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FRAPTRAN-2.0: Integral Assessment

May 2016

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Abstract

An integral assessment has been performed for the U.S. Nuclear Regulatory Commission by Pacific Northwest National Laboratory to quantify the predictive capabilities of FRAPTRAN, a transient fuel behavior code designed to analyze fuel behavior during a range of power and coolant transients with fuel burnup up to 62 gigawatt-days per metric ton of uranium. The FRAPTRAN code calculations are shown to compare satisfactorily to a set of experimental data from reactivity-initiated accident and loss-of-coolant-accident operating conditions.

This document describes the assessment of FRAPTRAN-2.0, which is the latest version of FRAPTRAN, released May, 2016.

Foreword

The ability to accurately calculate the performance of light-water reactor fuel rods under long-term burnup conditions is a major objective of the reactor safety research program being conducted by the U.S. Nuclear Regulatory Commission (NRC). To achieve this objective, the NRC has sponsored an extensive program of analytical computer code development. One product of this program is an updated version of NRC's FRAPTRAN code, which provides the ability to accurately calculate the performance of light-water reactor fuel during operational transients and hypothetical accidents.

NRC also continues to sponsor both in-pile and out-of-pile experiments to benchmark and assess the analytical code capabilities. Recently, 20 new assessment cases were added to the integral assessment database, bringing the database total to 43 assessment cases. The new assessment cases use data from recent reactivity-initiated accident and loss-of-coolant-accident test programs, which provided valuable information on modern cladding materials and high-burnup fuel behavior.

This report documents an integral assessment performed using the latest version FRAPTRAN, FRAPTRAN-2.0, to demonstrate the code's ability to accurately calculate the performance of modern fuel designs and operating conditions.

Executive Summary

An integral assessment was performed for the U.S. Nuclear Regulatory Commission of the transient fuel rod behavior code, FRAPTRAN-2.0. The code was developed to calculate the thermal and mechanical behavior of light-water reactor fuel rods during reactor power and coolant transients such as reactivity accidents, boiling-water reactor power oscillations without scram, and loss-of-coolant accidents (LOCAs) at burnup levels up to 62 gigawatt-days per metric ton of uranium (GWd/MTU). The code calculates the variation with time, power, and coolant conditions of fuel rod variables such as fuel and cladding temperatures, cladding stress, elastic and plastic strain, and fuel rod gas pressure. To provide calculations for fuel at high burnup levels, FRAPTRAN uses a fuel thermal conductivity model and cladding mechanical properties that are appropriate for high-burnup fuel and can be initiated with burnup-dependent dimensions and properties using the steady-state fuel performance code, FRAPCON (Geelhood and Luscher 2014). Volume 1 (Geelhood et al. 2014) of this report provides a complete description of the code and the input instructions.

The assessment was performed by comparing FRAPTRAN code calculations to data from selected integral irradiation experiments and post-irradiation examination programs.

The cases used for code assessment were selected on the criteria of having well-characterized design and operational data and spanning the ranges of interest for both design and operating conditions. Two principal sets of data were used: 1) data from recent reactivity-initiated accident (RIA) test programs and 2) data from LOCA test programs. The code assessment database consists of 43 integral assessment cases, as discussed in Section 2. A description of each assessment case and the FRAPTRAN input for each case is provided in Appendix A.

The comparisons of the FRAPTRAN calculations to the experimental data are provided in Section 3 (RIAs) and Section 4 (LOCAs). FRAPTRAN generally performed well in the comparison to data. Additional conclusions for this code-data assessment are as follows.

RIA Cases: FRAPTRAN-2.0 predicts reasonable values of cladding hoop strain for cases with less than 2 percent hoop strain. For cases with greater than 2 percent measured hoop strain, FRAPTRAN-2.0 underpredicts the measured hoop strain. FRAPTRAN-2.0 provides a best-estimate prediction of cladding failure. FRAPTRAN-2.0 predicts uranium dioxide (UO_2) transient fission gas release (FGR) well, with a standard deviation of 2.8 percent FGR absolute and a slight overprediction on average of 0.28 percent FGR absolute.

LOCA Cases: FRAPTRAN-2.0 predicts the occurrence of cladding failure well, and only incorrectly predicted two rods within the assessment cases (failure was predicted when none was observed). FRAPTRAN-2.0 often predicts failure before it was actually observed, but this may be because of an external gas plenum volume (not in the core) in the test for which information is not provided and FRAPTRAN-2.0 does not include. FRAPTRAN-2.0 predicts reasonable values of cladding hoop strain for rods before and after ballooning and burst, with predicted values 2 to 17 percent strain (absolute) higher than observed when failure was correctly calculated. In several cases failure was predicted when none was observed, leading to a large overestimation of the cladding strain (50% strain). Given the scatter in burst strain measurements from similar rods subjected to similar LOCA burst tests (±50 percent strain), this overprediction is reasonable and conservative from a flow blockage standpoint. FRAPTRAN-2.0 predicts reasonable values of high-temperature corrosion thickness following a LOCA. For rods with pre-existing oxide layers, the protective option in FRAPTRAN-2.0 tends to underpredict the oxide layer thickness and the non-protective option in FRAPTRAN-2.0 tends to predict reasonable or bounding values of high temperature corrosion thickness following a LOCA.

Acronyms and Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
atm	atmosphere
Btu	British thermal unit
BWR	boiling-water reactor
cal	calorie(s)
cm^3	cubic centimeter(s)
DNB	departure from nucleate boiling
FGR	fission gas release
FRAP-T	Fuel Rod Analysis Program-Transient
FRAPTRAN	Fuel Rod Analysis Program TRANsient
g	gram(s)
GWd/MTU	gigawatt-days per metric ton of uranium
hr	hour(s)
K	Kelvin
kg	kilogram(s)
kW	kilowatt(s)
LHGR	linear heat generation rate
LOCA	loss-of-coolant accident
LWR	light-water reactor
m	meter(s)
mm	millimeter(s)
ms	millisecond(s)
MOX	mixed oxide ($(U, Pu)O_2$)
MPa	megapascal(s)
MW	megawatt
MWth	megawatt thermal
NRC	U.S. Nuclear Regulatory Commission
NRU	National Research Universal
PBF	Power Burst Facility
PCMI	pellet/cladding mechanical interaction
ppm	parts per million
psia	pounds per square inch absolute
PWR	pressurized-water reactor
RIA	reactivity-initiated accident
s	second(s)

TREAT	Transient Reactor Test Facility
UO_2	uranium dioxide
VVER	water-cooled, water-moderated energy reactor
μm	micrometer(s)

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1.0 Introduction

This report is part of a two-volume series that describes the FRAPTRAN-2.0 code and its assessment. Volume 1 (Geelhood et al. 2016) describes the FRAPTRAN-2.0 code. Volume 2 (this document) describes the assessment of the integral performance of FRAPTRAN-2.0.

The ability to accurately calculate the performance of light-water reactor (LWR) fuel during irradiation, for both long-term steady-state and various operational transients and hypothetical accidents, is an objective of the reactor safety research program conducted by the U.S. Nuclear Regulatory Commission (NRC). To achieve this objective, the NRC has sponsored an extensive program of analytical computer code development and both in-reactor and out-of-reactor experiments to generate the data necessary for development and verification of the computer codes. This report provides an assessment of the performance of the FRAPTRAN (Fuel Rod Analysis Program TRANsient) code, developed to calculate the response of single fuel rods to operational transients and hypothetical accidents at burnup levels up to 62 gigawatt-days per metric ton of uranium (GWd/MTU) (Geelhood et al. 2014). The FRAPTRAN code is the successor to the FRAP-T (Fuel Rod Analysis Program-Transient) code series developed in the 1970s and 1980s (Siefken et al. 1981; Siefken et al. 1983). FRAPTRAN is also a companion code to the FRAPCON code (Geelhood and Luscher, 2014), developed to calculate the steady-state high-burnup response of a single fuel rod.

FRAPTRAN was first released in 2001 (Cunningham et al. 2001a). At that time an integral assessment was performed on FRAPTRAN (Cunningham et al. 2001b) that included separate effects assessment and integral assessment of reactivity-initiated accident (RIA) and loss-of-coolant accident (LOCA) cases. Since the initial release of FRAPTRAN, several new versions have been released. The integral assessments of these versions have been performed but not formally published. The matrix of RIA and LOCA test cases has grown considerably since the original assessment. This assessment is meant to show the integral assessment of the FRAPTRAN-2.0 predictions of RIA and LOCA cases.

FRAPTRAN is an analytical tool that calculates LWR fuel rod behavior when power or coolant boundary conditions, or both, are changing rapidly. The code calculates the variation with time, power, and coolant conditions of fuel rod variables such as fuel and cladding temperatures, cladding stress, elastic and plastic strain, and fuel rod gas pressure. To provide calculations for fuel at high burnup, FRAPTRAN uses a fuel thermal conductivity model and cladding mechanical properties that are appropriate for high-burnup fuel and can be initiated with burnup-dependent dimensions using the steady-state fuel performance code, FRAPCON (Geelhood and Luscher 2014). Volume 1 of this report (Geelhood et al. 2014) describes the fuel performance models, the code structure and limitations, and the code input instructions. Volume 2 (this document) provides the results of the assessment of the integral code predictions to measured data for various transient types. The assessment datasets are summarized in Section 2, with detailed descriptions of each individual dataset and FRAPTRAN-2.0 input files provided in Appendix A.

The results of the code-data assessments are provided in Sections 3 and 4. Because transient performance (and calculations) depends on the integrated thermal-mechanical response, the assessment results are discussed by transient type rather than model response (i.e., thermal, mechanical, specific model, etc.). The code is compared to two main types of transients: RIAs (discussed in Section 3) and LOCAs (discussed in Section 4). These two groups of transients represent the major applications to which FRAPTRAN will be applied by the NRC in evaluating transient fuel behavior. A summary and conclusions for the assessment are provided in Section 5.

2.0 Assessment Data Description

A variety of assessment cases were selected to perform the assessment of FRAPTRAN. A total of 43 integral assessment cases that have transient or post-irradiation examination data, or both, were selected to perform the integral assessment of the FRAPTRAN code. These integral assessment cases are of two principal types: 1) data from RIA test programs and 2) data from LOCA test programs.

The objective of the code assessment was to assess FRAPTRAN against a set of qualified data that span a range of operational conditions for commercial LWRs to which the code will be applied. The cases in this group were selected based on the following criteria for completeness and quality of fuel rod performance data:

- The cases should provide pre-irradiation and post-irradiation characterization data for the fuel rods of interest.
- The cases should provide well-qualified in-reactor fuel performance data such as power history, temperature history, and mechanical behavior history.
- The cases should include both low and high fuel burnup under the limiting conditions of interest.
- The cases should be of failed and non-failed rods in order to assess the cladding failure predictions in FRAPTRAN-2.0.

The selected cases generally fulfill the above criteria. As shown below, there is a mix of fuel rod types among the assessment cases.

A listing of the selected integral assessment cases is provided in Table 2.1. More information on the integral assessment cases is provided in Appendix A along with descriptions of how the FRAPTRAN runs were set up and copies of the input files.

During the assessment, and while getting the assessment cases to run before the release of FRAPTRAN-2.0, errors in the FRAPTRAN coding were identified and corrected. However, FRAPTRAN was not "tuned" to provide agreement with the assessment cases. For cases where cladding temperature data were available, the FRAPTRAN runs were made so that the calculated cladding temperatures matched the data; this was done to eliminate the effect of the thermal-hydraulic models in evaluating the performance of the fuel and cladding behavior models. Although FRAPTRAN-2.0 does contain a robust suite of thermal-hydraulic correlations, FRAPTRAN is not intended to be used primarily for predicting thermal hydraulic performance because other codes have been developed for that purpose. The primary purpose of FRAPTRAN is to predict the thermal response of the fuel and its impact on the mechanical response of the cladding. The approach to assigning cladding temperatures for each case is provided in Appendix A.

An input option for FRAPTRAN is to use an initialization file generated by using FRAPCON to simulate the steady-state irradiation prior to the transient. This initialization file defines burnup-dependent parameters for FRAPTRAN such as radial dimensions, gas composition and pressure, and radial power and burnup profiles. This option was used to initialize the assessment cases involving rods tested with burnup.

Table 2.1. Fuel Rod Cases Used for FRAPTRAN-2.0 Integral Assessment

Base Irradiation	Transient Reactor	Rod	Reference	Fuel Type	Rod Type	Rod-Average Burnup, GWd/MTU	Other Comments
RIAs							
Gravelines-5	CABRI	NA1	Papin et al. 2003	UO_2	PWR 17x17	64	113.7 cal/g, 9.5 ms, failed
BR-3	CABRI	NA2	Papin et al. 2003	UO_2	BR-3	66	199 cal/g, 9.6 ms, ε_{hoop}=3.5%
Gravelines-5	CABRI	NA3	Papin et al. 2003	UO_2	PWR 17x17	53.8	123.5 cal/g, 9.5 ms, ε_{hoop}=2.2%
Gravelines-5	CABRI	NA4	Papin et al. 2003	UO_2	PWR 17x17	62	85 cal/g, 76.4 ms, ε_{hoop}=0.4%
Gravelines-5	CABRI	NA5	Papin et al. 2003	UO_2	PWR 17x17	64	108 cal/g, 8.8 ms, ε_{hoop}=1.1%
St. Laurent B2	CABRI	NA6	Papin et al. 2003	MOX	PWR 17x17	47	133 cal/g, 32 ms, ε_{hoop}=2.6%
Gravelines-4	CABRI	NA7	Papin et al. 2003	MOX	PWR 17x17	55	138 cal/g, 40 ms, failed
Gravelines-5	CABRI	NA8	Papin et al. 2003	UO_2	PWR 17x17	60	98 cal/g, 75 ms, failed
St. Laurent B1	CABRI	NA9	Papin et al. 2003	MOX	PWR 17x17	28.1	197 cal/g, 33 ms, ε_{hoop}=7.2%
Gravelines-3 and 2	CABRI	NA10	Papin et al. 2003	UO_2	PWR 17x17	63	98 cal/g, 31 ms, failed
Vandellos 2	CABRI	CIP0-1	Georgenthum 2009; Jeury et al. 2003 and 2004	UO_2	PWR 17x17	74.8	98 cal/g, 32 ms, ε_{hoop}=0.5%
Fukushima-Daiichi #3	NSRR	FK-1	Nakamura et al. 2000	UO_2	BWR 10x10	45.3	125 cal/g, 4.5 ms, ε_{hoop}=0.9%
Genkai #1	NSRR	GK-1	Fuketa et al. 1997	UO_2	PWR 14x14	42.1	121 cal/g, 4.4 ms, ε_{hoop}=2.5%
Ohi #1	NSRR	HBO-1	Fuketa et al. 1997	UO_2	PWR 17x17	50.4	93 cal/g, 4.4 ms, failed
Ohi #1	NSRR	HBO-5	Fuketa et al. 1997	UO_2	PWR 17x17	44	100 cal/g, 4.4 ms, failed
Ohi #1	NSRR	HBO-6	Fuketa et al. 1997	UO_2	PWR 17x17	49	100 cal/g, 4.4 ms, ε_{hoop}=1.2%
Mihama #2	NSRR	MH-3	Fuketa et al. 1997	UO_2	PWR 14x14	38.9	87 cal/g, 4.5 ms, ε_{hoop}=1.6%
Ohi #2	NSRR	OI-2	Fuketa et al. 1997	UO_2	PWR 17x17	39.2	136 cal/g, 4.4 ms, ε_{hoop}=4.8%
Tsuruga #1	NSRR	TS-5	Nakamura et al. 1994	UO_2	BWR 7x7	26.6	104 cal/g, 4.6 ms, ε_{hoop}=0%
Vandellos 2	NSRR	VA-1	Georgenthum 2009; Sugiyama 2009	UO_2	PWR 17x17	71	142 cal/g, 4.4 ms, failed

Table 2.1. Continued

Base Irradiation	Transient Reactor	Rod	Reference	Fuel Type	Rod Type	Rod-Average Burnup, GWd/MTU	Other Comments
Vandellos 2	NSRR	VA-3	Georgenthum 2009; Sugiyama 2009	UO_2	PWR 17x17	72	114 cal/g, 4.4 ms, failed
Novovoronezhskay	BIGR	RT-1	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	48.3	142 cal/g, 3 ms
Novovoronezhskay	BIGR	RT-2	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	48.0	115 cal/g, 3 ms
Novovoronezhskay	BIGR	RT-3	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	47.5	138 cal/g, 3 ms
Kolskay	BIGR	RT-4	Yegorova et al. 2005a and 2005b	UO_2	VVER-440	60.1	125 cal/g, 3 ms
Novovoronezhskay	BIGR	RT-5	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	48.6	146 cal/g, 3 ms
Novovoronezhskay	BIGR	RT-6	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	47.8	153 cal/g, 3 ms
Kolskay	BIGR	RT-7	Yegorova et al. 2005a and 2005b	UO_2	VVER-440	60.5	134 cal/g, 3 ms
Kolskay	BIGR	RT-8	Yegorova et al. 2005a and 2005b	UO_2	VVER-440	60.0	164 cal/g, 3 ms, failed
Kolskay	BIGR	RT-9	Yegorova et al. 2005a and 2005b	UO_2	VVER-440	59.8	165 cal/g, 3 ms, failed
Novovoronezhskay	BIGR	RT-10	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	46.9	164 cal/g, 3 ms
Novovoronezhskay	BIGR	RT-11	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	47.2	188 cal/g, 3 ms, failed
Novovoronezhskay	BIGR	RT-12	Yegorova et al. 2005a and 2005b	UO_2	VVER-1000	47.3	155 cal/g, 3 ms, failed

Table 2.1. Continued

Base Irradiation	Transient Reactor	Rod	Reference	Fuel Type	Rod Type	Rod-Average Burnup, GWd/MTU	Other Comments
LOCAs							
None	NRU	MT-1	Russcher et al. 1981	UO_2	PWR 17x17	0	11 full length rods, adiabatic heatup
None	NRU	MT-4	Wilson et al. 1983	UO_2	PWR 17x17	0	11 full length rods, adiabatic heatup
None	NRU	MT-6A	Wilson et al. 1993	UO_2	PWR 17x17	0	21 full length rods
None	PBF	LOC-11C R1 and R4	Buckland et al. 1978; Larson et al. 1979	UO_2	PWR 15x15	0	Scram plus LOCA
None	PBF	LOC-11C R2	Buckland et al. 1978; Larson et al. 1979	UO_2	PWR 15x15	0	Scram plus LOCA
None	PBF	LOC-11C R3	Buckland et al. 1978; Larson et al. 1979	UO_2	PWR 15x15	0	Scram plus LOCA
None	TREAT	FRF-2	Lorenz and Parker 1972	UO_2	BWR 7x7	0	Power ramp, adiabatic heatup
Commercial PWR	Halden	IFA-650.5	Kekkonen 2007a	UO_2	PWR 15x15	83	LOCA
Loviisa	Halden	IFA-650.6	Kekkonen 2007b	UO_2	VVER-1000	56	LOCA
Commercial BWR	Halden	IFA-650.7	Jošek 2008	UO_2	BWR 10x10	44	LOCA

BWR = boiling-water reactor
MOX = mixed oxide ($(U, Pu)O_2$)
NRU = National Research Universal
PBF = Power Burst Facility
PWR = pressurized-water reactor
TREAT = Transient Reactor Test Facility
UO_2 = uranium dioxide
VVER = water-cooled, water-moderated energy reactor

3.0 Reactivity Initiated Accident Assessment

The RIA assessment cases consist of 33 rods that have been refabricated from full-length fuel rods that have been irradiated to burnup levels between 26 and 75 GWd/MTU. The refabricated rods have been taken from PWR, BWR, and VVER fuel rods with Zircaloy-4, Zircaloy-2, ZIRLO, and E-110 cladding and with UO_2 and MOX fuel. The refabricated rods have been tested in the CABRI reactor under flowing sodium, in the NSRR reactor under stagnant room temperature water and stagnant 285°C water, and in the BIGR reactor under stagnant room temperature water.

This assessment database represents a large range of rod designs and reactor conditions.

3.1 Cladding Hoop Strain Predictions

The residual cladding hoop strain prediction during RIA events was assessed using the 13 non-failed UO_2 and MOX rods from the CABRI and NSRR assessment cases. The measured and predicted residual cladding hoop strain values during the RIA transient are shown in Figure 3.1. These values are also listed in Table 3.1. The non-failed BIGR rods were not used for this assessment because of the large fuel heatup that occurred after the RIA test, which is not modeled in FRAPTRAN but is expected to cause a large amount of cladding hoop strain due to increased gas pressure and high cladding temperatures.

Figure 3.1 and Table 3.1 show that FRAPTRAN-2.0 provides reasonable predictions of permanent hoop strain for measured strains below 2 percent. There is significant underprediction of cladding hoop strain for the two NSRR rods with measured uniform strains greater than 2 percent. This may be due to departure from nucleate boiling (DNB) causing local overheating of the rod segments that was not captured by the thermocouples, which are not at the same axial location where DNB occurred (Fuketa et al. 2001).

The overall standard deviation for the 13 rods is 2.0 percent strain. If only the cases with strain less than 2 percent are considered, the standard deviation for the 7 rods is 0.7 percent strain.

This assessment demonstrates that FRAPTRAN-2.0 predicts reasonable strain for cases with less than 2 percent strain. For cases with greater than 2 percent measured strain, FRAPTRAN-2.0 underpredicts the measured strain, most likely because the code does not accurately predict the initiation of DNB in stagnant water. The determination of DNB in the NSRR or BIGR cores in the small test capsules used for these RIA tests is a very complex problem that requires modeling of the NSRR or BIGR core as well as the individual test capsules with thermal-hydraulic codes. Even with this detailed modeling, the uncertainty in DNB predictions would be relatively large.

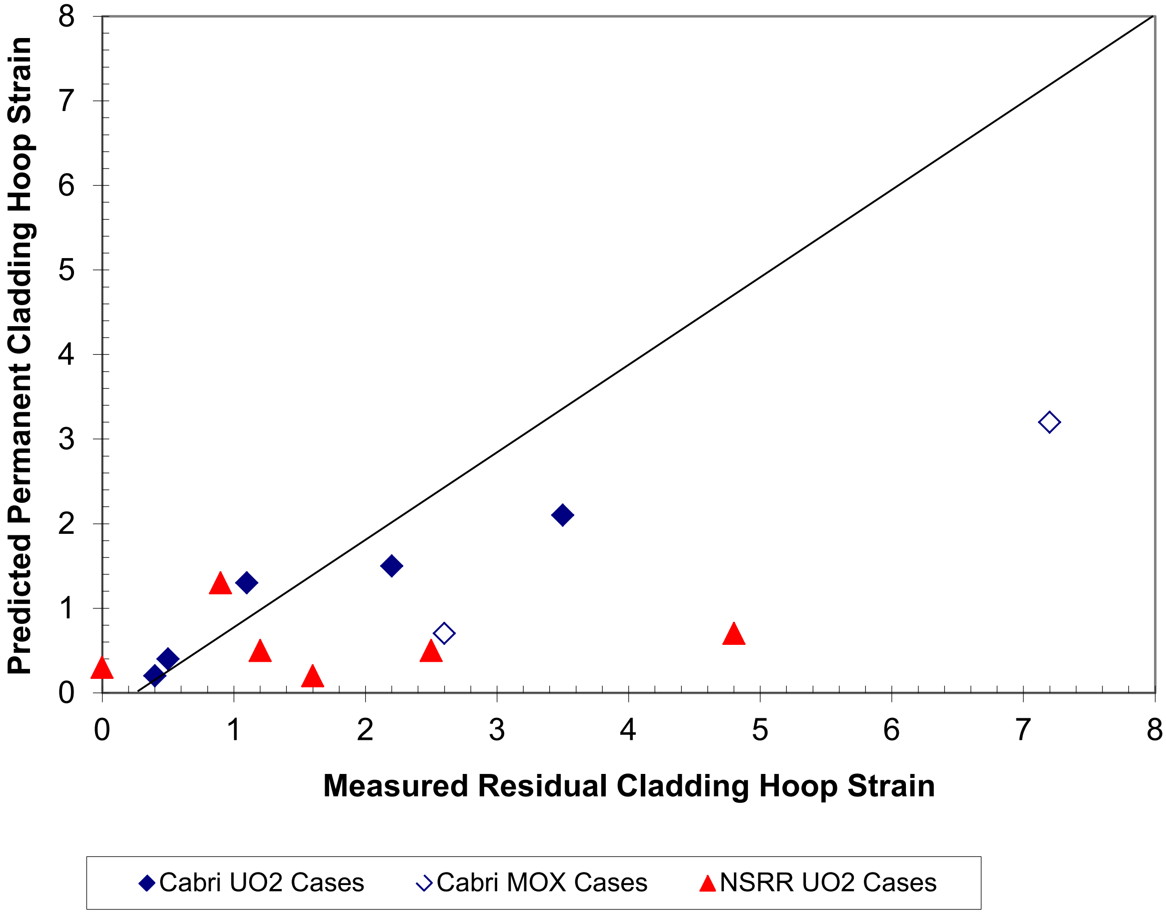

Figure 3.1. FRAPTRAN-2.0 Predictions of Residual Cladding Hoop Strain for CABRI and NSRR UO_2 and MOX Rods

Table 3.1. FRAPTRAN-2.0 Predictions of Residual Cladding Hoop Strain for CABRI and NSRR UO_2 and MOX Rods

Rod	Measured Residual Cladding Hoop Strain, %	Predicted Residual Cladding Hoop Strain, %
CABRI NA2	3.5	2.1
CABRI NA3	2.2	1.5
CABRI NA4	0.4	0.2
CABRI NA5	1.1	1.3
CABRI NA6	2.6	0.7
CABRI NA9	7.2	3.2
CABRI CIP0-1	0.5	0.4
NSRR FK-1	0.9	1.3
NSRR GK-1	2.5	0.5
NSRR HBO-6	1.2	0.5
NSRR MH-3	1.6	0.2
NSRR OI-2	4.8	0.7
NSRR TS5	0	0.3

3.2 Cladding Failure Predictions

FRAPTRAN-2.0 includes a strain-based failure model (Geelhood et al. 2016) that can be used to predict cladding failure during RIA events. The failure during RIA events was assessed using all 33 UO_2 and MOX rods from the CABRI, NSRR, and BIGR assessment cases. The failure predictions are compared to the observations from the experiments in Table 3.2. Table 3.2 also shows the predicted and reported maximum radially averaged fuel enthalpies and failure enthalpies for those rods predicted to fail. It should be noted that the enthalpies reported are not measured values, but rather are values determined by the experimentalists using a transient fuel performance code similar to FRAPTRAN-2.0 and are therefore code dependant.

It can be seen that FRAPTRAN predicts the maximum fuel enthalpies well, typically within less than 5 cal/g and not by more than 13 cal/g. It can also be seen in Table 3.2 that the failure or non-failure for the CABRI test are all predicted correctly. For the NSRR and BIGR tests, the code seems to underpredict failure. This is most likely due to the fact that all these tests are performed in sealed water capsules with no measument of cladding surface temperature. As such, the cladding temperature is difficult to model ann the failure criteria is dependent on cladding temperature.

The post-examination irradiation results from the BIGR tests (RT-1 through RT-12) indicated that some of the rods may have failed due to highly localized ballooning caused by localized DNB, resulting in a local hot spot and localized ballooning and burst. Of the failed rods, localized ballooning is evident in RT-11, but less evident in RT-8, RT-9, and RT-10. Rods RT-8, RT-9, and RT-10 had multiple failure locations, some of which appear to be due to ballooning while others may be due to pellet/cladding mechanical interaction (PCMI). For example, the RT-8 rod had two failure locations: one at the bottom with large local deformation typical of ballooning and one at the top with much less local deformation, characteristic of PCMI. The RT-10 rod also had characteristic deformation similar to that of RT-8: two failure locations, with the bottom failure having deformation characteristic of ballooning and the top having the less localized deformation characteristic of PCMI. The RT-9 rod had four different failure locations that also appear to demonstrate a combination of ballooning and PCMI. In addition, it seems unlikely that the RT-9 rod could close off gas communication at four different locations to cause ballooning at each of these locations, especially considering that the RT-9 failure locations are within 1 inch or less of one another.

This assessment demonstrates that FRAPTRAN-2.0 provides a best-estimate prediction of cladding failure when the cladding temperature is well known.

Table 3.2. FRAPTRAN-2.0 Failure and Enthalpy Predictions for RIA Assessment Cases

	Failure		Enthalpy at Failure, cal/g	
Test	Measured	Predicted	Reported	Predicted
NA1	Failed at 0.074 s	Failed at 0.07919 s	H_{fail}=30 H_{max}=114	H_{fail}=64 H_{max}=120
NA2	Not failed	Not failed	H_{max}=199	H_{max}=209
NA3	Not failed	Not failed	H_{max}=124	H_{max}=126
NA4	Not failed	Not failed	H_{max}=85.0	H_{max}=83
NA5	Not failed	Not failed	H_{max}=108	H_{max}=108
NA6	Not failed	Not failed	H_{max}=133	H_{max}=148
NA7	Failed at 0.405 s	Failed at 1.095 s	H_{fail}=113 H_{max}=138	H_{fail}=148 H_{max}=150
NA8	Failed at 0.5318 s	Failed at 0.5241 s	H_{fail}=78 H_{max}=98	H_{fail}=68 H_{max}=96
NA9	Not failed	Not failed	H_{max}=197	H_{max}=234
NA10	Failed at 0.456 s	Failed at 0.4479 s	H_{fail}=81 H_{max}=98	H_{fail}=61 H_{max}=96
CIP0-1	Not failed	Not failed	H_{max}=91	H_{max}=97
FK1	Not failed	Not failed	H_{max}=116	H_{max}=117
GK1	Not failed	Not failed	H_{max}=93	H_{max}=91
HBO1	Failed	Not failed	H_{fail}=60 H_{max}=73	H_{max}=73
HBO5	Failed	Not failed	H_{fail}=76 H_{max}=80	H_{max}=80

Table 3.2. Continued

Test	Failure: Measured	Failure: Predicted	Enthalpy at Failure, cal/g: Reported	Enthalpy at Failure, cal/g: Predicted
HBO6	Not failed	Not failed	H_{max}=85	H_{max}=85
MH3	Not failed	Not failed	H_{max}=67	H_{max}=67
OI2	Not failed	Not failed	H_{max}=108	H_{max}=107
TS5	Not failed	Not failed	H_{max}=98	H_{max}=98
VA1	Failed	Failed at 0.0089 s	H_{fail}=64±10 H_{max}=133	H_{fail}=115 H_{max}=132
VA3	Failed	Not failed	H_{fail}=82 H_{max}=122	H_{max}=121
RT1	Not failed	Not failed	H_{max}=142	H_{max}=139
RT2	Not failed	Not failed	H_{max}=115	H_{max}=114
RT3	Not failed	Not failed	H_{max}=138	H_{max}=135
RT4	Not failed	Not failed	H_{max}=125	H_{max}=120
RT5	Not failed	Not failed	H_{max}=146	H_{max}=143
RT6	Not failed	Not failed	H_{max}=153	H_{max}=150
RT7	Not failed	Not failed	H_{max}=134	H_{max}=125
RT8	Failed[2]	Not failed	H_{max}=164	H_{max}=152
RT9	Failed[2]	Not failed	H_{max}=165	H_{max}=155
RT10	Failed[2]	Not Failed	H_{max}=164	H_{max}=152
RT11	Failed[1]	Not failed	H_{max}=188	H_{max}=181
RT12	Not failed	Not failed	H_{max}=155	H_{max}=156

[1] This rod may have failed due to ballooning caused by localized DNB.

[2] These rods have multiple failure locations that appear to be a combination of some locations due to ballooning while others suggest PCMI.

3.3 Fission Gas Release Predictions

The fission gas release (FGR) predictions during RIA events were assessed using the measured release values from 10 non-failed UO_2 rods from the CABRI and NSRR assessment cases. The code predictions for these tests utilized the grain boundary gas inventory as predicted by the FRAPFGR model in FRAPCON-4.0. The grain boundary gas inventory is read in by FRAPTRAN-2.0 and the release model releases this gas when various temperature thresholds are reached (Geelhood et al. 2014). The measured and predicted gas release values during the RIA transient are shown in Figure 3.2 and in Table 3.3. The non-failed BIGR rods were not used for this assessment because of the large fuel heatup that occurred after the RIA test, which is not modeled in FRAPTRAN but is expected to cause a large amount of FGR. The CABRI MOX rods were not included as there are only two non-failed MOX rods and these were not enough to calibrate an empirical MOX transient FGR model.

This assessment demonstrates that FRAPTRAN-2.0 predicts UO_2 transient FGR reasonably well, with a standard deviation of 4.0 percent FGR and an overprediction on average of 1.9 percent FGR.

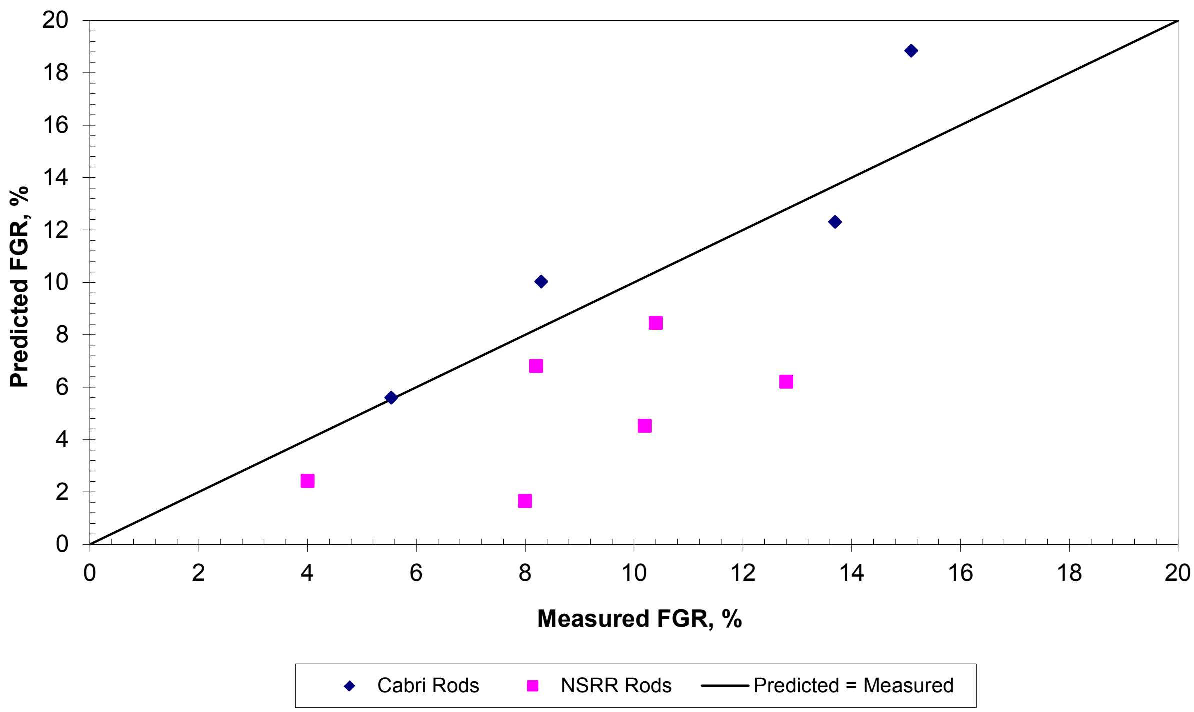

Figure 3.2. FRAPTRAN-2.0 Predictions of RIA FGR for CABRI and NSRR UO_2 Rods

Table 3.3. FRAPTRAN-2.0 Predictions of RIA FGR for CABRI and NSRR UO_2 Rods

Rod	Measured FGR, %	Predicted FGR, %
CABRI NA2	5.54	5.59
CABRI NA3	13.7	12.31
CABRI NA4	8.3	10.02
CABRI NA5	15.1	18.84
NSRR FK-1	8.2	6.8
NSRR GK-1	12.8	6.2
NSRR HBO-6	10.4	8.45
NSRR MH-3	4	2.42
NSRR OI-2	10.2	4.52
NSRR TS5	8	1.65

NRC has an empirical transient FGR model for stable and radioactive isotopes for RIA that is a function of burnup and maximum enthalpy only in Regulatory Guide 1.183. This model is not included in FRAPTRAN-2.0. The model may be input using the option to input FGR as a function of time. An option to use this model may be added to future code versions.

4.0 Loss-of-Coolant Accident Assessments

The LOCA assessment cases consist of 10 LOCA test case rods that have been refabricated from various full-length fuel rods that have been irradiated to burnup levels between 0 and 83 GWd/MTU. The refabricated rods have been taken from PWR, BWR, and VVER UO_2 fuel rods with Zircaloy-4, Zircaloy-2, and E-110 cladding. The refabricated rods have been tested in the NRU, PBF, TREAT, and Halden reactors under various LOCA scenarios.

FRAPTRAN-2.0 is not intended to predict assembly or core cooling during a LOCA. A systems code such as RELAP5 or TRAC is needed to predict assembly and core coolability during a LOCA for input to FRAPTRAN. FRAPTRAN has single-rod coolant models that can be used to predict the cladding temperature and oxidation. However, in some cases the coolant conditions are too complex for these models and cladding surface temperatures calculated with a systems code are input to FRAPTRAN. The purpose of the FRAPTRAN code is to predict fuel and cladding temperatures, rod pressures, cladding ballooning, and rupture strains and oxidation based on input from the system codes. The following assessments will provide comparisons to measured rod internal pressures, cladding strains and rupture times, and cladding oxidation.

The LOCA assessment database represents a large range of rod designs and reactor conditions.

4.1 Cladding Ballooning, Failure, and Pressure Predictions

The cladding ballooning behavior prediction during LOCA events was assessed using all 10 LOCA assessment cases. Table 4.1 shows the measured and predicted failure times for each of these cases. In addition, the measured and predicted rod internal pressure histories are shown for each of the assessment cases in Figures 4.1 through 4.8.

Table 4.1 shows that, in general, FRAPTRAN-2.0 predicts failure well for these tests. There is only one case (LOC-11C rod 2) where FRAPTRAN-2.0 predicts failure when none was observed. However, it can be seen that FRAPTRAN-2.0 often predicts failure to occur before it was actually measured. This can also be seen in the rod internal pressure predictions in Figures 4.1 through 4.8. It should be noted that in order to measure the rod internal pressure in these LOCA tests, there is often a rather large gas volume that is not within the heated zone that contains the pressure transducer. FRAPTRAN-2.0 can model an external plenum, but the lower temperature in this gas volume is often not reported. Therefore the typical plenum temperature calculation is used for the entire gas plenum. This may lead to larger predicted rod internal pressure values. Larger rod internal pressure values subsequently lead to failure predictions occurring earlier than measured.

Table 4.1. FRAPTRAN-2.0 Predicted and Measured Peak Cladding Residual Strain following LOCA Tests

Case	Measured Failure Time (Measured from Start of Transient)	FRAPTRAN-2.0 Predicted Failure Time
MT-1	60-95 s*	61 s
MT-4	52-58 s*	27 s
MT-6A	58-64 s*	31 s
LOC-11C rods 1 and 4	No failure	No failure
LOC-11C rod 2	No failure	12.1 s
LOC-11C rod 3	No failure	24.5
TREAT rod 16 and 17	30.3-37.5 s	26.5 s
IFA-650.5	179 s	169 s
IFA-650.6	525 s	419 s
IFA-650.7	247 s	152 s

*These tests were done on a bundle of rods. Range represents observed range of failure times for individual rods.

This assessment demonstrates that FRAPTRAN-2.0 predicts cladding failure well and only incorrectly predicted two rods (failure was predicted when none was observed). FRAPTRAN-2.0 often predicts failure before it was actually observed, but this may be due to an external gas plenum volume in the test (used in all the IFA-650 tests, MT-4, and MT-6A) that FRAPTRAN-2.0 is able to model but was not included as no temperature information for the external plenum was provided. The gas in an external plenum is not heated as much as the gas in the fuel rod or the rod plenum; therefore, when it is modeled to be in the rod plenum in FRAPTRAN, predicted rod pressures are higher.

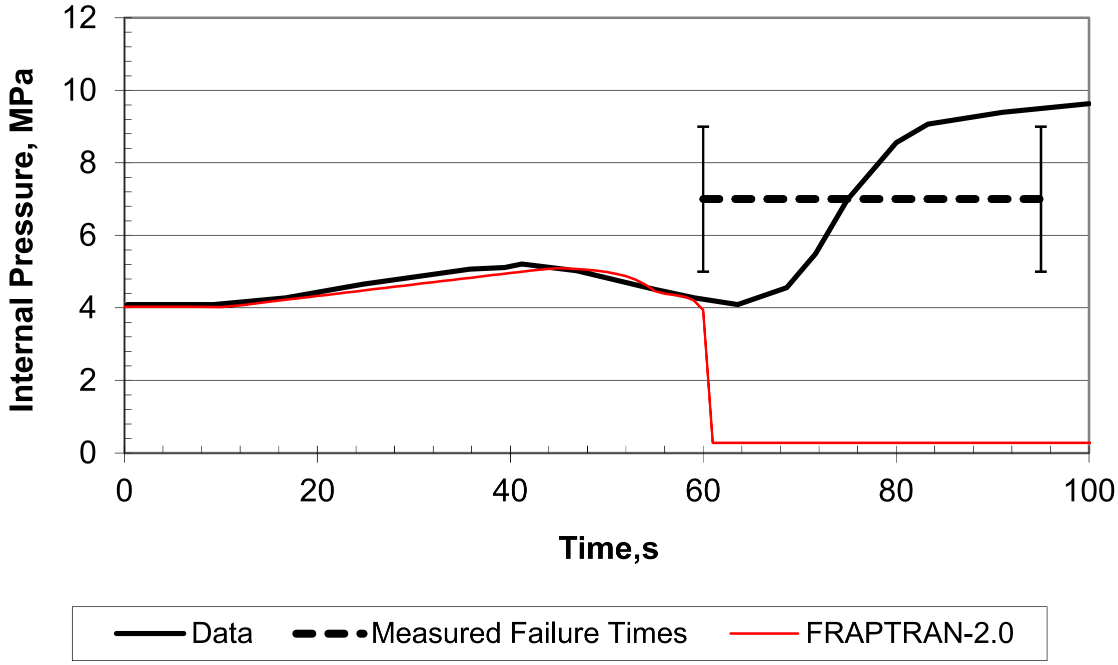

Figure 4.1. FRAPTRAN-2.0 Predicted and Measured Rod Internal Pressure for MT-1. (Solid line shows pressure for 1 rod (data suspect beyond 65 seconds). Dotted line shows failure time range for 11 rods in MT-1 bundle)

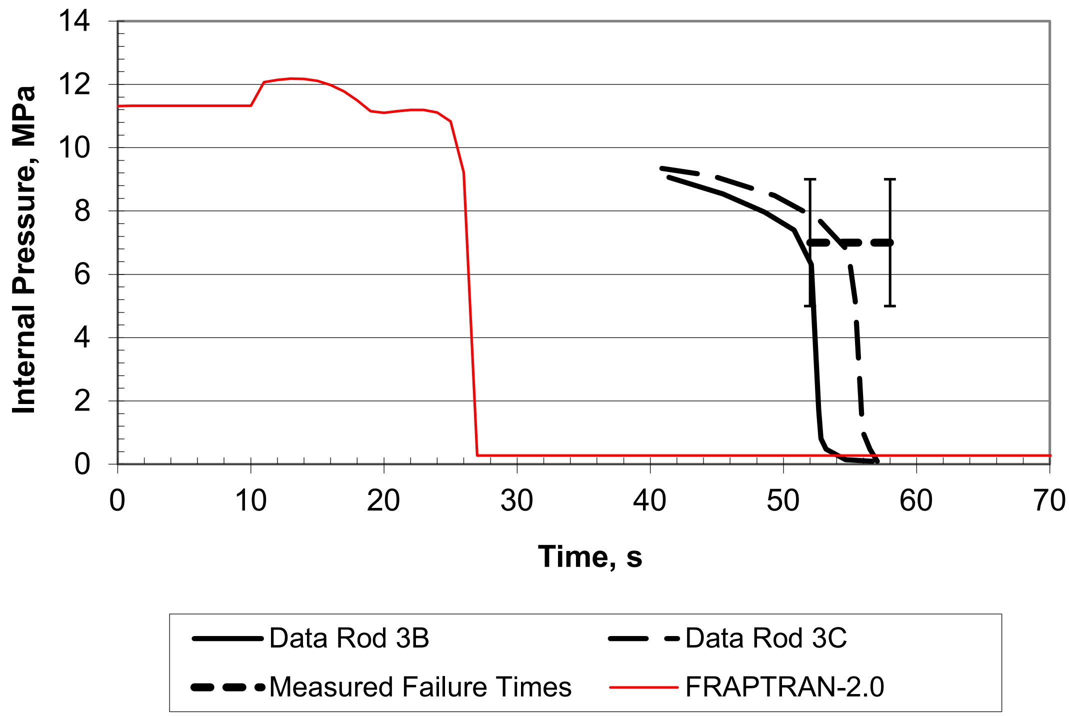

Figure 4.2. FRAPTRAN-2.0 Predicted and Measured Rod Internal Pressure for MT-4. (Solid and dashed lines shows pressure for 2 rods. Dotted line shows failure time range for 11 rods in MT-4 bundle)

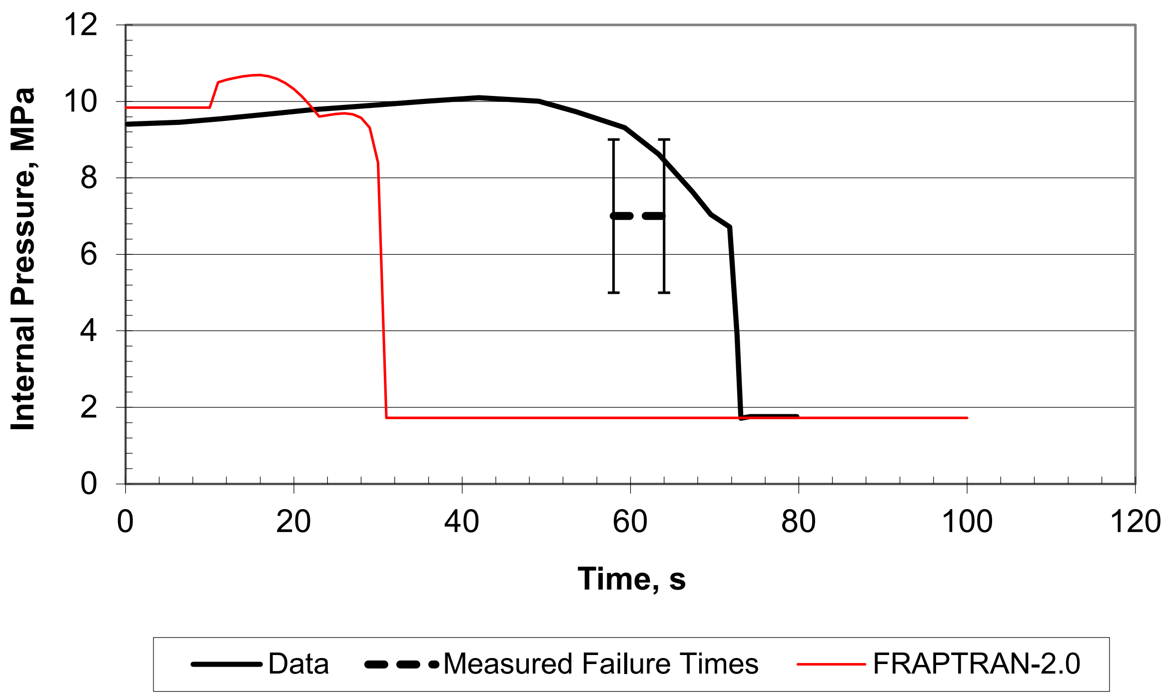

Figure 4.3. FRAPTRAN-2.0 Predicted and Measured Rod Internal Pressure for MT-6A. (Solid line shows pressure for 1 rod. Dotted line shows failure time range for 11 rods in MT-6A bundle)

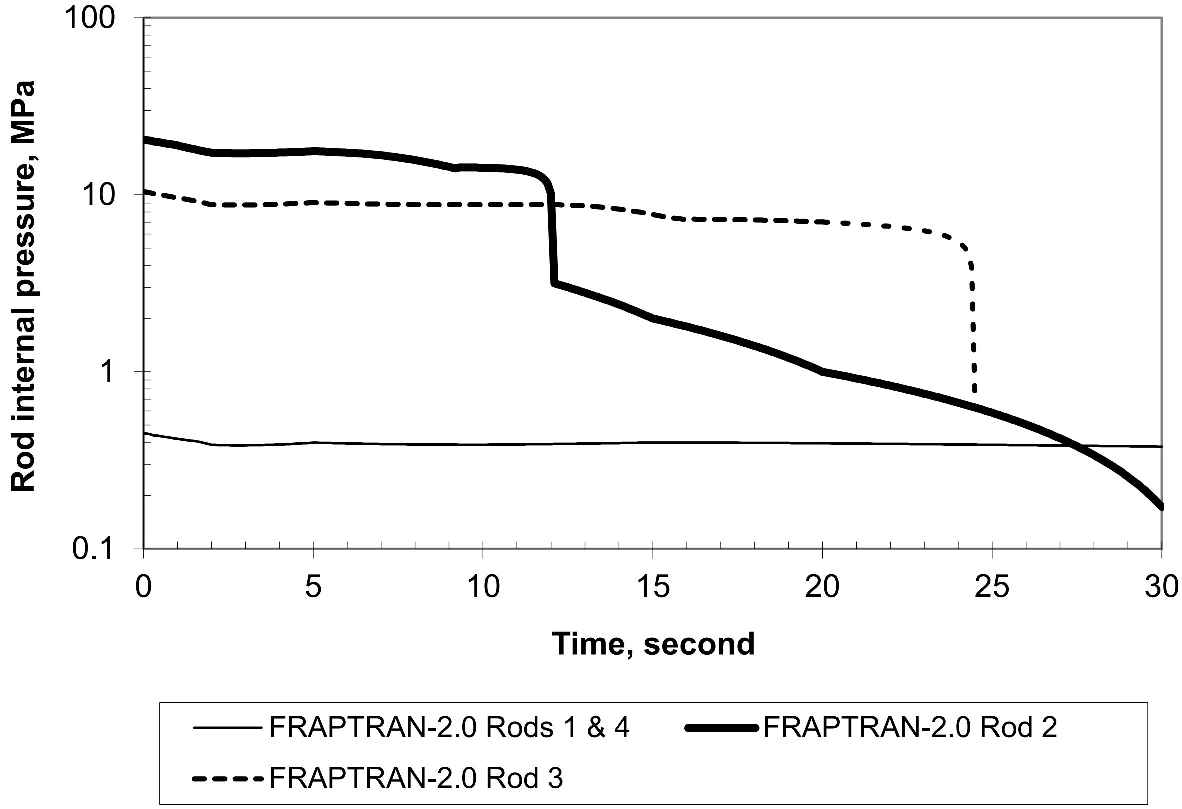

Figure 4.4. FRAPTRAN-2.0 Predicted Rod Internal Pressure for LOC-11C Rods. FRAPTRAN-2.0 predicted failure for rods 2 and 3. (None of the rods were measured to fail and rod internal pressure history was not available for these rods)

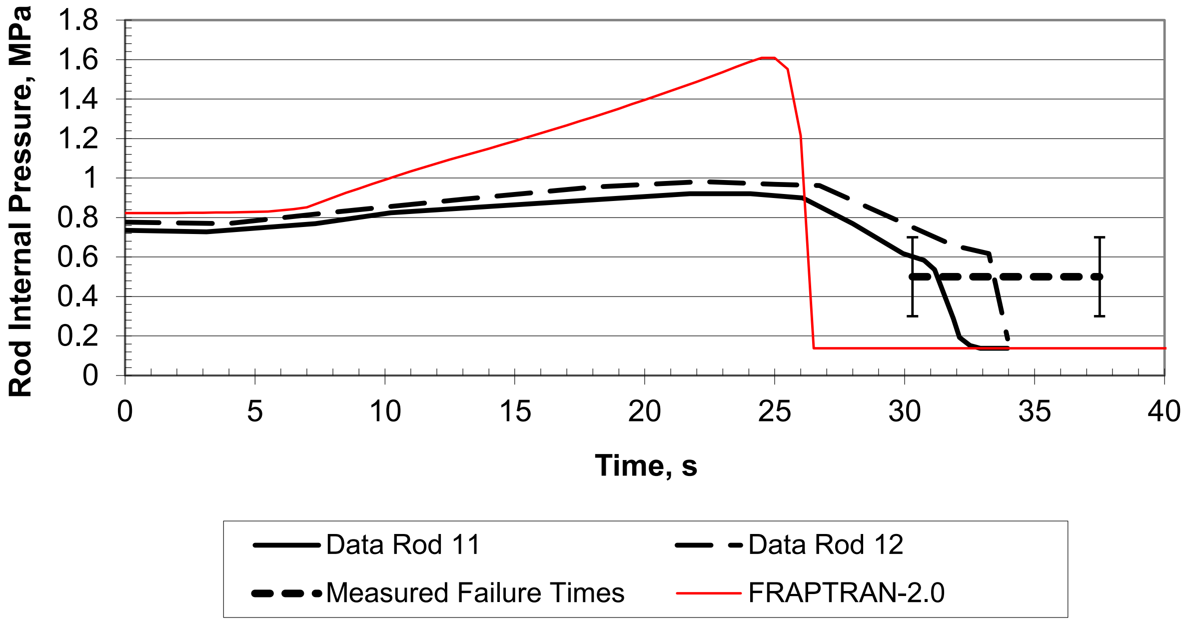

Figure 4.5. FRAPTRAN-2.0 Predicted Rod Internal Pressure for TREAT FRF-2 Rods. (Solid and dashed lines shows pressure for 2 rods. Dotted line shows failure time range for all 11 rods)

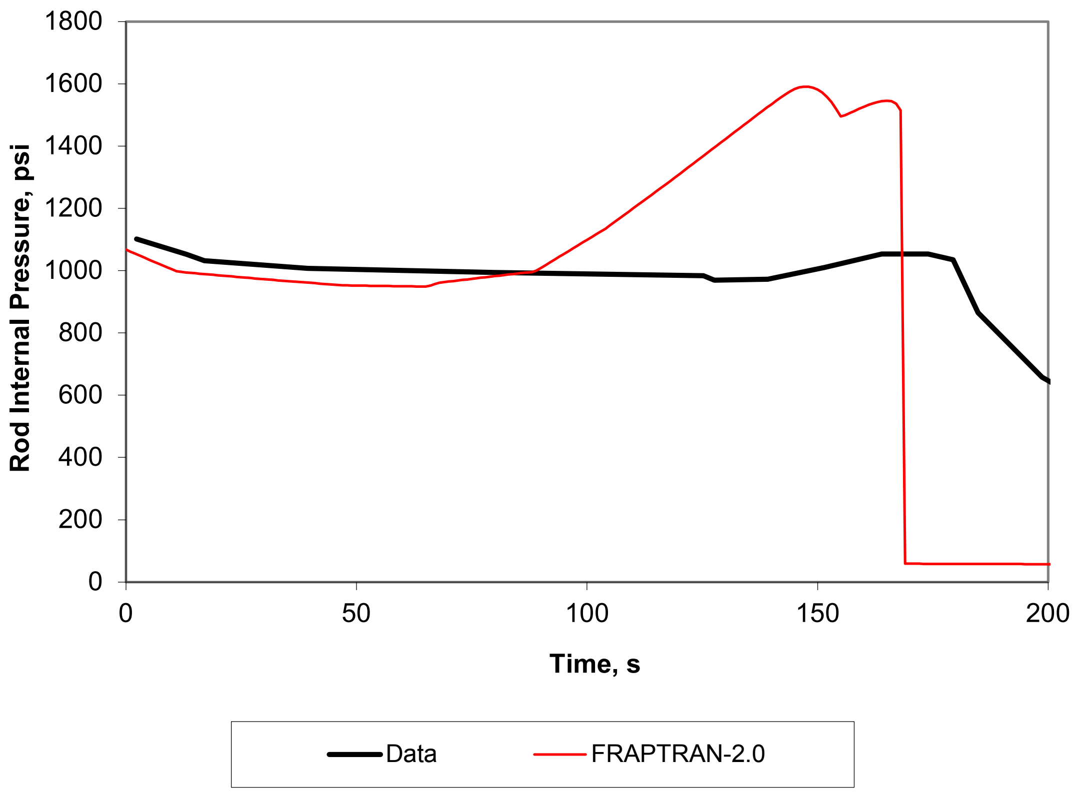

Figure 4.6. FRAPTRAN-2.0 Predicted Rod Internal Pressure for IFA-650.5

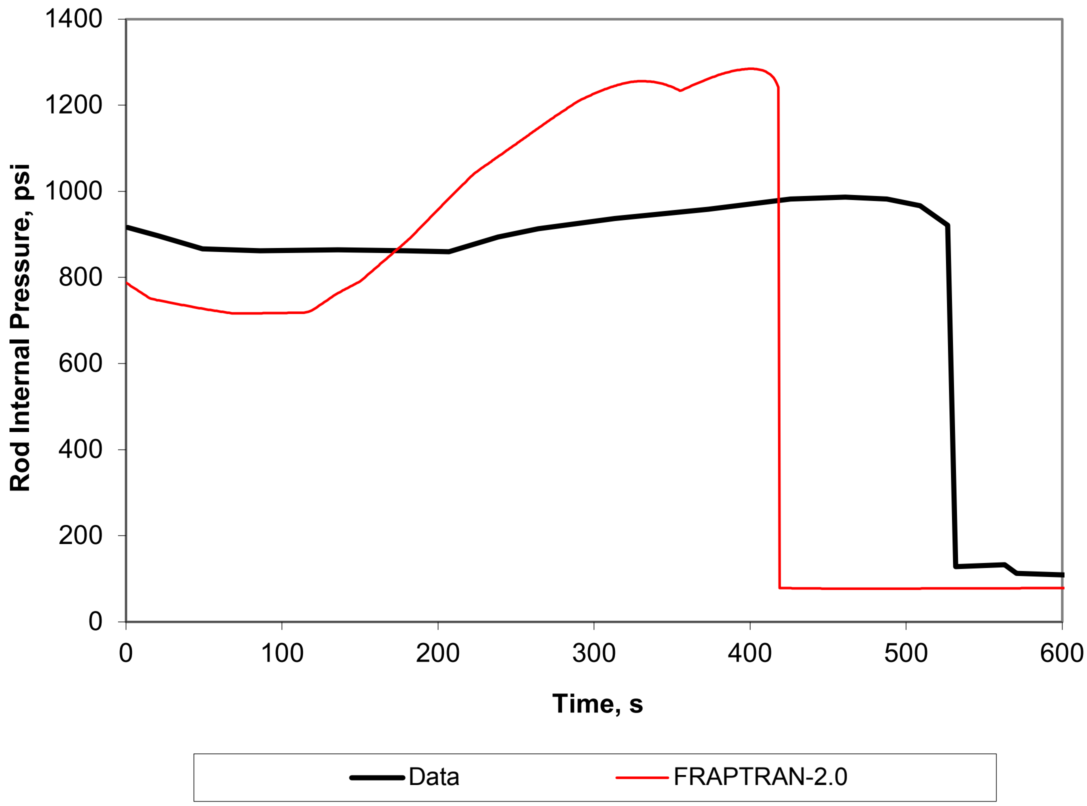

Figure 4.7. FRAPTRAN-2.0 Predicted Rod Internal Pressure for IFA-650.6

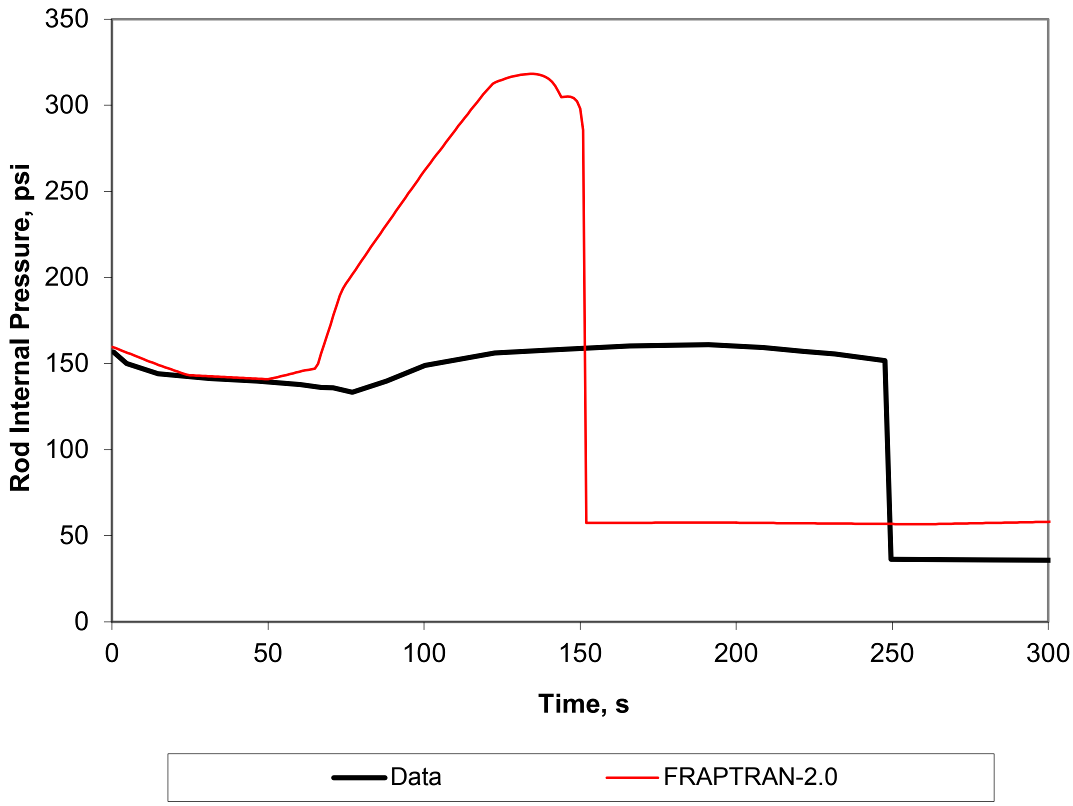

Figure 4.8. FRAPTRAN-2.0 Predicted Rod Internal Pressure for IFA-650.7

4.2 Residual Hoop Strain Predictions

The cladding residual hoop strain predictions during LOCA events were assessed using the seven LOCA assessment cases where residual cladding hoop strain was measured. Table 4.2 shows the measured and predicted peak residual hoop strain for each of these cases.

For the failed rods (IFA-650 and TREAT rods), FRAPTRAN-2.0 predicts cladding hoop strain well by slightly overpredicting the final hoop strain by 2 to 17 percent strain (absolute). Given the scatter typically observed in burst strain from LOCA burst tests (±50 percent strain) (Powers and Meyer 1980), this overprediction is within the uncertainty of the burst strain. Also, overpredicting the burst strain is conservative from the flow blockage standpoint.

For the non-failed rods (LOC-11C rods), FRAPTRAN-2.0 predicts cladding hoop strain well by slightly overpredicting the final hoop strain by about 1 percent strain for the cases that FRAPTRAN-2.0 predicts no failure (rods 1 and 4). However, for rods 2 and 3, where FRAPTRAN-2.0 predicts failure and none was observed, FRAPTRAN-2.0 significantly overpredicts the hoop strain by up to 50% strain (absolute).

With the exception of rods 2 and 3 in LOC-11C, this assessment demonstrates that FRAPTRAN-2.0 predicts reasonable values of cladding hoop strain for rods before and after ballooning and burst, with predicted values 1 to 17 percent strain higher than observed. Given the scatter in burst strain measurements from similar rods subjected to similar LOCA burst tests (±50 percent strain), this overprediction is reasonable and conservative from a flow blockage standpoint.

Table 4.2. FRAPTRAN-2.0 Predicted and Measured Peak Cladding Residual Strain Following LOCA Tests

Case	Measured Peak Residual Hoop Strain, %	FRAPTRAN-2.0 Peak Residual Hoop Strain, %
TREAT rod 16 and 17	58% and 33%	62.0%
LOC-11C rod 2	2.5%	67.6%
LOC-11C rod 3	1.6%	78.4%
LOC-11C rods 1 and 4	-0.96% and -0.84%	0.19%
IFA-650.5	16%	31%
IFA-650.6	36%	36%
IFA-650.7	24%	36%

4.3 High-Temperature Oxidation Predictions

The high-temperature oxidation prediction during LOCA events was assessed using the three rods from the IFA-650 assessment cases. The Cathcart-Pawel model was used for these cases as recommended in the FRAPTRAN-2.0 input instructions. FRAPTRAN-2.0 has two options to treat the existing oxide as protective or non-protective with respect to further high-temperature oxidation. Both of these options were exercised for these three cases to determine if one option was more applicable than the other.

The measured and predicted oxide thickness increase is shown in Figure 4.9 and Table 4.3. It can be seen that the non-protective option in FRAPTRAN-2.0 produces results that compare well with or bound the peak measured oxide thickness increase during the tests for the tests done on Zircaloy-4 (IFA-650.5), E-110 (IFA-650.6), and Zircaloy-2 (IFA-650.6). This is to be expected as the existing oxide layer is expected to offer some resistance to further oxidation, but the large deformations and high oxidation experienced during the LOCA are expected to cause some cracking in the oxide layer that would reduce its effectiveness as a barrier to further oxidation. The protective option underpredicts the oxide for all three cases.

This assessment demonstrates that FRAPTRAN-2.0 predicts reasonable or bounding values of high-temperature corrosion thickness following a LOCA if the non-protective option is used. For rods with pre-existing oxide layers, the protective option in FRAPTRAN-2.0 tends to underpredict the oxide layer thickness and the non-protective option in FRAPTRAN-2.0 tends to provide a best estimate or overpredict the oxide layer thickness.

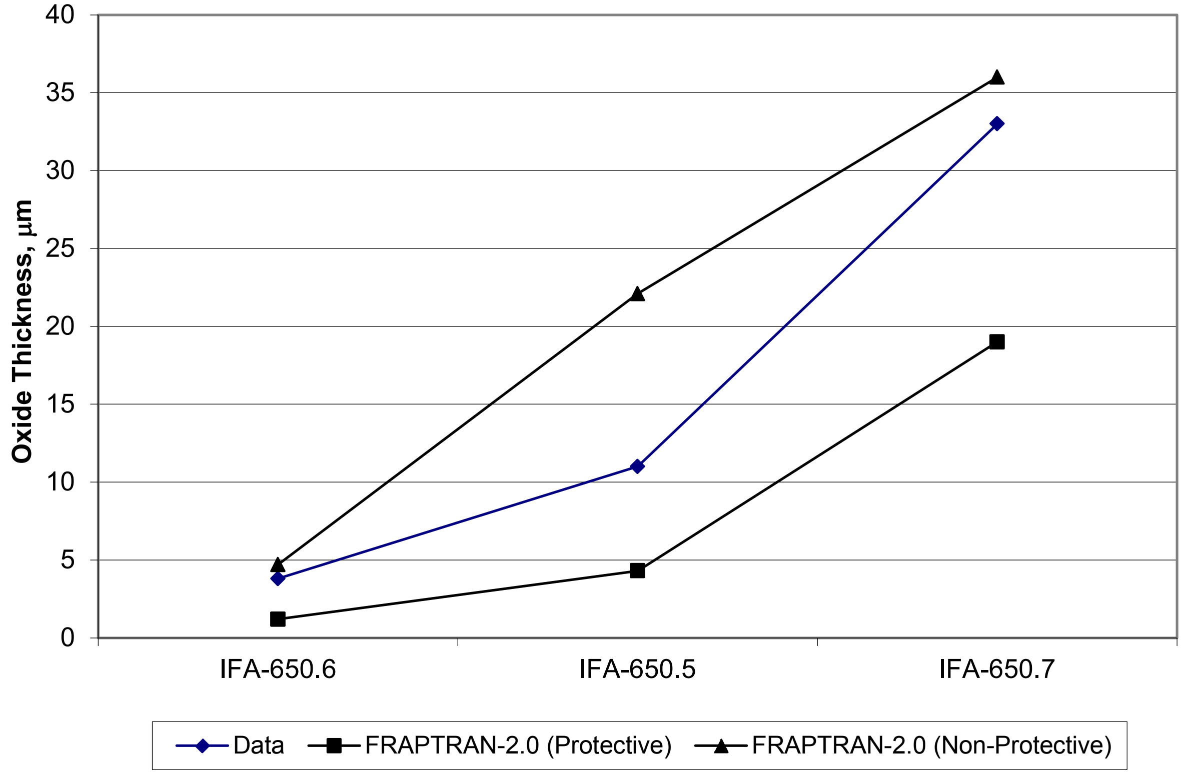

Figure 4.9. FRAPTRAN-2.0 Predicted and Measured Peak Oxide Thickness Increase During the LOCA Test Using Cathcart-Pawel Model and Treating the Existing Oxide Layer as Protective and Non-protective to Further Oxidation

Table 4.3. FRAPTRAN-2.0 Predicted and Measured Peak Oxide Thickness Increase During the LOCA Test Using Cathcart-Pawel Model and Treating the Existing Oxide Layer as Protective and Non-protective to Further Oxidation

	Measured Peak Outer Diameter Oxide Thickness Increase During Test	FRAPTRAN-2.0 Peak Outer Diameter Oxide Thickness Increase During Test	
		Protective	Non-protective
IFA-650.5	11 µm	4.3 µm	22.1 µm
IFA-650.6	3.8 µm	1.2 µm	4.7 µm
IFA-650.7	33 µm	19 µm	36 µm

5.0 Conclusions

The FRAPTRAN-2.0 transient fuel behavior computer code has been assessed against a selected set of experimental fuel rod transient data. The selected data are from tests simulating RIAs and LOCAs. Because of the sensitivity of the code calculations to the assumed thermal-hydraulic conditions, an effort was made to minimize the impact of the thermal-hydraulic calculations on the calculated fuel and cladding thermal and mechanical behavior. The FRAPCON-4.0 code was used to initialize burnup-dependent parameters for FRAPTRAN-2.0.

The FRAPTRAN-2.0 predictions compared reasonably well to the experimental data. Specific observations and conclusions about the performance of FRAPTRAN are summarized as follows.

RIA Cases: FRAPTRAN-2.0 predicts reasonable values of cladding hoop strain for cases with less than 2 percent hoop strain. For cases with greater than 2 percent measured hoop strain, FRAPTRAN-2.0 underpredicts the measured hoop strain. FRAPTRAN-2.0 provides a best-estimate prediction of cladding failure during a RIA when cladding surface temperatures are well known. FRAPTRAN-2.0 predicts UO_2 transient FGR well, with a standard deviation of 4.0 percent FGR (absolute) and an underprediction on average of 1.9 percent FGR absolute.

LOCA Cases: FRAPTRAN-2.0 predicts cladding failure well, correctly predicting 8 out of 10 cases (for the other two cases, failure was predicted when none was observed). FRAPTRAN-2.0 often predicts failure before it was actually observed, but this may be due to an external gas plenum volume in the test for which information is not provided and FRAPTRAN-2.0 does not model. FRAPTRAN-2.0 predicts reasonable values of cladding hoop strain for rods before and after ballooning and burst, with predicted values 2 to 17 percent strain (absolute) higher than observed when failure was correctly calculated. In several cases failure was predicted when none was observed, leading to a large overestimation of the cladding strain (50% strain). Given the scatter in burst strain measurements from similar rods subjected to similar LOCA burst tests (±50 percent strain) (Powers and Meyer 1980), this overprediction is reasonable and conservative from a flow blockage standpoint. FRAPTRAN-2.0 predicts reasonable values of high-temperature oxide thickness following a LOCA. For rods with pre-existing oxide layers, the protective option in FRAPTRAN-2.0 tends to underpredict the oxide layer thickness and the non-protective option in FRAPTRAN-2.0 tends to predict reasonable or bounding values of high-temperature corrosion thickness following a LOCA.

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Appendix A

Input Files for FRAPTRAN-2.0 Assessment Cases

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Input Files for FRAPTRAN-2.0 Assessment Cases

RIA Assessment Cases

A.1 CABRI Tests

The CABRI rodlets were taken from commercial rods that were base irradiated in various commercial pressurized-water reactors (PWRs). After base irradiation and refabrication, the rodlets were subjected to a reactivity-initiated accident (RIA) pulse in the CABRI reactor with 280°C flowing sodium (Papin et al. 2003) (Georgenthum 2009) (Jeury et al. 2003) (Jeury et al. 2004). The following describes the modeling approach and assumptions used to model these tests with FRAPTRAN-2.0 initialized with FRAPCON-4.0.

FRAPCON-4.0 was set up using the following assumptions and a FRAPTRAN initialization file was created.

The as-fabricated dimensions for each rodlet were taken from the data sheet for the father rod. When modeling the base irradiation of a rod that will later be cut into a segment to be tested, it is necessary to model the base irradiation on the short segment only.

The power history given for each father rod was used for the base irradiation in FRAPCON-4.0. This power history was uniformly scaled by a constant factor to achieve the measured burnup for the rodlet. The axial power profile was assumed to be flat over the length of the rodlet based on a flat axial gamma scan.

The coolant pressure and mass flow rate were taken as typical values for the commercial reactor in which each rodlet was irradiated. The coolant inlet temperature for modeling the rodlet should be greater than the reactor inlet temperature due to heatup along the length below the rodlet. To model the base irradiation accurately, the inlet temperature was set such that the average predicted end of life oxide thickness was close to the measured value while still being a reasonable value for the span from which the rodlet was taken.

A FRAPTRAN-2.0 input file was created using the unirradiated dimensions for the father rod in FRAPCON-4.0. These dimensions are adjusted for changes that occurred during the base irradiation by the FRAPTRAN initialization file that was created by FRAPCON-4.0. This process is critical to modeling an RIA that occurs after prior irradiation. The provided RIA power history was used for the linear heat generation rate (LHGR). The axial power profile from the final thermal balance was used as the axial power profile during the RIA test.

Measured cladding surface temperature histories were available for several axial locations during each of the CABRI tests. To model the coolant conditions, the rod was divided into several zones and the measured temperature histories for each of the axial elevations were set to the coolant temperature in each of these axial zones. To force the code to use the same coolant temperature and cladding surface temperature, a large cladding-to-coolant heat transfer coefficient (352,222 Btu/ft^{2}hr°F) was set in the code as recommended in the FRAPTRAN-2.0 input instructions.

The FRAPTRAN initialization file that was created with FRAPCON-4.0 includes gas from the initial father rod pressurization and subsequent calculated fission gas release (FGR) during the base irradiation. When the rodlets were refabricated, they were refilled with a different gas composition and pressure. The FRAPTRAN initialization file was manually adjusted to reflect this new gas mixture and pressure. Within each restart file, information is contained for each FRAPCON-4.0 time step. The first line is the time in seconds. The ninth and tenth lines after this contain the number of moles of gas and the relative amount of each gas species. These are the lines that are changed in the following listings of assessment cases.

The FRAPCON-4.0 and FRAPTRAN-2.0 input files for each case are listed below. Also shown below is the change made to the FRAPTRAN initialization file to account for the different fill gas conditions after the base irradiation.

REP-Na1 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-NA1-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na1', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-NA1-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*******************************************************************
Base Irradiation of REP NA-1
 $frpcn
 im=38, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3743, thkcld=2.2677e-2, thkgap=3.2283e-3, totl=1.8668, cpl=5.528,
 dspg=0.315, dspgw=0.0315, vs=5,
 hplt=0.561, rc=0.0, hdish=1.209e-2, dishsd=0.0452,
 enrch=4.5, fotmtl=2.0,
 den=95.25, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=377.1, amfair=0.03846, amfhe=0.96154,
 iplant=-2,nsp=0, p2=2248.08, tw=600.0, go=2.387e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=11, jst=38*1, iq=0, fa=1,
 x(1)=0.0,0.18668,0.37336,0.56004,0.74672,0.9334,1.12008,
         1.30676,1.49344,1.68012,1.8668
 qf(1)=0.940776,0.862671,0.969551,1.006548,1.027689,1.035323,
       1.048830,1.051766,1.038259,0.944299,1.089350,
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
                0.6,  50.0, 100.0, 150.0, 200.0,
              250.0, 300.0, 350.0, 400.0, 450.0,
              500.0, 550.0, 560.0, 600.0, 650.0,
              670.0, 700.0, 750.0, 800.0, 850.0,
              900.0, 950.0,1000.0,1050.0,1100.0,
             1150.0,1180.0,1200.0,1250.0,1300.0,
             1350.0,1400.0,1450.0,
 qmpy=       1.000,2.000,3.000,4.000,5.000,
             6.000,6.640,6.640,7.163,7.163,
             7.163,6.950,6.950,7.163,7.163,
             7.163,7.163,7.163,5.730,5.730,
```

```
            5.730,5.883,5.883,5.944,5.944,
            5.273,5.273,5.273,5.273,5.273,
            5.273,5.273,5.243,5.243,5.243,
            5.243,5.243,5.243,
 $end
```

REP-Na1 Change to Restart File

```
   0.0948E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na1 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                         *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='out.na1',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'           *
FILE66='stripf.na1', STATUS='UNKNOWN', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                         *
FILE22='restart.NA1' , STATUS='old', FORM='FORMATTED'                   *
/************************************************************************
REP-Na1, for EPRI review (8/26/03)
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
 $iodata
   unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.002, trest=1.2528e8,
 $end
 $solution
   dtmaxa(1)=0.0001,0.0, 0.0001,0.0702, 0.00001,0.079,
   0.00001,0.0815,0.0001, 0.09,
   0.001,0.15,
   naxn=11, nfmesh=20, ncmesh=5,
 $end
 $design
   RodLength=1.8668, RodDiameter=0.03119, gapthk=2.6903e-4,vplen=6.784e-5
   ncs=5, spl=0.5, scd=2.62e-2, swd=2.62e-3,
   FuelPelDiam=2.6877e-2, rshd=9.675e-3, dishd=1.008e-3, pelh=4.6752e-2,
   dishv0=2.975e-7,
   frden=0.9525, roughf=2.0,
   coldw=0.5, roughc=0.5,   cldwdc=0.04,
   gfrac(1)=0.96154, gfrac(6)=0.03846, gappr0=377.1, tgas0=71.6,
   pitch=4.15e-2, pdrato=1.32,
 $end
 $power
   fpowr=0.864
   RodAvePower = 0.,0., 0.,0.06,160.0,0.066,320.0,0.068,
                 640.0,0.07,3400.0,0.075,7200.0,0.079,
                 7360.0,0.0797,7200.0,0.0805,3200.0,0.085
                 1680.0,0.087,800.0,0.089,560.0,0.09,
                 180.0,0.093,80.0,0.095,0.0,0.1,0.0,1.0,
   AxPowProfile = 0.728,0.000,0.884,0.197,0.975,0.328,
                  1.047,0.459,1.100,0.591,1.136,0.722,
                  1.156,0.853,1.161,0.984,1.148,1.115,
                  1.113,1.247,1.053,1.378,0.966,1.509,
```

```
                  0.857,1.640,0.744,1.772,0.668,1.8668,
 $end
 $model
   internal='on',
   metal='on', cathca=1,
   deformation='on', noball=1,
   nthermex=1
 $end
 $boundary
   heat='on'
   press=2, pbh2(1)=72.52,0.0, 72.52,1.0,
   zone=3, htclev =0.502, 1.224,1.8668
   htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
           htca(1,2)= 352222.0,0., 352222.0,1.,
           htca(1,3)= 352222.0,0., 352222.0,1.,
   tem=9,
   tblka(1,1)= 536.,0.00,536.,0.08,806.,0.14,752.,0.16,662.,0.2
                  626.,0.27,590.,0.40,572.,0.70,554.,1.00
   tblka(1,2)= 536.,0.00,536.,0.08,1382.,0.14,1607.,0.16,1382.,0.2
                  1508.,0.27,1427.,0.40,1094.,0.70,896.,1.00
   tblka(1,3)= 536.,0.00,536.,0.08,932.,0.14,1022.,0.16,1121.,0.2
                  1112.,0.27,1202.,0.40,1310.,0.70,1247.,1.00
 $end
 $tuning
 $end
```

REP-Na2 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-NA2-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na2', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-NA2-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/***********************************************************************
Base Irradiation of REP NA-2
 $frpcn
 im=20, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3744, thkcld=2.508e-2, thkgap=3.6614e-3, totl=3.307, cpl=1.796,
 dspg=0.315, dspgw=0.0315, vs=5,
 hplt=0.472, rc=0.0, hdish=1.142e-2, dishsd=0.0384,
 enrch=6.85, fotmtl=2.0,
 den=94.30, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=1, fgpav=246.56,crdt=0.5,
 iplant=-2,nsp=0, p2=2030.5, tw=491.0, go=1.309e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=20, jst=20*1, iq=0, fa=1,
 x(1)=0.000,0.248,0.413,0.579,0.744,0.909,1.075,1.240,1.405,1.571,
      1.736,1.902,2.067,2.232,2.398,2.563,2.728,2.894,3.059,3.307,
 qf(1)=0.497,0.703,0.875,1.002,1.088,1.162,1.213,1.258,1.275,1.253,
       1.187,1.248,1.226,1.173,1.103,1.011,0.888,0.725,0.572,0.459,
```

```
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
              50.0, 100.0, 150.0, 200.0, 250.0,
             300.0, 350.0, 400.0, 450.0, 500.0,
             550.0, 560.0, 600.0, 650.0, 660.0,
 qmpy=       1.000,2.000,3.000,4.000,5.000,
            15*5.665
 $end
```

REP-Na2 Change to Restart File

```
   0.1709E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na2 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                     *
        CARRIAGE CONTROL='LIST'                                            *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                         *
*                                                                          *
FILE06='out.na2',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'              *
FILE66='stripf.na2', STATUS='UNKNOWN', FORM='FORMATTED',                   *
        CARRIAGE CONTROL='LIST'                                            *
FILE22='restart.NA2' , STATUS='old', FORM='FORMATTED'                      *
/**************************************************************************
REP-Na2, for EPRI review (1/16/04)
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=0.4,
 $end
 $iodata
   unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.002, trest=5.702e7,
 $end
 $solution
   dtmaxa(1)=0.0001,0.0, 0.00001,0.07, 0.000001, 0.085,0.00001,0.1,
   0.0001,0.15,
   naxn=11, nfmesh=20, ncmesh=5,
 $end
 $design
   RodLength=3.307, RodDiameter=0.0312, gapthk=3.0512e-4,vplen=8.581e-5
   ncs=5, spl=0.5, scd=2.62e-2, swd=2.62e-3,
   FuelPelDiam=2.6411e-2, rshd=1.000656e-2, dishd=9.5144e-4, pelh=3.933e-2,
   dishv0=3.18002e-7,
   frden=0.9430, roughf=2.0,
   coldw=0.5, roughc=0.5,cldwdc=0.04,
   gfrac(1)=1.0, gappr0=246.56, tgas0=71.6,
   pitch=4.15e-2, pdrato=1.32,
 $end
 $power
   fpowr=0.659
   RodAvePower =     0.0,0.000,    0.0,0.060,  137.0,0.065,
                   890.6,0.070, 5480.9,0.075,12263.5,0.0805,
                  6851.1,0.085, 1233.2,0.090,  137.0,0.095,
                    28.4,0.100,    0.0,0.4,
   AxPowProfile = 0.247, 0.000, 0.247, 0.328, 0.495, 0.574,
                  0.928, 0.984, 1.181, 1.234, 1.320, 1.365,
                  1.418, 1.496, 1.496, 1.627, 1.573, 1.759,
                  1.532, 1.890, 1.504, 2.021, 1.473, 2.152,
```

```
                  1.428, 2.283, 1.369, 2.415, 1.290, 2.546,
                  1.187, 2.677, 1.062, 2.808, 0.914, 2.940,
                  0.754, 3.071, 0.605, 3.202, 0.511, 3.307
 $end
 $model
   internal='on',
   metal='on', cathca=1,
   deformation='on', noball=1,
   nthermex=1
 $end
 $boundary
   heat='on'
   press=2, pbh2(1)=72.52,0.0, 72.52,1.0,
   zone=1, htclev =3.307,
   htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
   tem=9,
   tblka(1,1)= 536.0,0.00,536.0,0.05,545.0,0.10,
                  635.0,0.15,734.0,0.20,806.0,0.25,
                  878.0,0.30,914.0,0.35,950.0,0.40,
 $end
```

REP-Na3 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-NA3-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na3', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-NA3-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of REP NA-3
 $frpcn
 im=30, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3743, thkcld=2.2677e-2, thkgap=3.2283e-3, totl=1.4304, cpl=1.292,
 dspg=0.315, dspgw=0.0315, vs=5,
 hplt=0.535, rc=0.0, hdish=1.260e-2, dishsd=0.04316,
 enrch=4.5, fotmtl=2.0,
 den=94.75, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=377.1, amfair=0.03846, amfhe=0.96154,
 iplant=-2,nsp=0, p2=2248.08, tw=590.0, go=2.387e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=20, jst=30*1, iq=0, fa=1,
 x(1)= 0.000,0.170,0.179,0.250,0.322,0.393,0.465,0.536,0.608,0.679,
       0.751,0.822,0.894,0.966,1.037,1.109,1.180,1.252,1.323,1.4304,
 qf(1)=1.044,1.044,1.043,1.041,1.038,1.036,1.033,1.031,1.028,1.023,
       1.017,1.011,1.002,0.994,0.983,0.971,0.958,0.936,0.904,0.849,
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
                0.6,  50.0, 100.0, 150.0, 200.0,
              250.0, 300.0, 350.0, 400.0, 450.0,
              500.0, 550.0, 580.0,
```

```
              600.0, 650.0, 700.0, 750.0, 800.0,
              850.0, 900.0, 950.0,1000.0,1050.0,
             1100.0,1143.0,
 qmpy=       1.000,2.000,3.000,4.000,5.000,
             6.000,12*7.13,12*6.00
 $end
```

REP-Na3 Change to Restart File

```
   0.2809E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na3 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                    *
        CARRIAGE CONTROL='LIST'                                           *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                        *
*                                                                         *
FILE06='out.na3',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'             *
FILE66='stripf.na3', STATUS='UNKNOWN', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                           *
FILE22='restart.NA3' , STATUS='old', FORM='FORMATTED'                     *
/**************************************************************************
REP-Na3, for EPRI review (1/23/04)
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=0.4,
 $end
 $iodata
   unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.002, trest=9.876e7,
 $end
 $solution
   dtmaxa(1)=0.0001,0.0, 0.0001,0.0702, 0.00001,0.08,
   0.0001,0.0815,0.0001, 0.09,
   0.001,0.15,
   naxn=11, nfmesh=20, ncmesh=5,
 $end
 $design
   RodLength=1.4304, RodDiameter=0.03119, gapthk=2.6903e-4,vplen=6.3566e-5
   ncs=5, spl=0.5, scd=2.62e-2, swd=2.62e-3,
   FuelPelDiam=2.6877e-2, rshd=9.842e-3, dishd=1.05e-3, pelh=4.458e-2,
   dishv0=3.207e-7,
   frden=0.9475, roughf=2.0,
   coldw=0.5, roughc=0.5,cldwdc=0.04,
   gfrac(1)=0.96154, gfrac(6)=0.03846, gappr0=377.1, tgas0=71.6,
   pitch=4.15e-2, pdrato=1.32,
 $end
 $power
   fpowr=0.917
   RodAvePower = 0.0,0.0,0.0,0.06,102.7,0.065,410.8,0.07,2465.0,0.075,
   7723.5,0.0816,5751.6,0.084,3286.6,0.087,
   1027.1,0.09,82.2,0.095,25.1,0.1,0.0,0.4
   AxPowProfile = 0.857,0.0000,0.968,0.1937,
     1.027,0.3229,1.063,0.4521,1.082,0.5812,1.090,0.7104,1.084,0.8395,
     1.061,0.9687,1.011,1.0979,0.921,1.2270,0.834,1.3562,0.786,1.4304,
 $end
 $model
```

```
   internal='on',
   metal='on', cathca=1,
   deformation='on', noball=1,
   nthermex=1
 $end
 $boundary
   heat='on'
   press=2, pbh2(1)=72.52,0.0, 72.52,1.0,
   zone=2, htclev =1.01,1.4304,
   htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
           htca(1,2)= 352222.0,0., 352222.0,1.,
   tem=9,
   tblka(1,1)= 536.0,0.000,536.0,0.075,563.0,0.100,671.0,0.150,743.0,0.200,
                  743.0,0.250,725.0,0.300,710.6,0.350,696.2,0.400,
   tblka(1,2)= 536.0,0.000,536.0,0.075,554.0,0.100,698.0,0.150,770.0,0.200,
                  806.0,0.250,815.0,0.300,815.0,0.350,806.0,0.400,
 $end
 $tuning
 $end
```

REP-Na4 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-NA4-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na4', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-NA4-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of REP NA-4
 $frpcn
 im=48, na=10,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3745, thkcld=2.2766e-2, thkgap=3.2283e-3, totl=1.8622, cpl=5.528,
 dspg=0.315, dspgw=0.0315, vs=5,
 hplt=0.541, rc=0.0, hdish=1.181e-2, dishsd=0.04317,
 enrch=4.49, fotmtl=2.0,
 den=95.5, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=377.1, amfair=0.03846, amfhe=0.96154,
 iplant=-2,nsp=1, p2=48*2248.08,
tw=14*591.0,9*600.0,7*593.0,8*586.0,10*583.0,
 go=48*2.387e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=5, jst=48*1, iq=0, fa=1,
 x(1)=0.0,0.46555,0.9311,1.39665,1.8622,
 qf(1)=1.0,1.0,1.0,1.0,1.0,
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
               32.0,  50.0,  92.0, 100.0, 150.0,
              167.0, 200.0, 214.0, 237.0, 253.0,
              300.0, 350.0, 383.0, 400.0, 450.0,
              500.0, 550.0, 552.0, 600.0, 650.0,
```

```
             700.0, 750.0, 760.0, 800.0, 835.0,
             850.0, 900.0, 950.0, 996.0,1000.0,
            1050.0,1100.0,1122.0,1150.0,1200.0,
            1204.0,1250.0,1300.0,1343.0,1350.0,
            1400.0,1404.0,1443.0,
 qmpy=      1.00,2.00,3.00,4.00,5.00,
            6.18,6.49,6.49,6.56,6.56,
            6.56,6.66,6.66,6.56,7.93,
            7.98,7.98,7.98,7.79,7.79,
            7.79,7.79,7.79,6.77,6.77,
            6.77,6.77,6.77,6.84,6.84,
            5.63,5.63,5.63,5.63,5.84,
            5.84,5.84,5.84,4.85,4.85,
            4.85,5.12,5.12,5.12,5.26,
            5.26,5.26,4.50,
 $end
```

REP-Na4 Change to Restart File

```
   0.3045E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na4 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                    *
        CARRIAGE CONTROL='LIST'                                           *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                        *
*                                                                         *
FILE06='out.na4',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'             *
FILE66='stripf.na4', STATUS='UNKNOWN', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                           *
FILE22='restart.NA4' , STATUS='old', FORM='FORMATTED'                     *
/*************************************************************************
REP-Na4, for EPRI review (9/11/03)
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.2,
 $end
 $iodata
   unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.002, trest=1.247e8,
 $end
 $solution
   dtmaxa(1)=   0.01,0.00,  0.001,0.40, 0.0001,0.50,
              0.0001,0.55,   0.0001,0.70,    0.001,1.20,
   naxn=10, nfmesh=20, ncmesh=5,
 $end
 $design
   RodLength=1.8622, RodDiameter=0.03121, gapthk=2.6903e-4,vplen=6.78399e-5,
   ncs=5, spl=0.0583, scd=2.62e-2, swd=2.62e-3,
   FuelPelDiam=2.6880e-2, rshd=9.8425e-3, dishd=9.8417e-4, pelh=4.5083e-2,
   dishv0=3.0055e-7,
   frden=0.955, roughf=2.0,
   coldw=0.5, roughc=0.5,   cldwdc=0.04,
   gfrac(1)=0.96154, gfrac(6)=0.03846, gappr0=377.1, tgas0=71.6,
   pitch=4.15e-2, pdrato=1.32,
 $end
 $power
```

```
   fpowr=0.855
   RodAvePower =     0.0,0.000,   0.0,0.400,   1.1,0.403,
                     7.7,0.466,  29.5,0.489,  71.4,0.503,
                   148.6,0.515, 479.0,0.533, 546.1,0.542,
                   428.7,0.554, 707.1,0.583, 398.4,0.603,
                   217.2,0.611, 119.9,0.621, 105.9,0.625,
                    69.6,0.635,  52.8,0.647,  42.7,0.687,
                    34.1,0.809,  30.5,0.953,  23.8,1.000,
                    13.6,1.052,   8.5,1.101,   5.1,1.146,
                     0.0,1.200,
   AxPowProfile = 0.720,0.0000,0.899,0.1968,0.976,0.3281,
                  1.038,0.4593,1.091,0.5905,1.135,0.7218,
                  1.164,0.8530,1.174,0.9842,1.160,1.1155,
                  1.118,1.2467,1.049,1.3779,0.955,1.5092,
                  0.842,1.6404,0.717,1.7716,0.619,1.8622,
 $end
 $model
   internal='on',
   metal='on', cathca=1,
   deformation='on', noball=1,
   nthermex=1
 $end
 $boundary
   heat='on'
   press=2, pbh2(1)=72.52,0.0, 72.52,1.0,
   zone=2, htclev =1.22, 1.8622,
   htco=2, htca(1,1)= 352222.0,0., 352222.0,1.2,
           htca(1,2)= 352222.0,0., 352222.0,1.2,
   tem=9,
   tblka(1,1)= 537.2, 0.00, 537.8, 0.49, 590.2, 0.63,
                  640.8, 0.69, 656.0, 0.73, 662.4, 0.80,
                  646.1, 0.96, 610.6, 1.30, 600.0, 1.50,
   tblka(1,2)= 537.2, 0.00, 537.8, 0.52, 598.4, 0.62,
                  671.7, 0.69, 711.3, 0.78, 721.7, 0.87,
                  724.1, 0.93, 711.8, 1.10, 657.7, 1.50,
 $end
 $tuning
 $end
```

REP-Na5 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-NA5-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na5', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-NA5-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/***********************************************************************
Base Irradiation of REP NA-5
 $frpcn
 im=48, na=10,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
```

```
 dco=0.3745, thkcld=2.2766e-2, thkgap=3.2283e-3, totl=1.8488, cpl=5.528,
 dspg=0.315, dspgw=0.0315, vs=5,
 hplt=0.541, rc=0.0, hdish=1.181e-2, dishsd=0.04317,
 enrch=4.49, fotmtl=2.0,
 den=95.5, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=377.1, amfair=0.03846, amfhe=0.96154,
 iplant=-2,nsp=0, p2=2248.08, tw=548.6, go=2.387e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=10, jst=48*1, iq=0, fa=1,
 x(1)=0.0000,0.1253,0.2670,0.4295,0.7123,
      0.9688,1.2096,1.5289,1.6703,1.8488,
 qf(1)=0.974,0.922,0.977,1.006,1.016,
       1.022,1.022,1.013,1.005,0.938,
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
               32.0,  50.0,  92.0, 100.0, 150.0,
              167.0, 200.0, 214.0, 237.0, 253.0,
              300.0, 350.0, 383.0, 400.0, 450.0,
              500.0, 550.0, 552.0, 600.0, 650.0,
              700.0, 750.0, 760.0, 800.0, 835.0,
              850.0, 900.0, 950.0, 996.0,1000.0,
             1050.0,1100.0,1122.0,1150.0,1200.0,
             1204.0,1250.0,1300.0,1343.0,1350.0,
             1400.0,1404.0,1443.0,
 qmpy=       1.00,2.00,3.00,4.00,5.00,
             6.24,6.55,6.55,6.62,6.62,
             6.62,6.72,6.72,6.62,8.00,
             8.05,8.05,8.05,7.86,7.86,
             7.86,7.86,7.86,6.83,6.83,
             6.83,6.83,6.83,6.90,6.90,
             5.68,5.68,5.68,5.68,5.89,
             5.89,5.89,5.89,4.90,4.90,
             4.90,5.16,5.16,5.16,5.31,
             5.31,5.31,4.54,
 $end
```

REP-Na5 Change to Restart File

```
   0.3619E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na5 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                         *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='out.na5',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'           *
FILE66='stripf.na5', STATUS='UNKNOWN', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                         *
FILE22='restart.NA5' , STATUS='old', FORM='FORMATTED'                   *
/************************************************************************
REP-Na5, for EPRI review (9/12/03)
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=0.4,
 $end
```

```
 $iodata
   unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.002, trest=1.247e8,
 $end
 $solution
   dtmaxa(1)=  0.001,0.00,  0.0001,0.059, 0.00001,0.08,
              0.0001,0.10,   0.001,0.4,
   naxn=10, nfmesh=20, ncmesh=5,
 $end
 $design
   RodLength=1.8488, RodDiameter=0.03121, gapthk=2.6903e-4,vplen=8.490e-5,
   ncs=5, spl=0.0583, scd=2.62e-2, swd=2.62e-3,
   FuelPelDiam=2.6880e-2, rshd=9.8425e-3, dishd=9.8417e-4, pelh=4.5083e-2,
   dishv0=3.0055e-7,
   frden=0.955, roughf=2.0,
   coldw=0.5, roughc=0.5,cldwdc=0.04,
   gfrac(1)=0.96154, gfrac(6)=0.03846, gappr0=377.1, tgas0=71.6,
   pitch=4.15e-2, pdrato=1.32,
 $end
 $power
   fpowr=0.857
   RodAvePower =    0.0,0.000,   0.0,0.059,  71.1,0.063,
                  231.2,0.066, 729.3,0.070,2116.7,0.073,
                 4892.4,0.076,6741.3,0.079,4197.7,0.083,
                 2098.9,0.085, 711.5,0.088, 338.0,0.090,
                  213.4,0.091,  71.1,0.095,  63.8,0.096,
                   32.0,0.100,   0.0,0.400,
   AxPowProfile = 0.709,0.0000,0.890,0.1968,0.966,0.3281,
                  1.031,0.4593,1.087,0.5905,1.133,0.7218,
                  1.162,0.8530,1.168,0.9842,1.149,1.1155,
                  1.105,1.2467,1.037,1.3779,0.951,1.5092,
                  0.849,1.6404,0.727,1.7716,0.644,1.8488,
 $end
 $model
   internal='on',
   metal='on', cathca=1,
   deformation='on', noball=1,
   nthermex=1
 $end
 $boundary
   heat='on'
   press=2, pbh2(1)=72.52,0.0, 72.52,1.0,
   zone=1, htclev =1.8488,
   htco=2, htca(1,1)= 352222.0,0., 352222.0,1.2,
   tem=10,
   tblka(1,1)= 536.5,0.0000,537.5,0.0740,571.8,0.1062,
                  633.1,0.1333,676.8,0.1655,717.3,0.2026,
                  743.3,0.2499,764.1,0.3096,766.1,0.3470,
                  765.1,0.4000,
 $end
 $tuning
 $end
```

REP-Na6 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
```

```
*
* GOESOUTS:
FILE06='REP-Na6-Base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na6', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-Na6-Base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*****************************************************************************
Base Irradiation
 $frpcn
 im=38, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02244, thkgap=0.00329, totl=1.81594, cpl=1.1693
 dspg=0.315, dspgw=0.0394, vs=10, ngasmod=2
 hplt=0.4626, rc=0, hdish=0.0119, dishsd=0.0652
 enrch=0.253, imox=1, comp=5.925
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.34, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=0.3
 fgpav=377.1, idxgas=6
 amfair=0.0385, amfarg=0, amffg=0, amfhe=0.9615, amfh2=0
 amfh2o=0, amfkry=0, amfn2=0, amfxe=0
 iplant=-2, pitch=0.4961, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 8.25, 70.1, 79.38, 164.94, 192.78
 223.71, 244.84, 267, 294.84, 295.87
 312.88, 318.55, 338.14, 365.97, 397.93
 429.89, 444.32, 470.09, 501.53, 529.37
 554.62, 578.33, 588.64, 592.77, 593.8
 606.17, 657.2, 684.52, 706.17, 721.63
 753.59, 781.42, 806.16, 837.09, 891.73
 903.07, 907.19, 909.77
 qmpy=
 4.047, 8.08, 8.035, 7.98, 7.973
 7.667, 7.633, 7.76, 7.192, 3.393
 4.291, 8.613, 8.606, 8.545, 8.493
 8.493, 8.441, 8.431, 7.695, 7.667
 8.417, 8.386, 8.245, 8.111, 4.054
 3.778, 7.526, 7.216, 7.024, 7.017
 7.116, 7.295, 7.196, 7.165, 7.137
 6.934, 6.814, 3.407
 nsp=0
 p2= 2248.09, tw= 579.2, go= 2550000
 iq=0, fa=1
 x(1)=
 0, 0.65617, 1.24573, 1.35761, 1.44521
 1.57251, 1.65715, 1.81594
 qf(1)=
 578313, 581928, 572892, 554820, 502410
 554820, 562049, 560241
 jn=8
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
```

```
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
 $frpmox
 enrpu39=65.95, enrpu40=23.9, enrpu41=6.63, enrpu42=3.52
 $end
```

REP-Na6 Change to Restart File

```
   0.2650E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na6 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                        *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                     *
*                                                                      *
FILE06='Na6.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='Na6.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.na6' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
REP-Na6 Mox case Bu=47, h=156 cal/g, width=32ms
$begin
 ProblemStartTime=0, ProblemEndTime=1.2
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=78600000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.01, 0
 dtplta(1)=
0.002, 0
$end
$solution
 dtmaxa(1)=
0.0001, 0.0,0.00001, 1.0
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=5
$end
$design
RodLength=1.81592, FuelPelDiam=0.0269, gapthk=0.000274, vplen=0.00005756
volbp=0, dishv0=0.000000100667
scd=0.0262, swd=0.0033, spl=0.0974, ncs=10
RodDiameter=0.0312, pelh=0.0385, rshd=0.008009, dishd=0.000994
frpo2=0.05925, fotmtl=2, gadoln=0
```

```
roughf=2, frden=0.9534, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0.5, roughc=0.5, CladType=4, cldwdc=0.04
gfrac(1)=0.9615, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0.0385, gfrac(7)=0, gappr0=377.1, tgas0=68
pitch=0.0413, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 4.193, 0.0999, 2.478, 0.20087
0.737, 0.29974, 4.93, 0.39964, 62.512, 0.50784
169.265, 0.52235, 643.203, 0.54449, 820.978, 0.55674
1552.399, 0.57309, 1765.62, 0.57896, 1626.537, 0.58345
877.652, 0.59133, 256.152, 0.6063, 149.698, 0.61599
123.288, 0.63497, 85.193, 0.66661, 52.004, 0.85598
38.876, 0.99168, 7.921, 1.12216, 2.96, 1.2
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
0.729, 0, 0.871, 0.13123, 0.921, 0.19685
0.962, 0.26246, 0.997, 0.32808, 1.027, 0.3937
1.076, 0.52493, 1.097, 0.59054, 1.114, 0.65616
1.129, 0.72178, 1.14, 0.78739, 1.147, 0.85301
1.149, 0.91862, 1.147, 0.98424, 1.14, 1.04986
1.109, 1.18109, 1.085, 1.2467, 1.056, 1.31232
1.021, 1.37794, 0.98, 1.44355, 0.934, 1.50917
0.881, 1.57478, 0.821, 1.6404, 0.754, 1.70602
0.613, 1.81592
$end
$model
nthermex=1, tref=77
internal='on'
PlenumTemp=1, gasflo=0, prescri=0, presfgr=0
metal='off'
deformation='on'
noball=1, TranSwell=0
heat='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=16, zone=3
htclev(1)=0.48228, 1.20405, 1.81592
 pbh2(1)=
72.5189, 0, 72.5189, 1.2
 htca(1,1)=
62029.8164, 0, 62029.8164, 1.2
 tblka(1,1)=
534.8164, 0, 535.5054, 0.122700915992045, 536.2715, 0.267049497184795
535.5941, 0.376834084988375, 535.5248, 0.506417546709992, 543.2683,
0.569486540239222
553.7418, 0.597067144737948, 561.7115, 0.630185719487941, 562.017,
0.66998515364576
558.9088, 0.730474242975994, 556.9378, 0.770777892938178, 554.4367,
0.83113252472058
552.0855, 0.856570212050758, 549.4343, 0.951841788285386, 546.103,
1.10208129079246
543.6081, 1.2
```

```
 htca(1,2)=
62029.8164, 0, 62029.8164, 1.2
 tblka(1,2)=
535.2361, 0, 535.1716, 0.129499851244587, 535.0427, 0.387772305047767
534.9832, 0.50697497603385, 554.0413, 0.577352814782982, 639.7368,
0.650672705034544
685.0105, 0.702340418498562, 706.7015, 0.748000066113517, 705.9304,
0.792668010974844
698.4158, 0.846972000925589, 684.1427, 0.940712703712274, 675.8744,
1.00491719282007
666.1061, 1.07402234636872, 646.2002, 1.2
 htca(1,3)=
62029.8164, 0, 62029.8164, 1.2
 tblka(1,3)=
535.4686, 0, 535.4143, 0.13953488372093, 535.3218, 0.368770764119601
536.4736, 0.51328903654485, 543.105, 0.573089700996678, 636.8624,
0.632890365448505
772.3556, 0.722591362126246, 803.1846, 0.792358803986711, 816.4493,
0.906976744186046
806.7284, 1.00664451827243, 788.5269, 1.1312292358804, 775.7929, 1.2
$end
```

REP-Na7 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-Na7-Base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na7', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-Na7-Base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation
 $frpcn
 im=40, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02244, thkgap=0.00329, totl=1.81824, cpl=1.1142
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.4626, rc=0, hdish=0.0119, dishsd=0.0652
 enrch=0.253, imox=1, comp=5.948
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.34, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=0.3
 fgpav=377.1, idxgas=6
 amfair=0.0385, amfarg=0, amffg=0, amfhe=0.9615, amfh2=0
 amfh2o=0, amfkry=0, amfn2=0, amfxe=0
 iplant=-2, pitch=0.4961, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 16.07, 25.33, 29.32, 85.24, 221.6
 239.7, 267.9, 294.2, 308.8, 315.2
 317.6, 326.8, 352.7, 387.2, 417
```

```
 544.6, 558.2, 587.9, 621.5, 626.4
 635.7, 663.4, 704.3, 750.1, 781.3
 802.7, 859.7, 900.2, 920.6, 928.4
 933.3, 943, 972.3, 1040.1, 1070.6
 1090.1, 1174, 1203, 1219, 1229
 qmpy=
 4.031, 7.879, 7.74, 7.761, 7.733
 7.74, 7.706, 7.329, 6.536, 6.069
 3.035, 3.996, 8.038, 8.079, 8.097
 8.142, 8.155, 8.142, 7.595, 3.799
 3.381, 6.754, 6.754, 6.751, 6.681
 6.668, 6.706, 6.72, 6.598, 6.46
 3.232, 2.149, 4.38, 4.477, 4.54
 4.574, 4.623, 4.682, 4.467, 2.235
 nsp=0
 p2= 2248.09, tw= 588.2, go= 2550000
 iq=0, fa=1
 x(1)=
 0, 0.09393, 0.46982, 0.78576, 1.36089
 1.45768, 1.52592, 1.55709, 1.64534, 1.70243
 1.81824
 qf(1)=
 116855, 118752, 117614, 118373, 116096
 111923, 106232, 106232, 111164, 114389
  114769
 jn=11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 $end
 $frpmox
 enrpu39=65.95, enrpu40=23.9, enrpu41=6.63, enrpu42=3.52
 $end
```

REP-Na7 Change to Restart File

```
   0.2388E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na7 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                         *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='Na7.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='Na7.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.na7' ,
     STATUS='old', FORM='FORMATTED'
```

```
/**********************************************************************
REP-Na7 Mox case Bu=55, h=170 cal/g, width=40ms
$begin
 ProblemStartTime=0, ProblemEndTime=1.2
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=106200000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.01, 0
 dtplta(1)=
0.002, 0
$end
$solution
 dtmaxa(1)=
0.0001, 0
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=5
$end
$design
RodLength=1.81822, FuelPelDiam=0.0269, gapthk=0.0003, vplen=0.00005486
volbp=0, dishv0=0.000000100667
scd=0.0262, swd=0.0033, spl=0.0928, ncs=10
RodDiameter=0.0312, pelh=0.0385, rshd=0.008009, dishd=0.000994
frpo2=0.05948, fotmtl=2, gadoln=0
roughf=2, frden=0.9534, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0.5, roughc=0.5, CladType=4, cldwdc=0.04
gfrac(1)=0.9615, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0.0385, gfrac(7)=0, gappr0=377.1, tgas0=68
pitch=0.0413, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 0, 0.09933, 0, 0.19981
2.721, 0.29914, 29.298, 0.3608, 362.81, 0.3882
1027.523, 0.39848, 1450.776, 0.40419, 1629.836, 0.40761
1415.366, 0.41903, 1065.243, 0.42816, 972.943, 0.43273
484.318, 0.45442, 397.352, 0.46927, 209.966, 0.48639
106.709, 0.50238, 56.989, 0.59943, 47.268, 0.77412
42.819, 0.96594, 11.69, 1.10752, 2.713, 1.2
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
0.7, 0, 0.834, 0.13123, 0.884, 0.19685
0.926, 0.26246, 0.962, 0.32808, 0.995, 0.3937
1.024, 0.45931, 1.074, 0.59054, 1.094, 0.65616
1.112, 0.72178, 1.126, 0.78739, 1.137, 0.85301
1.143, 0.91862, 1.145, 0.98424, 1.142, 1.04986
1.121, 1.18109, 1.103, 1.2467, 1.08, 1.31232
1.051, 1.37794, 1.016, 1.44355, 0.976, 1.50917
0.929, 1.57478, 0.812, 1.70602, 0.738, 1.77163
0.665, 1.81822
```

```
$end
$model
nthermex=1, tref=77
internal='on'
PlenumTemp=1, gasflo=0, prescri=0, presfgr=0
metal='off'
deformation='on'
noball=1, TranSwell=0
heat='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=16, zone=3
htclev(1)=0.48228, 1.20405, 1.81822
 pbh2(1)=
72.5189, 0, 72.5189, 1.2
 htca(1,1)=
352222, 0, 352222, 1.2
 tblka(1,1)=
536, 0, 536.2715, 0.120049497184795, 535.5941, 0.229834084988375
535.5248, 0.359417546709992, 543.2683, 0.422486540239222, 553.7418,
0.450067144737948
561.7115, 0.483185719487941, 562.017, 0.52298515364576, 558.9088,
0.583474242975994
556.9378, 0.623777892938178, 554.4367, 0.68413252472058, 552.0855,
0.709570212050758
549.4343, 0.804841788285386, 546.103, 0.95508129079246, 543.6081, 1.053
539.6, 1.2
 htca(1,2)=
352222, 0, 352222, 1.2
 tblka(1,2)=
535.1716, 0, 535.0427, 0.240772305047767, 534.9832, 0.35997497603385
554.0413, 0.430352814782982, 639.7368, 0.503672705034544, 685.0105,
0.555340418498562
706.7015, 0.601000066113517, 705.9304, 0.645668010974844, 698.4158,
0.699972000925589
684.1427, 0.793712703712274, 675.8744, 0.85791719282007, 666.1061,
0.92702234636872
646.2002, 1.053, 626, 1.2
 htca(1,3)=
352222, 0, 352222, 1.2
 tblka(1,3)=
535.4143, 0, 535.3218, 0.221770764119601, 536.4736, 0.36628903654485
543.105, 0.426089700996678, 636.8624, 0.485890365448505, 772.3556,
0.575591362126246
803.1846, 0.645358803986711, 816.4493, 0.759976744186046, 806.7284,
0.85964451827243
788.5269, 0.9842292358804, 775.7929, 1.053, 752, 1.2
$end
```

REP-Na8 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
```

```
FILE06='REP-NA8-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na8', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-NA8-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of REP NA-8
 $frpcn
 im=33, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3740, thkcld=2.2441e-2, thkgap=3.3071e-3, totl=1.8340, cpl=1.11,
 dspg=0.315, dspgw=0.0315, vs=5,
 hplt=0.531, rc=0.0, hdish=1.260e-2, dishsd=0.0431,
 enrch=4.49, fotmtl=2.0,
 den=94.75, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=377.1, amfair=0.03846, amfhe=0.96154,
 iplant=-2,nsp=0, p2=2248.08, tw=603.0, go=2.385e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=11, jst=33*1, iq=0, fa=1,
 x(1)=0, 0.06, 0.125, 0.221, 0.932, 1.604,
  1.668, 1.744, 1.776, 1.827, 1.834
 qf(1)=0.96788, 0.94106, 0.97809, 1.01498, 1.00677, 1.00937,
        0.9878, 0.94488, 0.93943, 0.9552, 0.9658
 ProblemTime=   0.1, 0.2, 0.3, 0.4,
                50, 100, 150, 200, 250,
               270, 300, 350, 400, 450,
               500, 550, 600, 650, 700,
               750, 800, 850, 900, 950,
              1000, 1050, 1100, 1130, 1200,
              1250, 1300, 1350, 1370,
 qmpy=        1.5, 3, 4.5, 6,
              6, 6, 6, 6, 6,
              6, 7, 7.25, 7.25, 7.25,
              7.25, 7, 7, 7, 7,
              7, 7, 7, 6.2, 6.2,
              6.2, 6.2, 6.3, 6.2, 5,
              5.1, 5.1, 5.2, 5.2,
 $end
```

REP-Na8 Change to Restart File

```
   0.2565E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na8 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='out.na8',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'         *
FILE66='stripf.na8', STATUS='UNKNOWN', FORM='FORMATTED',              *
        CARRIAGE CONTROL='LIST'                                       *
FILE22='restart.NA8' , STATUS='old', FORM='FORMATTED'                 *
/**********************************************************************
```

```
 REP-Na8, for EPRI review (2/16/04)
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.2,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.002, trest=1.184e8,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.0001,0.45, 0.001,0.9,0.001,1.2,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=1.8340, RodDiameter=0.03117, gapthk=2.7559e-4,
  vplen=5.4642e-5, ncs=5, spl=0.5, scd=2.62e-2, swd=2.62e-3,
  FuelPelDiam=2.6877e-2, rshd=9.842e-3, dishd=1.05e-3, pelh=4.425e-2,
  dishv0=3.20719e-7,
  frden=0.9475, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=0.96154, gfrac(6)=0.03846, gappr0=377.1, tgas0=71.6,
  pitch=4.15e-2, pdrato=1.32,
$end
$power
  fpowr=0.858
  RodAvePower = 0, 0, 0, 0.3888, 8.65, 0.4179, 23.78, 0.4335,
  45.4, 0.4425, 261.58, 0.4648, 594.5, 0.4782, 732.86, 0.4827,
  737.18, 0.4872, 728.53, 0.4894, 521, 0.5006, 540.46, 0.5073,
  676.65, 0.5162, 882.02, 0.5274, 884.19, 0.53, 877.7, 0.5341,
  646.39, 0.543, 248.61, 0.5542, 88.63, 0.5676, 60.53, 0.5765,
   43.24, 0.6034, 38.91, 0.6458, 36.75, 0.6883, 36.75, 0.7017,
   23.78, 0.7486, 12.97, 0.8, 6.49, 0.9006, 0, 0.9654, 0, 1.2
  AxPowProfile = 0.725, 0, 0.885, 0.196, 0.956, 0.327, 1.019,
   0.458, 1.076, 0.588, 1.125, 0.719, 1.157, 0.85, 1.167,
   0.981, 1.152, 1.112, 1.11, 1.242, 1.044, 1.373, 0.958, 1.504,
   0.854, 1.635, 0.728, 1.765, 0.649, 1.834
$end
$model
  internal='on',
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=72.52,0.0, 72.52,1.0,
  zone=3, htclev =0.431,1.211,1.834,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
          htca(1,2)= 352222.0,0., 352222.0,1.,
          htca(1,3)= 352222.0,0., 352222.0,1.,
  tem=10,
  tblka(1,1)= 536, 0, 536, 0.45, 554, 0.5,
              563, 0.6, 557.6, 0.7, 554, 0.8,
              548.6, 0.9, 545, 1, 541.4, 1.1, 536, 1.2
  tblka(1,2)= 536, 0, 536, 0.45, 568.4, 0.5,
              662, 0.6, 671, 0.7, 660.2, 0.8,
              636.8, 0.9, 622.4, 1, 609.8, 1.1, 597.2, 1.2
  tblka(1,3)= 536, 0, 536, 0.45, 568.4, 0.5,
```

```
              723.2, 0.6, 761, 0.7, 752, 0.8,
              734, 0.9, 712.4, 1, 694.4, 1.1, 671, 1.2
$end
```

REP-Na9 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-Na9-Base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na9', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-Na9-Base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation
 $frpcn
 im=24, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02244, thkgap=0.00329, totl=1.84121, cpl=0.7953
 dspg=0.315, dspgw=0.0394, vs=10, ngasmod=2
 hplt=0.4626, rc=0, hdish=0.0119, dishsd=0.0652
 enrch=0.253, imox=1, comp=6.559
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.34, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=0.3
 fgpav=377.1, idxgas=6
 amfair=0.0385, amfarg=0, amffg=0, amfhe=0.9615, amfh2=0
 amfh2o=0, amfkry=0, amfn2=0, amfxe=0
 iplant=-2, pitch=0.4961, icor=0, crdt=0, crdtr=0, flux=10*22100000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 7.19, 81.2, 106.4, 135.8, 156.7
 168.9, 185.4, 212.7, 234.6, 260.5
 279.2, 296.1, 296.8, 307.2, 330.6
 353.6, 374, 429, 449.1, 472.8
 551.2, 566.3, 627.7, 628.8
 qmpy=
 3.332, 6.623, 6.579, 6.586, 6.559
 6.512, 6.491, 6.505, 6.522, 6.518
 6.539, 4.995, 1.722, 3.401, 6.893
 7.001, 7.001, 7.032, 7.103, 7.099
 7.049, 7.008, 6.174, 2.68
 nsp=0
 p2= 2248.09, tw= 564.8, go= 2550000
 iq=0, fa=1
 x(1)=
 0, 0.06047, 0.0977, 0.1791, 0.26286
 0.4977, 0.88386, 1.58169, 1.64698, 1.74705
 1.7956, 1.84121
 qf(1)=
 138818, 132338, 132338, 140520, 144492
 146005, 145815, 143735, 140331, 131253
```

```
 131253, 135224
 jn=12
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1
 $end
 $frpmox
 enrpu39=65.95, enrpu40=23.9, enrpu41=6.63, enrpu42=3.52
 $end
```

REP-Na9 Change to Restart File

```
   0.2151E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na9 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                          *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                        *
FILE06='Na9.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='Na9.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.na9' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
REP-Na9 Mox case Bu=28.1, h=233 cal/g, width=33ms
$begin
 ProblemStartTime=0, ProblemEndTime=1.2
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=54330000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.01, 0
 dtplta(1)=
0.002, 0
$end
$solution
 dtmaxa(1)=
0.0001, 0, 0.00001, 0.6,0.000001, 0.64, 0.00001,0.65,  0.0001, 0.9
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=5
$end
$design
RodLength=1.84118, FuelPelDiam=0.0269, gapthk=0.0003, vplen=0.00003916
volbp=0, dishv0=0.000000100667
scd=0.0262, swd=0.0033, spl=0.0663, ncs=10
```

```
RodDiameter=0.0312, pelh=0.0385, rshd=0.008009, dishd=0.000994
frpo2=0.06559, fotmtl=2, gadoln=0
roughf=2, frden=0.9534, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0.5, roughc=0.5, CladType=4, cldwdc=0.04
gfrac(1)=0.9615, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0.0385, gfrac(7)=0, gappr0=377.1, tgas0=68
pitch=0.0413, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 0, 0.10483, 0, 0.20226
7.073, 0.32436, 64.884, 0.36755, 244.098, 0.38117
883.72, 0.39743, 1940.239, 0.40272, 2919.162, 0.41416
3146.932, 0.41671, 3243.844, 0.41921, 2909.369, 0.42649
2347.134, 0.43, 1731.566, 0.43595, 1067.552, 0.43942
321.046, 0.4552, 243.361, 0.47244, 151.056, 0.49954
91.712, 0.64628, 91.273, 0.70055, 22.564, 0.80659
0, 0.92251, 0, 1.0002, 0, 1.10381
0, 1.2
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
0.66, 0, 0.836, 0.13123, 0.888, 0.19685
0.926, 0.26246, 0.956, 0.32808, 0.982, 0.3937
1.007, 0.45931, 1.057, 0.59054, 1.081, 0.65616
1.105, 0.72178, 1.127, 0.78739, 1.145, 0.85301
1.16, 0.91862, 1.17, 1.04986, 1.166, 1.11547
1.153, 1.18109, 1.133, 1.2467, 1.071, 1.37794
1.03, 1.44355, 0.982, 1.50917, 0.929, 1.57478
0.871, 1.6404, 0.739, 1.77163, 0.662, 1.83725
0.646, 1.84118
$end
$model
nthermex=1, tref=77
internal='on'
PlenumTemp=1, gasflo=0, prescri=0, presfgr=0
metal='off'
deformation='off'
heat='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=13, zone=3
htclev(1)=0.49212, 1.2139, 1.84118
 pbh2(1)=
72.5189, 0, 72.5189, 1.2
 htca(1,1)=
352222, 0, 352222, 1.2
 tblka(1,1)=
537.3489, 0, 537.4812, 0.1539860061954, 538.1204, 0.378615659321106
556.7091, 0.430806175594087, 583.2084, 0.464011289119678, 597.024,
0.495653627031995
593.0066, 0.520108744425842, 582.9625, 0.568771410799553, 572.9225,
0.697274890683072
567.276, 0.79138957056164, 559.3719, 0.940116295262469, 554.2318,
1.11413368075434
```

```
552.3526, 1.2
 htca(1,2)=
352222, 0, 352222, 1.2
 tblka(1,2)=
537.9281, 0, 538.0214, 0.365775395525328, 565.4766, 0.422724822195036
693.1453, 0.468539407385904, 762.5857, 0.510823812387252, 781.0907,
0.588767702739129
785.5807, 0.618268812076223, 775.5332, 0.699385199162295, 725.7735,
0.884914052294358
700.6138, 0.977709581769548, 659.8267, 1.2
 htca(1,3)=
352222, 0, 352222, 1.2
 tblka(1,3)=
536.7826, 0, 536.7826, 0.213656342213326, 541.6739, 0.392980953756629
636.5652, 0.461247188460824, 801.8913, 0.518432347661006, 920.2609,
0.64612781411857
945.6957, 0.725459647964342, 945.6957, 0.78526031241617, 940.8043,
0.855105136088814
899.7174, 0.975356472214771, 813.6304, 1.2
$end
```

REP-Na10 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REP-NA10-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.na10', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='REP-NA10-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of REP NA-10
 $frpcn
 im=38, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3743, thkcld=2.2677e-2, thkgap=3.2283e-3, totl=1.8340, cpl=5.528,
 dspg=0.315, dspgw=0.0315, vs=5,
 hplt=0.561, rc=0.0, hdish=1.209e-2, dishsd=0.0452,
 enrch=4.5, fotmtl=2.0,
 den=95.25, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=377.1, amfair=0.03846, amfhe=0.96154,
 iplant=-2,nsp=0, p2=2248.08, tw=600.0, go=2.387e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=10, jst=38*1, iq=0, fa=1,
 x(1)=0.0,0.0762,0.2713,0.3147,0.6732,1.1946,1.4958,
          1.5314,1.6511,1.8340
 qf(1)=0.9651,0.9460,0.9873,0.9905,1.0000,1.0000,
       1.0000,1.0000,0.9841,0.9365,
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
                0.6,  50.0, 100.0, 150.0, 200.0,
              250.0, 300.0, 350.0, 400.0, 450.0,
              500.0, 550.0, 560.0, 600.0, 650.0,
```

```
              670.0, 700.0, 750.0, 800.0, 850.0,
              900.0, 950.0,1000.0,1050.0,1100.0,
             1150.0,1180.0,1200.0,1250.0,1300.0,
             1350.0,1400.0,1450.0,
 qmpy=       1.000,2.000,3.000,4.000,5.000,
             6.000,6.640,6.640,7.163,7.163,
             7.163,6.950,6.950,7.163,7.163,
             7.163,7.163,7.163,5.730,5.730,
             5.730,5.883,5.883,5.944,5.944,
             5.273,5.273,5.273,5.273,5.273,
             5.273,5.273,5.243,5.243,5.243,
             5.243,5.243,5.243,
 $end
```

REP-Na10 Change to Restart File

```
   0.2934E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

REP-Na10 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                         *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='out.na10',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'          *
FILE66='stripf.na10', STATUS='UNKNOWN', FORM='FORMATTED',               *
        CARRIAGE CONTROL='LIST'                                         *
FILE22='restart.NA10' , STATUS='old', FORM='FORMATTED'                  *
/***********************************************************************
REP-Na10, for EPRI review (1/15/04)
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.2,
 $end
 $iodata
   unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.002, trest=1.2528e8,
 $end
 $solution
   dtmaxa(1)=0.001,0.0, 0.0001,0.415, 0.00001,0.450, 0.0001, 0.48,
   0.0001,0.5,
   naxn=11, nfmesh=20, ncmesh=5,
 $end
 $design
   RodLength=1.8340, RodDiameter=0.03119, gapthk=2.6903e-4,vplen=6.784e-5
   ncs=5, spl=0.5, scd=2.62e-2, swd=2.62e-3,
   FuelPelDiam=2.6877e-2, rshd=9.675e-3, dishd=1.008e-3, pelh=4.6752e-2,
   dishv0=2.975e-7,
   frden=0.9525, roughf=2.0,
   coldw=0.5, roughc=0.5,cldwdc=0.04,
   gfrac(1)=0.96154, gfrac(6)=0.03846, gappr0=377.1, tgas0=71.6,
   pitch=4.15e-2, pdrato=1.32,
 $end
 $power
   fpowr=0.861
   RodAvePower = 0.,0., 0.,0.38,66.86,0.4,371.43,0.42,1299.99,0.44,
     1578.56,0.446,742.85,0.46,130.0,0.48,107.71,0.49,107.71,0.505,
```

```
     74.29,0.54,55.71,0.6,37.14,0.72,0.0,1.0,0.0,1.2,
   AxPowProfile = 0.704,0.000,0.884,0.196,0.958,0.326,
                  1.020,0.457,1.076,0.587,1.122,0.718,
                  1.153,0.849,1.164,0.979,1.150,1.110,
                  1.111,1.240,1.048,1.371,0.964,1.501,
                  0.862,1.632,0.740,1.762,0.661,1.834,
 $end
 $model
   internal='on',
   metal='on', cathca=1,
   deformation='on', noball=1,
   nthermex=1
 $end
 $boundary
   heat='on',
   press=2, pbh2(1)=72.52,0.0, 72.52,1.0,
   zone=3, htclev =0.965, 1.204,1.834
   htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
           htca(1,2)= 352222.0,0., 352222.0,1.,
           htca(1,3)= 352222.0,0., 352222.0,1.,
   tem=8,
   tblka(1,1)= 536.,0.0,536.,0.2,536.,0.4,563.,0.5,
                  563.,0.6,552.,0.8,549.,1.0,545.,1.2,
   tblka(1,2)= 536.,0.0,536.,0.2,536.,0.4,617.,0.5,
                  680.,0.6,653.,0.8,621.,1.0,599.,1.2,
   tblka(1,3)= 536.,0.0,536.,0.2,536.,0.4,621.,0.5,
                  747.,0.6,783.,0.8,743.,1.0,693.,1.2,
 $end
 $tuning
 $end
```

CIP0-1 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='CIP0-1-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.cip01', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='CIP0-1-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
CIP0-1 Base Irradiation
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.0225, thkgap=0.00325, totl=1.77493, cpl=1.437
 dspg=0.3225, dspgw=0.0394, vs=5
 hplt=0.387, rc=0, hdish=0.0094, dishsd=0.0636
 enrch=4.5, imox=0, comp=0, ifba=0, b10=0, zrb2thick=0, zrb2den=90
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.7, deng=0, roughf=0.0000787, rsntr=52.6, tsint=2911
 icm=6, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=340.84, idxgas=1, nunits=1, zr2vintage=1
```

```
 iplant=-2, pitch=0.4862, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3, ngasmod=2
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 300, 350, 370, 400
 450, 500, 550, 600, 650
 700, 708, 750, 800, 850
 900, 950, 1000, 1050, 1100
 1114, 1150, 1200, 1250, 1300
 1350, 1400, 1450, 1500, 1550
 1600, 1633, 1650, 1700, 1750
 1800, 1850, 1900, 1950, 2000
 2050, 2100, 2118
 qmpy=
 6.216, 6.216, 6.216, 6.216, 6.216
 6.216, 6.216, 6.216, 6.216, 6.858
 6.858, 6.858, 6.858, 6.858, 6.858
 6.858, 6.858, 6.79, 6.79, 6.79
 6.79, 6.79, 6.79, 6.79, 6.79
 6.79, 1.453, 1.453, 1.453, 1.453
 1.453, 1.453, 1.453, 1.453, 1.453
 1.453, 1.453, 5.946, 5.946, 5.946
 5.946, 5.946, 5.946, 5.946, 5.946
 5.946, 5.946, 5.946
 nsp=0
 p2= 2249.54, tw= 590.9, go= 2550000
 iq=0, fa=1
 x(1)=
 0, 1.77493
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
```

CIP0-1 Change to Restart File

```
   0.2881E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

CIP0-1 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                          *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                        *
```

```
FILE06='CIP0-1-ria.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='CIP0-1-ria.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.cip01' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
CIP0-1 RIA test
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=183000000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.01, 0, 0.01, 1
 dtplta(1)=
0.01, 0, 0.0001, 0.35
$end
$solution
 dtmaxa(1)=
0.0001, 0, 0.0001, 1
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=5
$end
$design
RodLength=1.77491, FuelPelDiam=0.0269, gapthk=0.000271, vplen=0.00007063
volbp=0, dishv0=0.000000082086
scd=0.0269, swd=0.0033, spl=0.0922, ncs=5
RodDiameter=0.0312, pelh=0.0323, rshd=0.008136, dishd=0.000787
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.957, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0.5, roughc=0.5, CladType=5, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=340.84, tgas0=71.6
pitch=0.0405, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 0, 0.34662, 18.827, 0.39016
144.972, 0.40306, 394.825, 0.41403, 1065.272, 0.42289
1223.596, 0.42928, 1322.542, 0.43571, 1273.049, 0.44038
773.271, 0.44809, 607.497, 0.45283, 441.729, 0.45571
369.979, 0.45668, 273.481, 0.46045, 189.349, 0.46606
147.279, 0.47072, 115.082, 0.48464, 127.422, 0.49668
137.291, 0.50779, 105.082, 0.52635, 65.419, 0.55788
52.944, 0.60052, 50.38, 0.63667, 42.88, 0.66819
30.386, 0.71824, 20.386, 0.75995, 17.841, 0.78868
12.817, 0.81927, 12.696, 0.86839, 0, 0.92586
0, 1
CladPower=0, fpowr=1.0
NumAxProfiles=1
ProfileStartTime=0
```

```
 AxPowProfile(1,1)=
0.722, 0, 0.779, 0.06562, 0.828, 0.13123
0.91, 0.26246, 0.945, 0.32808, 0.978, 0.3937
1.009, 0.45931, 1.037, 0.52493, 1.063, 0.59054
1.106, 0.72178, 1.122, 0.78739, 1.133, 0.85301
1.141, 0.91862, 1.143, 0.98424, 1.141, 1.04986
1.121, 1.18109, 1.103, 1.2467, 1.08, 1.31232
1.051, 1.37794, 1.015, 1.44355, 0.972, 1.50917
0.854, 1.6404, 0.773, 1.70602, 0.674, 1.77163
0.665, 1.77491
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=1
deformation='on'
noball=1, TranSwell=0
heat='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=14, zone=3
htclev(1)=0.46095, 1.18273, 1.77491
 pbh2(1)=
72.5189, 0, 72.5189, 1
 htca(1,1)=
352222, 0, 352222, 1
 tblka(1,1)=
536, 0, 536, 0.398633840062591, 544.8906, 0.429451167622467
550.8413, 0.455446754226782, 556.2737, 0.492909982735162, 558.2561,
0.523933769663867
558.2544, 0.555017665016407, 556.6134, 0.592695193122812, 553.5915,
0.643502491722841
550.5683, 0.718849707706455, 547.1996, 0.802387349790192, 545.4709,
0.866243403182153
544.0013, 0.923547638375962, 542.617, 1
 htca(1,2)=
352222, 0, 352222, 1
 tblka(1,2)=
536, 0, 536, 0.395190380761523, 552.164, 0.441182364729459
581.35, 0.492284569138277, 610.1955, 0.531462925851703, 623.7482,
0.551903807615231
639.3774, 0.58937875751503, 643.8782, 0.623446893787575, 645.5964,
0.65751503006012
644.8767, 0.696693386773547, 637.5264, 0.771643286573146, 625.297,
0.861923847695391
617.9582, 0.91813627254509, 607.8221, 1
 htca(1,3)=
352222, 0, 352222, 1
 tblka(1,3)=
536, 0, 536, 0.39646676428825, 544.9137, 0.438702203458593
576.6581, 0.494604822759775, 626, 0.542212301587302, 652.2236,
0.574460704143212
679.8275, 0.615152422790202, 701.2204, 0.667601203154318, 717.7827,
0.735190837517115
```

```
721.2332, 0.790872540443227, 717.0927, 0.856614020741417, 708.1214,
0.929063815355748
696.7348, 1, 696.7348, 1.01
$end
```

A.2 NSRR Cold Capsule Tests

The NSRR cold capsule tests were taken from commercial rods that were base irradiated in various commercial PWRs. After base irradiation and refabrication, the rodlets were subjected to an RIA pulse in the NSRR reactor in a capsule with 20°C stagnant water (Nakamura et al. 2000) (Fuketa et al. 1997) (Nakamura et al. 1994) (Georgenthum 2009) (Sugiyama 2009). The following describes the modeling approach and assumptions used to model these tests with FRAPTRAN-2.0 initialized with FRAPCON-4.0.

FRAPCON-4.0 was set up using the following assumptions and a FRAPTRAN initialization file was created.

The as-fabricated dimensions for each rodlet were taken from the data sheet for the father rod. When modeling the base irradiation of a rod that will later be cut into a segment to be tested, it is necessary to model the base irradiation on the short segment only.

The power history given for each father rod was used for the base irradiation in FRAPCON-4.0. This power history was uniformly scaled by a constant factor to achieve the measured burnup for the rodlet. The axial power profile was assumed to be flat over the length of the rodlet based on a flat axial gamma scan over the length of the rodlet.

The coolant pressure and mass flow rate were taken as typical values for the commercial reactor in which each rodlet was irradiated. The coolant inlet temperature for modeling the rodlet should be greater than the reactor inlet temperature due to heatup along the length below the rodlet. To model the base irradiation accurately, the inlet temperature was set such that the average predicted end of life oxide thickness was close to the measured value while still being a reasonable value for the span from which the rodlet was taken.

A FRAPTRAN-2.0 input file was created using the unirradiated dimensions for the father rod in FRAPCON-4.0. These dimensions are adjusted for changes that occurred during the base irradiation by the FRAPTRAN initialization file that was created with FRAPCON-4.0. This process is critical to modeling an RIA that occurs after prior irradiation. The provided RIA power history was used for the LHGR. A flat power profile was assumed due to the short rodlet length in NSRR.

Cladding surface temperature histories were available from thermocouple measurements at several axial locations during most of these tests (GK-1, FK-1, HBO-1, HBO-5, HBO-6, MH-3, OI-2, and TS-5). To model the coolant conditions, the rod was divided into several zones and the measured cladding temperature histories for each of the axial elevations were set as the coolant temperature in each of these axial zones. To force the code to use the same coolant temperature and cladding surface temperature, a large cladding-to-coolant heat transfer coefficient (352,222 Btu/ft^{2}hr°F) was set in the code as recommended in the FRAPTRAN-2.0 input instructions. For the test, VA-1, no cladding surface temperature measurements were made. To model the coolant conditions, the recommendations from the FRAPTRAN-2.0 input instructions for stagnant water were used. The water temperature and pressure were set at constant values of 20°C and 0.1 MPa, respectively. The cladding-to-coolant heat transfer coefficient was set at the recommended value of 5 Btu/ft^{2}hr°F for stagnant water.

The FRAPTRAN initialization file that was created with FRAPCON-4.0 includes gas from the initial father rod pressurization and subsequent FGR during the base irradiation. When the rodlets were refabricated, they were refilled with a different gas composition and pressure. The FRAPTRAN initialization file was manually adjusted to reflect this new gas mixture and pressure. Within each restart file, information is contained for each FRAPCON-4.0 time step. The first line is the time in seconds. The ninth and tenth lines after this contain the number of moles of gas and the relative amount of each gas species. These are the lines that are changed in the following listings of assessment cases.

The FRAPCON-4.0 and FRAPTRAN-2.0 input files for each case are shown below. Also shown below is the change made to the FRAPTRAN initialization file to account for the different fill gas conditions after the base irradiation.

FK1 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='FK1-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.fk1', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='FK1-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of FK-1
 $frpcn
 im=49, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.4831, thkcld=3.3858e-2, thkgap=4.7244e-3, totl=0.3478, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,
 hplt=0.4055, rc=0.0, hdish=0.0, dishsd=0.0,
 enrch=3.9, fotmtl=2.0,ngasmod=2, grnsize=6.0
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=2, cldwks=0.0, roughc=1.97e-5
 idxgas=1, fgpav=43.51,
 iplant=-3,nsp=0, p2=1035.0, tw=549.0, go=1.14e6, pitch=0.640,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=49*1, iq=0, fa=1,
 x(1)=0.0,0.3478
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,   0.3,   0.4,
                50.0, 100.0, 150.0, 200.0, 250.0,
               300.0, 350.0, 400.0, 450.0, 500.0,
               550.0, 600.0, 650.0, 700.0, 750.0,
               800.0, 850.0, 900.0, 950.0,1000.0,
              1050.0,1100.0,1150.0,1200.0,1250.0,
              1300.0,1350.0,1400.0,1450.0,1500.0,
              1550.0,1600.0,1650.0,1700.0,1750.0,
              1800.0,1850.0,1900.0,1950.0,2000.0,
              2050.0,2100.0,2150.0,2200.0,2230.0,
 qmpy=        1.000,2.000,3.000,4.000
              5*4.785,
              9*5.278,
              10*5.043,
              10*4.082,
              11*4.621,
 $end
```

FK1 Change to Restart File

```
   0.1120E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

FK1 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                          *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                        *
FILE06='out.FK1',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'           *
FILE66='stripf.FK1', STATUS='UNKNOWN', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                          *
FILE22='restart.FK1' , STATUS='old', FORM='FORMATTED'                   *
/**********************************************************************
 FK-1
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=1.927e8,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.000001,0.15, 0.001,0.20,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=0.3478, RodDiameter=0.04026, gapthk=3.937e-4,
  vplen=3.8599e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.9367e-3,
  FuelPelDiam=3.383e-2, pelh=3.379e-2,rshd=0.0, dishd=0.0,
  dishv0=0.0,
  frden=0.95, roughf=2.0,
  coldw=0.0, roughc=0.5,cldwdc=0.04,
  gfrac(1)=1.0, gappr0=43.51, tgas0=71.6,
  pitch=5.333e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
                0.0,0.2003,
                29574.0,0.2048,
                14.0,0.2093
                0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.3478,
$end
$model
  internal='on',presfgr=0
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.3478,
```

```
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
  tem=8, tblka(1,1)= 89.3,0., 89.3,0.21, 247.7,0.25, 325.1,0.35, 458.3,0.50,
                     353.9,0.70,
                      353.9,0.85, 229.7,1.0,
$end
```

GK1 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='GK1-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.gk1', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='GK1-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of GK-1
 $frpcn
 im=28, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.4220, thkcld=2.4409e-2, thkgap=3.7402e-3, totl=0.4003, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,ngasmod=2, grnsize=8.0
 hplt=0.598, rc=0.0, hdish=2.1654e-2, dishsd=2.539e-2,
 enrch=3.4, fotmtl=2.0,
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=681.7, amfair=0.03, amfhe=0.97,
 iplant=-2,nsp=0, p2=2250.0, tw=552.0, go=2.65e6, pitch=0.580,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=28*1, iq=0, fa=1,
 x(1)=0.0,0.4003
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
                0.6,   0.7,
               50.0, 100.0, 150.0, 200.0, 250.0,
              300.0, 350.0, 400.0, 450.0, 500.0,
              550.0, 600.0, 650.0, 700.0, 750.0,
              800.0, 850.0, 900.0, 950.0,1000.0,
             1050.0,
 qmpy=       1.000,2.000,3.000,4.000,5.000,
             6.000,7.000,
             9*7.155,
             6*7.837,
             6*7.326,
 $end
```

GK1 Change to Restart File

```
   0.2195E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

GK1 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
```

```
        CARRIAGE CONTROL='LIST'                                          *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='out.GK1',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'           *
FILE66='stripf.GK1', STATUS='UNKNOWN', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                          *
FILE22='restart.GK1' , STATUS='old', FORM='FORMATTED'                   *
/**********************************************************************
GK1
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=9.072e7,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.0001,0.15, 0.00001,0.19,0.001,0.25,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=0.4003, RodDiameter=0.03517, gapthk=3.1168e-4,
  vplen=3.8599e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.562e-3,
  FuelPelDiam=3.0479e-2, pelh=4.9833e-2,rshd=1.3123e-2, dishd=1.8045e-3,
  dishv0=9.8243e-7,
  frden=0.95, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=0.97, gfrac(6)=0.03, gappr0=681.7, tgas0=71.6,
  pitch=4.83e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
                0.0,0.1900,
                18965.0,0.1946,
                54.0,0.1992
                0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.4003,
$end
$model
  internal='on',presfgr=0
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.4003,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
  tem=8, tblka(1,1)=
      67.7,0., 74.9,0.188, 208.1,0.212, 208.1,0.5, 514.1,0.682, 422.3,0.842,
      173.9,0.912, 166.7,1.,
$end
```

HBO1 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='HBO1-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.hbo1', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='HBO1-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of HBO-1
 $frpcn
 im=34, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3740, thkcld=2.2441e-2, thkgap=3.3465e-3, totl=0.4429, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,
 hplt=0.5315, rc=0.0, hdish=1.1811e-2, dishsd=2.6574e-2,
 enrch=3.2, fotmtl=2.0,
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6,amfair=0.03,amfhe=0.97, fgpav=511.7,
 iplant=-2,nsp=0, p2=2250.0, tw=596.0, go=2.55e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=34*1, iq=0, fa=1,
 x(1)=0.0,0.4429
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,
               50.0, 78.0,
              100.0, 150.0, 200.0, 250.0, 300.0,
              323.0,
              350.0, 400.0, 450.0, 500.0, 550.0,
              600.0, 641.0,
              650.0, 700.0, 750.0, 800.0, 850.0,
              900.0, 950.0,1000.0,1003.0,
             1050.0,1100.0,1150.0,1200.0,1250.0,
             1300.0,1350.0,1361.0,
 qmpy=       1.000,2.000,
             2*2.325,
             6*4.384,
             7*7.008,
             9*5.513,
             8*5.115,
 $end
```

HBO1 Change to Restart File

```
   0.3079E-04
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

HBO1 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                        *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                     *
```

```
*                                                                        *
FILE06='out.HBO1',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'            *
FILE66='stripf.HBO1', STATUS='UNKNOWN', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                          *
FILE22='restart.HBO1' , STATUS='old', FORM='FORMATTED'                    *
/************************************************************************
 HBO-1
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=1.176e8,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.00001,0.2, 0.001,0.3,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=0.4429, RodDiameter=0.03117, gapthk=2.789e-4,
  vplen=2.772e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.562e-3,
  FuelPelDiam=2.6870e-2, rshd=1.099e-2, dishd=9.8425e-4, pelh=4.429e-2,
  dishv0=3.745e-7,
  frden=0.95, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=0.97, gfrac(6)=0.03, gappr0=511.7, tgas0=71.6,
  pitch=4.15e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
                0.0,0.1957,
                11079.0,0.2004,
                32.6,0.2051
                0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.4429,
$end
$model
  internal='on',
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.4429,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
  tem=12, tblka(1,1)= 61.9,0.0,62.7,0.1,64.7,0.2,172.9,0.224,
                     104.0,0.255,86.0,0.272,77.9,0.296,70.7,0.33,
                      71.6,0.4,72.3,0.6,73.4,0.8,73.4,1.0,
$end
```

HBO5 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
```

```
*
* GOESOUTS:
FILE06='HBO5-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.hbo5', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='HBO5-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of HBO-5
 $frpcn
 im=32, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3740, thkcld=2.5197e-2, thkgap=3.3465e-3, totl=0.4544, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,
 hplt=0.3543, rc=0.0, hdish=1.1811e-2, dishsd=2.6574e-2,
 enrch=3.2, fotmtl=2.0,crdt=1.0,
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=1, fgpav=469.1,
 iplant=-2,nsp=0, p2=2250.0, tw=592.0, go=2.55e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=32*1, iq=0, fa=1,
 x(1)=0.0,0.4544
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,
               50.0, 100.0, 150.0, 200.0, 250.0,
              300.0, 308.6,
              350.0, 400.0, 450.0, 500.0, 550.0,
              600.0, 650.0, 653.5,
              700.0, 750.0, 800.0, 850.0, 900.0,
              950.0, 962.5,
             1000.0,1050.0,1100.0,1150.0,1200.0,
             1250.0,1300.0,1308.1,
 qmpy=       1.000,2.000,
             7*3.133,
             8*5.253,
             7*5.539,
             8*4.715,
 $end
```

HBO5 Change to Restart File

```
   0.3041E-04
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

HBO5 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',               *
        CARRIAGE CONTROL='LIST'                                      *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                   *
*                                                                    *
FILE06='out.HBO5',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'        *
FILE66='stripf.HBO5', STATUS='UNKNOWN', FORM='FORMATTED',             *
        CARRIAGE CONTROL='LIST'                                      *
FILE22='restart.HBO5' , STATUS='old', FORM='FORMATTED'                *
/**********************************************************************
```

```
 HBO-5
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=1.130e8,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.00001,0.2, 0.001,0.3,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=0.4544, RodDiameter=0.03117, gapthk=2.789e-4,
  vplen=2.560e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.562e-3,
  FuelPelDiam=2.6411e-2, rshd=1.099e-2, dishd=9.8425e-4, pelh=2.9525e-2,
  dishv0=3.745e-7,
  frden=0.95, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=0.97, gfrac(6)=0.03, gappr0=52.21, tgas0=71.6,
  pitch=4.15e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
                0.0,0.2025,
                12587.0,0.2069,
                31.4,0.2113
                0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.4544,
$end
$model
  internal='on',
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.4544,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
  tem=18, tblka(1,1)=67.6,0.0,64.5,0.2,340.6,0.23,
                   221.4,0.24,172,0.25,133.4,0.28,
                   136.9,0.34,118,0.37,144.6,0.41,
                   163.9,0.47,146.5,0.5,163.4,0.52,
                   140.2,0.55,143.2,0.65,152.2,0.74,
                   132.9,0.84,115.5,0.92,125,1
$end
```

HBO6 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='HBO6-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
```

```
FILE22='restart.hbo6', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='HBO6-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/************************************************************************
Base Irradiation of HBO-6
 $frpcn
 im=29, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3740, thkcld=2.5197e-2, thkgap=3.3465e-3, totl=0.4462, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,ngasmod=2, grnsize=9.0
 hplt=0.3543, rc=0.0, hdish=1.1811e-2, dishsd=2.6574e-2,
 enrch=3.2, fotmtl=2.0,
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=1, fgpav=469.1,
 iplant=-2,nsp=0, p2=2250.0, tw=584.0, go=2.55e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=29*1, iq=0, fa=1,
 x(1)=0.0,0.4462
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,   0.3,
               50.0, 100.0, 150.0, 200.0, 250.0,
              300.0, 350.0, 400.0, 450.0, 500.0,
              550.0, 600.0, 650.0, 700.0, 750.0,
              800.0, 850.0, 900.0, 950.0,1000.0,
             1050.0,1100.0,1150.0,1200.0,1250.0,
             1300.0,
 qmpy=       1.000,2.000,3.000,
             6*3.754,
             8*5.802,
             6*5.972,
             6*5.290,
 $end
```

HBO6 Change to Restart File

```
   0.3049E-04
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

HBO6 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='out.HBO6',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'         *
FILE66='stripf.HBO6', STATUS='UNKNOWN', FORM='FORMATTED',              *
        CARRIAGE CONTROL='LIST'                                       *
FILE22='restart.HBO6' , STATUS='old', FORM='FORMATTED'                 *
/************************************************************************
 HBO-6
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
```

```
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=1.123e8,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.00001,0.2, 0.001,0.3,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=0.4462, RodDiameter=0.03117, gapthk=2.789e-4,
  vplen=2.560e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.562e-3,
  FuelPelDiam=2.6411e-2, rshd=1.099e-2, dishd=9.8425e-4, pelh=2.9525e-2,
  dishv0=3.745e-7,
  frden=0.95, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=0.97, gfrac(6)=0.03, gappr0=52.21, tgas0=71.6,
  pitch=4.15e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
                0.0,0.2025,
                13435.0,0.2069,
                26.6,0.2113
                0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.4462,
$end
$model
  internal='on',presfgr=0
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.4462,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
  tem=13, tblka(1,1)=  62.3,0.0, 67.7,0.21, 181.1,0.225, 244.1,0.25,
253.1,0.275,
                        244.1,0.3, 217.1,0.325, 199.1,0.35, 190.1,0.375,
181.1,0.4,
                        166.7,0.6, 161.3,0.8, 161.3,1.0
$end
```

MH3 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='MH3-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.mh3', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='MH3-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/***********************************************************************
Base Irradiation of MH-3
 $frpcn
```

```
 im=28, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.4220, thkcld=2.4409e-2, thkgap=3.7402e-3, totl=0.4003, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,ngasmod=2
 hplt=0.598, rc=0.0, hdish=1.299e-2, dishsd=6.476e-2,
 enrch=2.6, fotmtl=2.0,grnsize=5.0
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=6, fgpav=464.12, amfair=0.03, amfhe=0.97,
 iplant=-2,nsp=0, p2=2250.0, tw=540.0, go=2.65e6, pitch=0.580,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=28*1, iq=0, fa=1,
 x(1)=0.0,0.4003
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,   0.3,   0.4,
               50.0, 100.0, 150.0, 200.0, 250.0,
              300.0, 350.0, 400.0, 450.0, 500.0,
              550.0, 600.0, 650.0, 700.0, 750.0,
              800.0, 850.0, 900.0, 950.0,1000.0,
             1050.0,1100.0,1150.0,1200.0,
 qmpy=       1.000,2.000,3.000,4.000
             6*4.275,
             6*7.473,
             6*6.674,
             6*5.936,
 $end
```

MH3 Change to Restart File

```
   0.1826E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

MH3 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                         *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='out.MH3',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'           *
FILE66='stripf.MH3', STATUS='UNKNOWN', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                         *
FILE22='restart.MH3' , STATUS='old', FORM='FORMATTED'                   *
/***********************************************************************
 MH-3
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=1.037e8,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.0001,0.15, 0.0001,0.25,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
```

```
$design
  RodLength=0.4003, RodDiameter=0.03517, gapthk=3.1168e-4,
  vplen=3.8599e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.562e-3,
  FuelPelDiam=3.0479e-2, pelh=4.9833e-2,rshd=9.843e-3, dishd=1.08e-3,
  dishv0=3.300e-7,
  frden=0.95, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=0.97, gfrac(6)=0.03, gappr0=464.12, tgas0=71.6,
  pitch=4.83e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
                0.0,0.1913,
                13991.0,0.1958,
                38.3,0.2003
                0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.4003,
$end
$model
  internal='on',presfgr=0
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.4003,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
  tem=12, tblka(1,1)=
       67.7,0., 67.7,0.2, 310.7,0.238, 290.9,0.272, 325.1,0.329,
     395.3,0.380, 353.9,0.507,
     310.7,0.641, 271.1,0.696, 213.5,0.743, 195.5,0.8, 184.7,1.0,
$end
```

OI2 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='OI2-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.oi2', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='OI2-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of OI-2
 $frpcn
 im=23, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.3740, thkcld=2.5197e-2, thkgap=3.3465e-3, totl=0.4364, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,ngasmod=2
 hplt=0.374, rc=0.0, hdish=1.969e-2, dishsd=3.05e-2,
 enrch=3.2, fotmtl=2.0,grnsize=7.0
```

```
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=4, cldwks=0.5, roughc=1.97e-5
 idxgas=1, fgpav=469.1,
 iplant=-2,nsp=0, p2=2250.0, tw=575.0, go=2.55e6, pitch=0.498,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=23*1, iq=0, fa=1,
 x(1)=0.0,0.4364
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,   0.3,   0.4,   0.5,
               50.0, 100.0, 150.0, 200.0, 250.0,
              300.0, 350.0, 400.0, 450.0, 500.0,
              550.0, 600.0, 650.0, 700.0, 750.0,
              800.0, 850.0, 900.0,
 qmpy=       1.000,2.000,3.000,4.000,5.000,
             18*5.9888,
 $end
```

OI2 Change to Restart File

```
   0.3099E-04
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

OI2 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='out.OI2',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'         *
FILE66='stripf.OI2', STATUS='UNKNOWN', FORM='FORMATTED',              *
        CARRIAGE CONTROL='LIST'                                       *
FILE22='restart.OI2' , STATUS='old', FORM='FORMATTED'                 *
/*********************************************************************
 OI-2
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=7.776e7,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.00001,0.15, 0.0001, 0.2, 0.001,0.25,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=0.4364, RodDiameter=0.03117, gapthk=2.789e-4,
  vplen=2.560e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.562e-3,
  FuelPelDiam=2.6411e-2, pelh=3.1167e-2,rshd=1.066e-2, dishd=1.6404e-3,
  dishv0=5.902e-7,
  frden=0.95, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=1.0, gappr0=47.86, tgas0=71.6,
  pitch=4.15e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
```

```
              0.0,0.1971,
              16882.0,0.2015,
              49.4,0.2059,
              0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.4364,
$end
$model
  internal='on',presfgr=0
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.4364,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
   tem=11, tblka(1,1)=
      67.7,0., 67.7,0.2, 100.1,0.282, 370.1,0.298, 640.1,0.316,
      708.5,0.371, 688.7,0.4,
      505.1,0.457, 186.5,0.5, 132.5,0.6, 132.5,1.,
$end
```

TS5 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='TS5-Base.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.ts5', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='TS5-Base.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of TS-5
 $frpcn
 im=40, na=11,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.5630, thkcld=3.1890e-2, thkgap=6.1024e-3, totl=0.4134, cpl=0.8268,
 dspg=0.2874, dspgw=4.7244e-2, vs=15,ngasmod=2, grnsize=7.0
 hplt=0.8268, rc=0.0, hdish=1.5748e-2, dishsd=4.8622e-2,
 enrch=2.79, fotmtl=2.0,
 den=95.0, roughf=7.874e-5, rsntr=74.11,
 icm=2, cldwks=0.5, roughc=1.97e-5
 idxgas=1, fgpav=14.50,
 iplant=-3,nsp=0, p2=1035.0, tw=550.0, go=1.19e6, pitch=0.704,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1, ntape=1,
 jn=2, jst=40*1, iq=0, fa=1,
 x(1)=0.0,0.4134
 qf(1)=1.0,1.0
 ProblemTime=   0.1,   0.2,   0.3,   0.4,
               50.0, 100.0, 150.0, 200.0, 250.0,
              300.0, 350.0, 400.0, 450.0, 500.0,
              550.0, 600.0, 650.0, 700.0, 750.0,
```

```
             800.0, 850.0, 900.0, 950.0,1000.0,
            1050.0,1100.0,1150.0,1200.0,1250.0,
            1300.0,1350.0,1400.0,1450.0,1500.0,
            1550.0,1600.0,1650.0,1700.0,1750.0,
            1800.0,
 qmpy=      1.000,2.000,3.000,4.000
            36*4.909,
 $end
```

TS5 Change to Restart File

```
   0.1111E-02
   0.1870E+00   0.0000E+00   0.0930e+00   0.7200e+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

TS5 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='out.TS5',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'         *
FILE66='stripf.TS5', STATUS='UNKNOWN', FORM='FORMATTED',              *
        CARRIAGE CONTROL='LIST'                                       *
FILE22='restart.TS5' , STATUS='old', FORM='FORMATTED'                 *
/**********************************************************************
 TS-5
 $begin
   ProblemStartTime=0.0,
   ProblemEndTime=1.0,
 $end
$iodata
  unitin=0, unitout=0, inp=1, dtpoa(1)=0.01, dtplta=0.0005, trest=1.555e8,
$end
$solution
  dtmaxa(1)=0.001,0.0, 0.0001,0.15, 0.000001, 0.2, 0.001,0.25,0.001,1.0,
  naxn=11, nfmesh=20, ncmesh=5,
$end
$design
  RodLength=0.4134, RodDiameter=0.04692, gapthk=5.0853e-4,
  vplen=7.992e-5, ncs=15, spl=0.0833, scd=2.395e-2, swd=3.9367e-3,
  FuelPelDiam=4.0584e-2, pelh=6.89e-2,rshd=1.624e-2, dishd=1.3123e-3,
  dishv0=1.0897e-6,
  frden=0.95, roughf=2.0,
  coldw=0.5, roughc=0.5,cldwdc=0.04,
  gfrac(1)=1.0, gappr0=14.50, tgas0=71.6,
  pitch=5.867e-2, pdrato=1.32,
$end
$power
  RodAvePower = 0.0,0.0,
                0.0,0.1956,
                33259.0,0.2004,
                16.1,0.2052
                0.0,1.0
  AxPowProfile = 1.0, 0.0, 1.0,0.4134,
$end
$model
  internal='on',presfgr=0
```

```
  metal='on', cathca=1,
  deformation='on', noball=1,
  nthermex=1
$end
$boundary
  heat='on',
  press=2, pbh2(1)=14.70,0.0, 14.70,1.0,
  zone=1, htclev =0.4462,
  htco=2, htca(1,1)= 352222.0,0., 352222.0,1.,
  tem=4, tblka(1,1)= 76.7,0., 76.7,0.2, 211.7,0.25, 211.7,1.,
$end
```

VA1 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='VA1-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.va1', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='VA1-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
VA1 Base Irradiation
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.0225, thkgap=0.00325, totl=0.20013, cpl=1.1063
 dspg=0.3225, dspgw=0.0394, vs=5
 hplt=0.387, rc=0, hdish=0.0094, dishsd=0.0636
 enrch=4.5, imox=0, comp=0, ifba=0, b10=0, zrb2thick=0, zrb2den=90
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.7, deng=0, roughf=0.0000787, rsntr=52.6, tsint=2911
 icm=6, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=340.84, idxgas=1, nunits=1, zr2vintage=1
 iplant=-2, pitch=0.4862, icor=0, crdt=0, crdtr=0, flux=10*22100000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3, ngasmod=2
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 300, 350, 370, 400
 450, 500, 550, 600, 650
 700, 708, 750, 800, 850
 900, 950, 1000, 1050, 1100
 1114, 1150, 1200, 1250, 1300
 1350, 1400, 1450, 1500, 1550
 1600, 1633, 1650, 1700, 1750
 1800, 1850, 1900, 1950, 2000
 2050, 2100, 2118
 qmpy=
 5.9, 5.9, 5.9, 5.9, 5.9
 5.9, 5.9, 5.9, 5.9, 6.509
 6.509, 6.509, 6.509, 6.509, 6.509
 6.509, 6.509, 6.445, 6.445, 6.445
```

```
 6.445, 6.445, 6.445, 6.445, 6.445
 6.445, 1.379, 1.379, 1.379, 1.379
 1.379, 1.379, 1.379, 1.379, 1.379
 1.379, 1.379, 5.644, 5.644, 5.644
 5.644, 5.644, 5.644, 5.644, 5.644
 5.644, 5.644, 5.644
 nsp=0
 p2= 2249.54, tw= 599.9, go= 2550000
 iq=0, fa=1
 x(1)=
 0, 0.20013
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
```

VA1 Change to Restart File

```
   0.5997E-04
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

VA1 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='VA1-ria.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='VA1-ria.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.va1' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
VA1 RIA test
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=183000000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.01, 0, 0.01, 1
 dtplta(1)=
0.0001, 0, 0.001, 0.02
```

```
$end
$solution
 dtmaxa(1)=
0.0001, 0, 0.0001, 1
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=5
$end
$design
RodLength=0.20013, FuelPelDiam=0.0269, gapthk=0.000271, vplen=0.00005442
volbp=0, dishv0=0.000000082086
scd=0.0269, swd=0.0033, spl=0.0922, ncs=5
RodDiameter=0.0312, pelh=0.0323, rshd=0.008136, dishd=0.000787
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.957, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0.5, roughc=0.5, CladType=5, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=340.84, tgas0=71.6
pitch=0.0405, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 0, 0.00177, 463.646, 0.00304
1945.853, 0.00462, 4445.036, 0.00564, 8624.804, 0.00651
13390.995, 0.00723, 16750.493, 0.00789, 18352.044, 0.00825
19249.852, 0.00881, 17490.056, 0.00957, 13190.152, 0.01037
9632.891, 0.01107, 5176.15, 0.01217, 2282.146, 0.01349
1029.562, 0.0147, 283.134, 0.01698, 84.667, 0.01875
42.598, 0.02047, 0, 0.04
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.20013
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=1
deformation='on'
noball=1, TranSwell=0
heat='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.20013
 pbh2(1)=
14.5038, 0, 14.5038, 1
 htca(1,1)=
5., 0, 5., 1
 tblka(1,1)=
68, 0, 68, 1
$end
```

A.3 NSRR Hot Capsule Test

The NSRR hot capsule test was taken from a commercial rod that was base irradiated in a commercial PWR. After base irradiation and refabrication, the rodlet was subjected to an RIA pulse in the NSRR reactor in a capsule with 285°C stagnant water (Georgenthum 2009) (Sugiyama 2009).

The modeling approach and assumptions used to model this test in FRAPTRAN-2.0 initialized with FRAPCON-4.0 were identical to the approach and assumptions used for the NSRR cold capsule tests, except that cladding surface temperature histories were not available for this test. To model the coolant conditions, the recommendations from the FRAPTRAN-2.0 input instructions for stagnant water were used. The water temperature and pressure were set at constant values of 285°C and 6.8 MPa, respectively. The cladding-to-coolant heat transfer coefficient was set at the recommended value of 5 Btu/ft^{2}hr°F for stagnant water.

The FRAPCON-4.0 and FRAPTRAN-2.0 input files for this case are shown below. Also shown below is the change made to the FRAPTRAN initialization file to account for the different fill gas conditions after the base irradiation. Within each restart file, information is contained for each FRAPCON-4.0 time step. The first line is the time in seconds. The ninth and tenth lines after this contain the number of moles of gas and the relative amount of each gas species. These are the lines that are changed in the following listings of assessment cases.

VA3 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='VA3-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.va3', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='VA3-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*********************************************************************
VA3 Base Irradiation
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.0225, thkgap=0.00325, totl=0.36549, cpl=1.1063
 dspg=0.3225, dspgw=0.0394, vs=5
 hplt=0.387, rc=0, hdish=0.0094, dishsd=0.0636
 enrch=4.5, imox=0, comp=0, ifba=0, b10=0, zrb2thick=0, zrb2den=90
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.7, deng=0, roughf=0.0000787, rsntr=52.6, tsint=2911
 icm=6, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=340.84, idxgas=1, nunits=1, zr2vintage=1
 iplant=-2, pitch=0.4862, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3, ngasmod=2
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 300, 350, 370, 400
```

```
 450, 500, 550, 600, 650
 700, 708, 750, 800, 850
 900, 950, 1000, 1050, 1100
 1114, 1150, 1200, 1250, 1300
 1350, 1400, 1450, 1500, 1550
 1600, 1633, 1650, 1700, 1750
 1800, 1850, 1900, 1950, 2000
 2050, 2100, 2118
 qmpy=
 5.9, 5.9, 5.9, 5.9, 5.9
 5.9, 5.9, 5.9, 5.9, 6.509
 6.509, 6.509, 6.509, 6.509, 6.509
 6.509, 6.509, 6.445, 6.445, 6.445
 6.445, 6.445, 6.445, 6.445, 6.445
 6.445, 1.379, 1.379, 1.379, 1.379
 1.379, 1.379, 1.379, 1.379, 1.379
 1.379, 1.379, 5.644, 5.644, 5.644
 5.644, 5.644, 5.644, 5.644, 5.644
 5.644, 5.644, 5.644
 nsp=0
 p2= 2249.54, tw= 601.7, go= 2550000
 iq=0, fa=1
 x(1)=
 0, 0.36549
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
```

VA3 Change to Restart File

```
   0.6115E-04
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

VA3 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                        *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                     *
*                                                                      *
FILE06='VA3-ria.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='VA3-ria.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.va3' ,
     STATUS='old', FORM='FORMATTED'
```

```
/*******************************************************************
VA3 RIA test
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=183000000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.01, 0, 0.01, 1
 dtplta(1)=
0.0001, 0, 0.001, 0.02
$end
$solution
 dtmaxa(1)=
0.0001, 0, 0.0001, 1
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=5
$end
$design
RodLength=0.36548, FuelPelDiam=0.0269, gapthk=0.000271, vplen=0.00005442
volbp=0, dishv0=0.000000082086
scd=0.0269, swd=0.0033, spl=0.0922, ncs=5
RodDiameter=0.0312, pelh=0.0323, rshd=0.008136, dishd=0.000787
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.957, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0.5, roughc=0.5, CladType=5, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=340.84, tgas0=71.6
pitch=0.0405, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 0, 0.00102, 153.223, 0.00208
842.725, 0.00389, 3217.676, 0.00553, 6703.493, 0.00653
9767.946, 0.00715, 11836.453, 0.00748, 13790.042, 0.00801
14747.684, 0.00838, 15169.046, 0.0089, 13866.653, 0.00963
10725.588, 0.01044, 8465.554, 0.01089, 6090.602, 0.01157
3332.593, 0.01252, 2106.812, 0.01321, 1302.393, 0.01399
574.585, 0.01519, 268.14, 0.01676, 153.223, 0.01769
38.306, 0.0194, 0, 0.04
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.36548
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=1
deformation='on'
```

```
noball=1, TranSwell=0
heat='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.36548
 pbh2(1)=
986.2564, 0, 986.2564, 1
 htca(1,1)=
5., 0, 5., 1
 tblka(1,1)=
545, 0, 545, 1
$end
```

A.4 BIGR Tests

Two full-length, water-cooled, water-moderated energy reactor (VVER)-440 rods irradiated to 60 gigawatt-days per metric ton of uranium (GWd/MTU) and four full-length VVER-1000 rods irradiated to 48 GWd/MTU were sectioned and refabricated into rodlets, and then subjected to a rapid energy pulse in the BIGR reactor, similar to what is experienced during an RIA. These tests were carried out in a sealed capsule within the BIGR reactor. The rodlets were submerged in room temperature water but the capsule was not completely filled with water, allowing the water to boil. The purpose of these tests was to determine the RIA failure threshold at each burnup level (Yegorova et al. 2005a and 2005b).

To determine the failure threshold, the rodlets were all subjected to pulses that were about 3 milliseconds wide at half peak. For the VVER-1000 rods irradiated to 48 GWd/MTU, eight rodlets were tested with peak fuel enthalpies between 115 cal/g and 188 cal/g. Based on these tests, the failure threshold was determined to be between 155 and 164 cal/g. For the VVER-440 rods irradiated to 60 GWd/MTU, four rodlets were tested with peak fuel enthalpies between 125 cal/g and 165 cal/g. Based on these tests, the failure threshold was determined to be between 134 and 164 cal/g.

The base irradiation for each of these rodlets was modeled using FRAPCON-4.0. The RIA tests were modeled using FRAPTRAN-2.0 and the burnup-dependent properties calculated using FRAPCON-4.0.

The base irradiation for each rodlet was modeled in FRAPCON-4.0 using the pre-irradiation dimensions of the full-length rods. When initializing a FRAPTRAN-2.0 calculation using FRAPCON-4.0, the plenum length and fuel stack length for each case must be the same. Because of this, the plenum length and stack length for the refabricated rodlet were used in the FRAPCON-4.0 calculation. VVER cladding consists of a Zr-1%Nb alloy. FRAPCON-4.0 does not have a specific model for VVER cladding, but it has been found that VVER cladding behaves similarly to M5™ cladding. For these calculations the M5™ correlation in FRAPCON-4.0 was used to model the corrosion, hydrogen pickup, and mechanical properties of the cladding.

The only information provided about the base irradiation power history was the cycle lengths and the average LHGR at beginning and end of cycle for each rodlet. A power history for each rodlet was created by interpolating between the LHGRs provided at beginning and end of each cycle. Since all of the rodlets used in these tests were taken at axial locations away from the end of the father rods, the axial power distribution over the length of the rodlet is assumed to be uniform. Axial gamma scans confirm this assumption.

For each rod, the reactor coolant conditions were provided, in particular the coolant pressure, inlet temperature, and mass flux. The coolant pressure and mass flux were input directly into FRAPCON-4.0. However, since the rodlets were taken from axial locations above the core base plate, the given inlet temperature for full-length rods was lower than the temperature at the bottom of each rodlet. Measurements were provided of oxide thickness and hydrogen content taken from cladding areas close to each rodlet. Based on these measurements, the coolant inlet temperature used in the FRAPCON-4.0 calculations was selected such that FRAPCON-4.0 predicted a hydrogen content level consistent with the measurement. The selected inlet temperature is less than the typical outlet temperature for a PWR and is therefore a reasonable assumption. Since the pellet/cladding mechanical interaction (PCMI) failure threshold used to predict cladding failure during a RIA in FRAPTRAN-2.0 is a function of hydrogen content, it is important that FRAPCON-4.0 predict the correct cladding hydrogen content to initialize the FRATPRAN 1.4 calculation.

The RIA test for each rodlet was modeled using FRAPTRAN-2.0 and the burnup-dependent properties calculated with FRAPCON-4.0. For each rodlet, a FRAPCON-4.0 case was run as described previously and a FRAPTRAN-2.0 initialization file was created. Because of the refabrication process, rodlets do not have the same gas composition and pressure as the full-length rods at the end of irradiation. To account for this change in gas composition and pressure, the initialization file was modified such that the stated pressure of the refabricated rodlet was used and the gas mixture was 100 percent helium.

For each rodlet, a FRAPTRAN-2.0 case was set up using the same dimensional input as the corresponding FRAPCON-4.0 case. For each test, a plot of the core average power was provided as well as the total energy deposited. To determine the LHGR to be input to FRAPTRAN-2.0, the core average power was scaled by a factor such that the integral of the LHGR curve was equal to the total energy deposited. The axial power distribution during the RIA tests was assumed to be constant for all of these cases. This assumption is supported by measurements from neutron detectors along the length of the rodlet.

The initial coolant conditions in the test capsule were stagnant water at room temperature and atmospheric pressure. For modeling these irradiations, Pacific Northwest National Laboratory decided to use the minimum heat transfer coefficient for stagnant water of 5 Btu/ft^{2}hr°F. It is acknowledged that, at some point after the initial power pulse, localized convection and boiling will occur. This behavior cannot be modeled in FRAPTRAN-2.0 as it is highly dependent on the geometry of the capsule and the heat transfer out of the capsule. Because of this, the heat transfer during the power pulse and immediately after (0 to 1 second) can be reasonably modeled using the minimum heat transfer, but potential heatup after this period cannot be modeled with any certainty. Because of this, only the period between 0 and 1 second is considered in FRAPTRAN-2.0.

The FRAPCON-4.0 and FRAPTRAN-2.0 input files for each case are shown below. Also shown below is the change made to the FRAPTRAN initialization file to account for the different fill gas conditions after the base irradiation. Within each restart file, information is contained for each FRAPCON-4.0 time step. The first line is the time in seconds. The ninth and tenth lines after this contain the number of moles of gas and the relative amount of each gas species. These are the lines that are changed in the following listings of assessment cases.

RT1 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT1-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt1', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT1-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT1 VVER-1000 Assembly 4108 Rod 165
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.50197, cpl=3.0118
 dspg=0.298, dspgw=0.0394, vs=10
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
```

```
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*2210000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 8.23, 8.179, 8.129, 8.078, 8.028
 7.977, 7.947, 7.925, 7.01, 6.545
 6.312, 6.079, 5.846, 5.791, 5.578
 5.261, 5.103, 4.945, 4.787, 4.628
   4.572
 nsp=0
 p2= 2277.09, tw= 572, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.50197
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT1 Change to Restart File

```
   0.3488E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT1 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                         *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='RT1-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT1-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT1' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT1 VVER-1000 Assembly 4108 Rod 165
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
```

```
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.50196, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=304.58, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 14652.361, 0.00311, 2763.769, 0.0056
745.779, 0.0087, 701.91, 0.01036, 921.256, 0.01264
1140.603, 0.01617, 921.256, 0.02052, 438.693, 0.02674
175.477, 0.09202, 131.608, 0.11088, 0, 0.12
0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.50196
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='on'
noball=1, TranSwell=0
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.502, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.50196
```

```
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT2 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT2-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt2', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT2-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT2 VVER-1000 Assembly 4108 Rod 165
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.49541, cpl=3.0118
 dspg=0.298, dspgw=0.0394, vs=10
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*22100000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 8.23, 8.144, 8.058, 7.972, 7.886
 7.8, 7.749, 7.712, 7.315, 6.698
 6.389, 6.081, 5.772, 5.7, 5.578
 5.194, 5.002, 4.811, 4.619, 4.427
   4.359
 nsp=0
 p2= 2277.09, tw= 599, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.49541
 qf(1)=
 1, 1
 jn=2
```

```
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT2 Change to Restart File

```
   0.3475E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT2 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                         *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                       *
FILE06='RT2-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT2-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT2' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT2 VVER-1000 Assembly 4108 Rod 165
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.4954, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
```

```
gfrac(6)=0, gfrac(7)=0, gappr0=304.58, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 11801.467, 0.00249, 3593.282, 0.00477
1726.185, 0.00601, 810.25, 0.0085, 739.793, 0.01078
810.25, 0.01409, 704.565, 0.01782, 493.196, 0.02259
317.054, 0.02674, 246.598, 0.09119, 140.913, 0.11067
0, 0.12, 0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.4954
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='on'
noball=1, TranSwell=0
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.4954, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.4954
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT3 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT3-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt3', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT3-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*********************************************************************
Base Irradiation of RT3 VVER-1000 Assembly 4108 Rod 165
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.48885, cpl=3.0118
```

```
 dspg=0.298, dspgw=0.0394, vs=10
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*22100000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 7.529, 7.493, 7.458, 7.423, 7.387
 7.352, 7.331, 7.315, 7.224, 6.641
 6.35, 6.059, 5.768, 5.7, 5.7
 5.345, 5.168, 4.99, 4.813, 4.635
   4.572
 nsp=0
 p2= 2277.09, tw= 599, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.48885
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT3 Change to Restart File

```
   0.3471E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT3 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                        *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                     *
*                                                                      *
FILE06='RT3-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT3-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT3' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT3 VVER-1000 Assembly 4108 Rod 165
```

```
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.48884, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=304.58, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 15882.928, 0.0029, 4267.055, 0.00497
1991.292, 0.00621, 1137.881, 0.00724, 711.176, 0.00931
853.411, 0.01241, 1090.47, 0.0151, 1090.47, 0.01697
758.588, 0.02193, 379.294, 0.02731, 331.882, 0.03269
142.235, 0.10448, 0, 0.12, 0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.48884
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='on'
noball=1, TranSwell=0
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.4888, inst='off'
$end
$boundary
```

```
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.48884
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT4 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT4-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt4', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT4-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT4 VVER-440 Assembly 222 Rod 081
 $frpcn
 im=34, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3583, thkcld=0.02717, thkgap=0.00315, totl=0.50853, cpl=3.0118
 dspg=0.2976, dspgw=0.0394, vs=10
 hplt=0.4331, rc=0.0325, hdish=0, dishsd=0.1488
 enrch=4.37, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.7, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=87.02, idxgas=1
 iplant=-2, pitch=0.4803, icor=0, crdt=0, crdtr=0, flux=10*22100000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 245.6, 295.6, 345.6, 395.6, 445.6
 495.6, 545.6, 581.6, 631.6, 681.6
 731.6, 781.6, 831.6, 880.1, 930.1
 980.1, 1030.1, 1080.1, 1130.1, 1180.1
 1230.1, 1259.8, 1309.8, 1359.8, 1409.8
 1459.8, 1509.8, 1559.8, 1565.3
 qmpy=
 4.572, 4.467, 4.361, 4.256, 4.15
 4.054, 6.096, 5.733, 5.552, 5.37
 5.189, 5.007, 4.877, 5.395, 5.119
 4.981, 4.844, 4.706, 4.572, 4.663
 4.503, 4.423, 4.342, 4.262, 4.182
 4.102, 4.054, 3.658, 3.528, 3.463
 3.398, 3.333, 3.269, 3.261
 nsp=0
```

```
 p2= 1856.48, tw= 599, go= 2943240
 iq=0, fa=1
 x(1)=
 0, 0.50853
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1
 $end
```

RT4 Change to Restart File

```
   0.3152E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT4 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='RT4-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT4-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT4' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT4 VVER-440 Assembly 222 Rod 081
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=135200000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
```

```
$design
RodLength=0.50852, FuelPelDiam=0.0248, gapthk=0.000262, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.0299, pelh=0.0361, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.967, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=304.58, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 14314.408, 0.0029, 3760.203, 0.00497
1580.994, 0.00641, 1068.239, 0.00703, 640.944, 0.0091
811.862, 0.01221, 1068.239, 0.01552, 1068.239, 0.01738
897.321, 0.02131, 640.944, 0.02545, 341.837, 0.03041
128.189, 0.10883, 0, 0.12, 0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.50852
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='on'
noball=1, TranSwell=0
heat='on'
cenvoi=1, rvoid=0.002707, zvoid1=0, zvoid2=0.5085, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.50852
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT5 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT5-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt5', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
```

```
FILE66='RT5-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT5 VVER-1000 Assembly 4108 Rod 157
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.50197, cpl=3.0118
 dspg=0.298, dspgw=0.0394, vs=10, ngasmod=2, grnsize=6.0
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*22100000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 7.315, 7.214, 7.113, 7.012, 6.911
 6.81, 6.75, 6.706, 7.712, 6.978
 6.611, 6.244, 5.877, 5.791, 5.7
 5.412, 5.268, 5.124, 4.981, 4.837
   4.785
 nsp=0
 p2= 2277.09, tw= 579, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.50197
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT5 Change to Restart File

```
   0.3492E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT5 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                        *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                     *
```

```
*                                                                       *
FILE06='RT5-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT5-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT5' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT5 VVER-1000 Assembly 4108 Rod 157
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.50196, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=304.58, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 16387.213, 0.00314, 4451.452, 0.00492
1516.429, 0.00681, 978.341, 0.00785, 733.756, 0.0093
880.507, 0.0122, 1174.009, 0.0153, 1222.926, 0.01675
978.341, 0.02006, 587.005, 0.02524, 391.336, 0.02793
146.751, 0.10965, 0, 0.12, 0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.50196
$end
$model
nthermex=1, tref=77
```

```
internal='on', presfgr=0
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='off'
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.502, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.50196
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT6 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT6-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt6', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT6-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT6 VVER-1000 Assembly 4108 Rod 154
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.49541, cpl=3.0118
 dspg=0.298, dspgw=0.0394, vs=10
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 7.925, 7.809, 7.693, 7.576, 7.46
 7.344, 7.274, 7.224, 7.102, 6.45
```

```
 6.124, 5.797, 5.471, 5.395, 5.486
 5.199, 5.055, 4.911, 4.767, 4.623
   4.572
 nsp=0
 p2= 2277.09, tw= 581, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.49541
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT6 Change to Restart File

```
   0.3484E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT6 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                        *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                     *
*                                                                      *
FILE06='RT6-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT6-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT6' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT6 VVER-1000 Assembly 4108 Rod 154
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
```

```
ncmesh=3
$end
$design
RodLength=0.4954, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=304.58, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 16436.737, 0.00293, 6623.76, 0.00469
4710.229, 0.00512, 2060.725, 0.0066, 1177.557, 0.00744
735.973, 0.00992, 1030.363, 0.01344, 1226.622, 0.01592
1226.622, 0.01757, 686.908, 0.02358, 441.584, 0.02813
147.195, 0.10655, 0, 0.12, 0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.4954
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='off'
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.4954, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.4954
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT7 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT7-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
```

```
FILE22='restart.rt7', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT7-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT7 VVER-440 Assembly 228 Rod 081
 $frpcn
 im=34, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3583, thkcld=0.02717, thkgap=0.00236, totl=0.5023, cpl=3.0118
 dspg=0.2992, dspgw=0.0394, vs=10, ngasmod=2, grnsize=6.6
 hplt=0.4331, rc=0.0236, hdish=0, dishsd=0.1496
 enrch=3.6, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.7, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=87.02, idxgas=1
 iplant=-2, pitch=0.4803, icor=0, crdt=0, crdtr=0, flux=10*22100000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 98.7, 148.7, 198.7
 248.7, 298.7, 348.7, 398.7, 423.8
 473.8, 523.8, 573.8, 623.8, 673.8
 723.8, 773.8, 795.9, 845.9, 895.9
 945.9, 995.9, 1045.9, 1095.9, 1135.9
 1146.6, 1196.6, 1246.6, 1296.6, 1346.6
 1396.6, 1446.6, 1496.6, 1514.7
 qmpy=
 5.075, 4.783, 4.499, 6.767, 6.381
 6.189, 5.996, 5.803, 5.611, 5.514
 6.09, 5.817, 5.681, 5.544, 5.408
 5.272, 5.135, 5.075, 5.313, 5.081
 4.965, 4.849, 4.733, 4.617, 4.524
 4.499, 4.06, 3.941, 3.881, 3.822
 3.762, 3.702, 3.643, 3.621
 nsp=0
 p2= 1856.48, tw= 599, go= 2943240
 iq=0, fa=1
 x(1)=
 0, 0.5023
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1
 $end
```

RT7 Change to Restart File

```
   0.2865E-02
```

```
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT7 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                  *
        CARRIAGE CONTROL='LIST'                                          *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                      *
*                                                                        *
FILE06='RT7-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT7-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT7' ,
     STATUS='old', FORM='FORMATTED'
/***********************************************************************
RIA Irradiation of RT7 VVER-440 Assembly 228 Rod 081
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=130900000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.50229, FuelPelDiam=0.0249, gapthk=0.000197, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0249, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.0299, pelh=0.0361, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.967, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=290.08, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 204.166, 0.00187, 694.163, 0.00249
13679.099, 0.0056, 3103.318, 0.00788, 1919.157, 0.0085
1184.161, 0.00933, 694.163, 0.01223, 857.496, 0.01575
1020.828, 0.01803, 1061.661, 0.0199, 857.496, 0.0228
489.998, 0.02922, 408.331, 0.03938, 367.498, 0.06964
```

```
204.166, 0.1001, 0, 0.12, 0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.50229
$end
$model
nthermex=1, tref=77
internal='on', presfgr=0
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='on'
noball=1, TranSwell=0
heat='on'
cenvoi=1, rvoid=0.001969, zvoid1=0, zvoid2=0.5023, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.50229
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT8 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT8-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt8', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT8-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT8 VVER-440 Assembly 222 Rod 081
 $frpcn
 im=34, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3583, thkcld=0.02717, thkgap=0.00315, totl=0.49213, cpl=3.0118
 dspg=0.2976, dspgw=0.0394, vs=10
 hplt=0.4331, rc=0.0325, hdish=0, dishsd=0.1488
 enrch=4.37, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.7, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=87.02, idxgas=1
 iplant=-2, pitch=0.4803, icor=0, crdt=0, crdtr=0, flux=10*2210000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
```

```
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 245.6, 295.6, 345.6, 395.6, 445.6
 495.6, 545.6, 581.6, 631.6, 681.6
 731.6, 781.6, 831.6, 880.1, 930.1
 980.1, 1030.1, 1080.1, 1130.1, 1180.1
 1230.1, 1259.8, 1309.8, 1359.8, 1409.8
 1459.8, 1509.8, 1559.8, 1565.3
 qmpy=
 4.572, 4.467, 4.361, 4.256, 4.15
 4.054, 6.096, 5.76, 5.593, 5.425
 5.257, 5.089, 4.968, 5.486, 5.18
 5.027, 4.874, 4.721, 4.572, 4.785
 4.593, 4.496, 4.4, 4.304, 4.207
 4.111, 4.054, 3.658, 3.528, 3.463
 3.398, 3.333, 3.269, 3.261
 nsp=0
 p2= 1856.48, tw= 599, go= 2943240
 iq=0, fa=1
 x(1)=
 0, 0.49213
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1
 $end
```

RT8 Change to Restart File

```
   0.2992E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT8 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
        CARRIAGE CONTROL='LIST'                                        *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                     *
*                                                                      *
FILE06='RT8-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT8-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT8' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT8 VVER-440 Assembly 222 Rod 081
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
```

```
$end
$iodata
 unitin=0, inp=1, trest=135200000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.49212, FuelPelDiam=0.0248, gapthk=0.000262, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.0299, pelh=0.0361, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.967, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=290.08, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 146.793, 0.00187, 1027.55, 0.0029
16342.937, 0.0058, 3229.443, 0.0085, 1370.067, 0.00995
880.757, 0.01161, 831.826, 0.01244, 1027.55, 0.01596
1272.205, 0.0199, 978.619, 0.02425, 538.24, 0.03026
440.379, 0.0342, 244.655, 0.10342, 0, 0.12
0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.49212
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='on'
noball=1, TranSwell=0
heat='on'
cenvoi=1, rvoid=0.002707, zvoid1=0, zvoid2=0.4921, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
```

```
htclev(1)=0.49212
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT9 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT9-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt9', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT9-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT9 VVER-440 Assembly 222 Rod 081
 $frpcn
 im=34, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3583, thkcld=0.02717, thkgap=0.00315, totl=0.48885, cpl=3.0118
 dspg=0.2976, dspgw=0.0394, vs=10
 hplt=0.4331, rc=0.0325, hdish=0, dishsd=0.1488
 enrch=4.37, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.7, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=87.02, idxgas=1
 iplant=-2, pitch=0.4803, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 245.6, 295.6, 345.6, 395.6, 445.6
 495.6, 545.6, 581.6, 631.6, 681.6
 731.6, 781.6, 831.6, 880.1, 930.1
 980.1, 1030.1, 1080.1, 1130.1, 1180.1
 1230.1, 1259.8, 1309.8, 1359.8, 1409.8
 1459.8, 1509.8, 1559.8, 1565.3
 qmpy=
 4.785, 4.636, 4.488, 4.339, 4.19
 4.054, 5.883, 5.647, 5.529, 5.411
 5.293, 5.175, 5.09, 5.182, 4.977
 4.875, 4.773, 4.671, 4.572, 4.572
 4.468, 4.416, 4.363, 4.311, 4.259
 4.207, 4.176, 3.444, 3.414, 3.399
 3.384, 3.369, 3.354, 3.353
 nsp=0
 p2= 1856.48, tw= 599, go= 2943240
 iq=0, fa=1
```

```
 x(1)=
 0, 0.48885
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1
 $end
```

RT9 Change to Restart File

```
   0.1495E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT9 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='RT9-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT9-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT9' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT9 VVER-440 Assembly 222 Rod 081
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=135200000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.48884, FuelPelDiam=0.0248, gapthk=0.000262, vplen=0.00012646
```

```
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.0299, pelh=0.0361, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.967, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=14.5, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 173.755, 0.00207, 868.777, 0.0031
14508.576, 0.006, 5082.346, 0.00786, 1476.921, 0.00993
1042.532, 0.01097, 825.338, 0.01303, 999.094, 0.01572
1259.727, 0.01966, 1129.41, 0.02276, 564.705, 0.03021
434.389, 0.06848, 304.072, 0.10469, 0, 0.12
0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.48884
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='on'
noball=1, TranSwell=0
heat='on'
cenvoi=1, rvoid=0.002707, zvoid1=0, zvoid2=0.4888, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.48884
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT10 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT10-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt10', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT10-base.plot',
```

```
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT10 VVER-1000 Assembly 4108 Rod 170
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.49869, cpl=3.0118
 dspg=0.298, dspgw=0.0394, vs=10
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 8.23, 8.088, 7.947, 7.805, 7.664
 7.522, 7.438, 7.376, 7.102, 6.45
 6.124, 5.797, 5.471, 5.395, 5.578
 5.233, 5.06, 4.887, 4.715, 4.542
   4.481
 nsp=0
 p2= 2277.09, tw= 581, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.49869
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT10 Change to Restart File

```
   0.3320E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT10 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
```

```
FILE06='RT10-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT10-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT10' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT10 VVER-1000 Assembly 4108 Rod 170
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.49868, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=290.08, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 301.556, 0.00145, 1405.559, 0.00269
16805.216, 0.00517, 4266.488, 0.00724, 1809.247, 0.00848
907.78, 0.01179, 1009.48, 0.0151, 1211.325, 0.018
962.522, 0.02276, 514.642, 0.03124, 383.02, 0.07634
243.182, 0.10179, 0, 0.12, 0, 1
CladPower=0, fpowr=1.0
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.49868
$end
$model
nthermex=1, tref=77
internal='off'
```

```
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='off'
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.4987, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.49868
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT11 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT11-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE22='restart.rt11', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT11-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Base Irradiation of RT11 VVER-1000 Assembly 4108 Rod 170
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.49869, cpl=3.0118
 dspg=0.298, dspgw=0.0394, vs=10
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 7.833, 7.763, 7.692, 7.621, 7.551
 7.48, 7.437, 7.407, 7.224, 6.525
 6.176, 5.826, 5.477, 5.395, 5.486
```

```
 5.17, 5.012, 4.853, 4.695, 4.537
   4.481
 nsp=0
 p2= 2277.09, tw= 599, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.49869
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT11 Change to Restart File

```
   0.3318E-02
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT11 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                *
        CARRIAGE CONTROL='LIST'                                       *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                    *
*                                                                     *
FILE06='RT11-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT11-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT11' ,
     STATUS='old', FORM='FORMATTED'
/**********************************************************************
RIA Irradiation of RT11 VVER-1000 Assembly 4108 Rod 170
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
```

```
$end
$design
RodLength=0.49868, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=290.08, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 165.888, 0.00187, 1589.968, 0.00311
18284.684, 0.0058, 6027.153, 0.00767, 2033.281, 0.00912
1322.374, 0.00974, 941.353, 0.01202, 887.947, 0.01347
1164.805, 0.01699, 1385.421, 0.01886, 1387.879, 0.02155
899.101, 0.0257, 468.077, 0.03316, 448.889, 0.07212
368.355, 0.10383, 0, 0.12, 0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
1, 0, 1, 0.49868
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='off'
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.4987, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.49868
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

RT12 FRAPCON Base Irradiation File

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='RT12-base.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
```

```
FILE22='restart.rt12', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT12-base.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/************************************************************************
Base Irradiation of RT12 VVER-1000 Assembly 4108 Rod 170
 $frpcn
 im=21, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3594, thkcld=0.02776, thkgap=0.00295, totl=0.50066, cpl=3.0118
 dspg=0.298, dspgw=0.0394, vs=10
 hplt=0.4528, rc=0.0472, hdish=0, dishsd=0.149
 enrch=4.4, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=97.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.33, idxgas=1
 iplant=-2, pitch=0.502, icor=0, crdt=0, crdtr=0, flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=1, nread=0, nrestr=0
 ProblemTime=
 0.1, 50, 100, 150, 200
 250, 280, 301.7, 351.7, 401.7
 451.7, 501.7, 551.7, 563.4, 613.4
 663.4, 713.4, 763.4, 813.4, 863.4
   881.2
 qmpy=
 7.62, 7.57, 7.519, 7.469, 7.418
 7.368, 7.337, 7.315, 7.224, 6.56
 6.228, 5.896, 5.564, 5.486, 5.486
 5.228, 5.098, 4.969, 4.839, 4.71
   4.663
 nsp=0
 p2= 2277.09, tw= 581, go= 3679050
 iq=0, fa=1
 x(1)=
 0, 0.50066
 qf(1)=
 1, 1
 jn=2
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 $end
```

RT12 Change to Restart File

```
   0.1662E-03
   1.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00   0.0000E+00
0.0000E+00   0.0000E+00   0.0000E+00
```

RT12 FRAPTRAN RIA File

```
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',                 *
```

```
        CARRIAGE CONTROL='LIST'                                      *
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'                  *
*                                                                    *
FILE06='RT12-RIA.out',
     STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='RT12-RIA.plot',
         STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
FILE22='restart.RT12' ,
     STATUS='old', FORM='FORMATTED'
/*********************************************************************
RIA Irradiation of RT12 VVER-1000 Assembly 4108 Rod 170
$begin
 ProblemStartTime=0, ProblemEndTime=1
 ncards=1
$end
$iodata
 unitin=0, inp=1, trest=76140000
 unitout=0, res=0, pow=0
 dtpoa(1)=
0.001, 0, 0.01, 0.12
 dtplta(1)=
0.001, 0, 0.01, 0.12
$end
$solution
 dtmaxa(1)=
0.00001, 0, 0.0001, 0.12
dtss=100000, prsacc=0.005, tmpac1=0.005
soltyp=0, maxit=200, noiter=200, epsht1=0.001
naxn=9
nfmesh=17
ncmesh=3
$end
$design
RodLength=0.50065, FuelPelDiam=0.0248, gapthk=0.000246, vplen=0.00012646
volbp=0, dishv0=0
scd=0.0248, swd=0.0033, spl=0.2526, ncs=10
RodDiameter=0.03, pelh=0.0377, rshd=0, dishd=0
frpo2=0, fotmtl=2, gadoln=0
roughf=2, frden=0.972, OpenPorosityFraction=0, tsntrk=2911, fgrns=10
coldw=0, roughc=0.5, CladType=6, cldwdc=0.04
gfrac(1)=1, gfrac(2)=0, gfrac(3)=0, gfrac(4)=0, gfrac(5)=0
gfrac(6)=0, gfrac(7)=0, gappr0=14.5, tgas0=77
pitch=0.0656, pdrato=1.32, rnbnt=1, totnb=289
$end
$power
 RodAvePower(1)=
0, 0, 180.66, 0.00187, 722.639, 0.0029
15130.255, 0.00601, 6052.102, 0.00788, 3026.051, 0.00891
1354.948, 0.01036, 1083.959, 0.01119, 858.134, 0.01285
948.464, 0.01575, 1083.959, 0.01907, 1038.794, 0.02073
722.639, 0.02549, 496.814, 0.0315, 496.814, 0.04352
316.155, 0.07689, 180.66, 0.09762, 0, 0.12
0, 1
CladPower=0, fpowr=1
NumAxProfiles=1
ProfileStartTime=0
 AxPowProfile(1,1)=
```

```
1, 0, 1, 0.50065
$end
$model
nthermex=1, tref=77
internal='off'
metal='on'
idoxid=0, odoxid=0, cathca=1, baker=0, ProtectiveOxide=0
deformation='off'
heat='on'
cenvoi=1, rvoid=0.003937, zvoid1=0, zvoid2=0.5007, inst='off'
$end
$boundary
heat='on'
press=2, htco=2, tem=2, zone=1
htclev(1)=0.50065
 pbh2(1)=
14.6959, 0, 14.6959, 1
 htca(1,1)=
5, 0, 5, 1
 tblka(1,1)=
77, 0, 77, 1
$end
```

LOCA Assessment Cases

A.5 NRU MT Tests

The U.S. Nuclear Regulatory Commission (NRC) conducted a series of thermal-hydraulic and cladding mechanical deformation tests in the National Research Universal (NRU) reactor at the Chalk River National Laboratory in Canada. The objective of these tests was to perform simulated loss-of-coolant accident (LOCA) experiments using full-length light-water reactor (LWR) fuel rods to study mechanical deformation, flow blockage, and coolability. Three phases of a LOCA (heatup, reflood, and quench) were performed in situ using nuclear fissioning to simulate the low-level decay power during a LOCA after shutdown. Three materials tests, MT-1 (Russcher et al. 1981), MT-4 (Wilson et al. 1983), and MT-6A (Wilson et al. 1993), were selected for the assessment of FRAPTRAN. All tests used PWR-type, nonirradiated fuel rods.

The NRU reactor is a heterogeneous, thermal, tank-type research reactor. It has a power level of 135 MWth and is heavy-water moderated and cooled. The coolant has an inlet temperature of 37°C at a pressure of 0.65 MPa. The MT tests were conducted in a specially designed test train to supply the specified coolant conditions.

Typical instrumentation for the MT tests included fuel centerline thermocouples, cladding inner surface thermocouples, cladding outer surface thermocouples, rod internal gas pressure transducers or pressure switches, coolant channel steam probes, and self-powered neutron detectors. This instrumentation allowed for determining rupture times and cladding temperature.

After the experiments, the test train was dismantled, cladding rupture sites were determined, and fuel rod profilometry was performed in the spent fuel pool. Only limited destructive post-irradiation examination was performed on these three tests.

Initial FRAPTRAN assessment runs for these three cases revealed a significant discrepancy between measured and calculated rod gas pressures before the transients. The stated fuel rod fill gas pressures were initially used to define the input fill gas pressure for the FRAPTRAN runs. However, this resulted in FRAPTRAN calculating significantly higher initial gas pressures than were measured. Analyses comparing the stated design data and the FRAPTRAN calculations, based on the perfect gas law concluded that FRAPTRAN was correctly calculating gas pressure changes with temperature and volume changes and that the stated fill gas pressures were not being interpreted properly.

For tests MT-4 and MT-6A, gas pressure was measured at a manifold in the reactor hall at room temperature. This manifold was connected via a capillary line to the test rods in the reactor core. Therefore, though the pressure in the rods was as-measured, the rods were at higher temperatures in the core than in the manifold in the reactor hall. Thus, the quantity of gas actually in the test rods was less than would be calculated from the design parameters and measured pressure at room temperature in the reactor hall. Because of this, FRAPTRAN, when using the room temperature design parameters, calculated a higher initial gas pressure than was measured. Therefore, it was decided to set the FRAPTRAN input gas pressures at values that would result in the initial FRAPTRAN-calculated pressures matching those as-measured.

For test MT-1, a similar discrepancy between measured and calculated gas pressures was observed. However, the MT-1 rods were filled and then sealed with gas without the capillary design used for MT-4 and MT-6A. The discrepancy was not resolved, but it was decided to treat MT-1 for the assessment the same as for MT-4 and MT-6A (i.e., set FRAPTRAN input such that measured and calculated pressures match at the beginning of the run).

MT-1

This case consists of 11 full-length PWR rods subjected to adiabatic heatup followed by reflood for providing data for supporting LOCA analyses. The primary objective of the MT-1 test was to determine the effects of fuel cladding dilation and rupture on heat transfer within a full-length fuel bundle during a LOCA. The desired cladding peak temperatures of up to 1172K were selected to allow swelling and rupture of the cladding in the high α, $\alpha+\beta$ microstructure range.

A preconditioning phase for the nonirradiated test rods was conducted at an average fuel rod power of 18.7 kW/m with water cooling at a pressure of 8.62 MPa. Three short runs were made under these conditions to permit the fuel pellets to crack and relocate.

The pretransient phase was conducted with steam cooling at a mass flow rate of 0.378 kg/s and an average fuel rod power of 1.24 kW/m.

In the transient phase, the test assembly was allowed to heat up in stagnant steam. The steam flow was turned off at 10 seconds. After 32 seconds, reflood water was introduced at a rate to fill the test section at 0.051 m/s (2 in./s). The test was terminated when all of the thermocouples were quenched. System pressure was held at 0.276 MPa (40 psia) during this phase also.

Measured cladding inner surface temperatures were available at elevations of 77, 98, and 119 inches. To expand the available data to provide a more comprehensive coolant temperature history input for FRAPTRAN, the following approach was taken. First, an initial axial temperature profile for MT-1 was not available; therefore, the initial temperature profile was assumed to be similar to the initial axial temperature profile for MT-4. Second, from the data given for each elevation, it was assumed that the rate of temperature rise at elevations below 77 inches was approximately 15.0°F/s and at an elevation of 119 inches the rate of rise was 11.2°F/s. For the time history, it was assumed that steam-off occurred at 10 seconds and reflood began at 40 seconds (30 seconds after steam-off). Data on the quench front were not available; therefore, the quench front behavior was assumed to be similar to that deduced for MT-4. Using these observations and assumptions, and dividing the coolant channel into 12 zones, a cladding temperature history was defined and input to FRAPTRAN for MT-1.

MT-4

Similar to MT-1, this case consists of 12 full-length PWR rods subjected to adiabatic heatup followed by reflood for providing data for supporting LOCA analyses. The primary objectives of the MT-4 test included providing sufficient time in the α-Zircaloy ballooning window of 1033 to 1200K to allow all 12 pressurized rods to rupture before reflood cooling was introduced, obtaining data to determine heat transfer coefficients for ballooned and ruptured rods, and measuring rod internal gas pressure during rod deformation. All of the objectives for the test were accomplished.

A preconditioning phase for the nonirradiated test rods was conducted for this test with water cooling at a pressure of 8.27 MPa and a flow rate of 16.3 kg/s. Two short runs to full power were made under these conditions to permit the fuel pellets to crack and relocate.

Three transients were run prior to the actual test for MT-4 (designated MT-4.04). These transients were for reflood calibration and ensuring that the correct powers were used to obtain the desired cladding heatup rate of ~8.3 K/s.

In the desired transient (MT-4.04), there was a short heatup phase of approximately 1.5 minutes and a longer phase at temperature that lasted approximately 20 minutes. Reflood was initiated 57 seconds after steam flow was shutoff. Since the rod failures occurred from 52 to 58 seconds, all but one rod failed during the adiabatic heatup before reflood occurred. Cladding temperatures at time of failure ranged from 1077 to 1114K. Peak internal gas pressures were approximately 8.9 to 9.3 MPa (initial value of 4.62 MPa), with gas pressures at failure of approximately 5.6 to 6.5 MPa.

Measured cladding inner surface temperature data were available at elevations of 77, 98, and 119 inches. In addition, a pretransient axial temperature profile was available. To expand the available data to provide a more comprehensive coolant temperature history input for FRAPTRAN, the following approach was taken. First, the axial profile data were used to define the axial cladding temperature profile along the test rod when steam flow was being turned off. Next, from the temperature data given for each elevation, it was assumed that the rate of temperature rise at elevations below 108 inches was 13.5°F/s, while for higher elevations it was assumed to be 12.3°F/s. For the time history, it was assumed that steam-off occurred at 10 seconds and reflood began at 67 seconds (57 seconds after steam-off). The quench front cycled between 60 and 100 inches during the test until scram and test shutdown at 1,050 seconds. For the regions of quench, cladding temperatures went quickly to about 450°F and then further decreased to about 300°F. Using the above observations, and dividing the coolant channel into 12 zones, a cladding temperature history was defined and input to FRAPTRAN for MT-4.

MT-6A

A principal difference between MT-6A and the other two tests was a redesign of the test train to reduce cladding circumferential temperature gradients and thus increase cladding ballooning and flow blockage. In addition, the 20 guard rods used in the previous tests were replaced with 9 pressurized rods that had been used in MT-3. Thus, a total of 21 test rods were in MT-6A.

A computer controlling the test malfunctioned during the test. As a result, system pressure during the transient heatup was 1.72 MPa instead of 0.28 MPa. In addition, the desired temperature control was not achieved.

This test was intended to provide the fuel cladding sufficient time in the α-Zircaloy temperature region (1050 to 1140K) to maximize expansion and to cause the fuel rods to rupture before they were cooled by reflooding. Other objectives included 1) evaluating expansion characteristics of a bundle in which all fuel rods expand and rod-to-rod interaction can occur; and 2) providing data on the rate of cooling for a bundle where all rods have expanded and ruptured. No post-irradiation examination data were obtained for this test.

Measured cladding inner surface temperature data were available at elevations of 56, 74, 90, 102, 115, and 172 inches. At each of these elevations, cladding inner surface thermocouples were present in three different test rods. To develop the cladding/coolant temperature history, the cladding temperature was averaged at each elevation. For the FRAPTRAN input, the coolant input history was assumed equal to the cladding inner surface temperature history. The coolant channel was divided into seven axial zones and the temperature measurements at each axial elevation defined the temperature history for each coolant axial zone. The resulting input coolant temperature history was input to FRAPTRAN for MT-6A.

The FRAPTRAN-2.0 input file for each case is shown below.

MT-1 FRAPTRAN Input File

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
```

```
        CARRIAGE CONTROL='LIST'
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'
*
* GOESOUTS:
FILE06='MT1BR.out',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.MT1BR', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
LOCA rod MT1 British Units Input and SI Units Output
 $begin
   ProblemStartTime = 0.0,
   ProblemEndTime = 160.0,
 $end
 $iodata
   unitout=1, dtpoa(1)=5.0, dtplta=1.0,
 $end
 $solution
   dtmaxa(1)=2.5,0.0, 2.5,15.0, 0.05,16.0, 0.005,40.0, 1.0,160.0,
   prsacc=0.001, tmpac1=0.001, maxit=100, noiter=100, epsht1=2.5,
   naxn=12, nfmesh=15, dtss=1.e5,ncmesh=2
 $end
 $design
   pitch=0.041831, pdrato=1.324, rnbnt=1.0, totnb=11,
   RodLength=12.0, RodDiameter=0.03159,
   rshd=1.125e-2, dishd=110.0e-5, pelh=3.127e-2, dishv0=43.868e-8,
   FuelPelDiam=2.71e-2, roughf=1.0, frden=0.95, bup=0.0, fotmtl=2.0,
tsntrk=1773.0,
   fgrns=10.0,gadoln=0.0, cldwdc=0.5,
   gapthk=24.6e-5, coldw=0.5, roughc=1.0, cfluxa=0.16e15, tflux=0.2e3,
   ncs=59, spl=0.7513, scd=2.583e-2, swd=4.2494e-3, vplen=48.1e-5,
   gfrac(1)=1.0, gappr0=225.0, tgas0=80.33,
 $end
 $power
   RodAvePower= 0.378,0.0, 0.378,1000.0,
   AxPowProfile= 0.08,0., 0.4, 1.667,0.75,3.333,1.05,5.00,
                 1.18,5.833,1.25,6.667,1.22,7.5,1.15,8.33,
                 0.9,10.0,0.6,11.667,0.53,12.0
   RadPowProfile=
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
     1.0,0.0, 1.0,4.130e-3,
 $end
 $model
   internal='on',
   metal='on', baker=1,
   deformation='on',noball=0,
 $end
 $boundary
```

```
   coolant='on',
   geomet=1, dhe=0.0389, dhy=0.0389, achn=96.6e-5,
   lowpl=2, hinta(1)= 1400.0, 0.0,  1400.0, 1000.0,
   pressu=2, pbh1(1)=   40.0, 0.0,    40.0, 1000.0,
   massfl=2, gbh(1)= 3105590.0, 0.0, 3105590.0, 1000.0,
   reflood='on',
   geometry=1, hydiam=0.0389, flxsec=96.6e-5, nbundl=15,
   time=1, emptm=10.0, refdtm=42.0,
   ruptur=1,
   inlet=2, temptm= 100.0,         0.0,     100.0,   300.0,
   pressure=2, prestm(1)= 40.0,    0.0,     40.0,  1000.0,
   reflo=2,    fldrat(1)=  2.1,    0.0,      2.1,  1000.0,
 $end
 $tuning
 $end
```

MT-4 FRAPTRAN Input File

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'
*
* GOESOUTS:
FILE06='MT4BR.out',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.MT4BR', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
LOCA rod MT4 British Units Input and SI Units Output
 $begin
   ProblemStartTime = 0.0,
   ProblemEndTime = 100.0,
 $end
 $iodata
  unitout=1, dtpoa(1)=5.0, dtplta=1.0,
 $end
 $solution
  dtmaxa(1)=0.01,
  dtss=1.e5, prsacc=0.001, tmpac1=0.001, maxit=100, noiter=100, epsht1=3.6,
  naxn=12, nfmesh=15,ncmesh=2,
 $end
 $design
  RodLength=12.0, RodDiameter=0.03159, FuelPelDiam=2.71e-2, gapthk=24.6e-5,
  pitch=0.041831, pdrato=1.324, rnbnt=1.0, totnb=12,
  rshd=1.125e-2, dishd=110.0e-5, pelh=3.127e-2, dishv0=43.868e-8,
  roughf=1.0, frden=0.95, fotmtl=2.0, tsntrk=1773.0, fgrns=10.0,
  coldw=0.1, roughc=1.0, cfluxa=0.16e15, tflux=0.2e3, cldwdc=0.5,
  ncs=59, spl=0.7513, scd=2.583e-2, swd=4.2494e-3, vplen=48.1e-5,
  gfrac(1)=1.0, gappr0=670.0, tgas0=73.0,
 $end
 $power
  RodAvePower=0.37,0.0, 0.37,1000.0,
  AxPowProfile=0.01,0.0, 0.45,2.0,1.18,4.0,1.5,6.0,
               1.53,7.0,1.48,8.0,1.15,10.0,0.3,12.0
  RadPowProfile=
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
```

```
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
    1.0,0.0, 1.0,4.130e-3,
 $end
 $model
  internal='on',
  metal='on', cathca=1,
  deformation='on',noball=0,
 $end
 $boundary
   coolant='on',
   geomet=1, dhe=0.0389, dhy=0.0389, achn=96.6e-5,
   lowpl=2, hinta(1)=1200.0, 0.0,  1200.0, 1000.0,
   pressu=2, pbh1(1)=  40.0, 0.0,    40.0, 1000.0,
   massfl=2, gbh(1)=97200.0, 0.0, 97200.0, 1000.0,
   reflood='on'
   geometry=1, hydiam=0.0389, flxsec=96.6e-5, nbundl=6,
   time=1, emptm=10.0, refdtm=67.0,
   ruptur=1,
   inlet=2, temptm= 100.0,         0.0,      100.0,     300.0,
   pressure=2, prestm(1)=40.0,    0.0,        40.0,    1000.0,
   reflo=8,    fldrat(1)= 8.0,    0.0,         8.0,       6.0,
                          4.0,    6.01,        4.0,      12.0,
                          1.0,   12.01,        1.0,      15.0,
                          2.0,   15.01,        2.0,     100.0
 $end
 $tuning
 $end
```

MT-6A FRAPTRAN Input File

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'
*
* GOESOUTS:
FILE06='MT6ABR.out',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.MT6ABR', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
LOCA rod MT-6A British Units Input and SI Units Output
 $begin
   ProblemStartTime = 0.0,
   ProblemEndTime = 100.0,
 $end
 $iodata
   unitout=1, dtpoa(1)=2.5, dtplta=1.0,
 $end
 $solution
```

```
  dtmaxa(1)=0.01,0.0,0.005,30.0, dtss=1.e5
  prsacc=0.001, tmpac1=0.001, maxit=100, noiter=100, epsht1=3.6,
  naxn=12, nfmesh=15, ncmesh=2
$end
$design
  RodLength=12.0, RodDiameter=0.03159, FuelPelDiam=2.71e-2, gapthk=24.6e-5,
  pitch=0.041831, pdrato=1.324, rnbnt=1.0, totnb=12,
  rshd=1.125e-2, dishd=110.0e-5, pelh=3.127e-2, dishv0=43.868e-8,
  roughf=1.0, frden=0.95, fotmtl=2.0, tsntrk=1773.0, fgrns=10.0,
  coldw=0.1, roughc=1.0, cfluxa=0.16e15, tflux=0.2e3, cldwdc=0.5,
  ncs=59, spl=0.7513, scd=2.583e-2, swd=4.2494e-3, vplen=48.1e-5,
  gfrac(1)=1.0, gappr0=538.0, tgas0=70.0,
$end
$power
 RodAvePower=0.345,0.0, 0.345,1000.0,
   AxPowProfile=0.01,0.00, 0.02,0.83, 0.20,1.67, 0.73,3.33,
              0.96,5.00, 0.98,5.83, 0.98,6.67, 0.95,7.50,
              0.88,8.33, 0.67,10.0, 0.27,12.0,
 RadPowProfile=
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
   1.0,0.0, 1.0,4.130e-3,
$end
$model
  internal='on',
  metal='on', cathca=1,
  deformation='on',noball=0
$end
$boundary
  coolant='on',
  geomet=1, dhe=0.0389, dhy=0.0389, achn=96.6e-5,
  lowpl=2, hinta(1)=1250.0, 0.0, 1250.0, 1000.0,
  pressu=2, pbh1(1)=40.0, 0.0, 40.0,1000.0,
  massfl=2, gbh(1)=97200.0, 0.0, 97200.0,1000.0,
  reflood='on'
  geometry=1, hydiam=0.0389, flxsec=96.6e-5, nbundl=6,
  time=1, emptm=10.0, refdtm=70.0,
  ruptur=1,
  inlet=2, temptm= 98.3,         0.0,        98.3,    1000.0,
  pressure=2, prestm(1)=250.0 ,  0.0,       250.0 ,  1000.0,
  reflo=6, fldrat(1)=8.0,        0.0,         8.0,       3.0,
                     7.0,        3.01,        7.0,       6.0,
                     2.0,        6.01,        2.0,     100.0,
$end
$tuning
$end
```

A.6 PBF LOC-11C Test

LOCA testing was conducted in the Power Burst Facility (PBF) as part of the Thermal Fuels Behavior Program for the NRC. The PBF was designed primarily for performing very-high-power excursions and consists of a driver core in a water pool and a pressurized-water test loop capable of providing a range of test conditions. The central test space operates as a neutron flux trap that permits high power densities in tested fuel rods relative to the active core. An in-pile tube fits in this central flux trap region and contains the test assemblies.

In the LOC-11 test series, four PWR-type, nonirradiated fuel rods were subjected to cladding temperatures similar to those expected for the highest powered PWR rods during blowdown and heatup of a 200 percent, double-ended cold leg break. The test sequence was heatup, power calibration, preconditioning, decay heat buildup, blowdown and quench, and cool down. Three sequential tests were run, LOC-11A, -11B, and -11C. The LOC-11C test was intended to result in peak cladding temperatures of approximately 1030K. There was no indication of fuel rod failure in any of the three tests (Buckland et al. 1978) (Larson et al. 1979).

Instrumentation for each test rod in the LOC-11C included four thermocouples for cladding surface temperature, cladding centerline temperature, cladding axial elongation, and plenum temperature and pressure. The effect of fuel rod pressurization was demonstrated with the two 0.1 MPa (1 atm) rods (rods 1 and 4) having diameter decreases and the two pressurized rods (2.41 MPa/24 atm and 4.8 MPa/48 atm) (rods 3 and 2) having ballooning at the axial mid-plane where cladding temperatures were the highest.

For the PBF LOC-11 assessment case, the FRAPTRAN input coolant temperature history was based on the measured cladding temperature histories. The four test rods for LOC-11C were irradiated in flowing steam following the scram that initiated the transient. Initial cladding temperatures were approximately 620K and increased to peak of approximately 950 to 1050K.

Cladding outer surface temperatures were measured on all four test rods at elevations of 0.53 and 0.61 m, and all four rods showed similar temperature behavior during the transient. The input cladding/coolant temperature history for FRAPTRAN was developed as follows. First, an initial cladding temperature of 620K was assumed along the full-length of the rods based on

FRAPCON calculation that showed minimal axial variation in cladding outer surface temperature before the transient. Next, cladding temperatures were assumed to remain constant for the first 2 seconds of the transient. The input coolant temperature history was then a lineal approximation of the measured cladding temperatures. The history at 0.5 m approximated the measurements at 0.53 m; the history at 0.3 and 0.6 m approximated the measurements at 0.61 m; and the history at the top of the fuel column (1.0 m) was assumed to be approximately 75K less than the measured history, at 0.61 m.

The FRAPTRAN-2.0 input file for each case is shown below.

LOC-11C Rods 1 and 4 FRAPTRAN Input File

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'
*
* GOESOUTS:
```

```
FILE06='PBF-LOC-11C-R1.out',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.pbf11c-R1', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
 PBF Test LOC 11C Rod 1
 $begin
   ProblemStartTime =  0.0,
   ProblemEndTime   = 30.0,
 $end
 $iodata
   unitout=1, dtpoa(1)=0.5, dtplta=0.1,
 $end
 $solution
   dtmaxa(1)=0.01,0.0,0.0001,8.0, 0.001,8.01, 0.01,30.0,
   prsacc=0.001, tmpac1=0.001, maxit=200, noiter=200, epsht1=1.0,
   nfmesh=9, ncmesh=2,
   zelev = 0.25,    0.75,    1.25,    1.50,
        1.73884,  2.0013,    2.25,    2.75,
 $end
 $design
   RodLength=3.0034, RodDiameter=0.0351706,
   rshd=0.0108, dishd=0.001083, pelh=0.05, dishv0=3.9818e-7,
   FuelPelDiam=0.030552, roughf=2.159, frden=0.945, fotmtl=2.0,
   fgrns=10.0, gadoln=0.0, tsntrk=1873.0, cldwdc=0.0,
   gapthk=0.32808e-3, coldw=0.5, roughc=1.143,
   ncs=17, spl=.19792, scd=.0307, swd=3.38e-3, vplen=1.162e-4,
   gfrac(1)=1.0, gappr0=14.94, tgas0=80.33,
 $end
 $power
   RodAvePower=     16.368,   0.0,   0.92,   0.01,    0.9,    0.1,
                     0.82 ,   1.0,   0.78,   2.0,     0.7,    5.0,
                     0.62 ,  10.0,   0.57,  15.0,     0.49,  30.0,
                     0.42 ,  60.0,

   AxPowProfile=
  0.163,     0.0000,    0.326,     0.0833,    0.620,     0.250,
  0.862,     0.4167,    1.047,     1.0833,    1.396,     1.250,
  1.400,     1.4167,    1.368,     1.5833,    1.304,     1.750,
  1.221,     1.9167,    1.128,     2.0833,    1.028,     2.250,
  0.910,     2.4167,    0.754,     2.5833,    0.548,     2.750,
  0.290,     2.9167,    0.256,     3.0034,

   RadPowProfile=
  0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
  0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
  0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
  1.0800,    0.00427616,  1.1460,   0.00530561,
  0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
  0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
  0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
  1.0800,    0.00427616,  1.1460,   0.00530561,
  0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
  0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
  0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
  1.0800,    0.00427616,  1.1460,   0.00530561,
  0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
  0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
```

```
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
  CladPower=0.0123,
$end
$model
  cenvoi=1,
  zvoid1=1.6545,
  zvoid2=3.0034,
  rvoid =0.00308,
  gasflo=0,
  cathca=1,
  noball=0,
  internal='on',
  metal='on',
  deformation='on',
$end
$boundary
  heat='on'
  press=10, pbh2(1) = 2190.0, 0.00, 2205.0, 0.25,
                      1784.0, 0.27, 1784.0, 0.38,
                      1958.0, 0.40, 1305.0, 5.00,
                       580.0,10.00,  290.0,15.00,
                       145.0,20.00,   25.0,30.00,
  zone=4, htclev(1)=0.75,1.8,2.25,3.0034
  htco=2, htca(1,1)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,2)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,3)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,4)=2000000.0, 0.0, 2000000.0, 30.0,
  tem=5,
  tblka(1,1)=655.0,0.0,655.0,2.0,1070.0,5.0,1270.0,15.0,1160.0,30.0
  tblka(1,2)=655.0,0.0,655.0,2.0,1160.0,5.0,1385.0,15.0,1295.0,30.0
  tblka(1,3)=655.0,0.0,655.0,2.0,1070.0,5.0,1270.0,15.0,1160.0,30.0
  tblka(1,4)=655.0,0.0,655.0,2.0, 980.0,5.0,1160.0,15.0,1070.0,30.0
$end
$tuning
$end
```

LOC-11C Rod 2 FRAPTRAN Input File

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'
*
* GOESOUTS:
FILE06='PBF-LOC-11C-R2.out',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.pbf11c-R2', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
 PBF Test LOC 11C Rod 2
 $begin
   ProblemStartTime =  0.0,
   ProblemEndTime   = 30.0,
 $end
 $iodata
   unitout=1, dtpoa(1)=0.5, dtplta=0.1,
 $end
 $solution
   dtmaxa(1)=0.01,0.0,0.0001,8.0, 0.001,8.01, 0.01,30.0,
   prsacc=0.001, tmpac1=0.001, maxit=200, noiter=200, epsht1=1.0,
   nfmesh=9, ncmesh=2,
   zelev = 0.25,    0.75,    1.25,    1.50,
        1.73884,  2.0013,    2.25,    2.75,
 $end
 $design
   RodLength=3.0034, RodDiameter=0.0351706,
   rshd=0.0108, dishd=0.001083, pelh=0.05, dishv0=3.9818e-7,
   FuelPelDiam=0.030552, roughf=2.159, frden=0.945, fotmtl=2.0,
   fgrns=10.0, gadoln=0.0, tsntrk=1873.0, cldwdc=0.0,
   gapthk=0.32808e-3, coldw=0.5, roughc=1.143,
   ncs=17, spl=.19792, scd=.0307, swd=3.38e-3, vplen=1.162e-4,
   gfrac(1)=1.0, gappr0=699.1, tgas0=80.33,
 $end
 $power
   RodAvePower=     16.368,   0.0,   0.92,   0.01,    0.9,    0.1,
                     0.82 ,   1.0,   0.78,   2.0,     0.7,    5.0,
                     0.62 ,  10.0,   0.57,  15.0,     0.49,  30.0,
                     0.42 ,  60.0,

   AxPowProfile=
  0.163,     0.0000,    0.326,     0.0833,    0.620,     0.250,
  0.862,     0.4167,    1.047,     1.0833,    1.396,     1.250,
  1.400,     1.4167,    1.368,     1.5833,    1.304,     1.750,
  1.221,     1.9167,    1.128,     2.0833,    1.028,     2.250,
  0.910,     2.4167,    0.754,     2.5833,    0.548,     2.750,
  0.290,     2.9167,    0.256,     3.0034,

   RadPowProfile=
  0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
  0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
  0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
  1.0800,    0.00427616,  1.1460,   0.00530561,
  0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
  0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
  0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
```

```
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
  CladPower=0.0123,
$end
$model
  cenvoi=1,
  zvoid1=1.6545,
  zvoid2=3.0034,
  rvoid =0.00308,
  gasflo=0,
  cathca=1,
  noball=0,
  internal='on',
  metal='on',
  deformation='on',
$end
$boundary
  heat='on'
  press=10, pbh2(1) = 2190.0, 0.00, 2205.0, 0.25,
                      1784.0, 0.27, 1784.0, 0.38,
                      1958.0, 0.40, 1305.0, 5.00,
                       580.0,10.00,  290.0,15.00,
                       145.0,20.00,   25.0,30.00,
  zone=4, htclev(1)=0.75,1.8,2.25,3.0034
  htco=2, htca(1,1)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,2)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,3)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,4)=2000000.0, 0.0, 2000000.0, 30.0,
  tem=5,
  tblka(1,1)=655.0,0.0,655.0,2.0,1070.0,5.0,1270.0,15.0,1160.0,30.0
  tblka(1,2)=655.0,0.0,655.0,2.0,1160.0,5.0,1385.0,15.0,1295.0,30.0
  tblka(1,3)=655.0,0.0,655.0,2.0,1070.0,5.0,1270.0,15.0,1160.0,30.0
  tblka(1,4)=655.0,0.0,655.0,2.0, 980.0,5.0,1160.0,15.0,1070.0,30.0
$end
```

```
 $tuning
 $end
```

LOC-11C Rod 3 FRAPTRAN Input File

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'
*
* GOESOUTS:
FILE06='PBF-LOC-11C-R3.out',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.pbf11c-R3', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
 PBF Test LOC 11C Rod 3
 $begin
   ProblemStartTime =  0.0,
   ProblemEndTime   = 30.0,
 $end
 $iodata
   unitout=1, dtpoa(1)=0.5, dtplta=0.1,
 $end
 $solution
   dtmaxa(1)=0.01,0.0,0.0001,8.0, 0.001,8.01, 0.01,30.0,
   prsacc=0.001, tmpac1=0.001, maxit=200, noiter=200, epsht1=1.0,
   nfmesh=9, ncmesh=2,
   zelev = 0.25,    0.75,    1.25,    1.50,
        1.73884,  2.0013,    2.25,    2.75,
 $end
 $design
   RodLength=3.0034, RodDiameter=0.0351706,
   rshd=0.0108, dishd=0.001083, pelh=0.05, dishv0=3.9818e-7,
   FuelPelDiam=0.030552, roughf=2.159, frden=0.945, fotmtl=2.0,
   fgrns=10.0, gadoln=0.0, tsntrk=1873.0, cldwdc=0.0,
   gapthk=0.32808e-3, coldw=0.5, roughc=1.143,
   ncs=17, spl=.19792, scd=.0307, swd=3.38e-3, vplen=1.162e-4,
   gfrac(1)=1.0, gappr0=349.5, tgas0=80.33,
 $end
 $power
   RodAvePower=     16.368,   0.0,   0.92,   0.01,    0.9,    0.1,
                     0.82 ,   1.0,   0.78,   2.0,     0.7,    5.0,
                     0.62 ,  10.0,   0.57,  15.0,     0.49,  30.0,
                     0.42 ,  60.0,

   AxPowProfile=
  0.163,     0.0000,    0.326,     0.0833,    0.620,     0.250,
  0.862,     0.4167,    1.047,     1.0833,    1.396,     1.250,
  1.400,     1.4167,    1.368,     1.5833,    1.304,     1.750,
  1.221,     1.9167,    1.128,     2.0833,    1.028,     2.250,
  0.910,     2.4167,    0.754,     2.5833,    0.548,     2.750,
  0.290,     2.9167,    0.256,     3.0034,

   RadPowProfile=
  0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
  0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
  0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
```

```
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
 0.8800,    0.00092878,  0.8810,   0.00130960,  0.886,    0.00168042,
 0.8978,    0.00205124,  0.9095,   0.00242206,  0.929,    0.00279288,
 0.9525,    0.00316370,  0.9825,   0.00252452,  1.031,    0.00390534,
 1.0800,    0.00427616,  1.1460,   0.00530561,
  CladPower=0.0123,
$end
$model
  cenvoi=1,
  zvoid1=1.6545,
  zvoid2=3.0034,
  rvoid =0.00308,
  gasflo=0,
  cathca=1,
  noball=0,
  internal='on',
  metal='on',
  deformation='on',
$end
$boundary
  heat='on'
  press=10, pbh2(1) = 2190.0, 0.00, 2205.0, 0.25,
                      1784.0, 0.27, 1784.0, 0.38,
                      1958.0, 0.40, 1305.0, 5.00,
                       580.0,10.00,  290.0,15.00,
                       145.0,20.00,   25.0,30.00,
  zone=4, htclev(1)=0.75,1.8,2.25,3.0034
  htco=2, htca(1,1)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,2)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,3)=2000000.0, 0.0, 2000000.0, 30.0,
          htca(1,4)=2000000.0, 0.0, 2000000.0, 30.0,
  tem=5,
  tblka(1,1)=655.0,0.0,655.0,2.0,1070.0,5.0,1270.0,15.0,1160.0,30.0
```

```
  tblka(1,2)=655.0,0.0,655.0,2.0,1160.0,5.0,1385.0,15.0,1295.0,30.0
  tblka(1,3)=655.0,0.0,655.0,2.0,1070.0,5.0,1270.0,15.0,1160.0,30.0
  tblka(1,4)=655.0,0.0,655.0,2.0, 980.0,5.0,1160.0,15.0,1070.0,30.0
$end
$tuning
$end
```

A.7 TREAT FRF-2 Test

The FRF-2 test was the second seven-rod bundle irradiated in the Transient Reactor Test Facility (TREAT) reactor. Power was increased to 7.16 kW/m for 20 seconds during steam cooling. The irradiation was performed to evaluate code simulations of fuel rod heat capacity by comparing predicted and measured cladding temperatures during beginning-of-life adiabatic heatup (Lorenz and Parker 1972).

The TREAT reactor is a solid, graphite-moderated, air-cooled reactor capable of steady-state operation at 0.1 MW or transient operation of 1000 MW-s. Removal of heat from the reactor is the limiting factor for operation. The core has an active height of 48 inches with a central, vertical test hole for materials testing. The LOCA test was performed in a water loop.

Instrumentation for the test included cladding surface thermocouples on two rods, rod gas pressure for two rods, and coolant conditions. The test rods were examined after irradiation and cladding strain measurements were obtained. Peak cladding temperatures were 2400 to 2450°F. The rods failed by rupture from 30 to 37 seconds when cladding temperatures were between 2200 and 2400°F.

Three principal gas volumes are important to the measured gas pressures for rods 11 and 12 in this test; the three volumes are the fuel and gap, the plenum, and an external pressure cell. Primarily because of the external pressure cell, gas pressures did not increase as much as would have been expected had the rods been sealed systems. For the FRAPTRAN calculation, it is important to note that 65 percent of the gas volume stayed at relatively low temperatures during the transient. Accounting for these volumes and temperature differences in the FRAPTRAN calculation is discussed further below.

For the TREAT FRF-2 assessment case, the FRAPTRAN input coolant temperature history was based on the measured cladding temperature histories. The seven test rods for FRF-2 were irradiated in a flowing steam/helium mixture during the transient. To achieve the desired cladding peak cladding temperature of approximately 2400°F, rod-average power levels up to approximately 11 kW/ft were induced during the transient. Cladding outer surface temperatures were measured on two rods (rods 12 and 13) at elevations of 11, 14, 15, and 19 inches below the top of the rods. The pretransient cladding axial temperature profile was approximately constant at 335°F.

The input cladding temperature history for FRAPTRAN was developed as follows. Cladding temperatures did not begin to increase until approximately 7 seconds into the transient. At that point, cladding temperature increased at an average rate of approximately 80°F/s until about 30 to 35 seconds, when temperatures reached a maximum and then began to decrease. It is assumed that cladding temperatures linearly increased from 335°F at 7 seconds to the peak measured cladding temperatures at 35 seconds, then decreased by 50°F from 35 to 50 seconds of the transient. The assumed cladding/coolant temperature history was input to FRAPTRAN for the FRF-2 test.

As discussed above, there were three principal gas volumes in the experimental setup which affect the interpretation of the gas pressure data. To model this with FRAPTRAN, the coolant temperature was forced to a low value at the top of the rod to simulate the exterior gas volume that was kept at a low temperature.

The FRAPTRAN-2.0 input file for this case is shown below.

FRF-2 FRAPTRAN Input File

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
```

```
        CARRIAGE CONTROL='LIST'
FILE15='sth2xt',  STATUS='old', FORM='UNFORMATTED'
*
* GOESOUTS:
FILE06='treatloca.out',   STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.treatloca', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
Treat LOCA experiment FRF-2 with steady state T/H
 $begin
   ProblemStartTime = 0.0,
   ProblemEndTime = 50.0,
 $end
 $iodata
  unitout=1, dtpoa(1)=1.0,0.0,2.0,25.0,2.0,50.0,
  dtplta=0.5,0.0,0.5,50.0, res=0, pow=1,
 $end
 $solution
  dtmaxa(1)=0.001, 0.0, 0.0001, 20, 0.001, 30.0,
  dtss=1.e5
  prsacc=0.001, tmpac1=0.001,
  maxit=100, noiter=200, epsht1=1.0
  naxn=10, nfmesh=15, ncmesh=2
 $end
 $design
  RodLength=2, RodDiameter=0.046942, FuelPelDiam=0.041208, gapthk=0.0002,
  rshd=0.006583, dishd=0.000942, pelh=0.0375, dishv0=1.291e-7,
  roughf=2.16, frden=0.95, bup=0.0, frpo2=0.0,
  fotmtl=2.0, tsntrk=1883.0, fgrns=10.0, gadoln=0.0,
  coldw=0.5, roughc=1.14, cldwdc=0.04,
  ncs=20, spl=.1979, scd=.02958, swd=3.42e-3, vplen=3.178e-4,
  gfrac(1)=1.0, gappr0=75.0, tgas0=77.0,
 $end
 $power
  RodAvePower= 0,0, 1.3,5, 11,7.2, 5.3,13.6,
           8.2,22.5, 5.3,30, 0,35, 0,50,
  AxPowProfile=0.85,0, 0.97,0.333, 1.05,0.666, 1.06,1, 1.04,1.333,
     0.97,1.666, 0.89,2,
  RadPowProfile=
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
```

```
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
     0.9234,0.00, 0.9259,9.418e-4, 0.9328,1.570e-3, 0.9425,2.198e-3,
0.954,2.825e-3,
       0.969,3.453e-3, 0.986,4.081e-3, 1.008,4.709e-3, 1.035,5.337e-3,
       1.064,5.965e-3, 1.0790,6.280e-3,
 $end
 $model
  internal='on', gasflo=0,
  deformation='on',noball=0
 $end
 $boundary
  heat='on',
  press=2,  pbh2(1) = 20, 0, 20, 50,
  zone = 5, htclev(1) = 0.5, 1, 1.5, 1.8, 2,
  htco=2, htca(1,1) = 2000000, 0, 2000000, 50,
          htca(1,2) = 2000000, 0, 2000000, 50,
          htca(1,3) = 2000000, 0, 2000000, 50,
          htca(1,4) = 2000000, 0, 2000000, 50,
          htca(1,5) = 2000000, 0, 2000000, 50,
  tem =4 , tblka(1,1)=335, 0, 335, 7, 2325, 35, 2275, 50,
           tblka(1,2)=335, 0, 335, 7, 2460, 35, 2410, 50,
           tblka(1,3)=335, 0, 335, 7, 2350, 35, 2300, 50,
           tblka(1,4)=335, 0, 335, 7, 2150, 35, 2100, 50,
           tblka(1,5)=335, 0, 335, 7,  370, 35,  370, 50,
 $end
 $tuning
 $end
```

A.8 IFA-650.5 Test

The IFA-650.5 rod was taken from a commercial PWR rod that was base irradiated for six cycles up to a burnup of 83.4 GWd/MTU for the segment. After base irradiation and refabrication, the rodlet was subjected to LOCA testing in the Halden reactor (Kekkonen 2007a). The following describes the modeling approach and assumptions used to model this test with FRAPTRAN-2.0 initialized with FRAPCON-4.0.

The dimensions for IFA-650.5 were taken from the data sheet for the father rod. When modeling the base irradiation of a rod that will later be cut into a segment to be tested, it is necessary to model the base irradiation on the short segment only. The active fuel length of IFA-650.5 is 480 mm. The total void volume for the test is 15 cm^3. From this value a plenum length can be calculated. However, a portion of this void volume was outside of the reactor core at a lower temperature. This external volume cannot be modeled in FRAPTRAN-2.0, so it must be included in the rod plenum volume. This will lead to an overprediction of rod pressure because of the assumption that all the gas is at elevated temperature, when in reality some of the gas is at a lower temperature.

Cycle-average power levels are given for the IFA-650.5 father rod. These power levels were adjusted to give the measured segment burnup when used as constant values of the length of each cycle. The axial power profile was assumed to be flat over the length of the rodlet.

The radial rod dimensions were the same as that of a 15 x 15 PWR rod. The axial length was that of the test segment. The rod internal pressure, coolant pressure, and coolant mass flow rate were all taken as standard 15 x 15 values. The coolant inlet temperature was adjusted up from the standard PWR 15 x 15 value to simulate the segment being taken from the sixth span of the rod. The predicted oxide thickness (66±11 μm) and hydrogen content (360 to 510 ppm) were close to the measured oxide thickness (65 μm mean, 80 μm maximum) and hydrogen content (650 ppm). This indicates that the base irradiation run with FRAPCON-4.0 is representative of the actual base irradiation.

FRAPCON-4.0 was run using this input deck and a FRAPTRAN initialization file was created.

A FRAPTRAN-2.0 input deck was created using the unirradiated dimensions for the father rod. These dimensions are adjusted for changes that occurred during the base irradiation by the FRAPTRAN initialization file that was created with FRAPCON-4.0. This process eliminates the need to specify burnup-dependent changes in the rod that occur after prior irradiation. A constant power history of 2.4 kW/m was used for the LHGR. The axial power profile of IFA-650.5 was provided.

The coolant conditions for this test were atypical of LWR LOCA conditions, and consisted of a fuel rod within a heated tube. Water was evacuated from this tube to start the test, spray was eventually applied, and the reactor was scrammed to end the test. Rather than attempt to model these conditions, FRAPTRAN was set up to use measured cladding surface temperatures as the temperature boundary condition. Cladding surface temperature histories were available for two axial locations during this test. To model the coolant conditions, the rod was divided into two zones and the temperature histories for each of the two axial elevations were set as the coolant temperature in each of these axial zones. To force the code to use the same coolant temperature and cladding surface temperature, a large cladding-to-coolant heat transfer coefficient (352,222 Btu/ft^2hr°F) was set in the code as recommended in the FRAPTRAN-2.0 input instructions.

The FRAPTRAN initialization file that was created with FRAPCON-4.0 includes gas from the initial father rod pressurization and subsequent FGR during the base irradiation. When the rodlet was refabricated, it was refilled with 40 bar of gas consisting of 90 percent argon and 10 percent helium. The FRAPTRAN initialization file was manually adjusted to reflect this new gas mixture and pressure. Within each restart file, information is contained for each FRAPCON-4.0 time step. The first line is the time in seconds. The ninth and tenth lines after this contain the number of moles of gas and the relative amount of each gas species. These are the lines that are changed in the following listings of assessment cases.

The FRAPCON-4.0 and FRAPTRAN-2.0 input files for this case are not included in this report due to the limited availablility and sensitivity of this information.

A.9 IFA-650.6 Test

The IFA-650.6 rod was taken from a commercial VVER rod that was base irradiated in Loviisa NPP (Finland) for four cycles up to a burnup of 55.5 GWd/MTU for the segment. After base irradiation and refabrication, the rodlet was subjected to LOCA testing in the Halden reactor (Kekkonen 2007b). The following describes the modeling approach and assumptions used to model this test with FRAPTRAN-2.0 initialized with FRAPCON-4.0.

The dimensions for IFA-650.6 were taken from the data sheet for the father rod. When modeling the base irradiation of a rod that will later be cut into a segment to be tested, it is necessary to model the base irradiation on the short segment only. The active fuel length of IFA-650.6 is 480 mm. The total void volume for the test is 16 to 18 cm^3. From this value a plenum length can be calculated. FRAPCON-4.0 does not have properties for E110. For the base irradiation, M5™ was assumed since it has the same chemical composition as E110 (Zr1%Nb).

The power history given for the IFA-650.6 father rod was used for the base irradiation in FRAPCON-4.0. The axial power profile was assumed to be flat over the length of the rodlet based on a flat axial gamma scan.

The radial rod dimensions were the same as that of a VVER-1000 rod. The axial length was that of the test segment. The rod internal pressure, coolant pressure, and coolant mass flow rate were all taken as standard VVER-1000 values. The coolant inlet temperature was adjusted up from the standard VVER-1000 value to simulate the segment being taken from the second span of the rod. The predicted oxide thickness (8 to 9 μm) and hydrogen content (48 to 50 ppm) were close to the measured oxide thickness (5 μm) and hydrogen content (44 ppm).

FRAPCON-4.0 was run using this input deck and a FRAPTRAN initialization file was created.

A FRAPTRAN-2.0 input deck was created using the unirradiated dimensions for the father rod. These dimensions are adjusted for changes that occurred during the base irradiation by the FRAPTRAN initialization file that was created with FRAPCON-4.0. This process eliminates the need to specify burnup-dependent changes in the rod that occur after prior irradiation. A constant power history of 1.3 kW/m was used for the LHGR. The axial power profile of IFA-650.6 was provided. Unlike FRAPCON-4.0, FRAPTRAN-2.0 has the option to model E110 cladding. For this calculation, E110 cladding was specified.

The coolant geometry for this test was atypical of LWR LOCA conditions, and consisted of a fuel rod within a heated tube. Water was evacuated from this tube to start the test, spray was eventually applied, and the reactor was scrammed to end the test. Rather than attempt to model these conditions, FRAPTRAN was set up to use measured cladding surface temperatures as the temperature boundary condition. Cladding surface temperature histories were available for two axial locations during this test. To model the coolant conditions, the rod was divided into two zones and the temperature histories for each of the two axial elevations were set as the coolant temperature in each of these axial zones. To force the code to use the same coolant temperature and cladding surface temperature, a large cladding-to-coolant heat transfer coefficient (352,222 Btu/ft^2hr°F) was set in the code as recommended in the FRAPTRAN-2.0 input instructions.

The FRAPTRAN initialization file that was created with FRAPCON-4.0 includes gas from the initial father rod pressurization and subsequent FGR during the base irradiation. When the rodlet was refabricated, it was refilled with 30 bar of gas consisting of 95 percent argon and 5 percent helium. The FRAPTRAN initialization file was manually adjusted to reflect this new gas mixture and pressure. Within each restart file, information is contained for each FRAPCON-4.0 time step. The first line is the time in seconds. The ninth and tenth lines after this contain the number of moles of gas and the relative amount of each gas species. These are the lines that are changed in the following listings of assessment cases.

The FRAPCON-4.0 and FRAPTRAN-2.0 input files for this case are not included in this report due to the limited availablility and sensitivity of this information.

A.10 IFA-650.7 Test

The IFA-650.7 rod was taken from a commercial rod that was base irradiated in a boiling-water reactor by Kernkraftwerk Leibstadt (KKL) for three cycles up to a burnup of 44.3 GWd/MTU for the segment. After base irradiation and refabrication, the rodlet was subjected to LOCA testing in the Halden reactor (Jošek 2008). The following describes the modeling approach and assumptions used to model this test with FRAPTRAN-2.0 initialized with FRAPCON-4.0.

The dimensions for IFA-650.7 were taken from the data sheet for the father rod. When modeling the base irradiation of a rod that will later be cut into a segment to be tested, it is necessary to model the base irradiation on the short segment only. The active fuel length of IFA-650.7 is 480 mm. The total void volume for the test is 17 to 18 cm^3. From this value a plenum length can be calculated.

The power history given for the IFA-650.7 father rod was used for the base irradiation in FRAPCON-4.0. The axial power profile was assumed to be flat over the length of the rodlet based on a flat axial gamma scan.

The rod internal pressure, coolant pressure, coolant mass flow rate, and coolant inlet temperature were all taken as standard 10 x 10 Westinghouse values. The predicted oxide thickness (17 μm) and hydrogen content (70 ppm) were close to the measured oxide thickness (4.4 μm) and hydrogen content (44 ppm) in that they were all quite low.

FRAPCON-4.0 was run using this input deck, and a FRAPTRAN initialization file was created.

A FRAPTRAN-2.0 input deck was created using the unirradiated dimensions for the father rod. These dimensions were adjusted for changes that occurred during the base irradiation by the FRAPTRAN initialization file that was created with FRAPCON-4.0. This process eliminated the need to specify burnup-dependent changes in the rod that occur after prior irradiation. A constant power history of 3.4 kW/m was used for the LHGR. The axial power profile of IFA-650.7 was provided.

The coolant geometry for this test was atypical of LWR LOCA conditions, and consisted of a fuel rod within a heated tube. Water was evacuated from this tube to start the test, spray was eventually applied, and the reactor was scrammed to end the test. Rather than attempt to model these conditions, FRAPTRAN was set up to use measured cladding surface temperatures as the temperature boundary condition. There were cladding surface temperature histories available for two axial locations during this test. To model the coolant conditions, the rod was divided into two zones and the temperature histories for each of the two axial elevations were set as the coolant temperature in each of these axial zones. To force the code to use the same coolant temperature and cladding surface temperature, a large cladding-to-coolant heat transfer coefficient (352,222 Btu/ft^2hr°F) was set in the code as recommended in the FRAPTRAN-2.0 input instructions.

The FRAPTRAN initialization file that was created with FRAPCON-4.0 includes gas from the initial father rod pressurization and subsequent FGR during the base irradiation. When the rodlet was refabricated, it was refilled with 6 bar of gas consisting of 95 percent argon and 5 percent helium. The FRAPTRAN initialization file was manually adjusted to reflect this new gas mixture and pressure. Within each restart file, information is contained for each FRAPCON-4.0 time step. The first line is the time in seconds. The ninth and tenth lines after this contain the number of moles of gas and the relative amount of each gas species. These are the lines that are changed in the following listings of assessment cases.

The FRAPCON-4.0 and FRAPTRAN-2.0 input files for this case are not included in this report due to the limited availablility and sensitivity of this information.

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