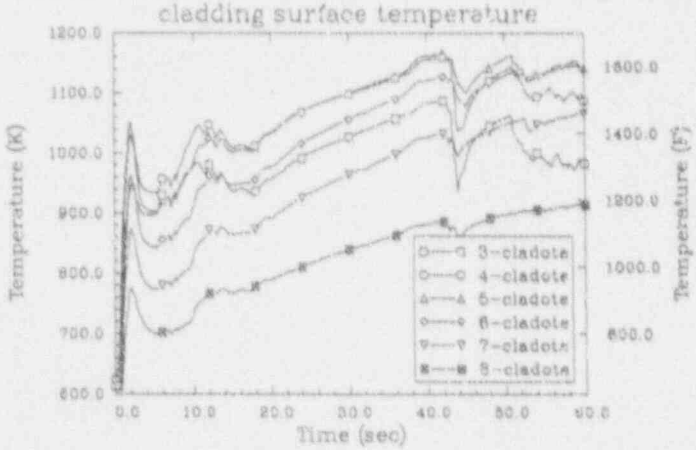
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/ECCS
failure probability



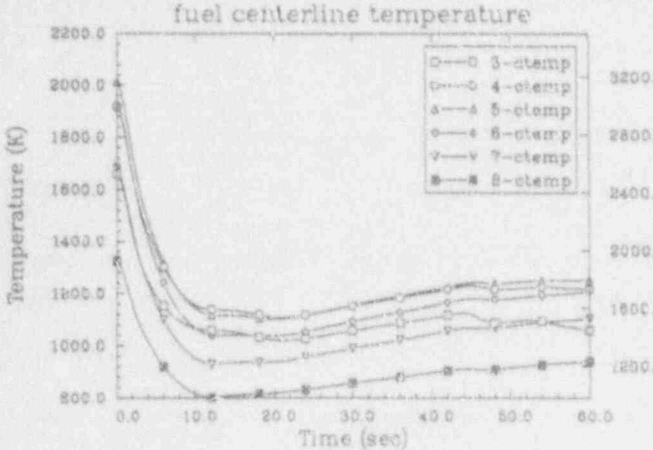
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/ECCS
cladding hoop strain



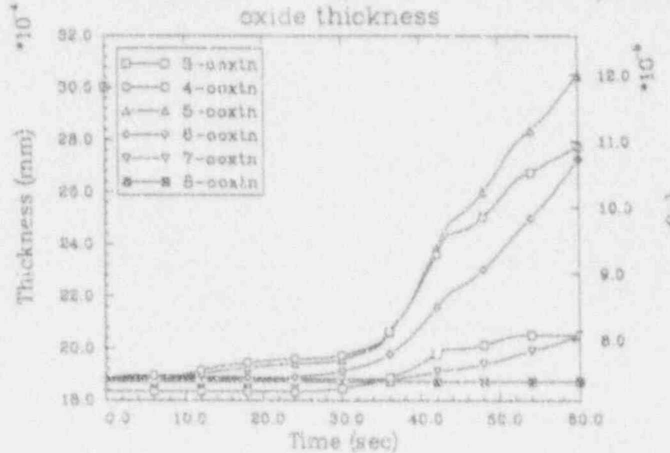
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/ECCS
cladding surface temperature

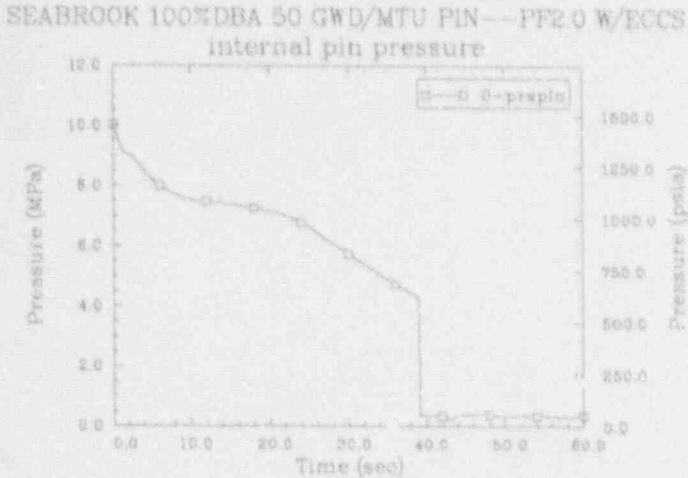


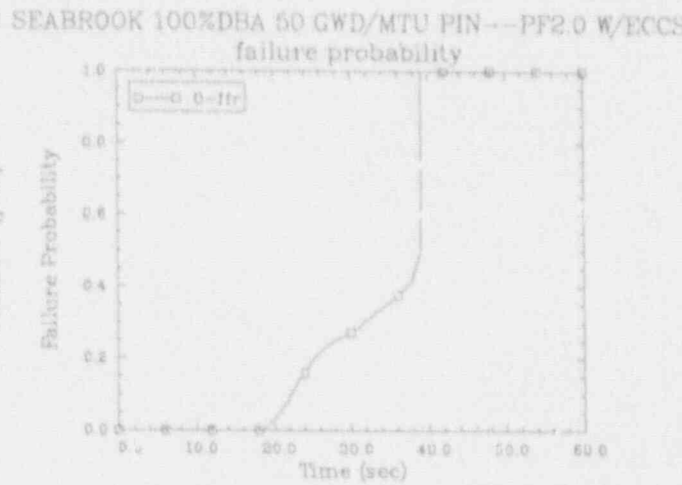
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/ECCS
fuel centerline temperature

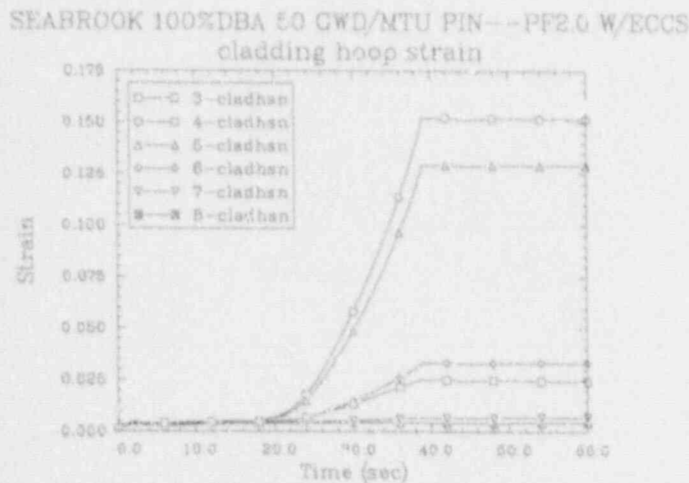


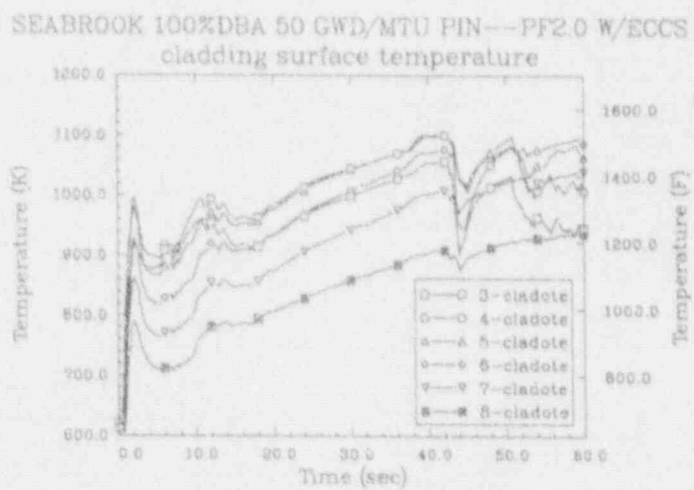
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/ECCS
oxide thickness

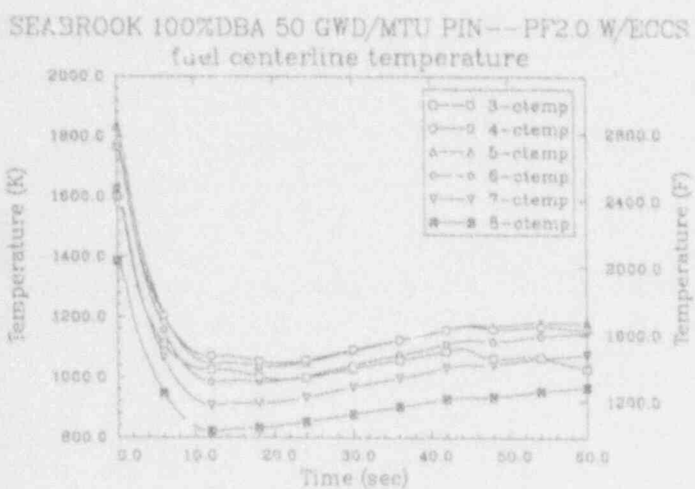


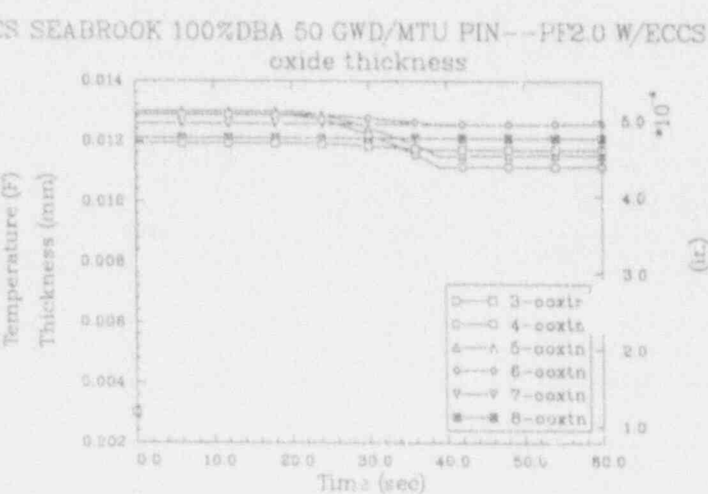

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

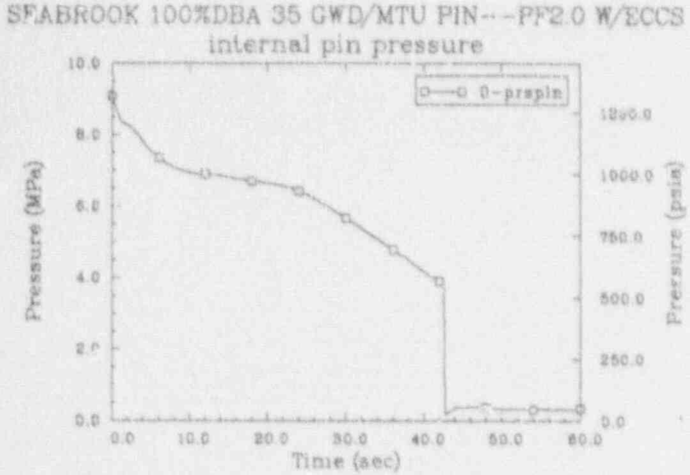

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

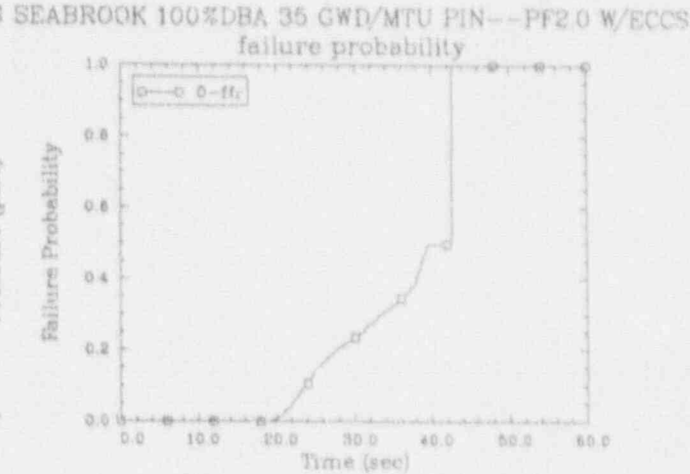

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

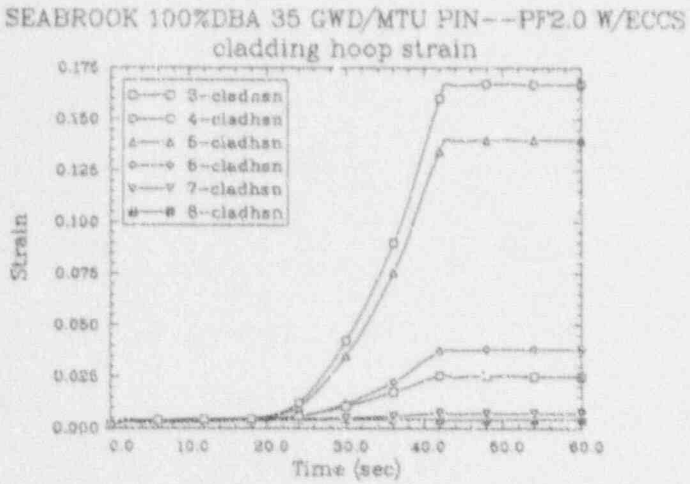

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

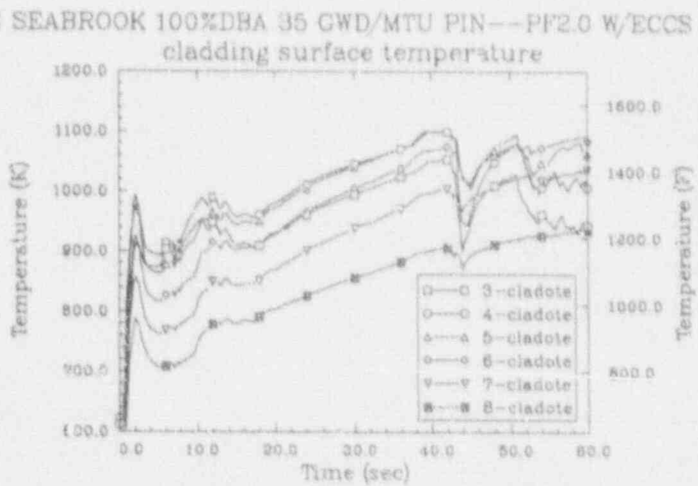

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

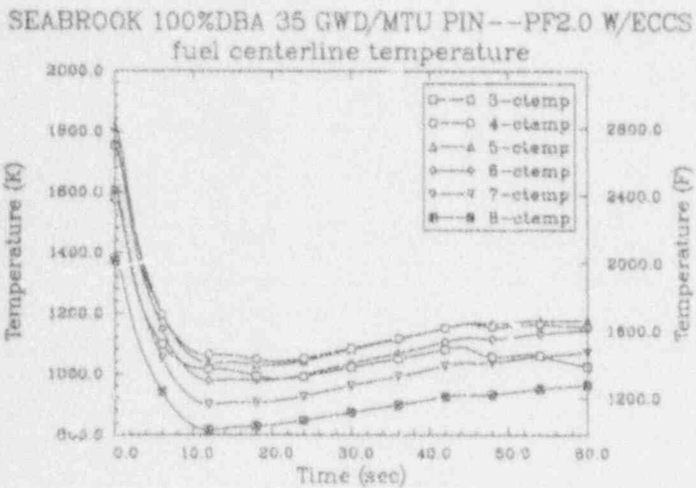

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in.)
Time (sec)

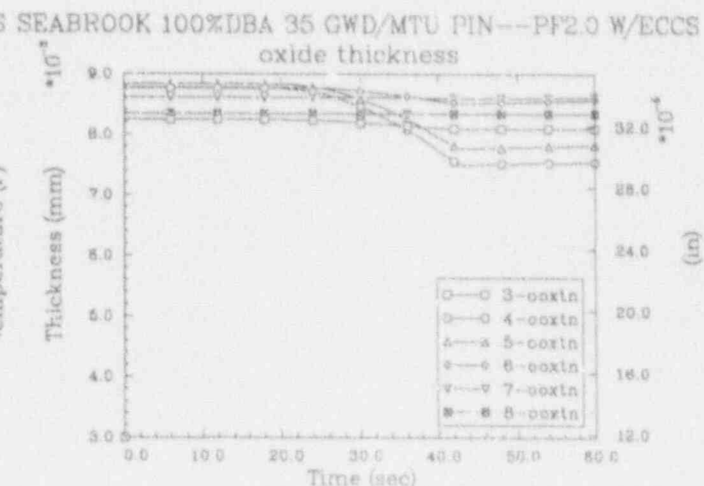

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/ECCS
failure probability
Failure Probability
Time (sec)

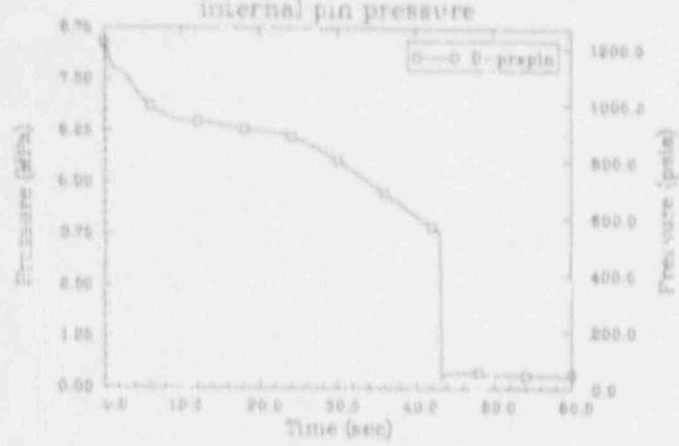

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

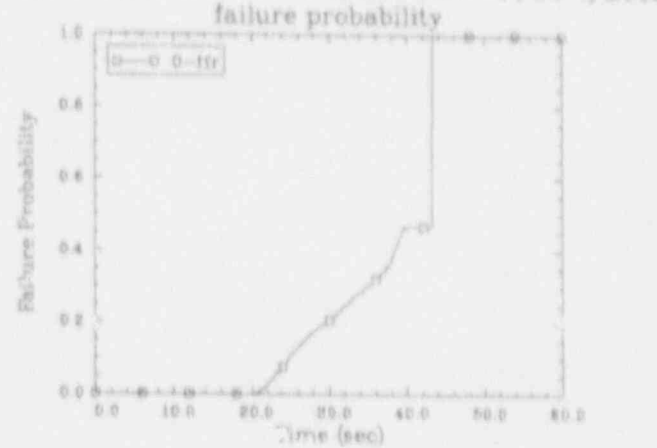

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

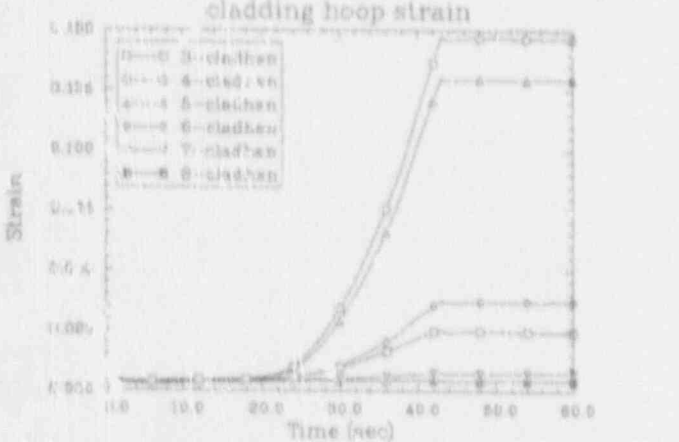
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/ECCS
internal pin pressure



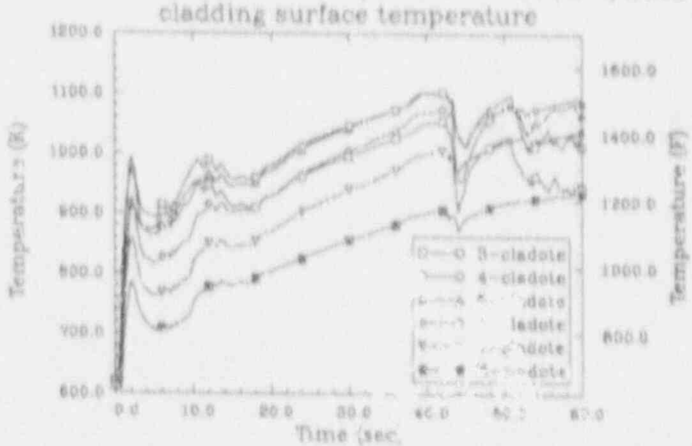
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/ECCS
failure probability



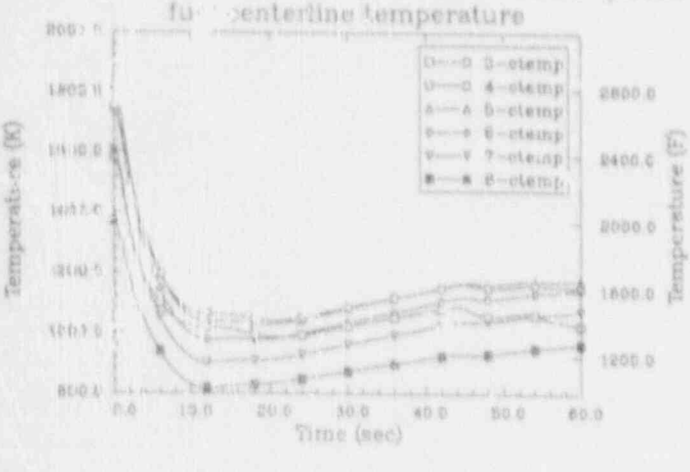
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/ECCS
cladding hoop strain



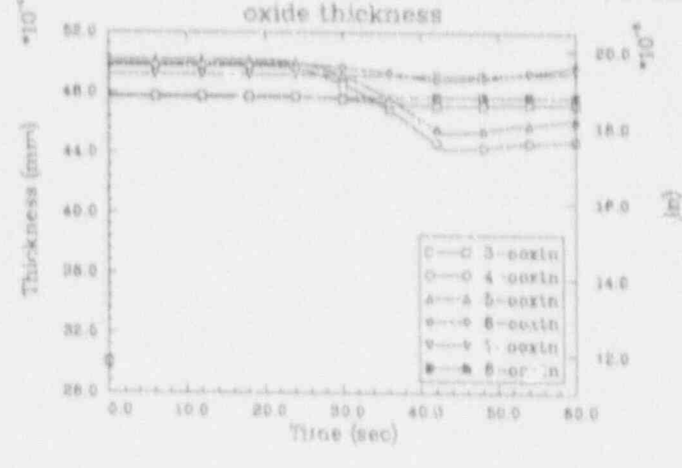
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/ECCS
cladding surface temperature

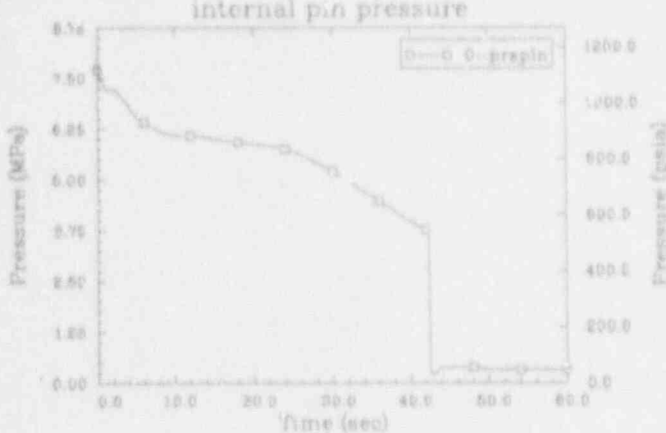


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/ECCS
fuel centerline temperature

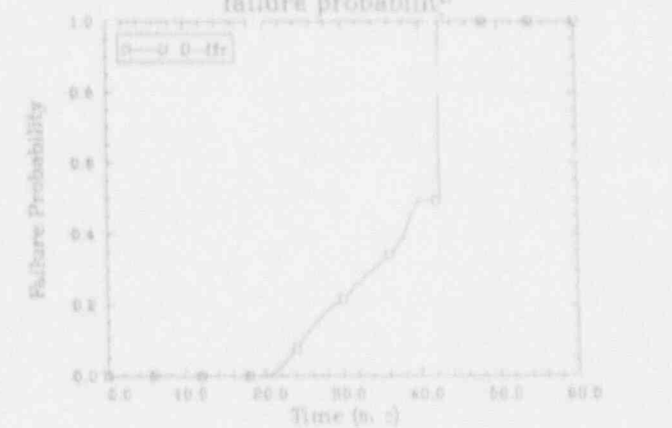


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/ECCS
oxide thickness

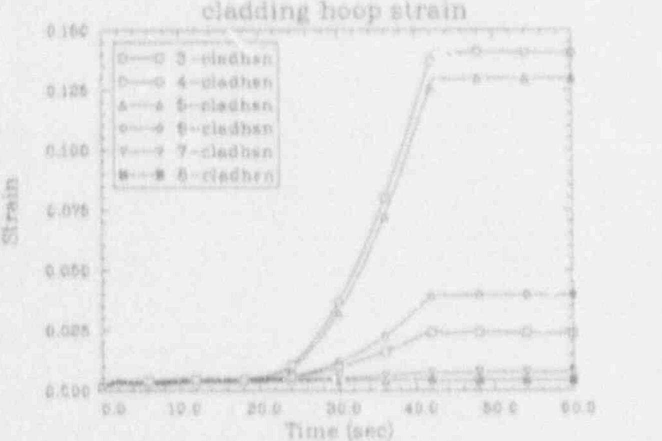




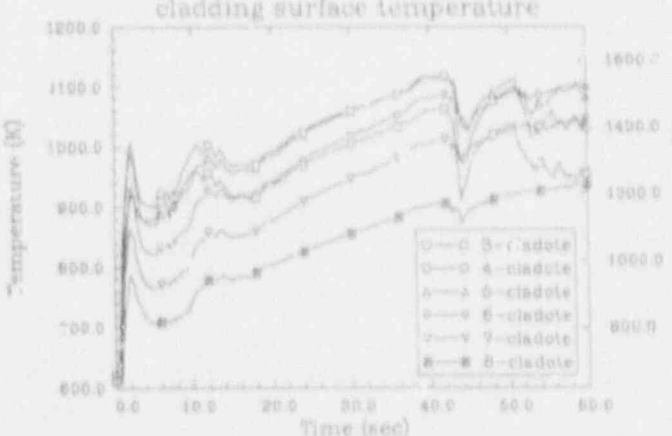
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/ECCS
internal pin pressure



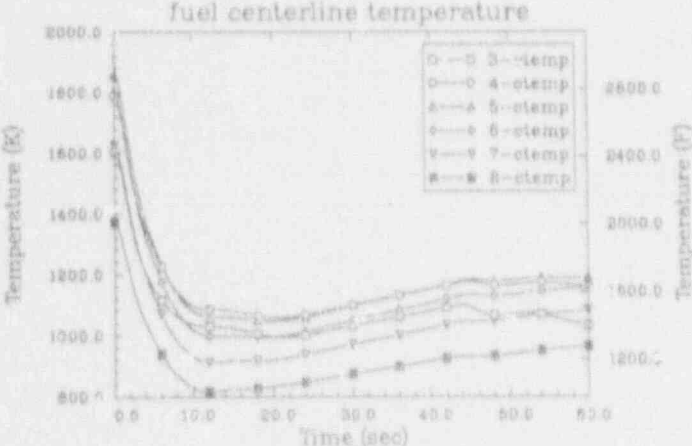
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/ECCS
failure probability



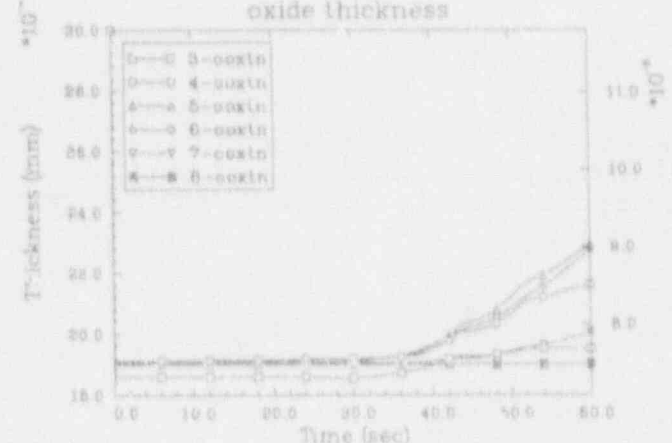
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/ECCS
cladding hoop strain



SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/ECCS
cladding surface temperature

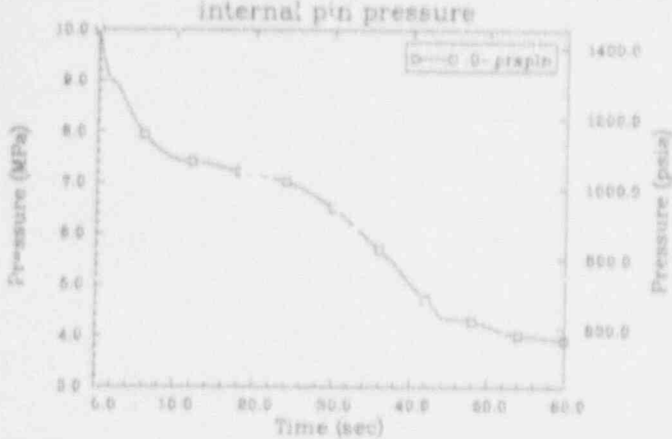


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/ECCS
fuel centerline temperature

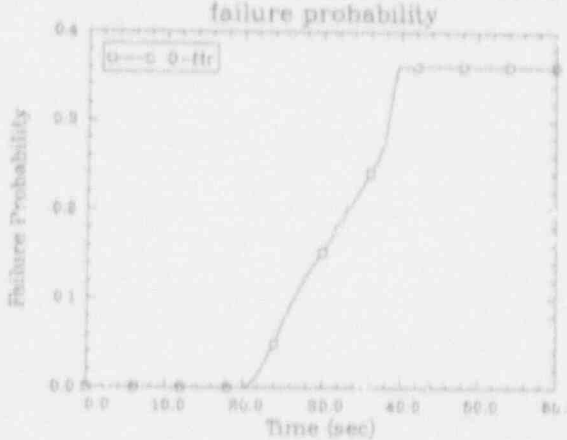


SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/ECCS
oxide thickness

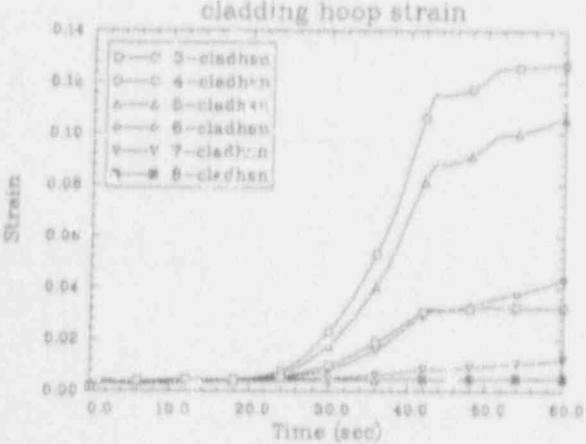
SEABROOK 100%DBA 50 GWD/MTU PIN---PF1.8 W/ECCS
internal pin pressure



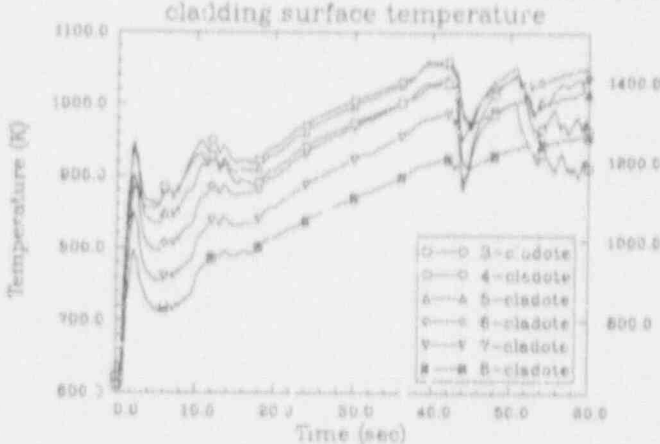
SEABROOK 100%DBA 50 GWD/MTU PIN---PF1.8 W/ECCS
failure probability



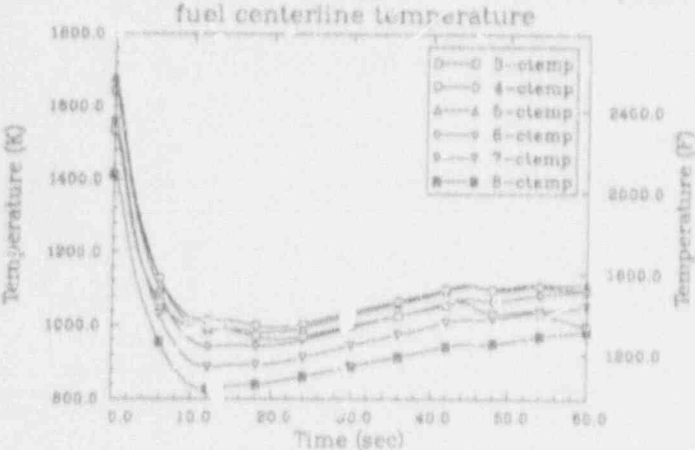
SEABROOK 100%DBA 50 GWD/MTU PIN---PF1.8 W/ECCS
cladding hoop strain



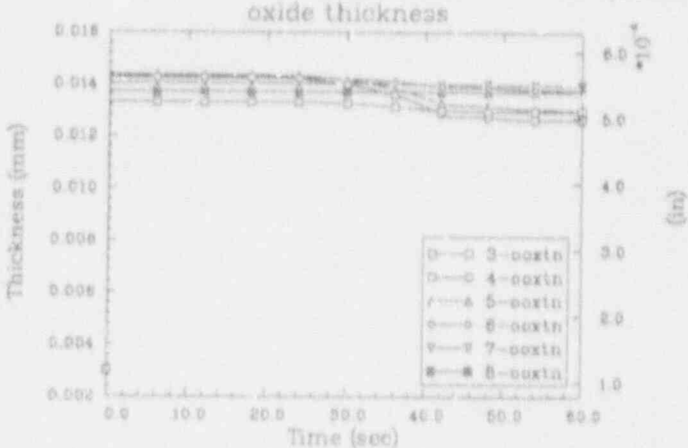
SEABROOK 100%DBA 50 GWD/MTU PIN---PF1.8 W/ECCS
cladding surface temperature



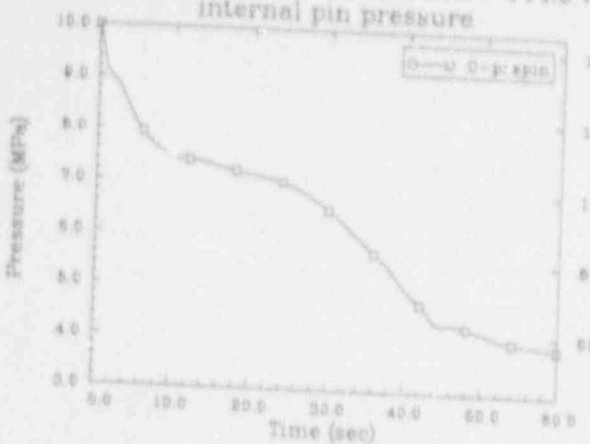
SEABROOK 100%DBA 50 GWD/MTU PIN---PF1.8 W/ECCS
fuel centerline temperature



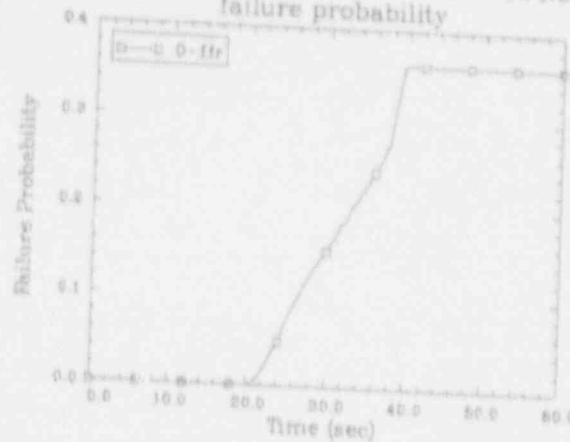
SEABROOK 100%DBA 50 GWD/MTU PIN---PF1.8 W/ECCS
oxide thickness



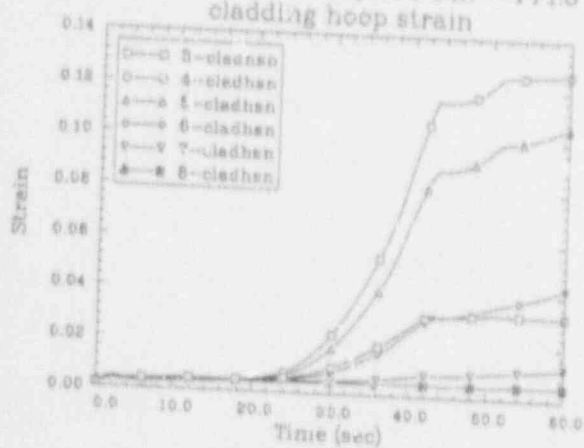
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
internal pin pressure



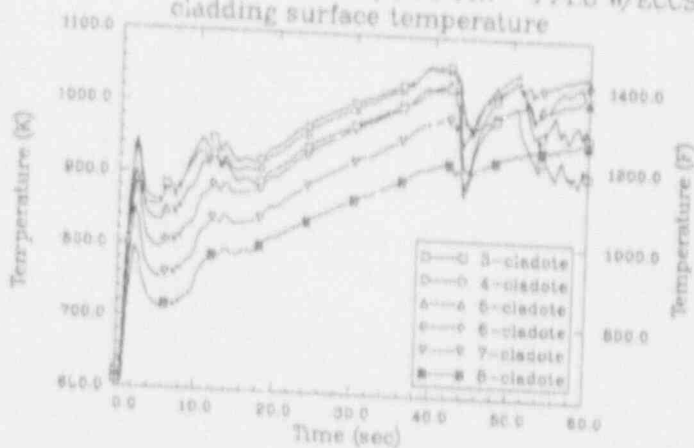
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
failure probability



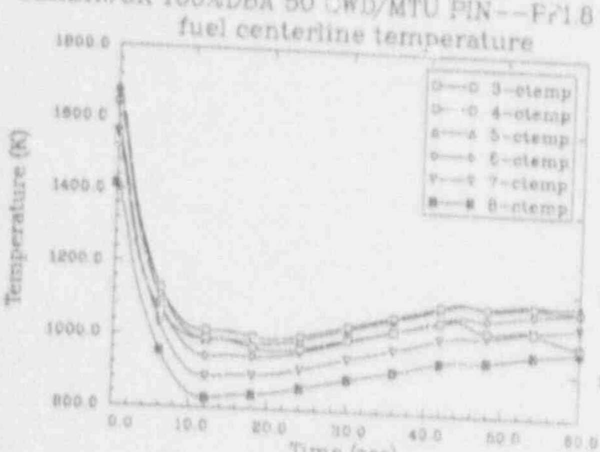
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
cladding hoop strain



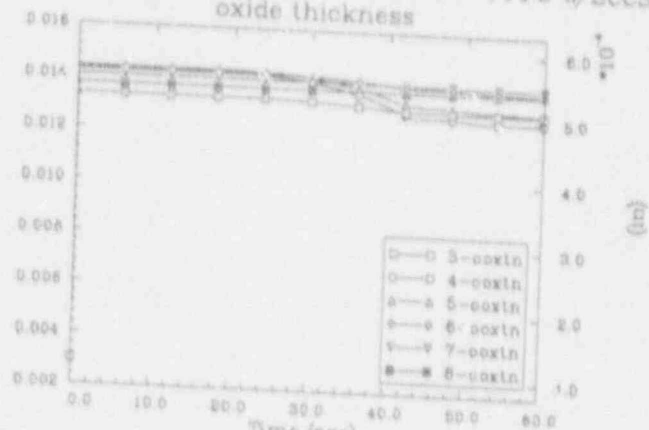
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
cladding surface temperature

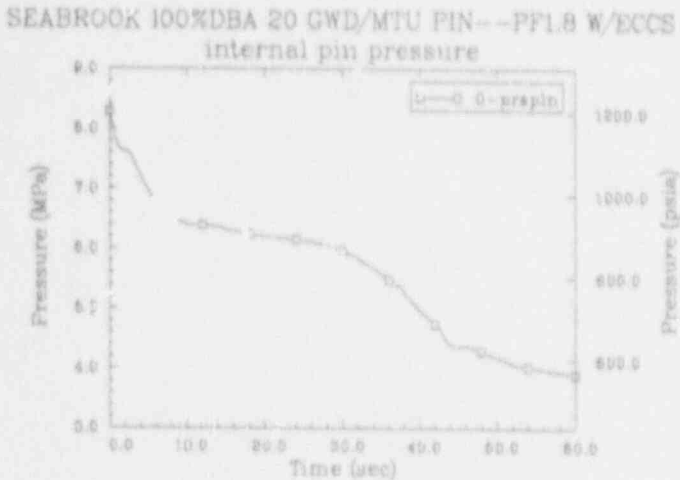


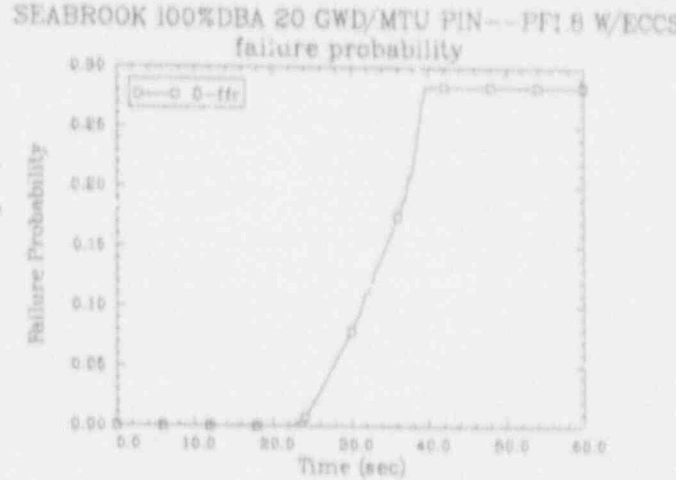
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
fuel centerline temperature

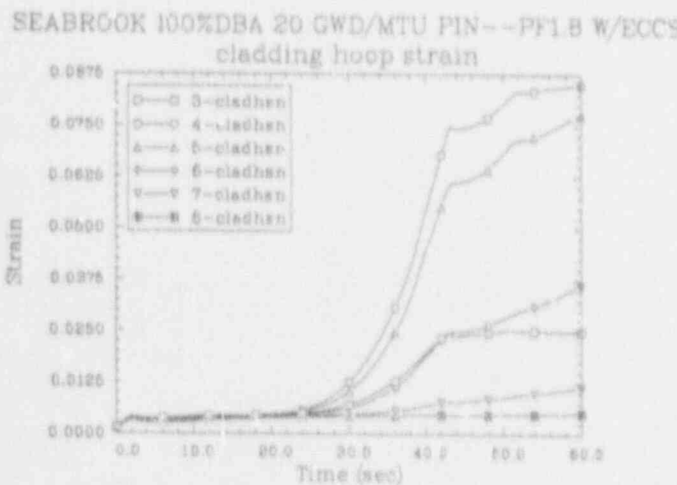


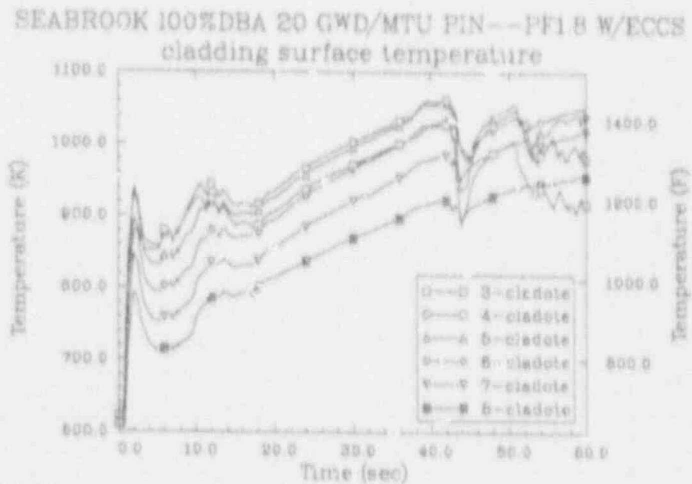
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
oxide thickness

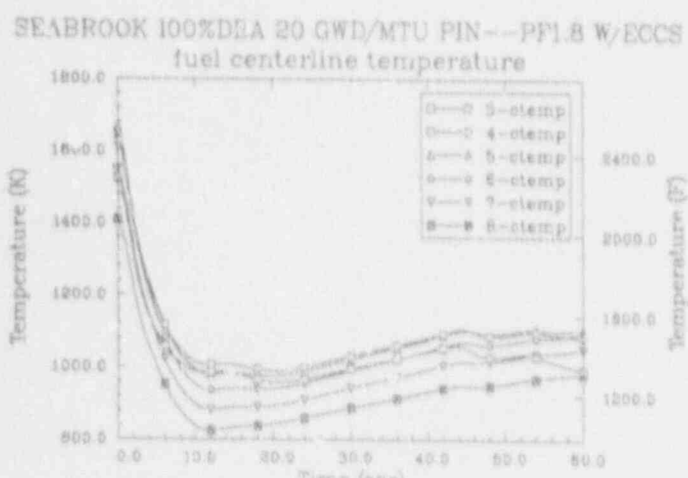


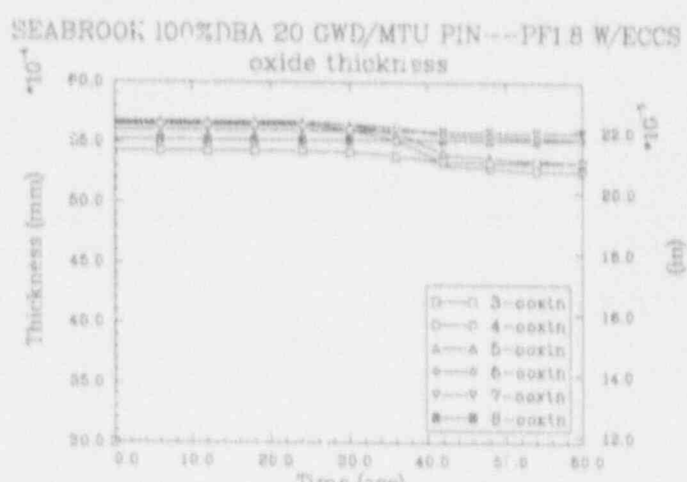

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

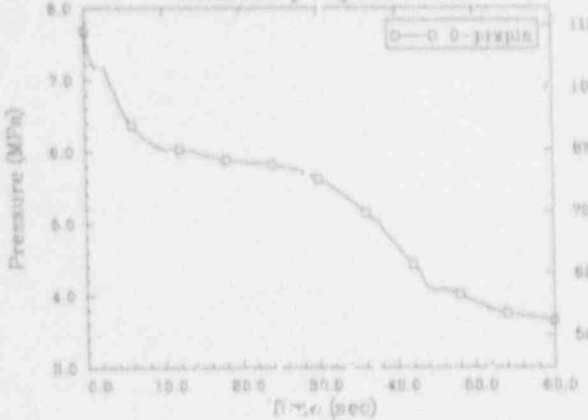

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

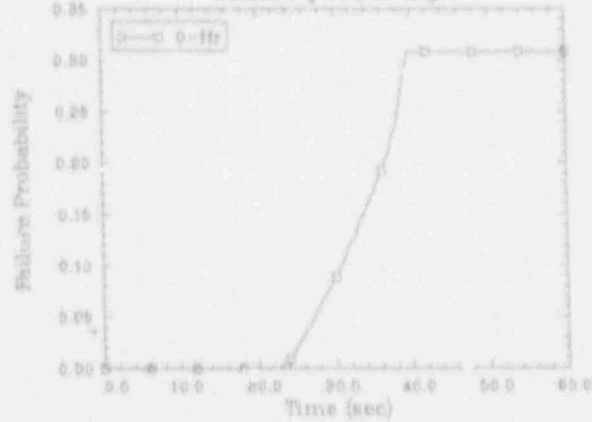

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
oxide thickness
3-oxxtn
4-oxxtn
5-oxxtn
6-oxxtn
7-oxxtn
8-oxxtn
Thickness (mm)
(in)
Time (sec)

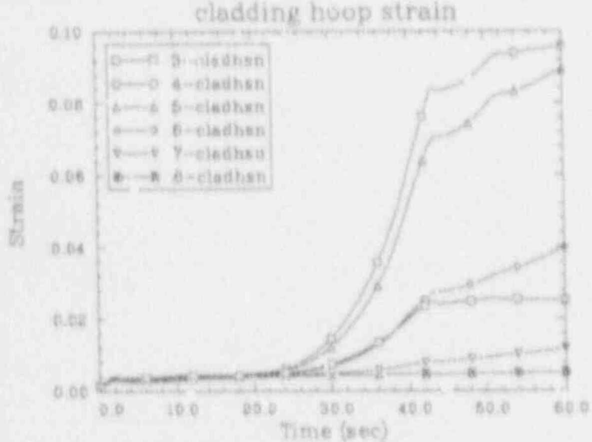
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS internal pin pressure



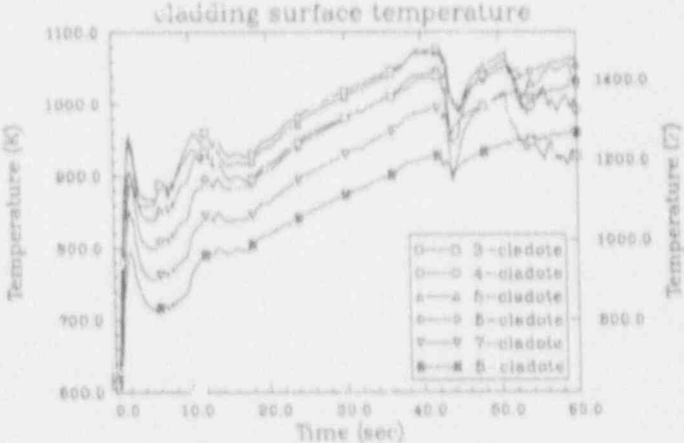
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS failure probability



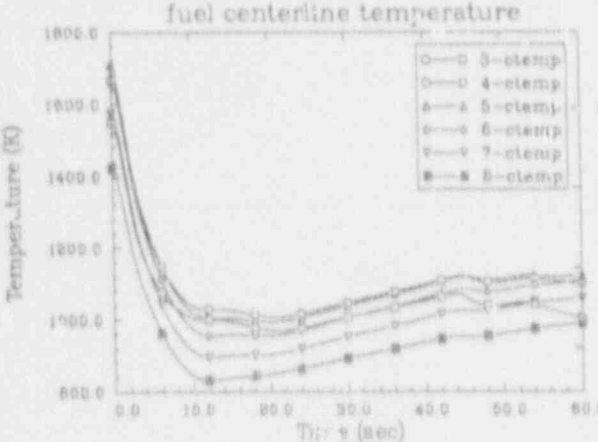
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS cladding hoop strain



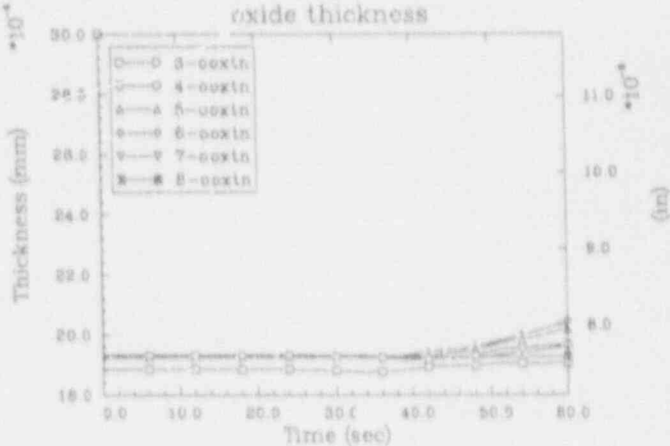
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS cladding surface temperature

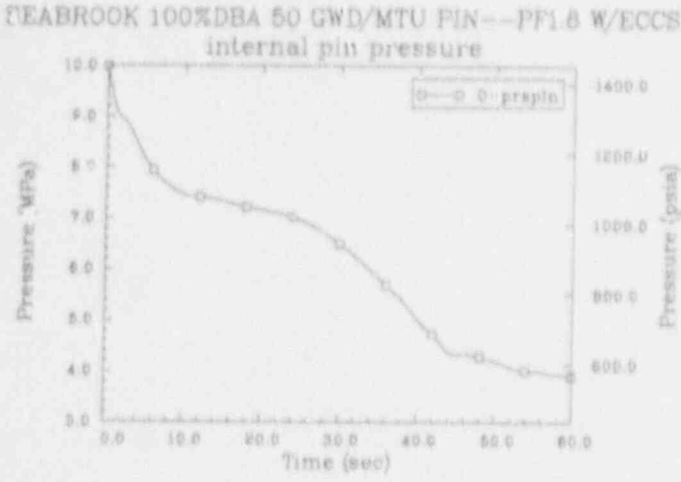


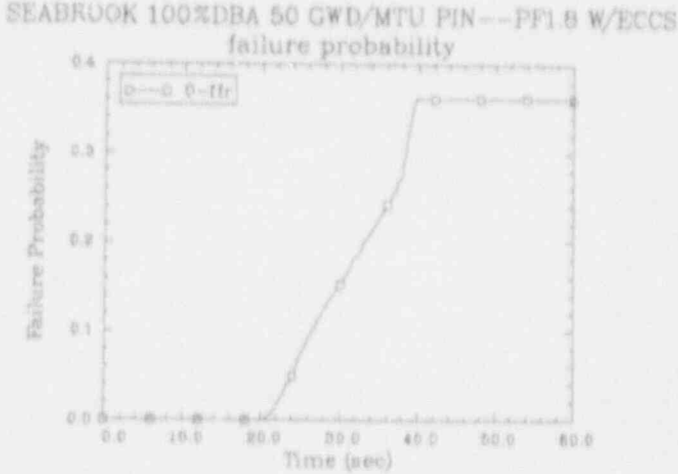
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS fuel centerline temperature

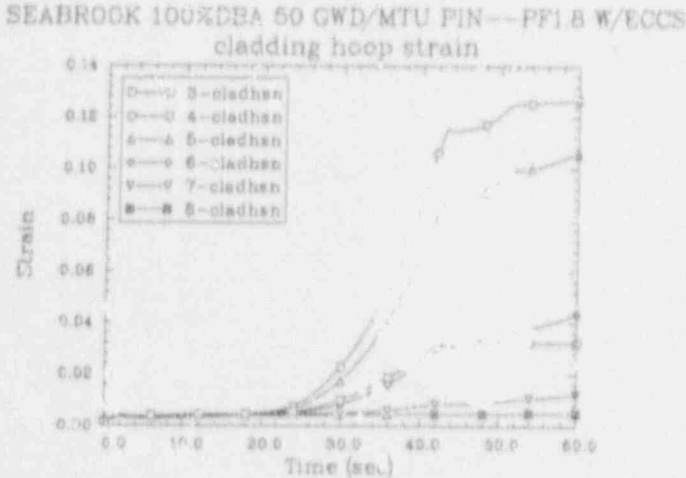


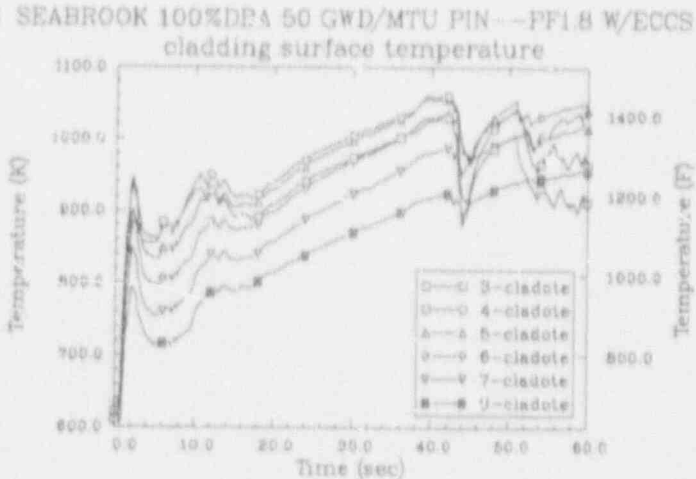
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS oxide thickness

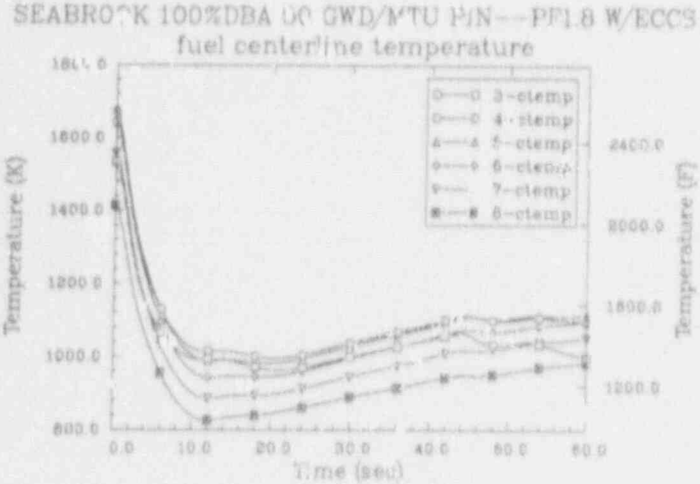


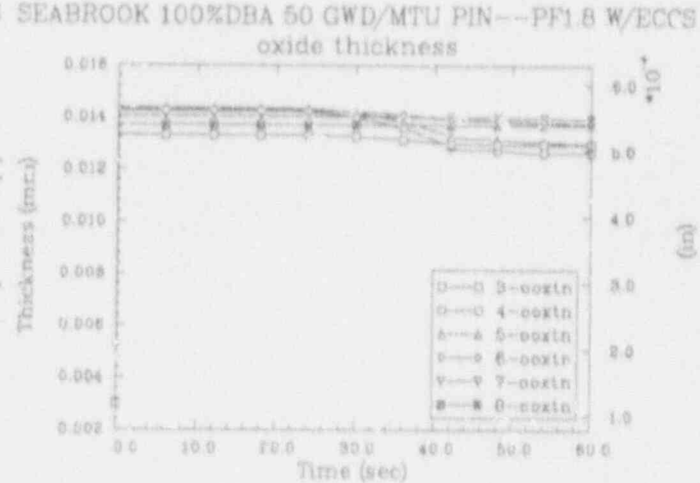

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

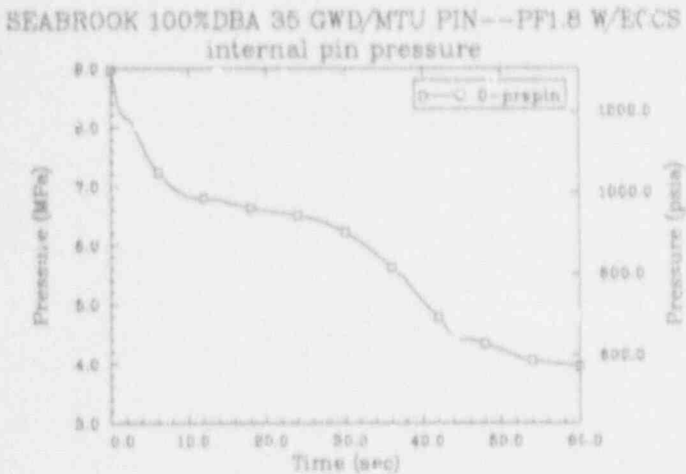

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

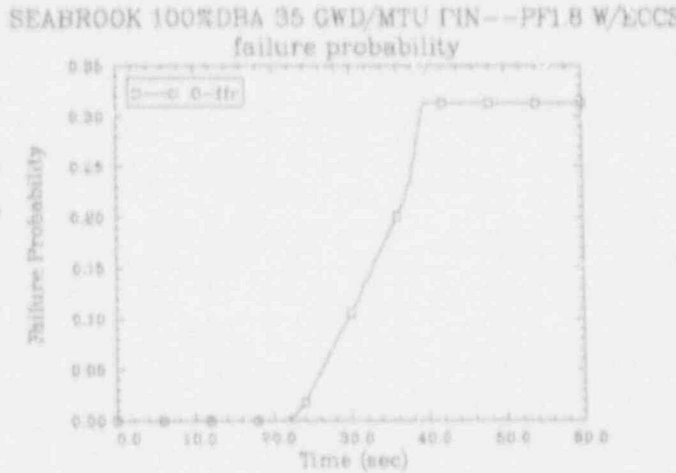

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

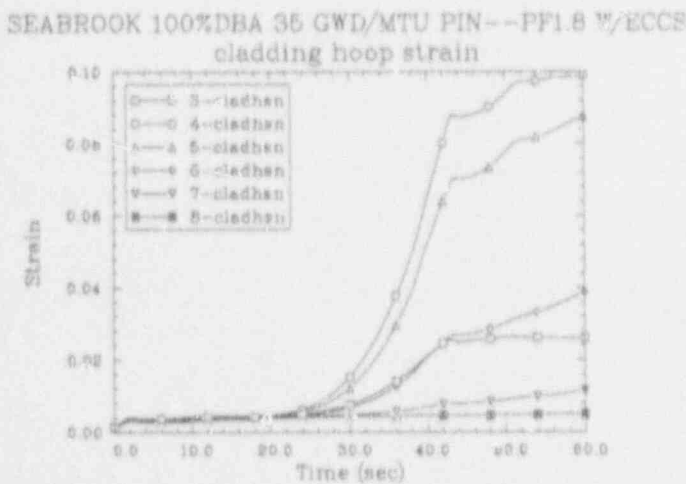

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

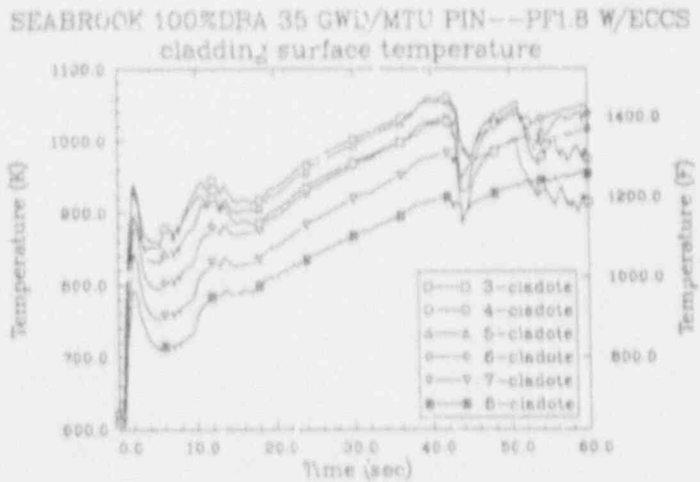

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

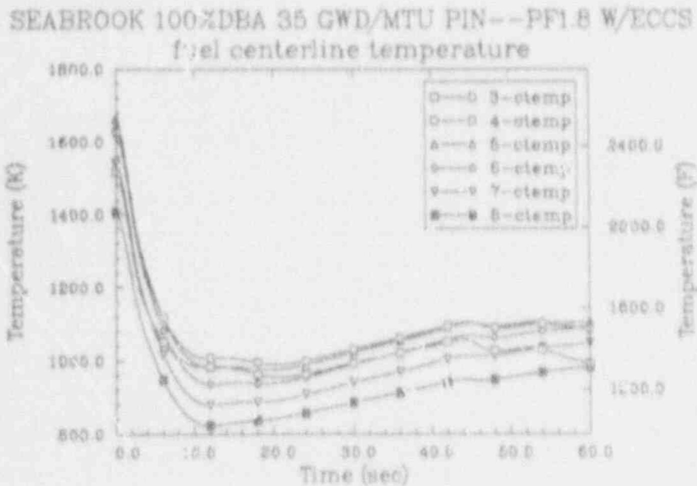

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

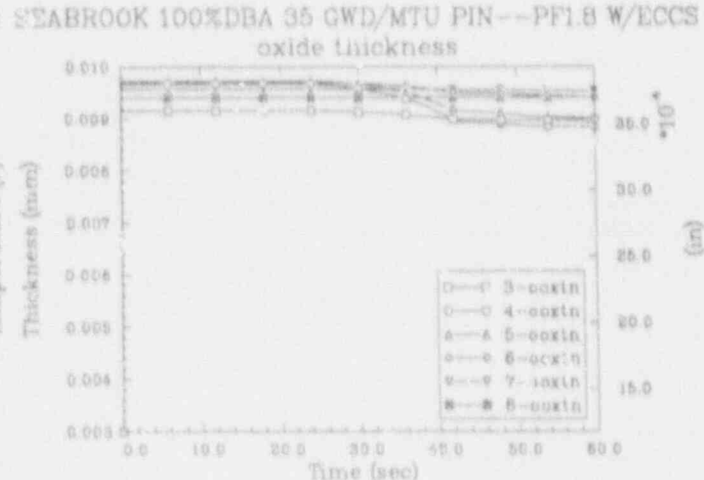

SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

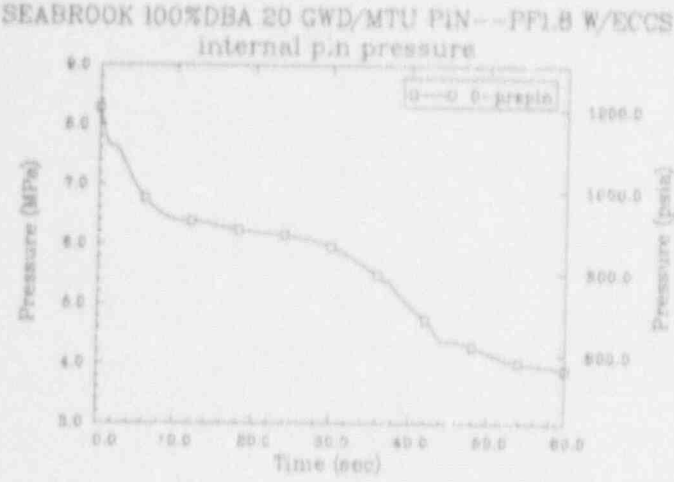

SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

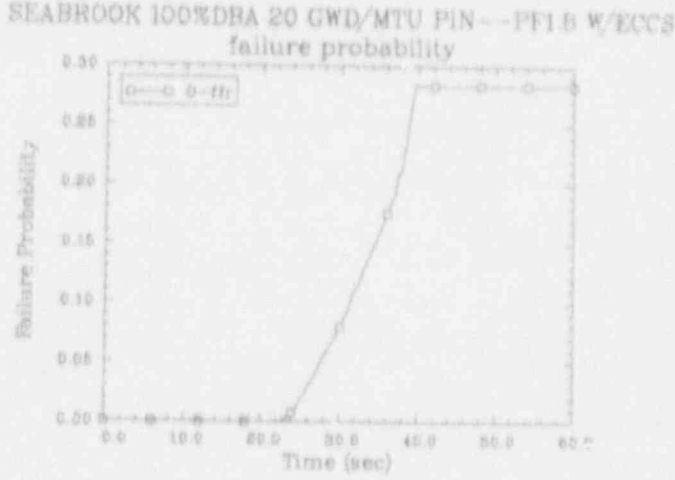

SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

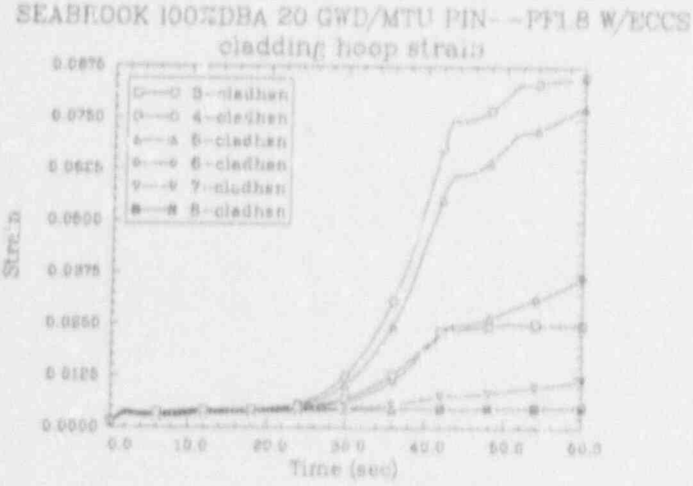

SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

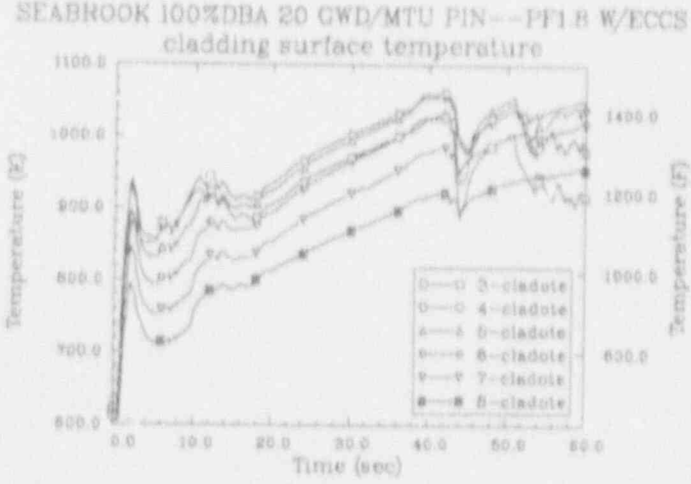

SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

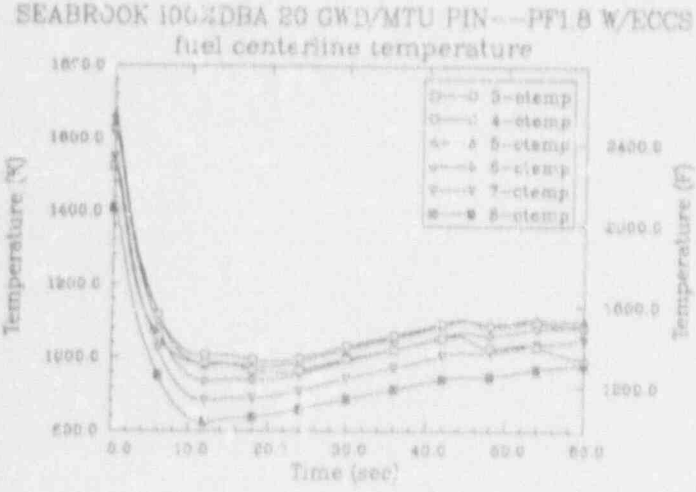

SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

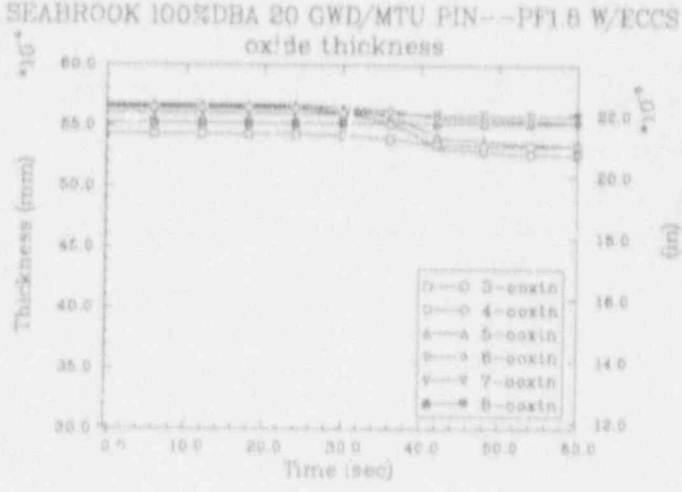

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

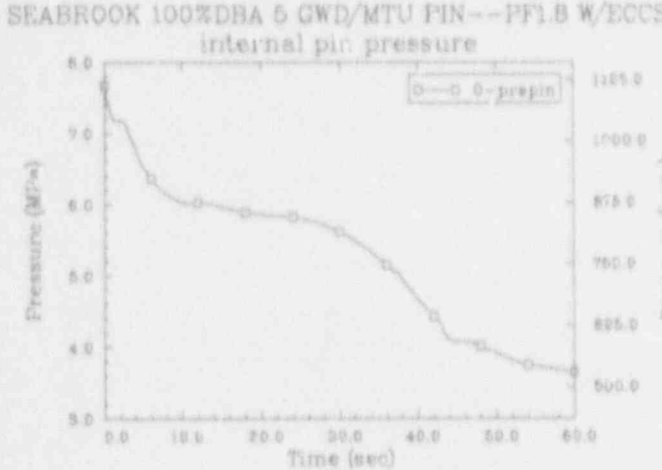

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
failure probability
Failure Probability
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
cladding hoop strain
Strain
Time (sec)

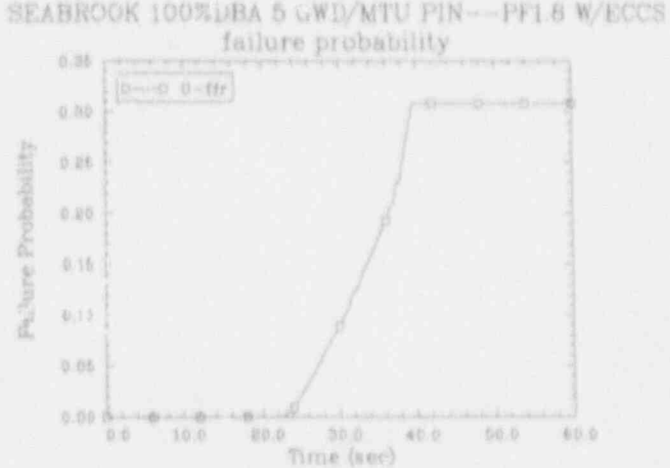

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)

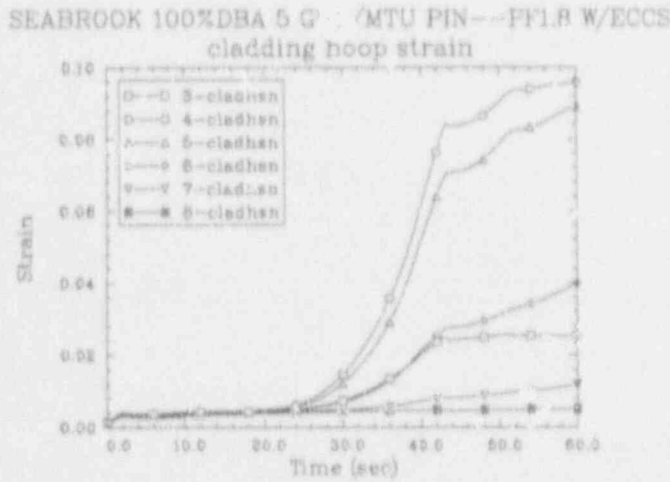

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/ECCS
oxide thickness
Thickness (mm)
(in)
Time (sec)



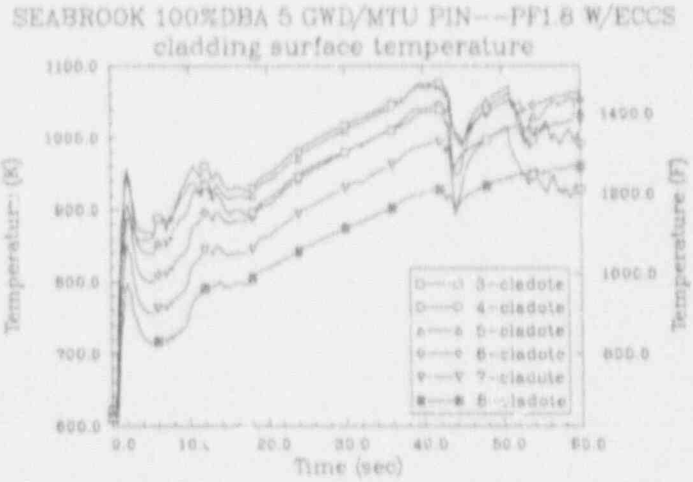
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)



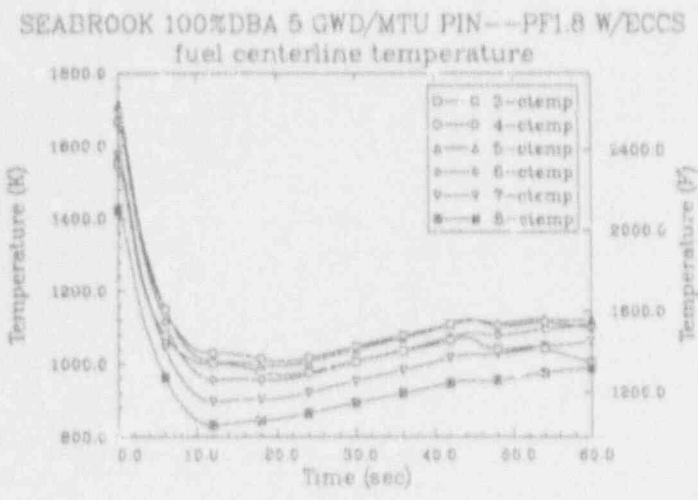
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)



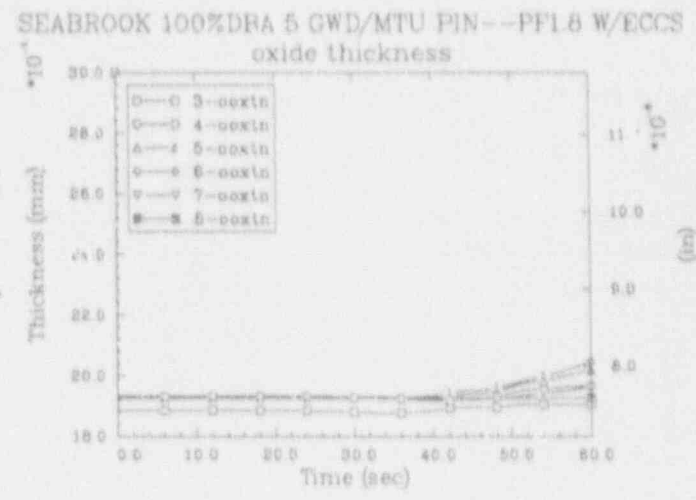
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
8-cladhsn
Strain
Time (sec)



SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
Temperature (K)
Temperature (F)
Time (sec)

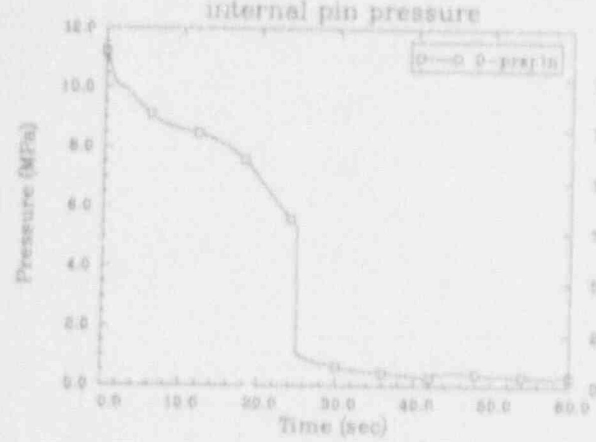


SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

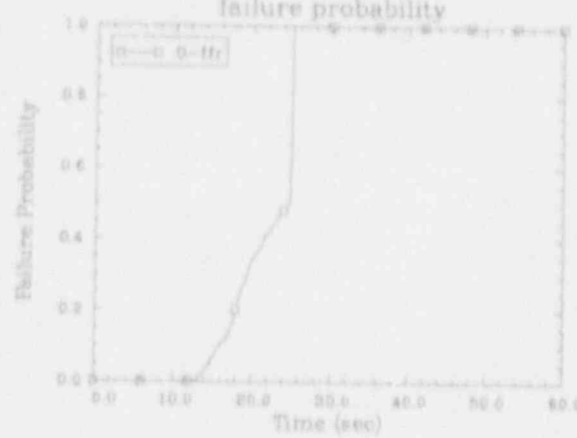


SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

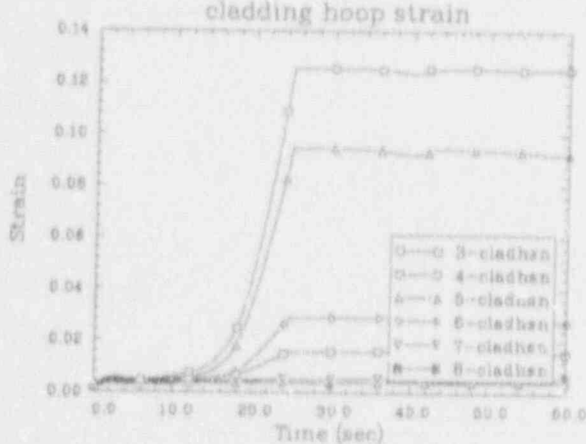
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/E&PT



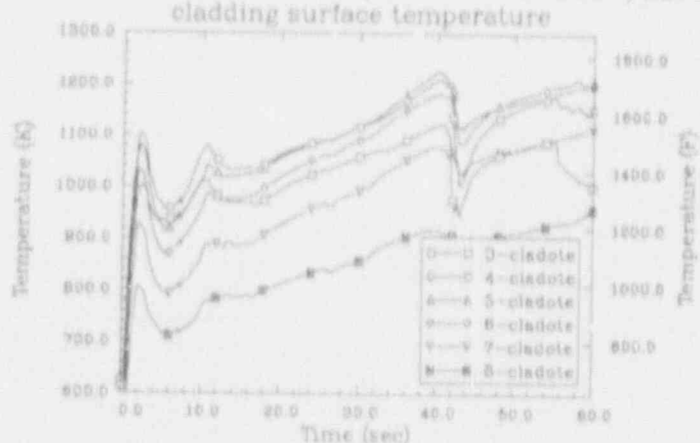
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/E&PT



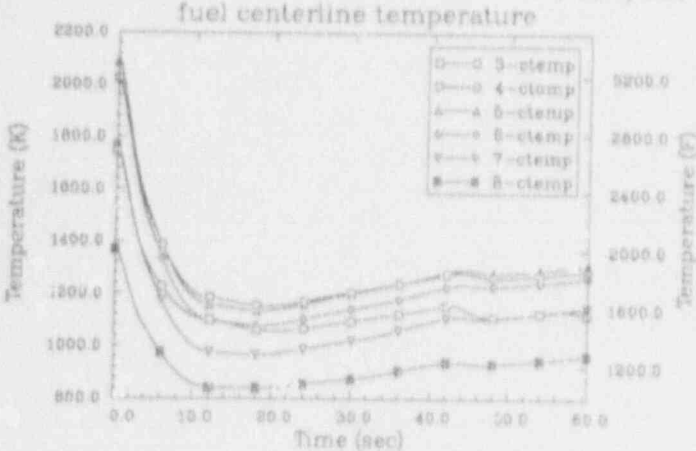
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/E&PT



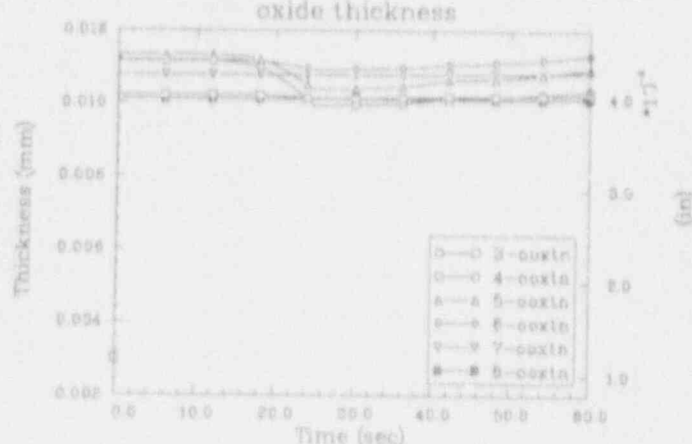
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/E&PT

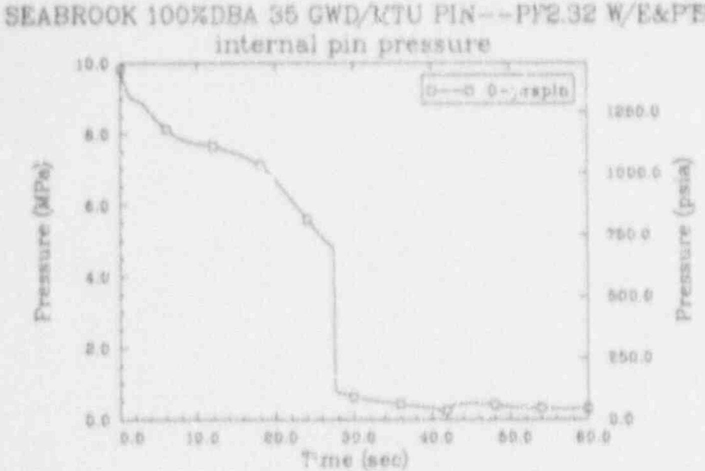


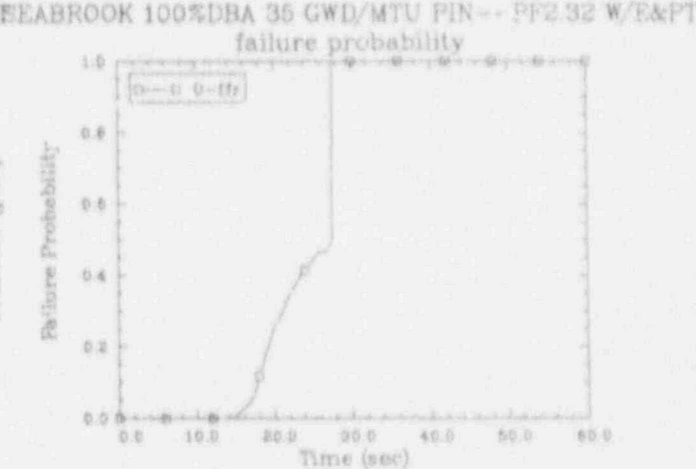
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/E&PT

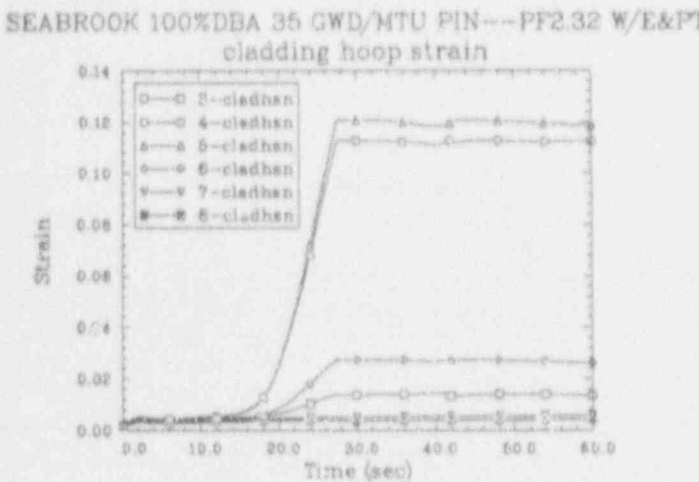


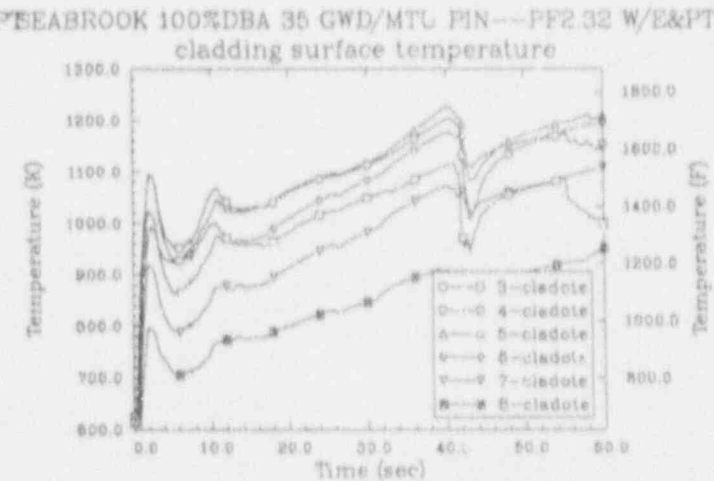
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.32 W/E&PT

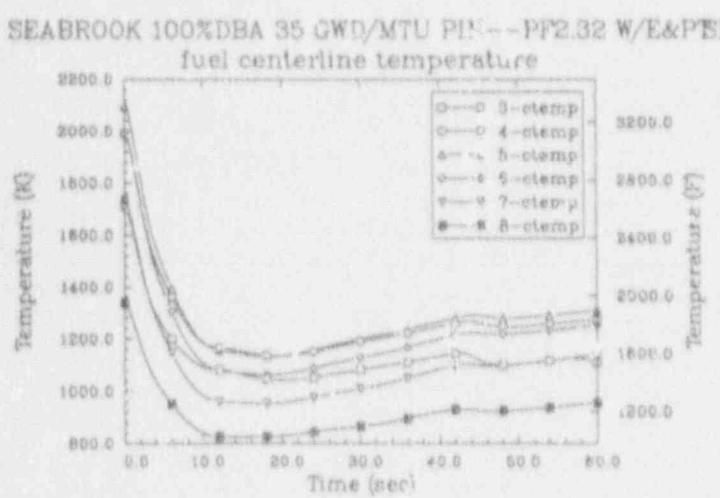


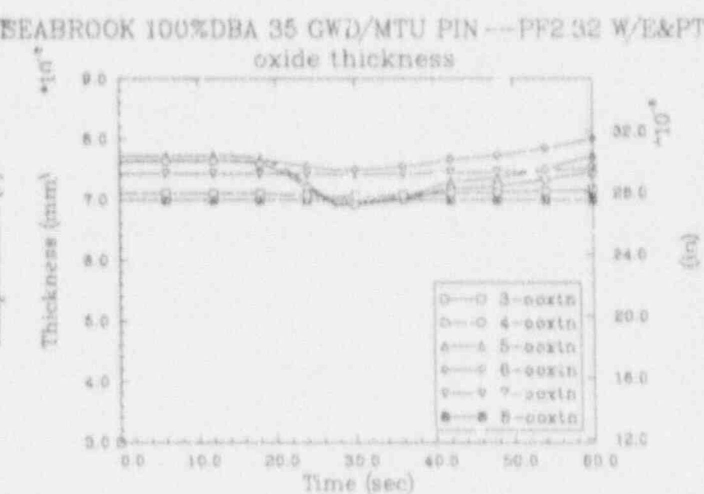

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/E&PT
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)

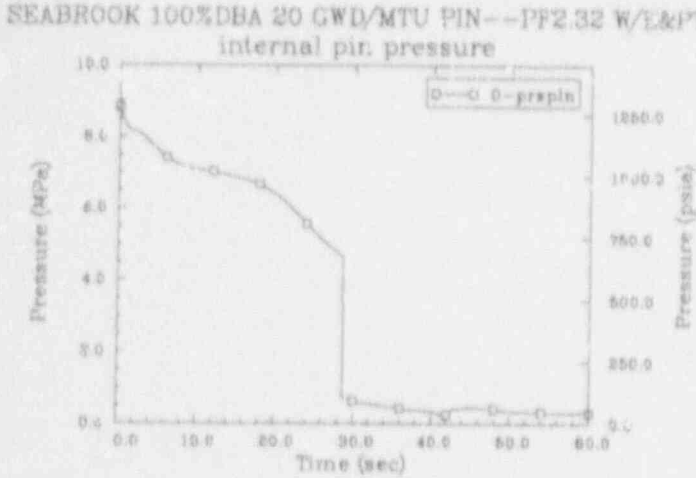

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

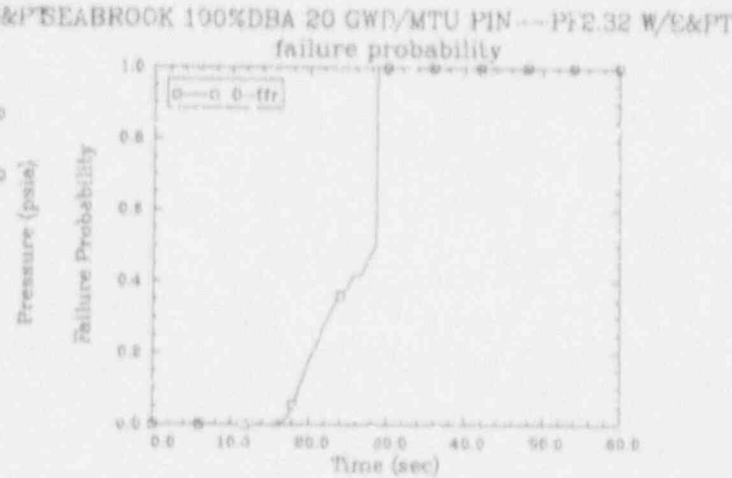

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

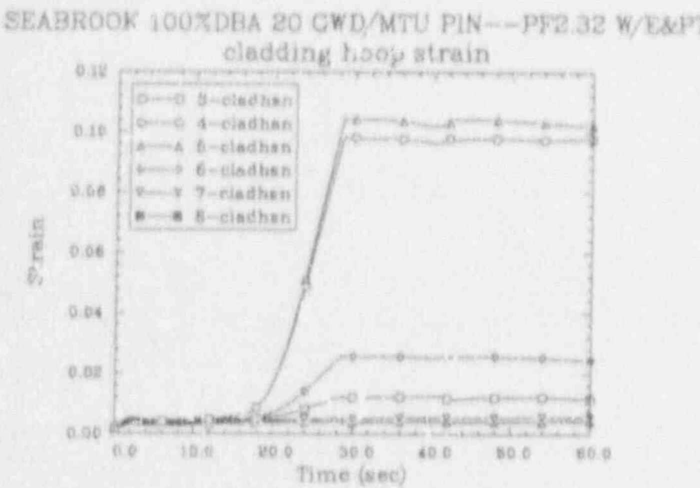

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

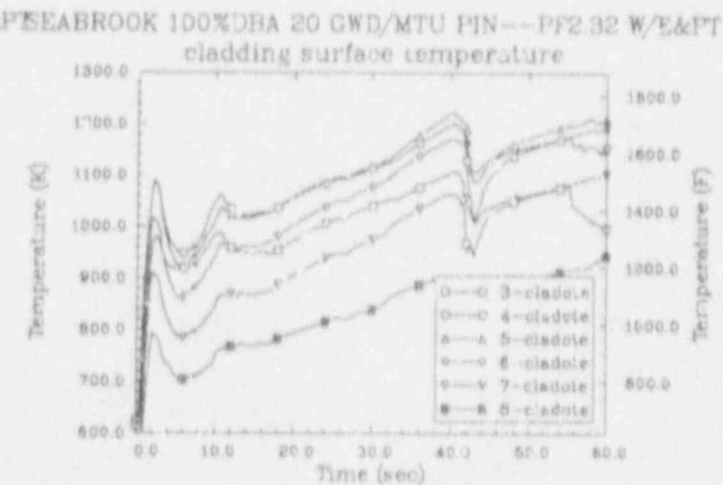

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

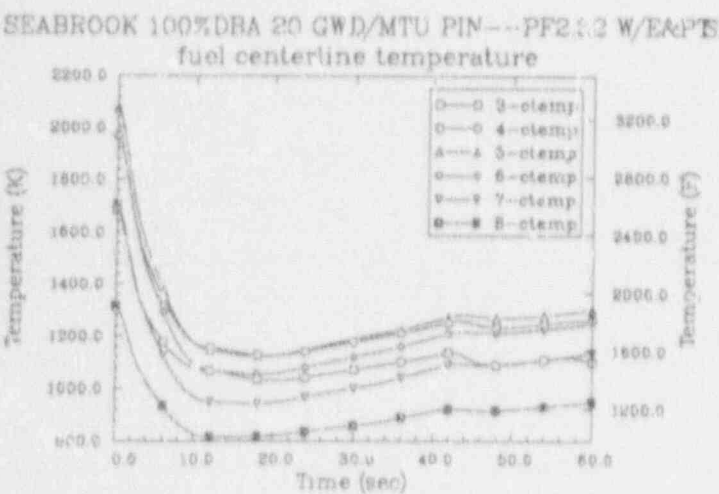

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.32 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

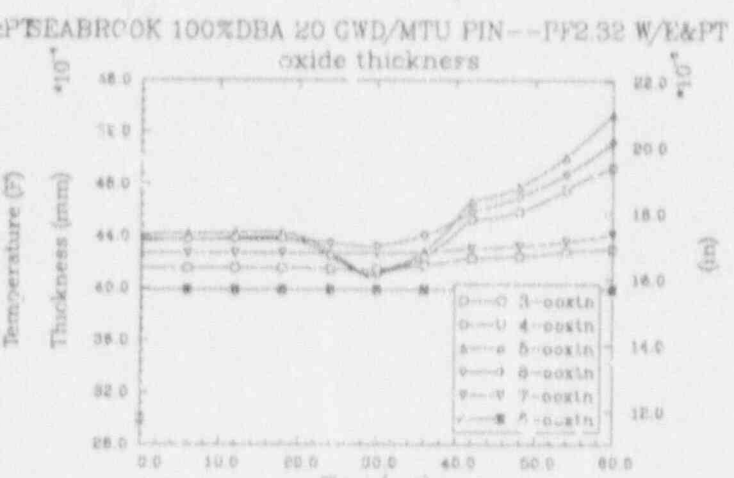

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/E&PT
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

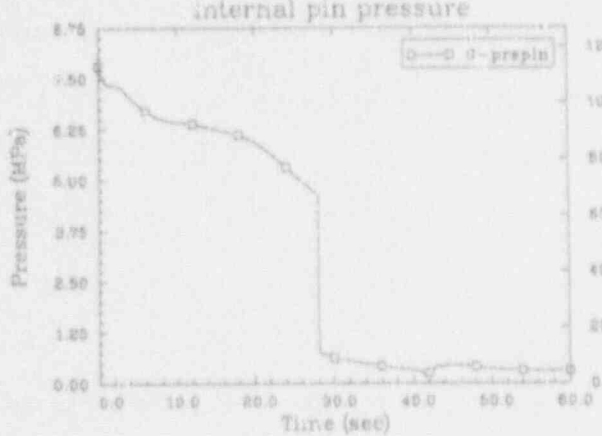

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

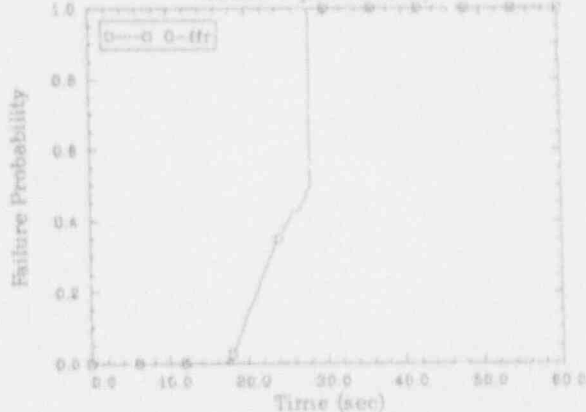

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.32 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

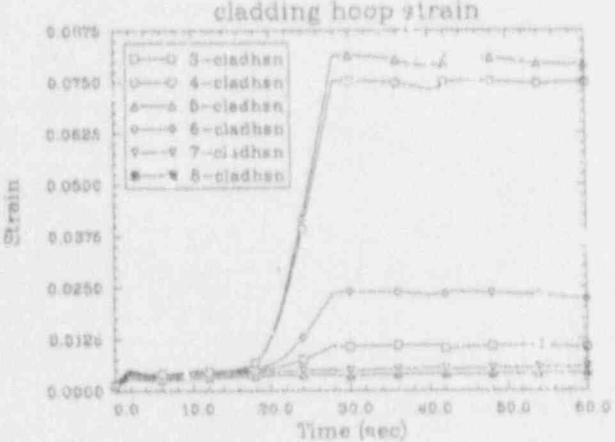
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/E&PT
internal pin pressure



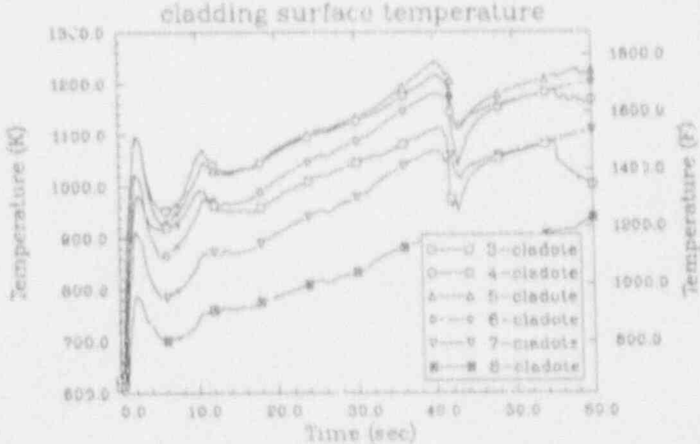
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/E&PT
failure probability



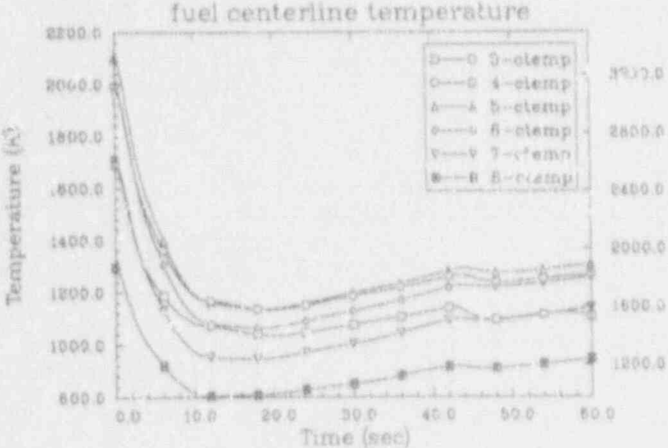
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/E&PT
cladding hoop strain



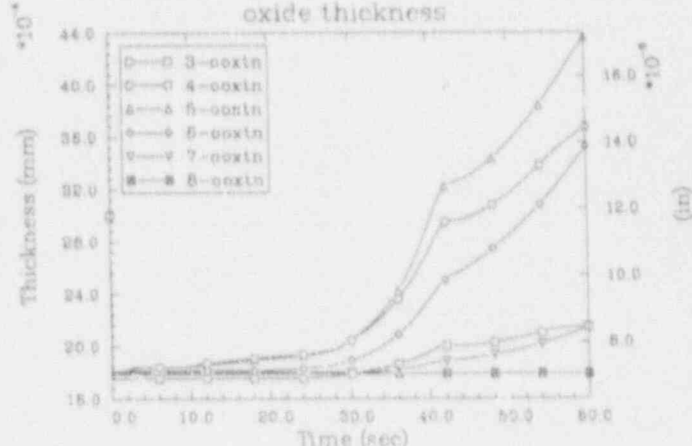
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/E&PT
cladding surface temperature



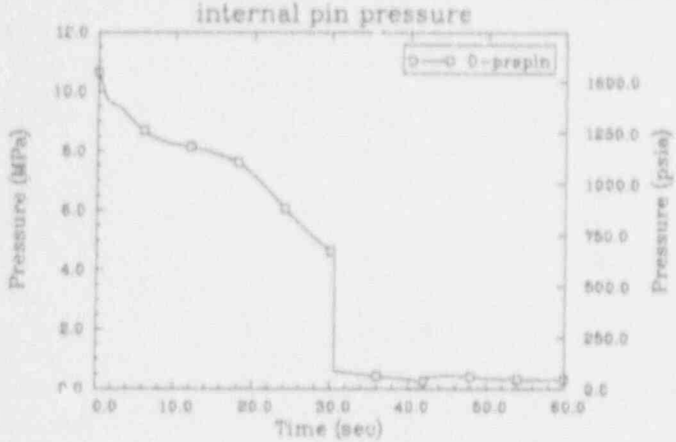
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/E&PT
fuel centerline temperature



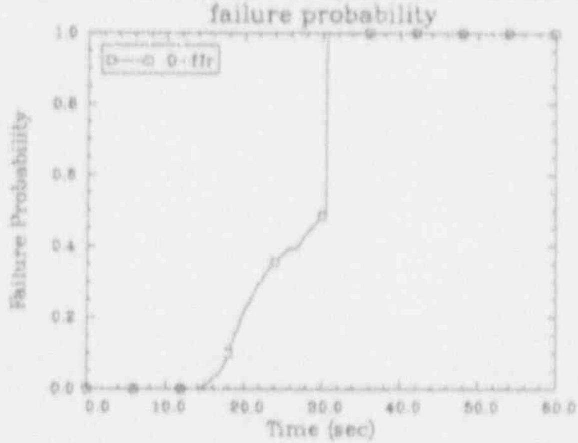
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.32 W/E&PT
oxide thickness



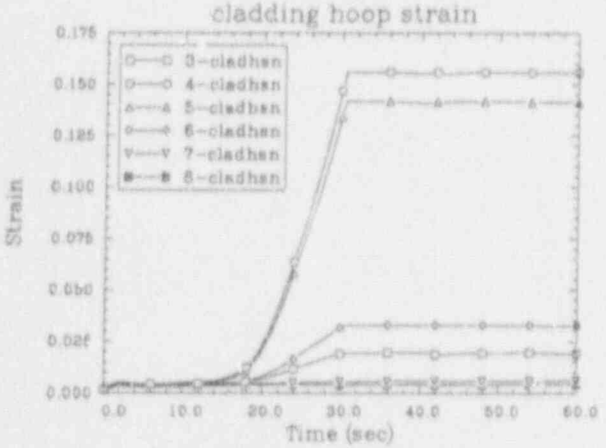
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/E&PT
internal pin pressure



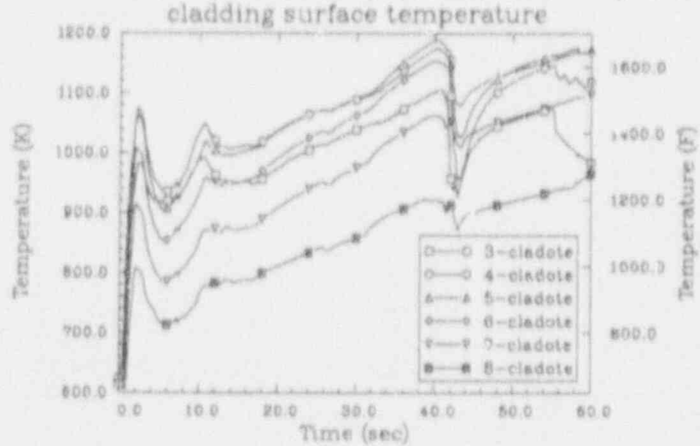
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/E&PT
failure probability



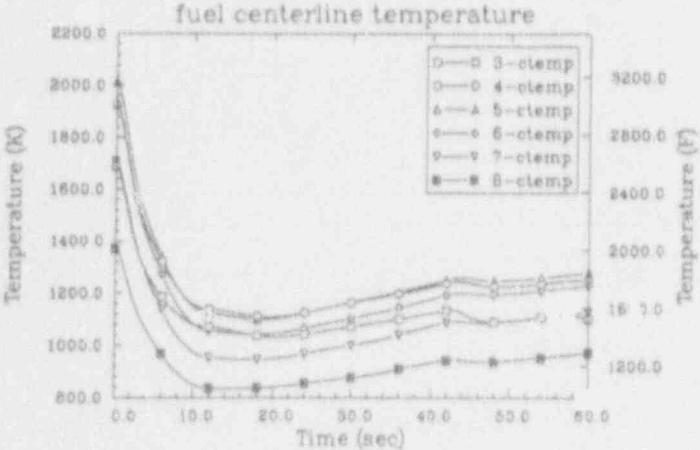
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/E&PT
cladding hoop strain



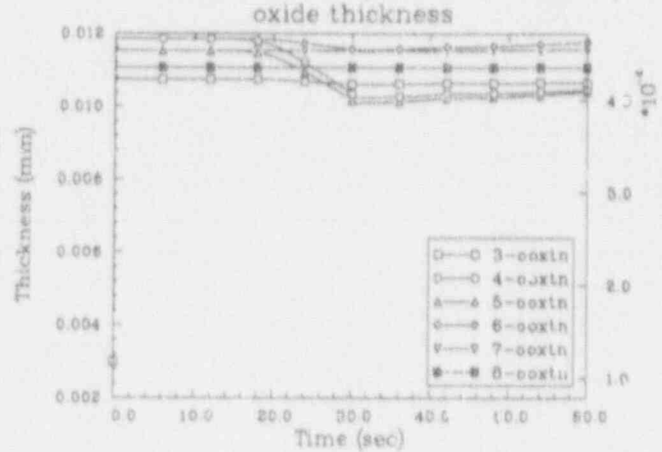
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/E&PT
cladding surface temperature



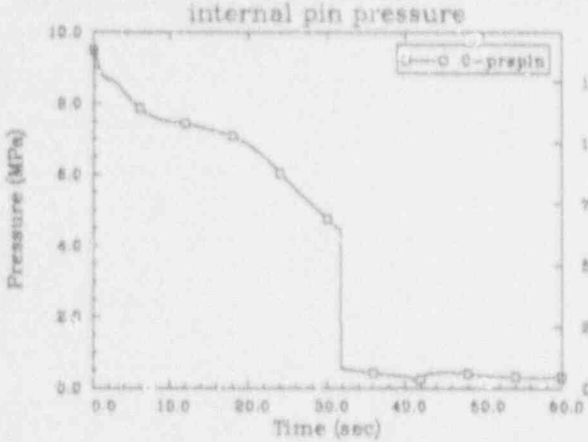
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/E&PT
fuel centerline temperature



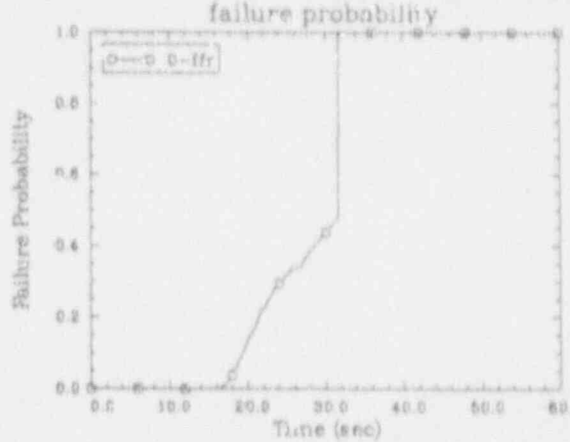
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/E&PT
oxide thickness



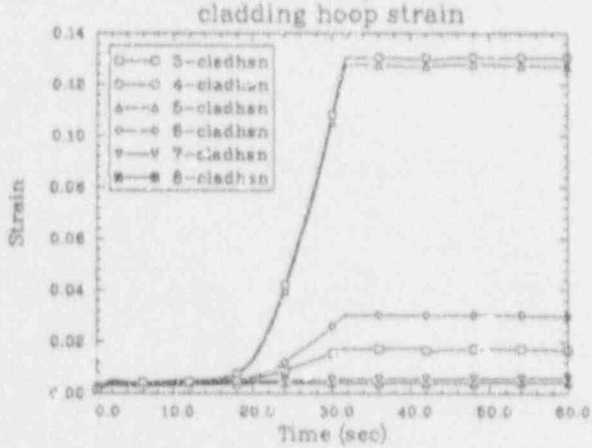
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/E&PT
internal pin pressure



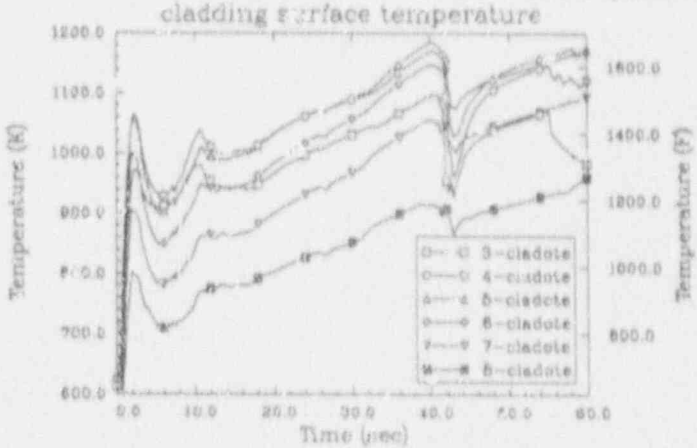
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/E&PT
failure probability



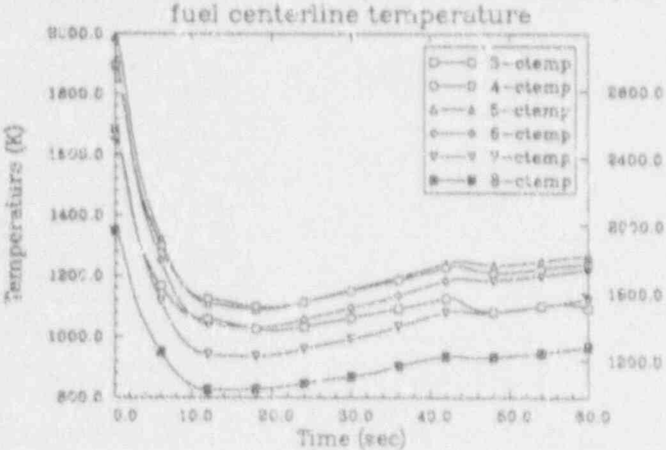
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/E&PT
cladding hoop strain



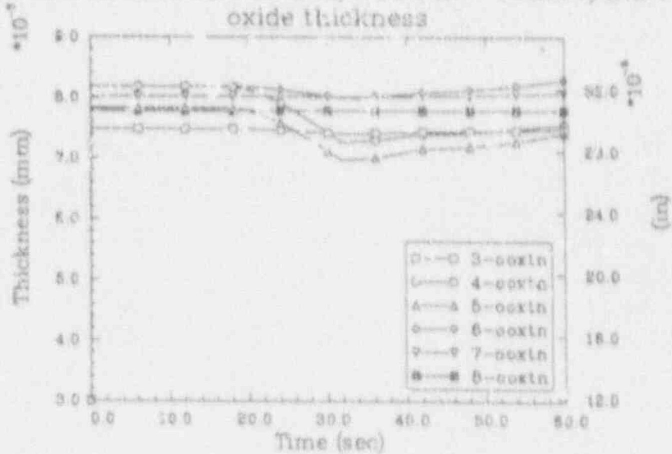
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/E&PT
cladding surface temperature



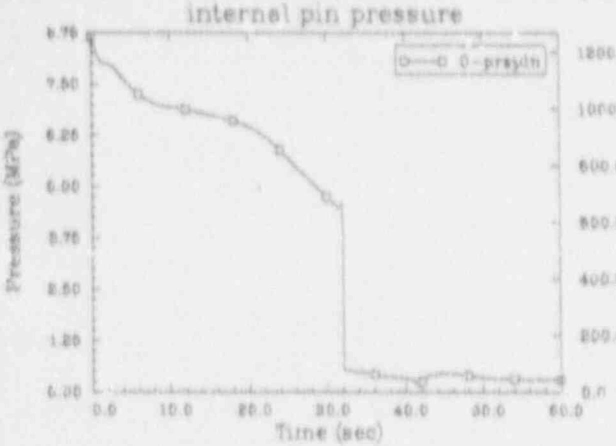
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/E&PT
fuel centerline temperature



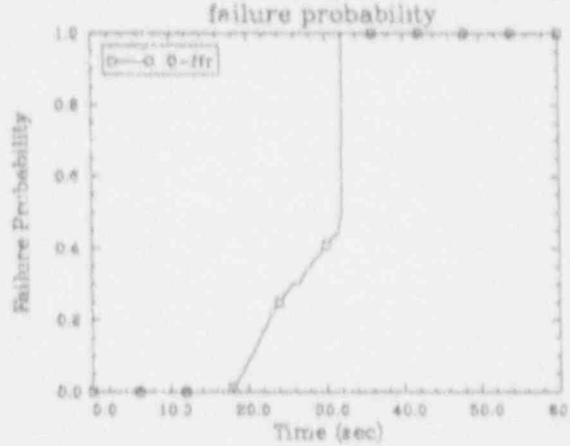
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/E&PT
oxide thickness



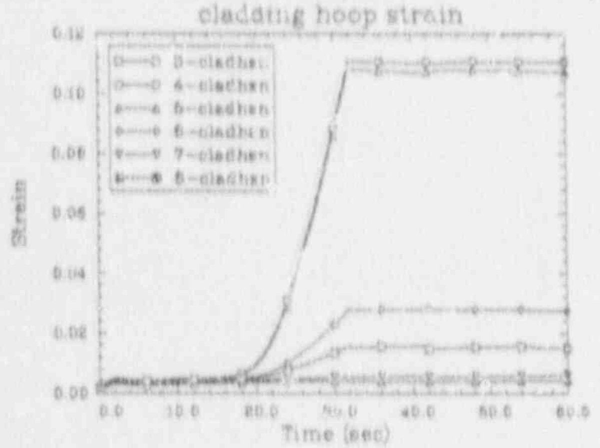
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/E&PT
internal pin pressure



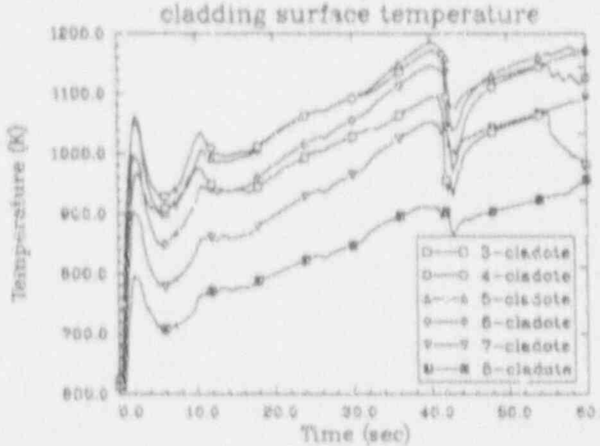
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/E&PT
failure probability



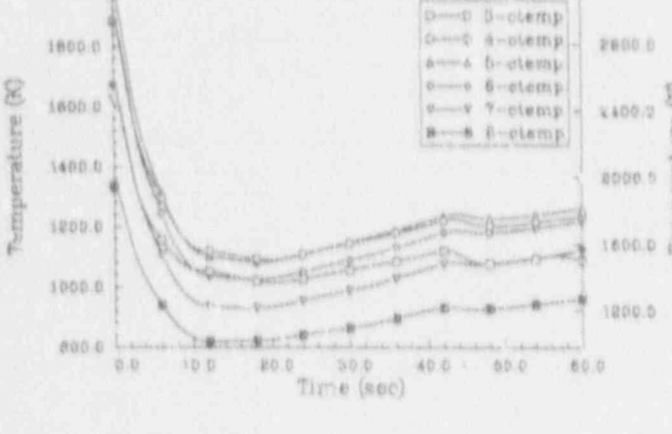
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/E&PT
cladding hoop strain



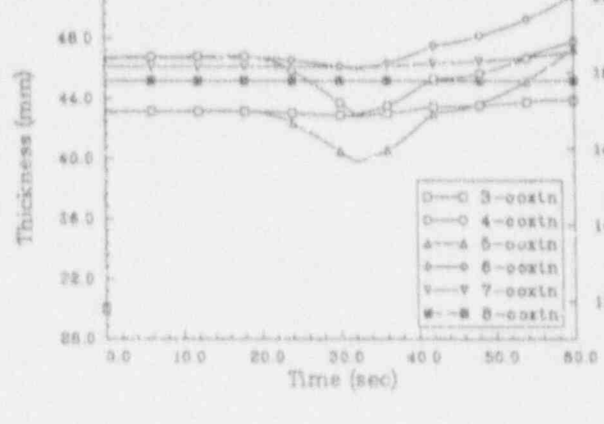
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/E&PT
cladding surface temperature



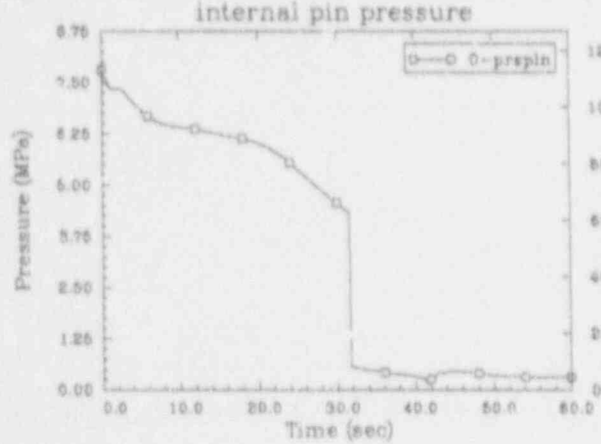
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/E&PT
fuel centerline temperature



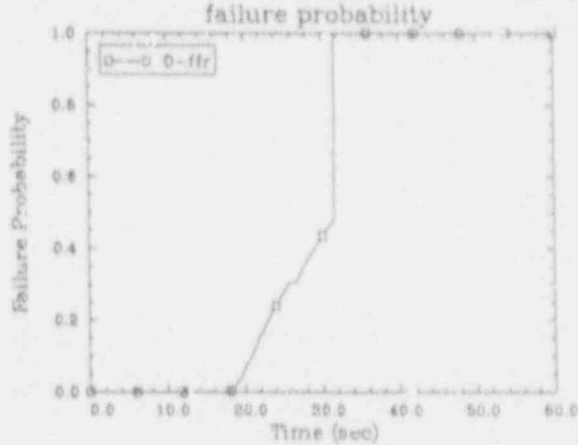
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/E&PT
oxide thickness



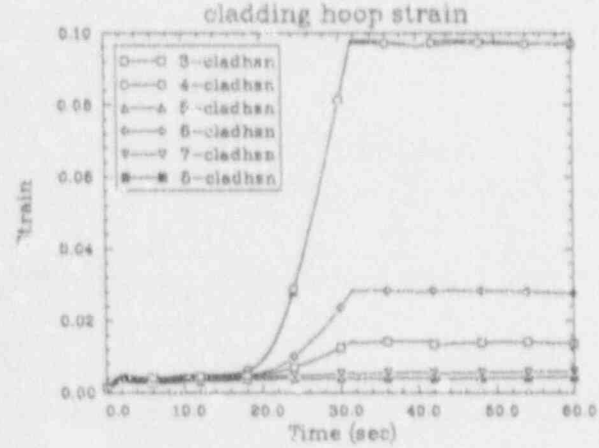
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/E&PT
internal pin pressure



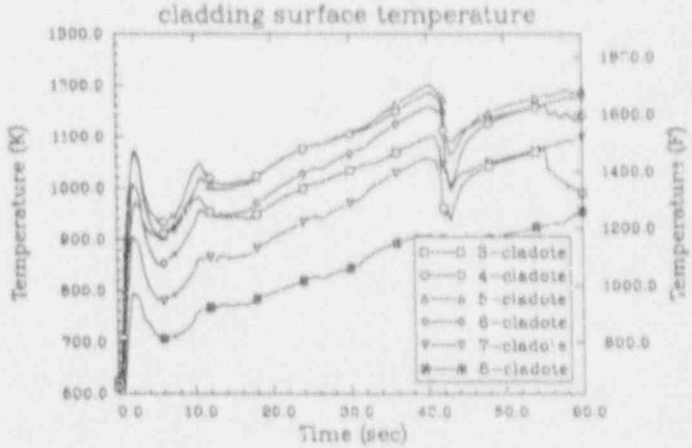
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/E&PT
failure probability



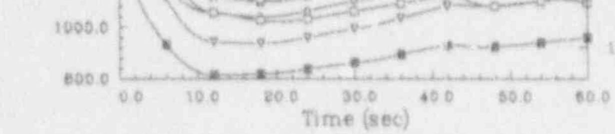
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/E&PT
cladding hoop strain



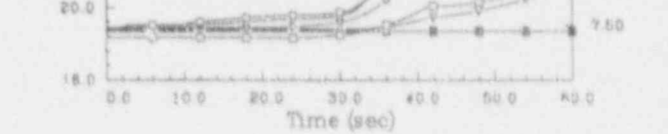
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/E&PT
cladding surface temperature



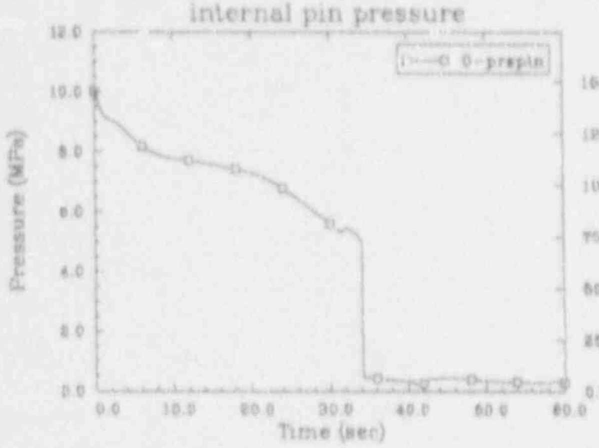
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/E&PT
fuel centerline temperature



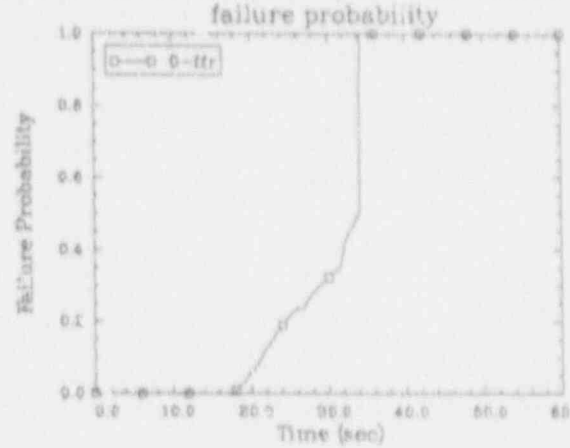
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/E&PT
oxide thickness



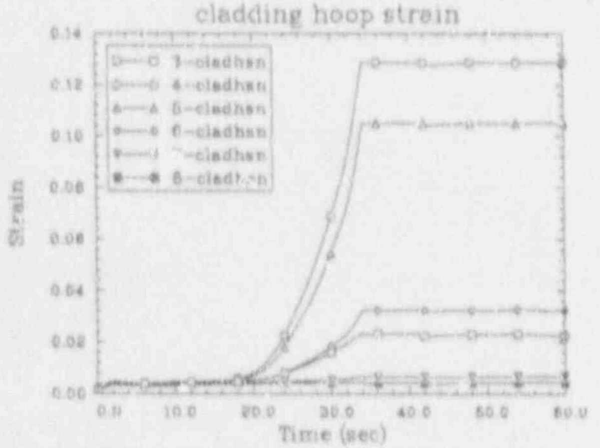
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/E&PT
internal pin pressure



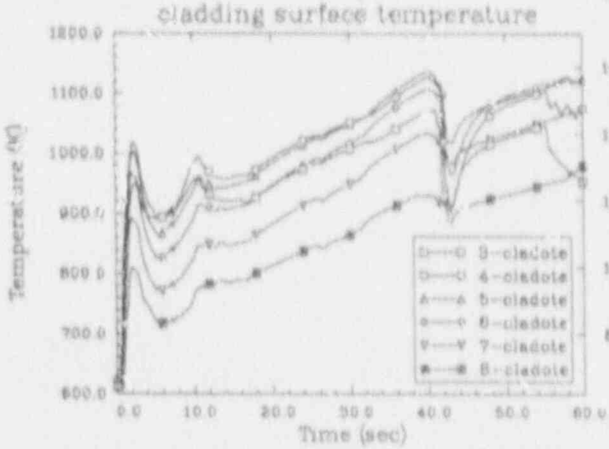
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/E&PT
failure probability



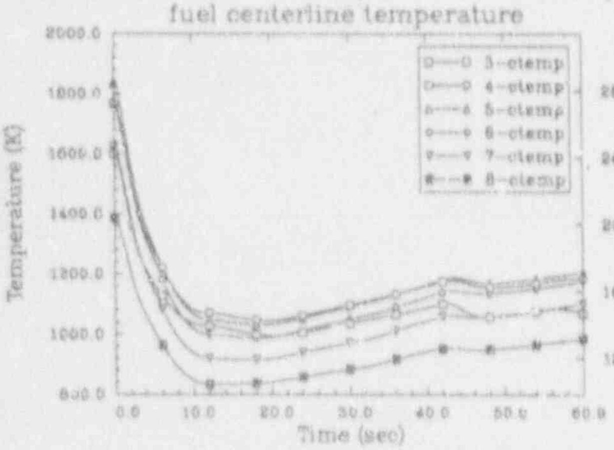
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/E&PT
cladding hoop strain



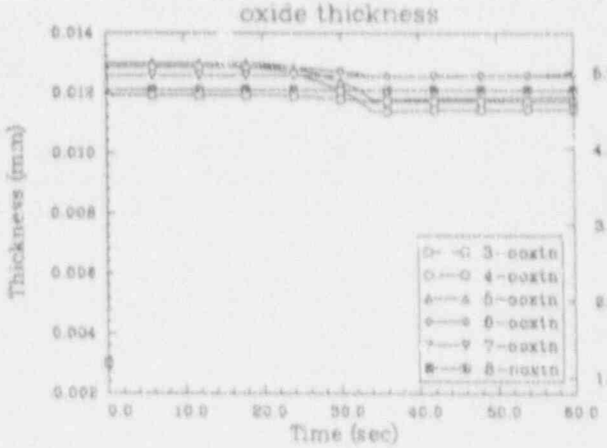
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/E&PT
cladding surface temperature

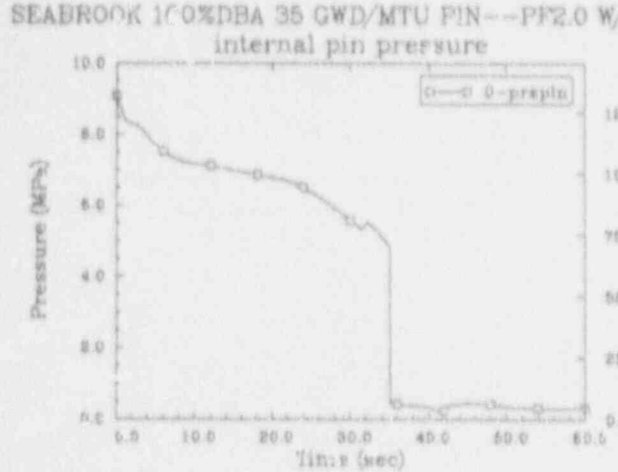


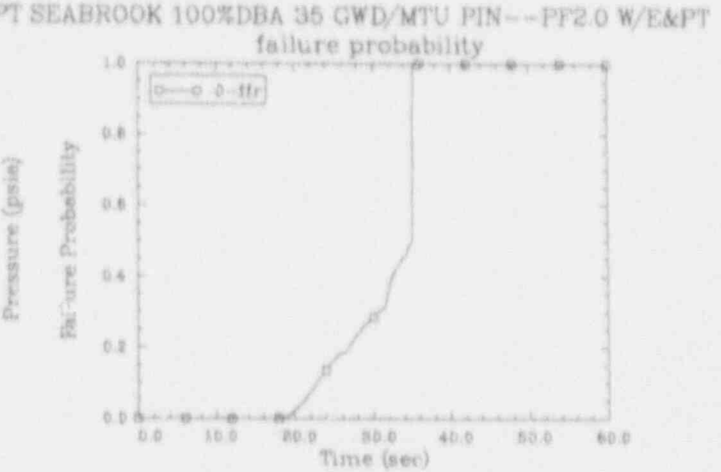
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/E&PT
fuel centerline temperature

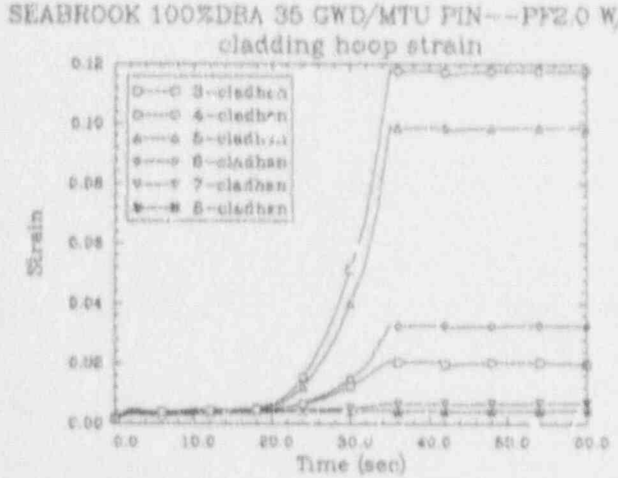


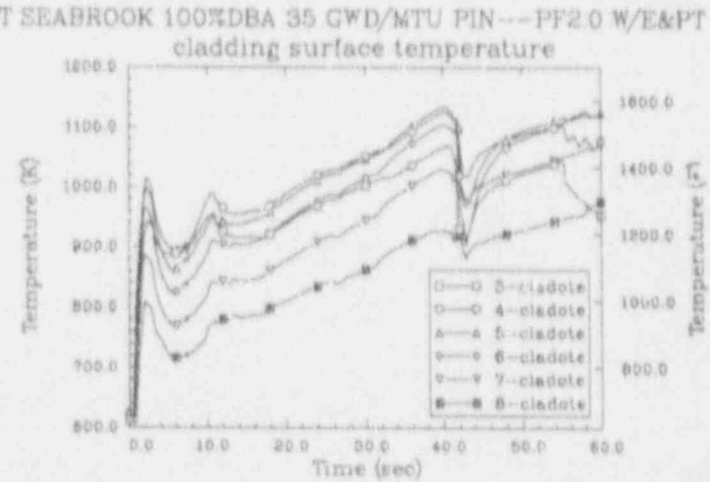
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/E&PT
oxide thickness

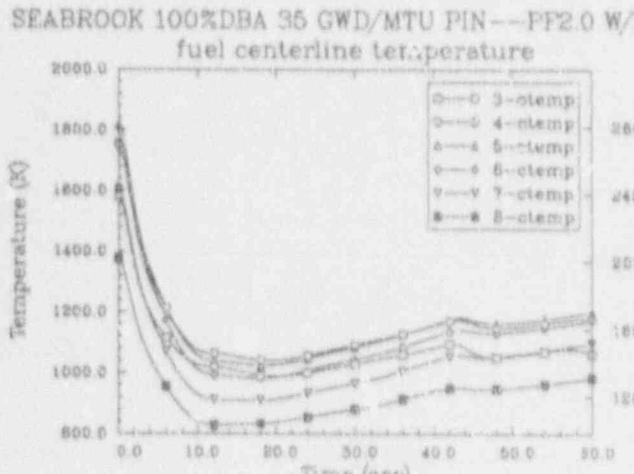


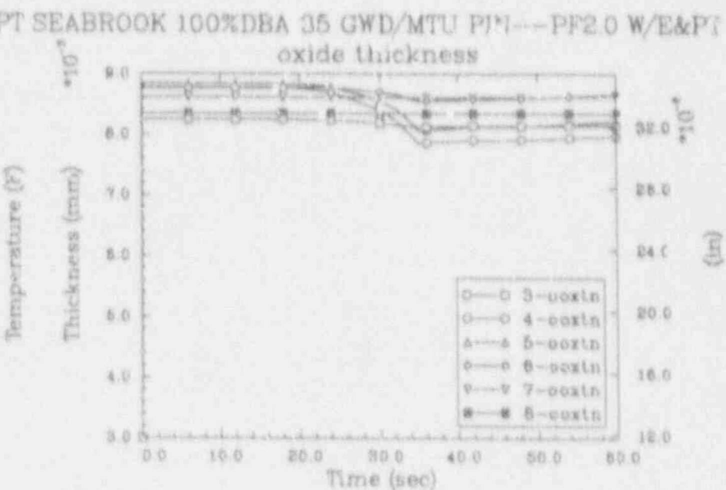

SEABROOK 1⁄0%DBA 35 GWD/MTU PIN--PF2.0 W/E&PT
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)

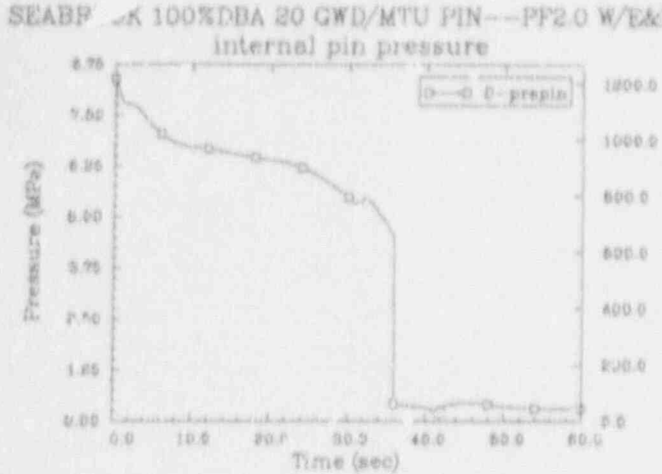

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

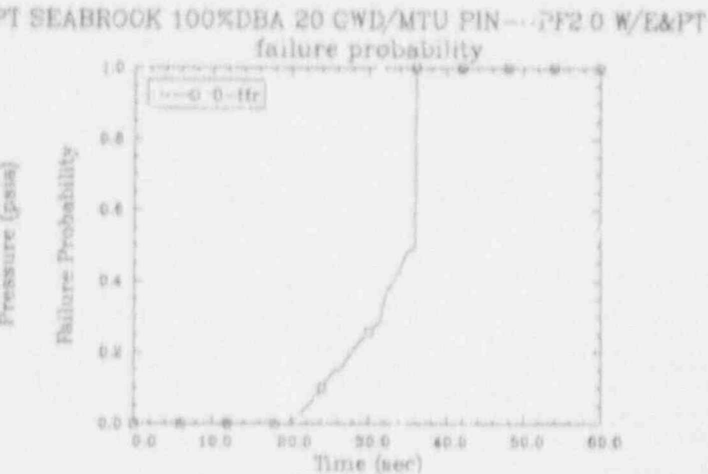

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

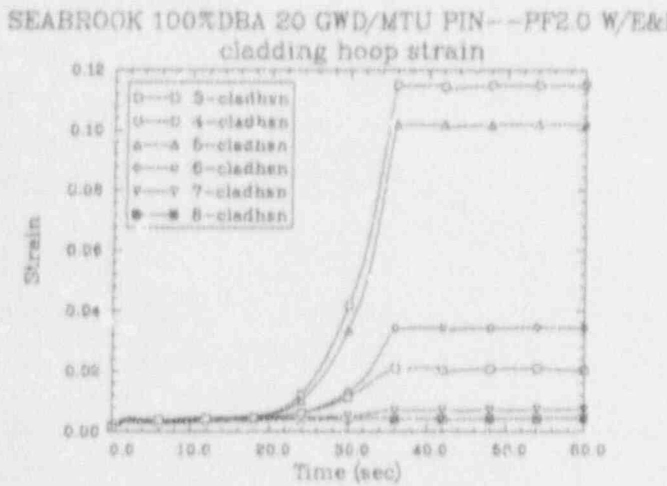

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

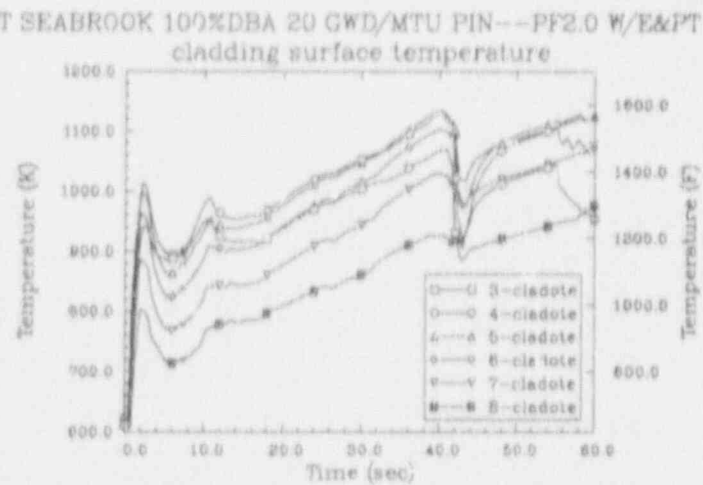

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/E&PT
fuel centerline ter.:perature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

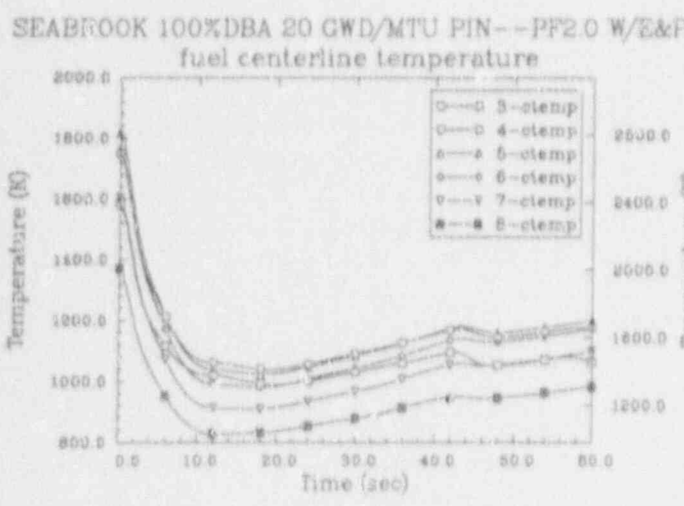

SEABROOK 100%DBA 35 GWD/MTU PI^N--PF2.0 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

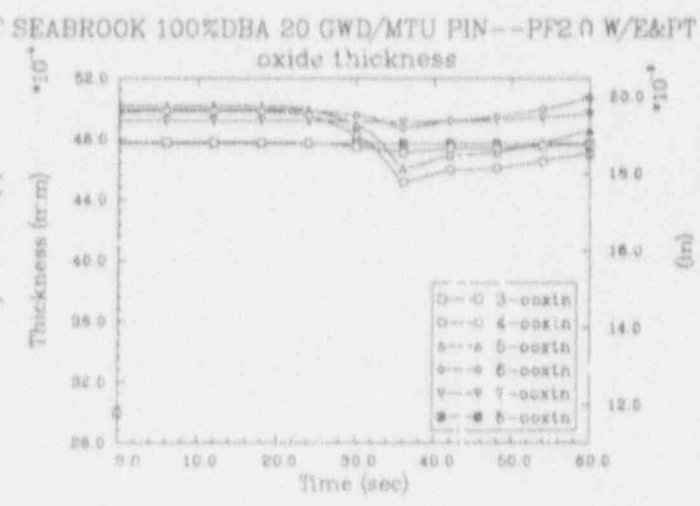

SEABR___K 100%DBA 20 GWD/MTU PIN--PF2.0 W/E&PT
internal pin pressure
0-prepin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

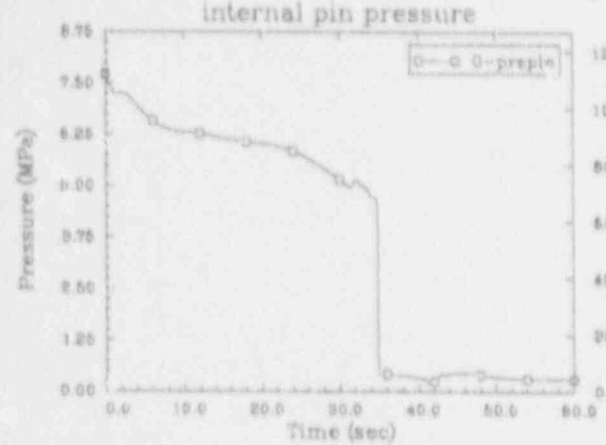

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

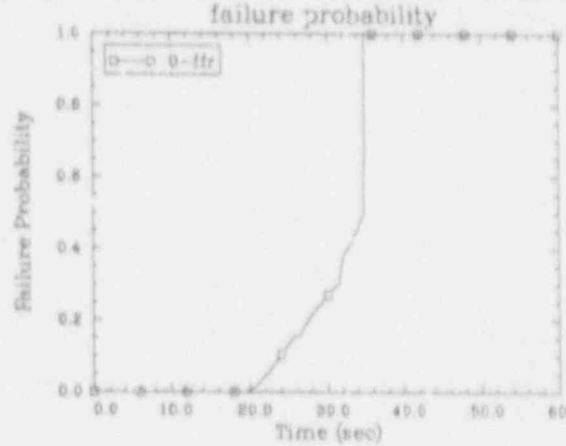

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (m)
(in)
Time (sec)

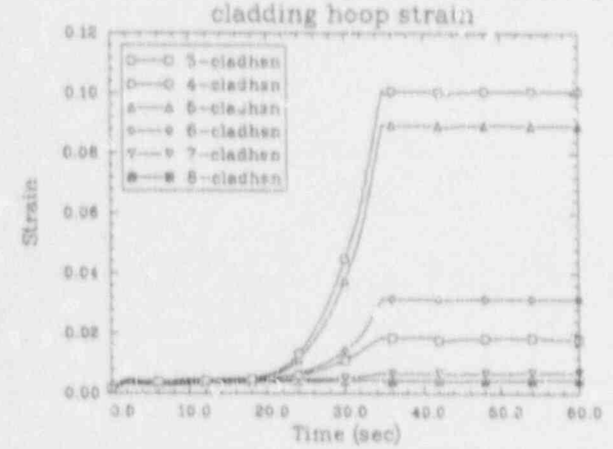
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/E&PT
internal pin pressure



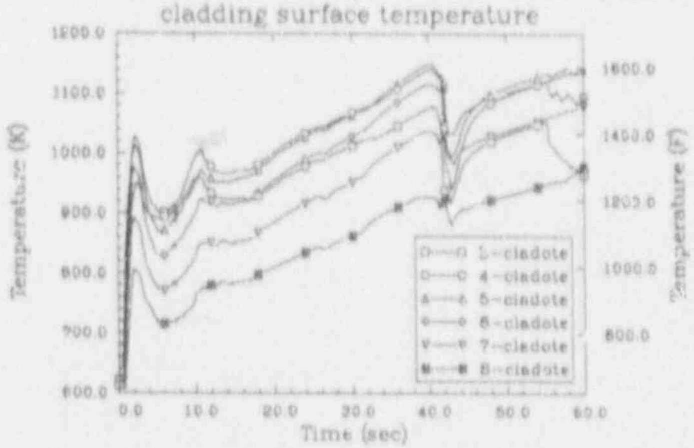
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/E&PT
failure probability



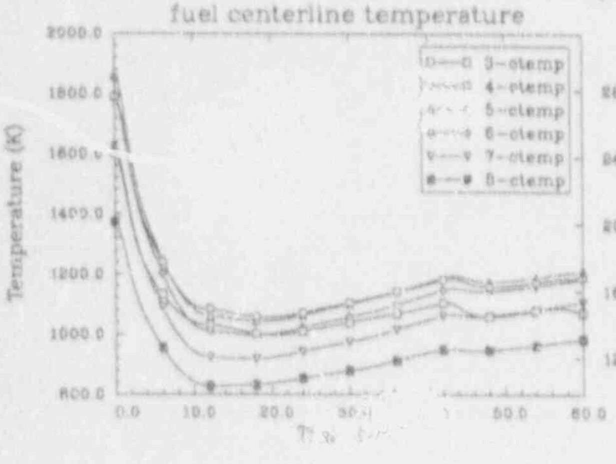
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/E&PT
cladding hoop strain



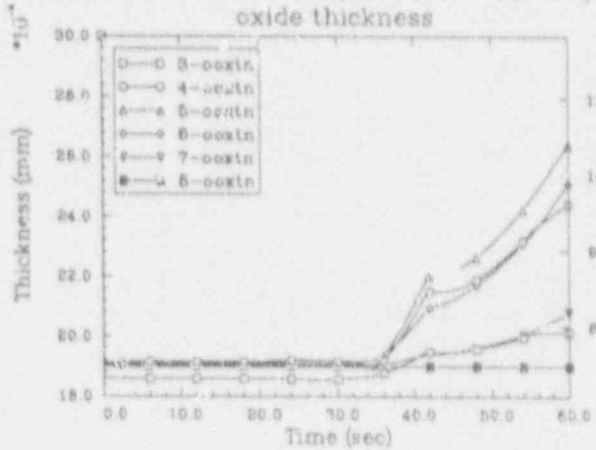
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/E&PT
cladding surface temperature

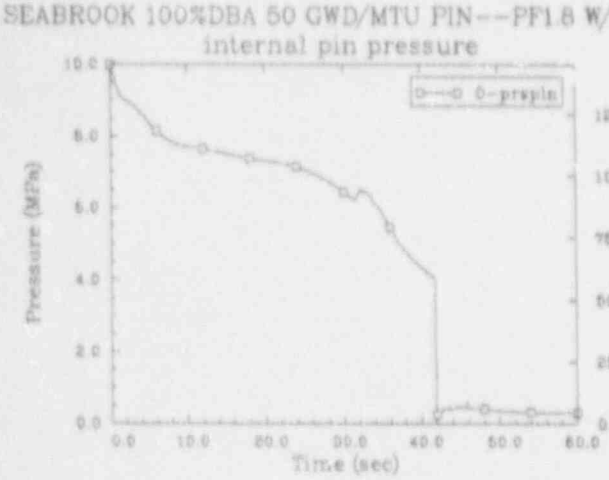


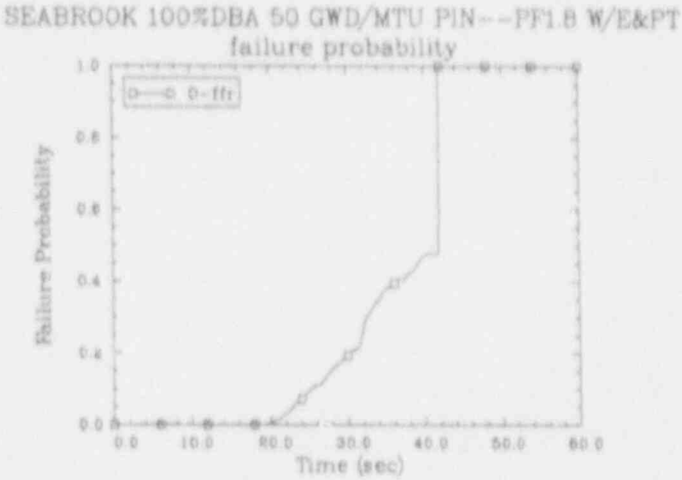
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/E&PT
fuel centerline temperature

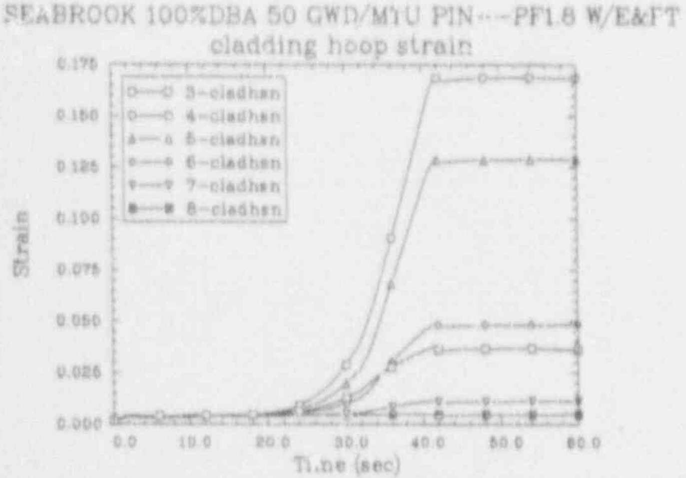


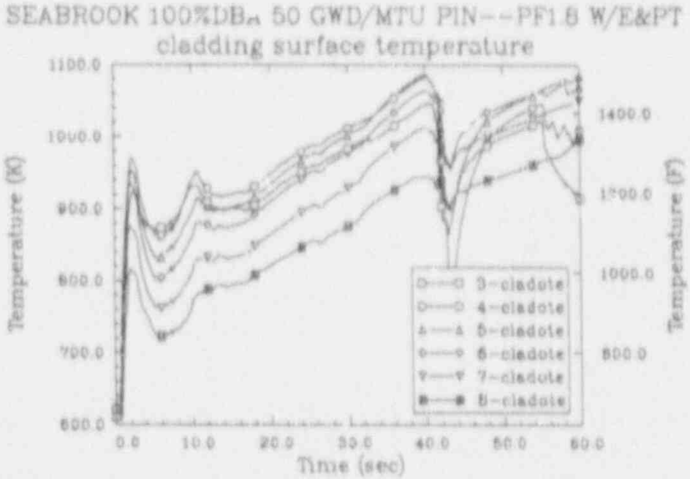
SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.0 W/E&PT
oxide thickness

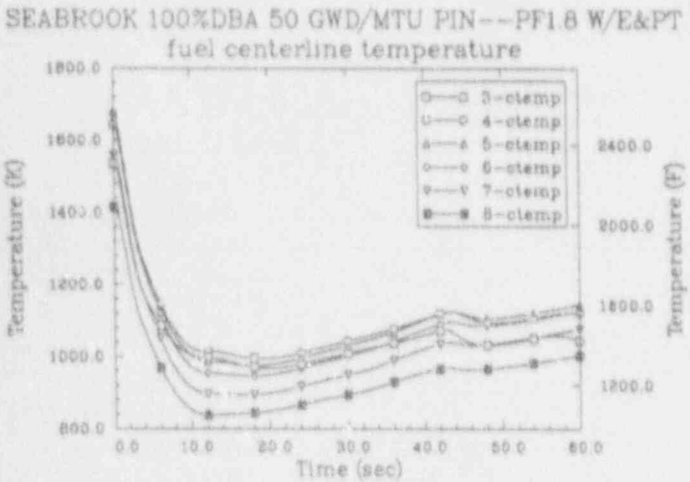


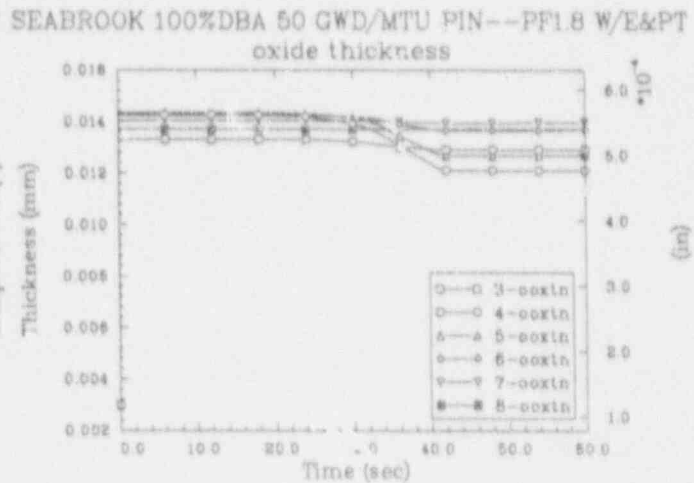

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/E&PT
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/E&PT
failure probability
0-ffr
Failure Probability
Time (sec)

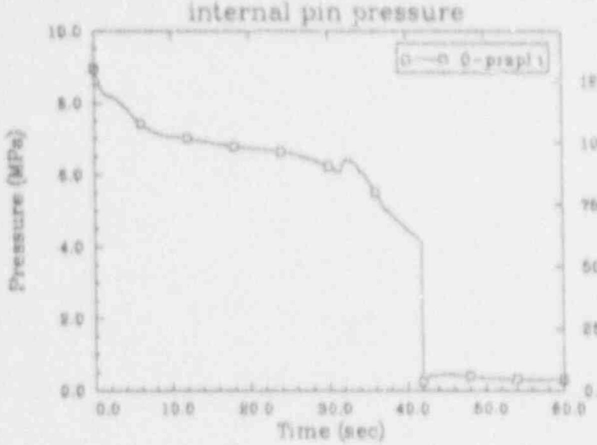

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/E&PT
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/E&PT
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

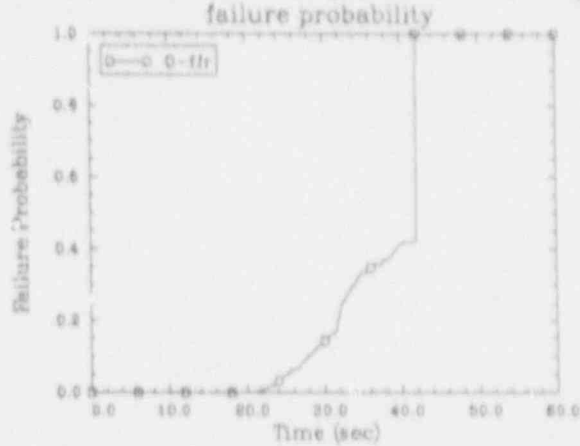

SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/E&PT
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/E&PT
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

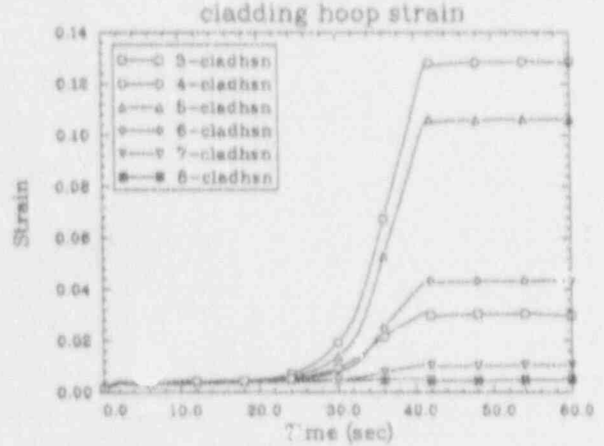
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/E&PT
internal pin pressure



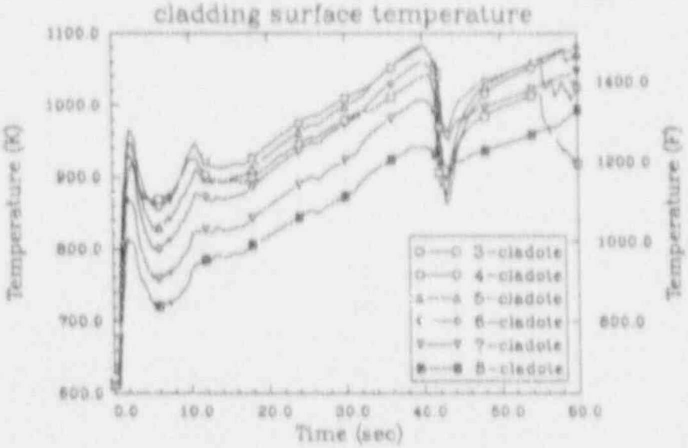
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/E&PT
failure probability



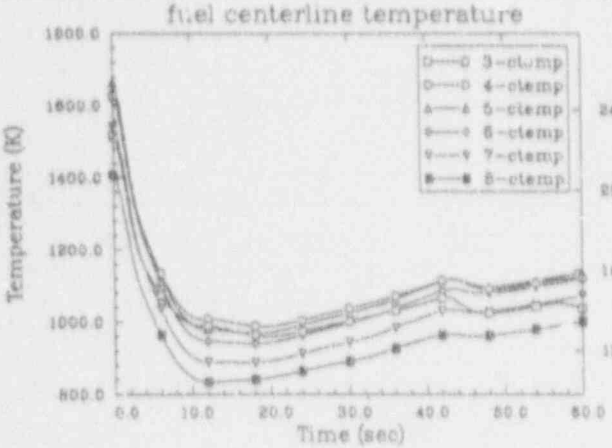
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/E&PT
cladding hoop strain



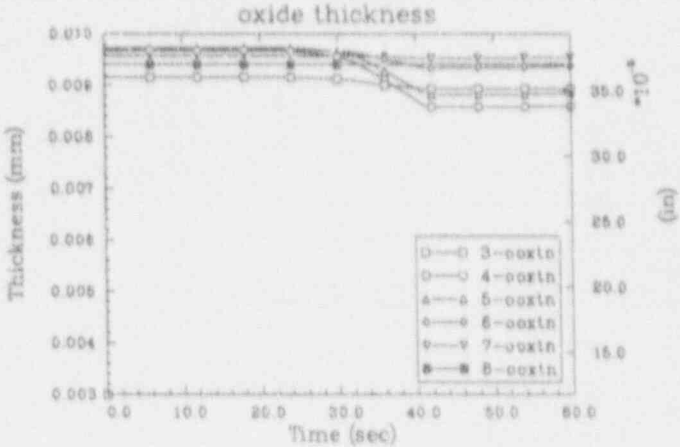
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/E&PT
cladding surface temperature



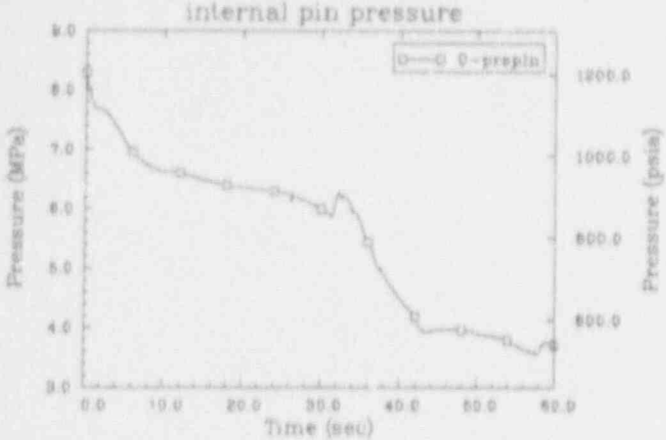
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/E&PT
fuel centerline temperature



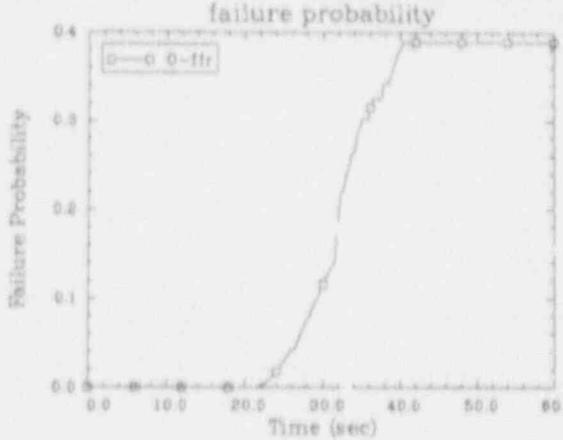
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/E&PT
oxide thickness



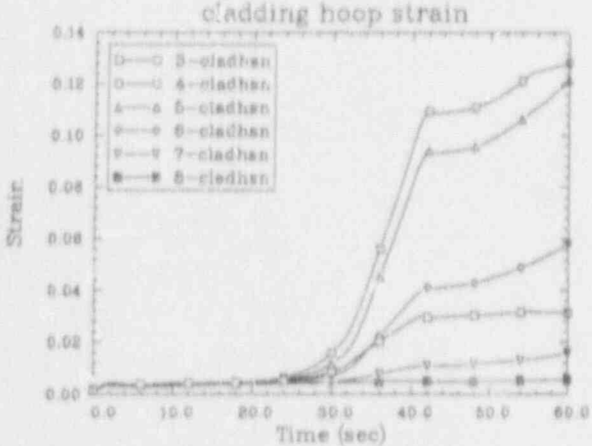
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/E&PT
internal pin pressure



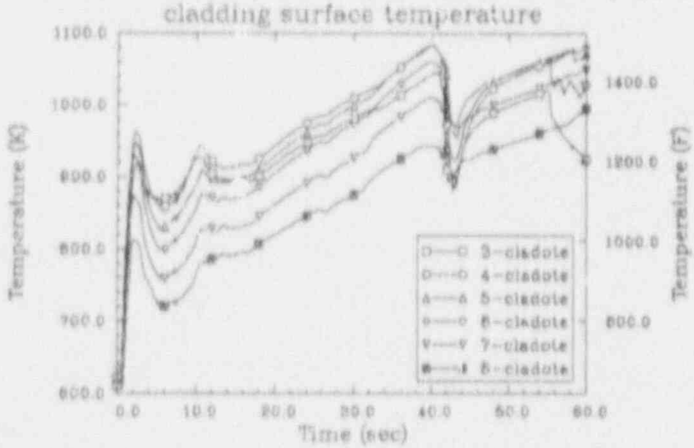
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/E&PT
failure probability



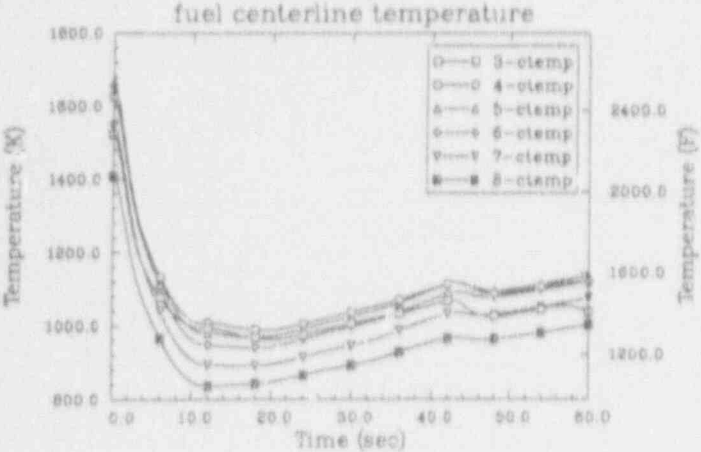
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/E&PT
cladding hoop strain



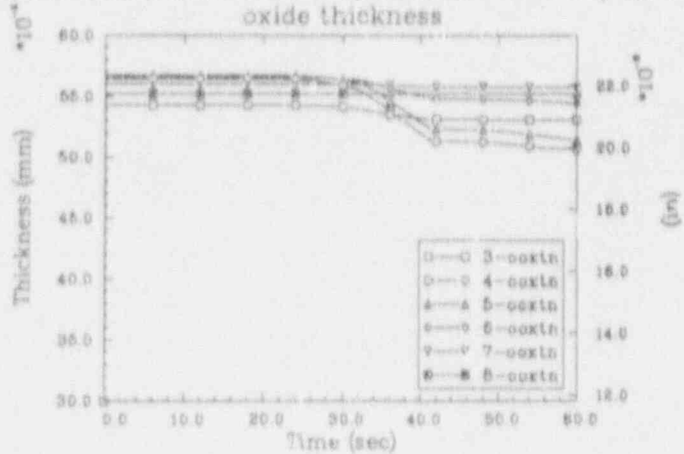
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/E&PT
cladding surface temperature



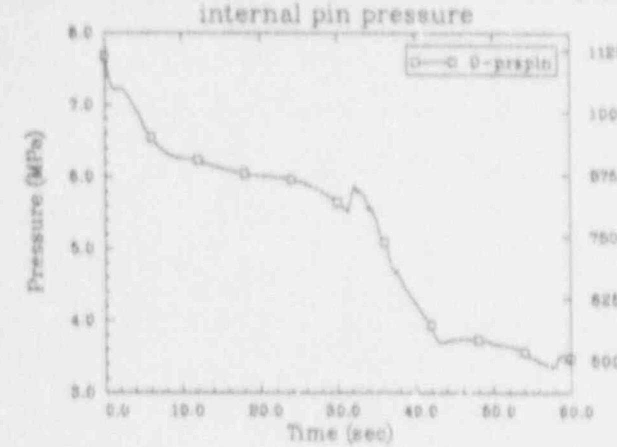
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/E&PT
fuel centerline temperature



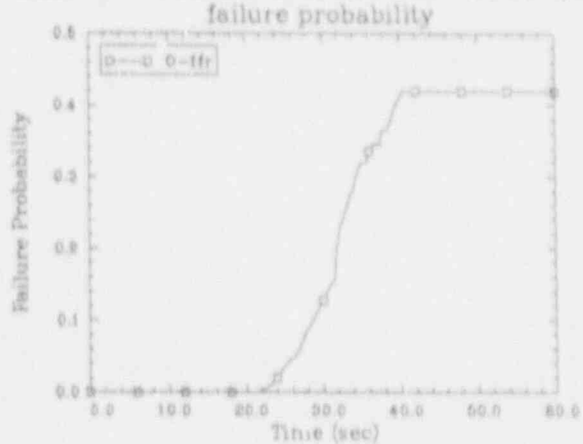
SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/E&PT
oxide thickness



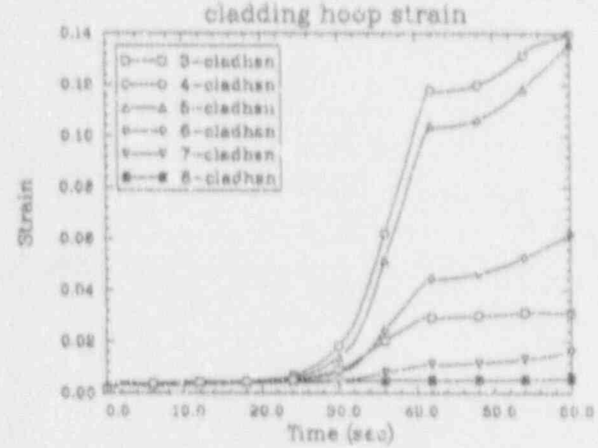
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ES&PT
internal pin pressure



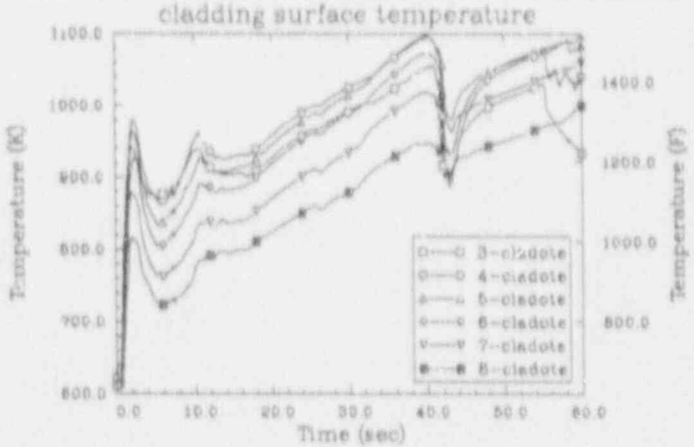
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ES&PT
failure probability



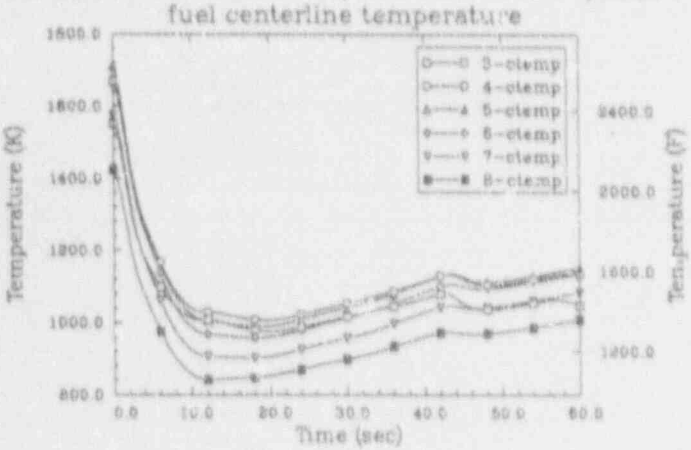
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ES&PT
cladding hoop strain



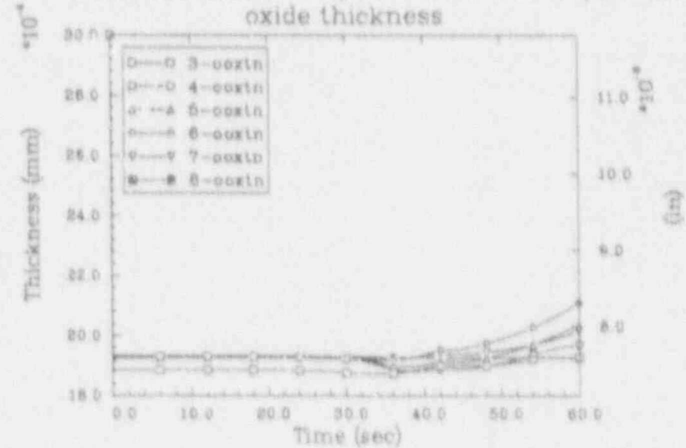
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ES&PT
cladding surface temperature

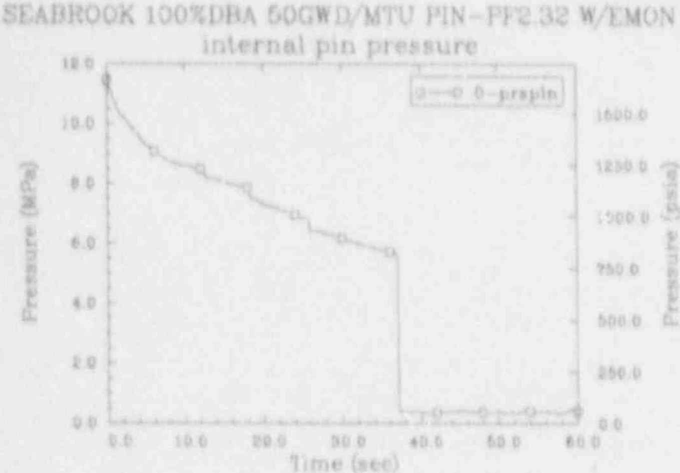


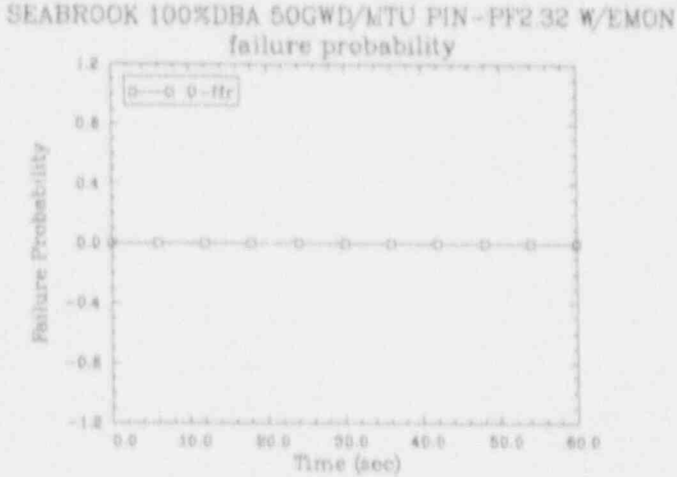
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ES&PT
fuel centerline temperature

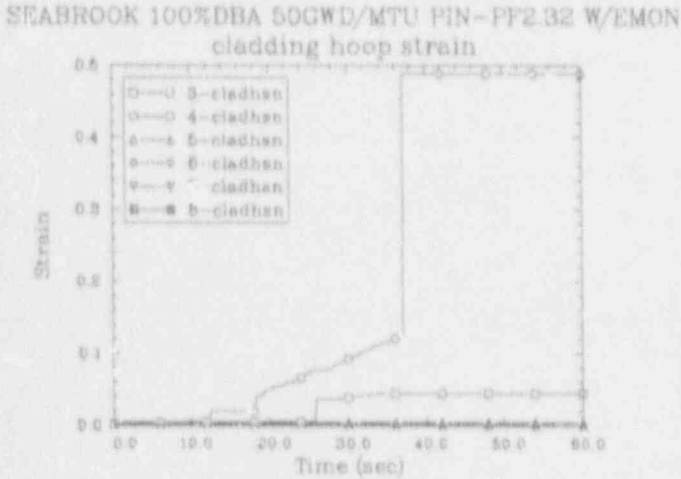


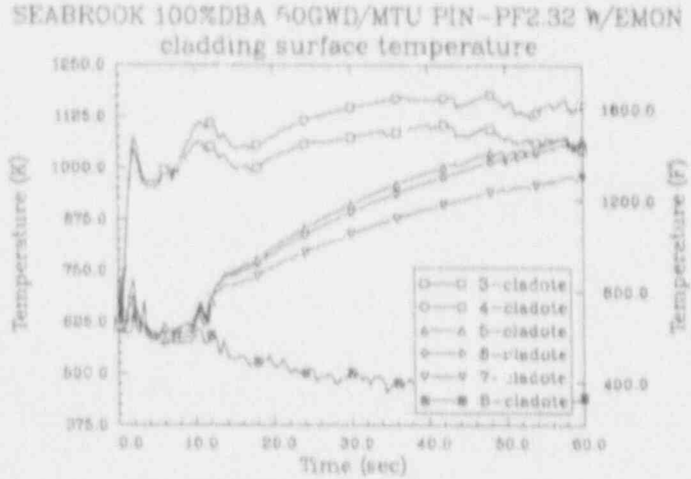
SEABROOK 100%DBA 5 GWD/MTU PIN--PF1.8 W/ES&PT
oxide thickness

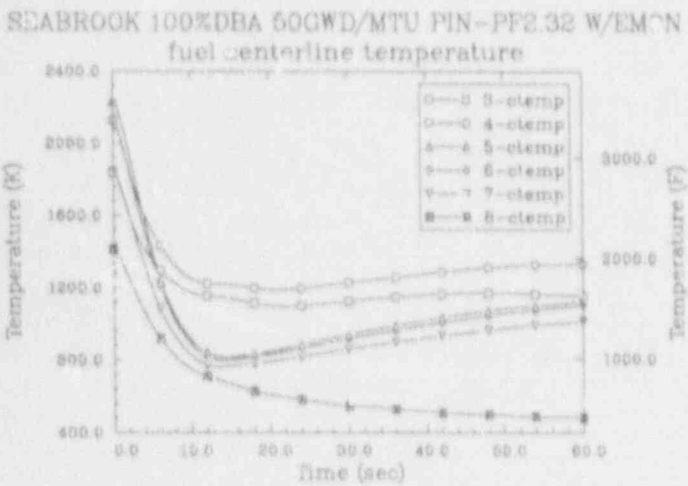


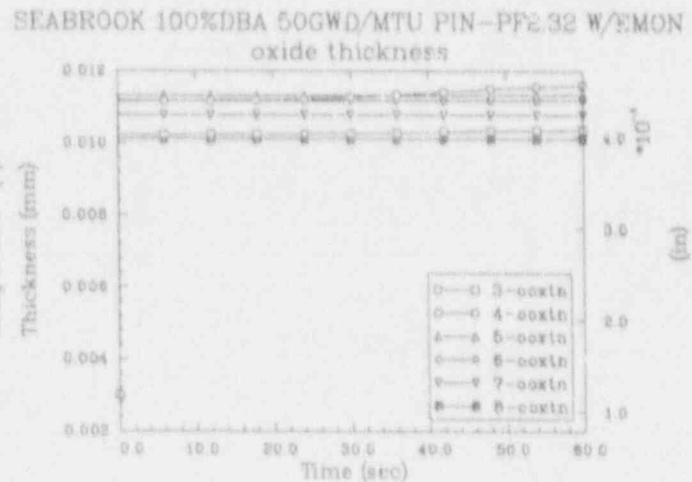

SEABROOK 100%DBA 50GWD/MTU PIN-PF2.32 W/EMON
internal pin pressure
0—0 0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 50GWD/MTU PIN-PF2.32 W/EMON
failure probability
0—0 0-ffr
Failure Probability
Time (sec)

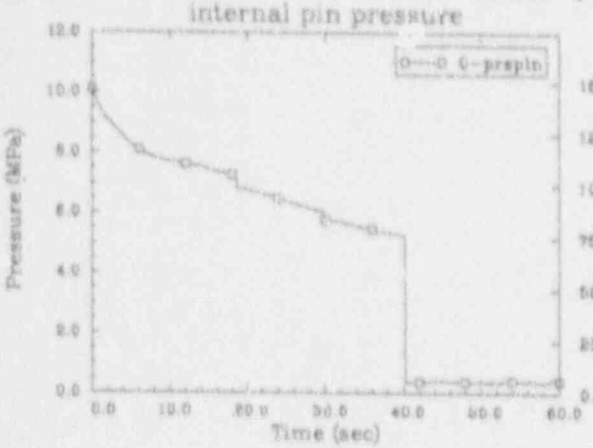

SEABROOK 100%DBA 50GWD/MTU PIN-PF2.32 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 50GWD/MTU PIN-PF2.32 W/EMON
cladding surface temperature
3-cladote
4-cladote
5-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

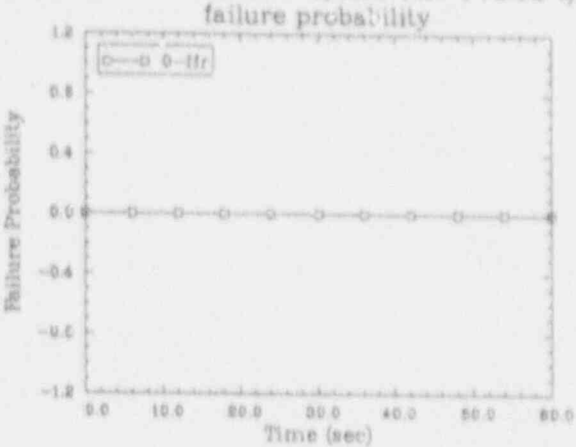

fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 50GWD/MTU PIN-PF2.32 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

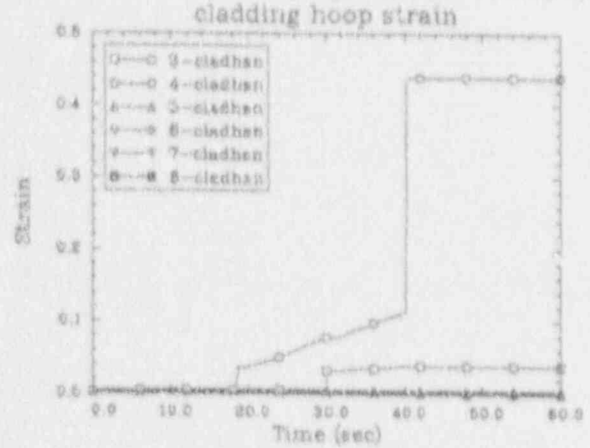
SEABROOK 100%DBA 35GWD/MTU PIN-PF2.32 W/EMON
internal pin pressure



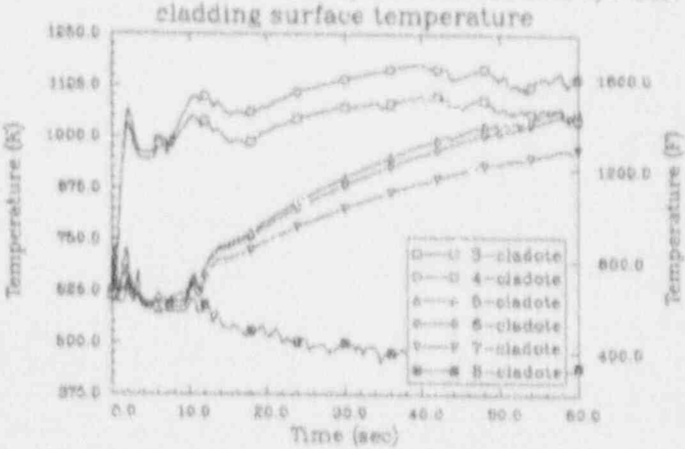
SEABROOK 100%DBA 35GWD/MTU PIN-PF2.32 W/EMON
failure probability



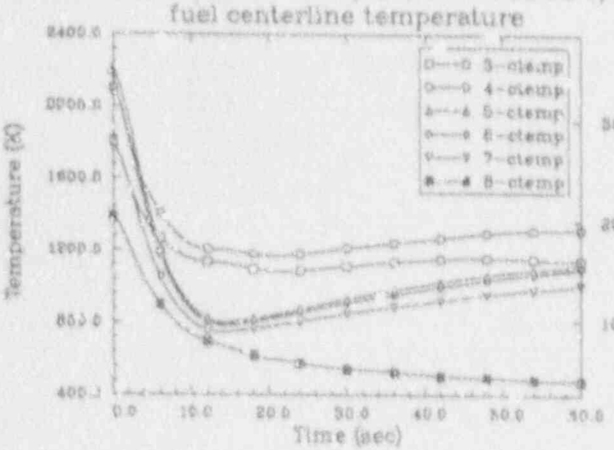
SEABROOK 100%DBA 35GWD/MTU PIN-PF2.32 W/EMON
cladding hoop strain



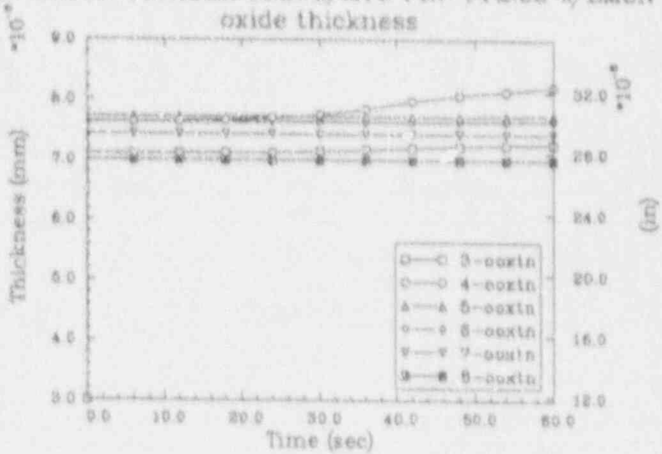
SEABROOK 100%DBA 35GWD/MTU PIN-PF2.32 W/EMON
cladding surface temperature



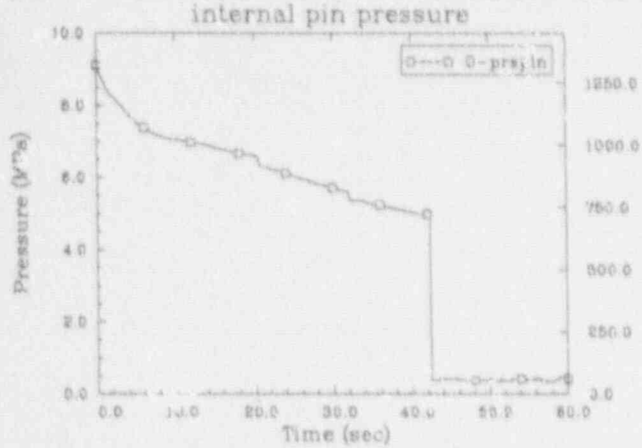
SEABROOK 100%DBA 35GWD/MTU PIN-PF2.32 W/EMON
fuel centerline temperature



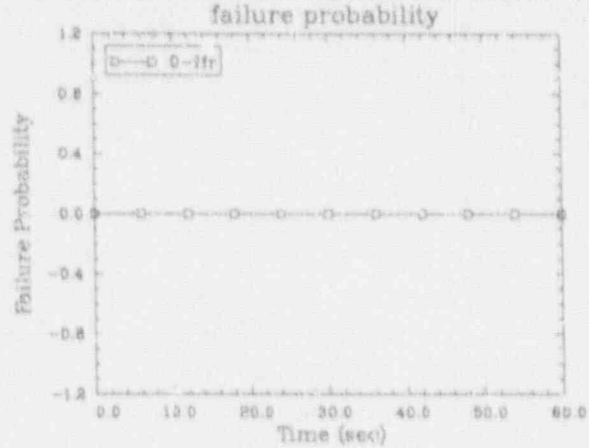
SEABROOK 100%DBA 35GWD/MTU PIN-PF2.32 W/EMON
oxide thickness



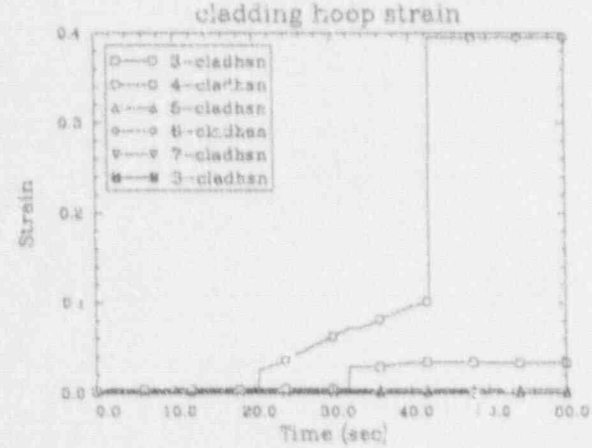
SEABROOK 100%DBA 20GWD/MTU PIN-PF2.32 W/EMON
internal pin pressure



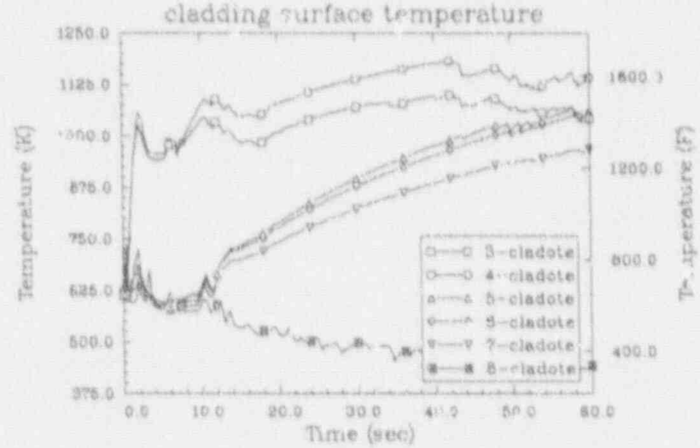
SEABROOK 100%DBA 20GWD/MTU PIN-PF2.32 W/EMON
failure probability



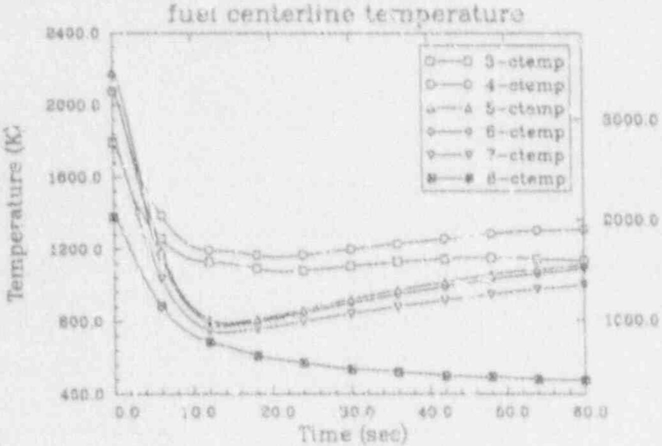
SEABROOK 100%DBA 20GWD/MTU PIN-PF2.32 W/EMON
cladding hoop strain



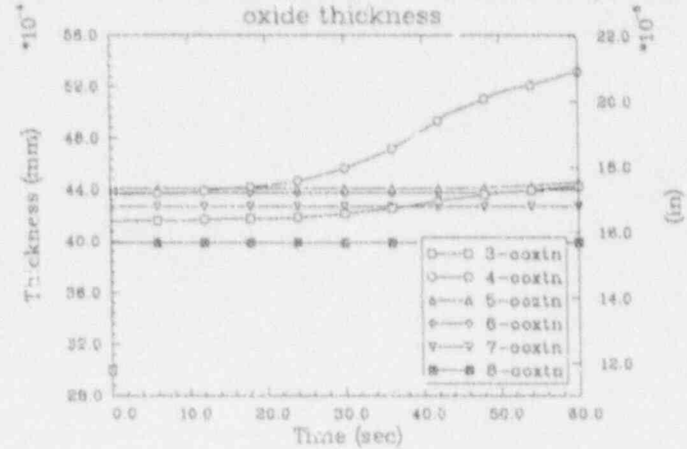
SEABROOK 100%DBA 20GWD/MTU PIN-PF2.32 W/EMON
cladding surface temperature

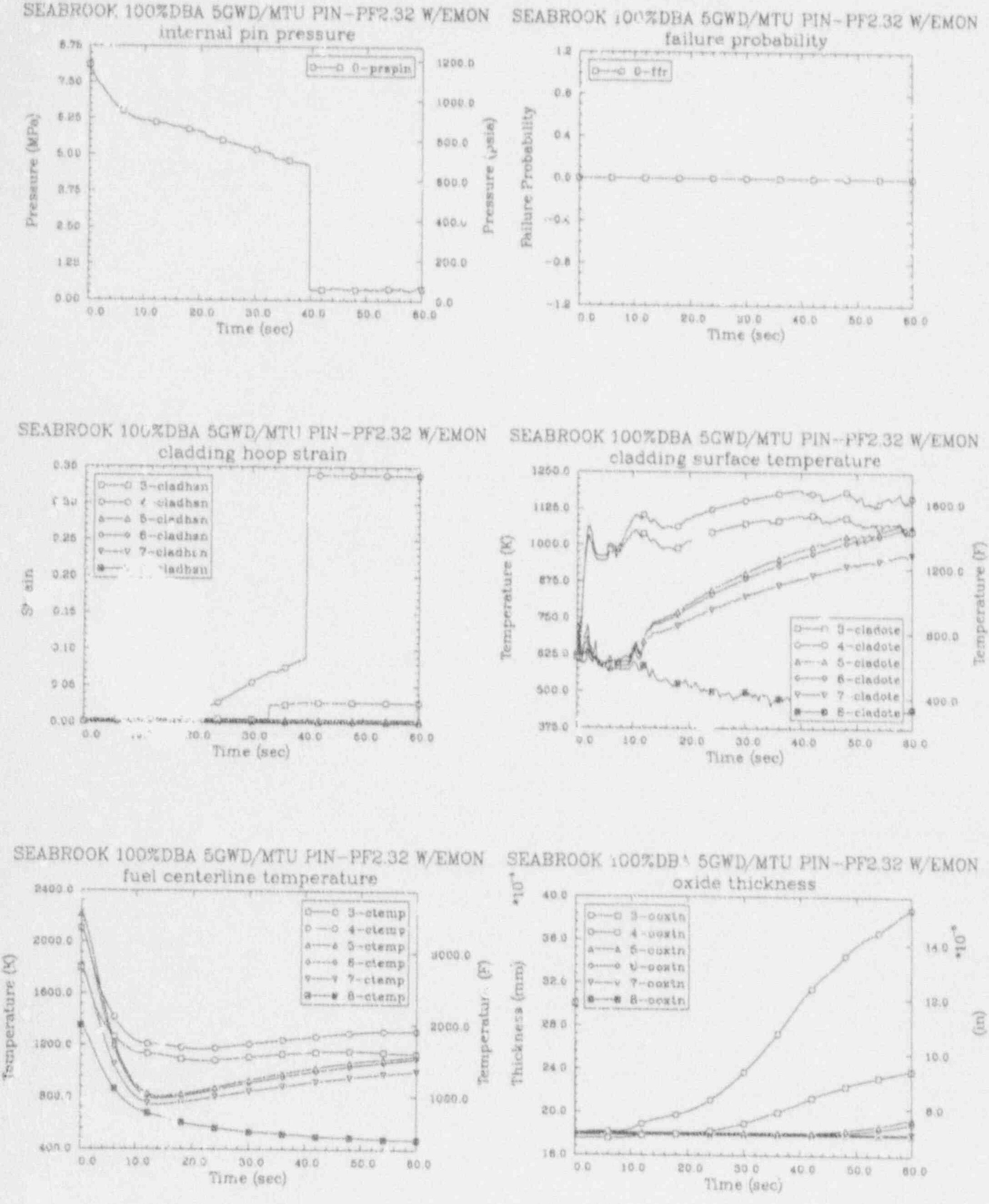


SEABROOK 100%DBA 20GWD/MTU PIN-PF2.32 W/EMON
fuel centerline temperature

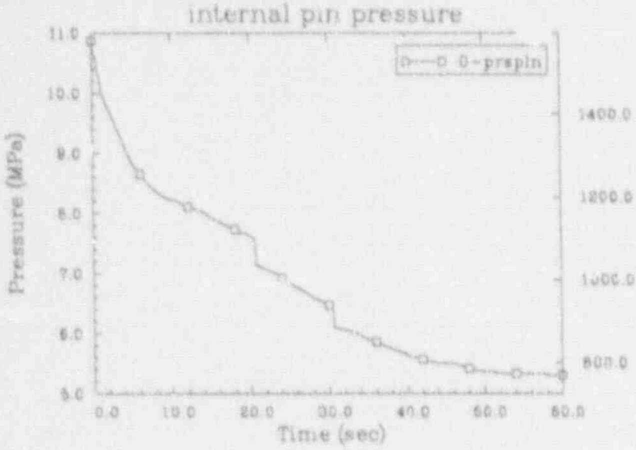


SEABROOK 100%DBA 20GWD/MTU PIN-PF2.32 W/EMON
oxide thickness

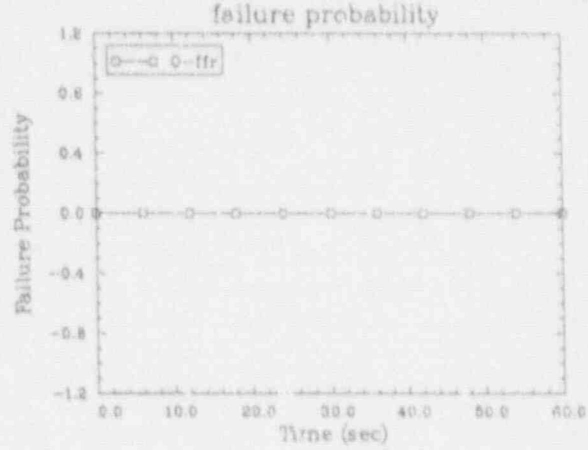



SEABROOK 100%DBA 5GWD/MTU PIN-PF2.32 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)
SEABROOK 100%DBA 5GWD/MTU PIN-PF2.32 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)
SEABROOK 100%DBA 5GWD/MTU PIN-PF2.32 W/EMON
cladding hoop strain
3-cladhsn
5-cladhsn
6-cladhsn
Time (sec)
SEABROOK 100%DBA 5GWD/MTU PIN-PF2.32 W/EMON
cladding surface temperature
4-cladote
5-cladote
6-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)
SEABROOK 100%DBA 5GWD/MTU PIN-PF2.32 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Time (sec)
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

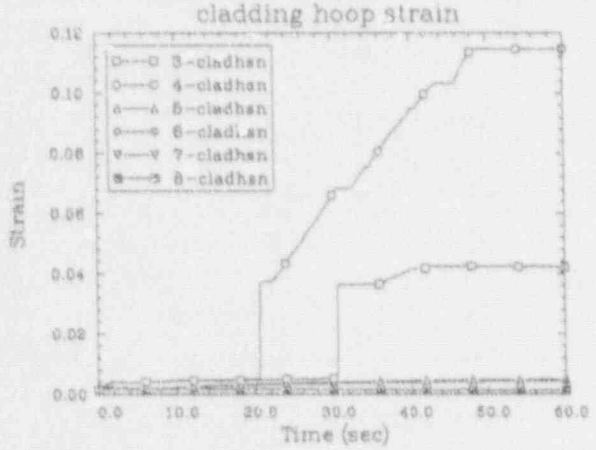
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/EMON
internal pin pressure



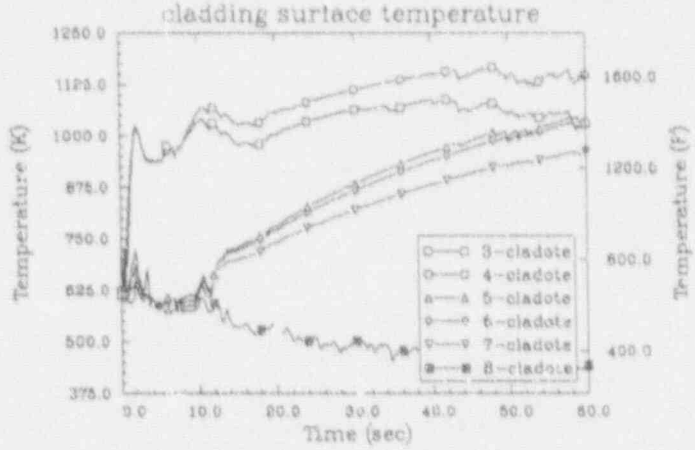
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/EMON
failure probability



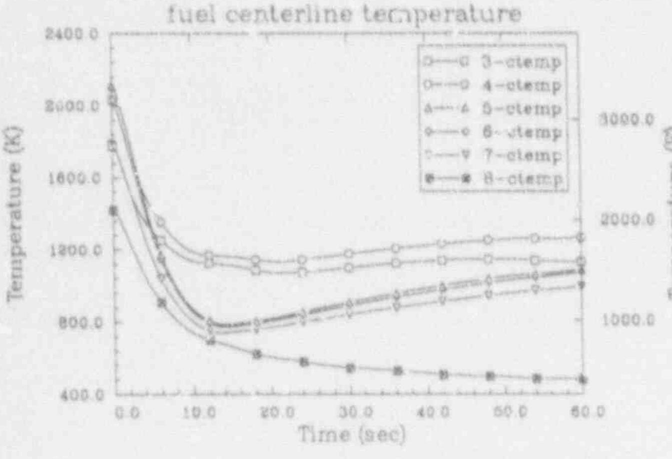
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/EMON
cladding hoop strain



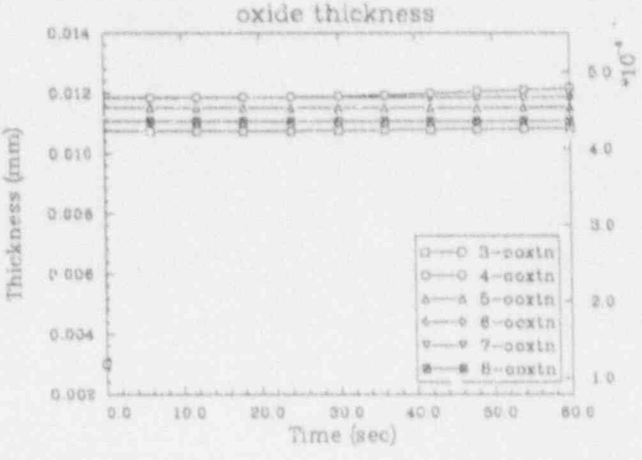
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/EMON
cladding surface temperature



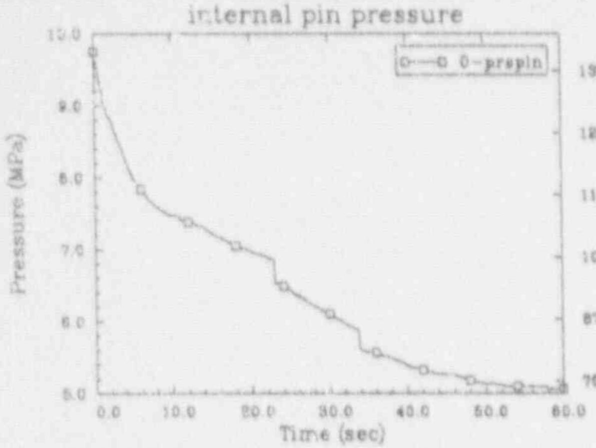
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/EMON
fuel centerline temperature



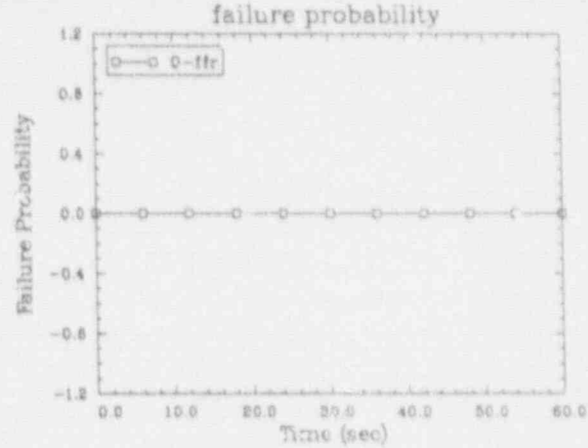
SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.2 W/EMON
oxide thickness



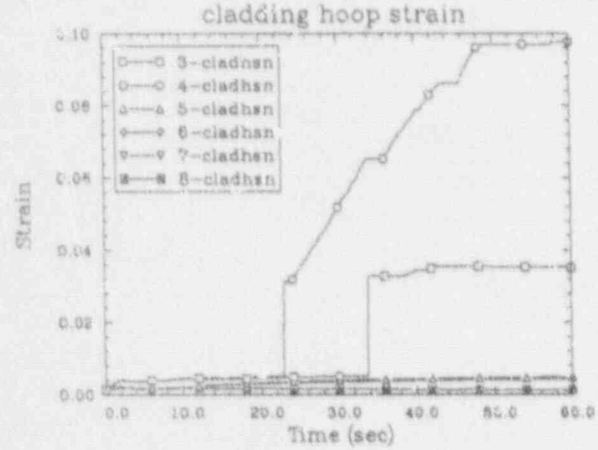
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/EMON
internal pin pressure



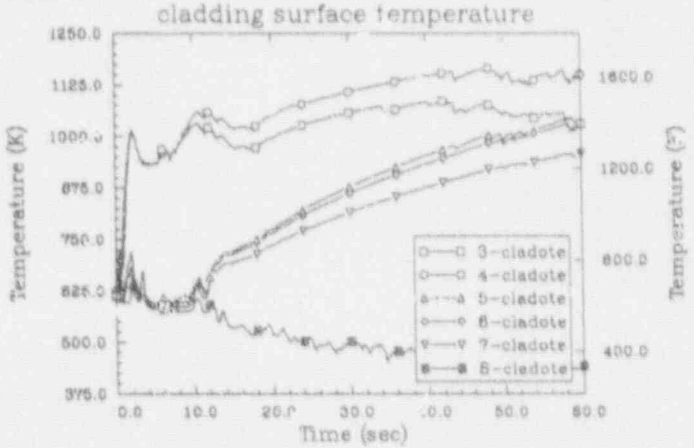
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/EMON
failure probability



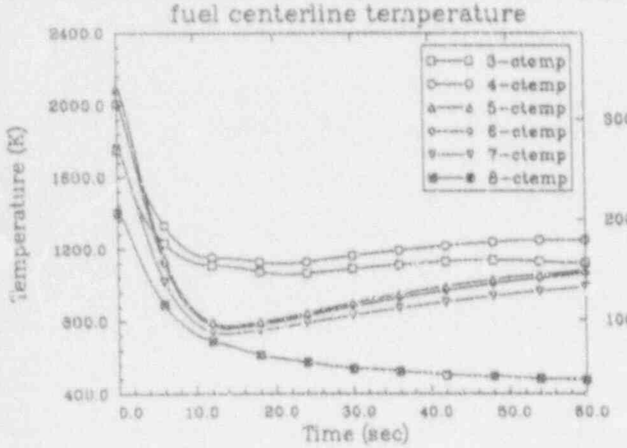
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/EMON
cladding hoop strain



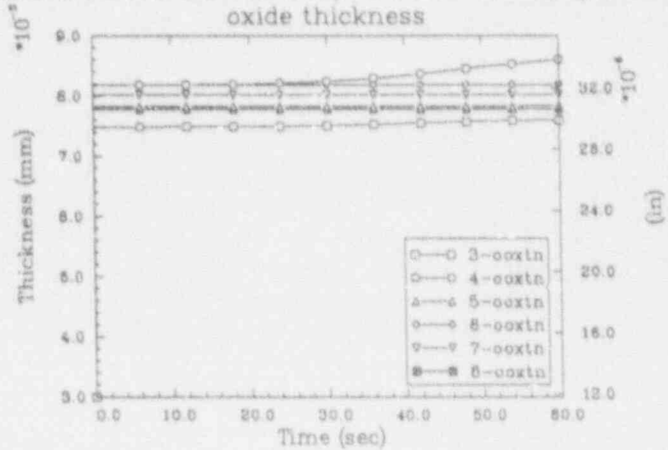
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/EMON
cladding surface temperature



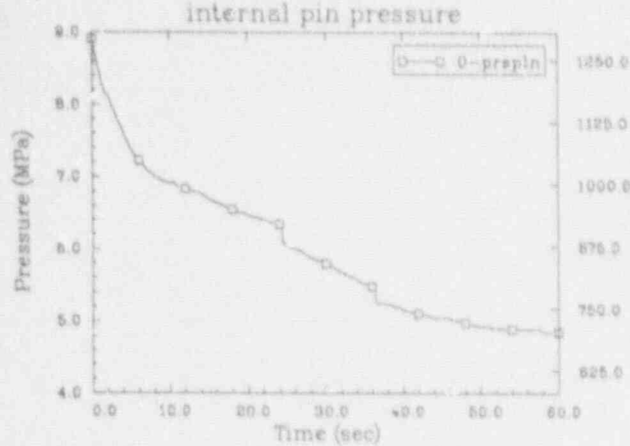
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/EMON
fuel centerline temperature



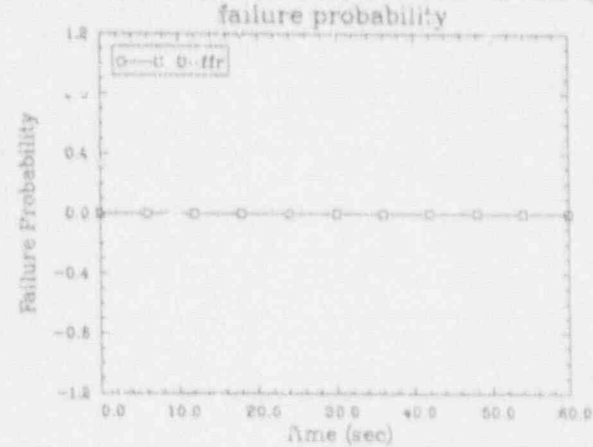
SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.2 W/EMON
oxide thickness



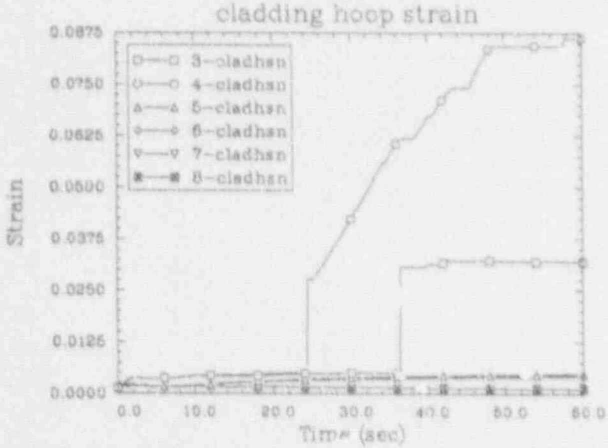
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/EMON
internal pin pressure



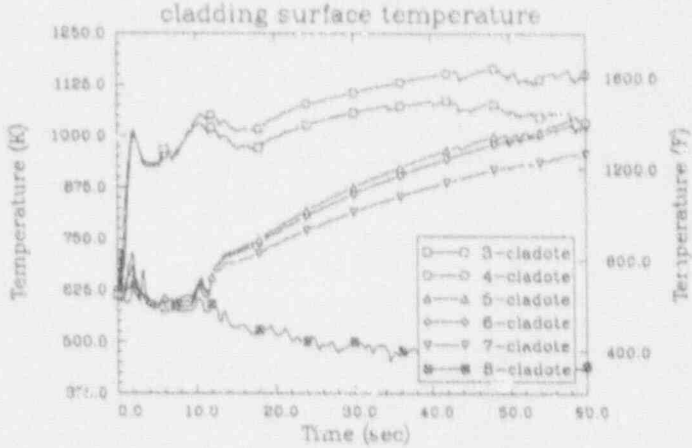
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/EMON
failure probability



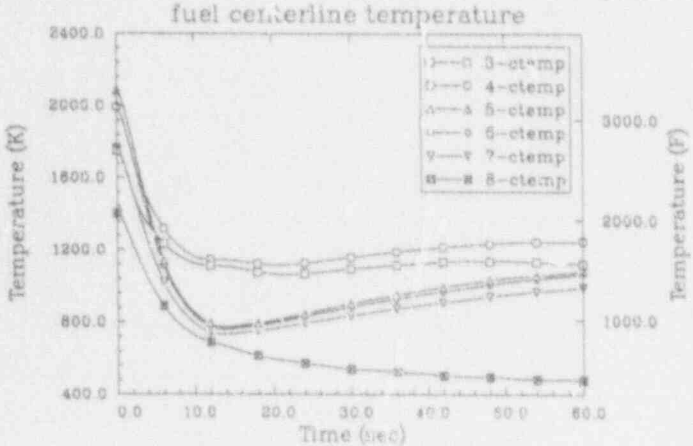
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/EMON
cladding hoop strain



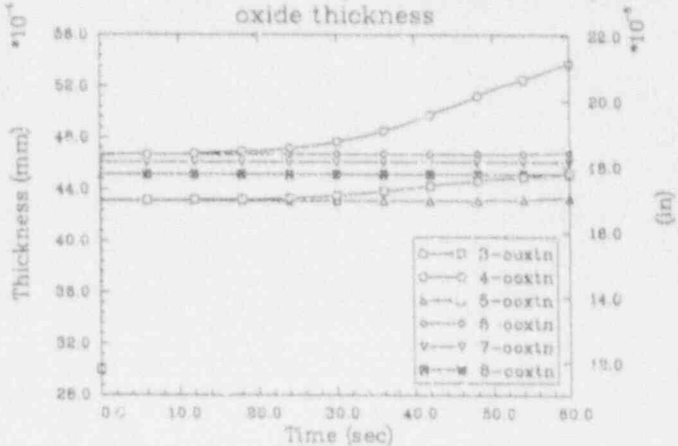
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/EMON
cladding surface temperature

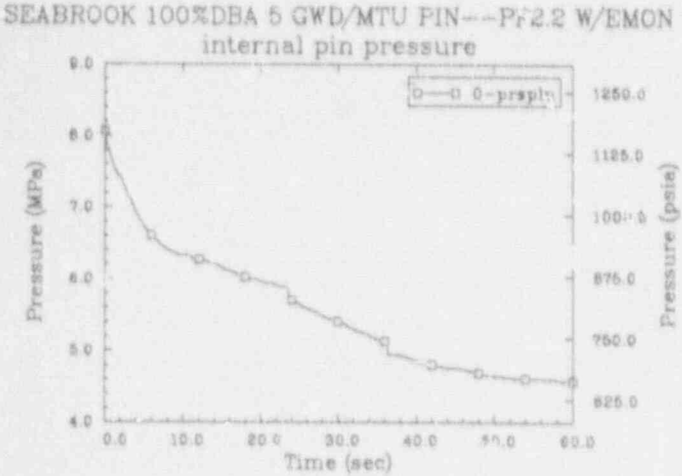


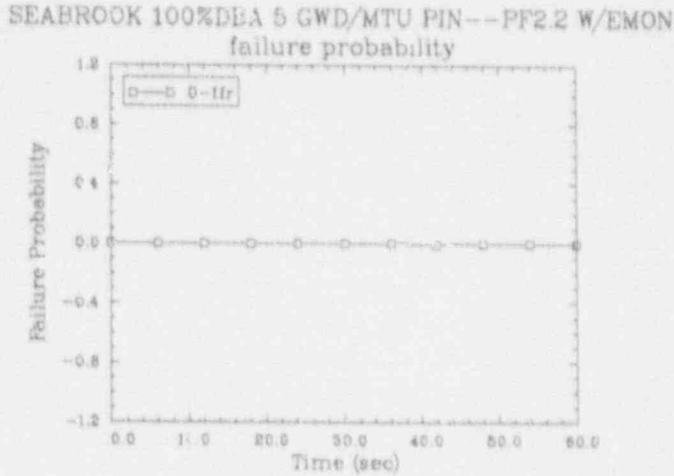
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/EMON
fuel centerline temperature

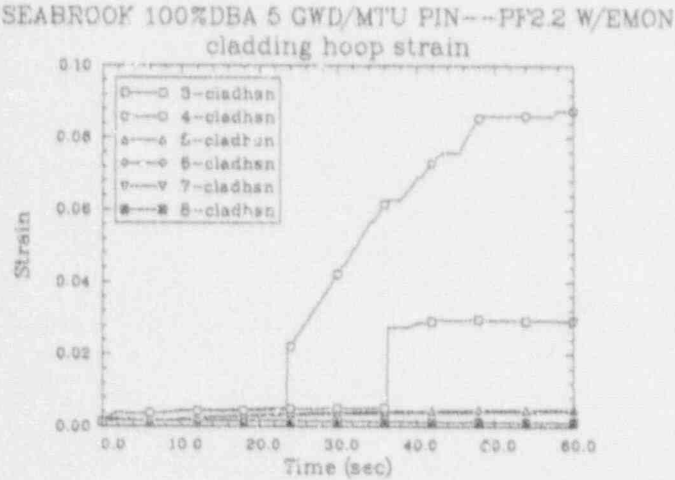


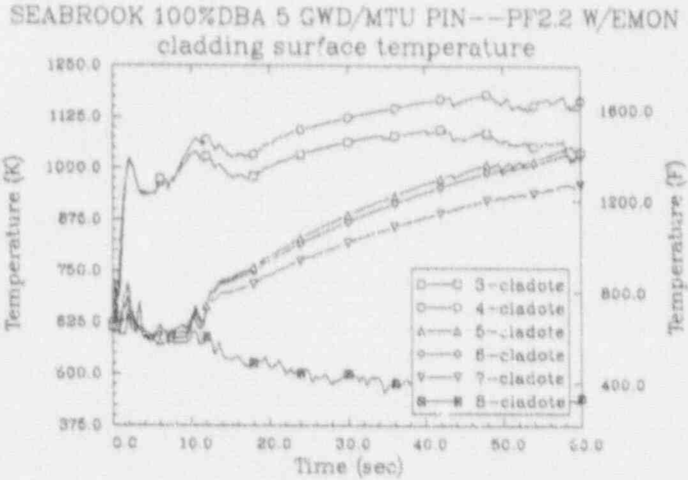
SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.2 W/EMON
oxide thickness

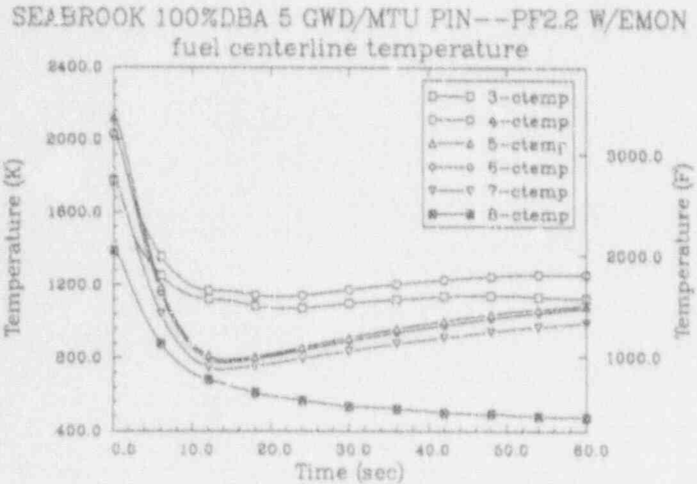


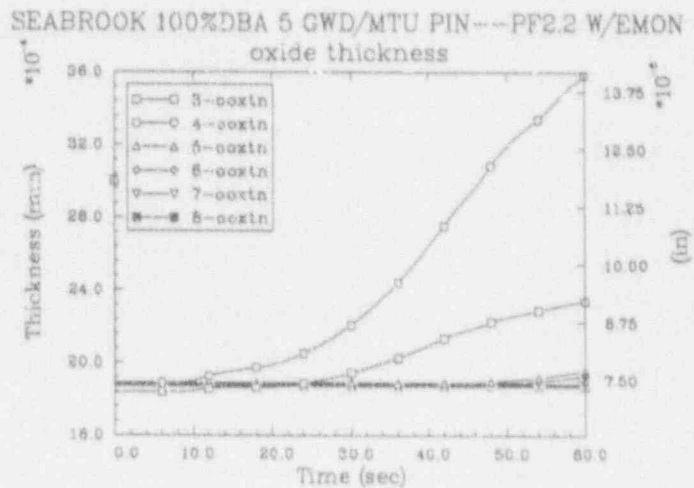

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

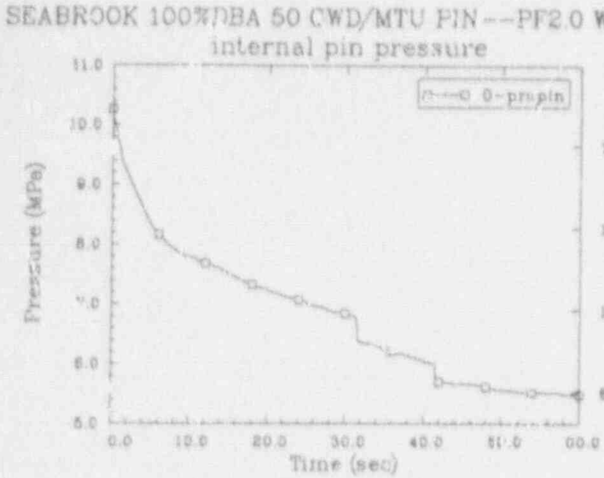

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/EMON
failure probability
0-flr
Failure Probability
Time (sec)

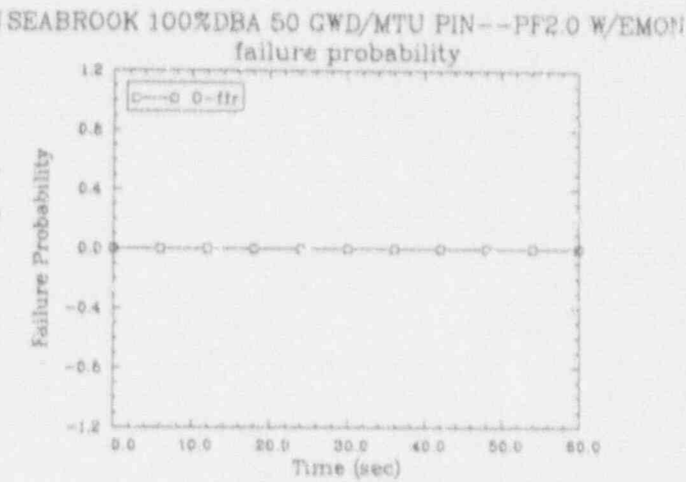

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

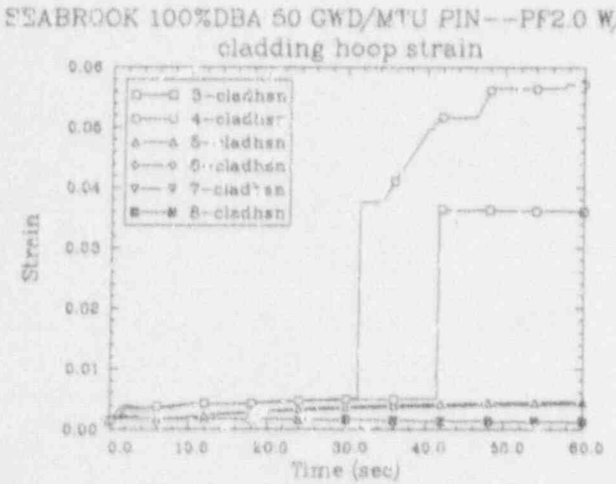

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/EMON
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

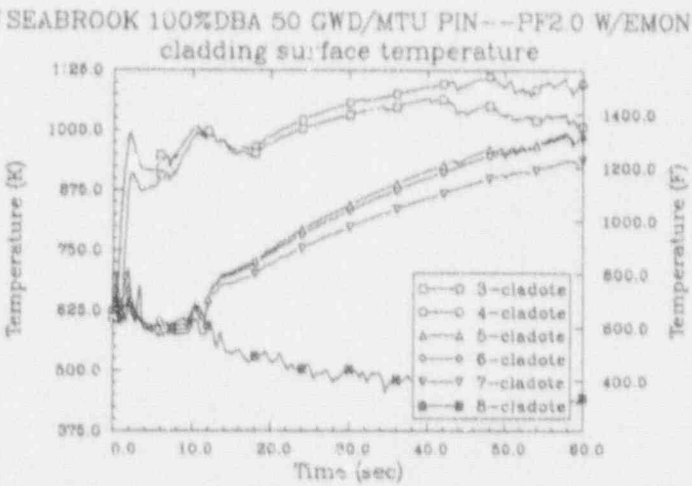

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

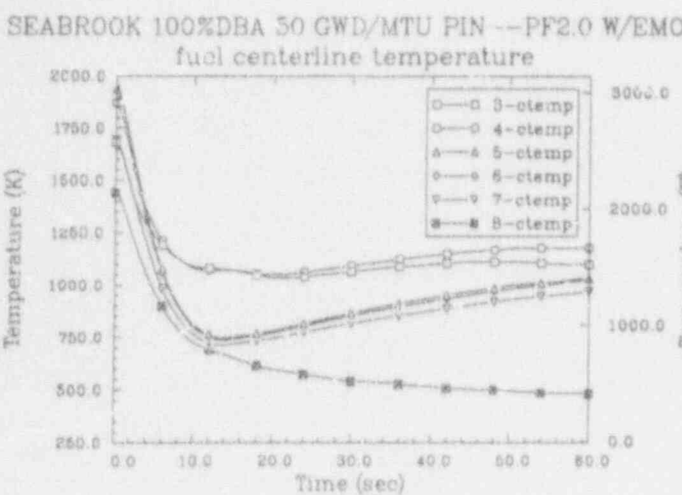

SEABROOK 100%DBA 5 GWD/MTU PIN--PF2.2 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

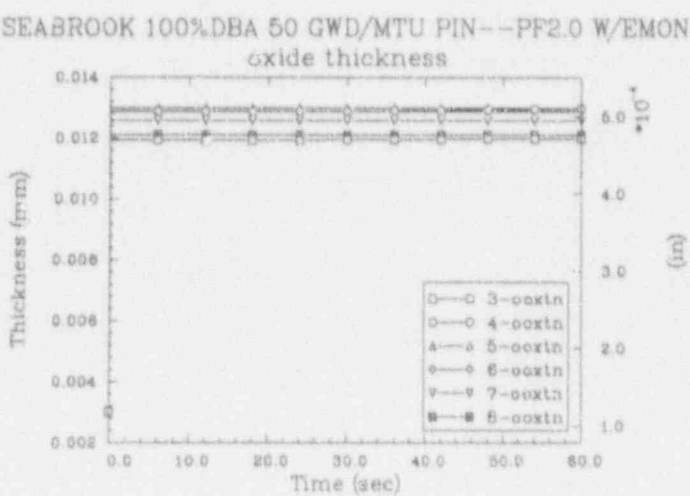

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

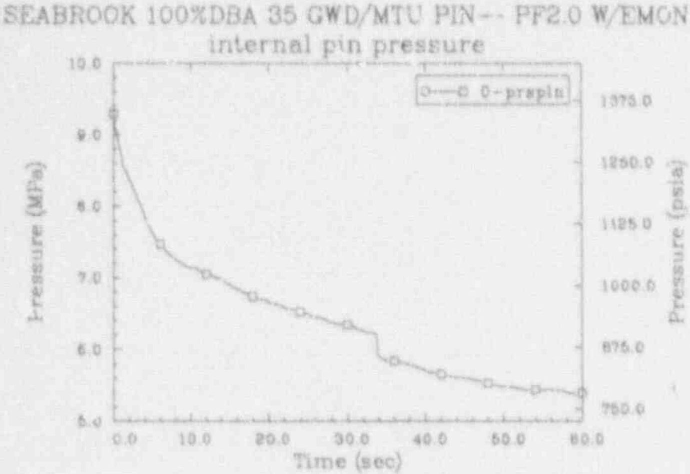

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)

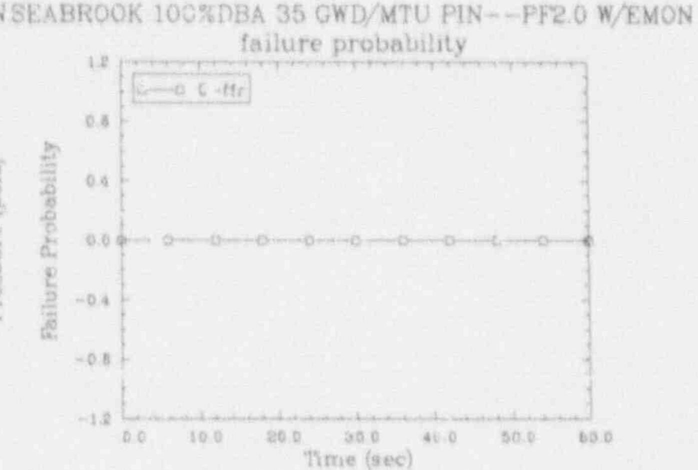

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

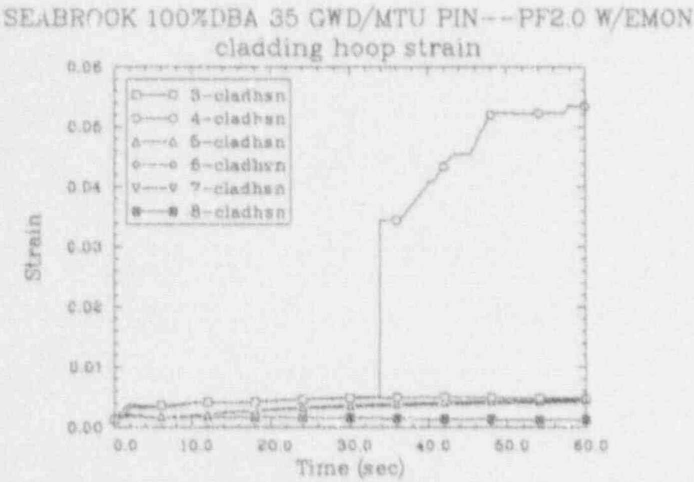

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/EMON
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

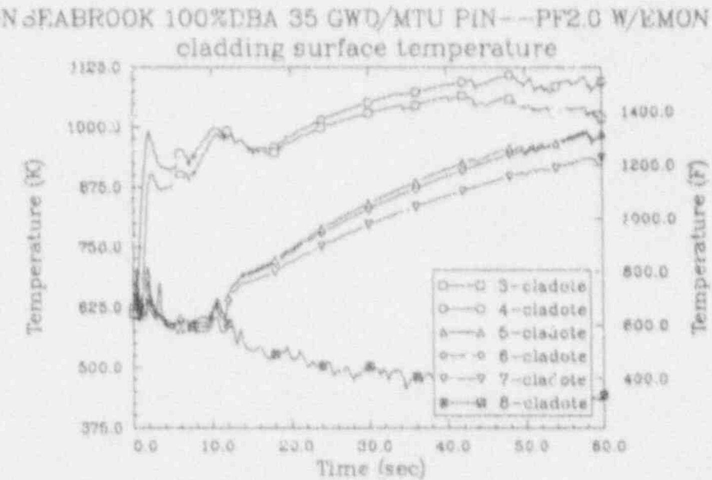

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

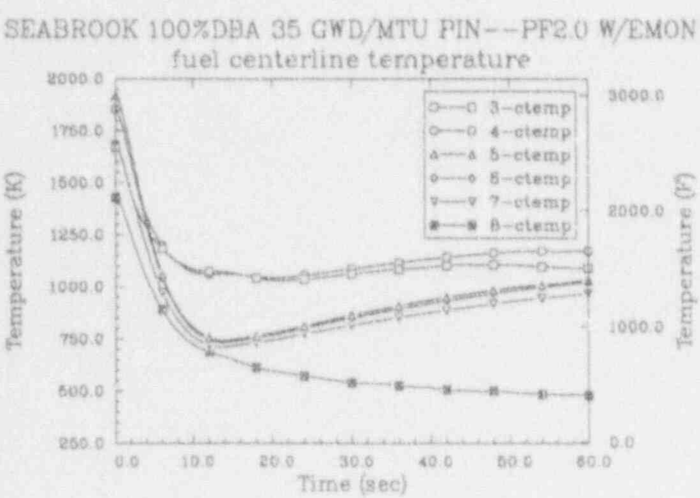

SEABROOK 100%DBA 50 GWD/MTU PIN--PF2.0 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

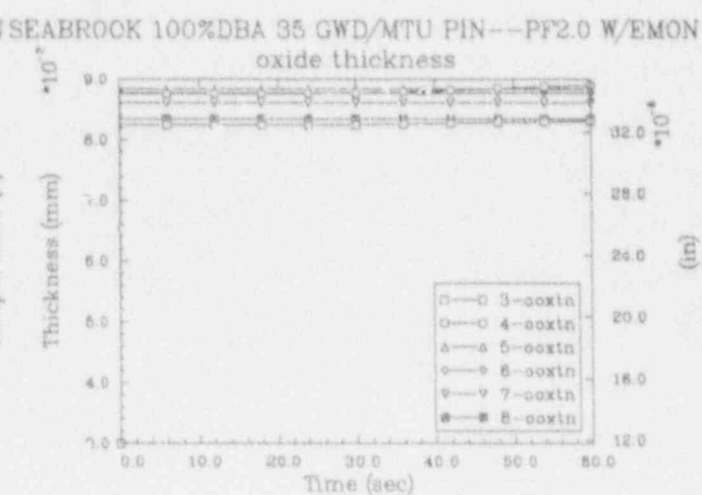

SEABROOK 100%DBA 35 GWD/MTU PIN-- PF2.0 W/EMON
internal pin pressure
0-prspin
I-pressure (MPa)
Pressure (psia)
Time (sec)

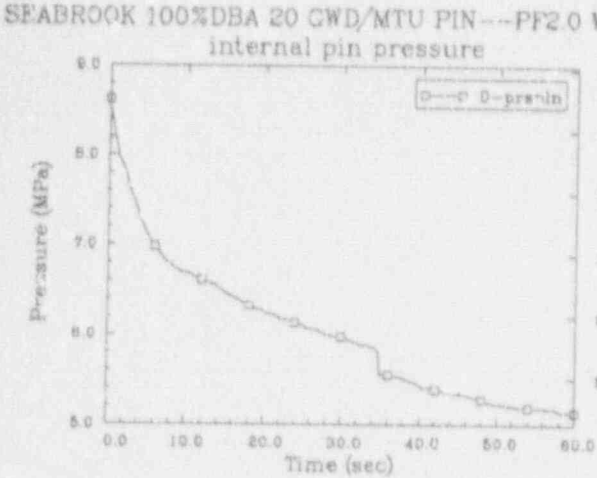

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)

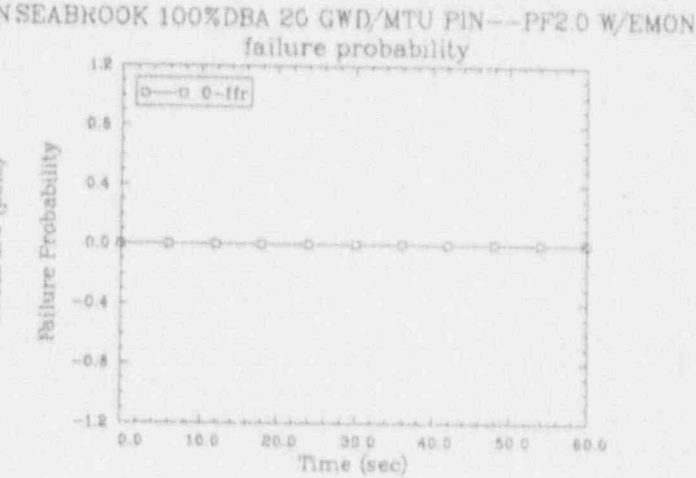

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

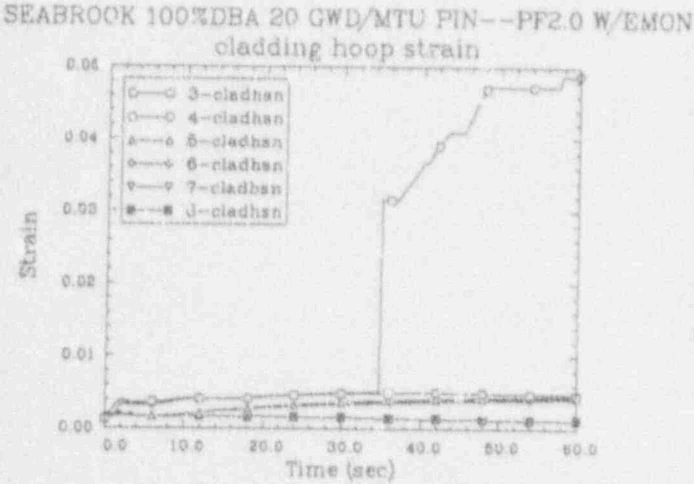

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/EMON
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

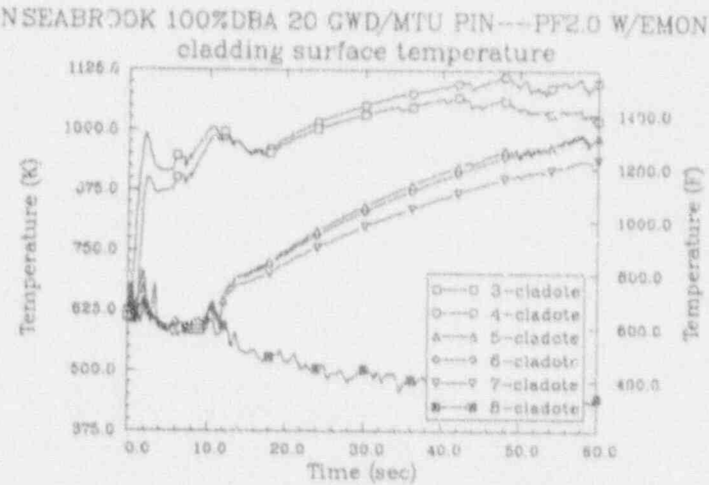

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

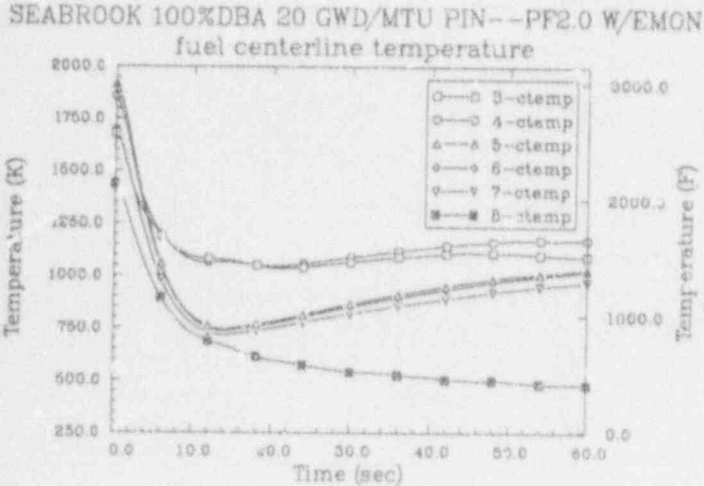

SEABROOK 100%DBA 35 GWD/MTU PIN--PF2.0 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

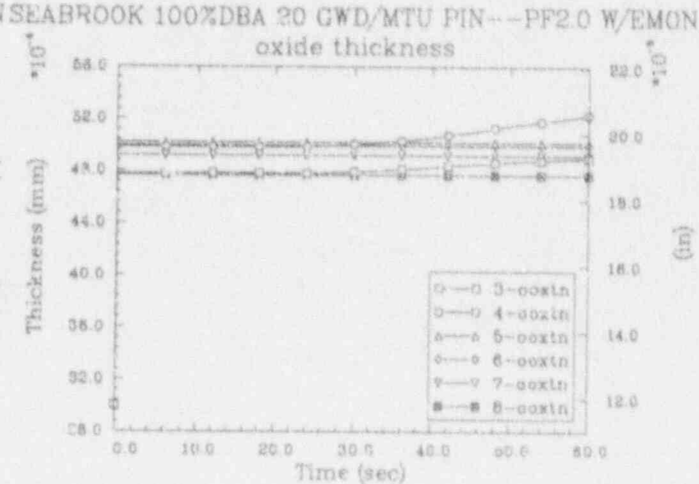

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/EMON
internal pin pressure
0-presin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)

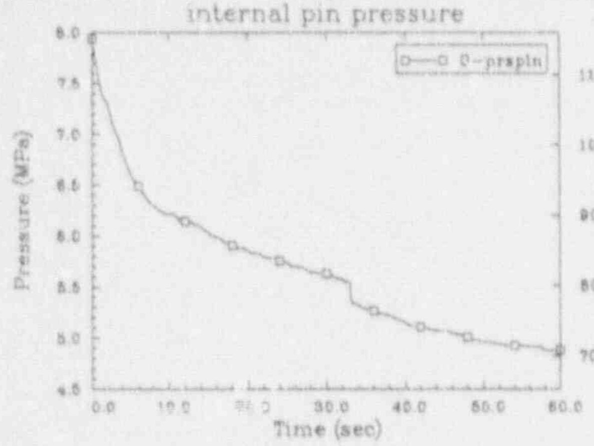

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/EMON
cladding surface temperature
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc
Temperature (K)
Temperature (F)
Time (sec)

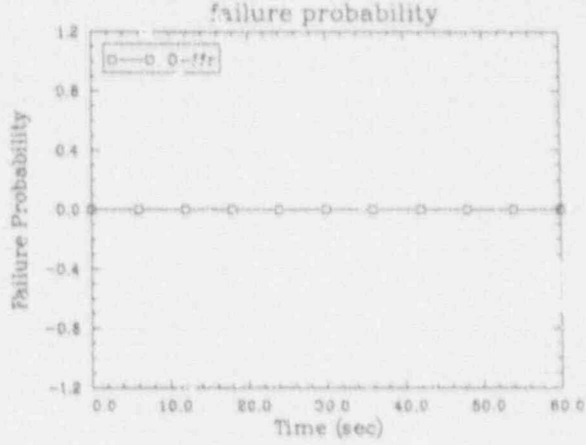

SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF2.0 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

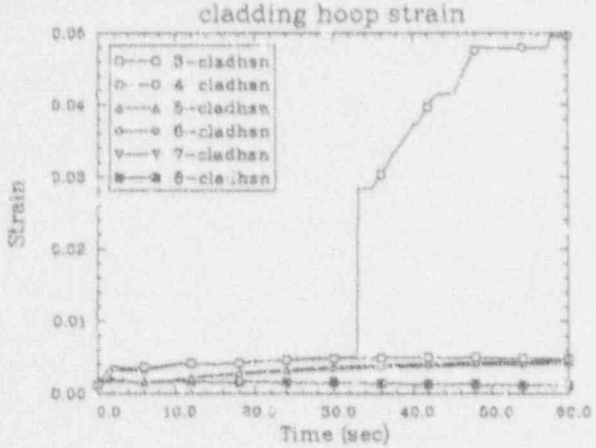
SEABROOK 100%DBA 5 GWD/MTU PIN---PF2.0 W/EMON
internal pin pressure



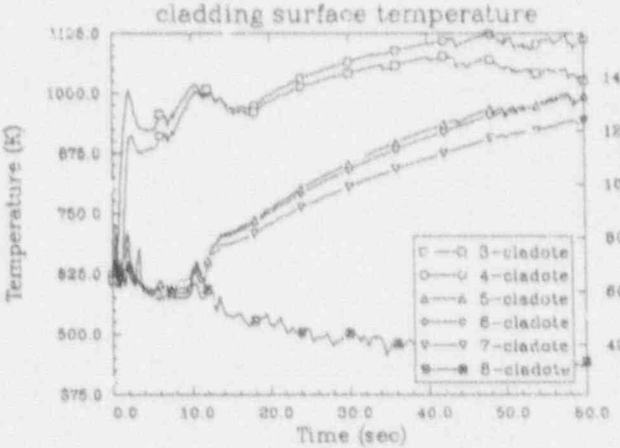
SEABROOK 100%DBA 5 GWD/MTU PIN---PF2.0 W/EMON
failure probability



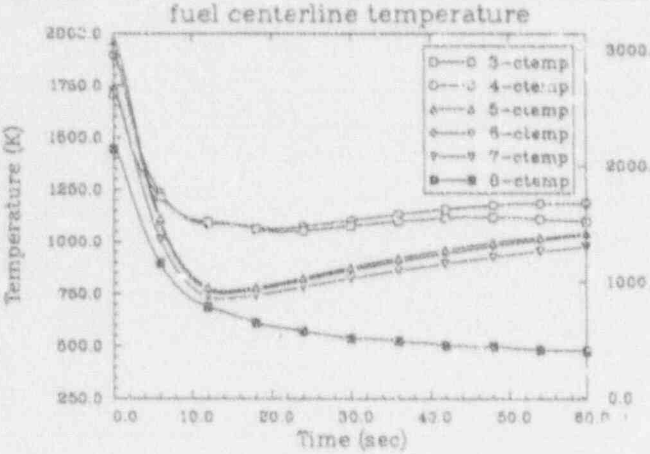
SEABROOK 100%DBA 5 GWD/MTU PIN---PF2.0 W/EMON
cladding hoop strain



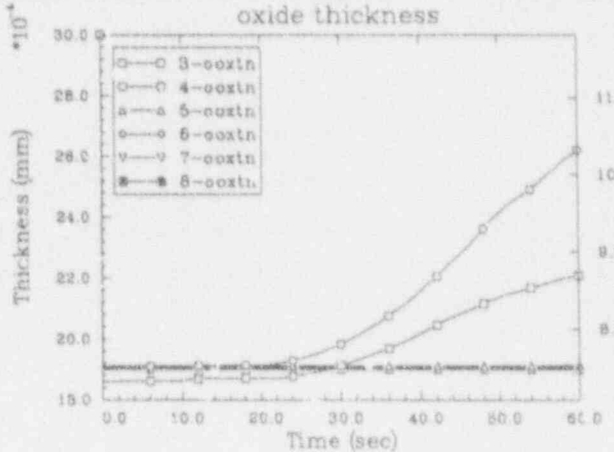
SEABROOK 100%DBA 5 GWD/MTU PIN---PF2.0 W/EMON
cladding surface temperature



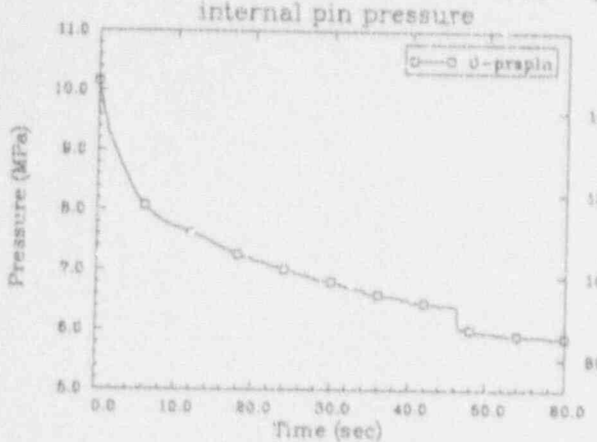
SEABROOK 100%DBA 5 GWD/MTU PIN---PF2.0 W/EMON
fuel centerline temperature



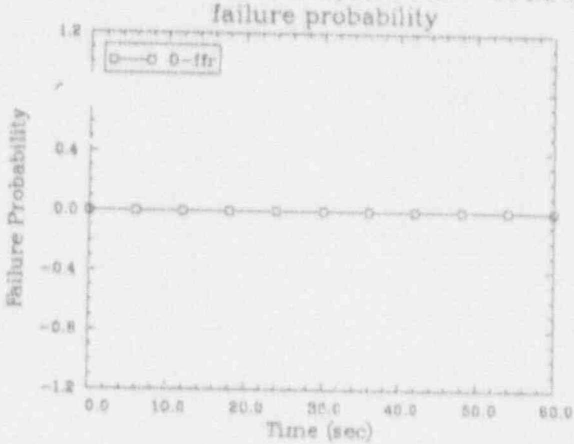
SEABROOK 100%DBA 5 GWD/MTU PIN---PF2.0 W/EMON
oxide thickness



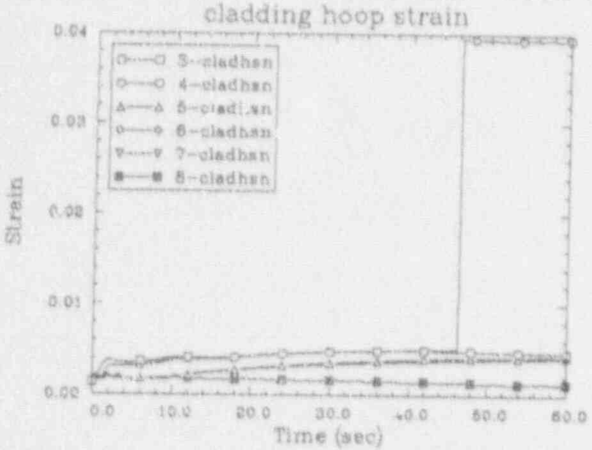
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/EMON
internal pin pressure



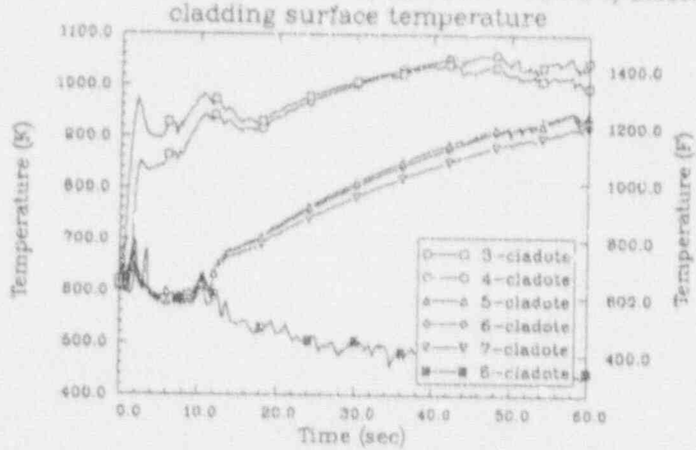
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/EMON
failure probability



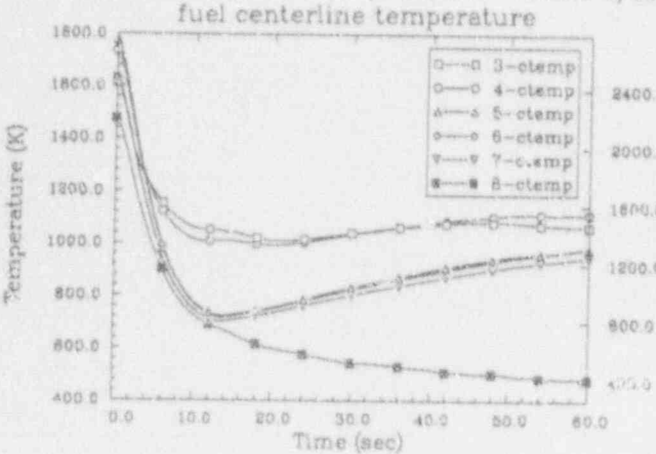
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/EMON
cladding hoop strain



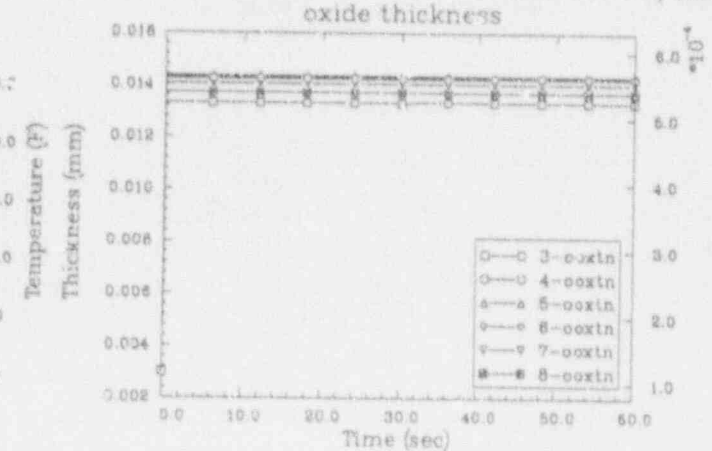
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/EMON
cladding surface temperature



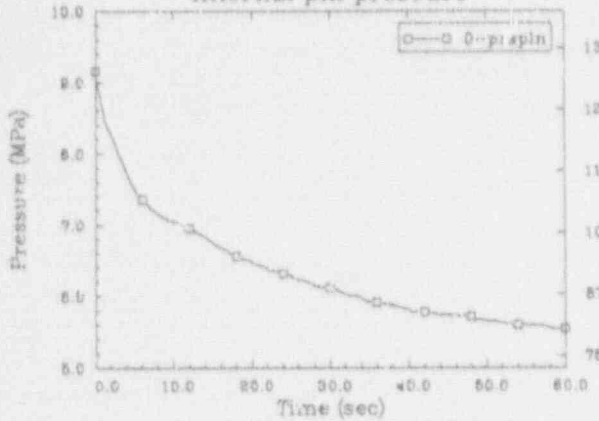
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/EMON
fuel centerline temperature



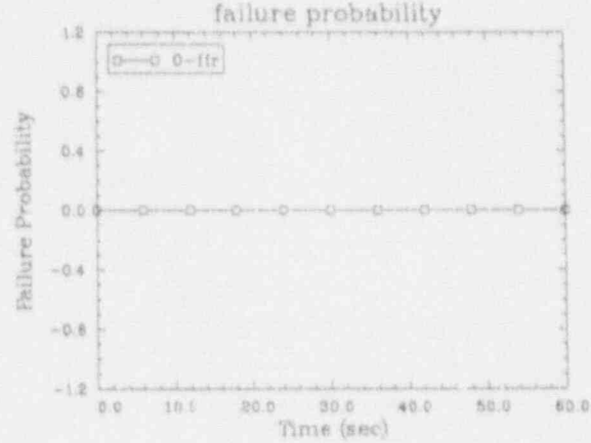
SEABROOK 100%DBA 50 GWD/MTU PIN--PF1.8 W/EMON
oxide thickness



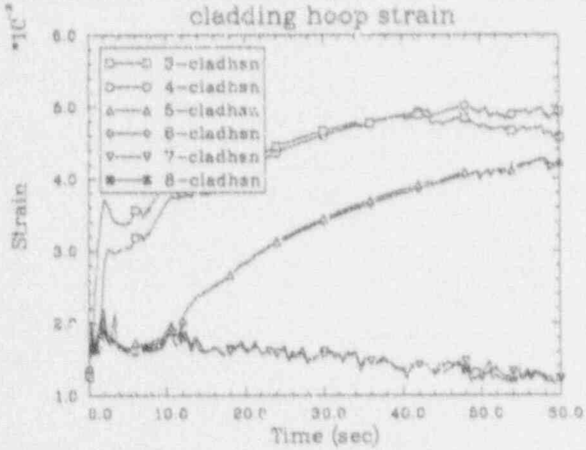
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/EMON
internal pin pressure



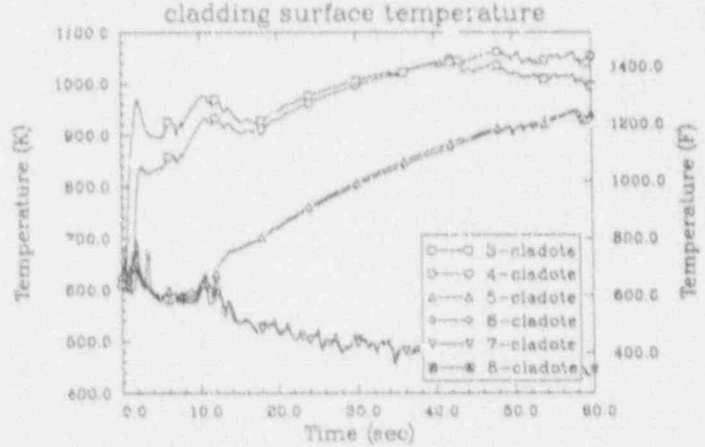
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/EMON
failure probability



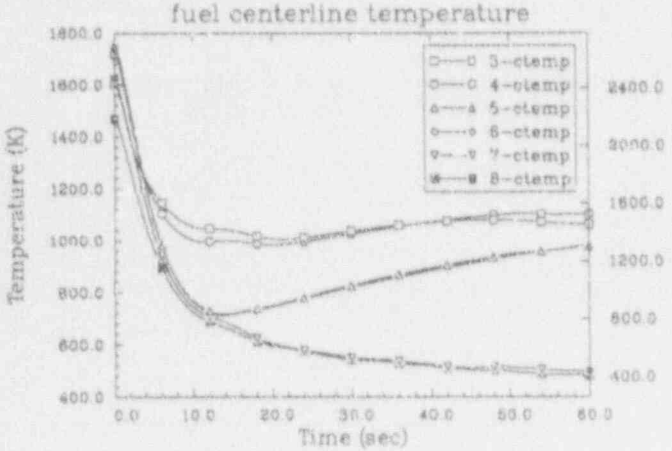
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/EMON
cladding hoop strain



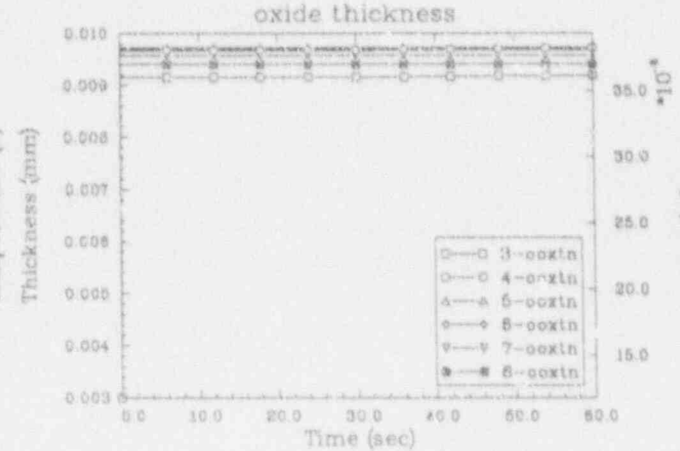
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/EMON
cladding surface temperature

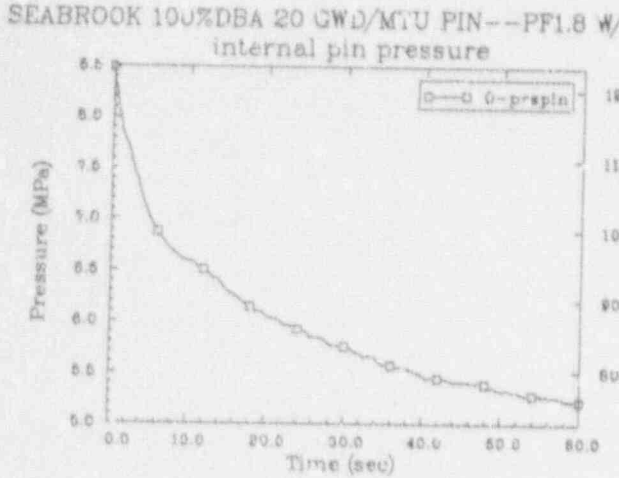


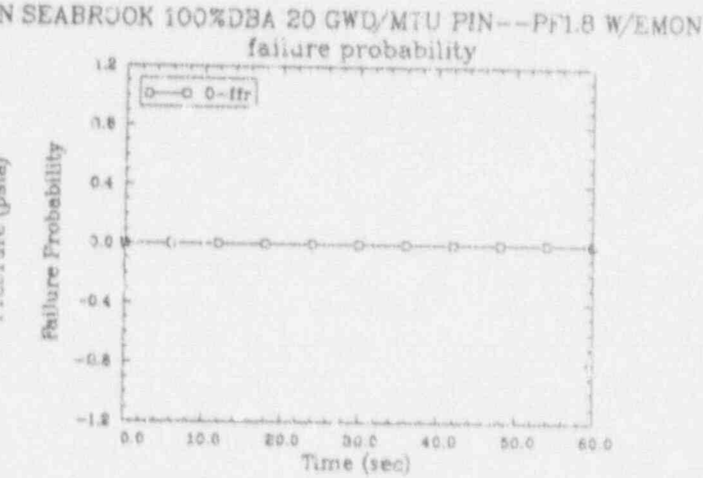
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/EMON
fuel centerline temperature

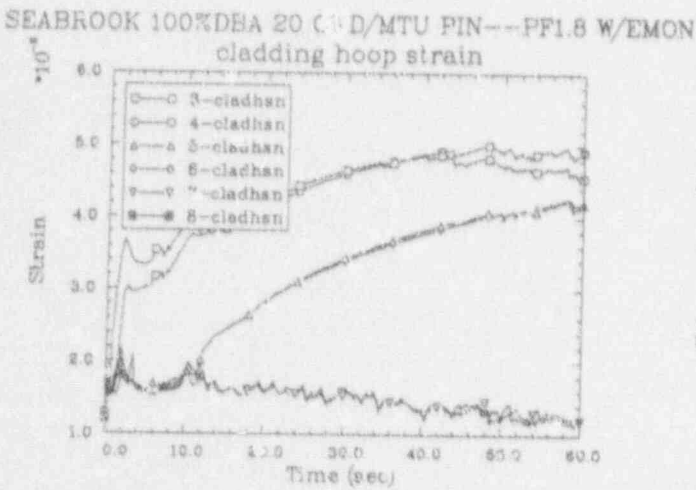


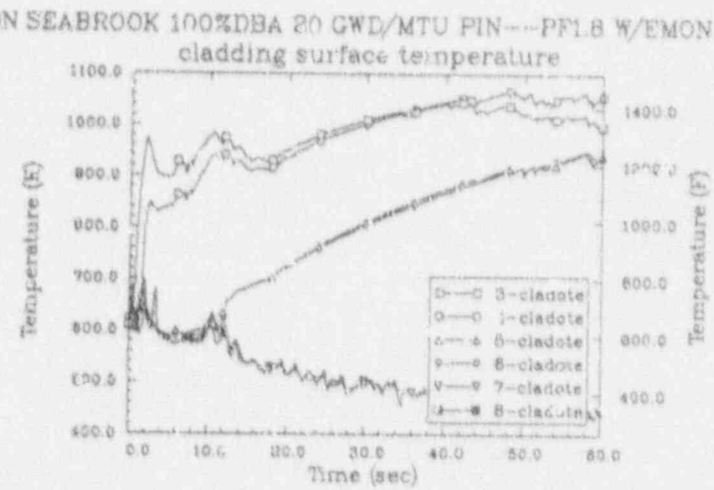
SEABROOK 100%DBA 35 GWD/MTU PIN--PF1.8 W/EMON
oxide thickness

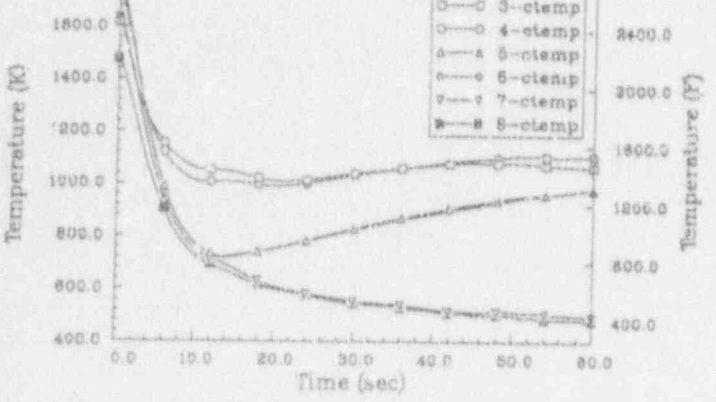


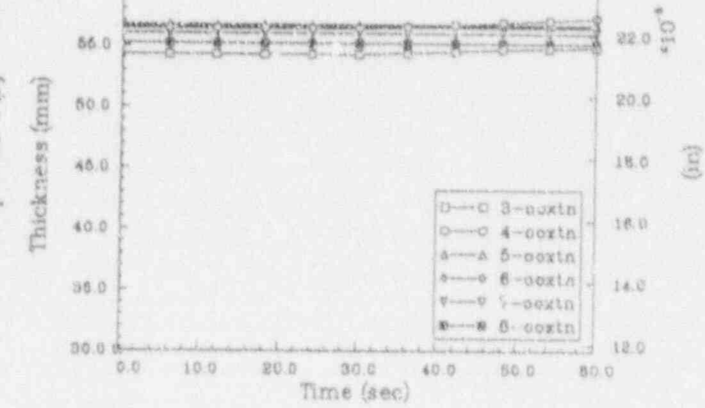

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/EMON
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/EMON
failure probability
0-ffr
Failure Probability
Time (sec)

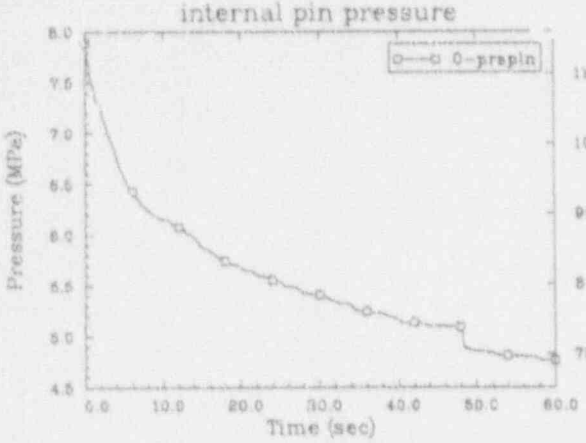

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/EMON
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/EMON
cladding surface temperature
3-cladote
5-cladote
6-cladote
7-cladote
Temperature (K)
Temperature (F)
Time (sec)

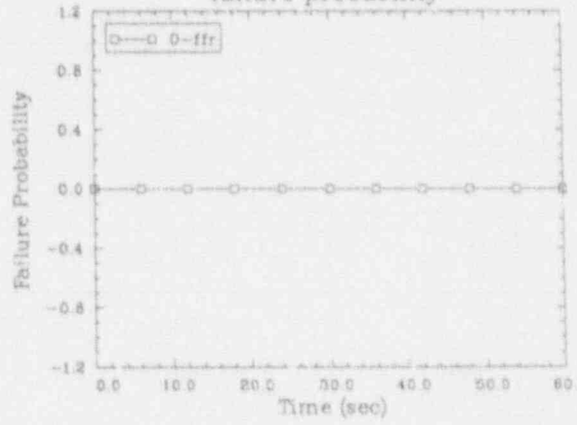

SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/EMON
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF1.8 W/EMON
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

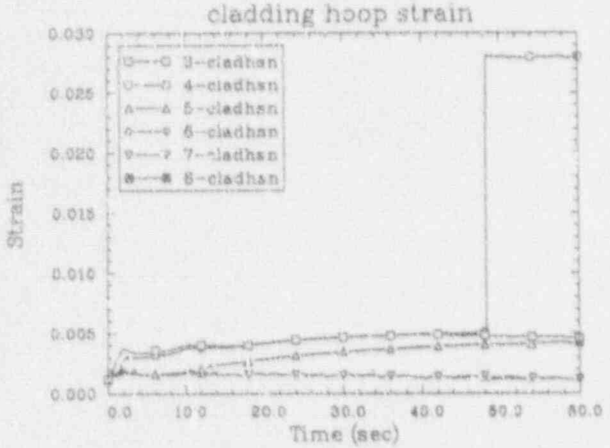
SEABROOK 100%DBA 5 GWD/MTU PIN---PF1.8 W/EMON
internal pin pressure



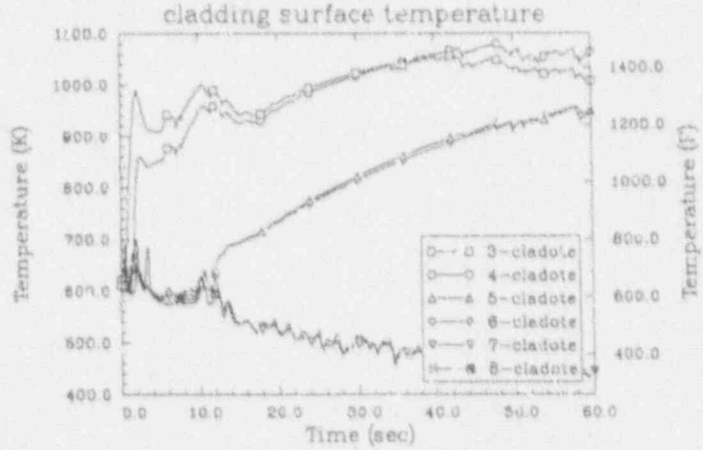
SEABROOK 100%DBA 5 GWD/MTU PIN---PF1.8 W/EMON
failure probability



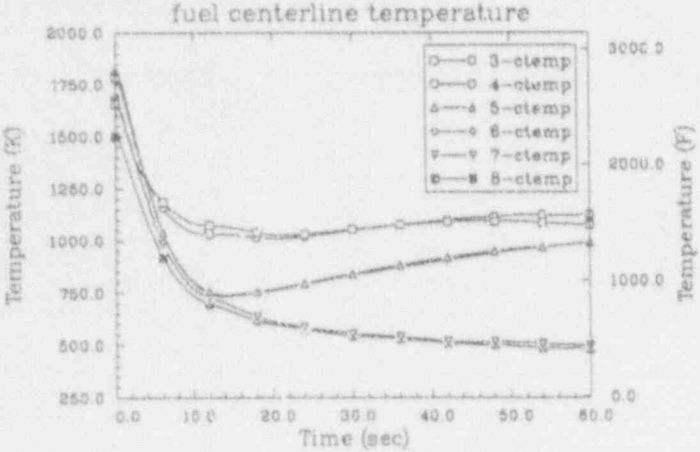
SEABROOK 100%DBA 5 GWD/MTU PIN---PF1.8 W/EMON
cladding hoop strain



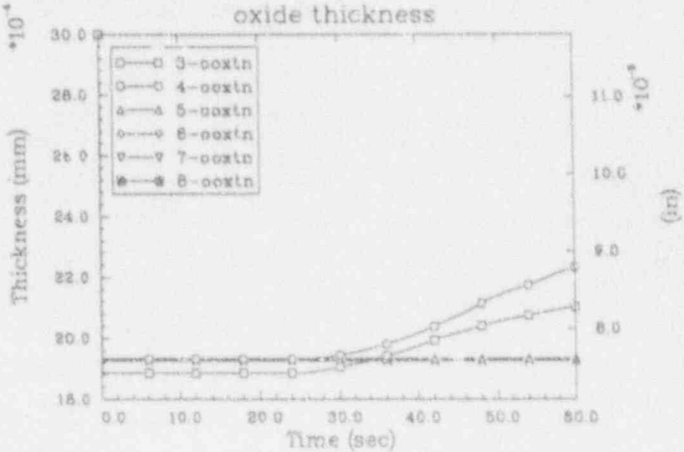
SEABROOK 100%DBA 5 GWD/MTU PIN---PF1.8 W/EMON
cladding surface temperature

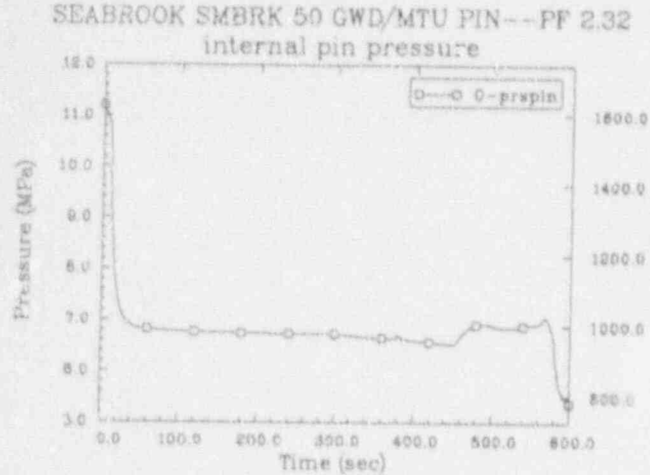


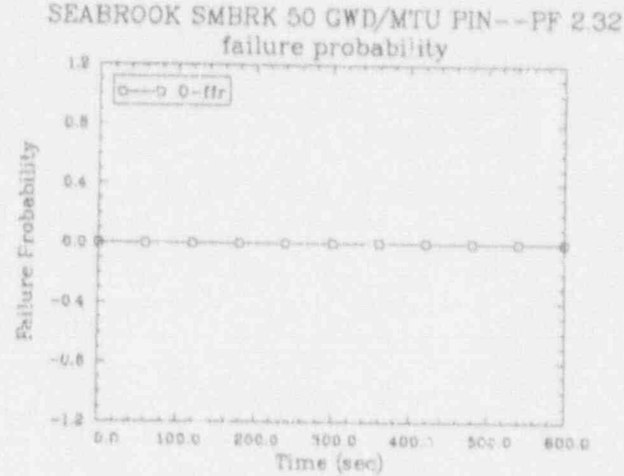
SEABROOK 100%DBA 5 GWD/MTU PIN---PF1.8 W/EMON
fuel centerline temperature

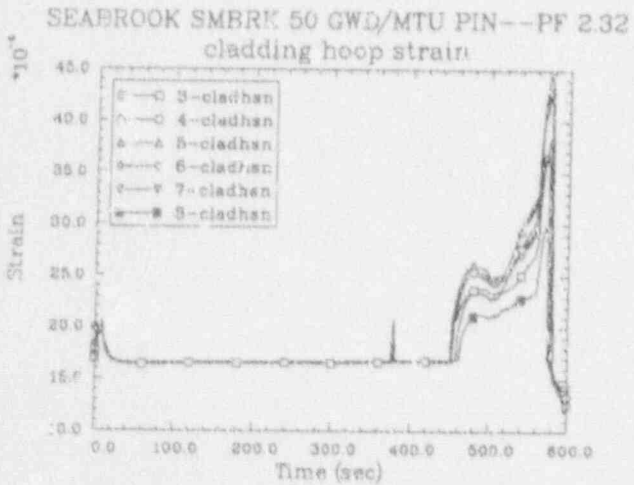


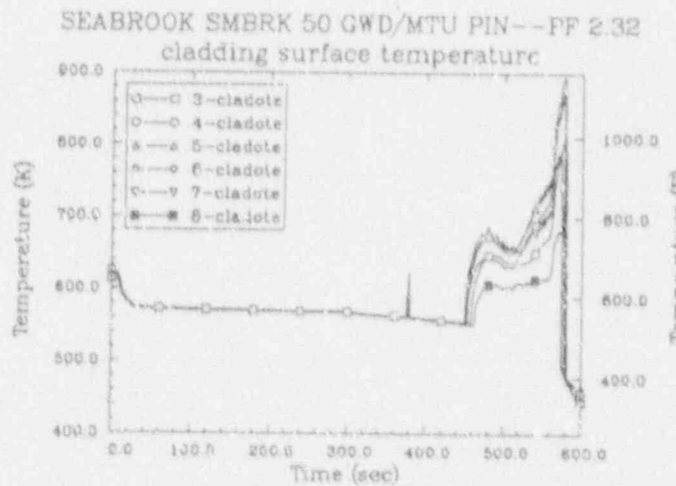
SEABROOK 100%DBA 5 GWD/MTU PIN---PF1.8 W/EMON
oxide thickness

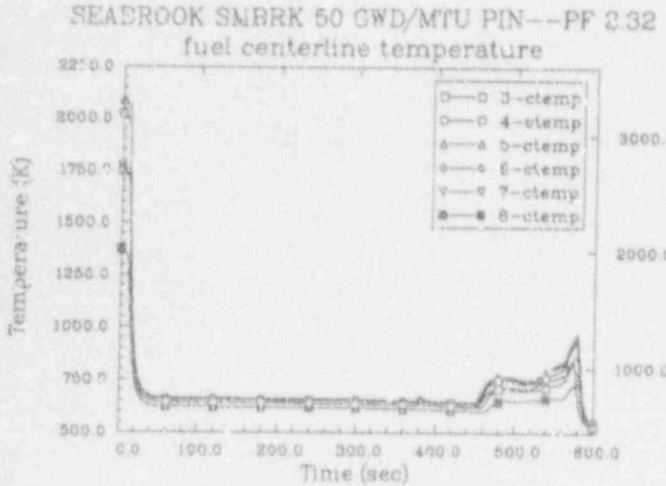


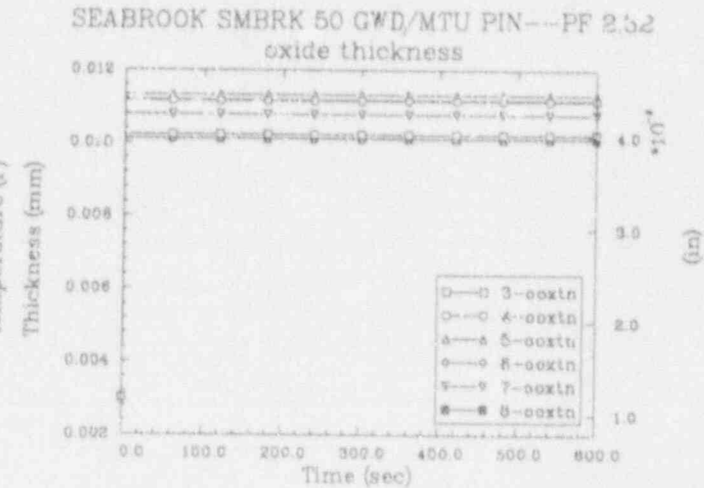

SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32
failure probability
0-ffr
Failure Probability
Time (sec)

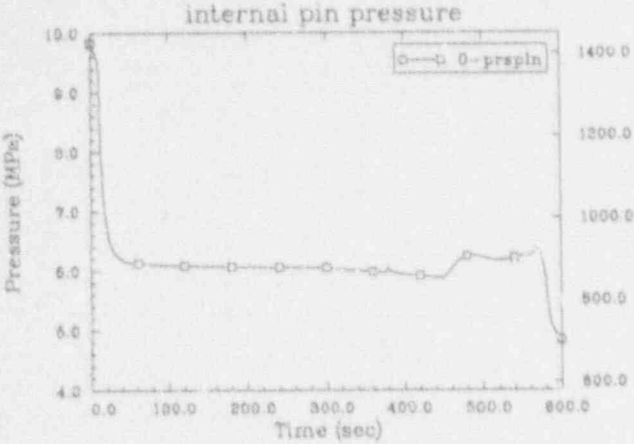

SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

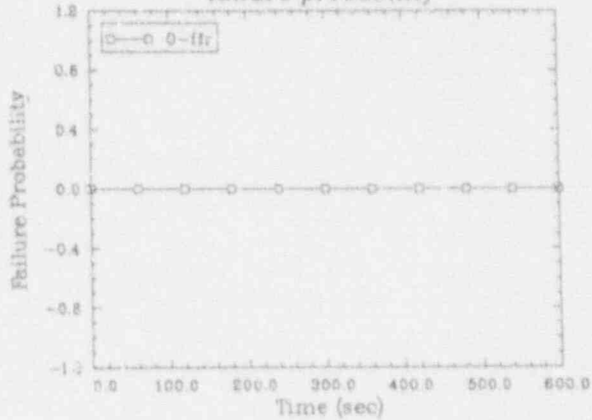

SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

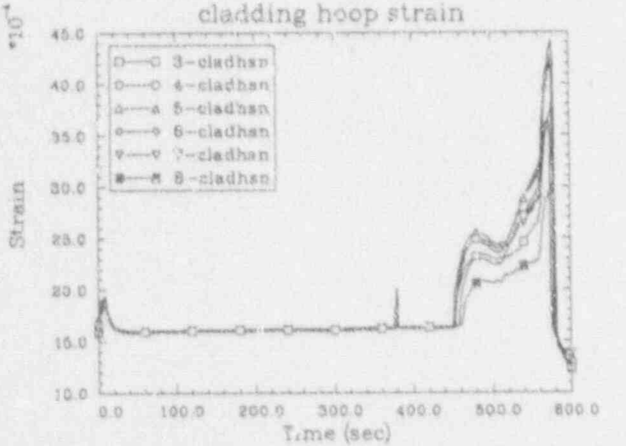
SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32
internal pin pressure



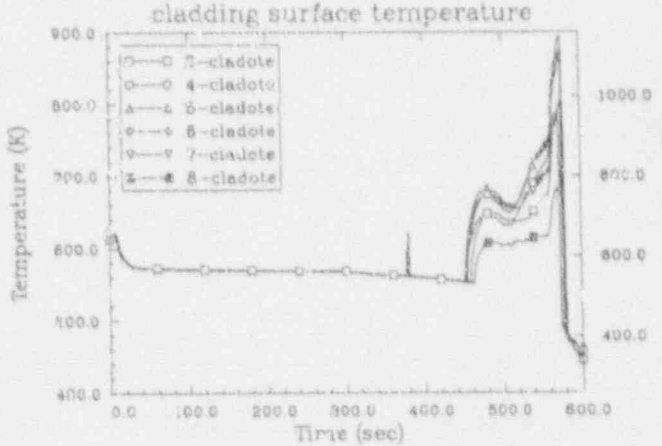
SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32
failure probability



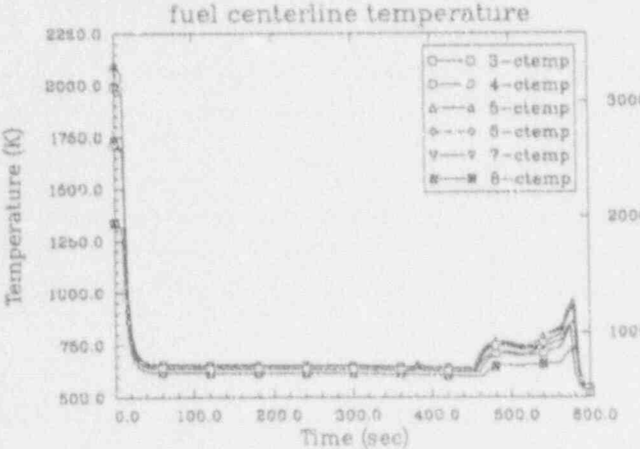
SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32
cladding hoop strain



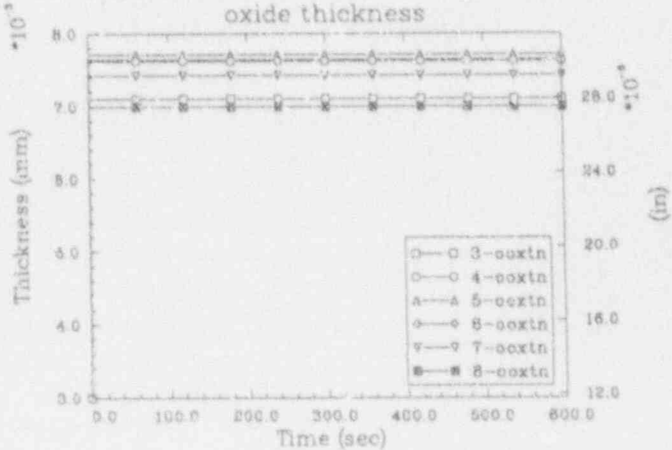
SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32
cladding surface temperature

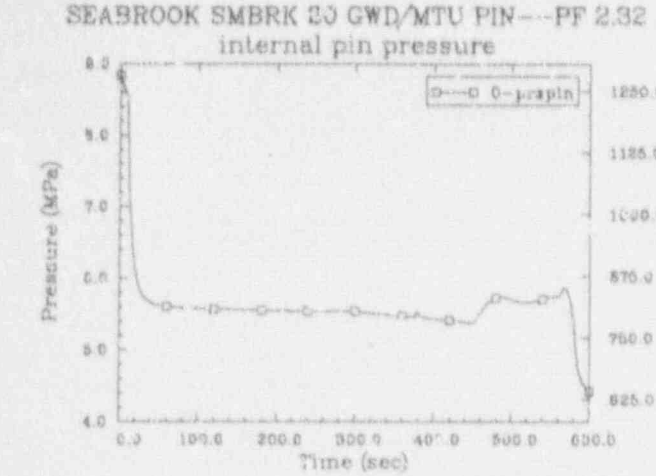


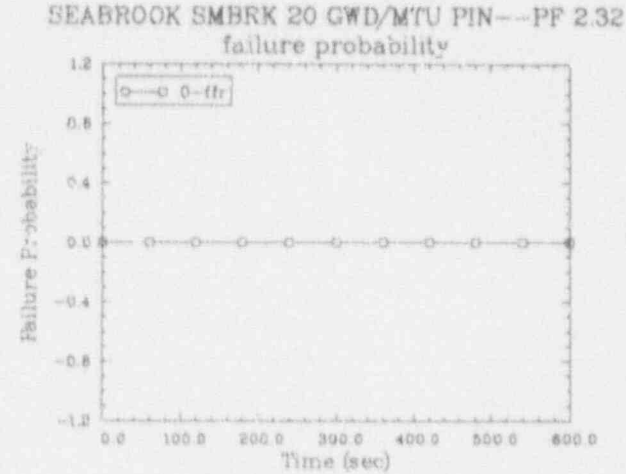
SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32
fuel centerline temperature

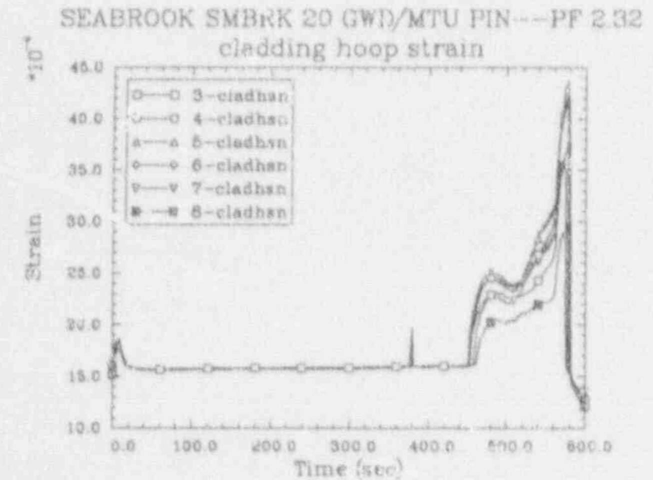


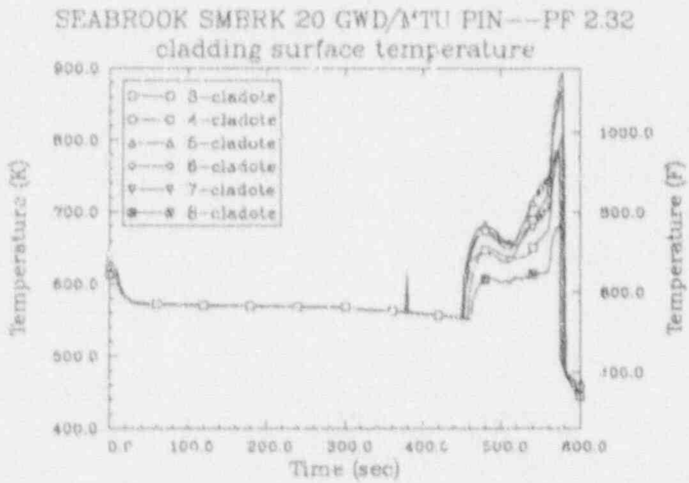
SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32
oxide thickness

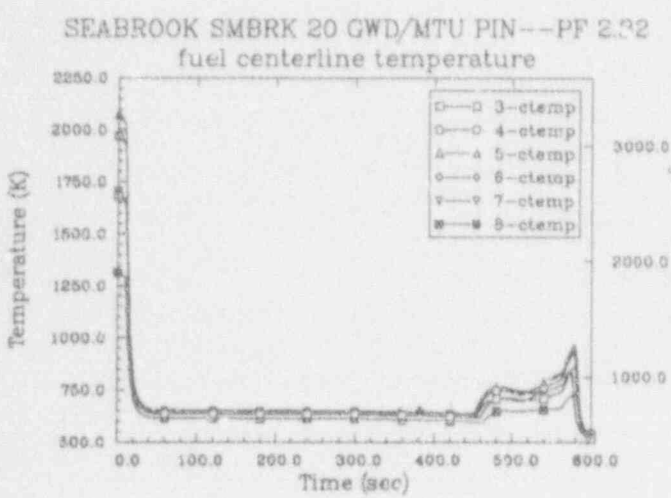


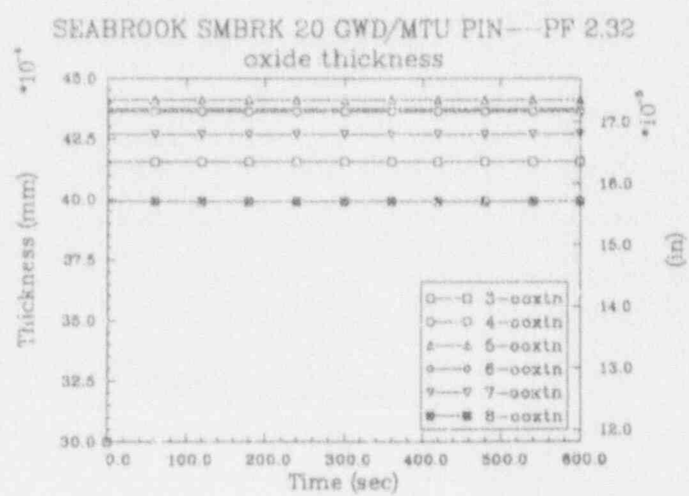

SEABROOK SMBRK 20 GWD/MTU PIN---PF 2.32
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

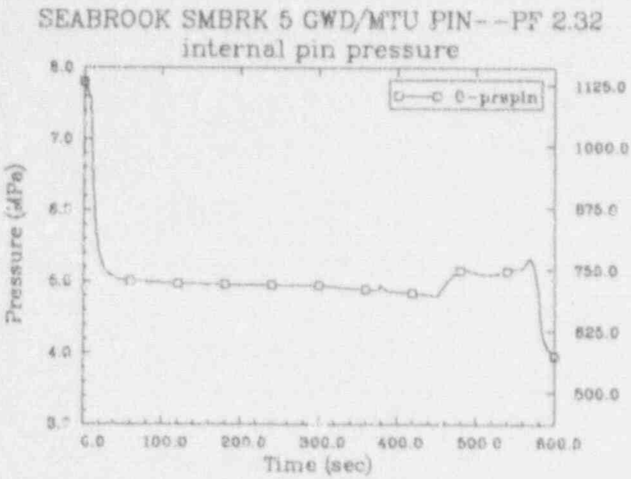

SEABROOK SMBRK 20 GWD/MTU PIN---PF 2.32
failure probability
0-ffr
Failure Probability
Time (sec)

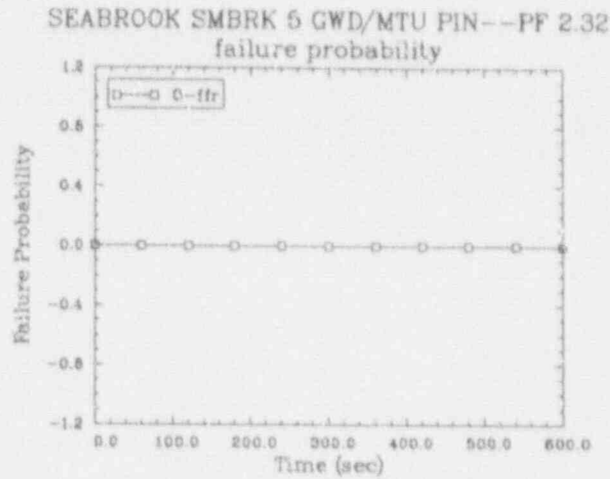

SEABROOK SMBRK 20 GWD/MTU PIN---PF 2.32
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

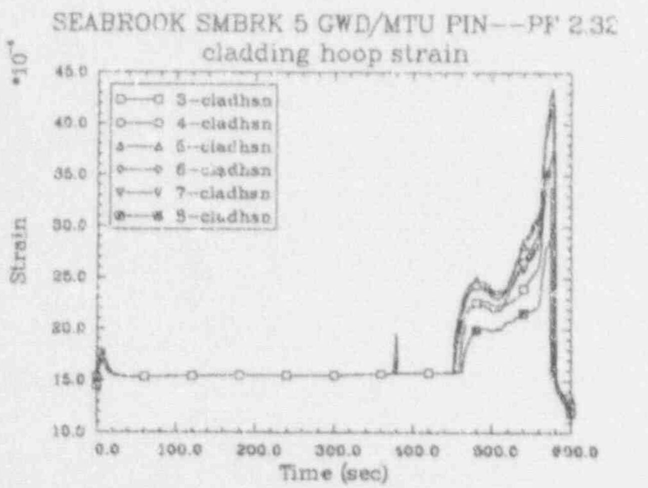

SEABROOK SMBRK 20 GWD/MTU PIN---PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

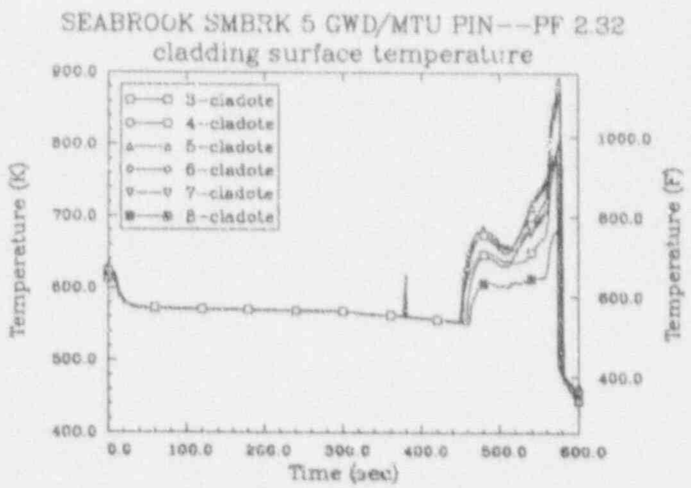

SEABROOK SMBRK 20 GWD/MTU PIN---PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

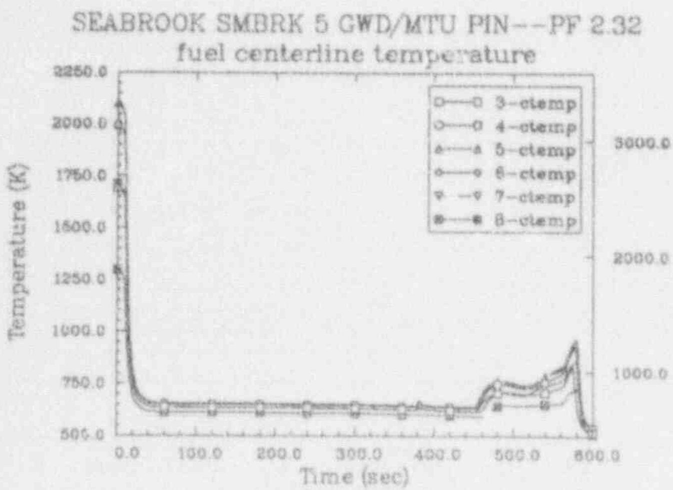

SEABROOK SMBRK 20 GWD/MTU PIN---PF 2.32
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

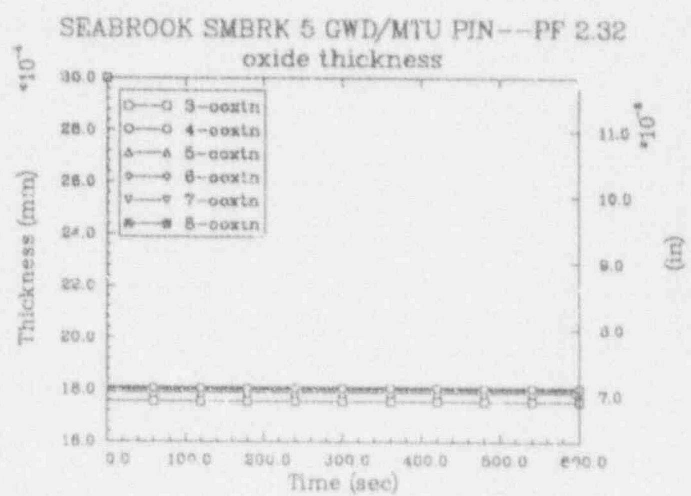

SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)

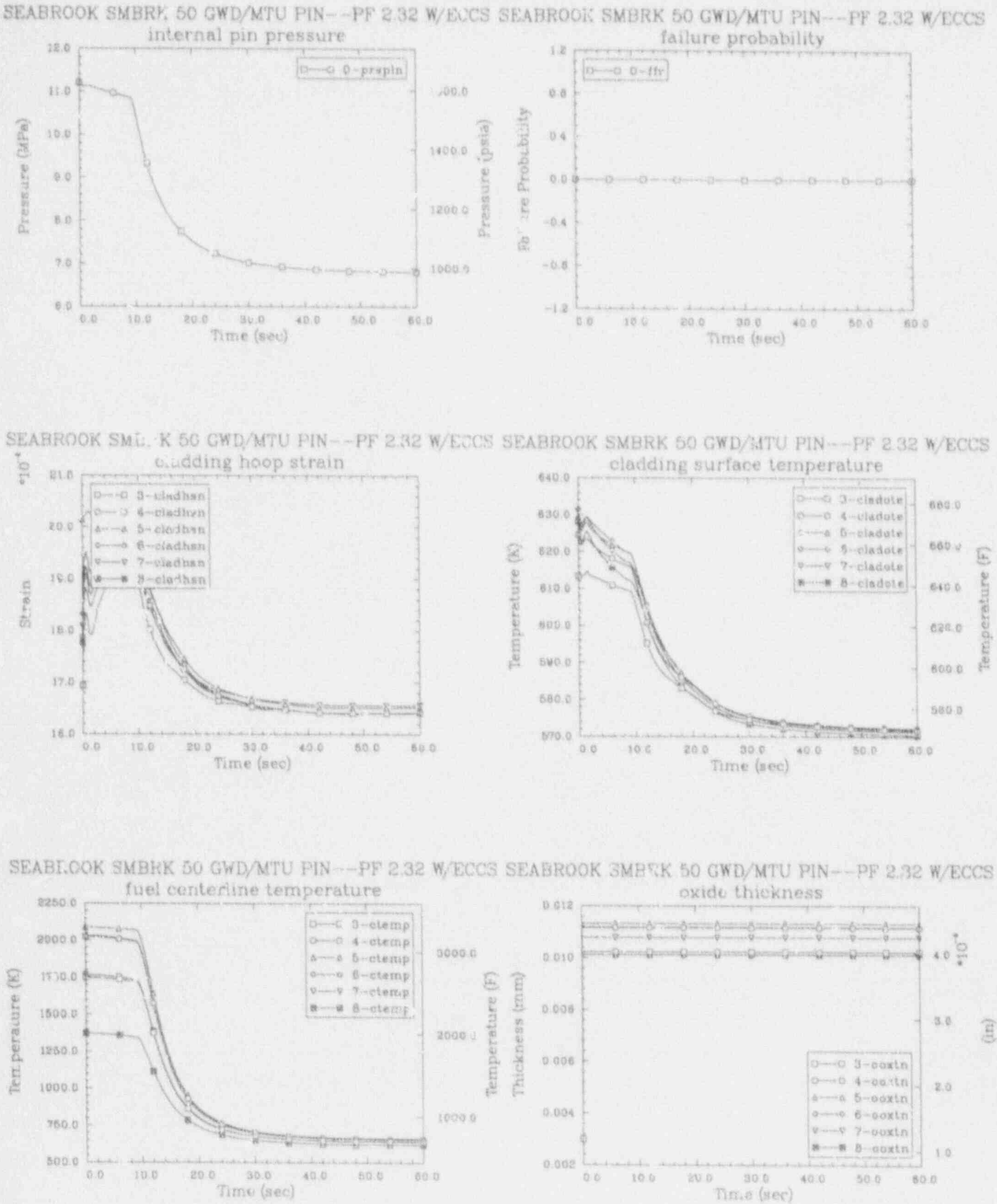

SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32
failure probability
0-ffr
Failure Probability
Time (sec)

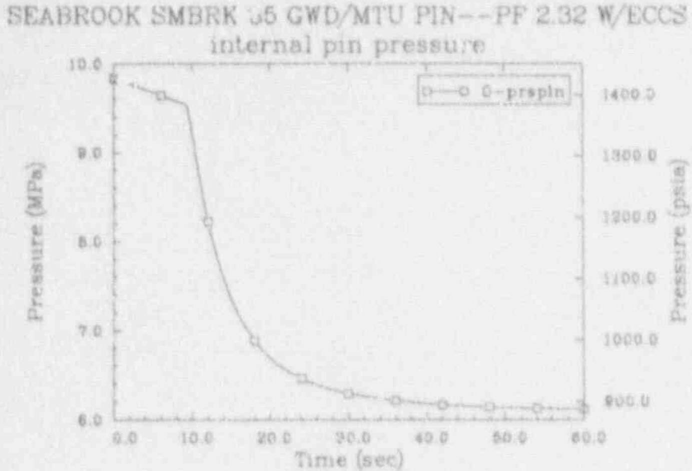

SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32
cladding hoop strain
*10⁻⁴
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)

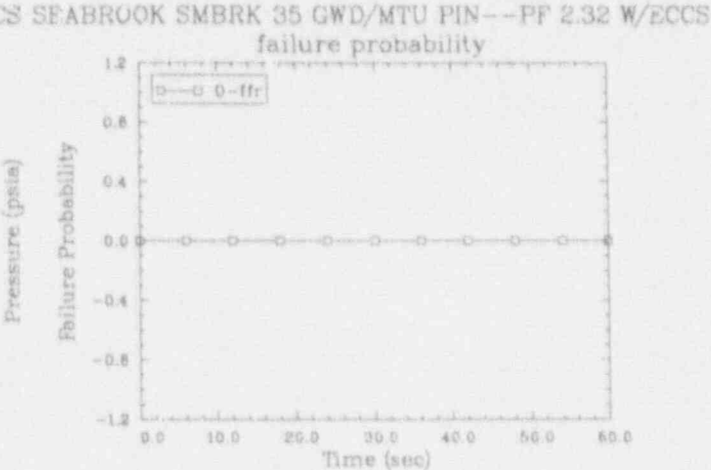

SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

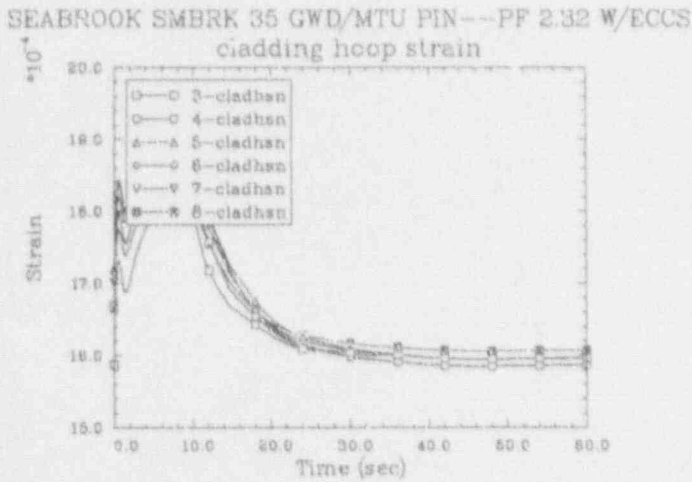

SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)

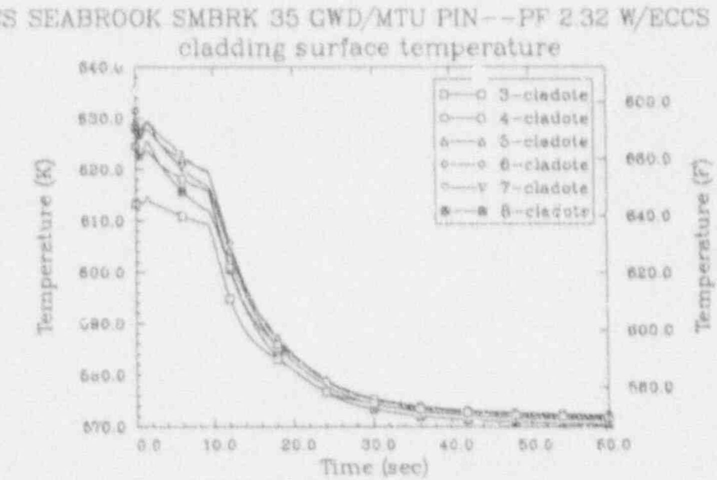

SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32
oxide thickness
*10⁻⁴
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

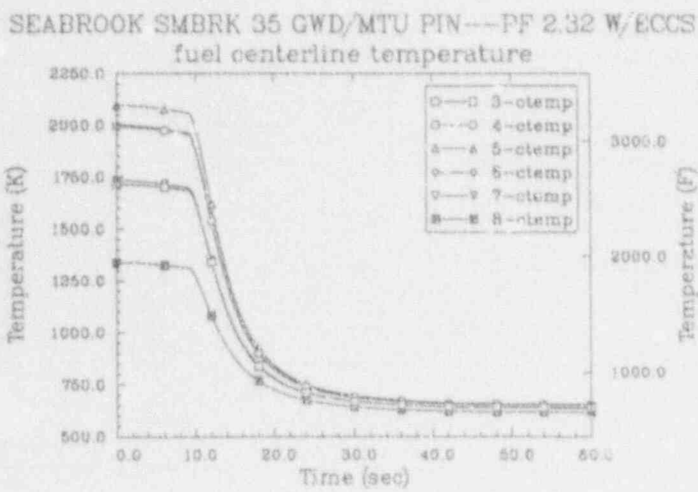

SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)
SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)
SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32 W/ECCS
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)
SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)
SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)
SEABROOK SMBRK 50 GWD/MTU PIN--PF 2.32 W/ECCS
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

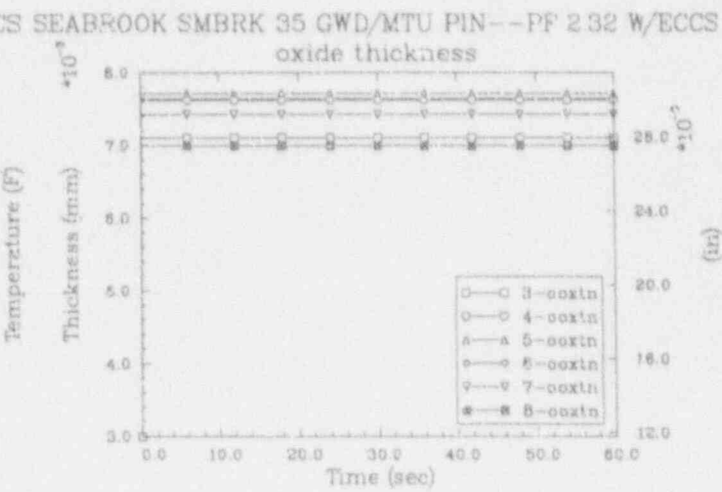

SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32 W/ECCS
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32 W/ECCS
failure probability
0-ffr
Failure Probability
Time (sec)

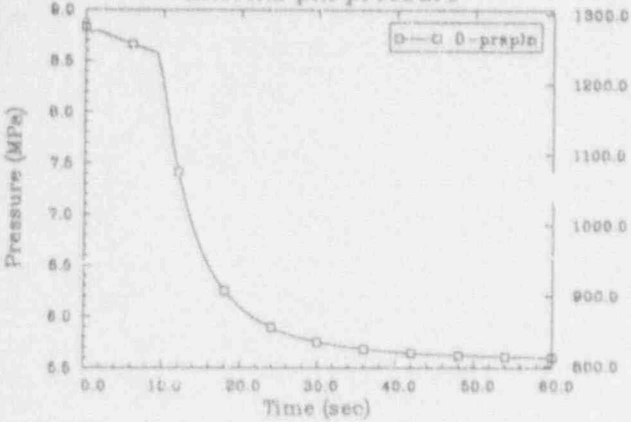

SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32 W/ECCS
cladding hoop strain
*10^-4
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32 W/ECCS
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

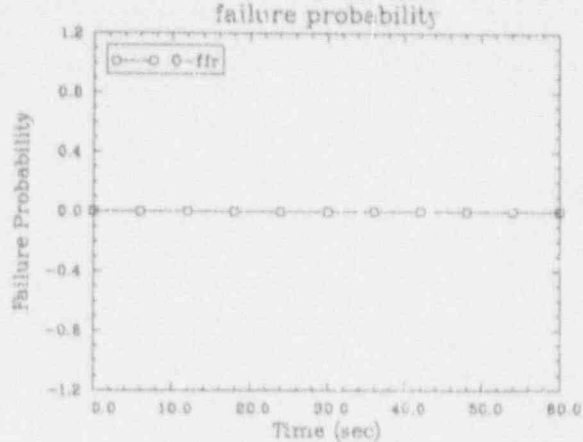

SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32 W/ECCS
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK SMBRK 35 GWD/MTU PIN--PF 2.32 W/ECCS
oxide thickness
*10^-3
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

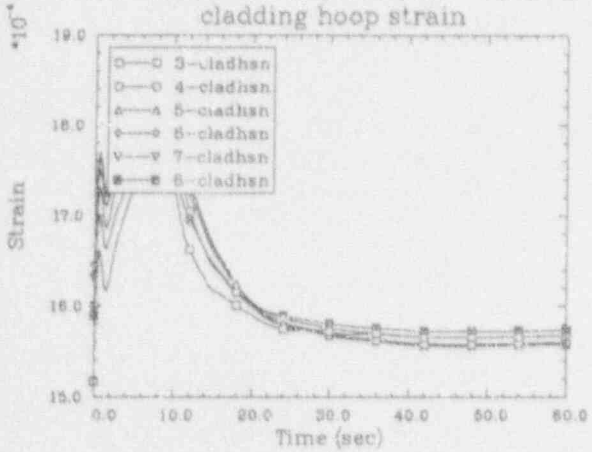
SEABROOK SMBRK 20 GWD/MTU PIN--PF 2.32 W/ECCS
internal pin pressure



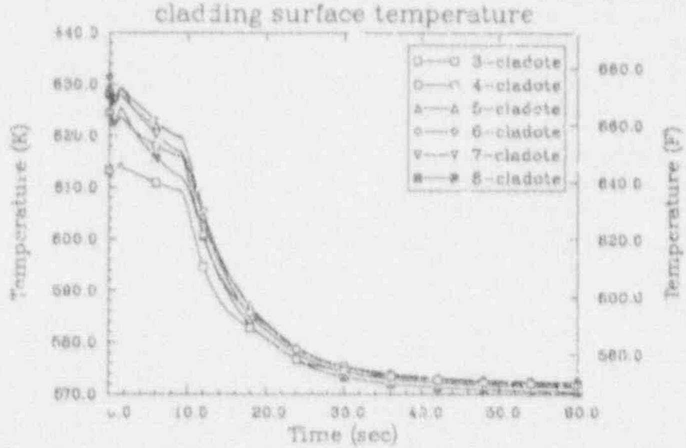
SEABROOK SMBRK 20 GWD/MTU PIN--PF 2.32 W/ECCS
failure probability



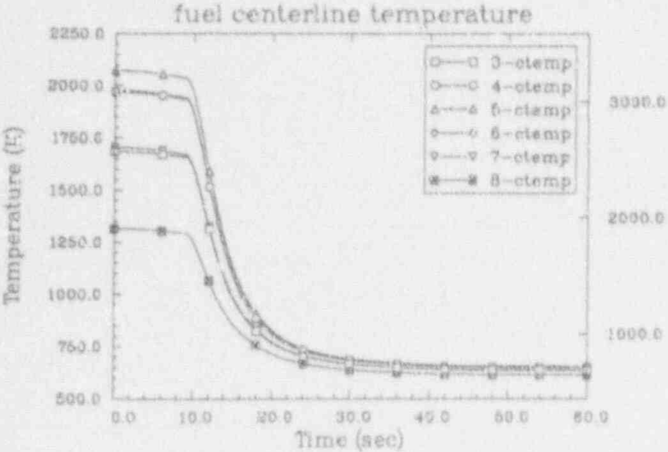
SEABROOK SMBRK 20 GWD/MTU PIN--PF 2.32 W/ECCS
cladding hoop strain



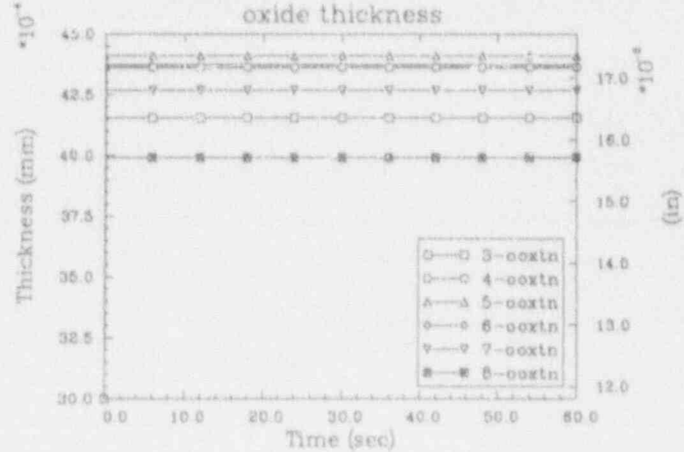
SEABROOK SMBRK 20 GWD/MTU PIN--PF 2.32 W/ECCS
cladding surface temperature



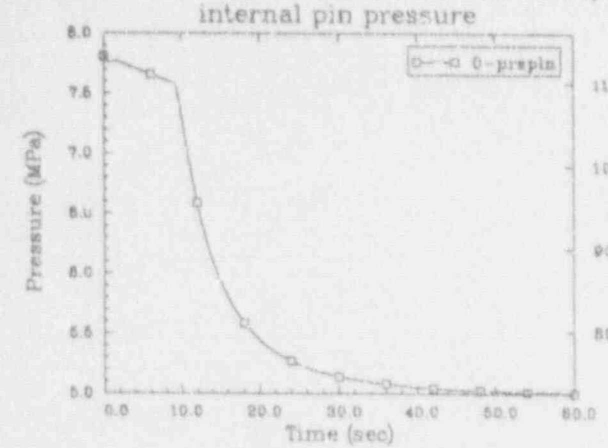
SEABROOK SMBRK 20 GWD/MTU PIN--PF 2.32 W/ECCS
fuel centerline temperature



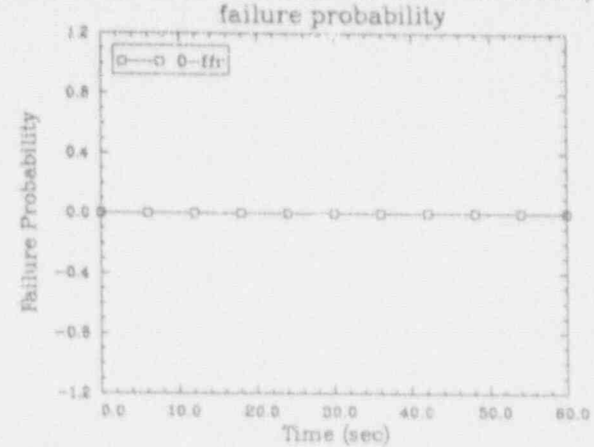
SEABROOK SMBRK 20 GWD/MTU PIN--PF 2.32 W/ECCS
oxide thickness



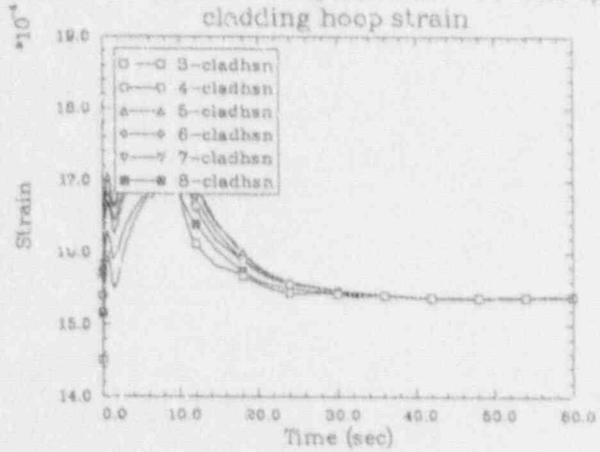
SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32 W/ECCS
internal pin pressure



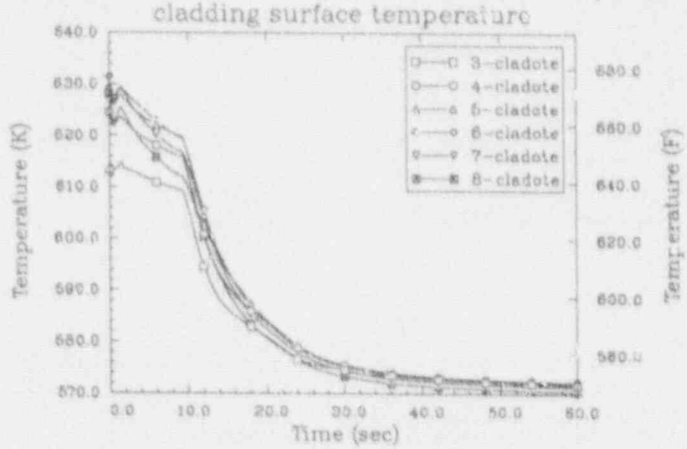
SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32 W/ECCS
failure probability



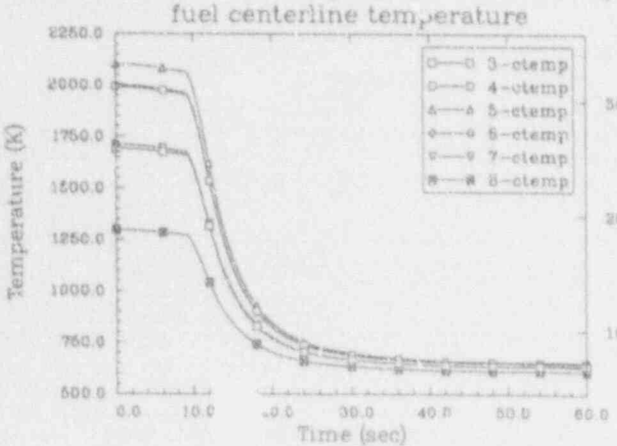
SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32 W/ECCS
cladding hoop strain



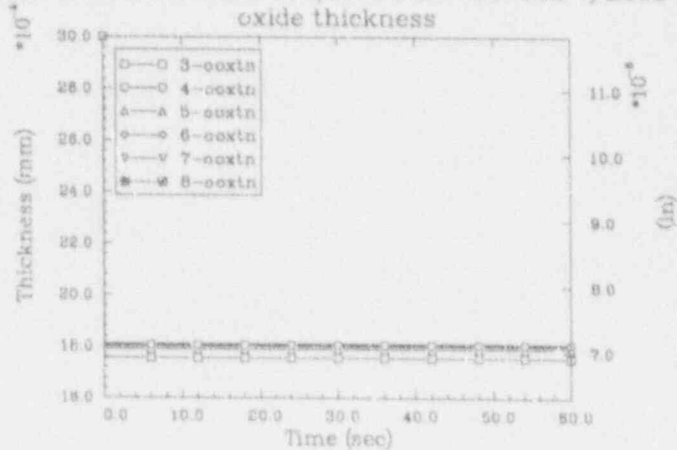
SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32 W/ECCS
cladding surface temperature



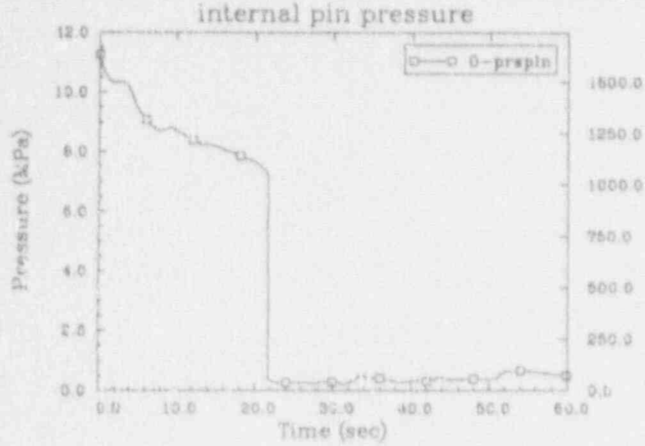
SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32 W/ECCS
fuel centerline temperature



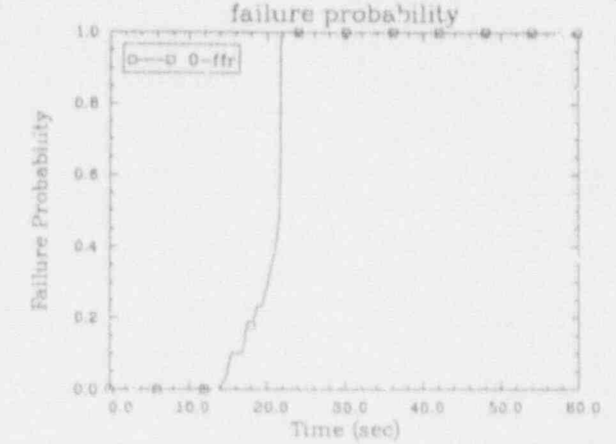
SEABROOK SMBRK 5 GWD/MTU PIN--PF 2.32 W/ECCS
oxide thickness



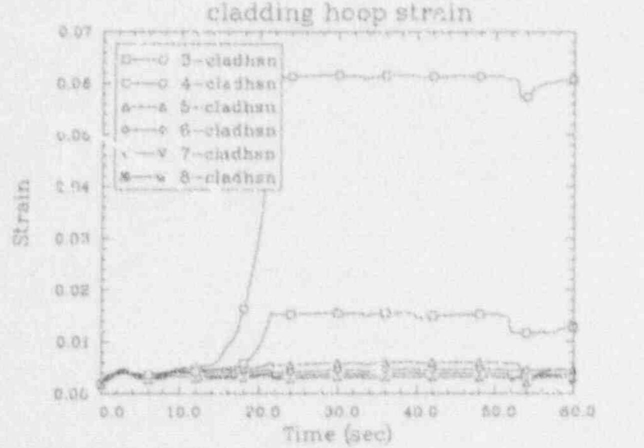
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32 (TRAC)
internal pin pressure



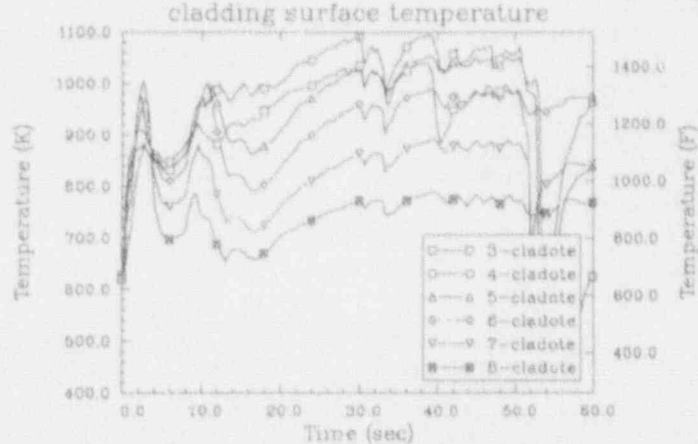
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32 (TRAC)
failure probability



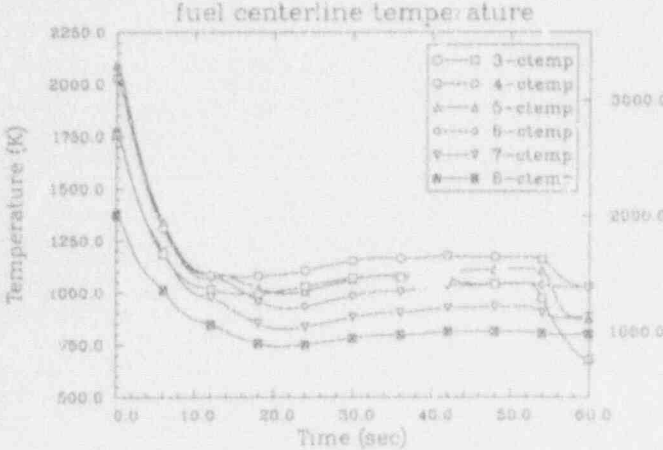
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32 (TRAC)
cladding hoop strain



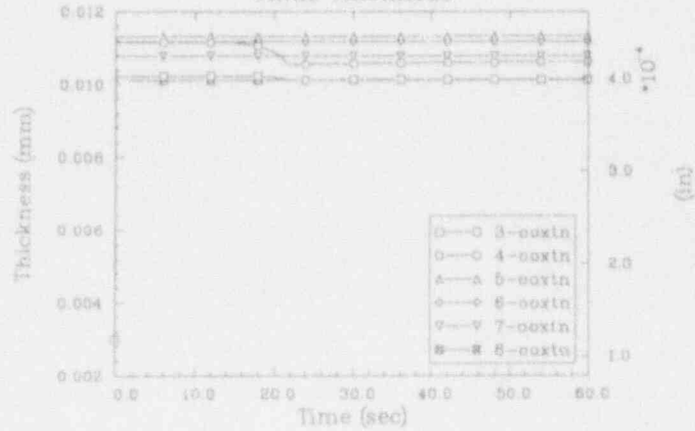
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32 (TRAC)
cladding surface temperature

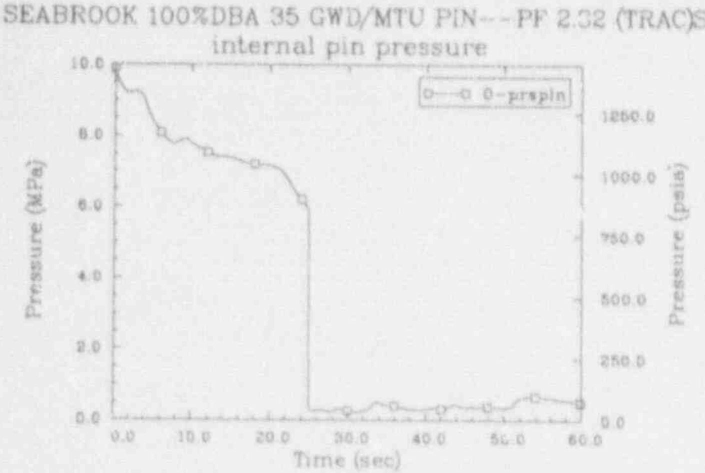


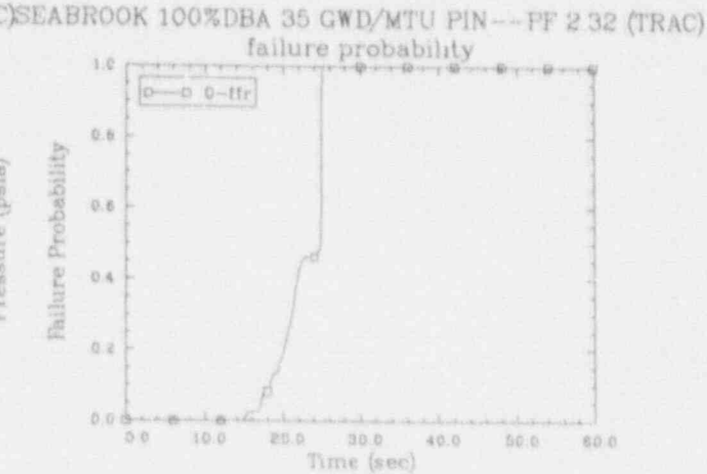
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32 (TRAC)
fuel centerline temperature

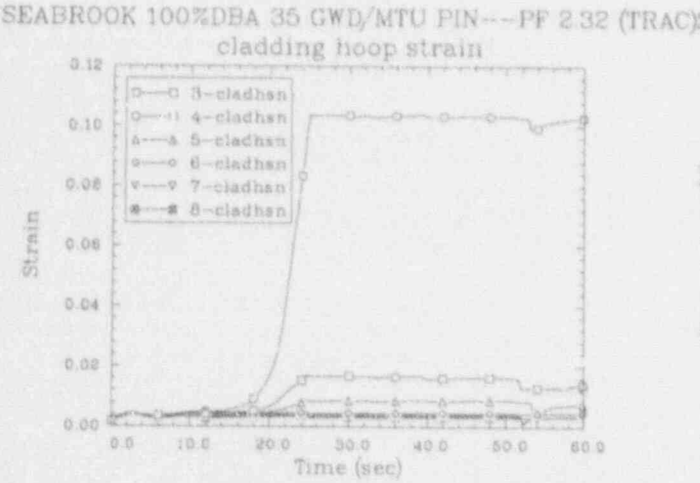


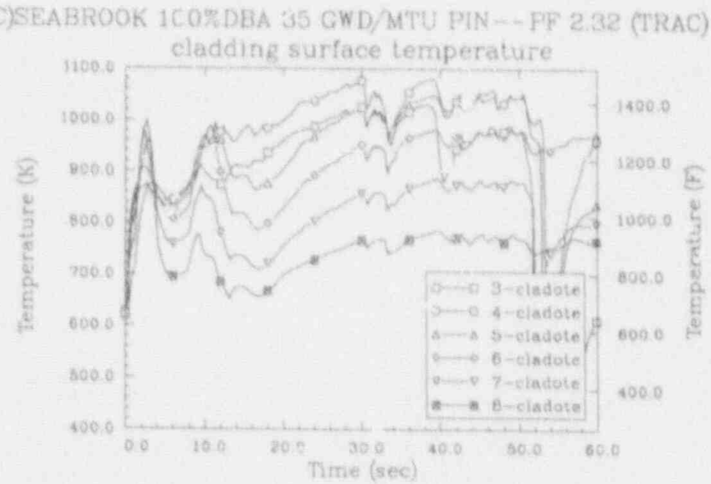
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.32 (TRAC)
oxide thickness

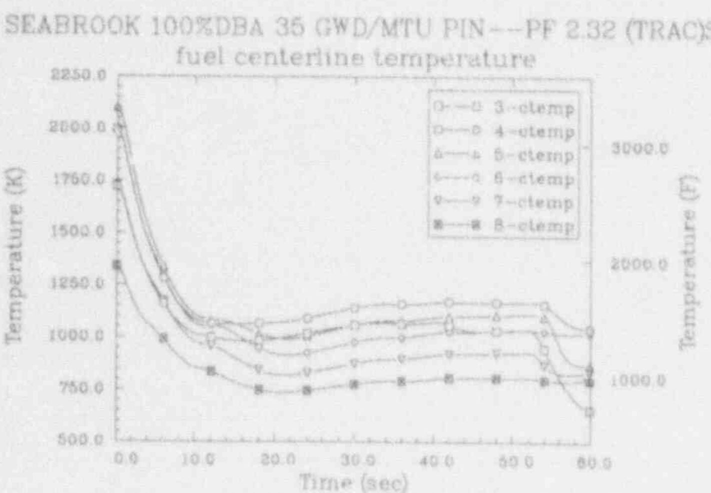


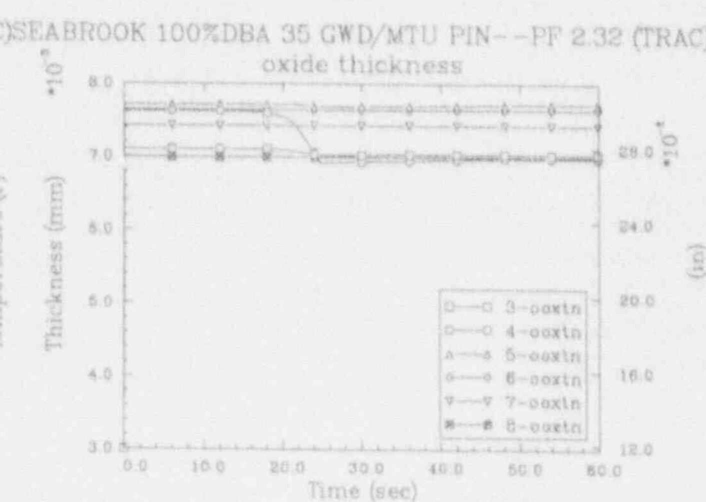

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32 (TRAC)
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)
0-prspin


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32 (TRAC)
failure probability
Failure Probability
Time (sec)
0-ffr

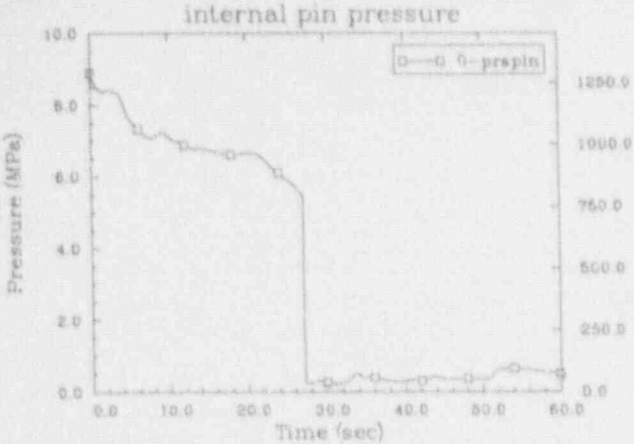

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32 (TRAC)
cladding hoop strain
Strain
Time (sec)
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32 (TRAC)
cladding surface temperature
Temperature (K)
Temperature (F)
Time (sec)
3-cladotc
4-cladotc
5-cladotc
6-cladotc
7-cladotc
8-cladotc

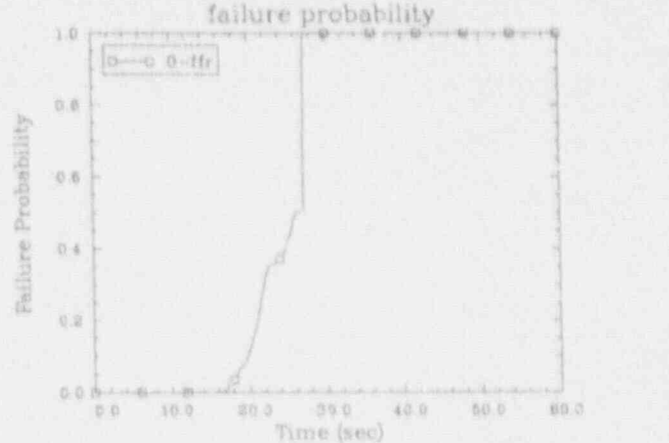

SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32 (TRAC)
fuel centerline temperature
Temperature (K)
Temperature (F)
Time (sec)
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp


SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.32 (TRAC)
oxide thickness
Thickness (mm)
(in)
Time (sec)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn

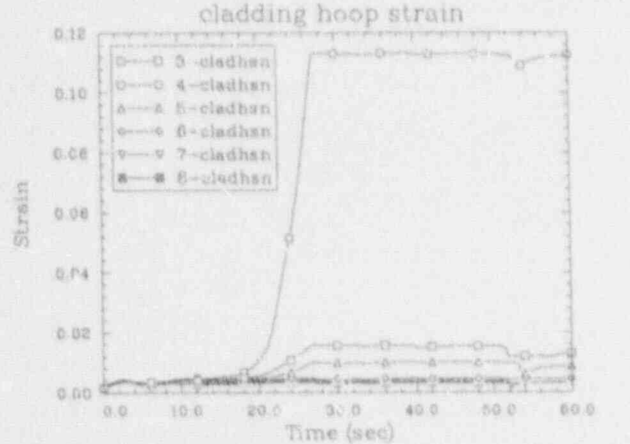
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32 (TRAC)
internal pin pressure



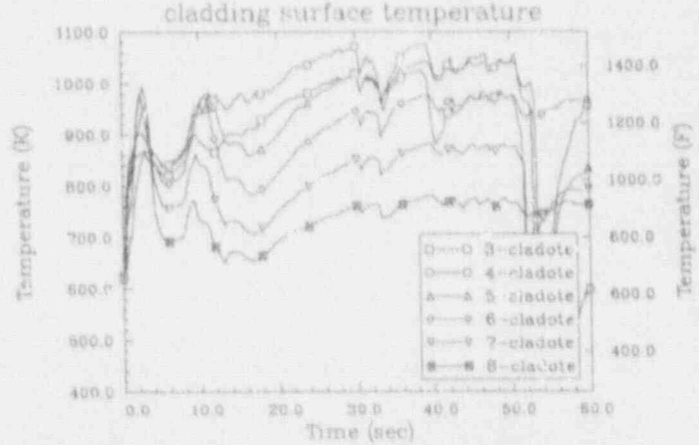
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32 (TRAC)
failure probability



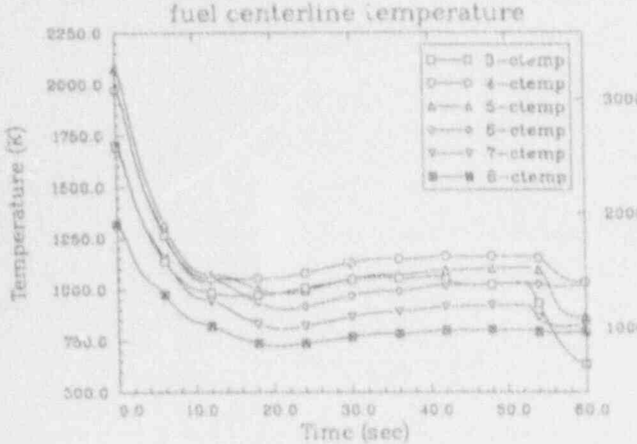
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32 (TRAC)
cladding hoop strain



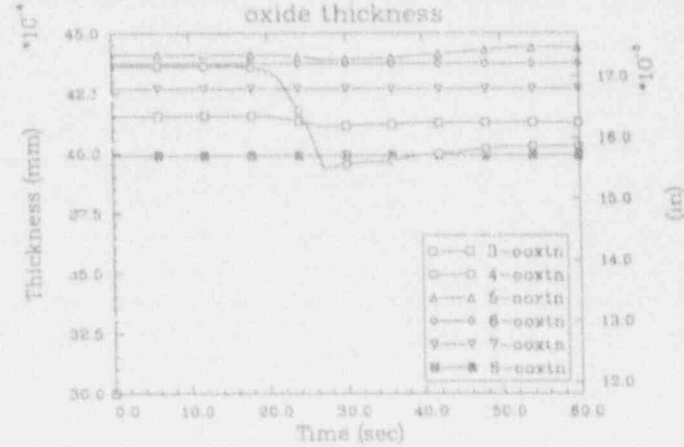
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32 (TRAC)
cladding surface temperature

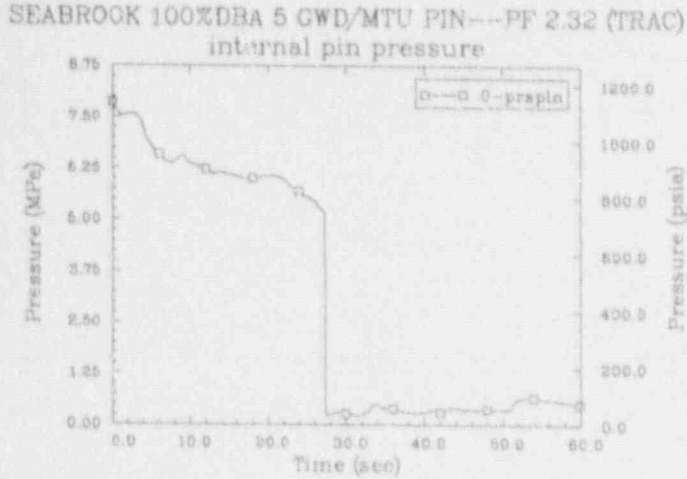


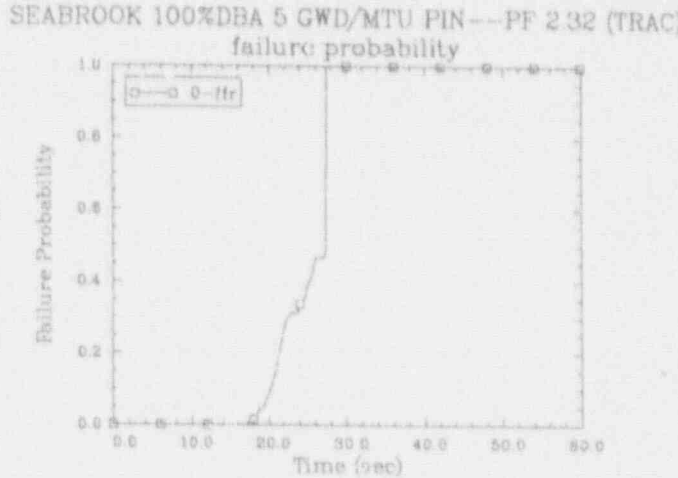
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32 (TRAC)
fuel centerline temperature

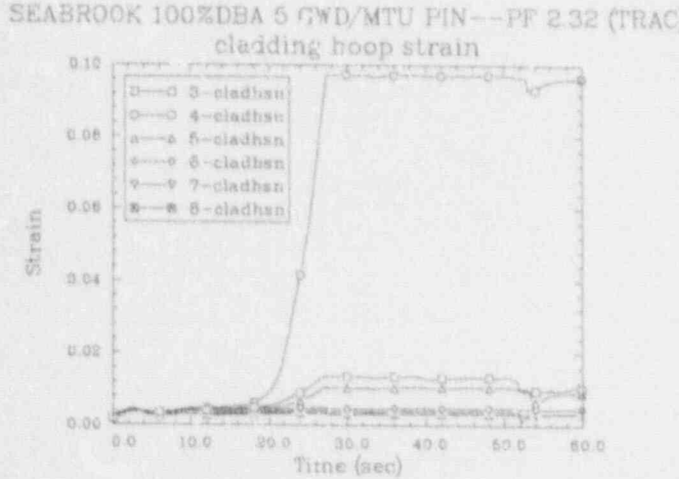


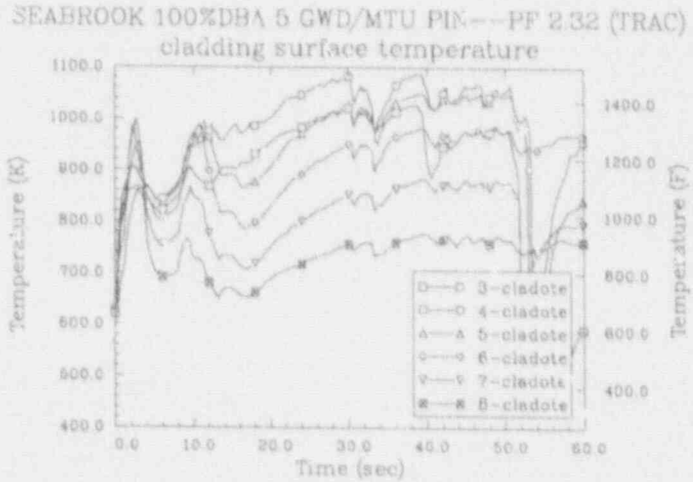
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.32 (TRAC)
oxide thickness

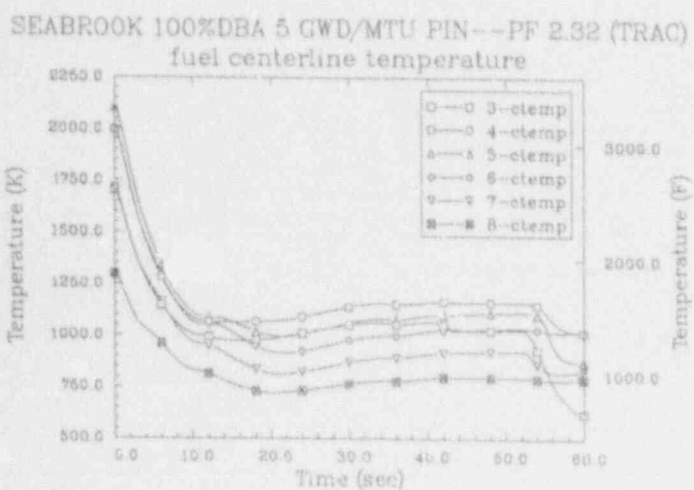


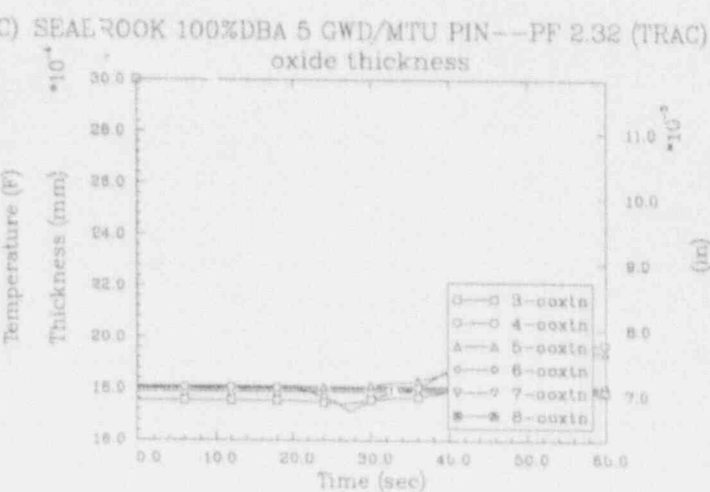

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32 (TRAC)
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32 (TRAC)
failure probability
0-ffr
Failure Probability
Time (sec)

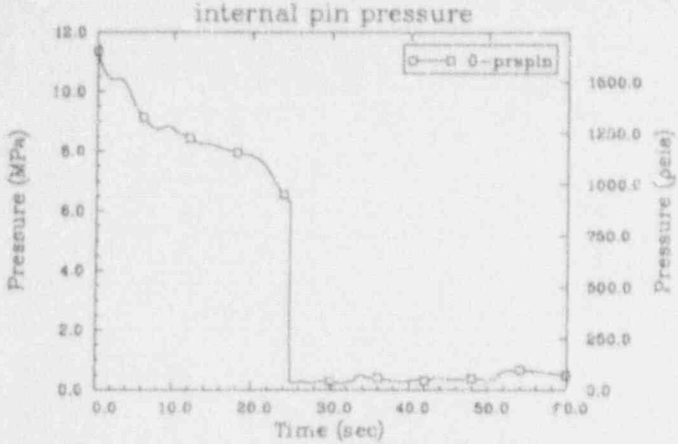

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32 (TRAC)
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32 (TRAC)
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

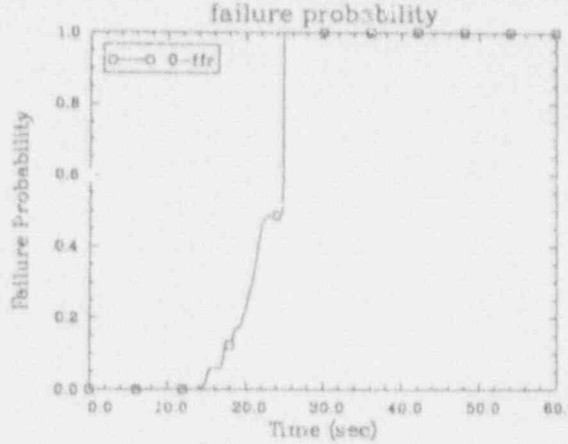

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32 (TRAC)
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.32 (TRAC)
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

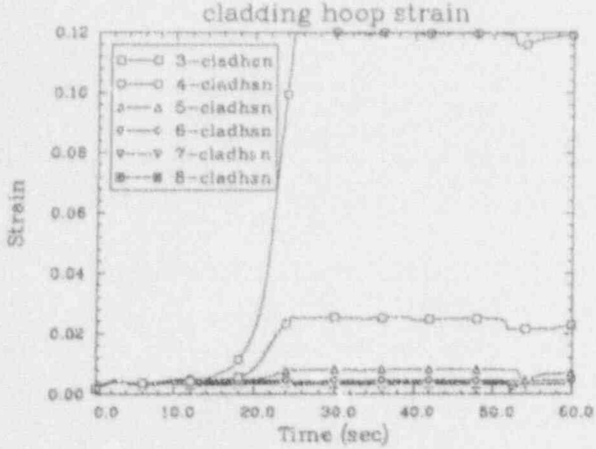
SEABROOK 100%DBA 50 GWD/MTU PIN---PF 2.2 (TRAC)
internal pin pressure



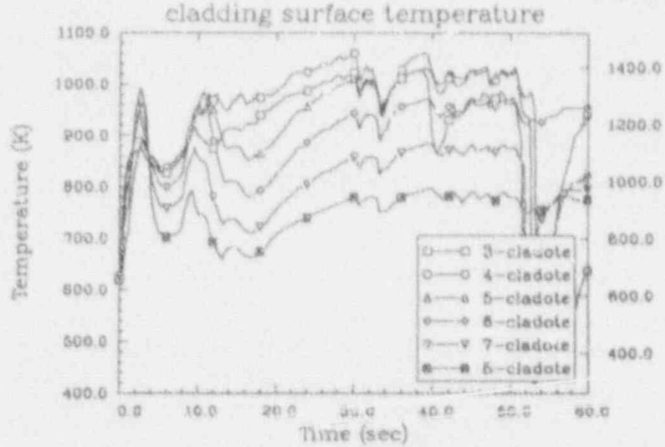
SEABROOK 100%DBA 50 GWD/MTU PIN---PF 2.2 (TRAC)
failure probability



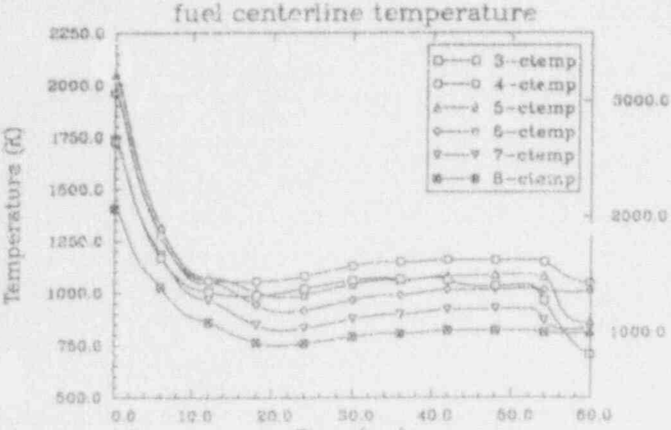
SEABROOK 100%DBA 50 GWD/MTU PIN---PF 2.2 (TRAC)
cladding hoop strain



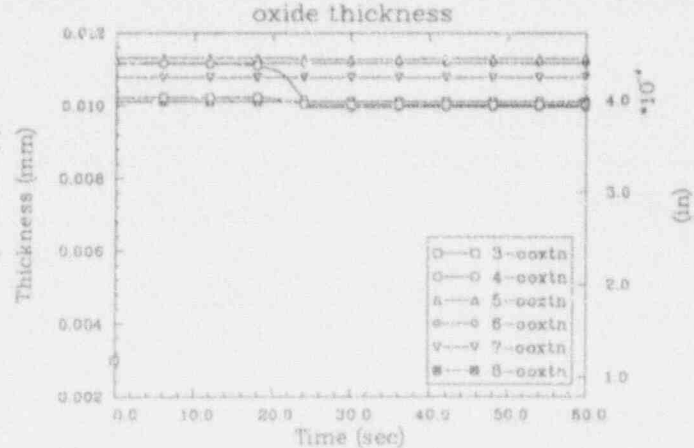
SEABROOK 100%DBA 50 GWD/MTU PIN---PF 2.2 (TRAC)
cladding surface temperature



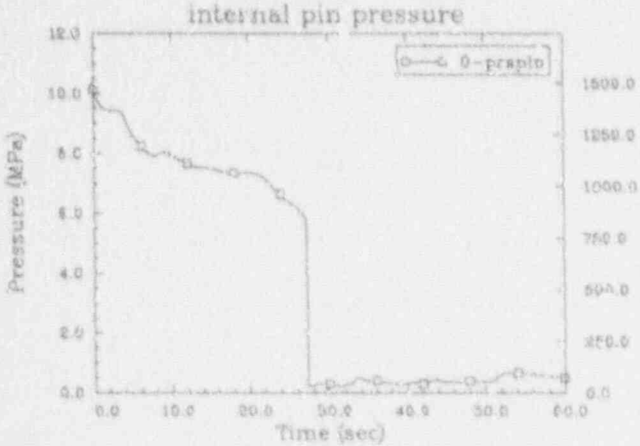
SEABROOK 100%DBA 50 GWD/MTU PIN---PF 2.2 (TRAC)
fuel centerline temperature



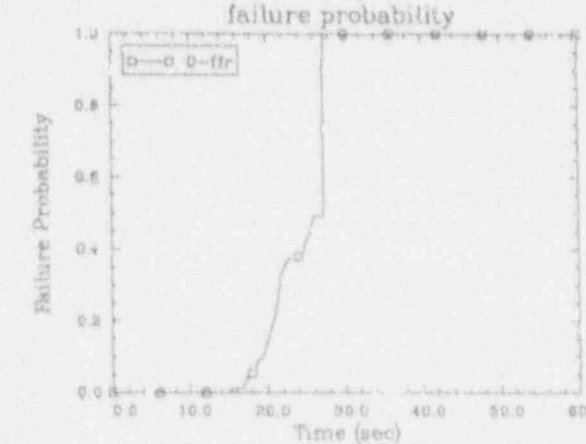
SEABROOK 100%DBA 50 GWD/MTU PIN---PF 2.2 (TRAC)
oxide thickness



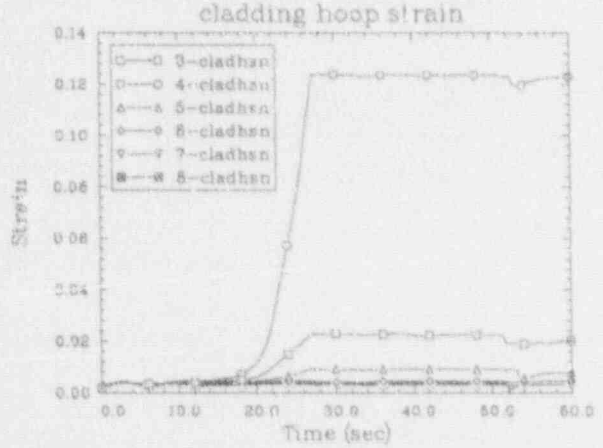
SEABROOK 100%DBA 35 GWD/MTU PIN---PF 2.2 (TRAC)
internal pin pressure



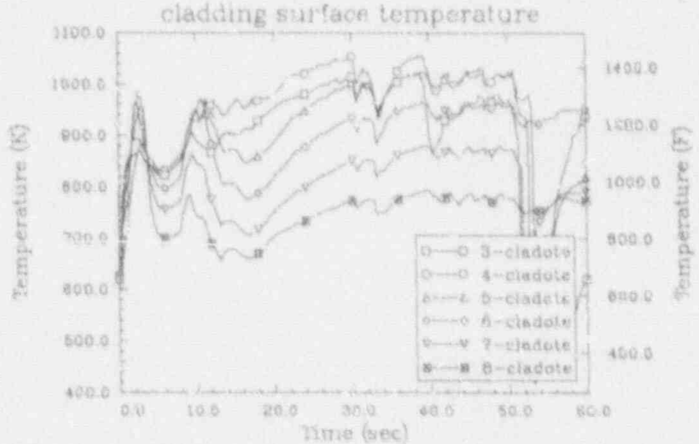
SEABROOK 100%DBA 35 GWD/MTU PIN---PF 2.2 (TRAC)
failure probability



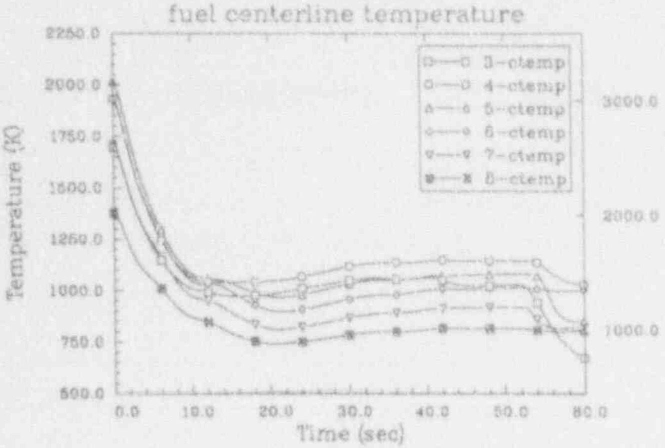
SEABROOK 100%DBA 35 GWD/MTU PIN---PF 2.2 (TRAC)
cladding hoop strain



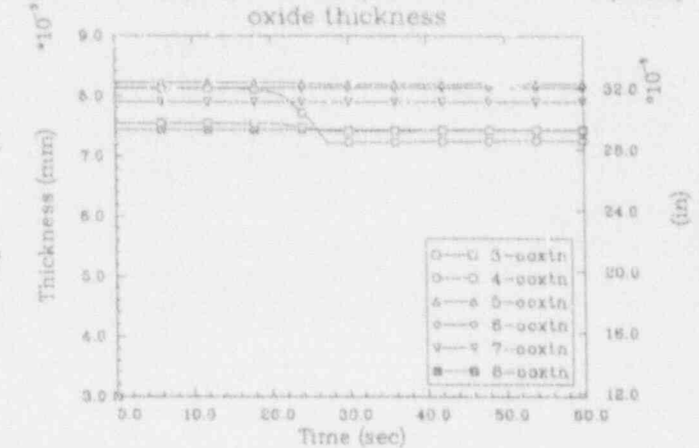
SEABROOK 100%DBA 35 GWD/MTU PIN---PF 2.2 (TRAC)
cladding surface temperature



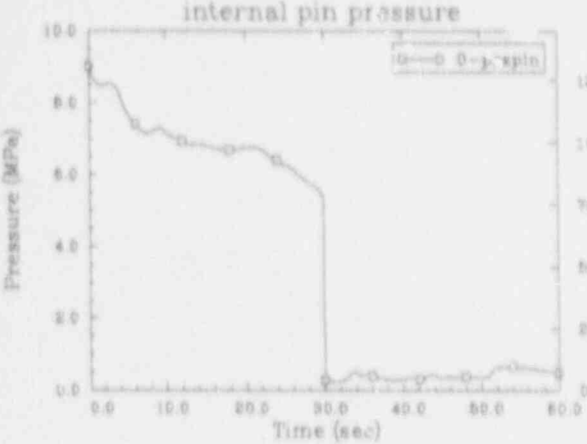
SEABROOK 100%DBA 35 GWD/MTU PIN---PF 2.2 (TRAC)
fuel centerline temperature



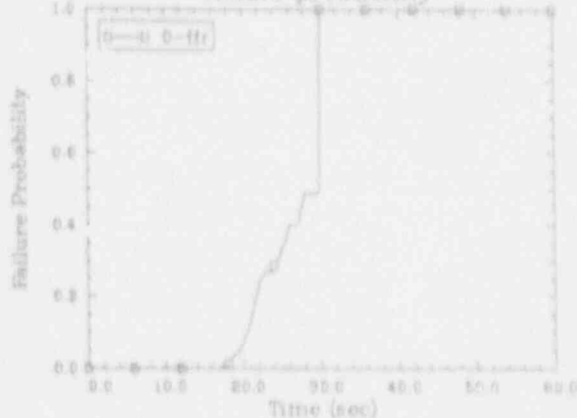
SEABROOK 100%DBA 35 GWD/MTU PIN---PF 2.2 (TRAC)
oxide thickness



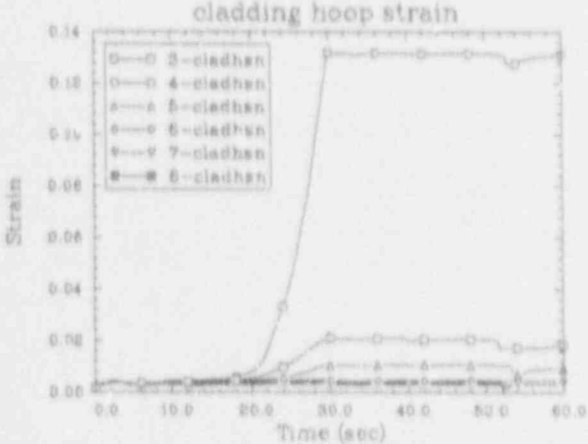
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2 (TRAC)
internal pin pressure



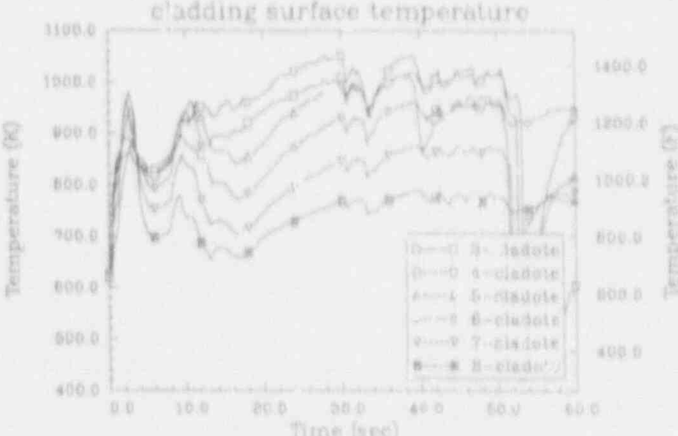
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2 (TRAC)
failure probability



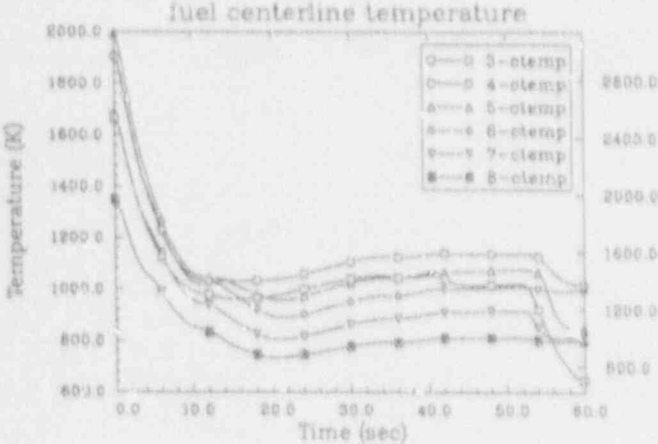
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2 (TRAC)
cladding hoop strain



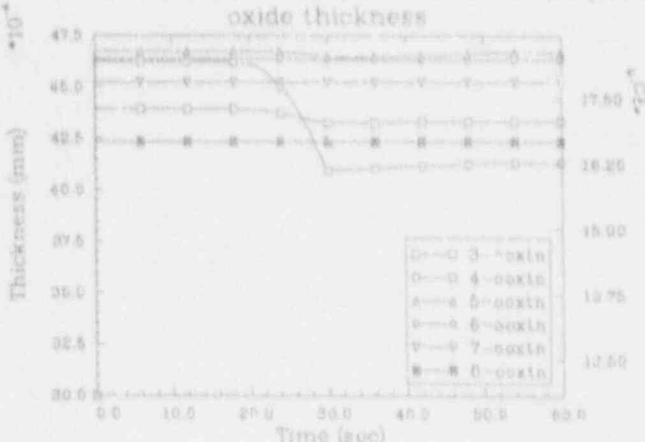
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2 (TRAC)
cladding surface temperature

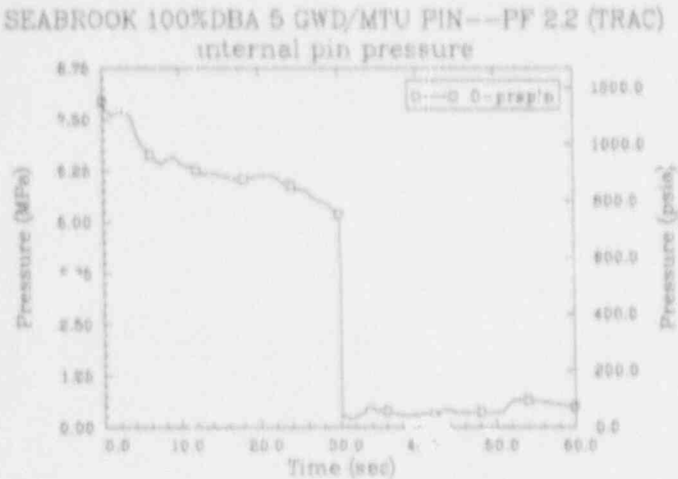


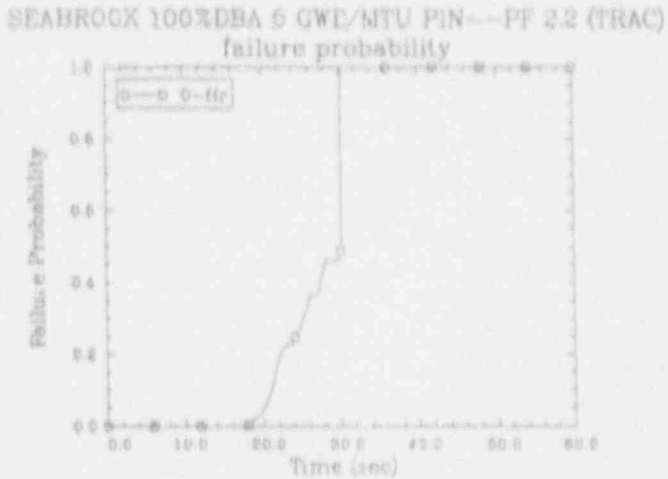
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2 (TRAC)
fuel centerline temperature

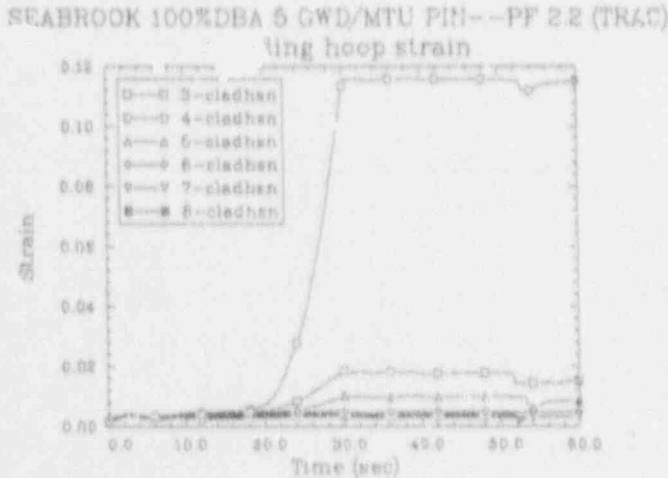


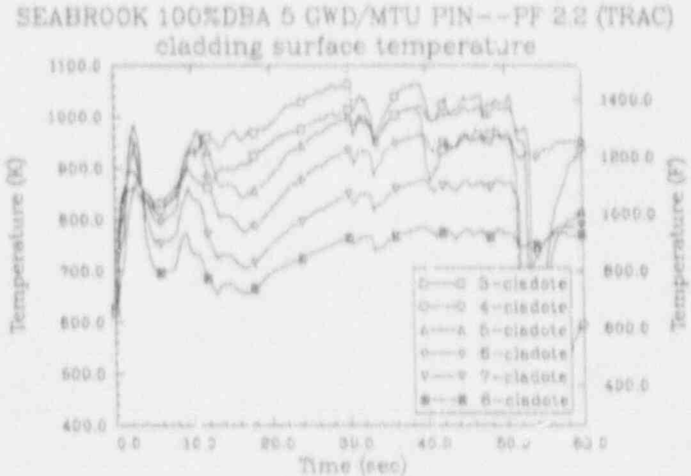
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.2 (TRAC)
oxide thickness

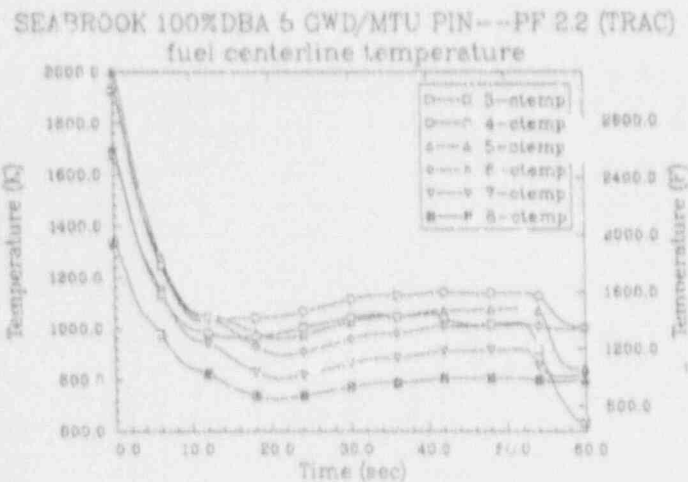


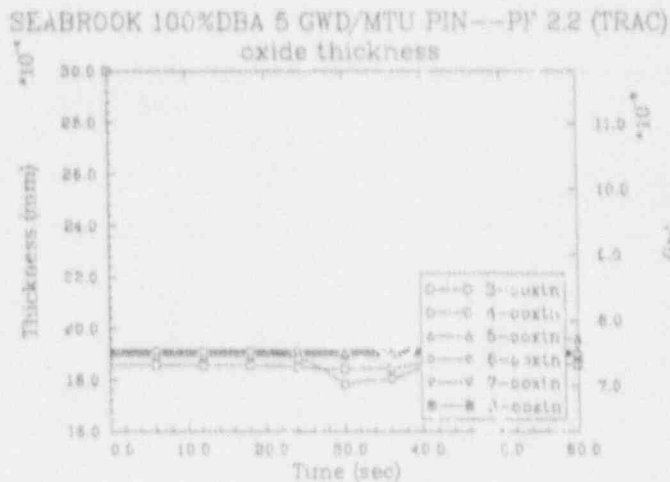

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2 (TRAC)
internal pin pressure
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2 (TRAC)
failure probability
Failure Probability
Time (sec)

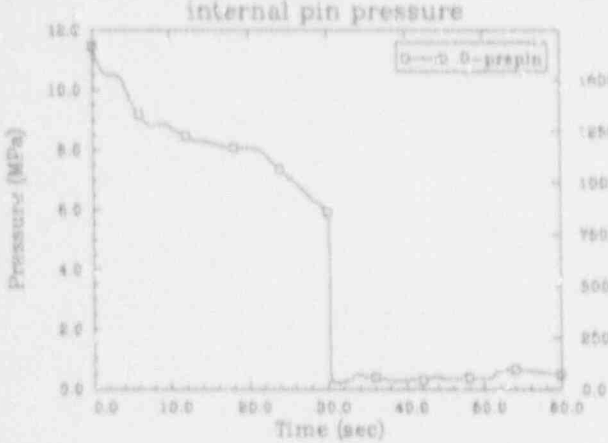

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2 (TRAC)
ling hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2 (TRAC)
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Time (sec)

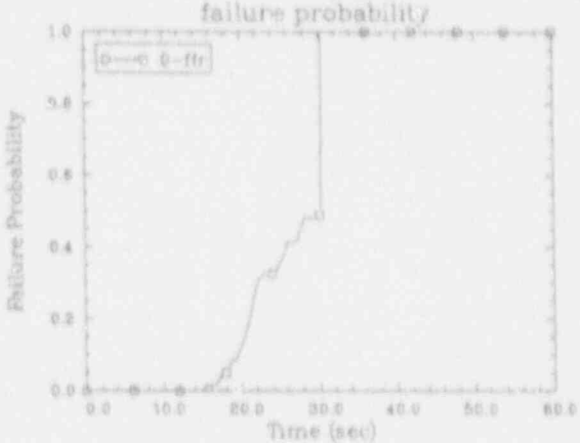

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2 (TRAC)
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.2 (TRAC)
oxide thickness
Thickness (mm)
(in)
7-coxin
Time (sec)

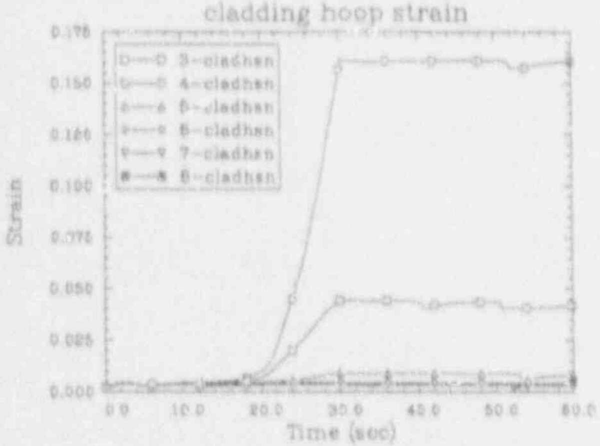
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0 (TRAC)
internal pin pressure



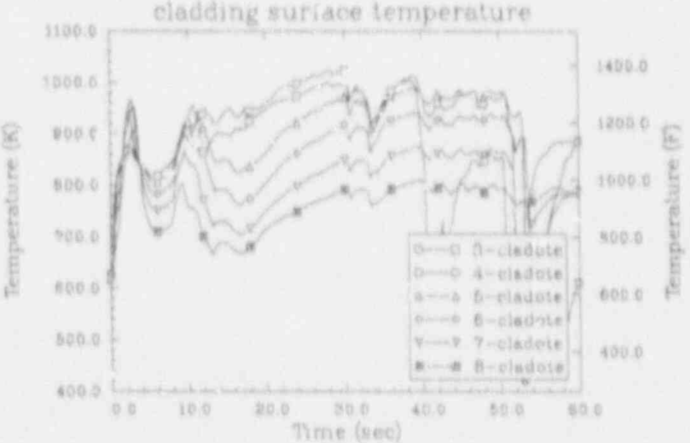
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0 (TRAC)
failure probability



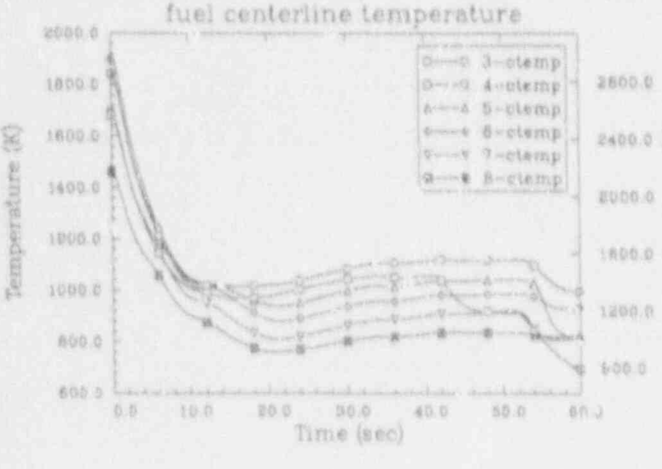
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0 (TRAC)
cladding hoop strain



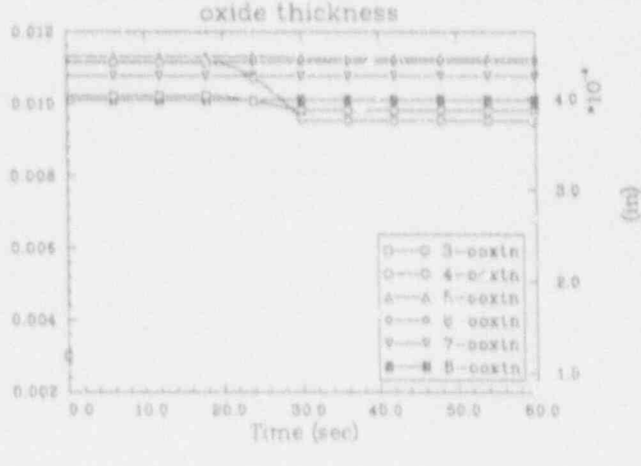
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0 (TRAC)
cladding surface temperature



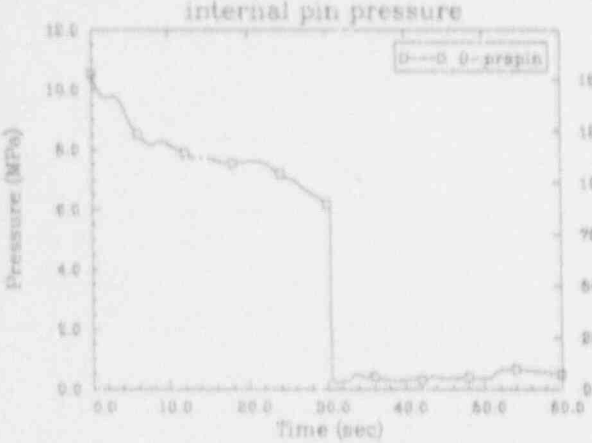
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0 (TRAC)
fuel centerline temperature



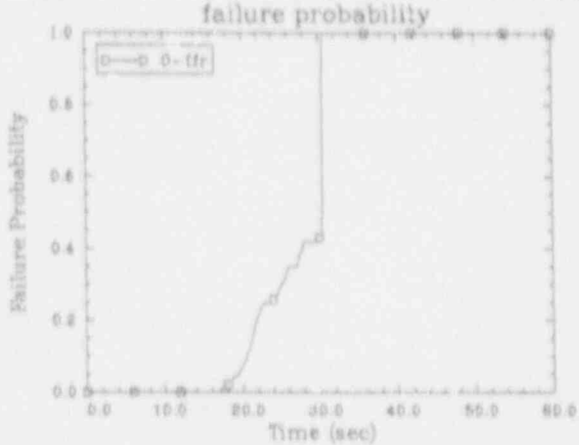
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 2.0 (TRAC)
oxide thickness



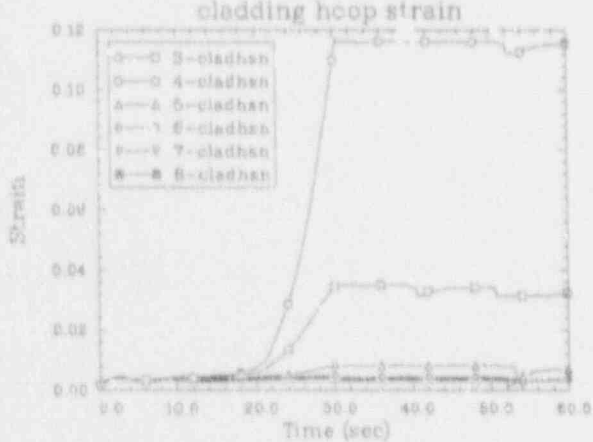
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0 (TRAC)
internal pin pressure



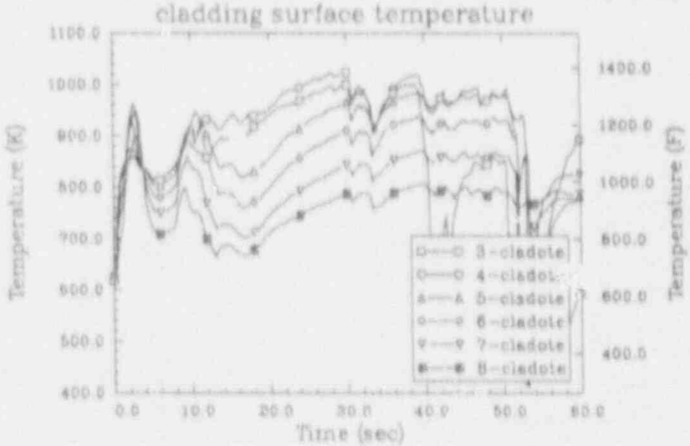
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0 (TRAC)
failure probability



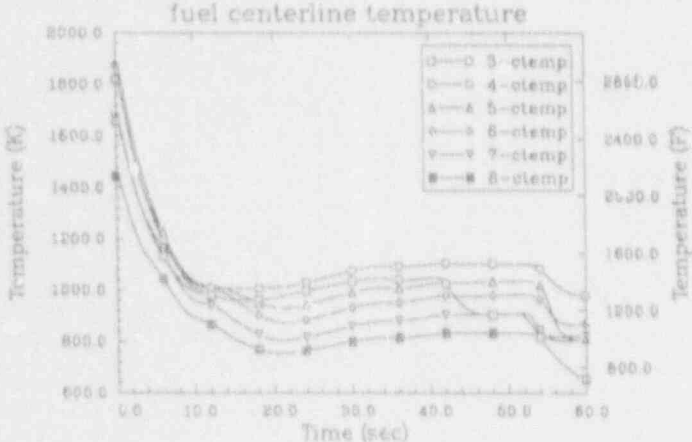
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0 (TRAC)
cladding hoop strain



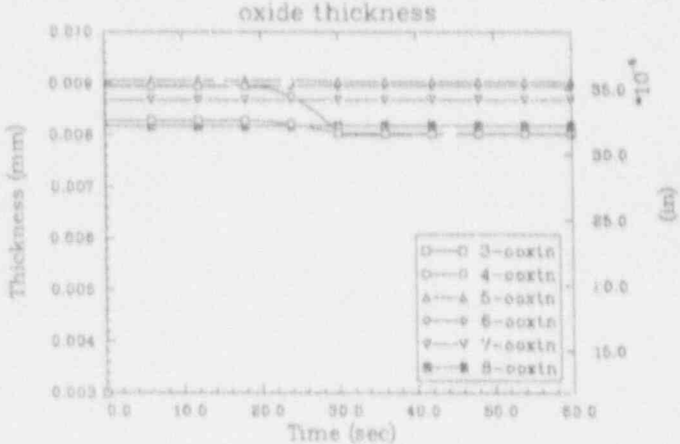
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0 (TRAC)
cladding surface temperature



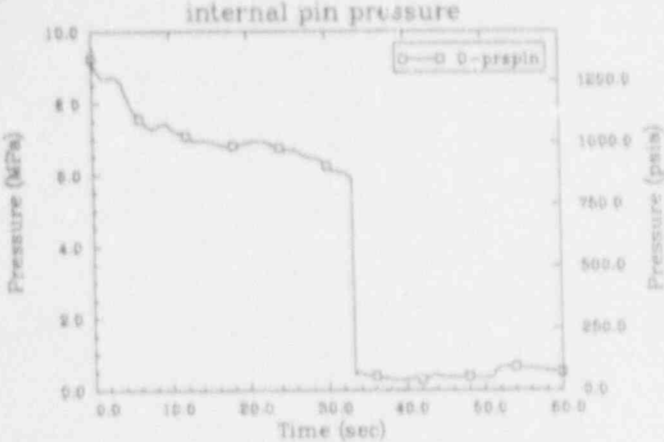
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0 (TRAC)
fuel centerline temperature



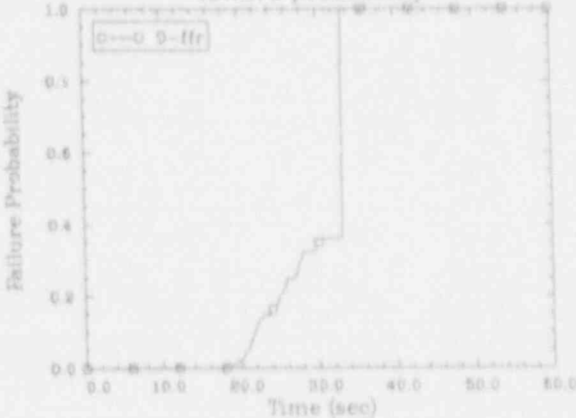
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 2.0 (TRAC)
oxide thickness



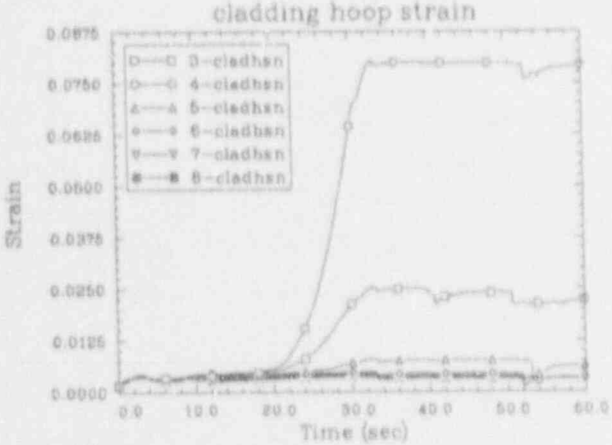
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.0 (TRAC)
internal pin pressure



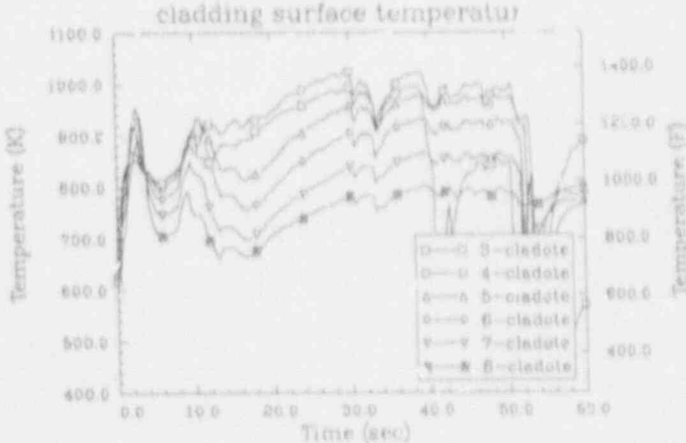
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.0 (TRAC)
failure probability



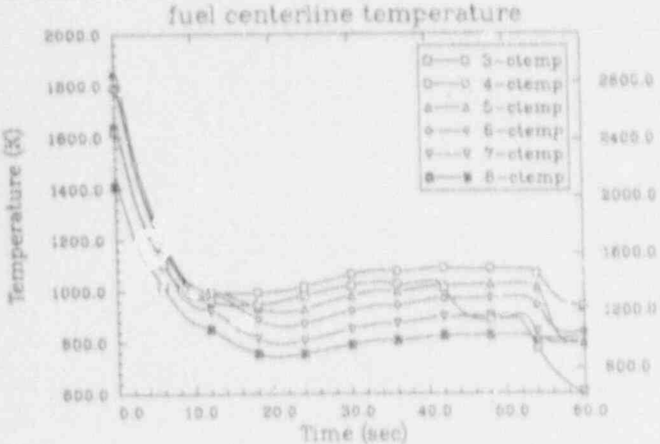
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.0 (TRAC)
cladding hoop strain



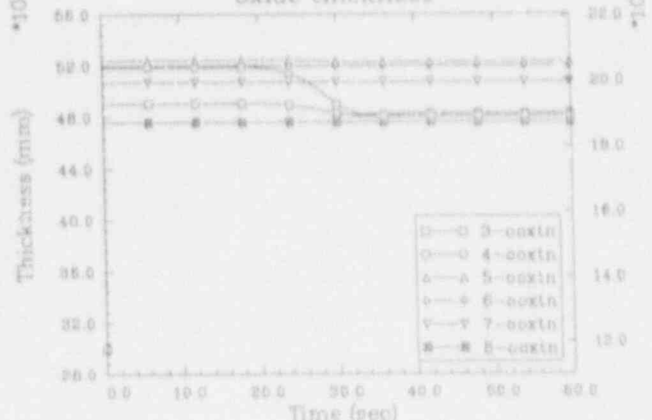
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.0 (TRAC)
cladding surface temperatur

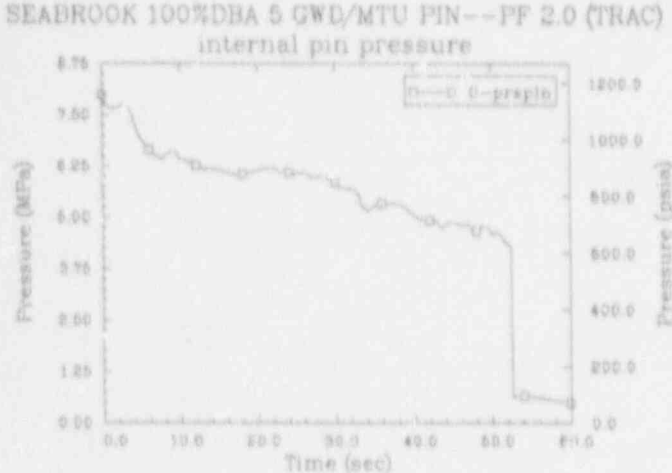


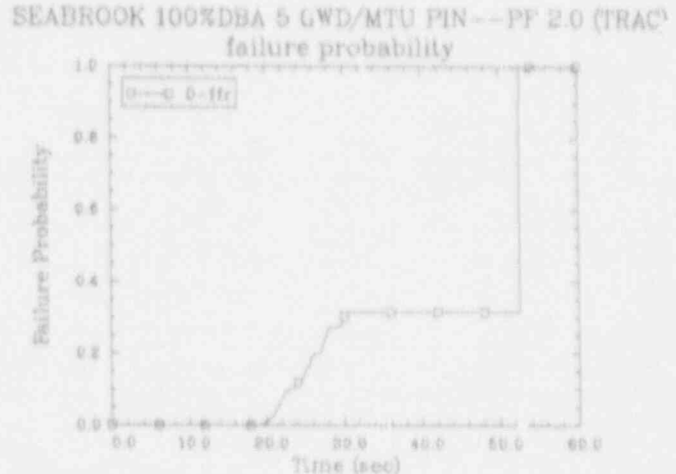
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.0 (TRAC)
fuel centerline temperature

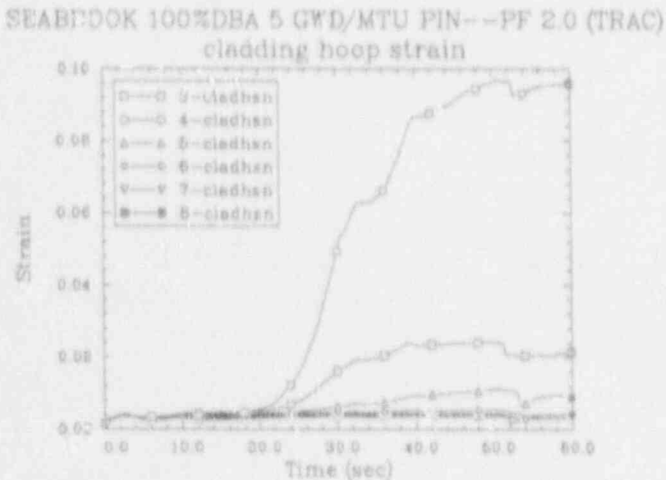


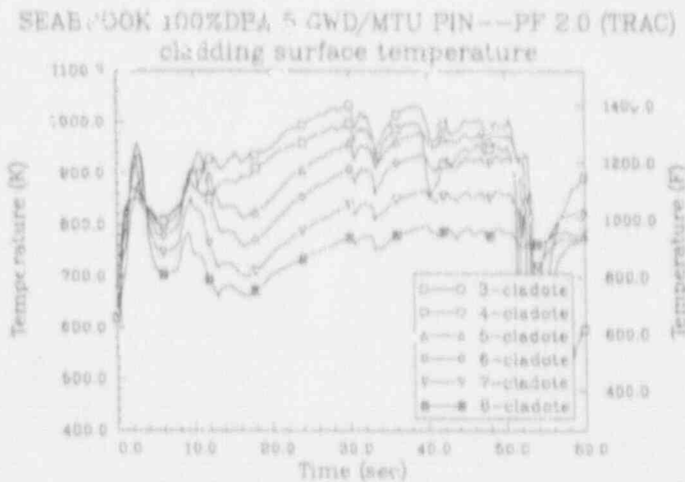
SEABROOK 100%DBA 20 GWD/MTU PIN--PF 2.0 (TRAC)
oxide thickness

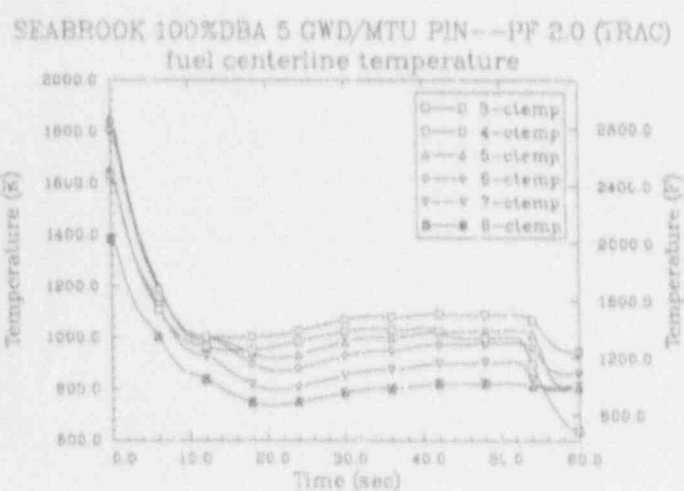


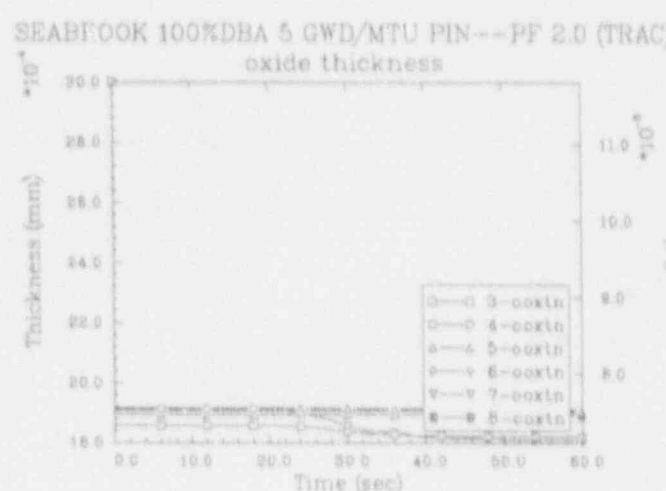

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0 (TRAC)
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0 (TRAC)
failure probability
0-ffr
Failure Probability
Time (sec)

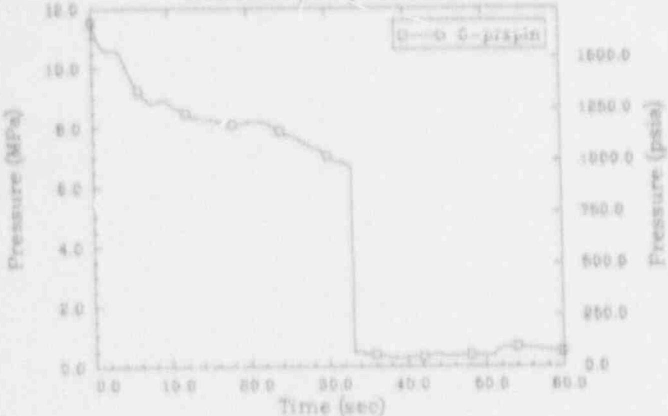

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0 (TRAC)
cladding hoop strain
3-cladhsn
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0 (TRAC)
cladding surface temperature
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Temperature (K)
Temperature (F)
Time (sec)

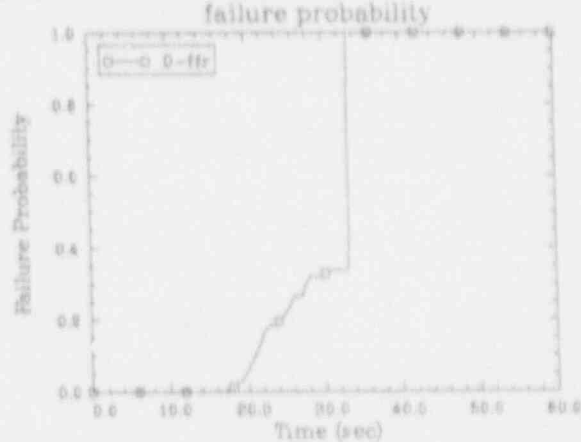

SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0 (TRAC)
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 5 GWD/MTU PIN--PF 2.0 (TRAC)
oxide thickness
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Thickness (mm)
(in)
Time (sec)

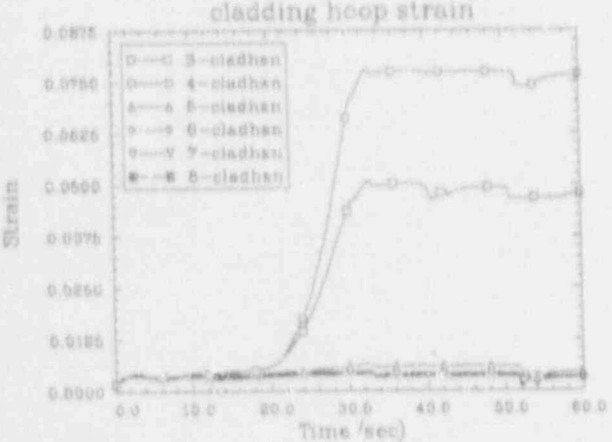
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8 (TRAC)
internal pin pressure



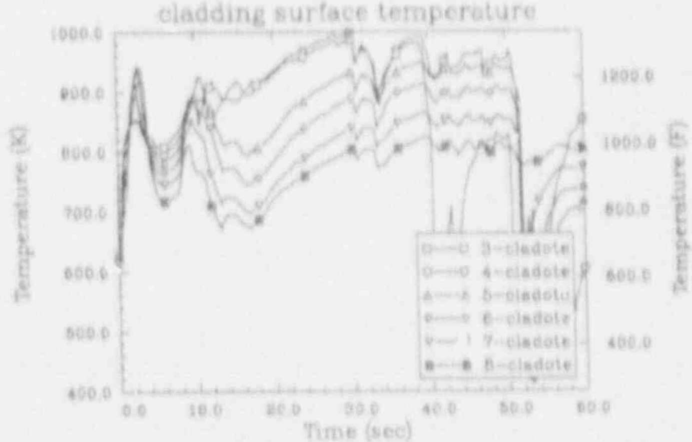
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8 (TRAC)
failure probability



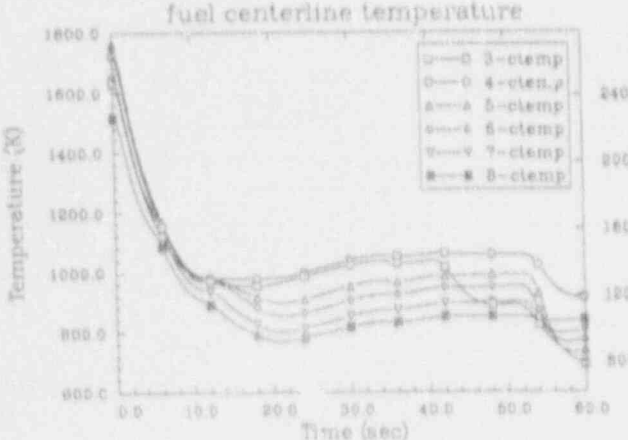
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8 (TRAC)
cladding hoop strain



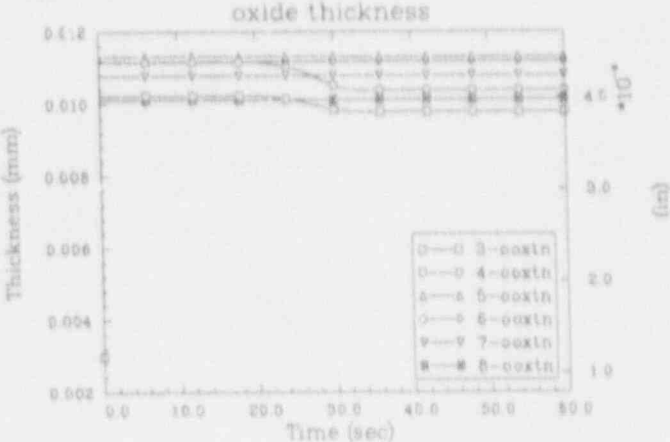
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8 (TRAC)
cladding surface temperature



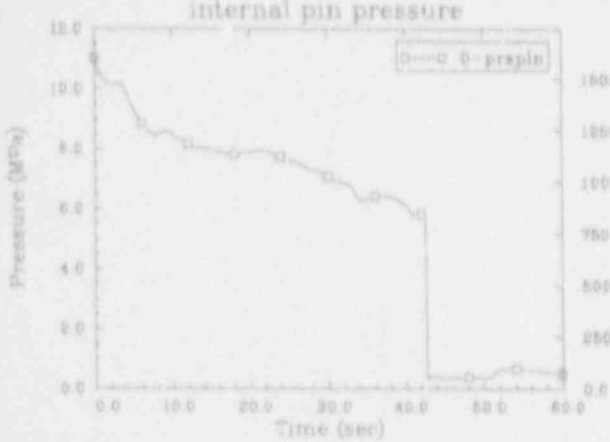
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8 (TRAC)
fuel centerline temperature



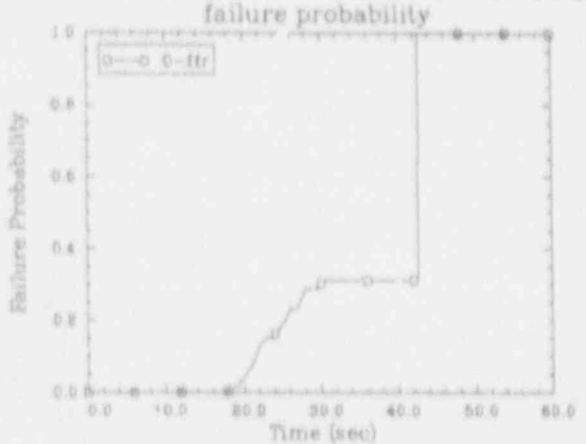
SEABROOK 100%DBA 50 GWD/MTU PIN--PF 1.8 (TRAC)
oxide thickness



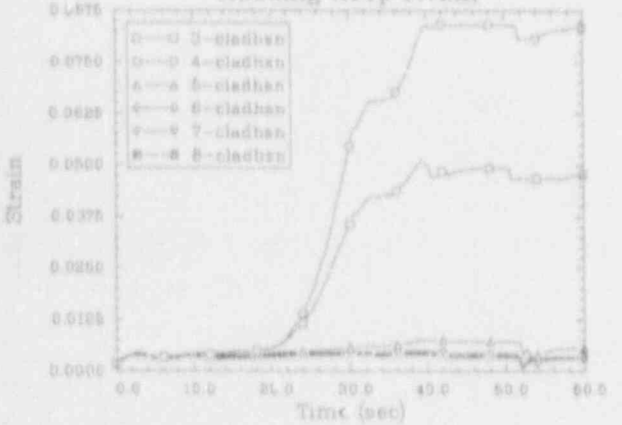
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8 (TRAC)
internal pin pressure



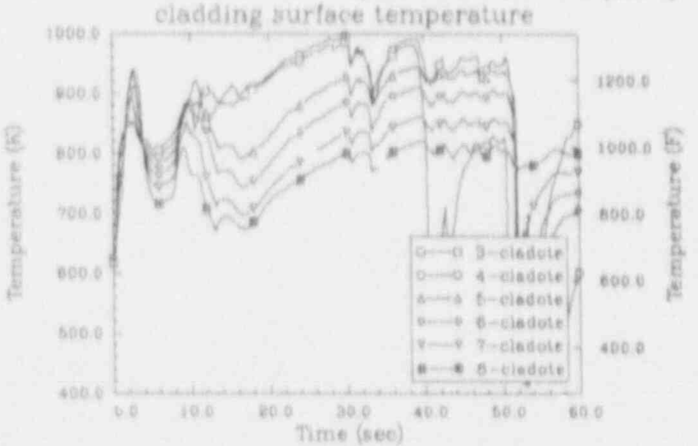
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8 (TRAC)
failure probability



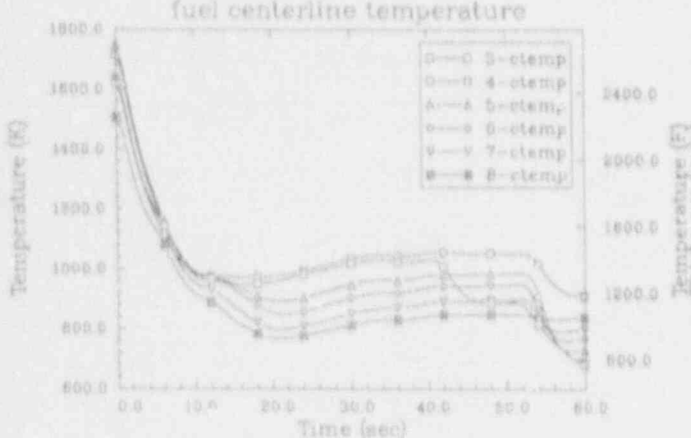
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8 (TRAC)
cladding hoop strain



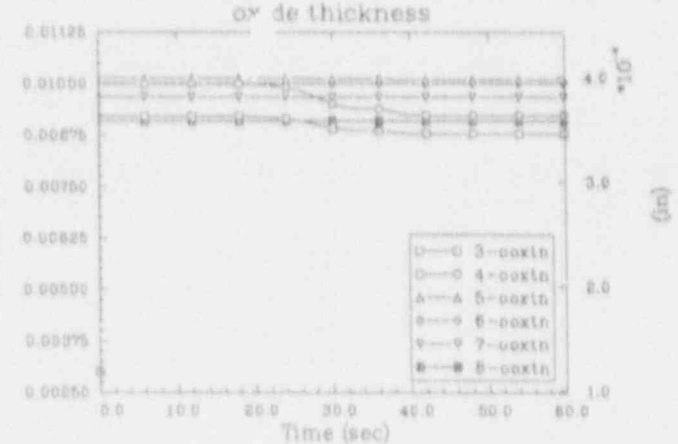
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8 (TRAC)
cladding surface temperature

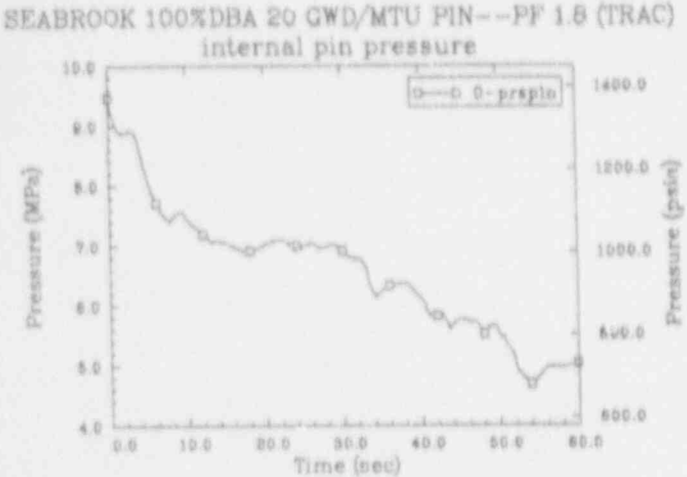


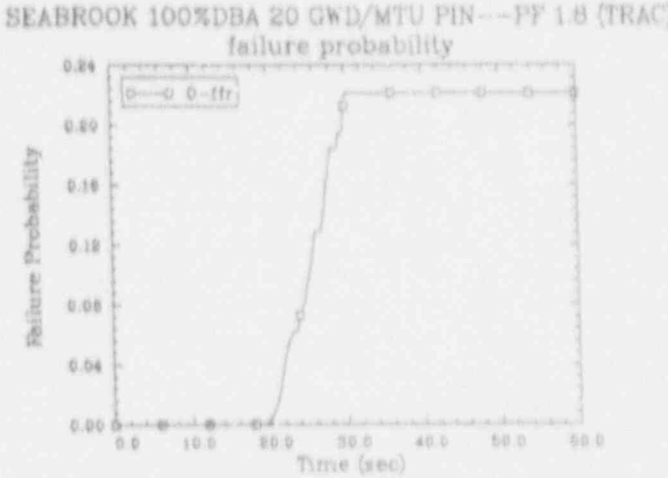
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8 (TRAC)
fuel centerline temperature

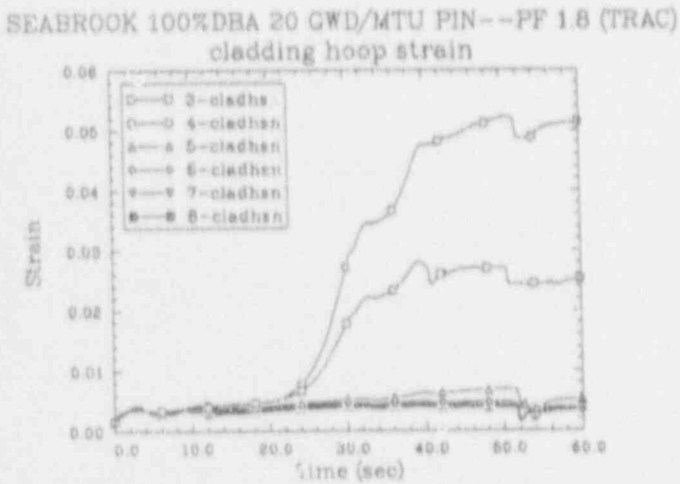


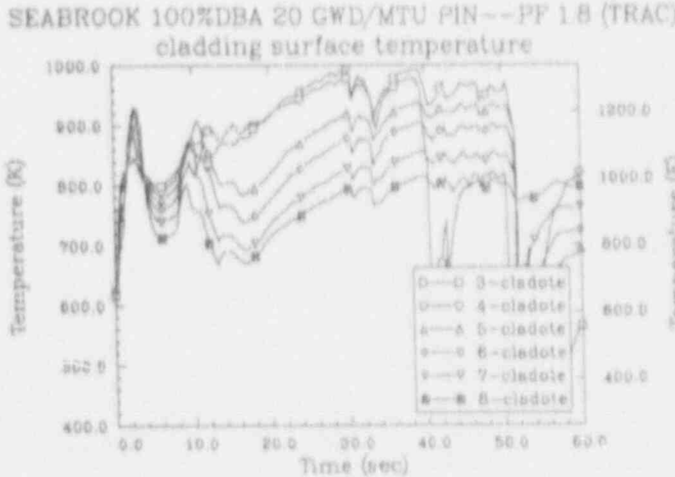
SEABROOK 100%DBA 35 GWD/MTU PIN--PF 1.8 (TRAC)
oxide thickness

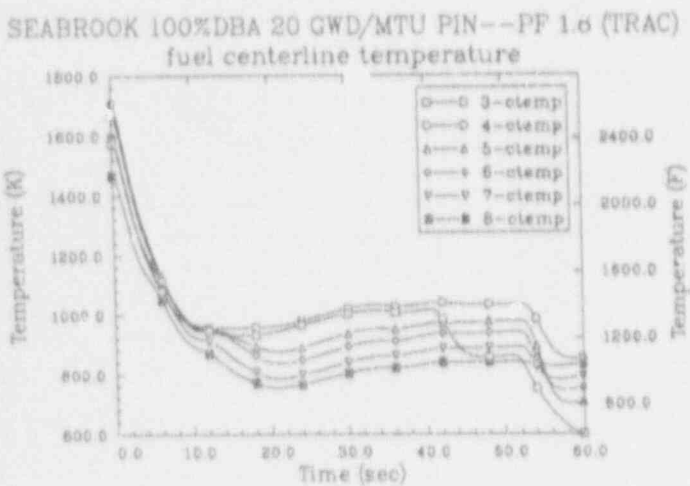


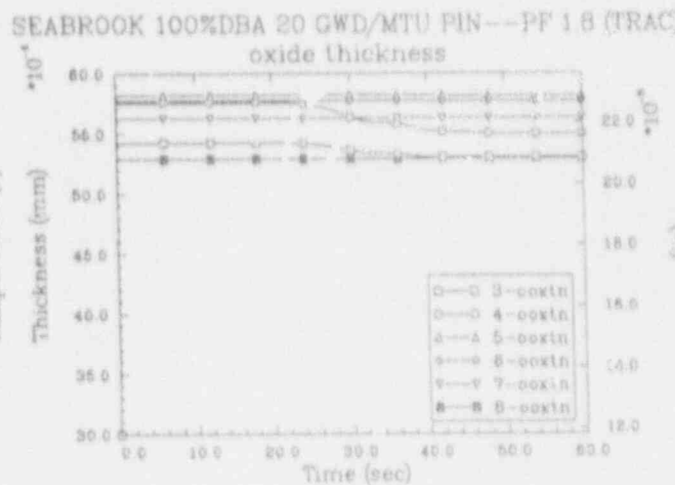

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8 (TRAC)
internal pin pressure
0-prspin
Pressure (MPa)
Pressure (psia)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8 (TRAC)
failure probability
0-ffr
Failure Probability
Time (sec)

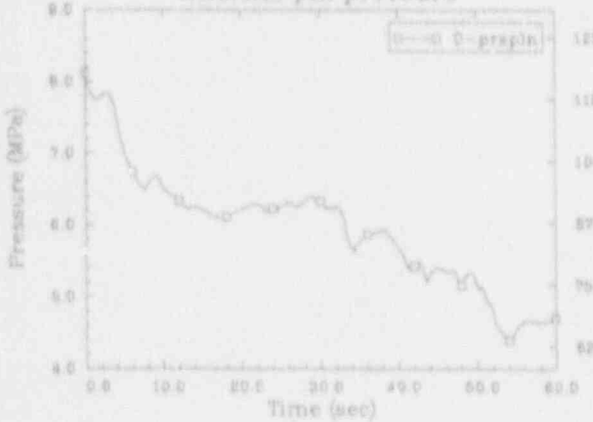

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8 (TRAC)
cladding hoop strain
3-cladhs
4-cladhsn
5-cladhsn
6-cladhsn
7-cladhsn
8-cladhsn
Strain
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8 (TRAC)
cladding surface temperature
Temperature (K)
Temperature (F)
3-cladote
4-cladote
5-cladote
6-cladote
7-cladote
8-cladote
Time (sec)

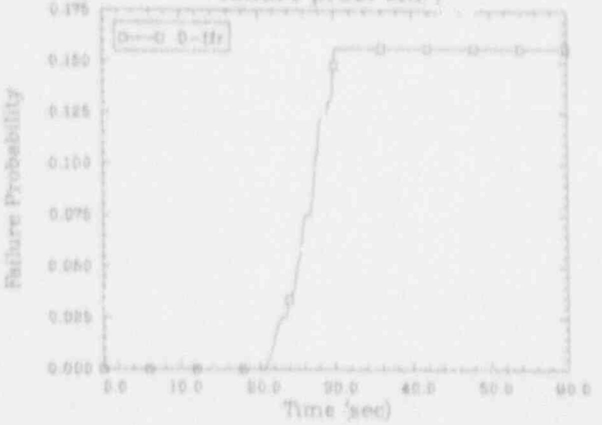

SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8 (TRAC)
fuel centerline temperature
3-ctemp
4-ctemp
5-ctemp
6-ctemp
7-ctemp
8-ctemp
Temperature (K)
Temperature (F)
Time (sec)


SEABROOK 100%DBA 20 GWD/MTU PIN--PF 1.8 (TRAC)
oxide thickness
Thickness (mm)
(in)
3-ooxtn
4-ooxtn
5-ooxtn
6-ooxtn
7-ooxtn
8-ooxtn
Time (sec)

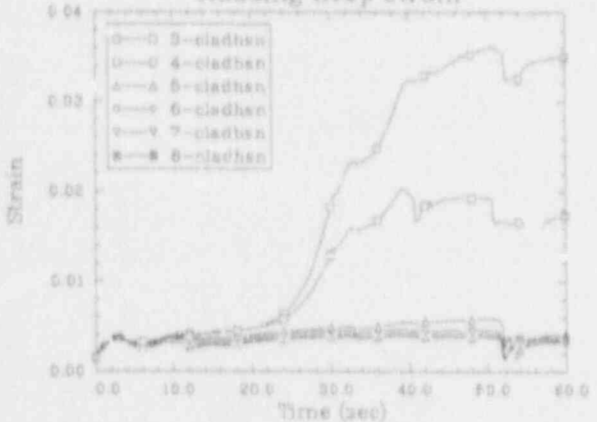
SEABROOK 100%DBA 5 GWD/MTU PIN---PF 1.8 (TRAC)
internal pin pressure



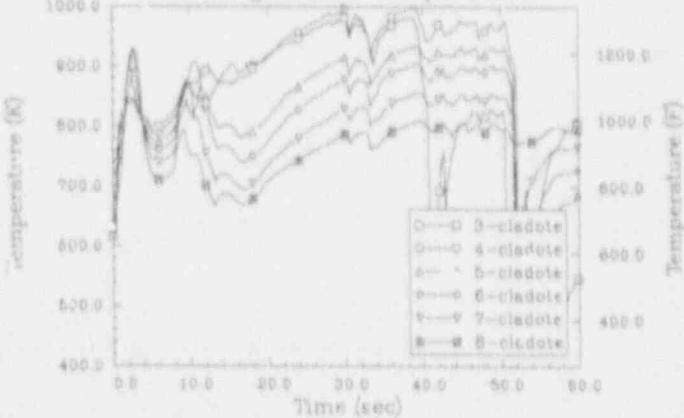
SEABROOK 100%DBA 5 GWD/MTU PIN---PF 1.8 (TRAC)
failure probability



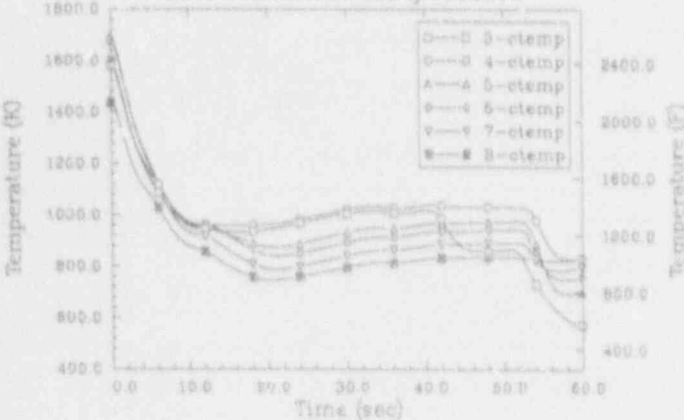
SEABROOK 100%DBA 5 GWD/MTU PIN---PF 1.8 (TRAC)
cladding hoop strain



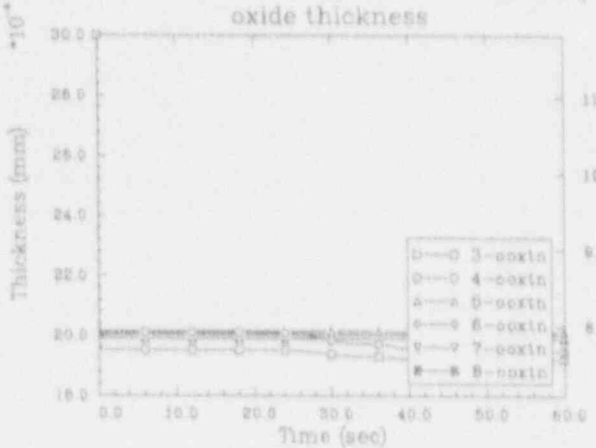
SEABROOK 100%DBA 5 GWD/MTU PIN---PF 1.8 (TRAC)
cladding surface temperature



SEABROOK 100%DBA 5 GWD/MTU PIN---PF 1.8 (TRAC)
fuel centerline temperature



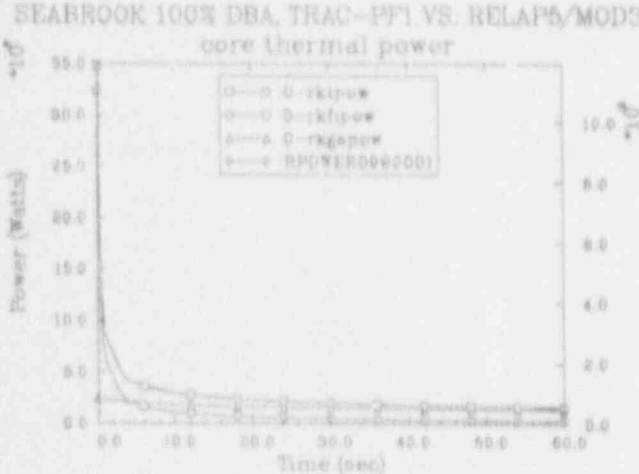
SEABROOK 100%DBA 5 GWD/MTU PIN---PF 1.8 (TRAC)
oxide thickness

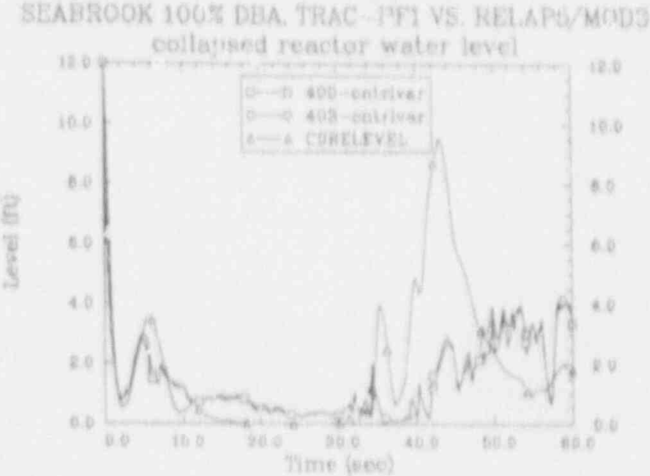


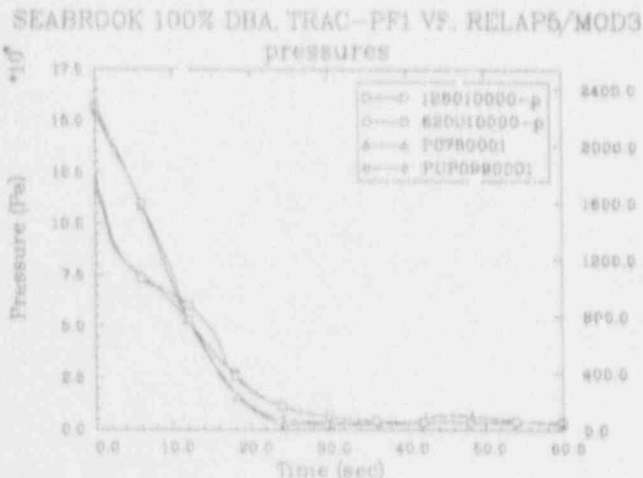
L-1.3 SCDAP/RELAP5/MOD3 AND TRAC-PF1/MOD1 PLOTTED RESULTS FOR SEABROOK

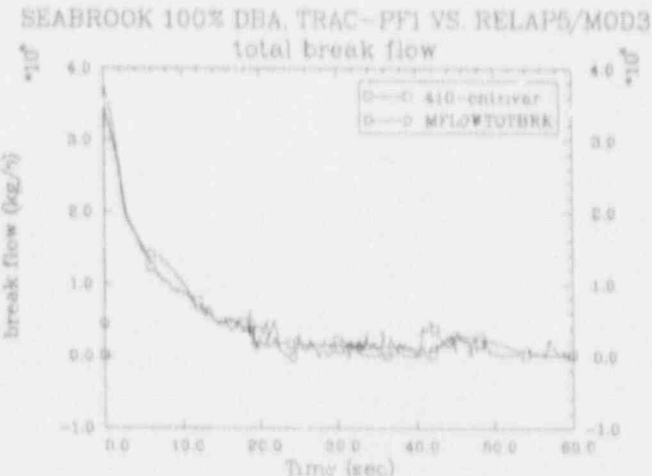
Table L-3. Description of SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 plot variables for Seabrook.

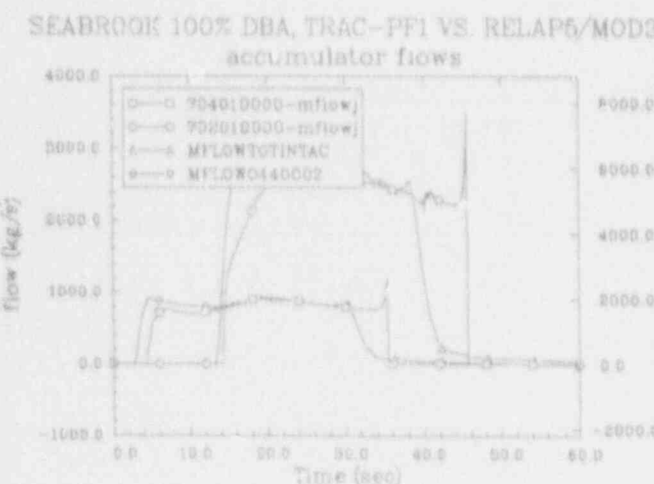
Variable	Description
SCDAP/RELAP5/MOD3 Variables:	
0-rktpow	Total core thermal power (W)
0-rkfipow	Total core fission power (W)
0-rkgapow	Total core decay heat (W)
400-cntrlvar	Hot channel collapsed reactor water level (m)
403-cntrlvar	Core-average collapsed reactor water level (m)
128010000-p	Reactor upper head pressure (Pa)
620010000-p	Pressurizer dome pressure (Pa)
410-cntrlvar	Total break flow (kg/s)
704010000-mflowj	Accumulator flow for the broken loop (kg/s)
702010000-mflowj	Total accumulator flow for the intact loop (kg/s)
702-acvlig	Accumulator liquid volume for the intact loop (m^3)
200010000-mflowj	Total hot leg flow for the intact loop (kg/s)
253010000-mflowj	Total cold leg flow for the intact loop (kg/s)
155010000-mflowj	Hot channel flows at the core midplane (kg/s)
1060n0000-voidg	Broken loop downcomer void fraction for node n at the core midplane elevation
1860n0000-voidg	Intact loop downcomer void fraction for node n at the core midplane elevation
0-dt	Time step size (s)
TRAC-PF1/MOD1 Variables:	
RPOWER0990001	Total core thermal power (W)
CORELEVEL	Core-average collapsed reactor water level (m)
PUP0990001	Reactor upper head pressure (Pa)
P078001	Pressurizer dome pressure (Pa)
MFLOWTOTBRK	Total break flow (kg/s)
MFLOW0440002	Accumulator flow for the broken loop (kg/s)
MFLOWTOTINTAC	Total accumulator flow for the intact loop (kg/s)
ACQLIQTOTINT	Accumulator liquid volume for the intact loop (m^3)
MFLOWINTHLEG	Total hot leg flow for the intact loop (kg/s)
MFLOWINTCLEG	Total cold leg flow for the intact loop (kg/s)
MFLOWTOT990801	Hot channel flows at the core midplane (kg/s)
ALPHA0990814	Broken loop downcomer void fraction for node n at the core midplane elevation
ALPHA0990813	Intact loop downcomer void fraction for node n at the core midplane elevation
DELT0000001	Time step size (s)

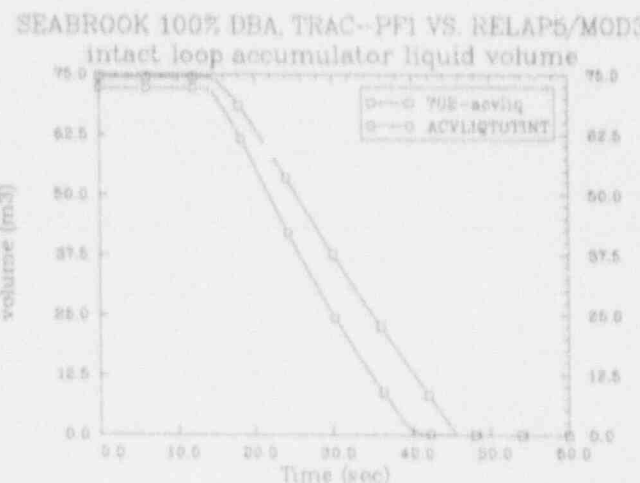

SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
core thermal power
0-rkipow
0-rkfipow
0-rkgapow
RPOWER0990001
Power (Watts)
Reactor Power (Btu/hr)
Time (sec)

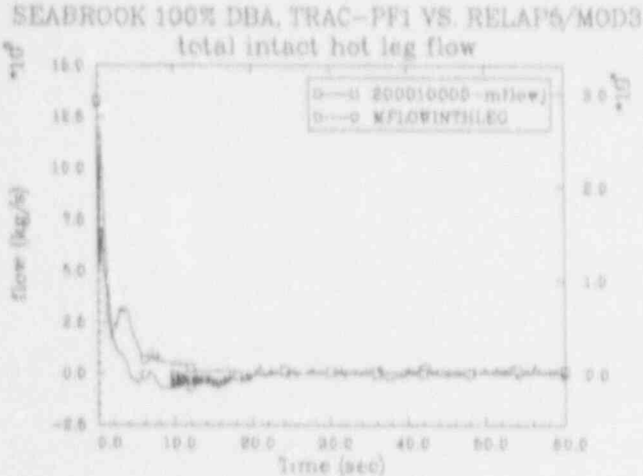

SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
collapsed reactor water level
400-cntrlvar
403-cntrlvar
CORELEVEL
Level (ft)
Time (sec)

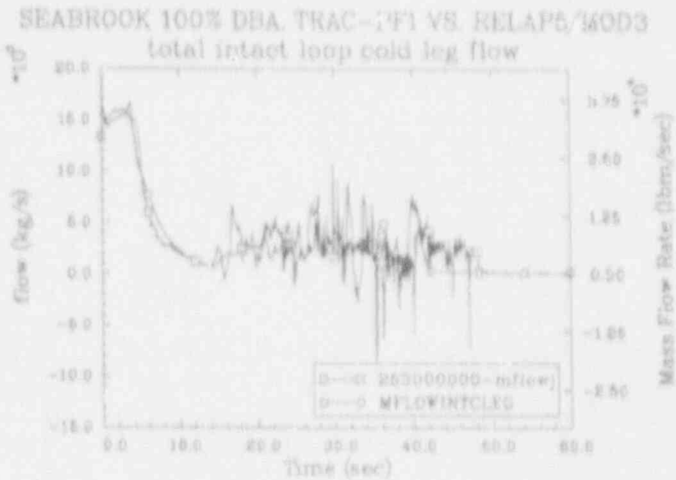

SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
pressures
Pressure (Pa)
Pressure (psia)
Time (sec)

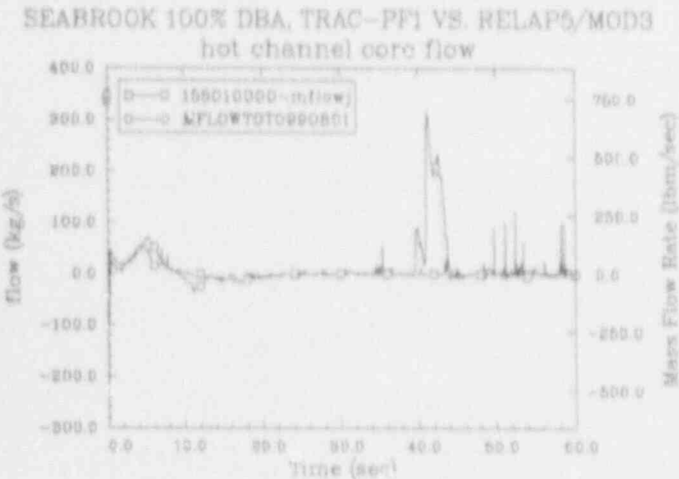

SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
total break flow
410-cntrlvar
MFLOWTOTBRK
break flow (kg/s)
Time (sec)

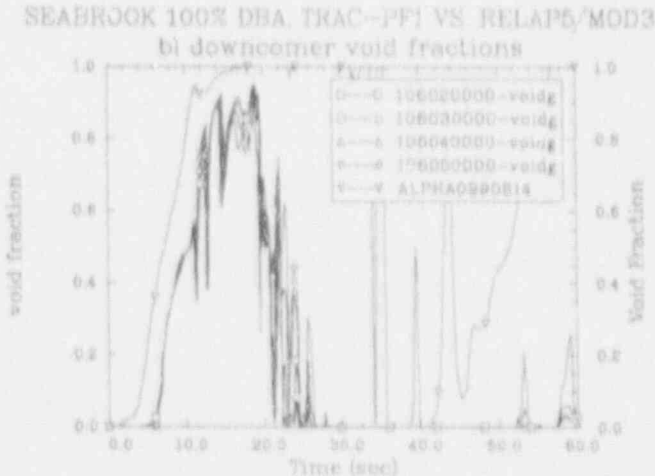

SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
accumulator flows
MFLOWTOTINTAC
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)

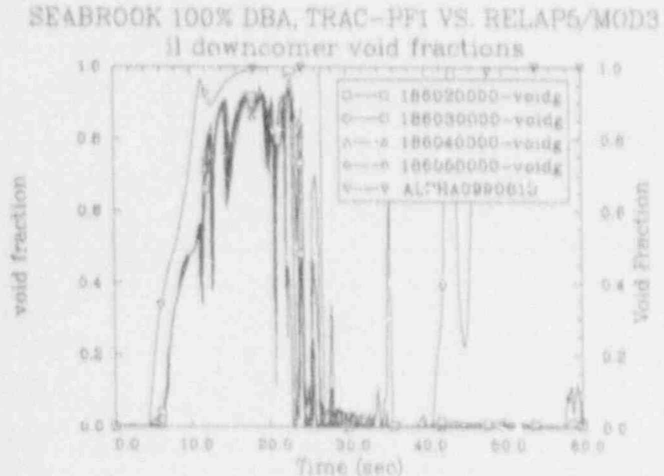

SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
intact loop accumulator liquid volume
702-acvliq
ACVLIQTOTINT
volume (m3)
Time (sec)

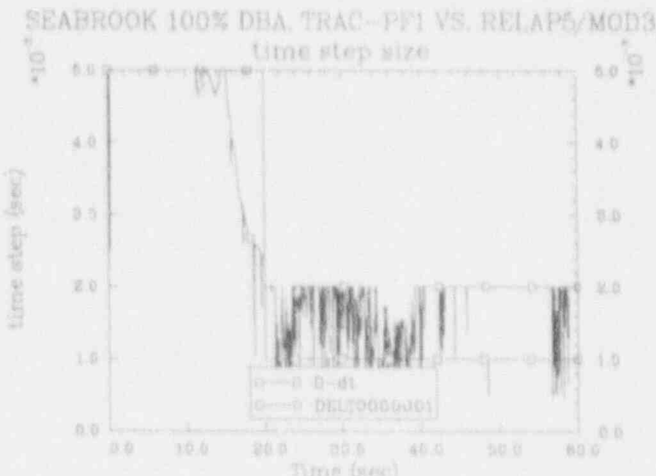

SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
total intact hot leg flow
200010000-mflowj
MFLOWINTHLEG
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)


SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
total intact loop cold leg flow
MFLOWINTCLEG
flow (kg/s)
Mass Flow Rate (lbm/sec)
Time (sec)


SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
hot channel core flow
flow (kg/s)
Mass Flow Rate (lbm/sec)


SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
bl downcomer void fractions
void fraction
Void Fraction
Time (sec)


SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
il downcomer void fractions
void fraction
Void Fraction
Time (sec)


SEABROOK 100% DBA, TRAC-PF1 VS. RELAP5/MOD3
time step size
time step (sec)
Time (sec)

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

Research has been conducted to develop and demonstrate a methodology for calculating the time interval between receipt of containment isolation signals and the first fuel pin failure for loss-of-coolant accidents (LOCAs). Demonstration calculations were performed for a Babcock and Wilcox design (Oconee) and a Westinghouse 4-loop design (Seabrook). Sensitivity studies assessed the impact of fuel pin burnup, axial peaking factor, break size, emergency core cooling system availability, and main coolant pump trip on these times. The analysis used SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 to calculate reactor system transient thermal-hydraulic conditions and FRAPCON-2 and FRAP-T6 to calculate steady-state and transient fuel behavior. This analysis also provides a comparison of SCDAP/RELAP5/MOD3 and TRAC-PF1/MOD1 results for large-break LOCA analysis.

Using SCDAP/RELAP5/MOD3 thermal-hydraulic data, the shortest time intervals calculated between containment isolation and fuel pin failure are 10.4 and 19.1 s for the B&W and W plants, respectively. Using data generated by TRAC-PF1/MOD1, the shortest interval for the W reactor is 29.1 s. These intervals are for a double-ended, offset-shear, cold leg break, using maximum peaking factor applied to fuel with maximum burnup.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

PWR LOCA, fuel pin failure

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