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FRAPCON-3.4: Integral Assessment

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FRAPCON-3.4: Integral Assessment

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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 FRAPCON-3, a steady-state fuel behavior code designed to analyze fuel behavior from beginning-of-life to rod-average burnup levels of 62 gigawatt-days per metric ton of uranium. FRAPCON-3 code calculations are shown to compare satisfactorily to a preselected set of experimental data with steady-state operating conditions.

This document describes the assessment of FRAPCON-3.4a, which is the latest version of FRAPCON-3, released April 13, 2010.

Foreword

The ability to accurately calculate the performance of light-water reactor fuel rods under high-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 NRC's FRAPCON code, which provides the ability to accurately calculate the high-burnup response of light-water reactor fuel rods.

NRC also continues to sponsor both in-pile and out-of-pile experiments to benchmark and assess the analytical code capabilities. Over 100 new assessment cases were recently added to the integral assessment database, bringing the database total to 133 assessment cases. The new assessment cases use data from recent integral irradiation experiments and post-irradiation examination 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 of FRAPCON, FRAPCON 3.4, to demonstrate the code's ability to accurately calculate the performance of newer fuel designs and operating conditions.

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Executive Summary

This document is Volume 2 of a two-volume series that describes the FRAPCON-3.4 code and its assessment. Volume 1 (Geelhood et al., 2010) describes the FRAPCON-3.4 code along with input instructions. Volume 2 (this document) describes the integral code assessment, done by comparing the code predictions for fuel temperatures, fission gas release (FGR), rod internal void volume, fuel swelling, cladding creep/growth, cladding corrosion/hydriding, and hoop strain to data from integral irradiation experiments and post-irradiation examination programs.

The cases used for code assessment were selected based on the following criteria:

- Well-characterized design and operational data were provided.
- The reported results spanned ranges of interest for both design and operating parameters.

Thus, the fuel rod cases were selected to represent both boiling-water reactor (BWR) and pressurized-water reactor (PWR) fuel types, with pellet-to-cladding gap sizes within, above, and below the normal range for power reactor rods. The fill gas is pure helium in most cases, but cases are included for which helium-xenon fill gas mixtures were used to assess the gap conductance model. The linear heat generation rates at beginning-of-life (BOL) range up to 60 kW/m (18 kW/ft), and during end-of-life (EOL) power ramps, they range up to 47 kW/m (14 kW/ft). The rod-average fuel burnups range up to 99 gigawatt-days per metric ton of uranium (GWd/MTU), but only up to 76 GWd/MTU for power-ramp cases. However, the code is only considered validated to rod-average burnup of 62 GWd/MTU. The EOL FGR ranges from less than 1 percent to greater than 50 percent of the produced quantity.

The primary code assessment database (used also for benchmarking the thermal and FGR models) consists of 133 well-characterized fuel rods. These include 45 test rods that experienced EOL power ramps (used for FGR and cladding hoop strain) and 88 "steady-state" cases including uranium dioxide (UO_2), mixed oxide (MOX) fuel, and urania-gadolinia (UO_2-Gd_2O_3) Halden rods used for fuel temperatures and UO_2 and MOX rods used for FGR.

Five rods from the primary set were used to assess FRAPCON-3.4 predictions of EOL void volume. The cases selected include full-length power reactor rods and shorter test reactor rods. A mix of test reactor and power reactor rods was also used to assess the fuel volume change due to densification and swelling.

The FRAPCON-3.4 model for cladding waterside oxidation was evaluated against BWR Zircaloy-2 and PWR Zircaloy-4, ZIRLO, and M5 rod data.

The FRAPCON-3.4 predictions of cladding hoop strain were assessed against 27 BWR and PWR rods that were power ramped in various test reactors.

The following conclusions about FRAPCON-3.4 were made as a result of this assessment:

Thermal: Comparisons were made for BOL UO_2 temperature measurements and UO_2. MOX, and UO_2-Gd_2O_3 temperature measurements as a function of burnup. Overall, FRAPCON-3.4 gave reasonable predictions of fuel centerline temperature for fuel rods with UO_2, MOX, and UO_2-Gd_2O_3 fuel (standard deviation of 5 percent relative).

Fission Gas Release: Comparisons were made for the UO_2 and MOX FGR measurements for rods with widely varying power levels and burnups. Overall, FRAPCON-3.4 gave reasonable predictions (within 5 percent FGR absolute) of fission gas release for fuel rods with UO_2 and MOX fuel.

Internal Void Volume: Comparisons were made to data from two commercial reactor and three test reactor fuel rods. The code predicted the two commercial rods well but overpredicted the BR-3 test rod data by approximately 15 percent (relative) on average.

Cladding Corrosion: Comparisons were made to data from two commercial BWR rods with Zircaloy-2 cladding, two commercial PWR rods with Zircaloy-4 cladding, two commercial PWR rods with ZIRLO cladding, and one commercial PWR rod with M5 cladding. The oxide corrosion predictions were very good and tend to bracket the data.

Cladding Hoop Strain: The original hoop strain assessment cases that were available up to a burnup of around 45 GWd/MTU demonstrated that, on average, FRAPCON-3.4 slightly overpredicts cladding hoop strain by 0.1 percent strain. On average, above 45 GWd/MTU FRAPCON-3.4 underpredicts cladding permanent hoop strain by 0.3 percent. Despite this overprediction, FRAPCON-3.4 provides reasonable hoop strain predictions up to 62 GWd/MTU.

Abbreviations

°C	degrees Celsius
ADU	ammonium diuranate
ANO-2	Arkansas Nuclear One-Unit 2
ANS	American Nuclear Society
AOO	anticipated operational occurrence
atm	atmosphere
ATR	Advanced Test Reactor
AUC	ammonium uranyl carbonate
B&W	Babcock and Wilcox
BN	Belgonucleaire
BNFL	British Nuclear Fuels, Ltd.
BOL	beginning of life
BWR	boiling-water reactor
cm	centimeter(s)
cm^3	cubic centimeter(s)
crud	Chalk River unidentified deposit (generic term for various residues deposited on fuel rod surfaces, originally coined by Atomic Energy of Canada, Ltd. to describe deposits observed on fuel from the test reactor at Chalk River)
EOL	end of life
FGR	fission gas release
g	gram(s)
Gd	gadolinium
Gd_2O_3	gadolinia
GNF	Global Nuclear Fuel
GWd/MTM	gigawatt-days per metric ton of metal
GWd/MTU	gigawatt-days per metric ton of uranium
HBEP	High Burnup Effects Program
HBWR	heavy boiling water reactor
HUHB	Halden Ultra High Burnup
K	Kelvin
kW	kilowatt(s)
KWU	Kraftwerk Union
LHGR	linear heat generation rate
LOCA	loss-of-coolant accident
LWR	light-water reactor
m	meter(s)
MIMAS	micronized master blend
mm	millimeter(s)
MOX	mixed oxide, $(U, Pu)O_2$
MPa	megapascal(s)
MWd/kgM	megawatt-days per kilogram of metal
MWd/kgU	megawatt-days per kilogram of uranium
MWd/MTU	megawatt-days per metric ton of uranium
NRC	U.S. Nuclear Regulatory Commission
PCI	pellet/cladding interaction
PCMI	pellet/cladding mechanical interaction
PIE	post-irradiation examination

PNNL	Pacific Northwest National Laboratory
Pu	plutonium
PuO_2	plutonium dioxide
PWR	pressurized-water reactor
SBR	short binderless route
SCC	stress corrosion cracking
SCIP	Studsvik Cladding Integrity Project
SPND	self-powered neutron detectors
TC	thermocouple
TD	theoretical density
UO_2	uranium dioxide
UO_2-Gd_2O_3	urania-gadolinia
WG	weapons-grade
μm	micrometer(s)

1.0 Introduction

This report is Volume 2 of a two-volume series that describes the FRAPCON-3.4 code and its assessment. Volume 1 (Geelhood et al., 2010) describes the FRAPCON-3.4 code. Volume 2 (this document) describes the assessment of the integral performance of FRAPCON-3.4.

This report provides the results of the assessment of the integral code predictions to measured data for fuel temperatures, fission gas release (FGR), internal void volume, cladding deformation, oxidation, and hydriding. The benchmark datasets are described in Section 2.0. Appendix A describes each set of benchmark data and gives the code input for each data comparison. The benchmark data are drawn from a wide range of burnup levels and operating conditions that are relevant to commercial operations. Experimental fuel rods with linear heat generation rates (LHGRs) at or near the maxima for commercial fuel operations were selected because the U.S. Nuclear Regulatory Commission (NRC) licenses fuel to the most limiting rod in the core. Not all the data selected are at limiting conditions. Some of the cases involve commercial fuel rods that operated at normal commercial operating conditions, which are significantly less than the limiting conditions. Also, it is noted that most of the thermal and FGR benchmark cases are drawn from experimental programs that involved numerous fuel rods, of which only a few were selected as benchmark cases. This was either because the rods in a given group were all irradiated under similar conditions and had similar FGR or because only rods with design parameters and operating conditions similar to current commercial practice were selected.

The integral code assessments include comparison to fuel temperature data in Section 3.0 and FGR data in Section 4.0. Comparisons of code predictions to internal void volume, cladding corrosion and hydriding, and hoop strain data are given in Sections 5.0, 6.0, and 7.0 respectively. A summary and conclusions are found in Section 8.0.

2.0 Assessment Data Description

A total of 133 benchmark cases (fuel rods) that have post-irradiation examination (PIE) were selected for the integral assessment of the FRAPCON-3.4 code. These include 88 fuel rods with steady-state power operation covering a wide range of burnup and 45 fuel rods with steady-state irradiations followed by an end-of-life (EOL) power ramp. The purpose of the code assessment was to assess the code against a limited set of well-qualified data that span the range of limiting operational conditions for commercial light-water reactors (LWRs) to verify that the code adequately predicts the integral data. The integral data of interest were fuel temperatures, FGR, corrosion, void volumes, and cladding deformation. The cases in this relatively limited group were selected using criteria regarding the completeness and the quality of the rod performance data, as follows:

- The cases should all provide pre-irradiation characterization with well-qualified fuel rod powers, and some data should include PIE data of interest (e.g., FGR, cladding dimensional changes).
- Cases for temperature assessment should provide well-qualified fuel centerline temperature data as a function of time or burnup to verify fuel temperature predictions.
- Cases ranging from low to high fuel burnup, as well as low to high (limiting) LHGR, should be provided to cover the operating ranges for LWR operation for each fuel performance issue of interest (e.g., fuel temperature, FGR, deformation).
- Cases should provide cladding oxidation, hydriding, and deformation under prototypic pressurized-water reactor (PWR) and boiling-water reactor (BWR) conditions.
- Cases should demonstrate the effects (FGR and cladding deformation) of normal operational transients, and overpower transients including anticipated operational occurrences (AOOs) at low and high burnup.

The selected cases fulfill the above criteria, and they provide a mix of well-qualified test reactor data and less qualified (fuel rod power uncertainties are generally greater) commercial power-reactor rod data.

Figures 2.1, 2.2, and 2.3 show the rod-average LHGRs as a function of rod-average burnup for the rods in the temperature, FGR, and hoop strain assessment databases, respectively. These figures demonstrate the range of burnup and LHGRs to which the FRAPCON-3.4 predictions have been qualified for each of these integral code predictions. For the code prediction of cladding corrosion, the predictions are a function of time, power level, and coolant temperature. FRAPCON-3.4 has been qualified to predict cladding corrosion of Zircaloy-2 under BWR conditions beyond a rod-average burnup of 62 gigawatt-days per metric ton of uranium (GWd/MTU), and Zircaloy-4, ZIRLO, and M5 under PWR conditions beyond a rod-average burnup of 70 GWd/MTU for 12 foot cores. The outlet temperature of 14 foot reactor cores may be higher than has been assessed for FRAPCON-3.4, and the corrosion predictions at these temperatures have not been assessed.

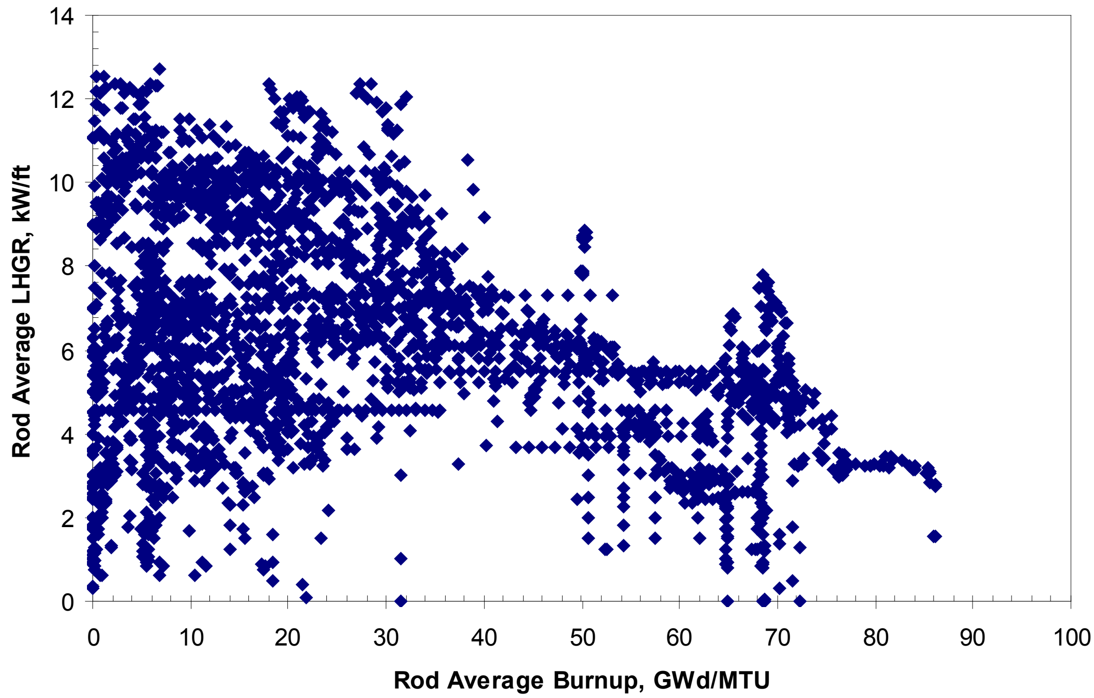


Figure 2.1 Rod-average LHGR vs. rod-average burnup for temperature assessment cases

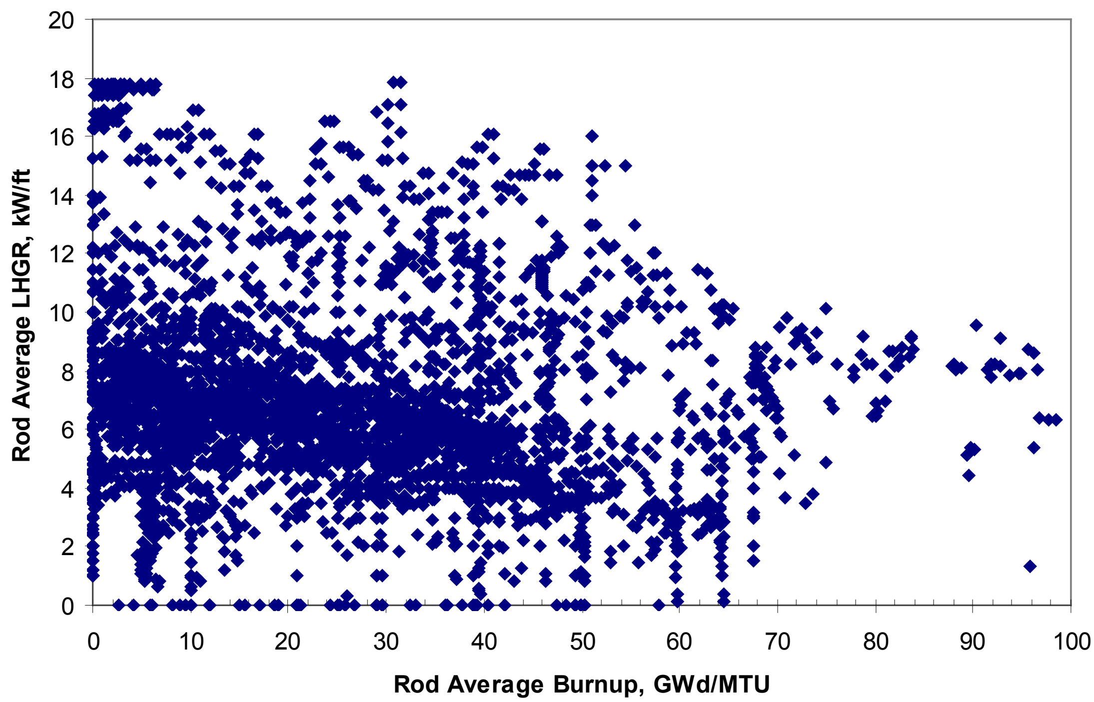


Figure 2.2 Rod-average LHGR vs. rod-average burnup for fission gas release assessment cases

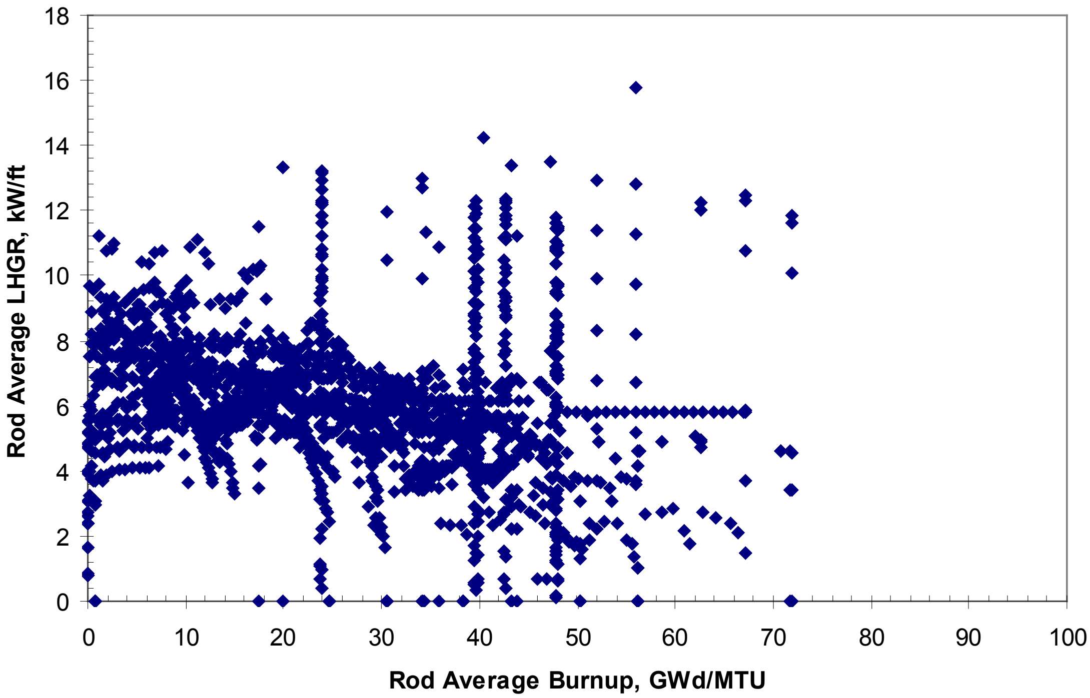


Figure 2.3 Rod-average LHGR vs. rod-average burnup for hoop strain assessment cases

2.1 Description of the Steady-State Cases

The steady-state assessment cases are listed in Table 2.1, and the EOL burnup and fuel type are given for each case. This table presents the steady-state fuel behavior phenomena that are assessed in this report and indicates which cases are used for that assessment. An "X" in a table cell indicates that the corresponding data comparison was performed for a particular case to assess code predictions.

Detailed information and FRAPCON-3.4 input files for each case are found in Appendix A.

Table 2.1 Steady-state fuel rod data cases used for FRAPCON-3.4 integral assessment

Reactor	Reference	Rod	Fuel Type	Rod-Average Burnup, GWd/MTU	Thermal vs. Burnup	BOL Thermal	FGR	Void Volume	Corrosion
Halden HBWR	Lanning, 1986	IFA-432r1	UO_2	45	X	X			
		IFA-432r2	UO_2	30		X			
		IFA-432r3	UO_2	45	X	X			
Halden HBWR	Bradley et al., 1981	IFA-513r1	UO_2	12	X	X			
		IFA-513r6	UO_2	12	X	X			
Halden HBWR	Rø and Rossiter, 2005	IFA-633r1	UO_2	40		X			
		IFA-633r3	UO_2	40		X			
		IFA-633r5	UO_2	40		X			
Halden HBWR	Thérache, 2005; Jošek, 2008	IFA-677.1r2	UO_2	32	X	X			
		IFA-677.1r3	UO_2	6		X			
		IFA-677.1r4	UO_2	6		X			
		IFA-677.1r6	UO_2	7		X			
Halden HBWR	Wiesnack, 1992	IFA-562r18	UO_2	76	X				
Halden HBWR	Matsson and Turnbull, 1998	IFA-597r8	UO_2	71	X		X		
Halden HBWR	Tverberg and Amaya, 2001	IFA-515.10rA1	UO_2	80	X				
		IFA-515.10rA2	UO_2-Gd_2O_3	80	X				
		IFA-515.10rB1	UO_2	80	X				
		IFA-515.10rB2	UO_2-Gd_2O_3	80	X				
Halden HBWR	Klecha, 2006	IFA-681r1	UO_2	33	X	X			
		IFA-681r2	UO_2-Gd_2O_3	23	X				
		IFA-681r3	UO_2-Gd_2O_3	12	X				
		IFA-681r4	UO_2-Gd_2O_3	22	X				
		IFA-681r5	UO_2	32	X				
		IFA-681r6	UO_2-Gd_2O_3	13	X				
Halden HBWR	Turnbull and White, 2002	IFA-558r6	UO_2	41	X				

Reactor	Reference	Rod	Fuel Type	Rod-Average Burnup, GWd/MTU	Thermal vs. Burnup	BOL Thermal	FGR	Void Volume	Corrosion
Halden HBWR	White, 1999	IFA-629-1r1	MOX	33	X				
		IFA-629-1r2	MOX	29 (FGR) 40 (Thermal)	X		X		
Halden HBWR	Beguin, 1999; Fujii and Claudel, 2001	IFA-610.2	MOX	56	X				
		IFA-610.4	MOX	57	X				
Halden HBWR	Claudel and Huet, 2001	IFA-648.1r1	MOX	62	X				
		IFA-648.1r2	MOX	62	X				
Halden HBWR	Petiprez, 2002	IFA-629.3r5	MOX	72	X		X		
		IFA-629.3r6	MOX	68	X		X		
Halden HBWR	Mertens et al., 1998; Mertens and Lippens, 2001	IFA-606 Phase 2	MOX	49	X		X		
Halden HBWR	Tverberg et al., 2005	IFA-636r2	UO_2-Gd_2O_3	25	X				
		IFA-636r4	UO_2-Gd_2O_3	25	X				
BR-3 PWR	Balfour, 1982; Balfour et al., 1982	24i6	UO_2	60.1			X	X	
		36i8	UO_2	61.5			X	X	
		111i5	UO_2	48.6			X	X	
		28i6	UO_2	53.3			X		
		30i8	UO_2	57.85			X		
DR-3 PWR	Bagger et al., 1978	m2-2c	UO_2	43.75			X		
		pa29-4	UO_2	47.39			X		
BR-3 PWR	Lanning et al., 1987	HBEP BNFL5-DH	UO_2	42			X		
BR-3 PWR	Barner et al., 1990	HBEP BNFL-DE	UO_2	33.9			X		
NRX PWR	De Meulemeester et al., 1973	EPL-4	UO_2	10.4			X		
NRX PWR	Notley et al., 1967; Notley and MacEwan, 1965	CBR	UO_2	2.7			X		
		CBY	UO_2	2.65			X		
		LFF	UO_2	3.29			X		
		CBP	UO_2	2.61			X		

Reactor	Reference	Rod	Fuel Type	Rod-Average Burnup, GWd/MTU	Thermal vs. Burnup	BOL Thermal	FGR	Void Volume	Corrosion
EL-3 PWR	Janvier et al., 1967	4110-ae2	UO_2	6.2			X		
		4110-be2	UO_2	6.6			X		
Zorita PWR	Balfour et al., 1982	332	UO_2	56.8			X		
Halden HBWR	Chantoin et al., 1997	FUMEX 6f	UO_2	55.45			X		
		FUMEX 6s	UO_2	55.45			X		
Halden HBWR	Turnbull, 2001	IFA429DH	UO_2	98.9			X		
ANO-2 PWR	Smith et al., 1994	TSQ002	UO_2	53.2			X	X	X
Oconee PWR	Newman, 1986	15309	UO_2	50			X	X	X
Halden HBWR	Blair and Wright, 2004	IFA-651.1r1	MOX	22.41	X		X		
		IFA-651.1r3	MOX	21.73	X		X		
		IFA-651.1r6	MOX	20.27	X		X		
ATR	Morris et al., 2000, 2001, 2005; Hodge et al., 2002, 2003	PII C2 P5	MOX	21			X		
		PIII C3 P6	MOX	30			X		
		PIII C10 P13	MOX	30			X		
		PIV C4 P7	MOX	40			X		
		PIV C5 P8	MOX	50			X		
		PIV C6 P9	MOX	50			X		
		PIV C12 P15	MOX	50			X		
Gravelines-4 PWR	Beguin, 1999; Fujii and Claudel, 2001; Claudel and Huet, 2001; Petiprez, 2002	N06	MOX	48			X		
		N12	MOX	57			X		
		P16	MOX	53			X		
Halden HBWR	Wright, 2004	IFA 633.1r6	MOX	32	X		X		
Beznau-1	Cook et al., 2003, 2004	M504 H8	MOX	37.5			X		
		M504 I2	MOX	43			X		
		M504 K9	MOX	42.5			X		
		M504 M9	MOX	44.2			X		
Beznau-1	Boulanger et al., 2004	M308 Segment 2	MOX	57.5			X		
Halden HBWR	Koike, 2004	IFA-597.4/.5/.6/.7r10	MOX	35.7	X		X		
		IFA-597.4/.5/.6/.7r11	MOX	36.8	X		X		

Reactor	Reference	Rod	Fuel Type	Rod-Average Burnup, GWd/MTU	Thermal vs. Burnup	BOL Thermal	FGR	Void Volume	Corrosion
Fugen HBWR	Ozawa, 2004	E09 Rods Inner	MOX	29.6			X		
		E09 Rods Intermediate	MOX	39.3			X		
		E09 Rods Outer	MOX	42			X		
Monticello BWR	Baumgartner, 1984	MTB99 Rod A1	UO_2	45					X
TVO-1 BWR	Barner et al., 1990	HBEP H8/36-6	UO_2	51.4					X
Vandellos PWR	CSN, ENUSA, 2002	A06	UO_2	68					X
		A12	UO_2	68					X
Vandellos PWR	Segura et al., 2002	N05	UO_2	70					X

ATR = Advanced Test Reactor
BOL = beginning of life
HBWR = heavy boiling water reactor
MOX = mixed oxide
UO_2 = uranium dioxide
UO_2-Gd_2O_3 = urania-gadolinia

2.2 Description of the Power-Ramp Cases

The power-ramp assessment cases are listed in Table 2.2, and the EOL burnup, fuel type, ramp terminal power level, and hold time are given for each case. This table presents the power-ramp fuel behavior phenomena that are assessed in this report and indicates which cases are used for that assessment. An "X" in a table cell indicates that the corresponding data comparison was performed for a particular case to assess code predictions.

Detailed information and FRAPCON-3.4 input files for each case is found in Appendix A.

Table 2.2 Power-ramped fuel rod data cases used for FRAPCON-3.4 integral assessment

Base Irradiation/Ramp Testing	Reference	Rod	Fuel Type	Rod-Average Burnup, GWd/MTU	Ramp Terminal Level, kW/m	Ramp Hold Time	FGR	Hoop Strain
Obringheim/Petten	Barner et al., 1990	HBEP D200	UO_2	25	45.3	2.4 days	X	
		HBEP D226	UO_2	44	45.0	2.6 days	X	
Obringheim/Petten	Djurle, 1985	PK1/1	UO_2	35.4	37.2	12 hr		X
		PK1/3	UO_2	35.2	42.6	12 hr		X
		PK2/1	UO_2	45.2	36.8	12 hr		X
		PK2/3	UO_2	44.6	44.0	12 hr		X
		PK2-S	UO_2	43.4	44.0	12 hr		X
		PK4/1	UO_2	33.7	34.3	12 hr		X
		PK4/2	UO_2	33.8	39.2	12 hr		X
		PK6/1	UO_2	36.7	43.7	1 hr		X
		PK6/2	UO_2	36.8	35.7	12 hr	X	X
		PK6/3	UO_2	36.5	43.3	12 hr	X	
		PK6/S	UO_2	35.9	41.0	12 hr	X	
Studsvik/Studsvik	Mogard et al., 1979; Lysell and Birath, 1979	Inter-Ramp Rod 16	UO_2	21	43.8	24 hr	X	X
		Inter-Ramp Rod 18	UO_2	18	37.79	24 hr	X	X
Halden/DR-2	Knudson et al., 1983	RISØ F14-6	UO_2	27	28.7	3 days	X	
		RISØ F7-3	UO_2	35	30.2	17 hr	X	
		RISØ F9-3	UO_2	33	29.7	30 hr	X	
Quad Cities 1 / DR3	Chantoin et al., 1997	ge2	UO_2	41.9	41.9	38 hr	X	X
		ge4	UO_2	24.0	24.0	34 hr	X	X
		ge6	UO_2	42.3	38.1	5 days	X	X
		ge7	UO_2	41	35.5	4 hr	X	X
ANO-1/Studsvik	Wesley et al., 1994	BW stud R1	UO_2	62.3	22.1	12 hr	X	
		BW stud R3	UO_2	62.1	24.7	12 hr	X	
Biblis A /DR3	Chantoin et al., 1997	RISØ AN1	UO_2	41.3	40.3	3 days	X	X
		RISØ AN8	UO_2	40.3	30.1	12 hr	X	X
Gravelines-5/Siloe	Struzik, 2004	regate	UO_2	50.2	38.5	1.5 hr	X	
Beznau-1/Petten	White et al., 2001; Cook et al., 2000, 2003, 2004	M501 HR-1	MOX	37	38.1	12 hr	X	
		M501 HR-2	MOX	37	35.7	12 hr	X	
		M501 HR-3	MOX	37	46.2	12 hr	X	
		M501 HR-4	MOX	36	47.0	12 hr	X	

Base Irradiation/Ramp Testing	Reference	Rod	Fuel Type	Rod-Average Burnup, GWd/MTU	Ramp Terminal Level, kW/m	Ramp Hold Time	FGR	Hoop Strain
		M501 MR-1	MOX	34	38.1	12 hr	X	
		M501 MR-2	MOX	34	41.9	12 hr	X	
		M501 MR-3	MOX	34	40.5	12 hr	X	
		M501 MR-4	MOX	33	41.7	20 min	X	
Leibstadt/Studsvik	Kallstrom, 2005	KKL-1	UO_2	63	42.5	40 min		X
		KKL-2	UO_2	67	41	30 s		X
		KKL-3	UO_2	56	52	12 hr		X
		KKL-4	UO_2	40	45	5 s		X
Ringhals/Studsvik		M5-H1	UO_2	67	40	5 s		X
		M5-H2	UO_2	68	40	12 hr		X
Oskarshamn/Studsvik		O2	UO_2	55	40	30 s		X
Vandellos/Studsvik		Z-2	UO_2	76	40	6 hr		X
		Z-3	UO_2	76	40	< 1 s*		X
		Z-4	UO_2	76	38	6 hr		X

* Rod failed during ramp to power

3.0 Thermal Behavior Assessment

Thermal predictions are important for calculating initial fuel stored energy, which is used as input to loss-of-coolant accident (LOCA) analyses. The fuel temperatures are also used to calculate FGRs and EOL rod pressures and to verify no fuel melting. In general, PWR LOCA and fuel melting analyses are calculated with FRAPCON-3.4 to be more limiting at burnups between 25 and 35 GWd/MTU, while the same analyses for BWRs are generally more limiting at burnups between 15 and 25 GWd/MTU.

Comparisons of predicted and measured fuel center temperatures from instrumented Halden reactor test assemblies have been used to evaluate the code's ability to predict BOL temperatures and through-life temperature histories (i.e., rod power vs. burnup). The BOL and through-life temperature comparisons are separated because they have different biases and uncertainties (based on standard deviation) in the code thermal predictions. The through-life temperature history comparisons will be used to bound the uncertainties on PWR and BWR LOCA initialization and fuel melting analyses. The BOL temperature database includes not only rods with helium-filled gaps, but also rods with xenon and xenon-helium filled gaps and rods with pellet/cladding gap sizes both larger and smaller than nominal. These variations in gap size and fill gas indicate that the code can properly account for the thermal resistance across the fuel cladding gap as a function of gap size and gas composition and is not just tuned to provide good results for typical LWR conditions.

The comparisons of measured and predicted through-life fuel center temperature histories were done with two goals in mind. The first was to determine if the code properly accounts for the fuel thermal conductivity degradation with burnup. The second goal was to determine if the code properly predicts the effect of thermal feedback on fuel temperature caused by gas release and consequent contamination of the initial helium fill gas with lower-conductivity fission gas.

The BOL and through-life code-data comparisons are discussed separately in the following sections.

3.1 BOL Fuel Center Temperature Predictions

The BOL fuel centerline temperature predictions are assessed against centerline temperature measurements taken during the first ramp to power. This power ramp occurs during the first 1 to 2 days of operation. Because of this, the initial fuel rod dimensions apply and there is no time for phenomena such as FGR, fuel densification and swelling, cladding creep, or cladding corrosion.

3.1.1 UO_2 BOL Center Temperature Predictions

FRAPCON-3.4 was assessed against BOL temperature measurements taken during the first ramp to power. Thirteen rods are used to assess the performance of FRAPCON-3 at BOL: IFA-432 rod 1, IFA-432 rod 2, IFA-432 rod 3, IFA-513 rod 1, IFA-513 rod 6, IFA-681 rod 1, IFA-633 rod 1, IFA-633 rod 3, IFA-633 rod 5, IFA-677.1 rod 2, IFA-677.1 rod 3, IFA-677.1 rod 4, and IFA-677.1 rod 6. Figure 3.1 shows the predicted vs. measured temperature for the BOL ramp up to power for the 13 assessment cases. This figure shows that FRAPCON-3.4 predicts these centerline temperatures within a standard error of 7.0 percent of the measured centerline temperature with an average deviation of -5.5 percent. For the IFA-513 rod 6 case and all the

IFA-677.1 cases, FRAPCON-3.4 tends to underpredict the centerline temperature, but for all other rods, FRAPCON 3.4 predicts centerline temperature within a standard error of 4.8 percent and average deviation of -2.8 percent. A standard error of 4.5 percent corresponds to around a ±50K uncertainty on temperature predictions and is reasonable given the uncertainty in the thermocouple data and the calculated rod power. For rods with greater standard error, there may have been a bias in the reported power or temperature, or FRAPCON-3.4 may not be properly modeling some aspect of these rods' behavior.

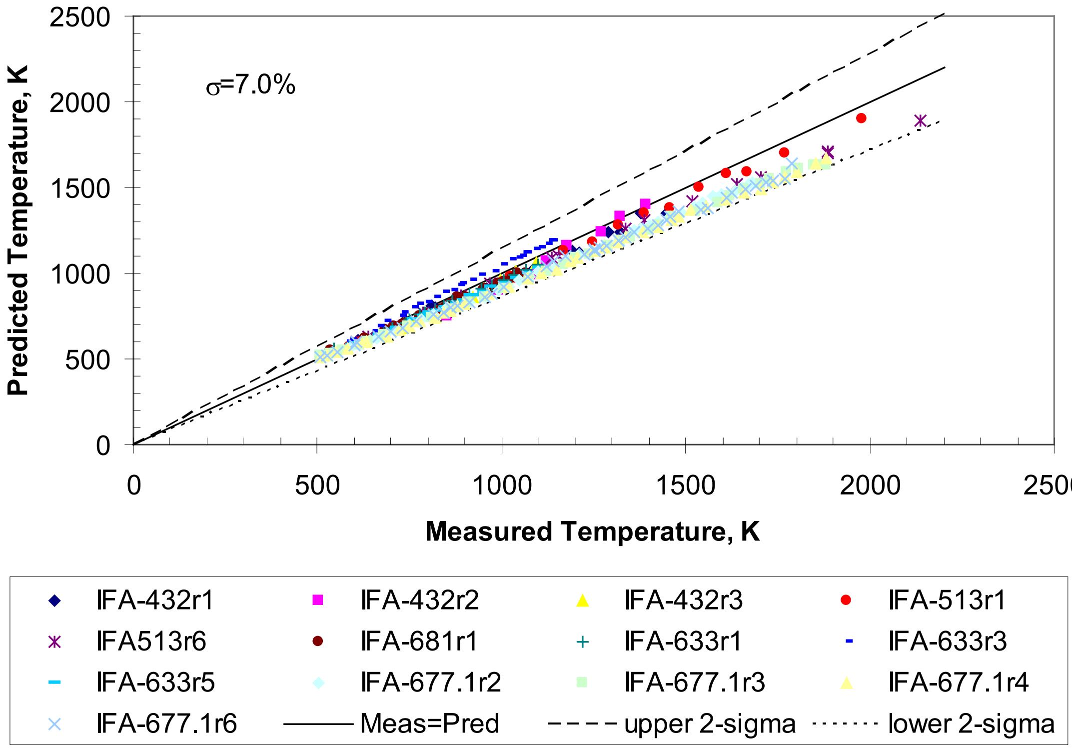


Figure 3.1 Measured and predicted centerline temperature for the first ramp to power for 13 assessment cases

3.2 Assessment of Temperature Predictions as a Function of Burnup

3.2.1 UO_2 Center Temperature Predictions as a Function of Burnup

The assessment of FRAPCON-3.4 UO_2 temperature predictions was performed using the same cases that were used for the BOL assessment, with the following differences.

1. IFA-432 rod 2 has been removed as an assessment of FRAPCON-3 as a function of burnup, as the test is not prototypic of current fuel designs due to its large gap, and a small overprediction in FGR can result in a large temperature overprediction.
2. IFA-633 rods 1, 3, and 5 and IFA-677.1 rods 3, 4, and 6 originally only had BOL temperature reported and only recently had measured temperature as a function of burnup reported. Therefore, these rods are not included in this assessment.
3. IFA-562 rod 18, IFA-597 rod 8, IFA-515.10 rods A1 and B1, IFA-681 rod 5, and IFA-558 rod 6 have been added in addition to the BOL assessment cases.

The following figures show measured and predicted fuel centerline temperatures from rods with centerline temperature measurements. Individual rod predictions may demonstrate a systematic error (bias) that may be due to thermocouple decalibration or a systematic error in the power history or axial power shape (power at thermocouple location) provided due to decalibration in or with the neutron detectors. However, when all the comparisons are examined, it is found that there is no overall systematic error (bias) in the prediction of UO_2 fuel temperature throughout life, as can be seen in Figure 3.2. For all the cases, a standard error of 4.7 percent on the centerline temperature was calculated. These data are also shown in terms of relative bias in Figure 3.3 as a function of burnup. There appears to be no systematic bias in the predictions with increasing burnup.

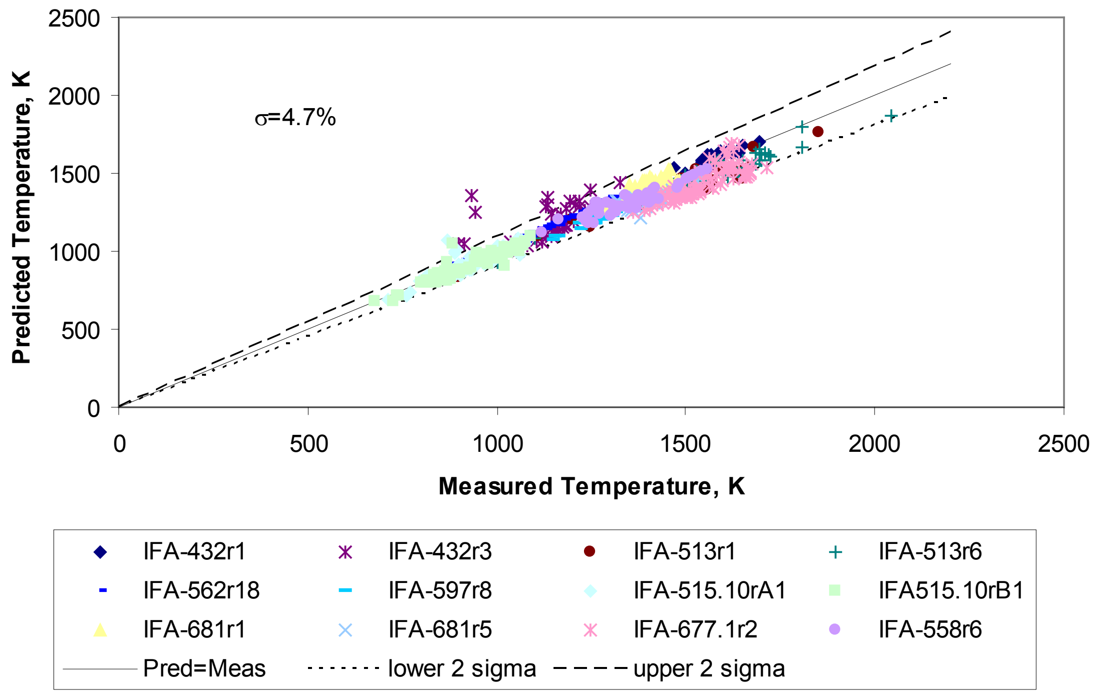


Figure 3.2 Measured and predicted centerline temperature for the UO_2 assessment cases throughout life

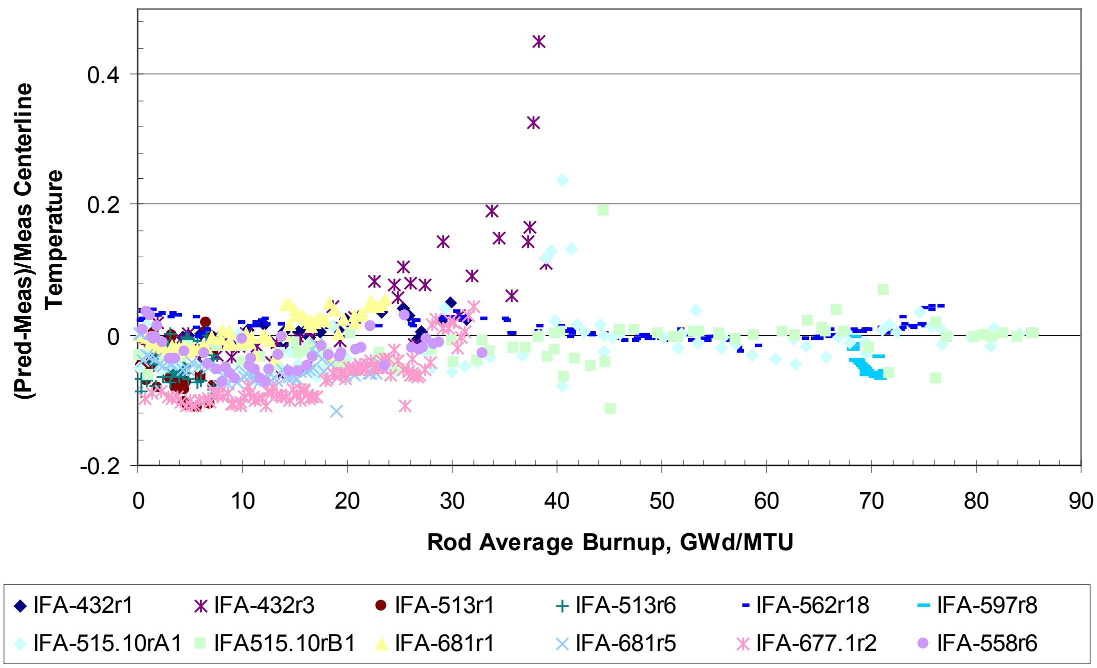


Figure 3.3 Predicted minus measured divided by measured centerline temperature for the UO_2 assessment cases as a function of burnup

Figure 3.4 shows the measured and predicted centerline temperature for IFA-432r1. This figure contains data from the lower thermocouple. This rod also contained an upper thermocouple, but it failed after 150 days. The comparisons to the upper thermocouple data are similar to the lower thermocouple. This figure shows excellent agreement between the FRAPCON-3.4 predictions and the data.

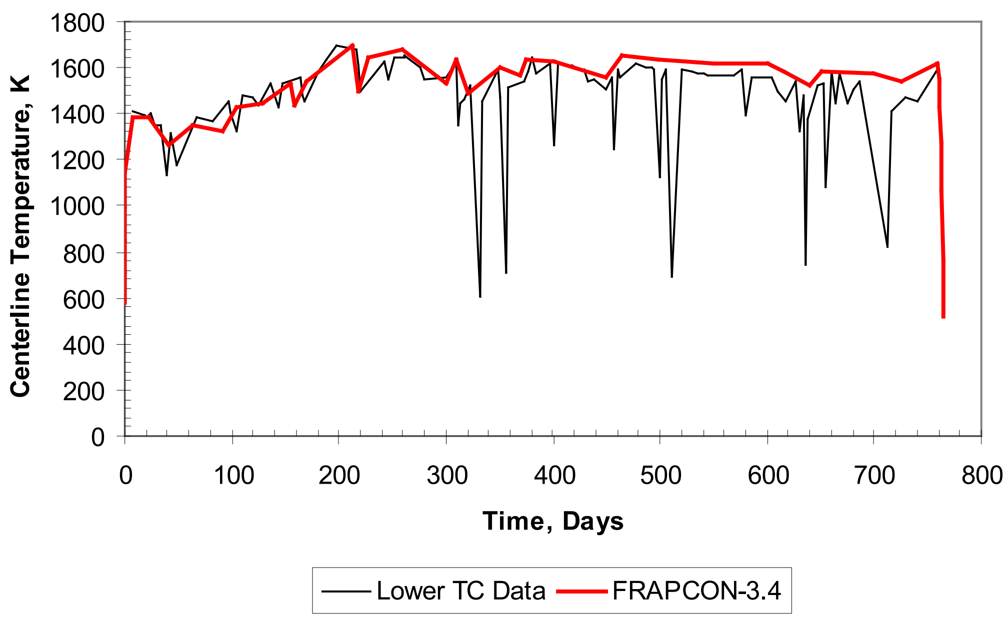


Figure 3.4 Measured and predicted centerline temperature for IFA-432r1 UO_2 lower thermocouple (burnup=45 GWd/MTU, as-fabricated radial gap=114 µm)

Figure 3.5 shows the measured and predicted centerline temperature for IFA-432r3. This figure contains data from the lower thermocouple. This rod also contained an upper thermocouple, but it failed after 550 days. The comparisons to the upper thermocouple data are similar to the lower thermocouple. This figure shows excellent agreement between the FRAPCON-3.4 predictions and the data at BOL, and an overprediction of about 100K at EOL. This overprediction may be due to FRAPCON-3.3 overpredicting the gas release, leading to higher predicted temperatures. As noted earlier, overprediction of gas release leads to lower gap conductivity and results in higher fuel temperature predictions. It should also be noted that some of the helium fill and fission gases were found to have leaked out of these IFA-432 rods based on rod puncture data (i.e., the leak was theorized to have occurred around the thermocouple penetrations through the end caps).

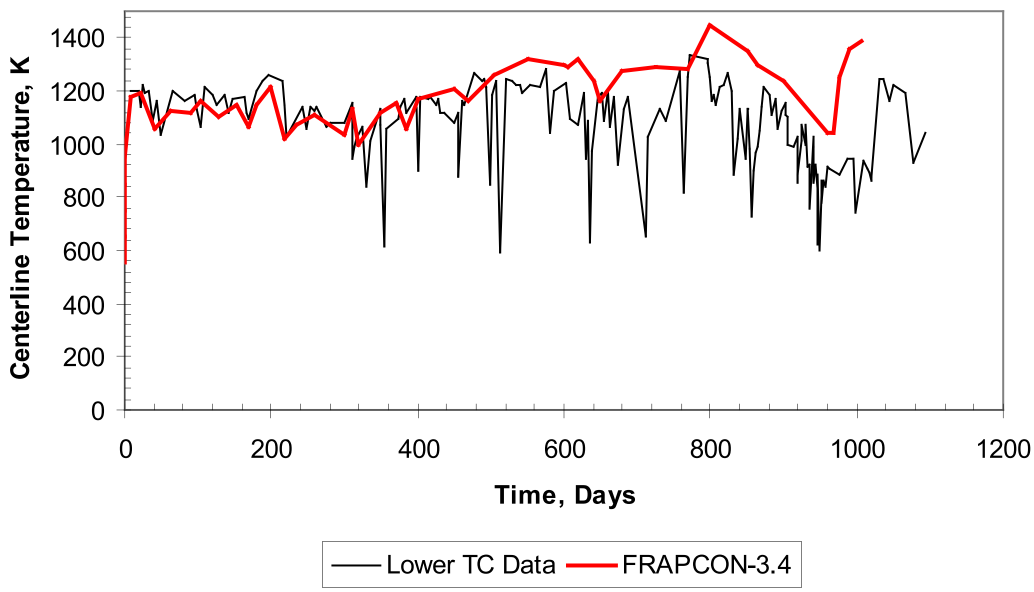
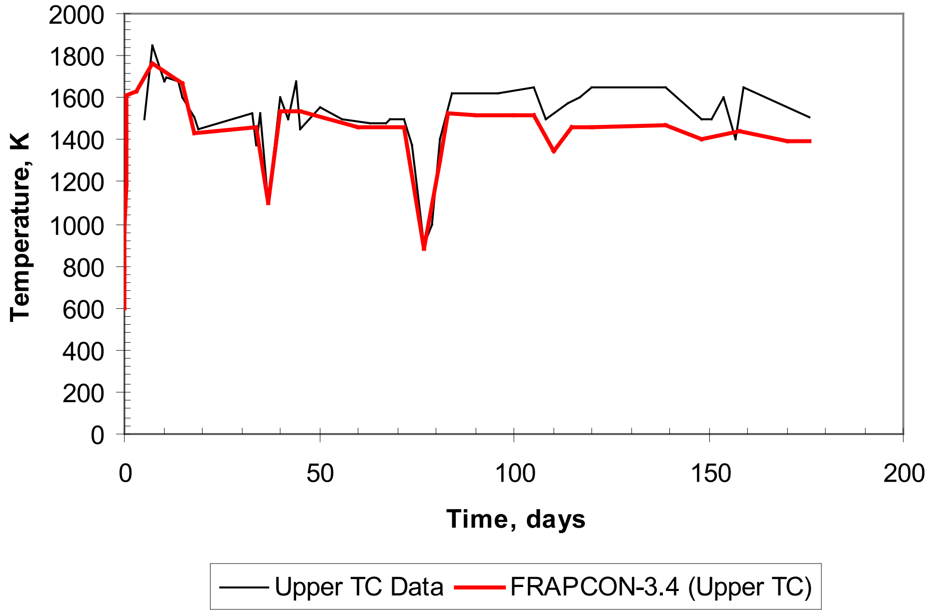
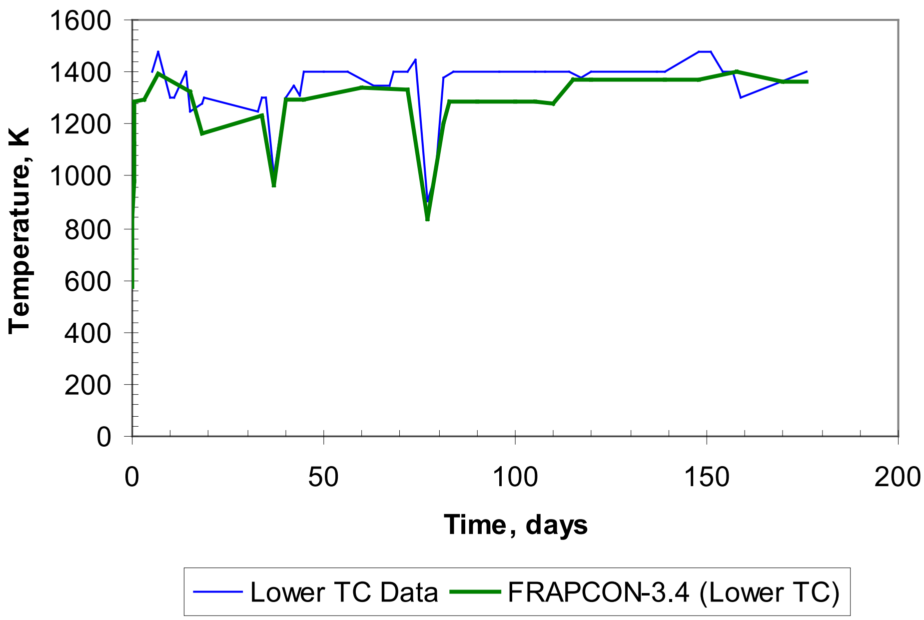


Figure 3.5 Measured and predicted centerline temperature for IFA-432r3 UO_2 lower thermocouple (burnup=45 GWd/MTU, as-fabricated radial gap=38 μm)

Figure 3.6 shows the measured and predicted centerline temperature for IFA-513r1. This figure contains data from the upper and lower thermocouples. This figure shows reasonable agreement between the FRAPCON-3.4 predictions and the data.



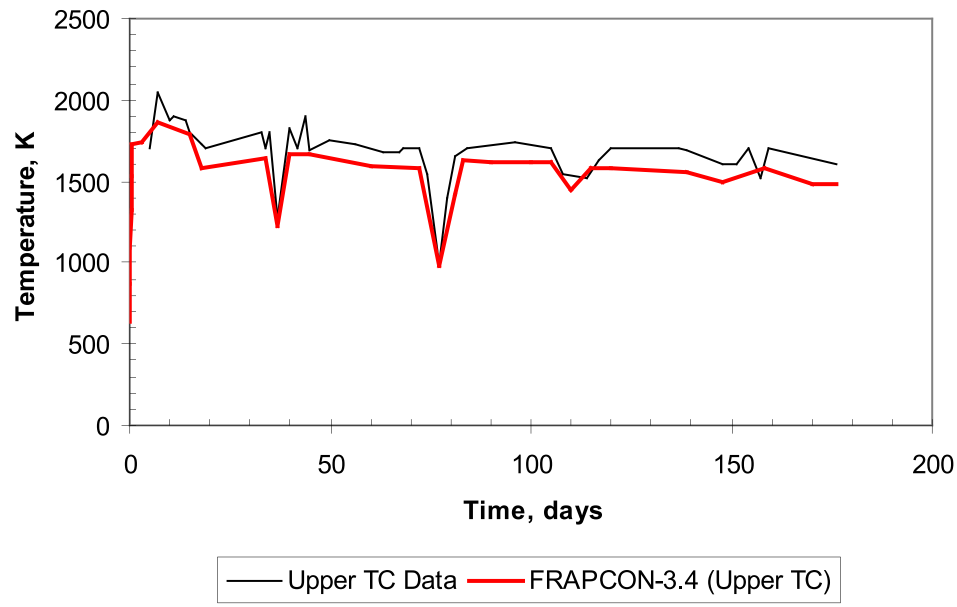
(a)



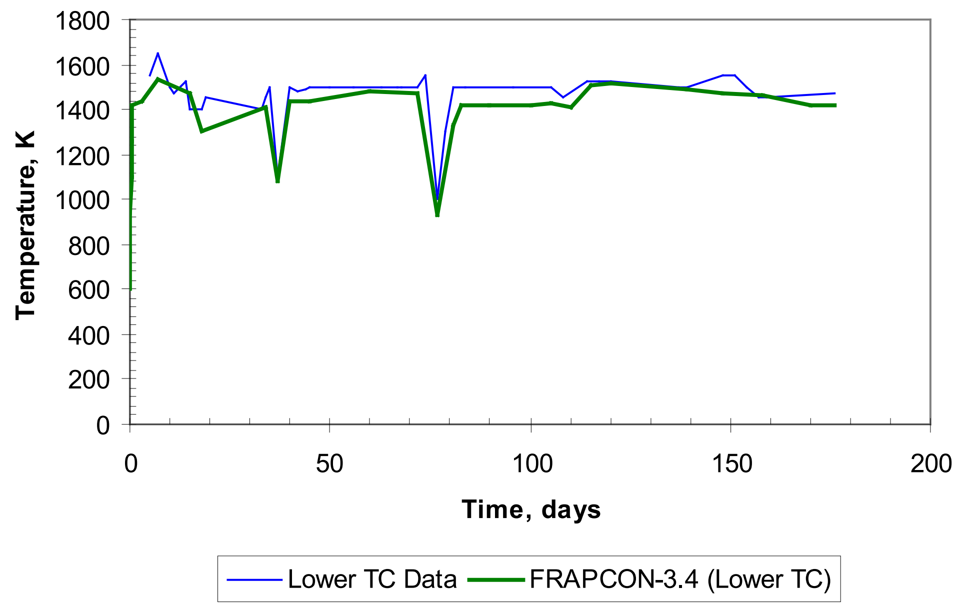
(b)

Figure 3.6 Measured and predicted centerline temperature for IFA-513r1 UO_2 upper thermocouple (a) and lower thermocouple (b) (burnup=10 GWd/MTU, as-fabricated radial gap=108 µm)

Figure 3.7 shows the measured and predicted centerline temperature for IFA-513r6. This figure contains data from the upper and lower thermocouples. This figure shows reasonable agreement between the FRAPCON-3.4 predictions and the data.



(a)



(b)

Figure 3.7 Measured and predicted centerline temperature for IFA-513r6 UO_2 upper thermocouple (a) and lower thermocouple (b) (burnup=10 GWd/MTU, as-fabricated radial gap=108 μm)

Figure 3.8 shows the measured and predicted centerline temperature for IFA-562r18. This figure contains rod axial-averaged temperature data from the expansion thermometer. This figure shows excellent agreement between the FRAPCON-3.4 predictions and the data.

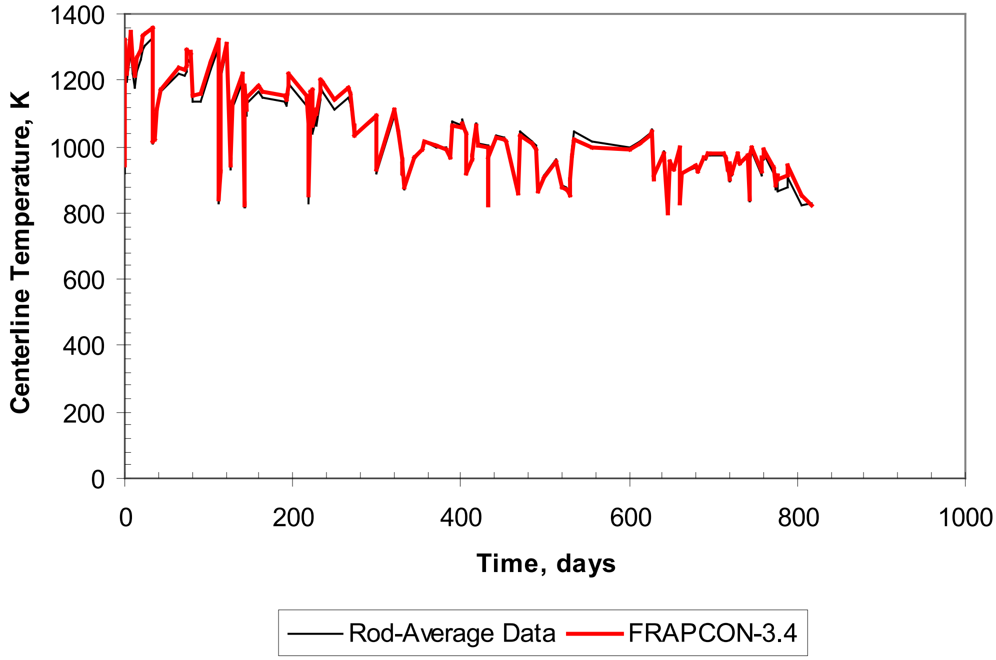


Figure 3.8 Measured and predicted rod-average centerline temperature for IFA-562r18 UO_2 (burnup=76 GWd/MTU, as-fabricated radial gap=50 µm)

Figure 3.9 shows the measured and predicted centerline temperature for IFA-597r8. This rod was refabricated from a commercial rod that was irradiated to 68 GWd/MTU. This figure contains upper thermocouple data. This figure shows reasonable agreement between the FRAPCON-3.4 predictions and the data (±75K).

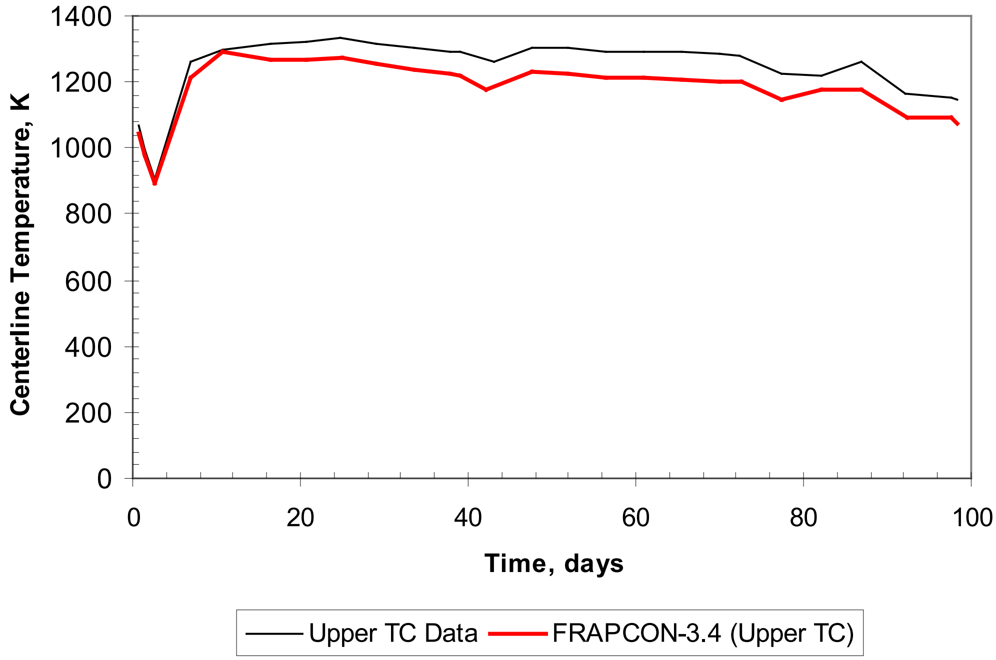


Figure 3.9 Measured and predicted centerline temperature for IFA-597r8 (starting burnup=68 GWd/MTU, ending burnup=71 GWd/MTU, as-fabricated radial gap=105 µm)

Figures 3.10 and 3.11 show the measured and predicted centerline temperature for IFA-515.10 rods A1 and B1. These figures contain upper thermocouple data. These figures show reasonable agreement between the FRAPCON-3.4 predictions and the data (±50K).

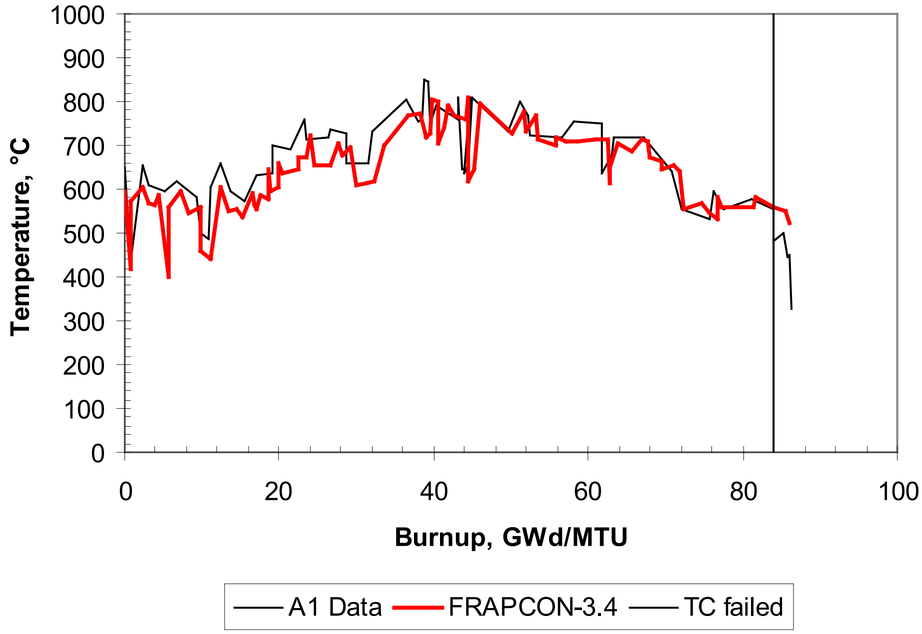


Figure 3.10 Measured and predicted centerline temperature for IFA-515.10rA1 UO_2 (burnup=80 GWd/MTU, as-fabricated radial gap=25 μm)

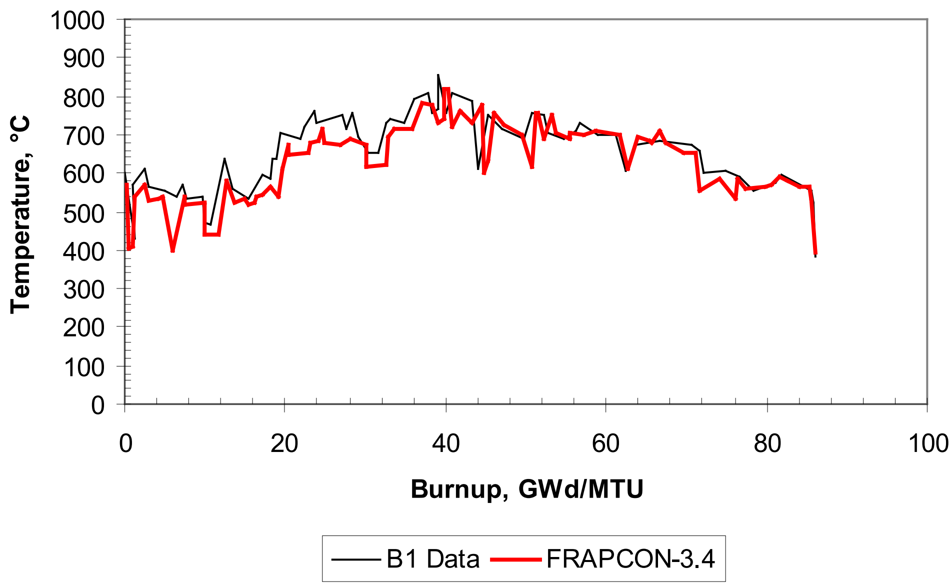


Figure 3.11 Measured and predicted centerline temperature for IFA-515.10rB1 UO_2 (burnup=80 GWd/MTU, as-fabricated radial gap=25 μm)

Figures 3.12 and 3.13 show the measured and predicted centerline temperature for IFA-681 rods 1 and 5. These figures contain upper thermocouple data (rod 1) and expansion thermometer data (rod 5). These figures show reasonable agreement between the FRAPCON-3.4 predictions and the data (±30K).

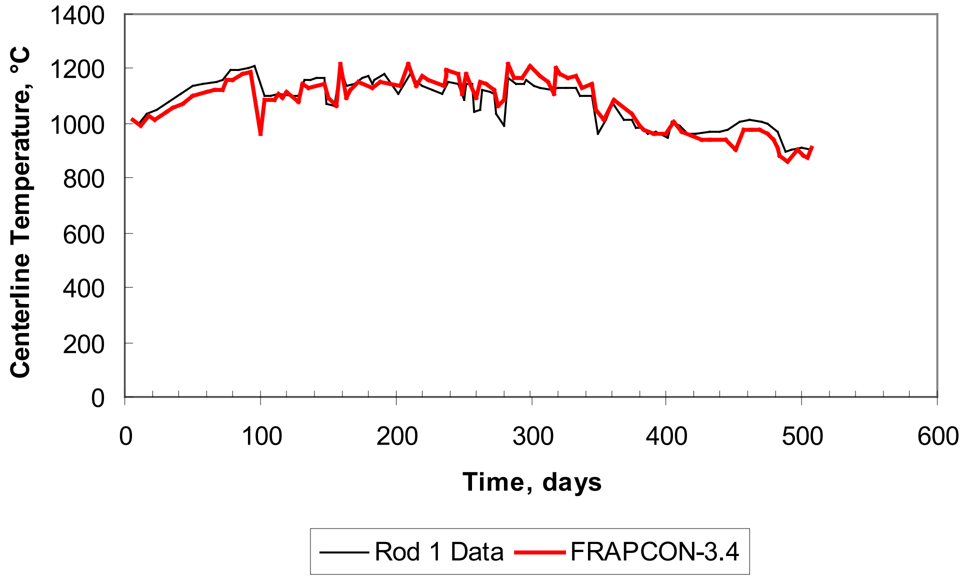


Figure 3.12 Measured and predicted centerline temperature for IFA-681r1 UO_2 (burnup=33 GWd/MTU, as-fabricated radial gap=85 μm)

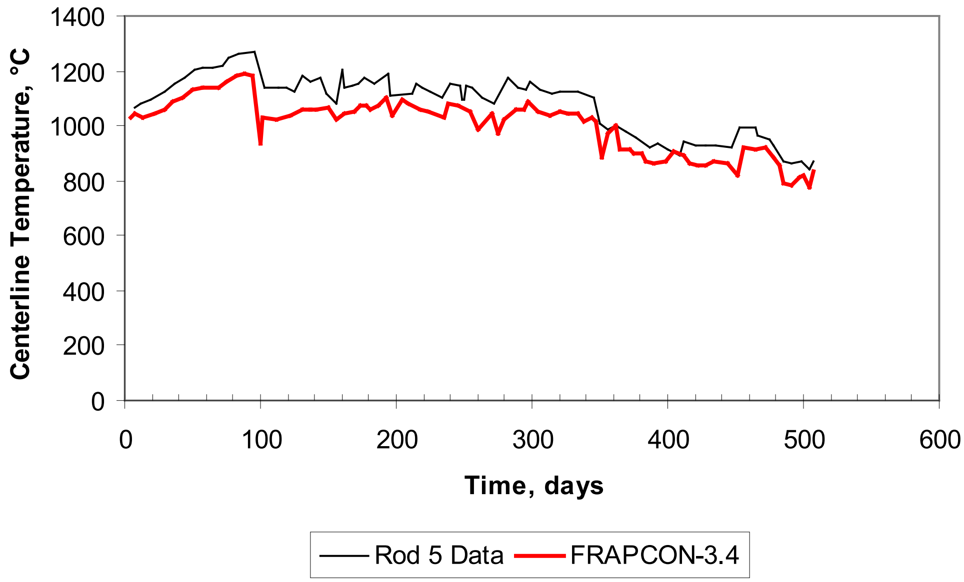


Figure 3.13 Measured and predicted centerline temperature for IFA-681r5 UO_2 (burnup=32 GWd/MTU, as-fabricated radial gap=85 μm)

Figure 3.14 shows the measured and predicted centerline temperature for IFA-677 rod 2. This figure contains upper thermocouple data. This figure shows significant underprediction of the FRAPCON-3.4 predictions relative to the data at BOL of up to 150K. However, by 300 days, the underprediction has been reduced to a more reasonable level of 75K or less. This rod (Figure 3.14) had similar LHGR and burnup and the same gap size as IFA-681 rod 5 (Figure 3.13) but significantly higher fuel centerline temperatures (~ 130°C) at low burnups.

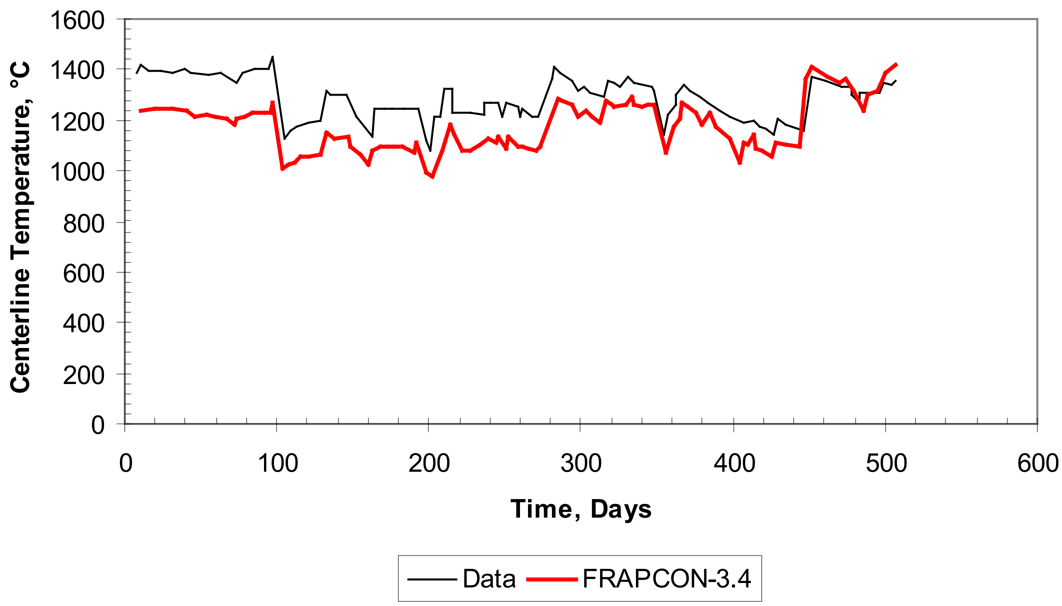


Figure 3.14 Measured and predicted centerline temperature for IFA-677.1r2 UO_2 (burnup=32 GWd/MTU, as-fabricated radial gap=85 μm)

Figure 3.15 shows the measured and predicted centerline temperature for IFA-558 rod 6. This figure contains upper thermocouple data. This figure shows reasonable agreement between the FRAPCON-3.3 predictions and the data (±50−75K), except between 25.5 and 28 GWd/MTU burnup, where temperatures are underpredicted by up to 120K but then start to provide good agreement at 29 GWd/MTU.

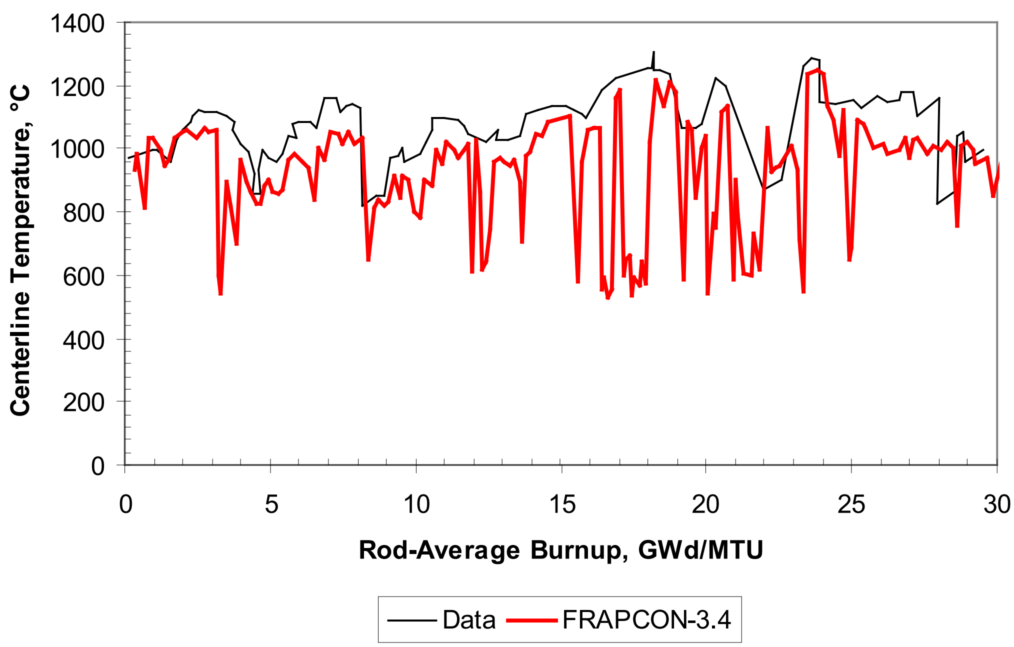


Figure 3.15 Measured and predicted centerline temperature for IFA-558r6 UO_2 (burnup=41 GWd/MTU, as-fabricated radial gap=95 μm)

This section demonstrates that FRAPCON-3.4 continues to provide a best-estimate prediction of centerline temperature for UO_2 rods to within a standard error of 4.7 percent for recent experimental data (see Figure 3.2). The largest deviation was for IFA-677 rod 2, which shows a 150K underprediction at BOL that decreases to less than 75K by 300 days. All the IFA-677 rods were also underpredicted in the BOL temperature section, perhaps demonstrating a bias in this data, particularly compared with rods of similar power, burnup levels, and gap size that demonstrate better agreement with the code.

It is noted that in some of these cases the temperatures are predicted well throughout life, while in other cases there is a deviation with time, and in others there is a consistent bias throughout life. The cases with a deviation with time are likely due to a small difference in FGR predictions that affect the calculated centerline temperature or a drift in neutron detectors with time that affects measured rod powers. In some cases, the neutron detectors are recalibrated between reactor cycles such that at a given burnup or time the predicted and measured temperatures begin to agree better or deviate. The cases with a constant bias throughout life are likely due to a bias in the reported rod power or measured temperature.

3.2.2 MOX Center Temperature Predictions as a Function of Burnup

FRAPCON-3.3 predictions have been benchmarked against centerline temperatures taken from eight Halden tests with instrumented fuel assemblies containing 15 MOX fuel rods. The results of these comparisons are provided in this section.

The following figures show measured and predicted fuel centerline temperatures from rods with centerline temperature measurements. Individual rod predictions may demonstrate a systematic error (bias) that may be due to thermocouple decalibration or a systematic error in the power history or axial power shape (power at thermocouple location) provided due to decalibration in or with the neutron detectors. However, when all the comparisons are examined, no overall systematic error (bias) is found in the prediction of MOX fuel temperature throughout life, as can be seen in Figure 3.16. For all the cases, a standard error of 4.7 percent on the centerline temperature was calculated. These data are also shown in terms of relative bias in Figure 3.17 as a function of burnup. There appears to be no systematic bias in the predictions with increasing burnup.

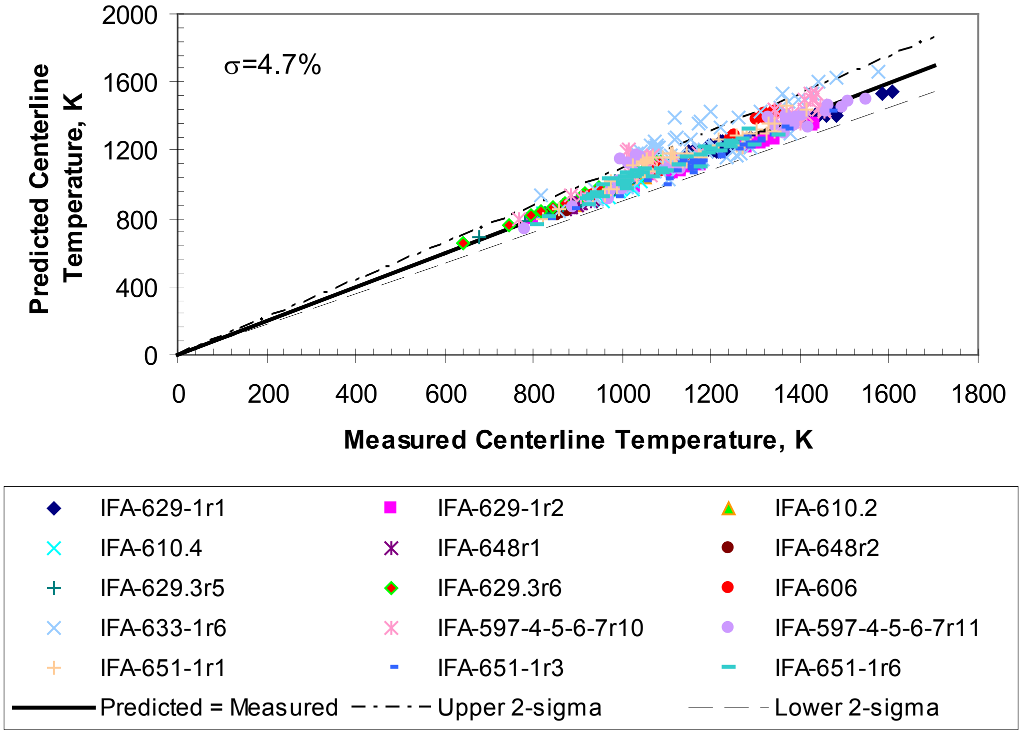


Figure 3.16 Measured and predicted centerline temperature for the MOX assessment cases throughout life

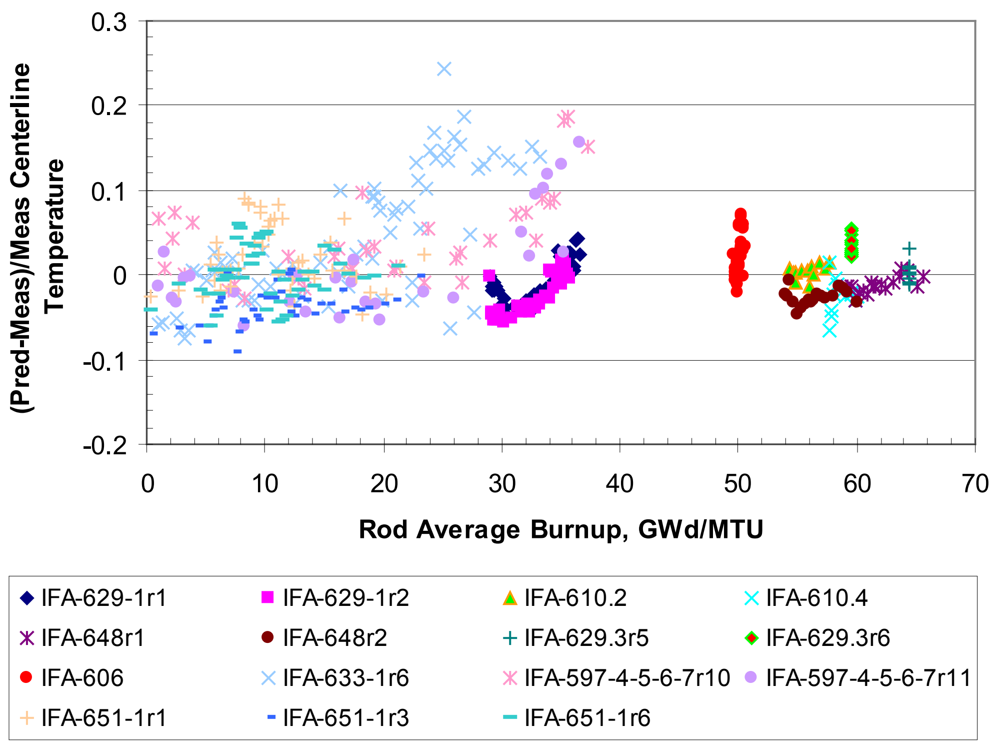


Figure 3.17 Predicted minus measured divided by measured centerline temperature for the MOX assessment cases as a function of burnup

Figures 3.18 and 3.19 show the measured and predicted centerline temperatures for IFA-629-1 rods 1 and 2. These figures show good agreement between the FRAPCON-3.4 predictions and the data. The slight offset during parts of the irradiation could be due to power or thermocouple calibration changes at the end of each cycle.

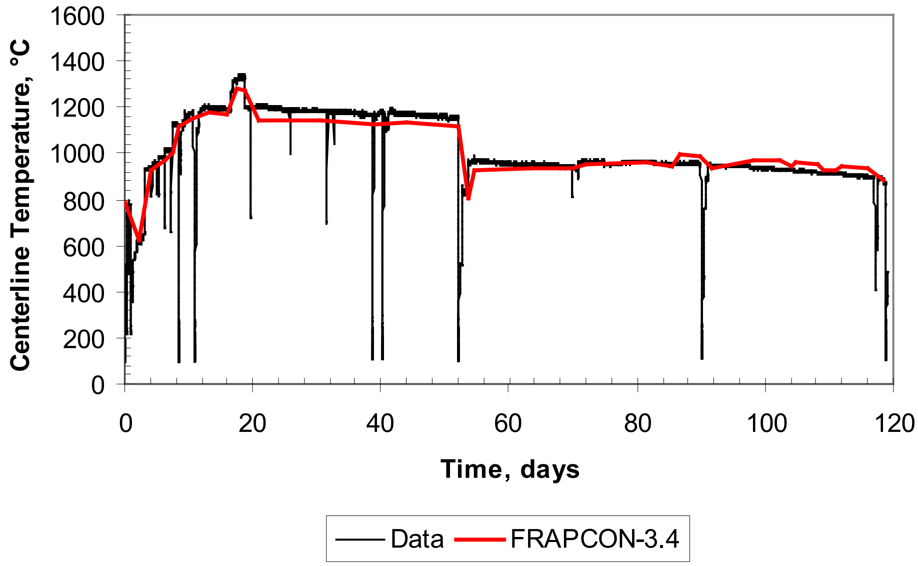


Figure 3.18 Measured and predicted centerline temperature for IFA-629-1 rod 1 MOX (starting burnup=27 GWd/MTU, ending burnup=33 GWd/MTU, as-fabricated radial gap=84 μm)

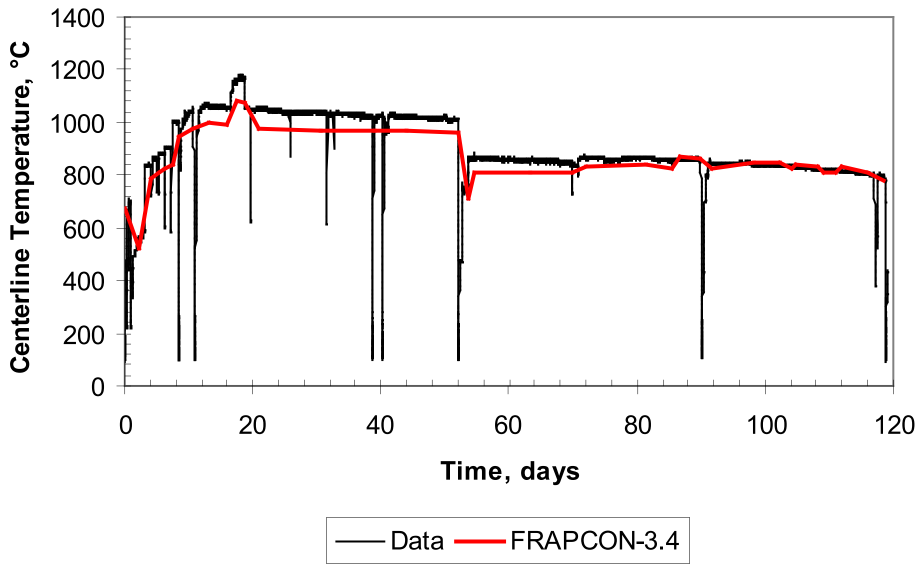


Figure 3.19 Measured and predicted centerline temperature for IFA-629-1 rod 2 (starting burnup=29 GWd/MTU, ending burnup=40 GWd/MTU, as-fabricated radial gap = 84 μm)

Figures 3.20 and 3.21 show the measured and predicted centerline temperature for IFA-610.2 and IFA-610.4. These figures show excellent agreement between the FRAPCON-3.4 predictions and the data.

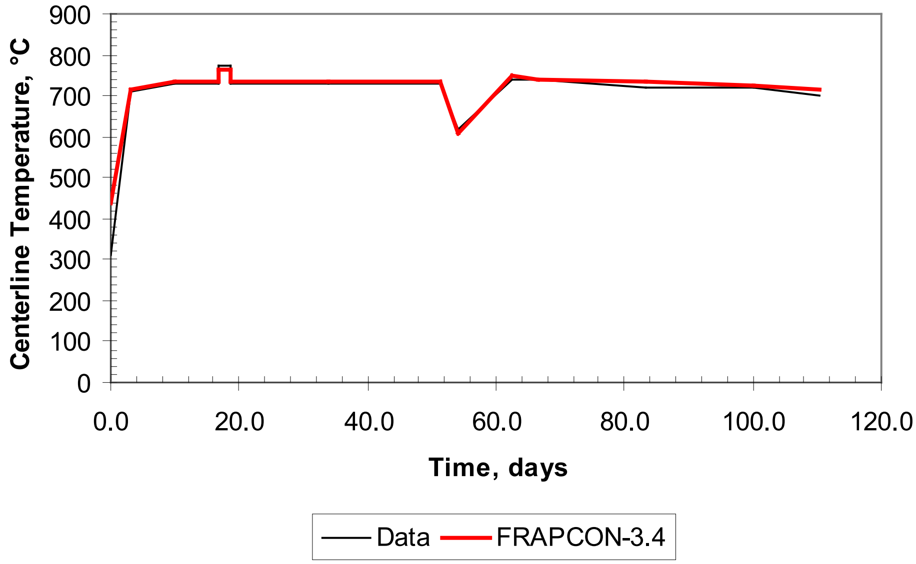


Figure 3.20 Measured and predicted centerline temperature for IFA-610.2 MOX (starting burnup=55 GWd/MTU, ending burnup=56 GWd/MTU, as-fabricated radial gap = 84 μm)

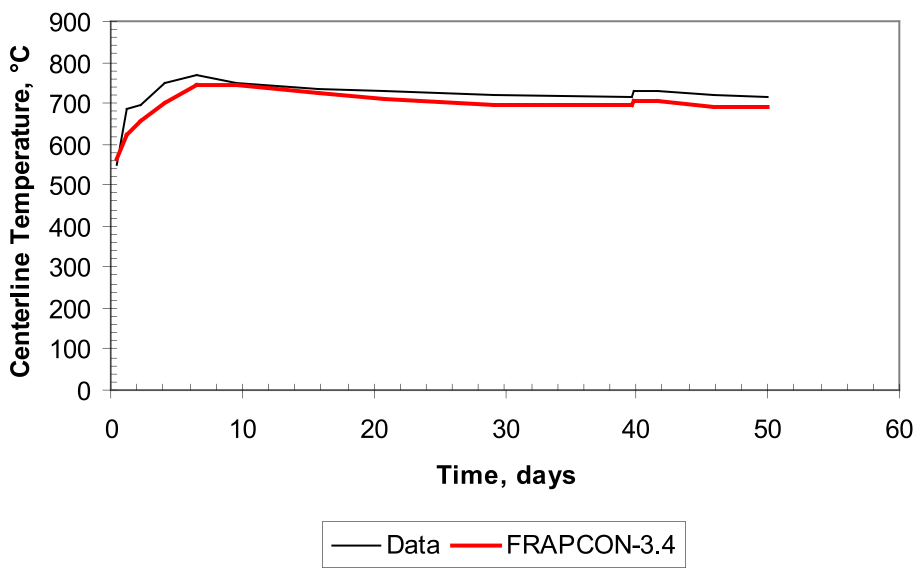


Figure 3.21 Measured and predicted centerline temperature for IFA-610.4 MOX (starting burnup=56, ending burnup=57 GWd/MTU, as-fabricated radial gap=84 μm)

Figures 3.22 and 3.23 show the measured and predicted centerline temperature for IFA-648.1 rods 1 and 2. These figures show excellent agreement between the FRAPCON-3.4 predictions and the data.

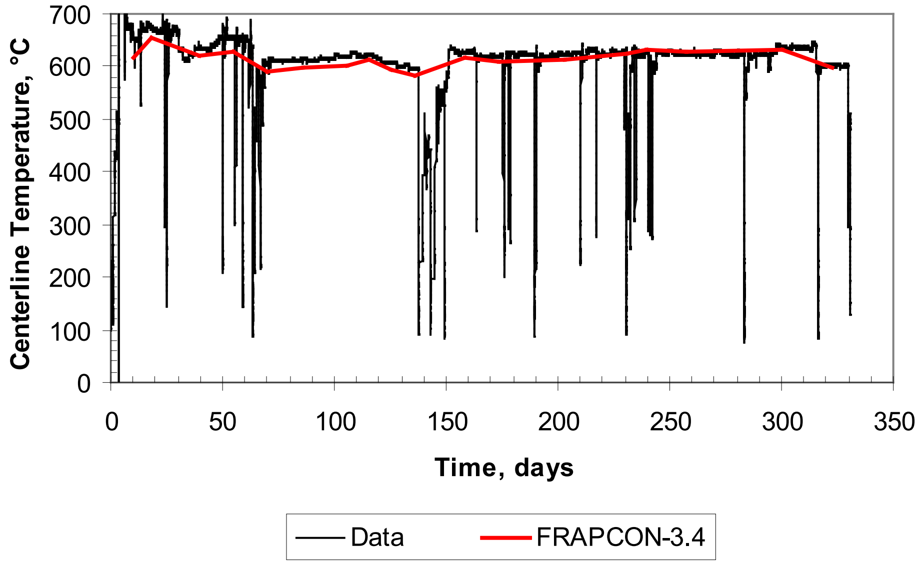


Figure 3.22 Measured and predicted centerline temperature for IFA-648.1 rod 1 MOX (starting burnup=55 GWd/MTU, ending burnup=62 GWd/MTU, as-fabricated radial gap=84 μm)

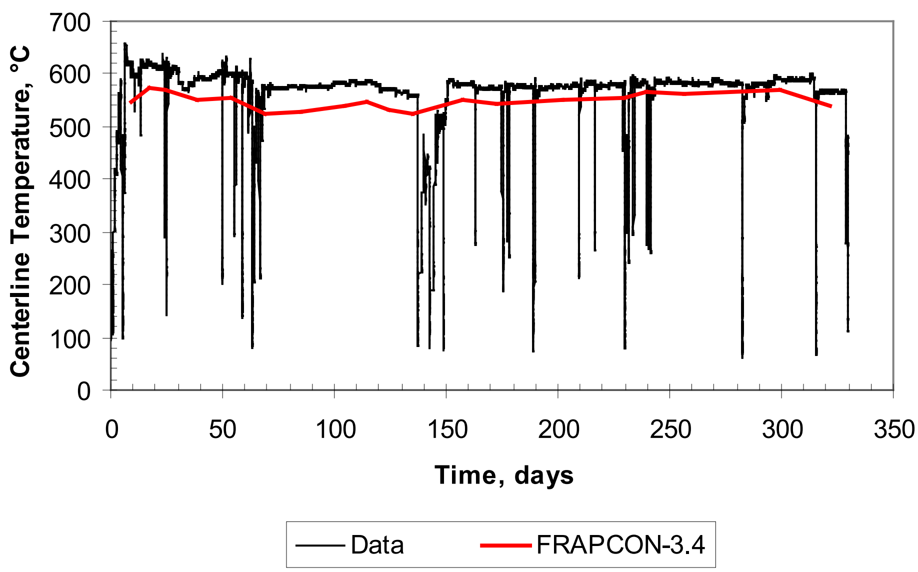


Figure 3.23 Measured and predicted centerline temperature for IFA-648.1 rod 2 MOX (starting burnup=55 GWd/MTU, ending burnup=62 GWd/MTU, as-fabricated radial gap=84 μm)

Figures 3.24 and 3.25 show the measured and predicted centerline temperature for IFA-629.3 rods 5 and 6. These figures show excellent agreement between the FRAPCON-3.4 predictions and the data.

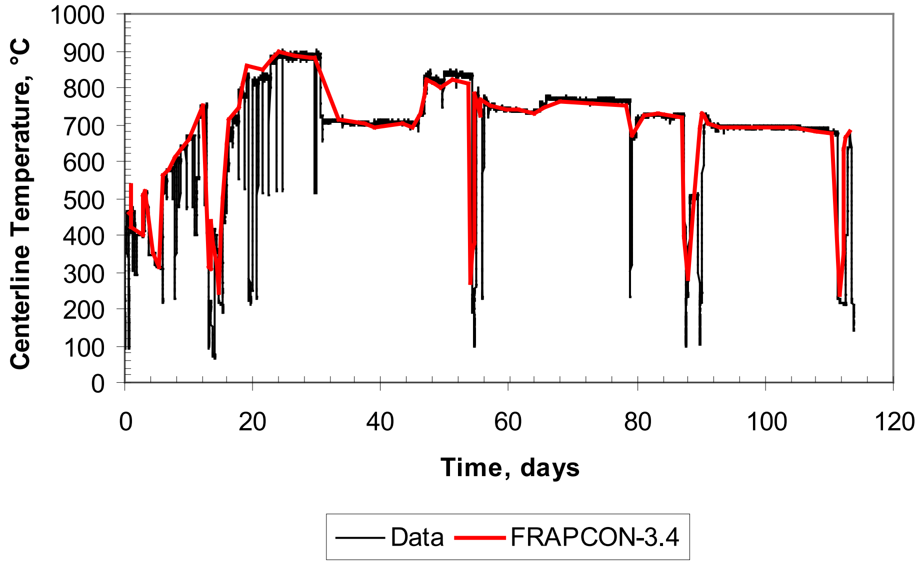


Figure 3.24 Measured and predicted centerline temperature for IFA-629.3 rod 5 MOX (starting burnup=62 GWd/MTU, ending burnup=72 GWd/MTU, as-fabricated radial gap=84 μm)

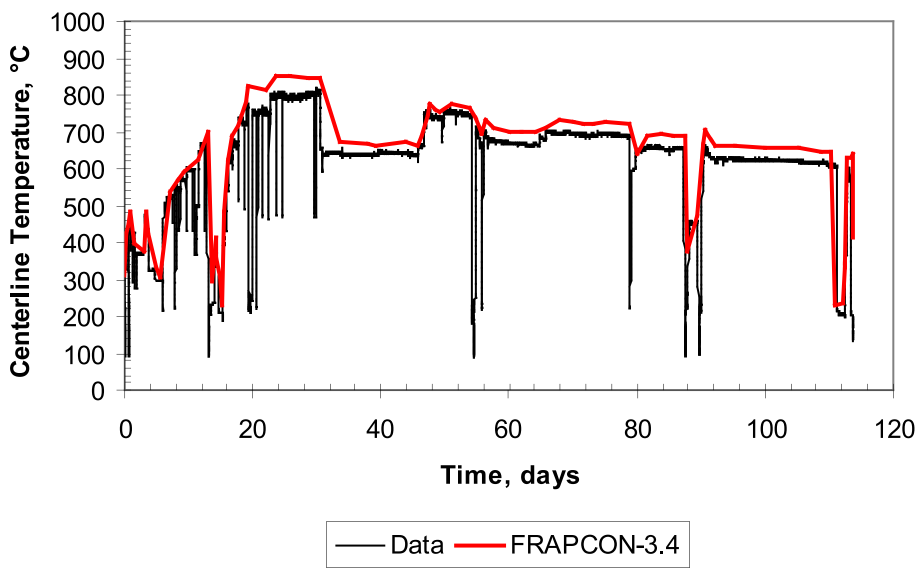


Figure 3.25 Measured and predicted centerline temperature for IFA-629.3 rod 6 MOX (starting burnup=62 GWd/MTU, ending burnup=68 GWd/MTU, as-fabricated radial gap=84 μm)

Figure 3.26 shows the measured and predicted centerline temperature for IFA-606 Phase 2. This figure shows reasonable agreement between the FRAPCON-3.4 predictions and the data (within ±75K).

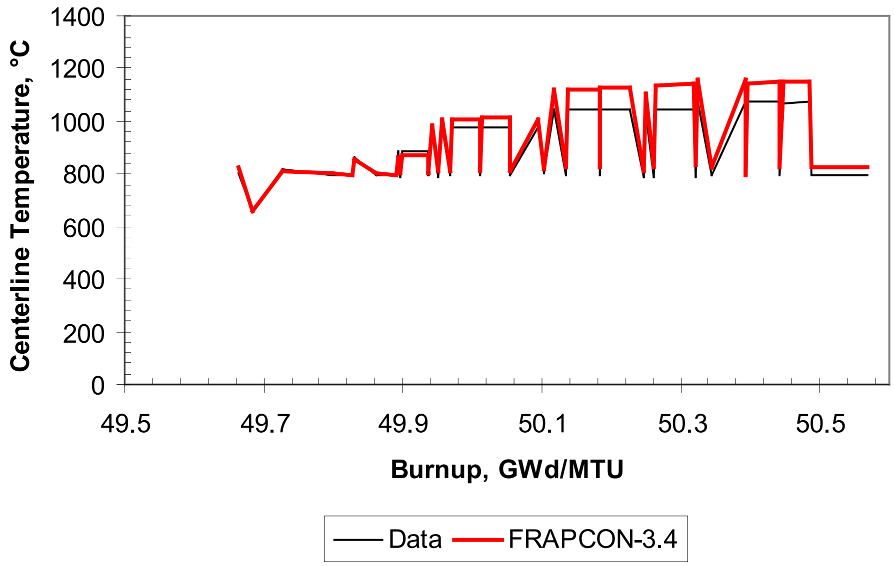


Figure 3.26 Measured and predicted centerline temperature for IFA-606 Phase 2 MOX (starting burnup=49 GWd/MTU, as-fabricated radial gap=94 μm)

Figure 3.27 shows the measured and predicted centerline temperature for IFA-633-1 rod 6. This figure shows reasonable agreement between the FRAPCON-3.4 predictions and the data (within ±75K) until about 26 GWd/MTU, when FRAPCON-3.4 overpredicts the data by about 125 to 150K. This may be because FRAPCON-3.4 overpredicts the FGR (measured FGR=6 percent, predicted=13 percent) for this rod, which will lead to increased fuel temperatures.

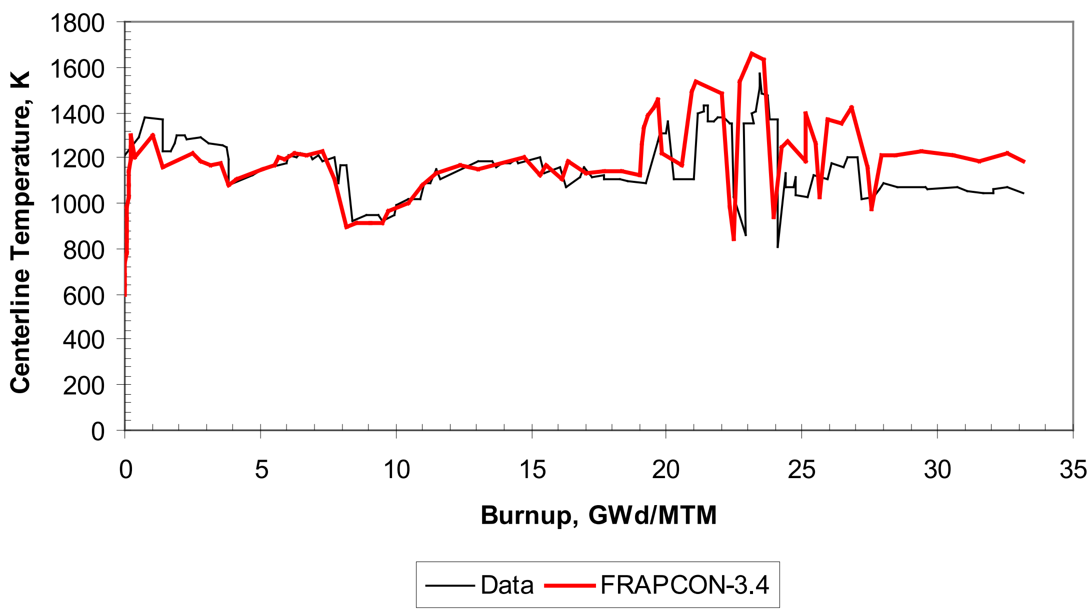


Figure 3.27 Measured and predicted centerline temperature for IFA-633-1 rod 6 MOX (burnup=32 GWd/MTU, as-fabricated radial gap= 104 μm)

Figures 3.28 and 3.29 show the measured and predicted centerline temperature for IFA-597-4, -5, -6, -7 rods 10 and 11. These figures show excellent agreement between the FRAPCON-3.4

predictions and the data up to 25 GWd/MTU, when the code begins to overpredict the data by up to 100K.

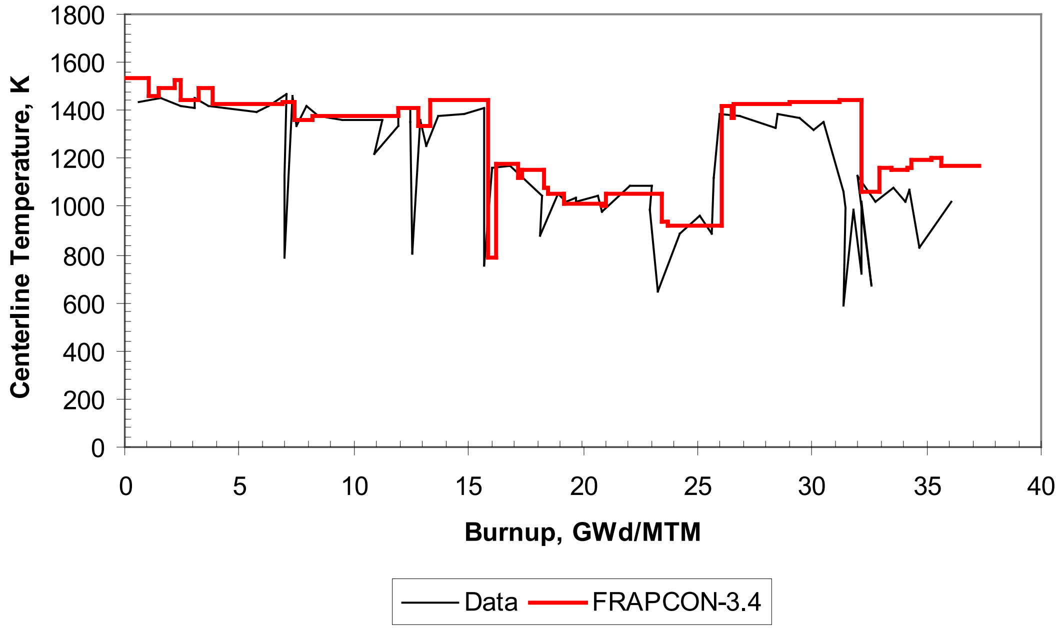


Figure 3.28 Measured and predicted centerline temperature for IFA-597-4, -5, -6, -7 rod 10 MOX (burnup=36 GWd/MTU as-fabricated radial gap=95μm)

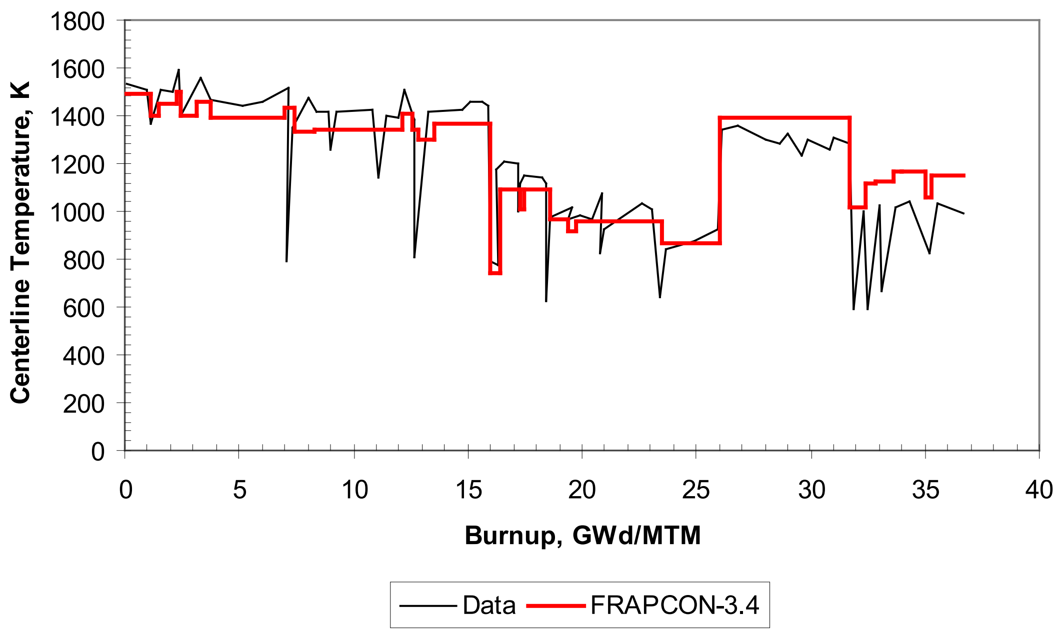


Figure 3.29 Measured and predicted centerline temperature for IFA-597-4, -5, -6, -7 rod 11 MOX (burnup=37 GWd/MTU as-fabricated radial gap=95 μm)

Figures 3.30, 3.31, and 3.32 show the measured and predicted centerline temperature for IFA-651-1 rods 1, 3, and 6. These figures show excellent agreement between the FRAPCON-3.4 predictions and the data from rods 1 and 6 that were instrumented with centerline thermocouple, and reasonable agreement (±50K) with the data from rod 3 that was instrumented with an expansion thermometer.

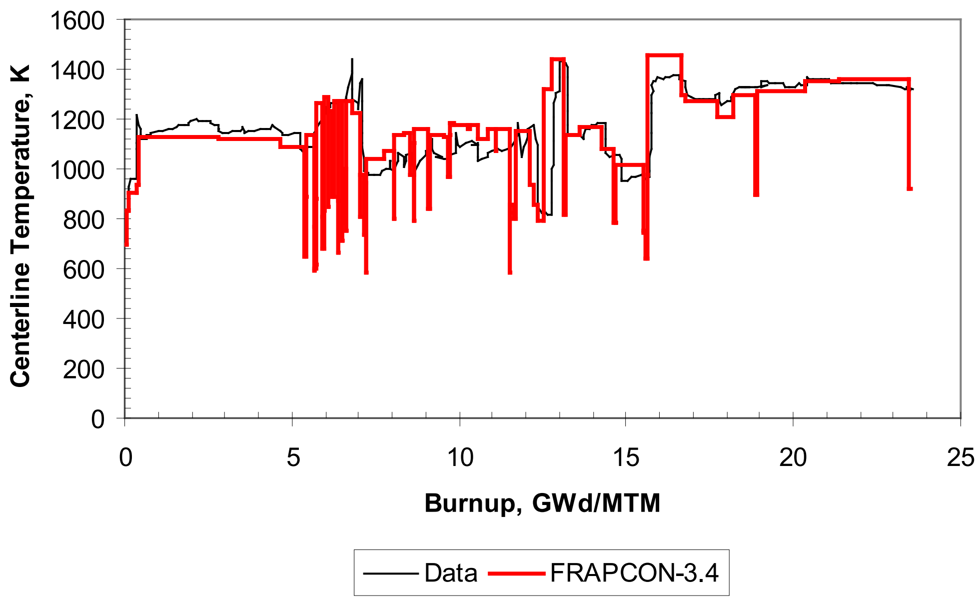


Figure 3.30 Measured and predicted centerline temperature for IFA-651-1 rod 1 MOX (burnup=22 GWd/MTU as-fabricated radial gap=79 μm)

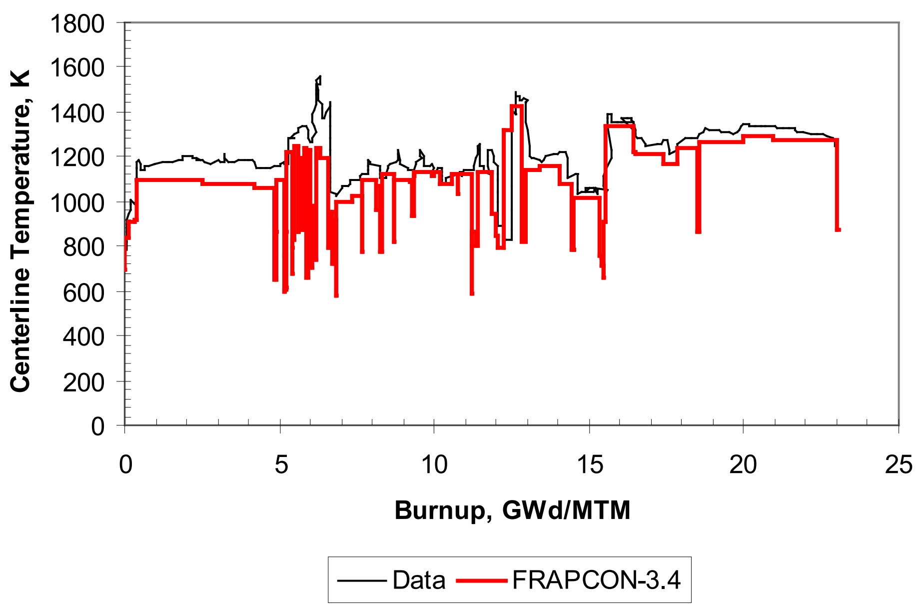


Figure 3.31 Measured and predicted centerline temperature for IFA-651-1 rod 3 MOX (burnup=22 GWd/MTU as-fabricated radial gap=79 μm)

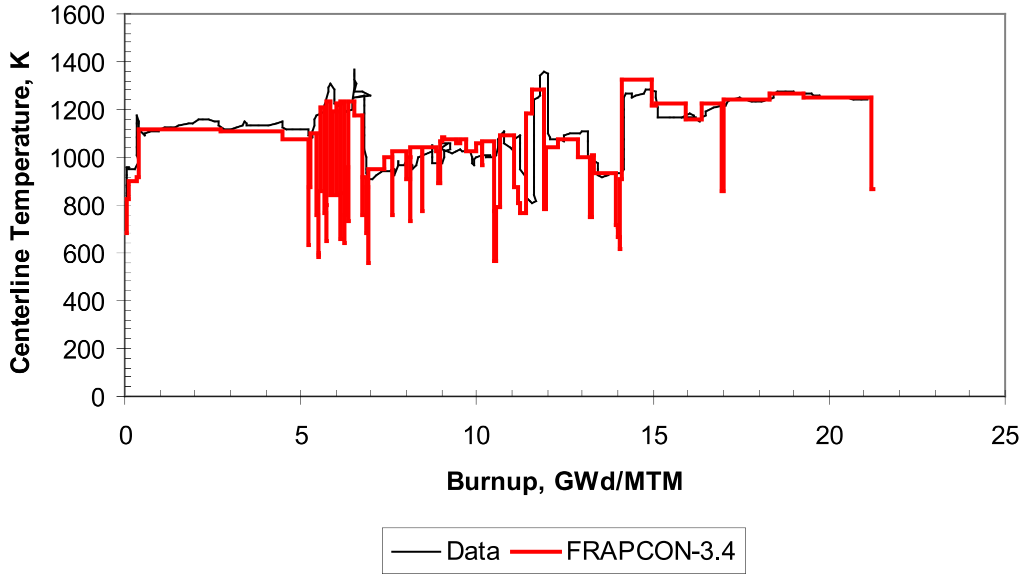


Figure 3.32 Measured and predicted centerline temperature for IFA-651-1 rod 6 MOX (burnup=20 GWd/MTU as-fabricated radial gap=81 μm)

This section demonstrates that FRAPCON-3.4 continues to provide a best-estimate prediction of centerline temperature for MOX rods to within a standard error of 4.7 percent. The largest deviation was for 633-1 rod 6, which shows up to a 150K overprediction at higher burnup. This may be due to overpredicting the FGR for this rod.

3.2.3 UO_2-Gd_2O_3 Center Temperature Predictions as a Function of Burnup

The adjustment for gadolinia in the thermal conductivity model has been assessed against centerline temperature predictions from three instrumented fuel assemblies irradiated at the Halden reactor. The results of these comparisons are provided in this section.

The following figures show measured and predicted fuel centerline temperatures from rods with centerline temperature measurements. Individual rod predictions may demonstrate a systematic error (bias) that may be due to thermocouple decalibration or a systematic error in the power history or axial power shape (power at thermocouple location) provided due to decalibration in or with the neutron detectors with time. However, when all the comparisons are examined, no overall systematic error (bias) is found in the prediction of UO_2-Gd_2O_3 temperature throughout life, as can be seen in Figure 3.33. For all the cases, a standard error of 4.9 percent on the centerline temperature was calculated. These data are also shown in terms of relative bias in Figure 3.34 as a function of burnup. It can be seen that there appears to be no systematic bias in the predictions with increasing burnup.

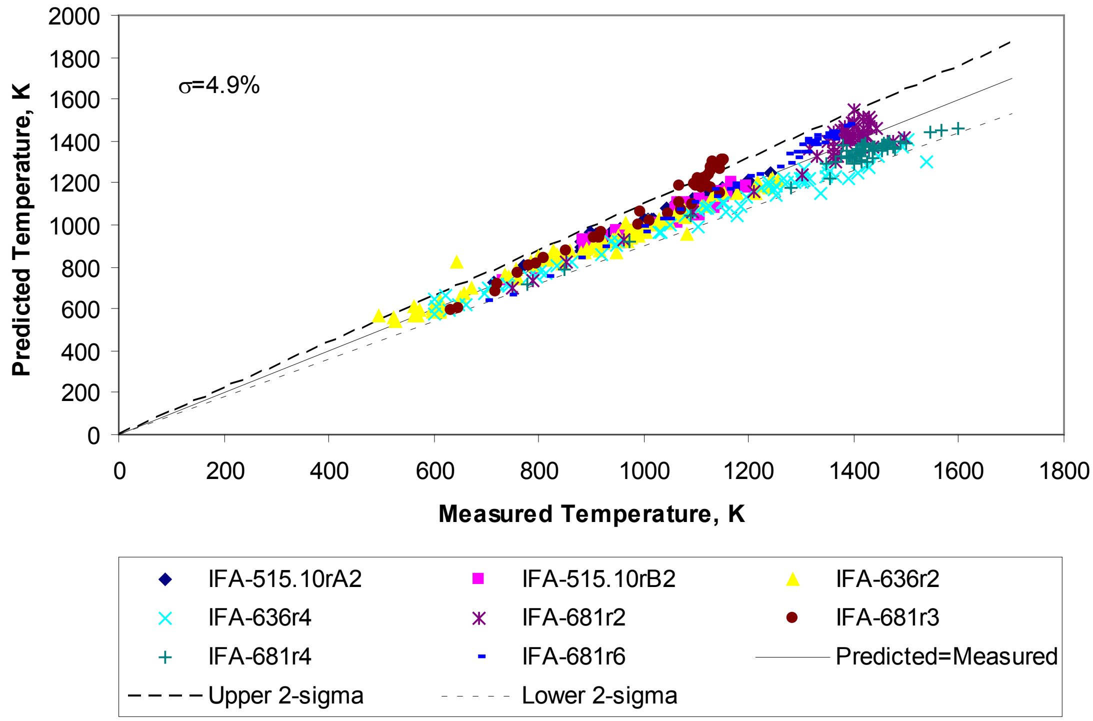


Figure 3.33 Measured and predicted centerline temperature for the UO_2-Gd_2O_3 assessment cases throughout life

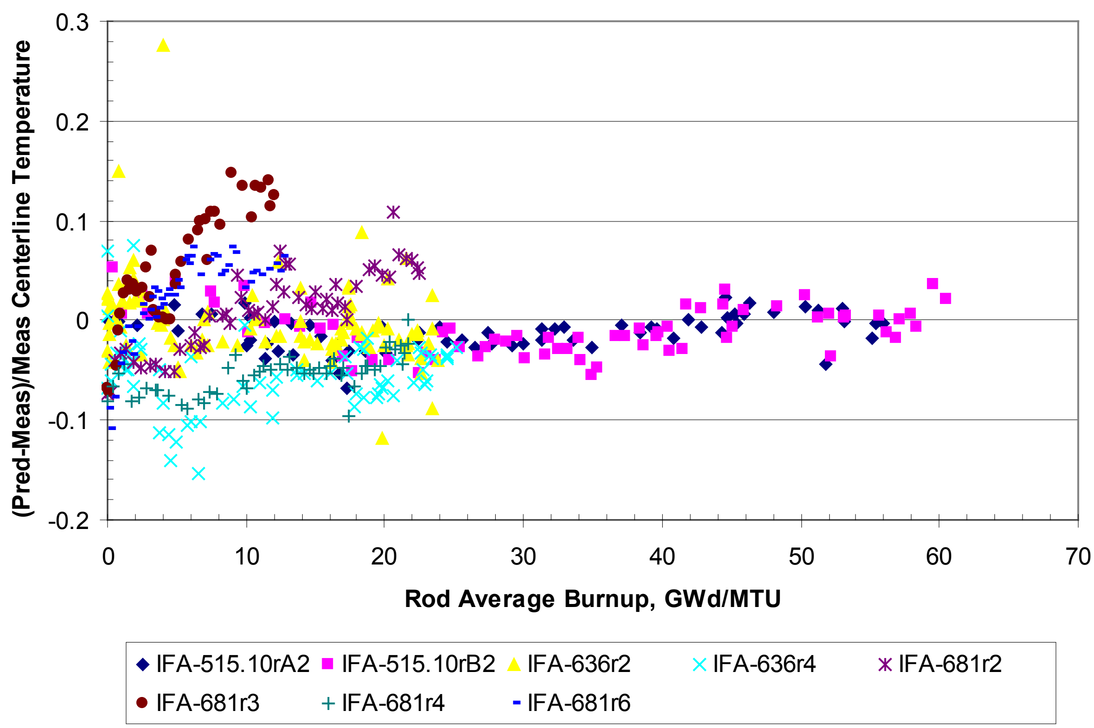
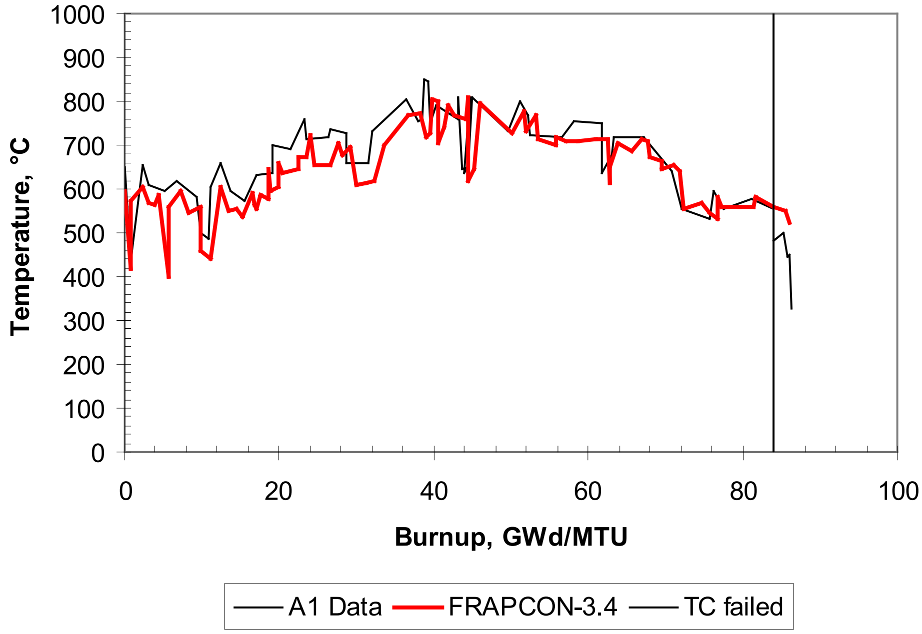
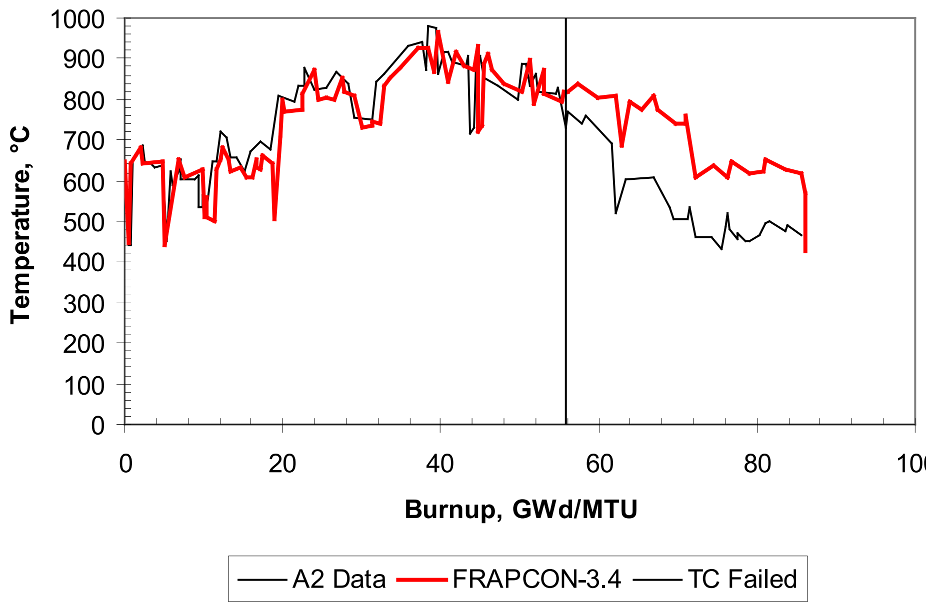


Figure 3.34 Predicted minus measured divided by measured centerline temperature for the UO_2-Gd_2O_3 assessment cases as a function of burnup

Figures 3.35 and 3.36 show the measured and predicted centerline temperature for IFA-515.10. Rods A1 and B1 are UO_2 rods and rods A2 and B2 are UO_2-Gd_2O_3 rods with depleted gadolinium (Gd) that did not contain any ^{155}Gd or ^{157}Gd. There are two factors that influence the centerline temperature for UO_2-Gd_2O_3 rods relative to UO_2 rods: 1) degradation in thermal conductivity due to Gd addition and 2) radial power profile due to the neutron absorption of ^{155}Gd and ^{157}Gd. These rods were meant to show the difference only due to the thermal conductivity degradation from gadolinia (Gd_2O_3), not due to the difference in radial power profile. A modified version of FRAPCON-3.4 that uses the UO_2 radial power profile model (TUBRNP) for UO_2-Gd_2O_3 rods (A2 and B2) was used to perform these calculations. These figures show that FRAPCON-3.4 predicts the centerline temperatures for UO_2-Gd_2O_3 rods as well as for UO_2 rods. In these figures, the vertical line denotes where the thermocouple failed. Although data was reported after this point, it is not valid.

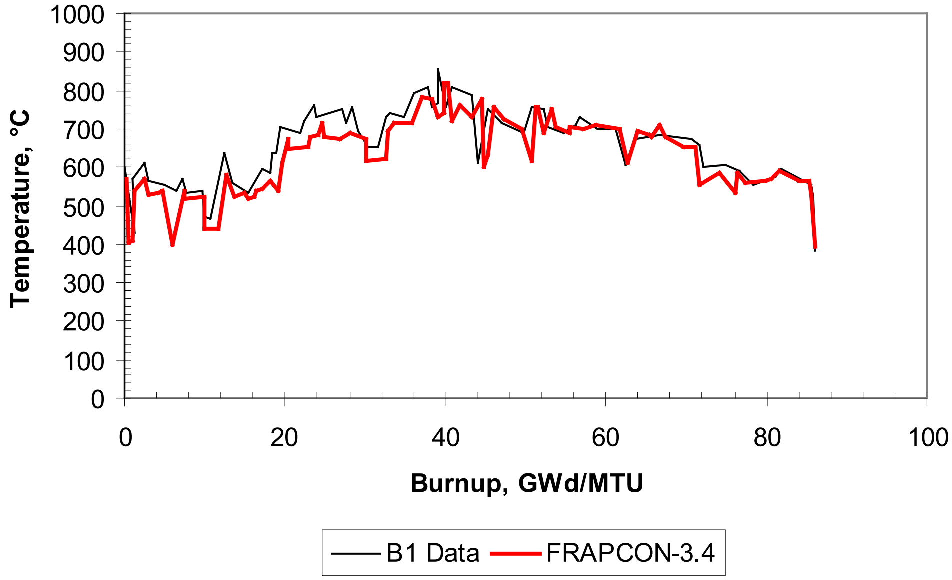


(a)

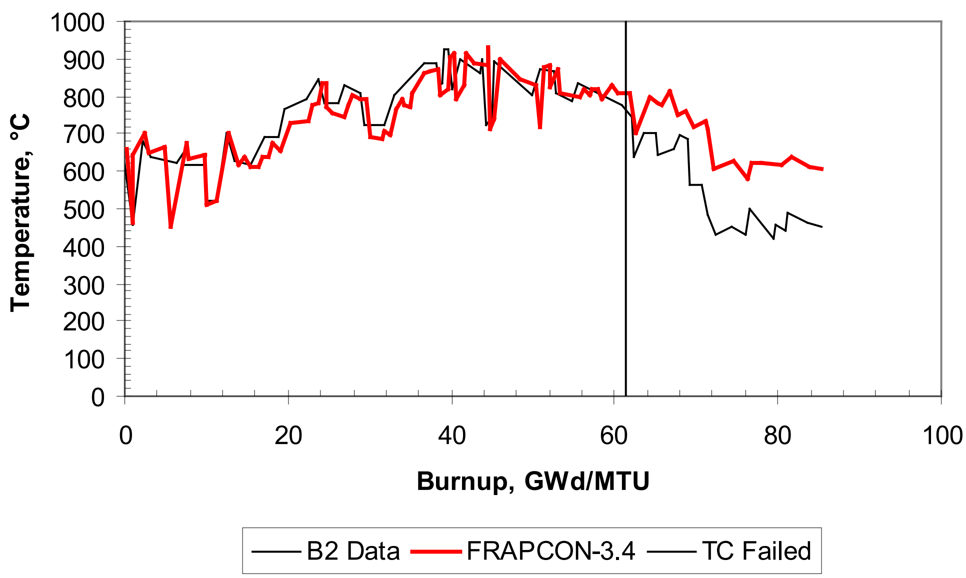


(b)

Figure 3.35 Measured and predicted centerline temperature for IFA-515.10 rod A1 (UO_2) (a), and for IFA-515.10 rod A2 (UO_2-8%Gd_2O_3) (b) (burnup=80 GWd/MTU, as-fabricated radial gap=25 μm)



(a)



(b)

Figure 3.36 Measured and predicted centerline temperature for IFA-515.10 rod B1 (UO_2) (a), and for IFA-515.10 rod B2 (UO_2-8%Gd_2O_3) (b) (burnup=80 GWd/MTU, as-fabricated radial gap=25 μm)

Figures 3.37 and 3.38 show the measured and predicted centerline temperature for IFA-636 rods 2 and 4. These rods contain standard Gd (no Gd depletion like IFA-515.10), so the release version of FRAPCON-3.4 could be used. Rod 2 was equipped with a centerline thermocouple, and the data from this thermocouple is shown in Figure 3.37. Rod 4 contains solid pellets, and the data shown in Figure 3.38 is estimated from rod 2. Because rod 4 does not have a direct measurement of temperature (no thermocouple), there is more uncertainty in the data from rod 4 because this is estimated by Halden using the rod 2 temperature data and correcting for no thermocouple hole. In addition, during the first rise to power, as the Gd is burning out, there is a high level of uncertainty on the reported rod power. Because of this, FRAPCON-3.4 may not predict the centerline temperature well during this period. These figures show excellent agreement between the FRAPCON-3.4 predictions and the data for rod 2 and reasonable agreement for rod 4, which has greater uncertainty.

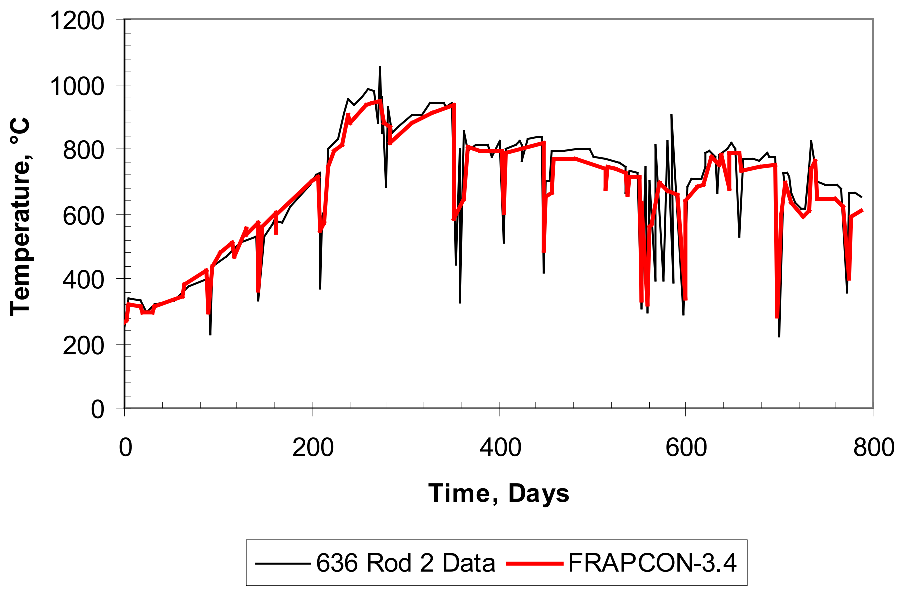


Figure 3.37 Measured and predicted centerline temperature for IFA-636r2 (UO_2-8%Gd_2O_3) (burnup=25 GWd/MTU, as-fabricated radial gap=77 μm)

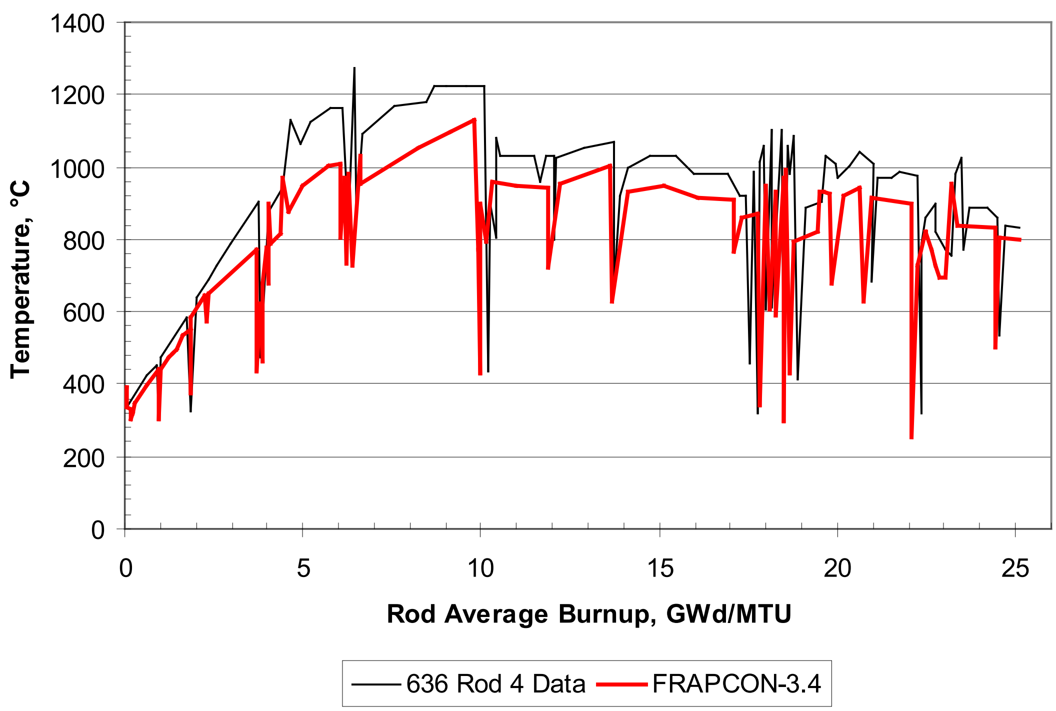


Figure 3.38 Measured and predicted centerline temperature for IFA-636r4 (UO_2-8%Gd_2O_3) (burnup=25 GWd/MTU, as-fabricated radial gap=77 μm)

Figures 3.39 through 3.44 show the measured and predicted centerline temperature for IFA-681 rods 1, 2, and 3 with centerline thermocouples and rods 4, 5, and 6 with hollow pellets and expansion thermometers. Rods 1 and 5 are UO_2 rods. Rods 2 and 4 contain standard Gd with 2 wt% Gd_2O_3. Rods 3 and 6 contain standard Gd with 8 wt% Gd_2O_3. Since these rods contain standard Gd, the release version of FRAPCON-3.4 could be used. During the first rise to power, as the Gd is burning out, there is a high level of uncertainty on the reported rod power. Because of this, FRAPCON-3.4 may not predict the centerline temperature well during this period. This does not significantly affect future predictions because power levels while the Gd is burning out are low and will not cause significant FGR that will affect future temperature predictions.

These figures show excellent agreement between the FRAPCON-3.4 predictions and the data for rods 1 and 2 (Figures 3.39 and 3.40). For rod 3 (Figure 3.41), the FRAPCON-3.4 predictions are in excellent agreement with the data for the first 200 days. After this, FRAPCON-3.4 overpredicts the data by up to 100K. The reason for this is not clear, as both the power and the FRAPCON-3.4 temperature prediction increase during this time period, but the measured temperature does not increase with increasing power. For the hollow pellet rods, the UO_2 and 2 wt% Gd_2O_3 rods (IFA-681 rods 5 and 4 in Figures 3.43 and 3.42, respectively) are uniformly underpredicted by about 50K while the 8 wt% Gd_2O_3 rod (IFA-681 rod 6) is predicted well (Figure 3.44). These differences are well within the uncertainty of temperature measurement and power levels.

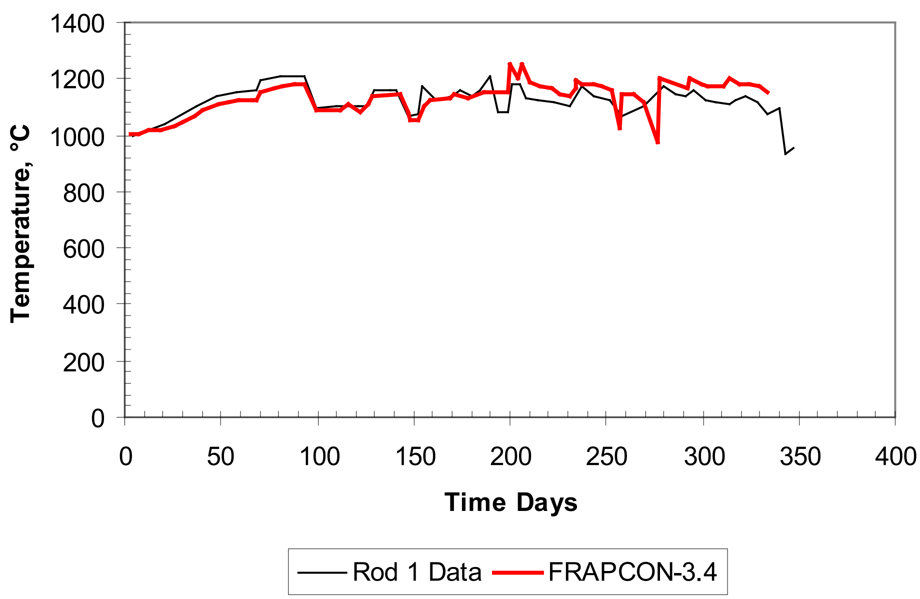


Figure 3.39 Measured and predicted centerline temperature for IFA-681r1 (UO_2) (burnup=24 GWd/MTU, as-fabricated radial gap=85 μm)

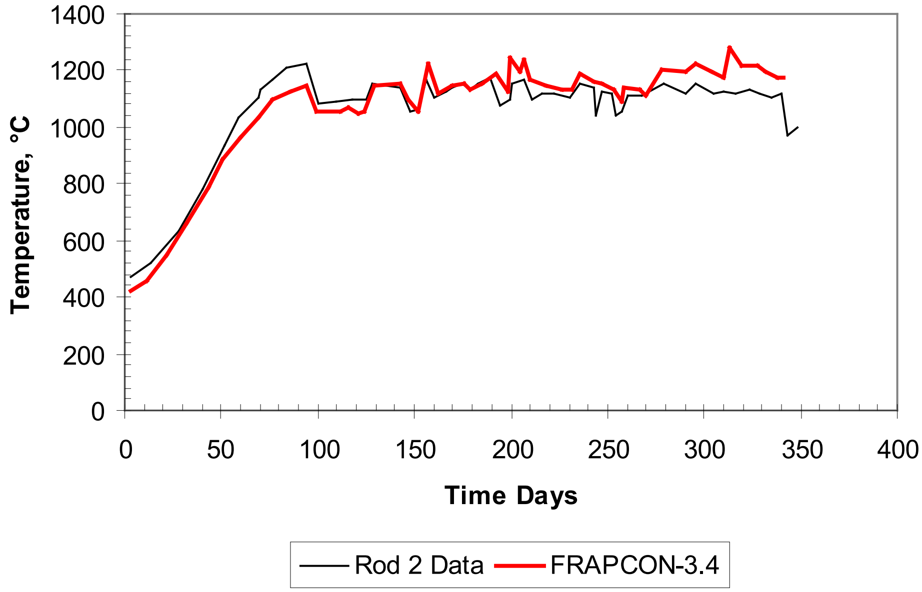


Figure 3.40 Measured and predicted centerline temperature for IFA-681r2 (UO_2 2%Gd_2O_3) (burnup=23 GWd/MTU, as-fabricated radial gap=85 µm)

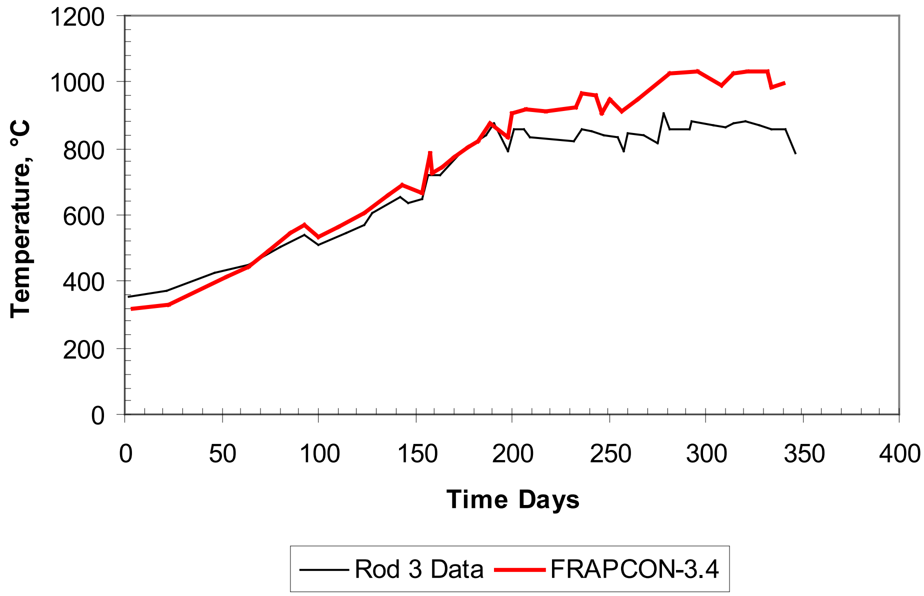


Figure 3.41 Measured and predicted centerline temperature for IFA-681r3 (UO_2 8%Gd_2O_3) (burnup=12 GWd/MTU, as-fabricated radial gap=85 µm)

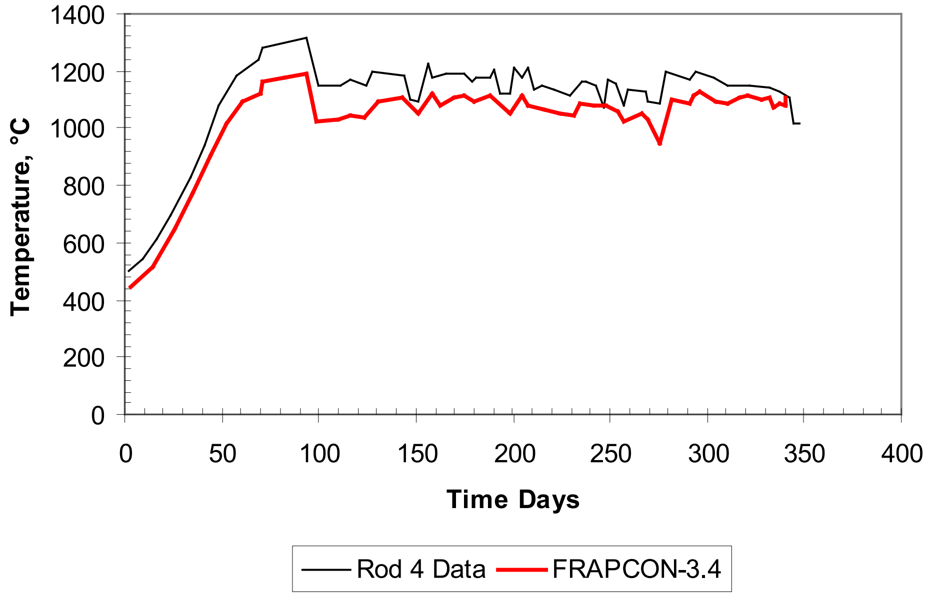


Figure 3.42 Measured and predicted centerline temperature for IFA-681r4 (UO_2 2%Gd_2O_3) (burnup=22 GWd/MTU, as-fabricated radial gap=85 μm)

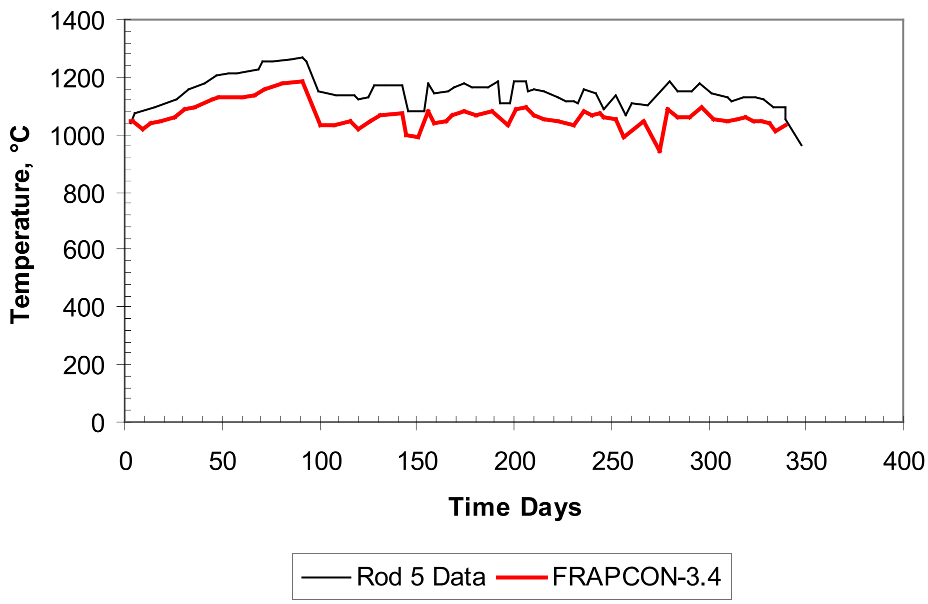


Figure 3.43 Measured and predicted centerline temperature for IFA-681r5 (UO_2) (burnup=23 GWd/MTU, as-fabricated radial gap=85 μm)

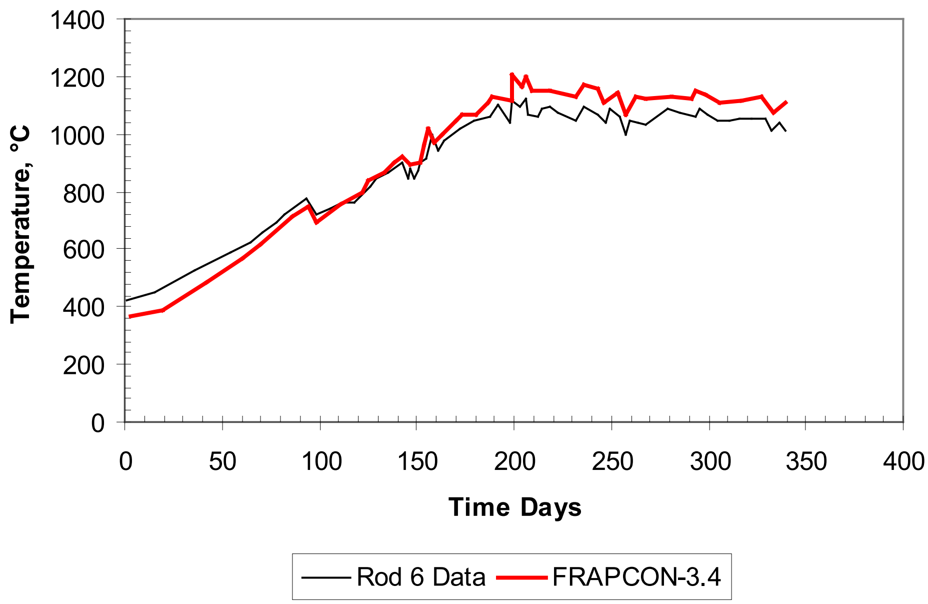


Figure 3.44 Measured and predicted centerline temperature for IFA-681r6 (UO_2 8%Gd_2O_3) (burnup=13 GWd/MTU, as-fabricated radial gap=85 μm)

This section demonstrates that FRAPCON-3.4 continues to provide a best-estimate prediction of centerline temperature for UO_2-Gd_2O_3 rods to within a standard error of 4.9 percent for recent experimental data.

4.0 Fission Gas Release Assessment

4.1 Assessment of Steady-State FGR Predictions

An accurate prediction of FGR is important for two reasons: 1) it has a significant impact on the prediction of gap conductance and, therefore, fuel temperatures (e.g., as demonstrated in Section 3.0, an overprediction of FGR can result in an overprediction of fuel temperatures, and the converse is also true), and 2) it is necessary for the calculation of rod internal pressures that affect LOCA analyses and EOL rod pressures. In many cases, for current operating plants, the limits on and analyses of EOL rod pressures determine the LHGR limits for commercial fuel at burnups greater than 30 GWd/MTU. In addition, the NRC requires that these EOL rod pressure analyses include bounding normal operation transients (e.g., xenon transients lasting several hours) and AOOs (e.g., overpower transients lasting several minutes to hours). Therefore, the accurate prediction of transient FGR under conditions of power increases above steady-state operation is important for licensing analyses.

The code's ability to predict FGR in UO_2 fuel has been assessed based on comparisons to FGR data from 23 UO_2 fuel rods with power histories that are relatively steady-state through the rods' irradiation life and 19 UO_2 rods with power bumping (increase in rod power) at EOL to simulate an overpower AOO or normal operational transients. The code's ability to predict FGR in MOX fuel has been assessed based on comparisons to FGR data from 34 MOX fuel rods with power histories that are relatively steady-state through the rods' irradiation life and 8 MOX rods with power bumping (increase in rod power) at EOL to simulate an overpower AOO or normal operational transients. The fuel rods with greater than 5 percent FGR were selected because the limiting rods in terms of EOL rod pressure in today's plants (particularly for power uprated plants) have releases above 10 percent FGR.

No fuel rods with UO_2-Gd_2O_3 fuel were available for assessment of the code's ability to predict FGR in UO_2-Gd_2O_3 fuel. However, it has been observed that the measured FGR from UO_2-Gd_2O_3 rods is similar to the FGR from UO_2 rods with the same power history (Hirai et al., 1995). FRAPCON-3.4 will predict slightly higher FGR for a UO_2-Gd_2O_3 rod than for an identical UO_2 rod due to the lower fuel thermal conductivity in the UO_2-Gd_2O_3. Based on the above observation, this modeling assumption is conservative.

The assessment in this section has used the default FGR model in the MASSIH subroutine in the code that is based on a modified release model proposed by Forsberg and Massih (1985). This release model is described in Volume 1 of this report (Geelhood et al., 2010). The other FGR models in FRAPCON-3.4 (i.e., ANS-5.4 and FRAPFGR) provide reasonable predictions of FGR for fuel rods with steady-state power histories, but on average underpredicted FGR for fuel rods with power bumping for a few hours duration.

The following discussions are divided into comparisons of the code predictions to steady-state FGR data and to power bumping (transient) FGR data

4.1.1 UO_2 Steady-State FGR Predictions

Figure 4.1 shows the predicted FGR as a function of measured FGR for the steady-state UO_2 rods. Figure 4.2 shows the predicted minus measured FGR as a function of burnup for the steady-state UO_2 rods. The steady-state UO_2 cases with measured and predicted FGRs are shown in Table 4.1.

The standard deviation for the steady-state predictions is 2.6 percent absolute FGR up to 70 GWd/MTU. These figures demonstrate that FRAPCON-3.4 provides a best-estimate calculation of fission gas over a wide range of gas release levels up to a rod-average burnup of 62 GWd/MTU. There are a few cases at higher burnup, but these cases indicated that FRAPCON-3.4 may begin to underpredict FGR at burnup levels beyond 62 GWd/MTU (Figure 4.2).

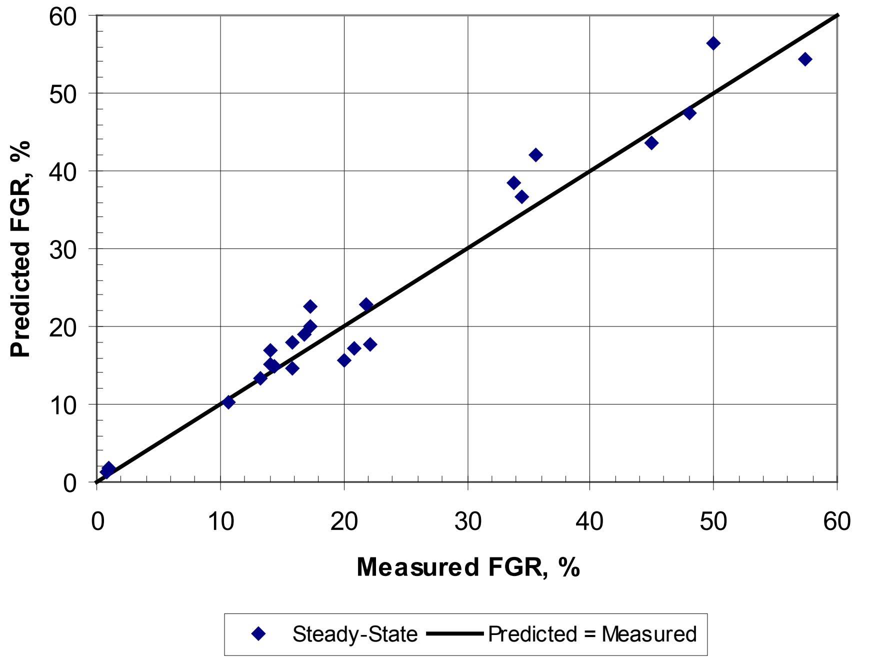


Figure 4.1 Comparison of FRAPCON-3.4 predictions to measured FGR data for the UO_2 steady-state assessment cases

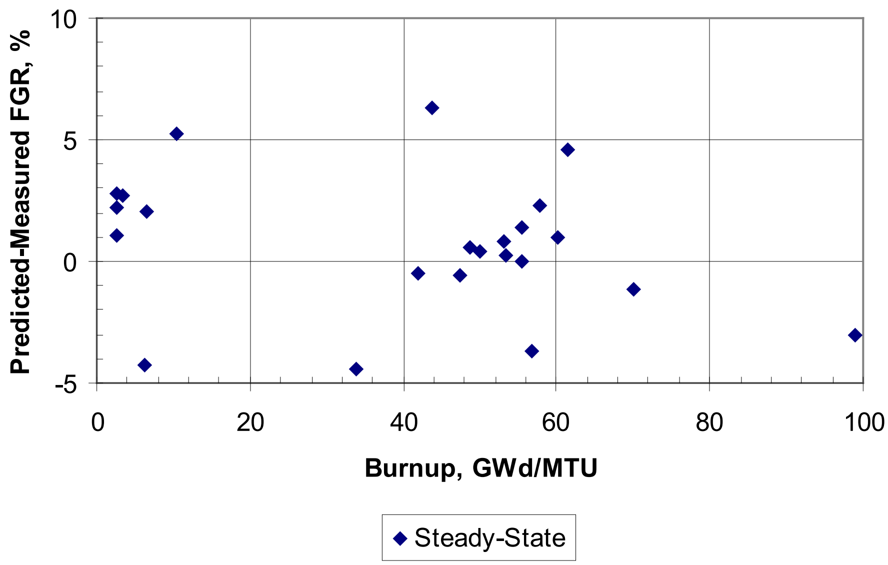


Figure 4.2 Predicted minus measured FGR versus rod-average burnup for the UO_2 steady-state assessment cases

Table 4.1 Steady-state UO_2 FGR assessment cases

Rod	Rod-Average Burnup GWd/MTU	Measured FGR %	FRAPCON-3.4 Predicted FGR, %
24i6	60.1	21.8	22.81
36i8	61.5	33.8	38.38
111i5	48.6	14.4	14.98
28i6	53.3	13.2	13.46
HBEP BNFL-DE	42	10.7	10.21
LFF	3.29	17.3	20.02
CBP	2.61	14.1	15.13
4110-ae2	6.2	22.1	17.81
4110-be2	6.6	15.9	17.94
332	56.8	20.9	17.22
EPL-4	10.4	17.3	22.58
CBR	2.7	14.1	16.92
CBY	2.65	16.8	19.05
HBEP BNFL5-DH	33.9	20	15.58
FUMEX 6f	55.45	45±5	43.47
FUMEX 6s	55.45	50±5	56.36
IFA 597.3	70	15.8	14.68
IFA429DH	98.9	57.4	54.37
ANO TSQ002	53.2	1	1.78
Oconee 15309	50	0.8	1.25
30i8	57.85	34.5	36.76
m2-2c	43.75	35.6	41.93
pa29-4	47.39	48.1	47.51

4.1.2 MOX Steady-State FGR Predictions

Figure 4.3 shows the predicted FGR as a function of measured FGR for the steady-state MOX rods. Figure 4.4 shows the predicted minus measured FGR as a function of burnup for the steady-state MOX rods. The steady-state MOX cases with measured and predicted FGRs are shown in Table 4.2. The standard deviation for the steady-state predictions is 6.7 percent FGR. It is noted that some of these MOX rods are from the Advanced Test Reactor (ATR) at Idaho National Laboratory and are subject to large radial flux profiles. Because of this, it is difficult to estimate the rod-average power. If the ATR rods are removed from the calculation of standard deviation, a standard deviation of 4.5 percent absolute FGR is calculated. These figures demonstrate that FRAPCON-3.4 provides a best-estimate calculation of fission gas over a wide range of gas release levels up to a rod-average burnup of 62 GWd/MTU. There are a few cases at higher burnup, but these cases indicated that FRAPCON-3.4 may begin to underpredict FGR at burnup levels beyond 62 GWd/MTU (Figure 4.4).

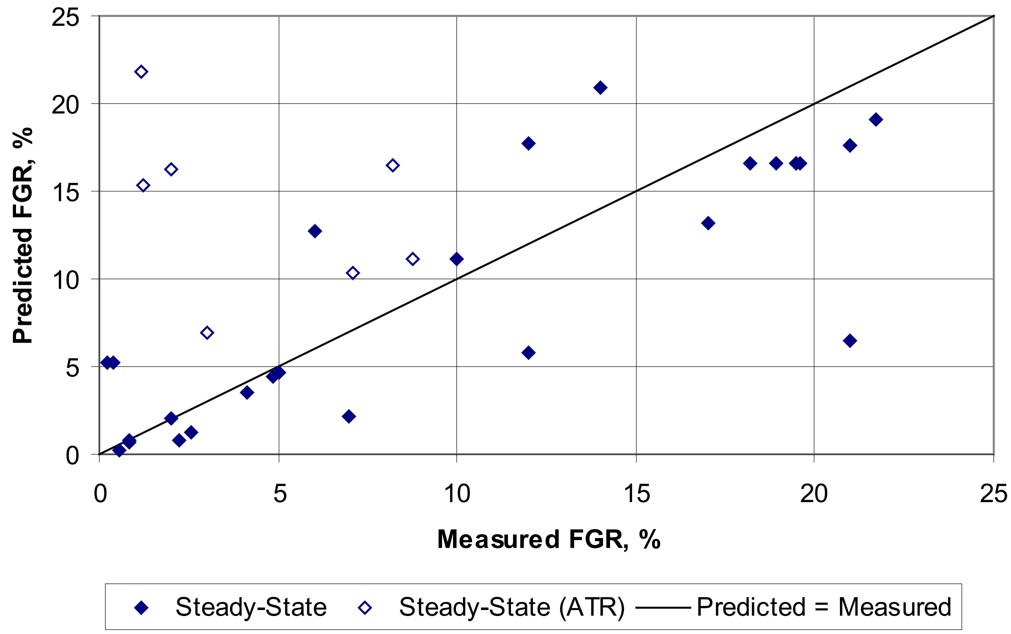


Figure 4.3 Comparison of FRAPCON-3.4 predictions to measured FGR data for the MOX steady-state assessment cases

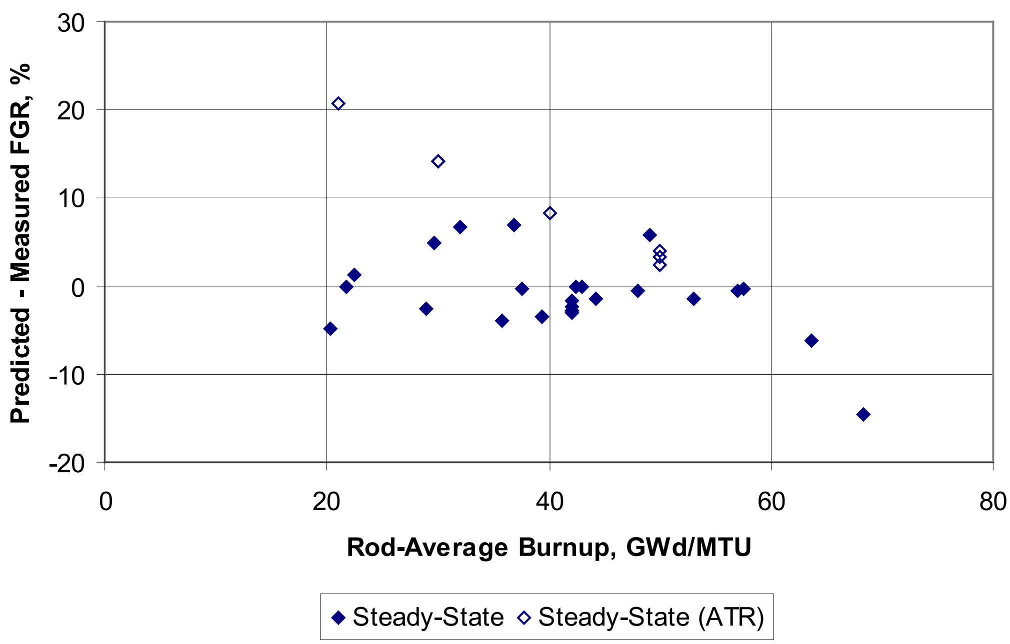


Figure 4.4 Predicted minus measured FGR versus rod-average burnup for the MOX steady-state assessment cases

Table 4.2 Steady-state MOX FGR assessment cases

Rod	Rod-Average Burnup GWd/MTU	Measured FGR %	FRAPCON-3.4 Predicted FGR, %
IFA-651.1r1	22.41	10*	11.19
IFA-651.1r3	21.73	2*	2.02
IFA-651.1r6	20.27	7*	2.21
ATR PII C2 P5	21	1.146	21.83
ATR PIII C3 P6	30	1.253	15.33
ATR PIII C10 P13	30	2.019	16.22
ATR PIV C4 P7	40	8.214	16.5
ATR PIV C5 P8	50	3.009	6.98
ATR PIV C6 P9	50	7.066	10.29
ATR PIV C12 P15	50	8.761	11.1
Gravelines N06	48	4.12	3.53
Gravelines N12	57	4.86	4.39
Gravelines P16	53	2.58	1.21
IFA-629.1	29	21.7	19.05
IFA-606 Phase 2	49	12	17.75
IFA 633.1r6	32	6	12.78
M504 H8	37.5	0.54	0.26
M504 I2	43	0.85	0.75
M504 K9	42.5	0.85	0.65
M504 M9	44.2	2.26	0.82
IFA-597.4/.5/.6/.7r10	35.7	17	13.15
IFA-597.4/.5/.6/.7r11	36.8	14	20.96
IFA-629-3r5	68.3	21	6.46
IFA-629-3r6	63.6	12	5.83
E09 Rods Inner	29.6	0.2	5.19
E09 Rods Inner	29.6	0.4	5.19
E09 Rods Intermediate	39.3	21	17.56
E09 Rods Intermediate	39.3	21	17.56
E09 Rods Outer	42	19.5	16.61
E09 Rods Outer	42	18.2	16.61
E09 Rods Outer	42	19.5	16.61
E09 Rods Outer	42	18.9	16.61
E09 Rods Outer	42	19.6	16.61
M308 Segment 2	57.5	5	4.61

*End-of-life FGR estimated from rod pressure data (larger error than data from puncture).

4.2 Assessment of Power-Ramped FGR Predictions

4.2.1 UO_2 Power-Ramped FGR Predictions

Figure 4.5 shows the predicted FGR as a function of measured FGR for the power-ramped UO_2 rods. Figure 4.6 shows the predicted minus measured FGR as a function of burnup for the power-ramped UO_2 rods. The power-ramped UO_2 cases with measured and predicted FGRs are shown in Table 4.3. These comparisons show that the code provides a good prediction of the transient FGR data except for the two High Burnup Effects Program (HBEP) rods, D200 and D226, which are underpredicted by 21 percent and 12 percent release, respectively. The fuel in both of these rods is considered atypical of today's fuel used in commercial rods because it is prone to significant fuel densification (> 2.5 percent theoretical density (TD)), unlike the less densification prone (stable) fuel (< 1.5 percent TD) of current fuel designs. In addition, there is evidence that fuel with significant densification releases more fission gas than current stable fuel. The standard deviation for the power-ramped predictions without D200 and D226 is 5.1 percent absolute FGR. These figures demonstrate that FRAPCON-3.4 provides a best-estimate calculation of fission gas over a wide range of gas release levels up to a rod-average burnup of 62 GWd/MTU.

Normal operational transients typically last between 4 and 12 hours, while AOO power transients last less than 30 minutes. Because both of these types of transients can lead to FGR, the NRC requires that both be included in the rod internal pressure analyses to demonstrate that they meet the no cladding liftoff criterion. In general, the short hold time AOO transient results in the lower FGR. However, the burst release typically seen in transients on the order of less than 30 minutes appears to be increasing with increasing burnups, particularly above 62 GWd/MTU, such that the code may be underpredicting release for short time period transients at high burnup. Therefore, future code verification will examine FGR data with power ramps of short duration.

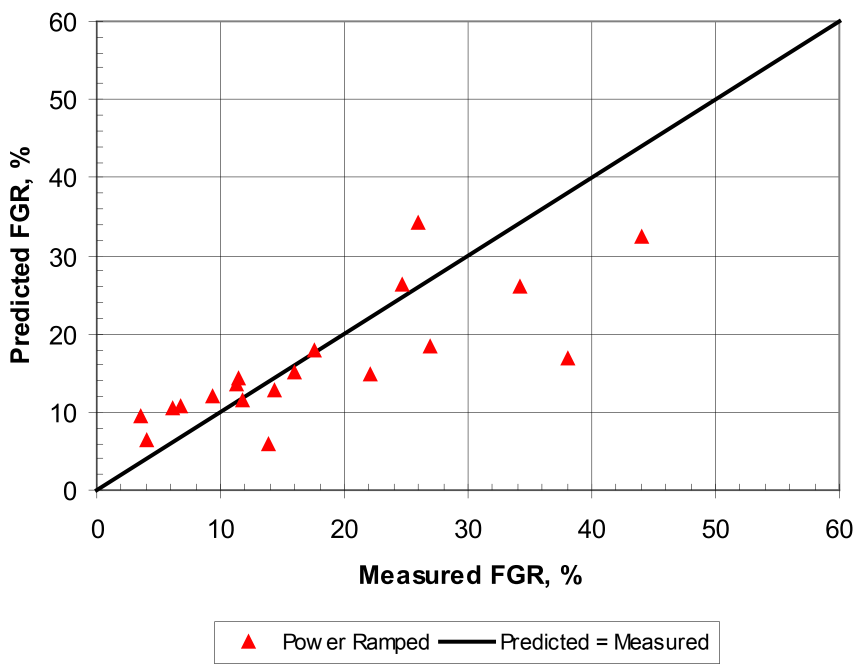


Figure 4.5 Comparison of FRAPCON-3.4 predictions to measured FGR data for the UO_2 power-ramped assessment cases

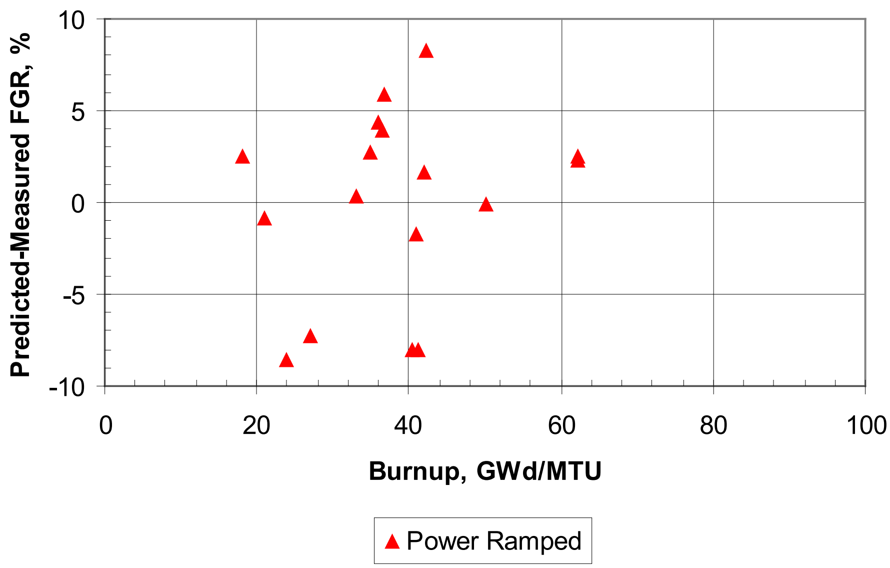


Figure 4.6 Predicted minus measured FGR versus rod-average burnup for the UO_2 power-ramped assessment cases

Table 4.3 Power-ramped UO_2 FGR assessment cases

Rod	Rod-Average Burnup GWd/MTU	Measured FGR %	FRAPCON-3.4 Predicted FGR, %
HBEP D200	25	38	16.87
HBEP D226	44	44.1	32.47
pk6-2	36.8	3.5	9.35
pk6-3	36.5	6.7	10.65
pk6-S	35.9	6.1	10.41
Inter Ramp Rod 16	21	16	15.14
Inter Ramp Rod 18	18	4	6.48
Risø f14-6.in	27	22.1	14.85
Risø f7-3.in	35	11.5	14.23
Risø f9-3.in	33	17.5	17.87
Risø ge2	41.9	24.6	26.2
Risø ge4	23.96	27	18.38
Risø ge6	42.29	26	34.21
Risø ge7	41	14.4	12.69
B&W Studsvik R1	62.3	9.4	11.89
B&W Studsvik R3	62.1	11.3	13.58
Risø AN1	41.3	34.16	26.16
Risø AN8	40.3	13.85	5.77
regate	50.2	11.7	11.59

4.2.2 MOX Power-Ramped FGR Predictions

Figure 4.7 shows the predicted FGR as a function of measured FGR for the power-ramped MOX rods. Figure 4.8 shows the predicted minus measured FGR as a function of burnup for the power-ramped MOX rods. The power-ramped MOX cases with measured and predicted FGRs are shown in Table 4.4. The standard deviation for the steady-state predictions is 13.4 percent absolute FGR and the average deviation (bias) is 11.8 percent absolute FGR. These figures demonstrate that FRAPCON-3.4 tends to overpredict the gas release measurement for power-ramped rods. However, it is noted that a limited number of power-ramped rods from only one experimental program are represented here. In addition, it is conservative to overpredict FGR during a power ramp.

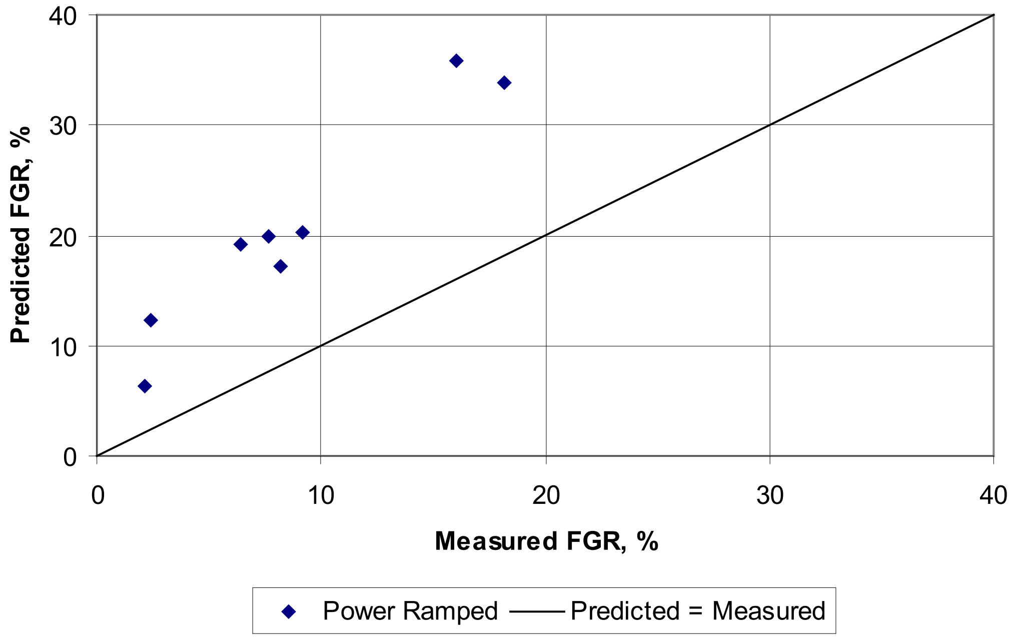


Figure 4.7 Comparison of FRAPCON-3.4 predictions to measured FGR data for the MOX power-ramped assessment cases

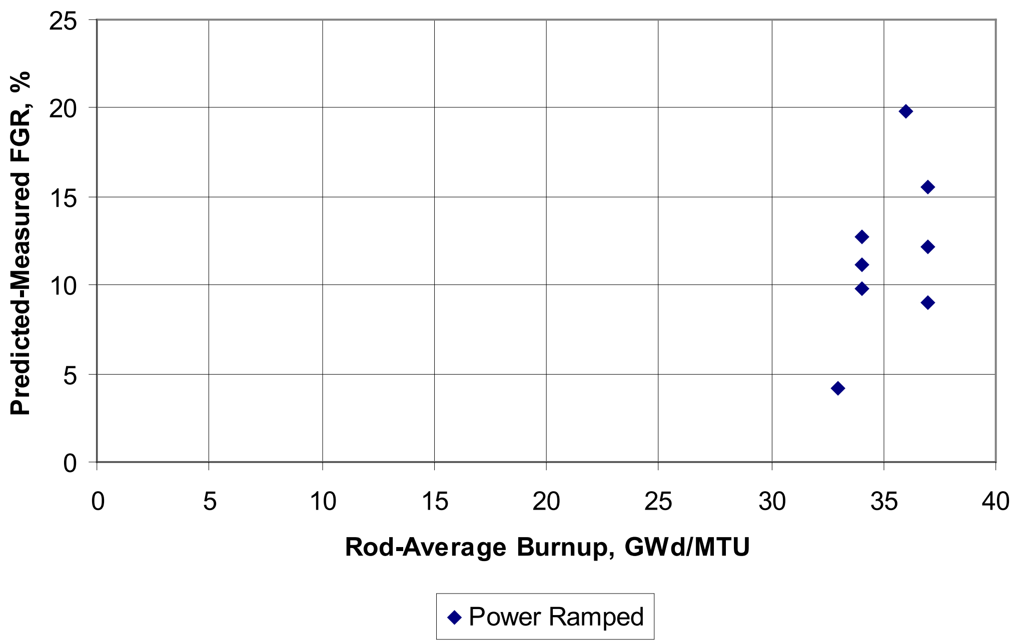


Figure 4.8 Predicted minus measured FGR versus rod-average burnup for the MOX power-ramped assessment cases

Table 4.4 Power-ramped MOX FGR assessment cases

Rod	Rod-Average Burnup GWd/MTU	Measured FGR %	FRAPCON-3.4 Predicted FGR, %
M501 HR-1	37	7.67	19.85
M501 HR-2	37	8.24	17.25
M501 HR-3	37	18.21	33.8
M501 HR-4	36	16.04	35.82
M501 MR-1	34	2.43	12.24
M501 MR-2	34	9.2	20.31
M501 MR-3	34	6.39	19.13
M501 MR-4	33	2.17	6.37

5.0 Internal Rod Void Volume Assessment

5.1 Fuel Rod Void Volume

An accurate prediction of the internal void volume of a fuel rod is important in the calculation of the internal rod pressures along with the FGR prediction. The change in the fuel rod void volume with burnup is primarily due to the combined effects of cladding creep, fuel swelling, and axial cladding growth. Five well-characterized fuel rods were selected to assess the capability of FRAPCON-3 to accurately calculate fuel rod void volumes for high burnup. The cases selected include two full-length rods (rod TSQ002 from ANO-2 and rod 15309 from Oconee) and three short (44 inches long) rods (36-I-8, 111-I-5, and 24-I-6) that were irradiated in the BR-3 reactor. The set includes only PWR fuel rods with standard Zircaloy-4. The burnup levels achieved on these rods range from 48.6 to 61.5 GWd/MTU.

Table 5.1 presents the measured and FRAPCON-3 calculated void volume at both BOL and EOL for the five fuel rods. The calculations were made at 25°C (77°F) and atmospheric pressure, which should be reasonably close to the temperature at which the data were collected. A range of values for void volume is provided for Oconee rod 15309 because this is the range of void volumes measured from 16 sibling fuel rods from the same assembly—including the representative rod 15309. All sixteen rods have very similar EOL burnups and similar power histories. Therefore, the void volume range includes representative uncertainty in the fabricated void volumes, measured rod power histories, and burnup.

The FRAPCON-3.4 code does a good job of calculating the integral fuel rod void volumes, particularly for the commercial reactor rods where as-fabricated void volumes were provided. The three BR-3 test rods are overpredicted by 15 percent on average, but this may be due to an overestimation in the as-fabricated void volumes.

Table 5.1 Measured and calculated void volume for five high-burnup fuel rods

Reactor	Rod	Burnup, GWd/MTU	BOL Void Volume, $in.^3$		EOL Void Volume, $in.^3$	
			Measured	Calculated	Measured	Calculated
BR-3	36-I-8	61.5	NA	0.645	0.508	0.606
BR-3	111-I-5	48.6	NA	0.648	0.516	0.567
BR-3	24-I-6	60.1	NA	0.646	0.491	0.570
ANO-2	TSQ002	53.0	1.55	1.55	1.086	1.152
Oconee	15309	49.5 to 49.9	2.14	2.14	1.60 to 1.72	1.54

6.0 Cladding Corrosion Assessment

Seven well-characterized fuel rods were selected to demonstrate the capability of FRAPCON-3 to accurately calculate fuel rod waterside oxidation and hydrogen concentration for high burnup. The cases selected include seven full-length rods (rod TSQ002 from ANO-2; rod 15309 from Oconee; rod A1 from Monticello bundle MTB99; rod H8/36-6 from TVO-1; and rods A06, A12, and N05 from Vandellos II). The set includes both PWR and BWR fuel rods that are standard Zircaloy-4, ZIRLO, or M5 in PWRs and Zircaloy-2 in BWRs. (These are the cladding alloys currently modeled in FRAPCON-3.4.) The rod-average burnup levels achieved on these rods range from 45 to 53 GWd/MTU.

Table 6.1 shows the measured and FRAPCON-3.4 calculated peak oxide layer thickness for the two selected high-burnup BWR rods. The measured and predicted corrosion layer thicknesses as a function of axial position along the rod are shown for the two PWR rods in Figures 6.1 and 6.2. The comparisons indicate that FRAPCON-3.4 can satisfactorily predict peak and axial variation in cladding waterside oxidation.

FRAPCON-3 calculated peak oxide layer thickness and peak hydrogen concentrations are bracketed by the choice of crud layer thickness for the PWR rods and are in good agreement for the two BWR rods. The purpose of these code-data comparisons is to demonstrate similar predictions as with standalone versions of the corrosion/hydriding models. The BWR peak corrosion values are fairly well matched by the FRAPCON-3 predictions, and these predictions are not as sensitive to the crud layer input because of the relatively lower heat fluxes and lower operating temperatures.

The conclusion is that the modeling of waterside oxidation is sufficient in FRAPCON-3.4 for best-estimate analyses. Using integral effect and separate effect data the following standard deviations for each alloy has been calculated or estimated

- Zircaloy-2: σ=7.6 μm
- Zircaloy-4: σ=15.3 μm
- ZIRLO: σ=15 μm
- M5: σ=5 μm

6.1 BWR Cladding Corrosion

The only alloy currently used in the United States for BWR conditions is Zircaloy-2. The following assessment shows the FRAPCON-3.4 predictions of cladding corrosion for two commercial rods with Zircaloy-2.

6.1.1 Zircaloy-2 Corrosion

Table 6.1 shows the measured and FRAPCON-3.4 calculated peak oxide layer thickness for the two selected high-burnup BWR rods.

Table 6.1 Measured and calculated oxidation for two high-burnup BWR fuel rods

Reactor	Rod	Burnup, GWd/MTU	Peak Oxide Layer Thickness, µm	
			Measured	Calculated
Monticello	MTB99 rod A1	45.0	25	29
TVO-1	H8/36-6	51.4	28	22

These comparisons indicate satisfactory capability of FRAPCON-3.4 to predict peak cladding waterside oxidation under BWR conditions.

6.2 PWR Cladding Corrosion

The alloys currently used in the United States for PWR conditions are Zircaloy-4, ZIRLO, and M5. The following assessment shows the FRAPCON-3.4 predictions of cladding corrosion for two commercial rods with Zircaloy-4, two commercial rods with ZIRLO, and one commercial rod with M5.

6.2.1 Zircaloy-4 Corrosion

Figures 6.1 and 6.2 show the measured and predicted corrosion layer thicknesses as a function of axial position along the rod for the two PWR rods with Zircaloy-4 cladding.

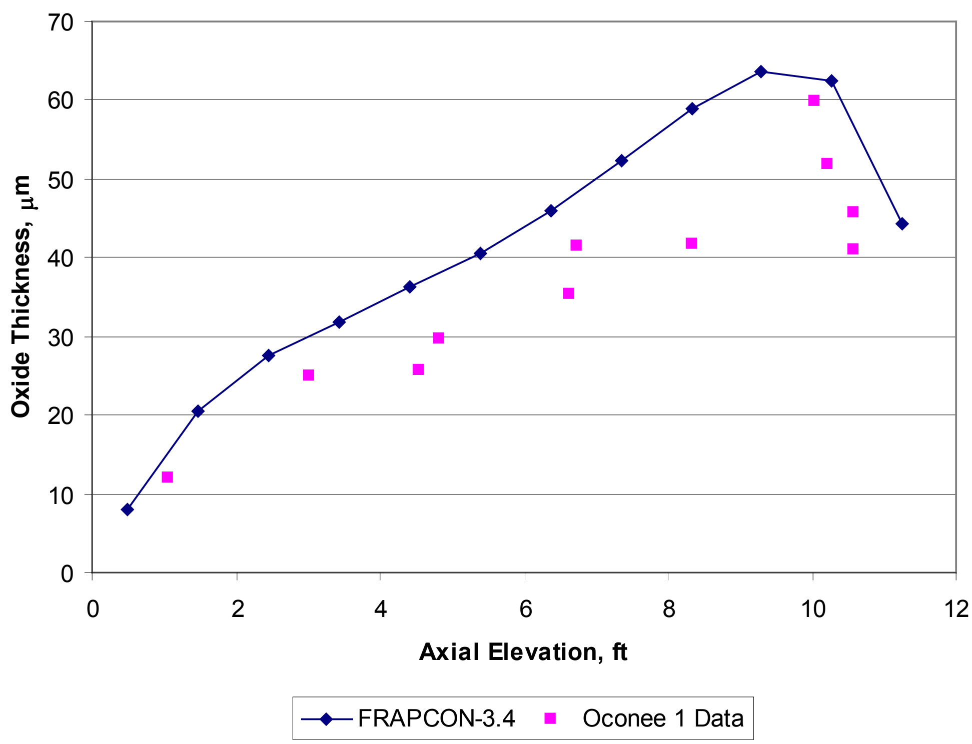


Figure 6.1 Measured and predicted corrosion layer thickness as a function of axial position for Oconee 5-cycle PWR Zircaloy-4 rod 15309, 49.5 GWd/MTU (rod average)

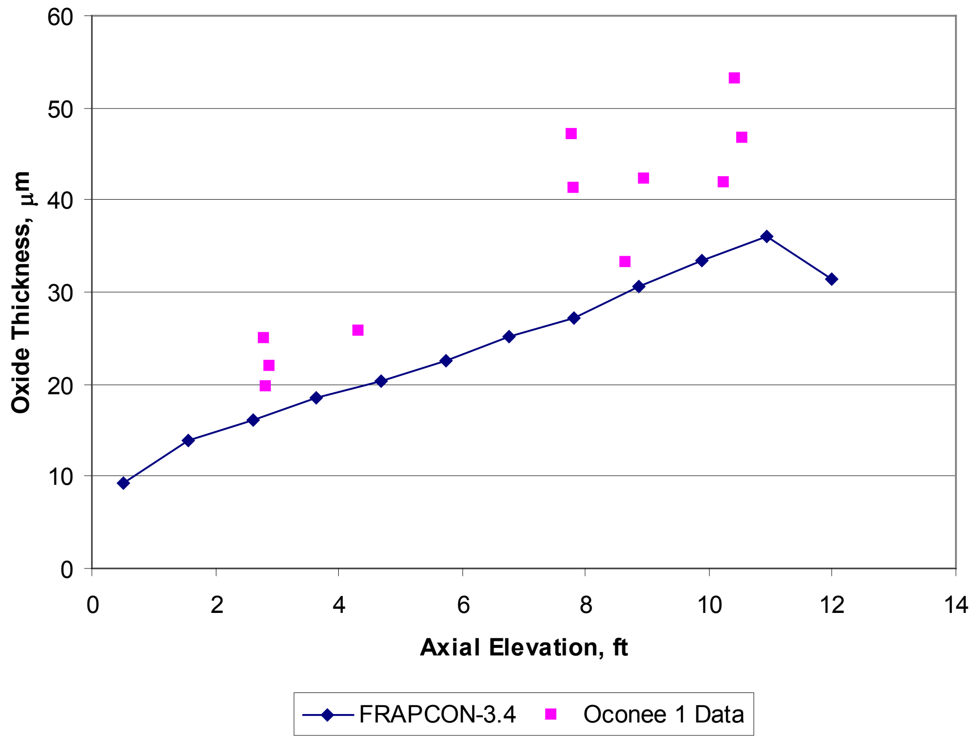


Figure 6.2 Measured and predicted corrosion layer thickness as a function of axial position for ANO-2 5-cycle PWR Zircaloy-4 rod TSQ002, 53 GWd/MTU (rod average)

These comparisons indicate satisfactory capability of FRAPCON-3.4 to predict peak cladding waterside oxidation of Zircaloy-4 under PWR conditions.

6.2.2 ZIRLO Corrosion

Figures 6.3 and 6.4 show the measured and predicted corrosion layer thicknesses as a function of axial position along the rod for the two PWR rods with ZIRLO cladding.

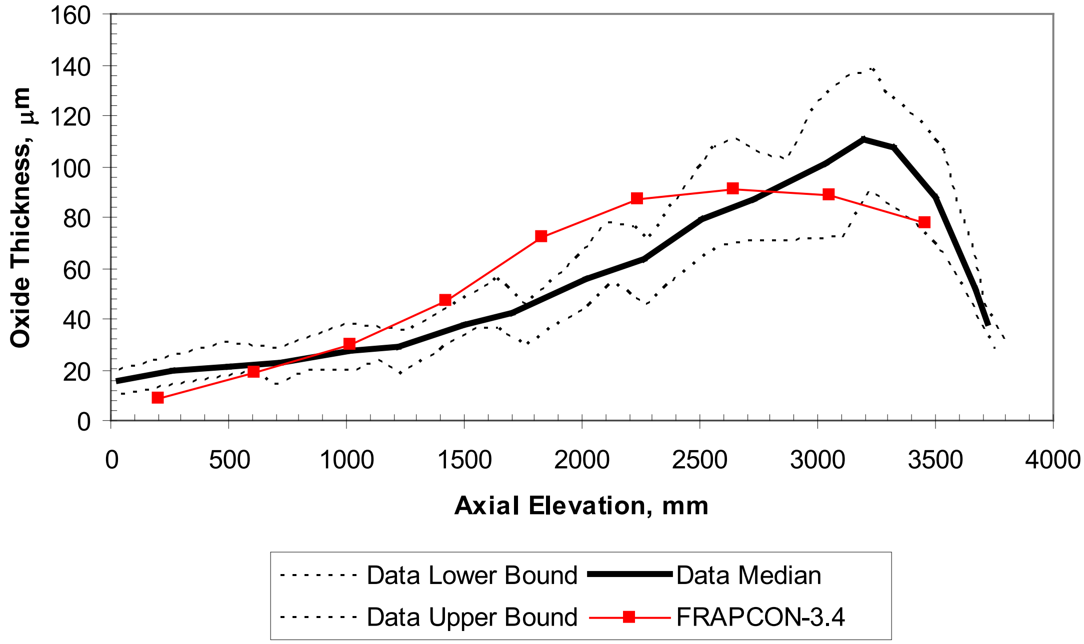


Figure 6.3 Measured and predicted corrosion layer thickness as a function of axial position for Gravelines 5-cycle PWR ZIRLO rod A06, 65.9 GWd/MTU (rod average)

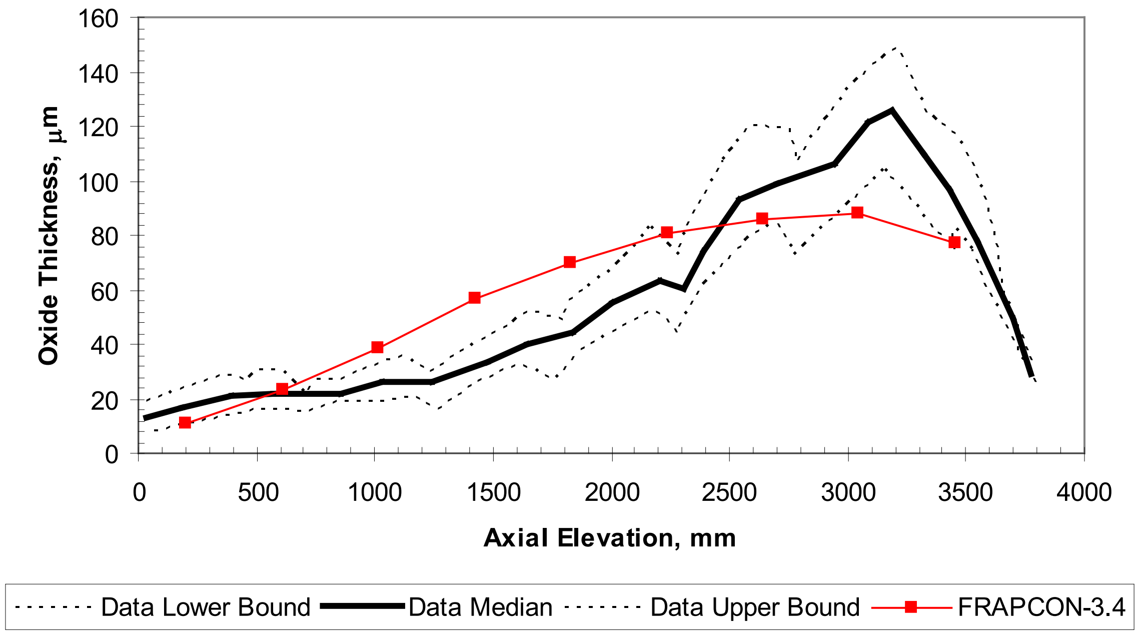


Figure 6.2 Measured and predicted corrosion layer thickness as a function of axial position for Gravelines 5-cycle PWR ZIRLO rod A12, 66.4 GWd/MTU (rod average)

These comparisons indicate satisfactory capability of FRAPCON-3.4 to predict peak cladding waterside oxidation of ZIRLO under PWR conditions.

6.2.3 M5 Corrosion

Figure 6.5 shows the measured and predicted corrosion layer thicknesses as a function of axial position along the rod for the PWR rod with M5 cladding.

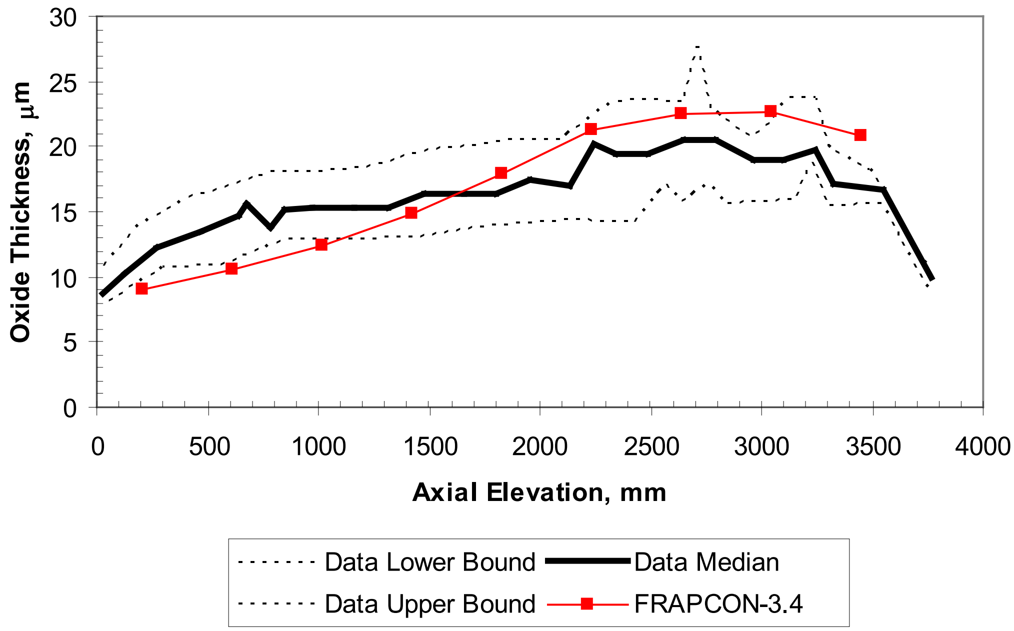


Figure 6.5 Measured and predicted corrosion layer thickness as a function of axial position for Gravelines 5-cycle PWR M5 rod N05, 68.1 GWd/MTU (rod average)

This comparison indicates satisfactory capability of FRAPCON-3.4 to predict peak cladding waterside oxidation of M5 under PWR conditions.

7.0 Cladding Hoop Strain during Power Ramps

7.1 Assessment Cases

The ability of FRAPCON-3.4 to predict permanent hoop strain during power ramps was originally assessed against a database consisting of 17 power-ramped rods at burnup levels between 18 and 45 GWd/MTU to ramp terminal levels between 30 and 44 kW/m. All of these rods were held at the ramp terminal level for a significant period of time (> 4 hours). The measured and predicted rod-average permanent hoop strains are shown in Figure 7.1. This figure shows that in general FRAPCON-3.4 overpredicts the measured hoop strain. It was found that FRAPCON-3.4 overpredicts cladding permanent strain by 0.1 percent (on average) with significant variation between predicted and measured.

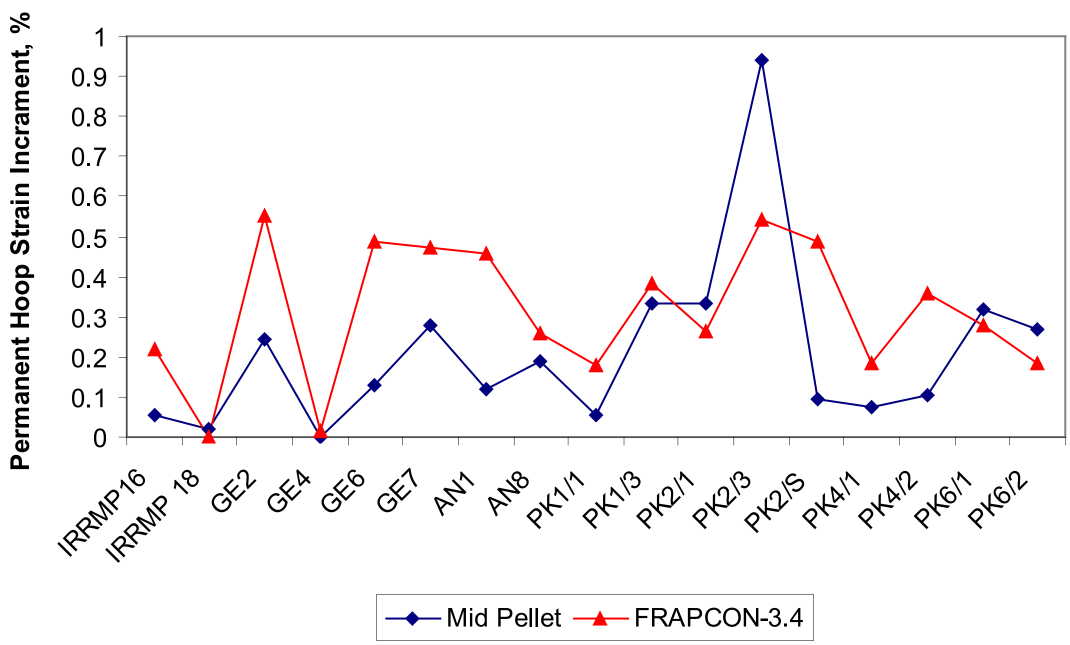


Figure 7.1 Measured and predicted rod-average permanent hoop strain for original assessment database

This overprediction is consistent with the fact that FRAPCON-3.4 uses a rigid pellet assumption. This means that the pellet is assumed to be significantly stronger than the cladding such that it will not deform, other than the code-assumed accommodation of 50 percent of the relocation, when it comes in contact with the cladding.

FRAPCON-3.4 was compared to a more recent database of power-ramped rods that were ramped under the Studsvik Cladding Integrity Project (SCIP). This database consists of 10 power-ramped rods at burnup levels between 40 and 76 GWd/MTU to ramp terminal levels between 38 and 52 kW/m. Some of these rods were held at the ramp terminal level for a significant period of time (> 30 minutes), while other rods were held for a very short period of time (1 to 30 seconds). The measured and predicted peak node permanent hoop strains are shown in Figure 7.2. For these rods, FRAPCON-3.4 underpredicts cladding permanent strain by 0.3 percent on average.

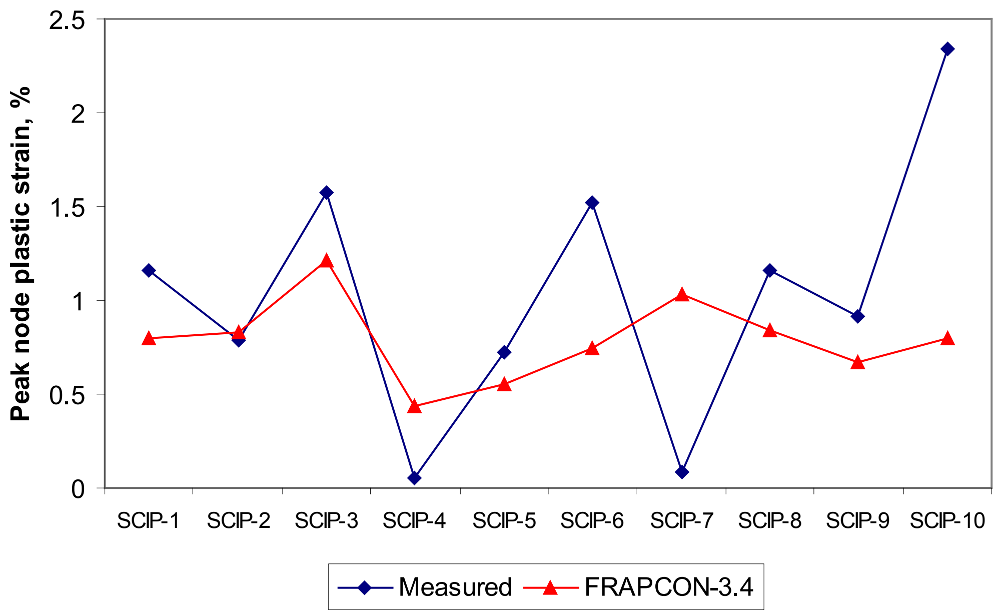


Figure 7.2 Measured and predicted peak node permanent hoop strain for SCIP ramp tests. Tests are not explicitly labled to protect the sensitivity of this information.

To determine if the overpredictions noted in the SCIP ramp tests are due to ramp terminal level, hold time, or burnup, the predicted minus measured permanent hoop strain for all the assessment cases were plotted as a function of ramp terminal level and burnup, with the short hold time SCIP ramps and the long hold time SCIP ramps separated.

Normal operational transients typically last 4 to 12 hours, while AOO power transients last less than 30 minutes but have a higher terminal power level than normal transients. Because both of these types of transients need to demonstrate that they meet the NRC 1percent strain (elastic + plastic) criterion, the code needs to be evaluated for both short and long hold time transients. In general, the short hold time AOO transient is the most limiting due to its higher terminal powers, although pellet/cladding-interaction (PCI) failures have been significant in recent years for BWR fuel designs. It should be noted that PCI failures are due to stress corrosion cracking (SCC) and are known to exist below the NRC 1 percent strain criterion. It is further noted that FRAPCON-3.4 currently does not have a failure criterion for these very low stress/strain PCI failures.

7.2 Comparisons vs. Ramp Terminal Level

Figure 7.3 shows the predicted minus measured permanent hoop strain for all the assessment cases as a function of ramp terminal power level. There does not appear to be any bias in the predictions with increase ramp terminal power level. However, it does appear that the SCIP ramps with long hold times are underpredicted more than the SCIP ramps with short hold times.

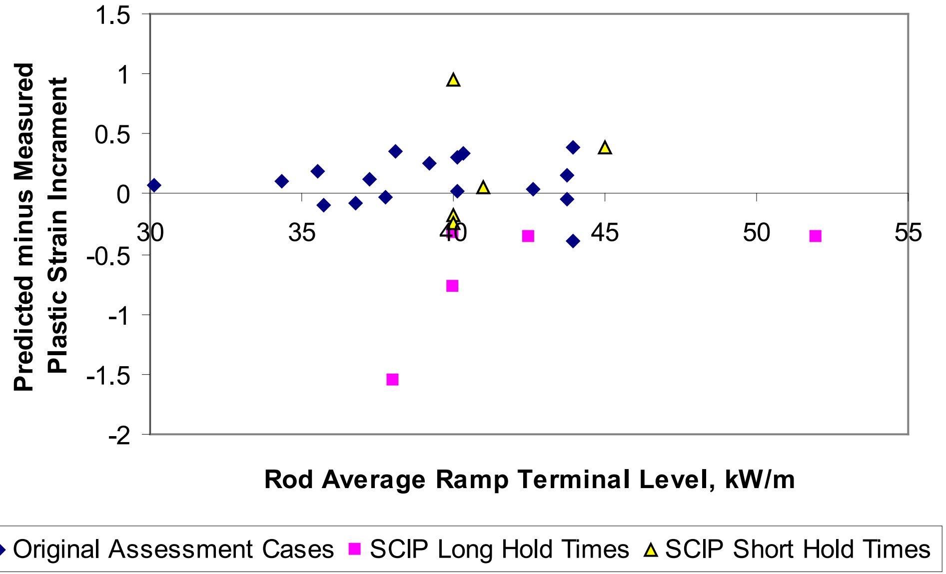


Figure 7.3 Predicted minus measured permanent hoop strain as a function of ramp terminal power level

7.3 Comparisons vs. Burnup

Figure 7.4 shows the predicted minus measured permanent hoop strain for all the assessment cases as a function of burnup. For burnup levels greater than 45 to 55 GWd/MTU, it appears that FRAPCON-3.4 begins to underpredict permanent hoop strain with increasing burnup. In addition, it appears that this underprediction is more severe for the long hold time cases.

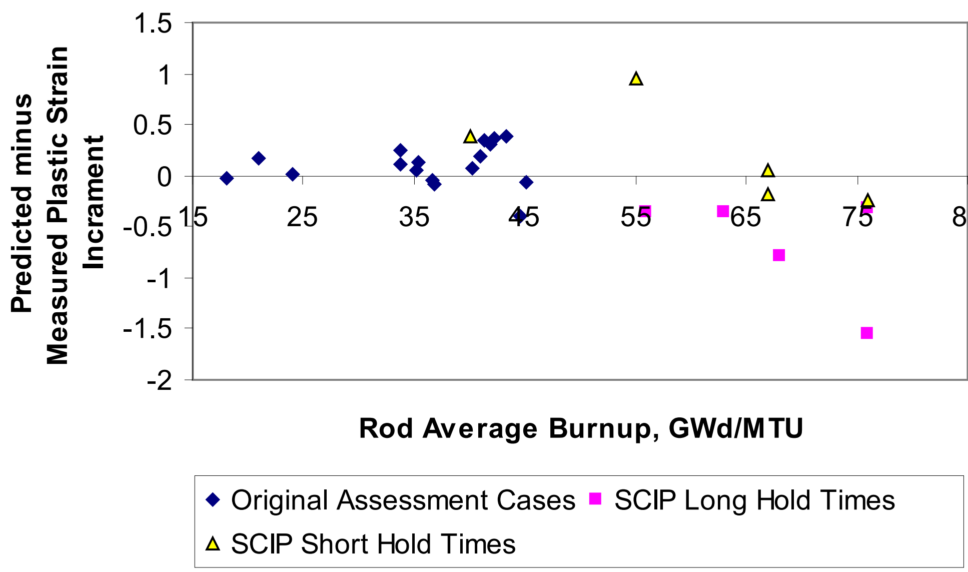


Figure 7.4 Predicted minus measured permanent hoop strain as a function of burnup

The FRAPCON-3.4 predictions for the short hold time data appear to be predicted well up to 62 GWd/MTU. The adequacy of the FRAPCON-3.4 predictions for long hold times between 45 to 52 GWd/MTU is less certain due to lack of data. There is a definite trend of underprediction with burnup above 60 GWd/MTU for power ramps with long hold times. The code should be modified to address this apparent underprediction at high burnup.

8.0 Conclusions

The FRAPCON-3.4 steady-state fuel performance code has been assessed against a set of pre-selected data from 133 well-characterized fuel rods. The data used for the assessment consisted of measurements of thermal (fuel temperature), FGR, rod internal void volume, and cladding corrosion. The fuel rods represent a range of design parameters, including different fuel rod diameters, lengths, gap sizes, and fill-gas compositions and a wide range of operating conditions with peak LHGRs varying from 8 to 18 kW/ft, rod-average burnups from 0 to 99 GWd/MTU, and FGRs ranging from less than 1 percent to greater than 50 percent. The estimates of code thermal and FGR predictive error are based on code comparisons to both the benchmark and independent data sets.

Thermal: Comparisons were made for BOL UO_2 temperature measurements and UO_2, MOX, and UO_2-Gd_2O_3 temperature measurements as a function of burnup. For the UO_2 BOL temperature measurements, the FRAPCON-3.4 predictions were within a standard error of 7.0 percent of measured values and a biased underprediction of 5.5 percent. The bias and standard error become small (-2.8 percent and 4.8 percent, respectively) if the IFA-513 rod 6 with helium/xenon gas and all the IFA-677 rods are eliminated. For the UO_2 temperature measurements as a function of burnup, the FRAPCON-3.4 predictions were within a standard error of 4.7 percent of the measured values. Only IFA-677 rod 2 was underpredicted by up to 150K at BOL, similar to what was seen in the BOL assessments for the IFA-677 rods. Typically, a standard error of 3 to 4 percent is the uncertainty in temperature due to power level uncertainty. For the MOX temperature measurements as a function of burnup, the FRAPCON-3.4 predictions were within a standard error of 4.7 percent of the measured values and much closer in most cases. Only IFA-633.1 was overpredicted by up to 150K at EOL. This overprediction may be due to the code overpredicting the FGR leading to higher fuel temperatures.

For the UO_2-Gd_2O_3 temperature measurements as a function of burnup, the FRAPCON-3.4 predictions were within a standard error of 4.9 percent of the measured values and much closer in most cases.

Overall, FRAPCON-3.4 gives reasonable predictions (standard error of 5 percent) of fuel centerline temperature for fuel rods with UO_2, MOX, and UO_2-Gd_2O_3 fuel.

Fission Gas Release: Comparisons were made for the UO_2 and MOX FGR measurements for rods with widely varying power levels and burnups. No assessment cases were available to assess the FGR predictions for UO_2-Gd_2O_3 fuel, but it was concluded that the FGR from these rods should be conservatively bounded with the UO_2 FGR model. The UO_2 FGR model was assessed for steady-state conditions and power-ramped rods. For the UO_2 cases, a standard deviation of 2.6 percent FGR (absolute) was calculated for the steady-state rods and a standard deviation of 5.1 percent FGR (absolute) was calculated for the power-ramped rods when two rods with non-prototypical pellets were removed. These standard deviations are considered reasonable. Although there is little data above 62 GWd/MTU, it appears that FRAPCON-3.4 may underpredict UO_2 fuel above this burnup level.

For the MOX cases, a standard deviation of 4.5 percent FGR (absolute) was calculated for the steady-state rods when the ATR rods with large power uncertainty were removed, and a standard deviation of 13.4 percent FGR (absolute) was calculated for the limited number of power-ramped rods that all came from one experimental program. The steady-state standard deviation is considered reasonable. The power-ramped rods were all overpredicted, which is conservative for rod internal pressure and temperature calculations. However, a larger database of MOX power-ramped cases is needed to further assess if this overprediction is due to a code deficiency. Although there is little data above 62 GWd/MTU, it appears that FRAPCON-3.4 may underpredict MOX fuel above this burnup level.

FGR data was not available for comparison for UO_2-Gd_2O_3 fuel rods.

Overall, FRAPCON-3.4 gives reasonable predictions (within 5 percent FGR absolute) of fuel centerline temperature for fuel rods with UO_2 and MOX fuel.

Internal Void Volume: Comparisons were made to data from four commercial reactor and three test reactor fuel rods. The code predicted the two commercial rods well but overpredicted the BR-3 test rod data by approximately 15 percent (relative) on average.

Cladding Corrosion: Comparisons were made to data from two commercial BWR rods with Zircaloy-2 cladding, two commercial PWR rods with Zircaloy-4 cladding, two commercial PWR rods with ZIRLO cladding, and one commercial PWR rod with M5 cladding. The oxide corrosion predictions were very good and tend to bracket the data. Using integral effect and separate effect data, the following standard deviations for each alloy have been calculated or estimated.

- Zircaloy-2: σ=7.6 μm
- Zircaloy-4: σ=15.3 μm
- ZIRLO: σ=15 μm
- M5: σ=5 μm

Cladding Hoop Strain: The original hoop strain assessment cases that were available up to a burnup of around 45 GWd/MTU demonstrated that, on average, FRAPCON-3.4 slightly overpredicts cladding hoop strain by 0.1 percent strain, with a significant variation between the prediction and measured. This overprediction is conservative for hoop strain calculations. New high-burnup ramp test rods demonstrate that, at burnups between 45 and 55 GWd/MTU, FRAPCON-3.4 begins to underpredict hoop strain during power ramps with long hold times. This underprediction appears to become larger with increasing burnup. On average, above 45 GWd/MTU, FRAPCON-3.4 underpredicts cladding permanent hoop strain by 0.3 percent for long hold time ramps. Despite these overpredictions at lower burnup and underpredictions above 45 GWd/MTU for long hold times, FRAPCON-3.4 provides reasonable hoop strain predictions up to 62 GWd/MTU, considering the large degree of scatter in strain for these ramp data. However, to address underpredictions at higher burnups, new code capability should be developed for the code to predict hoop strain at higher burnup.

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Appendix A

Input Files for FRAPCON-3.4 Assessment Cases

Appendix A Input Files for FRAPCON-3.4 Assessment Cases

Steady-State Assessment Cases

A.1 Halden IFA-432 Rods

The IFA-432 test (Lanning, 1986) was irradiated under a research program on fuel rod steady-state performance sponsored by the U.S. Nuclear Regulatory Commission (NRC) from 1974 to 1986. The IFA-432 test assembly was a heavily instrumented, six-rod assembly irradiated in the Halden heavy boiling-water reactor (HBWR), Norway, from 1975 to 1984. The purpose was to test the long-term steady-state performance of BWR-6 type fuel rods, operated at power levels that were at the upper bound for full-length commercial fuel rods. The fuel pellets were fabricated at Pacific Northwest National Laboratory (PNNL) and shipped to Norway; final rod and assembly fabrication was completed at the Halden site. Destructive examinations of selected rods were carried out at Harwell Laboratories, UK.

The assembly included six instrumented rods and three replaceable noninstrumented spares. Each instrumented fuel rod had a centerline thermocouple in both the top and the bottom end of the fuel column and a pressure transducer to monitor rod internal pressure. The assembly instrumentation included six vanadium self-powered neutron detectors (SPNDs) and one cobalt neutron detector, together with rod elongation sensors at each rod position, coolant thermocouples at the top and bottom of the assembly, and a coolant flow meter (turbine).

The test rods were designed to simulate BWR-6 rod cladding type and radial dimensions, with variations in fuel-cladding gap sizes, fuel types, and fill gas compositions. The fuel rod length was much shorter than full-length (~144-inch) commercial reactor rods to fit well within the short length of the Halden reactor core. Fuel rod overall length was 25 inches, with an active fuel column length of 22.8 inches. The overall void volume was held to 0.5 cubic inches (by selection of a ~1-inch plenum length at the upper end); this was done to approximate the ratio between fuel volume and void volume found in full-length rods. The cladding for all rods was Zircaloy-2.

Rods 1, 2, and 3 all had typical high-density (95 percent theoretical density (TD)) stable sintered UO_2 fuel pellets and helium fill gas at 1 atm pressure; slight differences in the pellet diameters created variations in fuel-cladding gap size among the rods. Data taken from rod 1 upper and lower thermocouple, rod 2 lower thermocouple, and rod 3 upper and lower thermocouple during the first ramp to power were used in the beginning-of-life (BOL) temperature assessment. Data from the rod 1 lower thermocouple and the rod 3 lower thermocouple were used in the temperature assessment as a function of burnup. It should be noted that much of the helium fill gas was lost from some of these rods during irradiation due to leakage past the thermocouple penetration through the end caps.

The input files used for the assessments listed in Table 2.1 are shown below.

IFA-432 Rod 1 BOL Upper Thermocouple Case

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* GOESINS:
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CONTROL='LIST'
FILE66='plot432r1BOLupper.n', STATUS='UNKNOWN', FORM='FORMATTED'
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 im=8, na=4, nr=11,
 ngasr = 45,
 $end
 $frpcon
 cpl = 2.0, dco = 0.5035 thkcld = 0.037,
 den = 95.5, thkgap=0.0045, rc = 0.0345, dspg = 0.35,
 dspgw = 0.03, enrch = 10.0,fgpav = 14.7, hplt = 0.5, icm = 2,
 icor = 0, idxgas = 1, iplant = -4, iq = 0,fa = 1.,
 totl = 1.9, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,pitch = 0.56, nplot=1,
 flux = 5*5.0e15, p2(1) = 500., tw(1) = 464., go(1) = 0.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,5,5,
 jst(1) = 1,1,1,1,1,1,1,1,6,3,3,2,2,1,4,5,5,
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 6*4
 qf(1)=1.0,1.0,1.0,1.0,1.0,
 x(1)= 0.0, 0.5,1.0,1.5,1.9,
 qf(6)=1.1696,1.1696,1.0,0.8304,0.8304,
 x(6)= 0.0, 0.5,1.0,1.5,1.9,
 qf(11)=1.1905,1.1905,1.0,0.8095,0.8095,
 x(11)= 0.0, 0.5,1.0,1.5,1.9,
 qf(16)=1.105,1.105,1.00,0.895,0.895,
 x(16)= 0.0, 0.5,1.0,1.5,1.9,
 qf(21)=1.1364,1.1364,1.,0.8636,0.8636,
 x(21)= 0.0, 0.5,1.0,1.5,1.9,
 qf(26)=1.2195,1.2195,1.0,0.7805,0.7805,
 x(26)= 0.0,0.5,1.0,1.5,1.9,
 qf(31)=1.1236,1.1236,1.0,0.8764,0.8764,
 x(31)= 0.0, 0.5,1.0,1.5,1.9,
 qf(36)=1.087,1.087,1.0,0.913,0.913,
 x(36)= 0.0, 0.5,1.0,1.5,1.9,
 ProblemTime = 0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8
 7., 23., 41.,63.,
 91.,104.,129.,154.,159.,
 170.,213.,218.,228.,260.,
 300.,310.,320.,350.,370.,
 374.,400.,450.,465.,498.,
 550.,600.,605.,615.,640.,650.,
 700.,725.,759.,
 760., 761.,762.,763., 764., 765.
 qmpy = 1.21,2.44,3.65,4.88,6.09,
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  1.,3.,5.,7.,9.,
 11.87,11.74,11.00,11.78,11.52,
 11.86,11.14,11.21, 9.38,10.74,
```

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 11.54,9.75,11.26,11.40, 8.98,
 10.29,7.92,9.77,8.85,10.29,
 10.17, 8.97,9.94,10.06,9.79,
 9.91,9.77, 8.98, 8.14, 9.29,
 9.38,8.83,10.43,
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 slim = .05,
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IFA-432 Rod 1 BOL Lower Thermocouple Case

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 im=8, na=4, nr=11,
 ngasr = 45,
 $end
 $frpcon
 cpl = 2.0, dco = 0.5035 thkcld = 0.037,
 den = 95.5, thkgap=0.0045, rc = 0.0345, dspg = 0.35,
 dspgw = 0.03, enrch = 10.0,fgpav = 14.7, hplt = 0.5, icm = 2,
 icor = 0, idxgas = 1, iplant = -4, iq = 0,fa = 1.,
 totl = 1.9, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,pitch = 0.56, nplot=1,
 flux = 5*5.0e15, p2(1) = 500., tw(1) = 464., go(1) = 0.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,5,5,
 jst(1) = 1,1,1,1,1,1,1,1,6,3,3,2,2,1,4,5,5,
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 6*4
 qf(1)=1.0,1.0,1.0,1.0,1.0,
 x(1)= 0.0, 0.5,1.0,1.5,1.9,
 qf(6)=1.1696,1.1696,1.0,0.8304,0.8304,
 x(6)= 0.0, 0.5,1.0,1.5,1.9,
 qf(11)=1.1905,1.1905,1.0,0.8095,0.8095,
 x(11)= 0.0, 0.5,1.0,1.5,1.9,
 qf(16)=1.105,1.105,1.00,0.895,0.895,
 x(16)= 0.0, 0.5,1.0,1.5,1.9,
 qf(21)=1.1364,1.1364,1.,0.8636,0.8636,
 x(21)= 0.0, 0.5,1.0,1.5,1.9,
 qf(26)=1.2195,1.2195,1.0,0.7805,0.7805,
 x(26)= 0.0,0.5,1.0,1.5,1.9,
 qf(31)=1.1236,1.1236,1.0,0.8764,0.8764,
 x(31)= 0.0, 0.5,1.0,1.5,1.9,
 qf(36)=1.087,1.087,1.0,0.913,0.913,
 x(36)= 0.0, 0.5,1.0,1.5,1.9,
 ProblemTime = 0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8
 7., 23., 41.,63.,
 91.,104.,129.,154.,159.,
 170.,213.,218.,228.,260.,
```

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 300.,310.,320.,350.,370.,
 374.,400.,450.,465.,498.,
 550.,600.,605.,615.,640.,650.,
 700.,725.,759.,
 760., 761.,762.,763., 764., 765.
 qmpy = 1.23,2.45,3.67,4.89,6.12,
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 11.87,11.74,11.00,11.78,11.52,
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 11.54,9.75,11.26,11.40, 8.98,
 10.29,7.92,9.77,8.85,10.29,
 10.17, 8.97,9.94,10.06,9.79,
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IFA-432 Rod 1 Case

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 dspgw = 0.03, enrch = 10.0,fgpav = 14.7, hplt = 0.5, icm = 2,
 icor = 0, idxgas = 1, iplant = -4, iq = 0,fa = 1., cldwks=0.0
 totl = 1.9, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,pitch = 0.56, nplot=1,
 flux = 5*5.0e15, p2(1) = 500., tw(1) = 464., go(1) = 0.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,5,5,
 jst(1) = 1,1,1,1,1,1,1,6,3,3,2,2,1,4,5,5,
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 qf(6)=1.1696,1.1696,1.0,0.8304,0.8304,
 x(6)= 0.0, 0.5,1.0,1.5,1.9,
 qf(11)=1.1905,1.1905,1.0,0.8095,0.8095,
 x(11)= 0.0, 0.5,1.0,1.5,1.9,
 qf(16)=1.105,1.105,1.00,0.895,0.895,
 x(16)= 0.0, 0.5,1.0,1.5,1.9,
 qf(21)=1.1364,1.1364,1.,0.8636,0.8636,
 x(21)= 0.0, 0.5,1.0,1.5,1.9,
 qf(26)=1.2195,1.2195,1.0,0.7805,0.7805,
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 x(26)= 0.0,0.5,1.0,1.5,1.9,
 qf(31)=1.1236,1.1236,1.0,0.8764,0.8764,
 x(31)= 0.0, 0.5,1.0,1.5,1.9,
 qf(36)=1.087,1.087,1.0,0.913,0.913,
 x(36)= 0.0, 0.5,1.0,1.5,1.9,
 ProblemTime = 0.1,0.2,0.3,0.4,0.5,
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 170.,213.,218.,228.,260.,
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 374.,400.,450.,465.,498.,
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 700.,725.,759.,
 760., 761.,762.,763., 764., 765.
 qmpy = 1.,3.,5.,7.,9.,
 11.87,11.74,11.00,11.78,11.52,
 11.86,11.14,11.21, 9.38,10.74,
 11.54,9.75,11.26,11.40, 8.98,
 10.29,7.92,9.77,8.85,10.29,
 10.17, 8.97,9.94,10.06,9.79,
 9.91,9.77, 8.98, 8.14, 9.29,
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IFA-432 Rod 2 BOL Lower Thermocouple Case

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 ngasr = 45,
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 den = 95.5, thkgap=0.0075, rc = 0.0345, dspg = 0.35,
 dspgw = 0.03, enrch = 10.,fgpav = 14.7, hplt = 0.5, icm = 2,
 icor = 0, idxgas =1, iplant = -4, iq = 0,nplot=1,
 totl = 1.9, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,fa=1., pitch=0.56,
 flux = 5*5.0e15, p2(1) = 500., tw(1) = 464., go(1) = 0.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,5,5,
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         1,1,1,6,3,3,
         2,2,1,4,5,5,
         6,3,3,2,2,5,
         2,5,2,2,1,4,
         5,7,7,7,8,4,
```

```
         4,4,4,4
 qf(1)=1.0,1.0,1.0,1.0,1.0,
 x(1)= 0.0, 0.5,1.0,1.5,1.9,
 qf(6)=1.1696,1.1696,1.0,0.8304,0.8304,
 x(6)= 0.0, 0.5,1.0,1.5,1.9,
 qf(11)=1.1905,1.1905,1.0,0.8095,0.8095,
 x(11)= 0.0, 0.5,1.,1.5,1.9,
 qf(16)=1.105,1.105,1.00,0.895,0.895,
 x(16)= 0.0, 0.5,1.0,1.5,1.9,
 qf(21)=1.1364,1.1364,1.,0.8636,0.8636,
 x(21)= 0.0, 0.5,1.0,1.5,1.9,
 qf(26)=1.2195,1.2195,1.0,0.7805,0.7805,
 x(26)= 0.0,0.5,1.0,1.5,1.9,
 qf(31)=1.1236,1.1236,1.0,0.8764,0.8764,
 x(31)= 0.0, 0.5,1.0,1.5,1.9,
 qf(36)=1.087,1.087,1.0,0.913,0.913,
 x(36)= 0.0, 0.5,1.0,1.5,1.9,
 ProblemTime = 0.1,0.2,0.3,0.4,0.5,
 0.6,0.7,0.8,0.9,1.0
 7., 23., 41.,63.,
 91.,104.,129.,154.,159.,
 170.,213.,218.,228.,260.,
 300.,310.,320.,350.,370.,
 374.,400.,450.,465.,498.,
 550.,600.,605.,615.,640.,
 650.,700.,725.,759.,810.,
 864.,888.,950.,1017.,1022.,
 1027.,1075.,1094.
 qmpy = 1.52,2.29,3.05,3.82,4.58,
 5.36,6.12,6.88,7.62,8.25,
 12.54,12.54,11.00,11.78,
 11.52,11.86,11.14,11.21, 9.38,
 10.74,11.54, 9.78,10.08,10.08,
  8.98,10.29, 7.92, 9.77, 8.85,
 10.29,10.17, 8.97, 9.94,10.34,
 10.07, 9.91, 9.77, 8.98, 8.14,
  9.29, 9.38, 8.83,10.43,10.43,
  8.36, 9.24, 6.56, 6.56, 8.40,
 10.56, 9.84, 7.04
  slim   = .05,
 $end
```

IFA-432 Rod 3 BOL Upper Thermocouple Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out432r3BOLupper.n',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='plot432r3BOLupper.n', STATUS='UNKNOWN', FORM='FORMATTED'
/*******************************************************************
         ifa 432 rod 3
 $frpcn
 im=6, na=4, nr=11,
 ngasr = 45,
 $end
```

```
$frpcon
cpl = 2.0, dco = 0.5035 thkcld = 0.037,
den = 95.5, thkgap=0.0015, rc = 0.0345, dspg = 0.35,
dspgw = 0.03, enrch = 10.0,fgpav = 14.7, hplt = 0.5, icm = 2,
icor = 0, idxgas = 1, iplant = -4, iq = 0,fa = 1.,pitch = 0.56,
totl = 1.9, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
nunits = 1, rsntr = 75.,nplot=1,
flux = 5*5.0e15, p2(1) = 500., tw(1) = 464., go(1) = 0.0,
jdlpr = 0, jn(1) = 5,5,5,5,5,5,5,5,
jst(1) = 6*1,1,1,1,
1,1,1,6,3,3,
2,3,1,4,5,5,
6,3,3,2,2,5,
2,5,2,2,1,4,
4,4,7,7,8,4,
4,4,4,4,4,5,5,
6,6,6,5,6,5
qf(1)=1.0,1.0,1.0,1.0,1.0,
x(1)= 0.0, 0.5,1.0,1.5,1.9,
qf(6)=1.1696,1.1696,1.0,0.8304,0.8304,
x(6)= 0.0, 0.5,1.0,1.5,1.9,
qf(11)=1.1905,1.1905,1.0,0.8095,0.8095,
x(11)= 0.0, 0.5,1.0,1.5,1.9,
qf(16)=1.105,1.105,1.00,0.895,0.895,
x(16)= 0.0, 0.5,1.0,1.5,1.9,
qf(21)=1.1364,1.1364,1.,0.8636,0.8636,
x(21)= 0.0, 0.5,1.0,1.5,1.9,
qf(26)=1.2195,1.2195,1.0,0.7805,0.7805,
x(26)= 0.0,0.5,1.0,1.5,1.9,
qf(31)=1.1236,1.1236,1.0,0.8764,0.8764,
x(31)= 0.0, 0.5,1.0,1.5,1.9,
qf(36)=1.087,1.087,1.0,0.913,0.913,
x(36)= 0.0, 0.5,1.0,1.5,1.9,
ProblemTime = 0.1,0.2,0.3,0.4,0.5,0.6
7., 23., 41.,63.,
91.,104.,129.,154.,170.,
180.,200.,218.,235.,260.,
300.,310.,320.,350.,370.,
384.,400.,450.,470.,505.,
550.,600.,605.,620.,640.,
650.,680.,725.,770.,800.,
850.,865.,900.,960.,968.,
975.,989.,1007.
qmpy = 1.52,3.05,4.57,6.1,7.62,9.14,
12.54,12.54,11.00,11.78
11.52,11.86,11.14,11.21, 9.38,
10.74,11.54,9.78,10.08,10.40,
8.98,10.29,7.92,9.77,9.77,8.85,
10.29,10.17, 8.97,9.94,10.34,
10.07,9.91,9.77, 8.98, 8.14,
9.29,9.38,8.83,10.5,9.7,
9.1,9.24,6.56,6.56,8.40,
10.56,9.84,7.04
slim = .05,
$end
```

IFA-432 Rod 3 BOL Lower Thermocouple Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out432r3BOLlower.n',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='plot432r3BOLlower.n', STATUS='UNKNOWN', FORM='FORMATTED'
/*********************************************************************
         ifa 432 rod 3
 $frpcn
 im=10, na=4, nr=11,
 ngasr = 45,
 $end
 $frpcon
 cpl = 2.0, dco = 0.5035 thkcld = 0.037,
 den = 95.5, thkgap=0.0015, rc = 0.0345, dspg = 0.35,
 dspgw = 0.03, enrch = 10.0,fgpav = 14.7, hplt = 0.5, icm = 2,
 icor = 0, idxgas = 1, iplant = -4, iq = 0,fa = 1.,pitch = 0.56,
 totl = 1.9, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,nplot=1,
 flux = 5*5.0e15, p2(1) = 500., tw(1) = 464., go(1) = 0.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,5,5,
 jst(1) = 10*1,1,1,1,
 1,1,1,6,3,3,
 2,3,1,4,5,5,
 6,3,3,2,2,5,
 2,5,2,2,1,4,
 4,4,7,7,8,4,
 4,4,4,4,4,5,5,
 6,6,6,5,6,5
 qf(1)=1.0,1.0,1.0,1.0,1.0,
 x(1)= 0.0, 0.5,1.0,1.5,1.9,
 qf(6)=1.1696,1.1696,1.0,0.8304,0.8304,
 x(6)= 0.0, 0.5,1.0,1.5,1.9,
 qf(11)=1.1905,1.1905,1.0,0.8095,0.8095,
 x(11)= 0.0, 0.5,1.0,1.5,1.9,
 qf(16)=1.105,1.105,1.00,0.895,0.895,
 x(16)= 0.0, 0.5,1.0,1.5,1.9,
 qf(21)=1.1364,1.1364,1.,0.8636,0.8636,
 x(21)= 0.0, 0.5,1.0,1.5,1.9,
 qf(26)=1.2195,1.2195,1.0,0.7805,0.7805,
 x(26)= 0.0,0.5,1.0,1.5,1.9,
 qf(31)=1.1236,1.1236,1.0,0.8764,0.8764,
 x(31)= 0.0, 0.5,1.0,1.5,1.9,
 qf(36)=1.087,1.087,1.0,0.913,0.913,
 x(36)= 0.0, 0.5,1.0,1.5,1.9,
 ProblemTime = 0.1,0.2,0.3,0.4,0.5,0.6
 0.7,0.8,0.9,1.0
 7., 23., 41.,63.,
 91.,104.,129.,154.,170.,
 180.,200.,218.,235.,260.,
 300.,310.,320.,350.,370.,
 384.,400.,450.,470.,505.,
 550.,600.,605.,620.,640.,
 650.,680.,725.,770.,800.,
```

```
 850.,865.,900.,960.,968.,
 975.,989.,1007.
 qmpy = 1.52,2.28,3.05,3.82,4.58,5.36,6.12,
 6.88,7.64,8.4,
 12.54,12.54,11.00,11.78
 11.52,11.86,11.14,11.21, 9.38,
 10.74,11.54,9.78,10.08,10.40,
 8.98,10.29,7.92,9.77,9.77,8.85,
 10.29,10.17, 8.97,9.94,10.34,
 10.07,9.91,9.77, 8.98, 8.14,
 9.29,9.38,8.83,10.5,9.7,
 9.1,9.24,6.56,6.56,8.40,
 10.56,9.84,7.04
 slim = .05,
 $end
```

IFA-432 Rod 3 Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out432r3.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plot432r3.n', STATUS='UNKNOWN', FORM='FORMATTED'
/*******************************************************************
         ifa 432 rod 3
 $frpcn
 im=47, na=4, nr=11,
 ngasr = 45,
 $end
 $frpcon
 cpl = 2.0, dco = 0.5035 thkcld = 0.037,
 den = 95.5, thkgap=0.0015, rc = 0.0345, dspg = 0.35,
 dspgw = 0.03, enrch = 10.0,fgpav = 14.7, hplt = 0.5, icm = 2,
 icor = 0, idxgas = 1, iplant = -4, iq = 0,fa = 1.,pitch = 0.56,
 totl = 1.9, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,nplot=1,
 flux = 5*5.0e15, p2(1) = 500., tw(1) = 464., go(1) = 0.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,5,5,
 jst(1) = 1,1,1,1,
 1,1,1,6,3,3,
 2,3,1,4,5,5,
 6,3,3,2,2,5,
 2,5,2,2,1,4,
 4,4,7,7,8,4,
 4,4,4,4,4,5,5,
 6,6,6,5,6,5
 qf(1)=1.156,1.156,1.0,0.844,0.844,
 x(1)= 0.0, 0.5,1.0,1.5,1.9,
 qf(6)=1.1696,1.1696,1.0,0.8304,0.8304,
 x(6)= 0.0, 0.5,1.0,1.5,1.9,
 qf(11)=1.1905,1.1905,1.0,0.8095,0.8095,
 x(11)= 0.0, 0.5,1.0,1.5,1.9,
 qf(16)=1.105,1.105,1.00,0.895,0.895,
 x(16)= 0.0, 0.5,1.0,1.5,1.9,
 qf(21)=1.1364,1.1364,1.,0.8636,0.8636,
```

```
x(21)= 0.0, 0.5,1.0,1.5,1.9,
qf(26)=1.2195,1.2195,1.0,0.7805,0.7805,
x(26)= 0.0,0.5,1.0,1.5,1.9,
qf(31)=1.1236,1.1236,1.0,0.8764,0.8764,
x(31)= 0.0, 0.5,1.0,1.5,1.9,
qf(36)=1.087,1.087,1.0,0.913,0.913,
x(36)= 0.0, 0.5,1.0,1.5,1.9,
ProblemTime = 0.1,0.2,0.3,0.4,0.5,
7., 23., 41.,63.,
91.,104.,129.,154.,170.,
180.,200.,218.,235.,260.,
300.,310.,320.,350.,370.,
384.,400.,450.,470.,505.,
550.,600.,605.,620.,640.,
650.,680.,725.,770.,800.,
850.,865.,900.,960.,968.,
975.,989.,1007.
qmpy = 1.,3.,5.,7.,9.,
12.54,12.54,11.00,11.78
11.52,11.86,11.14,11.21, 9.38,
10.74,11.54,9.78,10.08,10.40,
8.98,10.29,7.92,9.77,9.77,8.85,
10.29,10.17, 8.97,9.94,10.34,
10.07,9.91,9.77, 8.98, 8.14,
9.29,9.38,8.83,10.5,9.7,
9.1,9.24,6.56,6.56,8.40,
10.56,9.84,7.04
slim = .05,
$end
```

A.2 Halden IFA-513 Rods

The IFA-513 test fuel assembly (Bradley et al., 1981) was irradiated in the Halden reactor in Norway from November 1978 to mid-1981 under a continuation of an NRC program to test the performance of BWR-6 type fuel and the effects of fission gas contamination of the helium fill gas.

Rods 1 and 6 both had typical high-density (95 percent TD) stable sintered uranium dioxide (UO_2) fuel pellets. Rod 1 had helium fill gas at one atmosphere while rod 6 had 23 percent xenon and 77percent helium fill gas at one atmosphere. Data taken from rod 1 upper and lower thermocouple and rod 6 upper and lower thermocouple during the first ramp to power were used in the BOL temperature assessment. Data from the rod 1 upper and lower thermocouple and the rod 6 upper and lower thermocouple were used in the temperature assessment as a function of burnup.

The input files used for the assessments listed in Table 2.1 are shown below.

IFA-513 Rod 1 BOL Upper Thermocouple Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out513r1BOLupper.n',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='plot513r1BOLupper.n', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
         ifa 513 rod 1
 $frpcn
 im=8, na=5, nr=10,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.14, dco = 0.5035, thkcld = 0.0372,
 den = 95.5, thkgap = 0.00425, rc = 0.0345, dspg = 0.42,
 dspgw = 0.04, enrch = 9.9,fgpav = 14.7, hplt = 0.5, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1, iplant = -4, iq = 0,nplot=1,
 jdlpr = 0, jn(1) = 6,6,6,6,6,
 jst(1) = 10*1, 4*2, 4*3, 4*2, 4*4, 4*5,
 totl = 2.56, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,fa= 1., pitch=0.56,
 flux = 6*5.0e15, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
 qf(1)=1.0,1.0, 1.0, 1.0, 1.0,1.0
 x(1)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(7)=1.13, 1.13, 1.0, 1.0, 0.87, 0.87,
 x(7)=0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(13)=1.07, 1.07, 1.0, 1.0, 0.93, 0.93,
 x(13)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(19)=1.05, 1.05, 1.0, 1.0, 0.95, 0.95,
 x(19)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(25)=1.02, 1.02, 1.0, 1.0, 0.98, 0.98
 x(25)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 ProblemTime =
 0.1, 0.2, 0.3, 0.4,0.5,0.6,0.7,0.8,
 3.1, 7., 15, 18,
```

```
 34, 37, 40, 45, 60,
 72, 77, 81, 83, 90.,
 100., 105, 110.,115.,120,
 139, 148, 158, 170., 176
 qmpy =
 1.16,3.48,5.8,8.12,10.44,12.76,13.92,16.24,
 11.06, 11.06, 12.2, 11.2, 9.1,
 9.6,   6.2,  10.4,  10.4, 10.3,
 10.3,  4.3,  8.7,  10.4, 10.4,
 10.4, 10.4, 9.5, 10.6, 10.6,
 10.6, 10.3, 10.6, 10.1, 10.1
 $end
```

IFA-513 Rod 1 BOL Lower Thermocouple Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out513r1BOLlower.n',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='plot513r1BOLlower.n', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
         ifa 513 rod 1
 $frpcn
 im=9, na=5, nr=10,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.14, dco = 0.5035, thkcld = 0.0372,
 den = 95.5, thkgap = 0.00425, rc = 0.0345, dspg = 0.42,
 dspgw = 0.04, enrch = 9.9,fgpav = 14.7, hplt = 0.5, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1, iplant = -4, iq = 0,nplot=1,
 jdlpr = 0, jn(1) = 6,6,6,6,6,
 jst(1) = 10*1, 4*2, 4*3, 4*2, 4*4, 4*5,
 totl = 2.56, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,fa= 1., pitch=0.56,
 flux = 6*5.0e15, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
 qf(1)=1.0,1.0, 1.0, 1.0, 1.0,1.0
 x(1)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(7)=1.13, 1.13, 1.0, 1.0, 0.87, 0.87,
 x(7)=0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(13)=1.07, 1.07, 1.0, 1.0, 0.93, 0.93,
 x(13)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(19)=1.05, 1.05, 1.0, 1.0, 0.95, 0.95,
 x(19)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(25)=1.02, 1.02, 1.0, 1.0, 0.98, 0.98
 x(25)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 ProblemTime =
 0.1, 0.2, 0.3, 0.4,0.5,0.6,0.7,0.8,0.9
 3.1, 7., 15, 18,
 34, 37, 40, 45, 60,
 72, 77, 81, 83, 90.,
 100., 105, 110.,115.,120,
 139, 148, 158, 170., 176
 qmpy =
```

```
 0.84,2.52,4.2,5.88,7.56,9.24,10.08,11.76,12.6,
 11.06, 11.06, 12.2, 11.2, 9.1,
 9.6,   6.2,  10.4,  10.4, 10.3,
 10.3,  4.3,  8.7,  10.4, 10.4,
 10.4, 10.4, 9.5, 10.6, 10.6,
 10.6, 10.3, 10.6, 10.1, 10.1
 $end
```

IFA-513 Rod 1 Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out513r1.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plot513r1.n', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
         ifa 513 rod 1
 $frpcn
 im=30, na=5, nr=10,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.14, dco = 0.5035, thkcld = 0.0372,
 den = 95.5, thkgap = 0.00425, rc = 0.0345, dspg = 0.42,
 dspgw = 0.04, enrch = 9.9,fgpav = 14.7, hplt = 0.5, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1, iplant = -4, iq = 0,nplot=1,
 jdlpr = 0, jn(1) = 6,6,6,6,6,
 jst(1) = 10*1, 4*2, 4*3, 4*2, 4*4, 4*5,
 totl = 2.56, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,fa= 1., pitch=0.56,
 flux = 6*5.0e15, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
 qf(1)=1.16,1.16, 1.0, 1.0, 0.84, 0.84
 x(1)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(7)=1.13, 1.13, 1.0, 1.0, 0.87, 0.87,
 x(7)=0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(13)=1.07, 1.07, 1.0, 1.0, 0.93, 0.93,
 x(13)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(19)=1.05, 1.05, 1.0, 1.0, 0.95, 0.95,
 x(19)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(25)=1.02, 1.02, 1.0, 1.0, 0.98, 0.98
 x(25)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 ProblemTime =
 0.01,0.1, 0.2, 0.3, 0.4,
 0.7, 3.1, 7., 15, 18,
 34, 37, 40, 45, 60,
 72, 77, 81, 83, 90.,
 100., 105, 110.,115.,120,
 139, 148, 158, 170., 176
 qmpy =
 1.,  3.,  5.,  7.,  9.0,
 11.06, 11.06, 12.2, 11.2, 9.1,
 9.6,   6.2,  10.4,  10.4, 10.3,
 10.3,  4.3,  8.7,  10.4, 10.4,
 10.4, 10.4, 9.5, 10.6, 10.6,
 10.6, 10.3, 10.6, 10.1, 10.1
```

```
 $end
```

IFA-513 Rod 6 BOL Upper Thermocouple Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out513r6BOLupper.n',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='plot513r6BOLupper.n', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
         ifa 513 rod 6
 $frpcn
 im=7, na=5, nr=17,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.14, dco = 0.5035, thkcld = 0.0372,
 den = 95.5, thkgap = 0.00425, rc = 0.0345, dspg = 0.42,
 dspgw = 0.04, enrch = 9.9,fgpav = 14.7, hplt = 0.5, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 6,fa=1., pitch=0.56,
 amfhe=0.77, amfxe=0.23,nplot=1,
 iplant = -4, iq = 0,
 jdlpr = 0, jn(1) = 6,6,6,6,6,6,6,
 jst(1) = 10*1, 4*2, 4*3, 4*2, 4*4, 1*5,1*6,2*7,
 totl = 2.56, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,
 flux = 6*5.0e15, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
 qf(1)=1.0,1.0, 1.0, 1.0, 1.0, 1.0
 x(1)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(7)=1.13, 1.13, 1.0, 1.0, 0.87, 0.87,
 x(7)=0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(13)=1.07, 1.07, 1.0, 1.0, 0.93, 0.93,
 x(13)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(19)=1.05, 1.05, 1.0, 1.0, 0.95, 0.95,
 x(19)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(25)=1.02, 1.02, 1.0, 1.0, 0.98, 0.98,
 x(25)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56,
 qf(31)=1.02, 1.02, 1.0, 1.0, 0.87, 0.87,
 x(31)= 0.0, 0.5,1.0,1.5,2.0,2.56,
 qf(37)=1.02,1.02,1.0, 1.0, 0.93, 0.93,
 x(37) = 0.0, 0.5,1.0,1.5,2.0,2.56,
 ProblemTime =
 0.1, 0.2, 0.3, 0.4,0.5,0.6,0.7,
 3.1, 7., 15, 18,
 34, 37, 40, 45, 60,
 72, 77, 81, 83, 90.,
 100., 105, 110.,115.,120,
 139, 148, 158, 170., 176
 qmpy =
 1.16,3.48,5.8,8.12,10.44,12.76,15.08,
 11.06, 11.06, 12.2, 11.2, 9.1,
 10,   6.2,  10.4,  10.4, 10.3,
 10.3,  4.3,  8.7,  10.4, 10.4,
 10.4, 10.6,  9.5,  10.9,  11.,
 10.7, 10.2,  10.9  9.9,  9.9
 $end
```

IFA-513 Rod 6 BOL Lower Thermocouple Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out513r6BOLlower.n',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='plot513r6BOLlower.n', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
         ifa 513 rod 6
 $frpcn
 im=8, na=5, nr=17,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.14, dco = 0.5035, thkcld = 0.0372,
 den = 95.5, thkgap = 0.00425, rc = 0.0345, dspg = 0.42,
 dspgw = 0.04, enrch = 9.9,fgpav = 14.7, hplt = 0.5, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 6,fa=1., pitch=0.56,
 amfhe=0.77, amfxe=0.23,nplot=1,
 iplant = -4, iq = 0,
 jdlpr = 0, jn(1) = 6,6,6,6,6,6,6,
 jst(1) = 10*1, 4*2, 4*3, 4*2, 4*4, 1*5,1*6,2*7,
 totl = 2.56, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,
 flux = 6*5.0e15, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
 qf(1)=1.0,1.0, 1.0, 1.0, 1.0, 1.0
 x(1)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(7)=1.13, 1.13, 1.0, 1.0, 0.87, 0.87,
 x(7)=0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(13)=1.07, 1.07, 1.0, 1.0, 0.93, 0.93,
 x(13)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(19)=1.05, 1.05, 1.0, 1.0, 0.95, 0.95,
 x(19)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(25)=1.02, 1.02, 1.0, 1.0, 0.98, 0.98,
 x(25)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56,
 qf(31)=1.02, 1.02, 1.0, 1.0, 0.87, 0.87,
 x(31)= 0.0, 0.5,1.0,1.5,2.0,2.56,
 qf(37)=1.02,1.02,1.0, 1.0, 0.93, 0.93,
 x(37) = 0.0, 0.5,1.0,1.5,2.0,2.56,
 ProblemTime =
 0.1, 0.2, 0.3, 0.4,0.5,0.6,0.7,0.8
 3.1, 7., 15, 18,
 34, 37, 40, 45, 60,
 72, 77, 81, 83, 90.,
 100., 105, 110.,115.,120,
 139, 148, 158, 170., 176
 qmpy =
 0.84,2.52,4.2,5.88,7.56,9.24,10.92,12.6,
 11.06, 11.06, 12.2, 11.2, 9.1,
 10,   6.2,  10.4,  10.4, 10.3,
 10.3,  4.3,  8.7,  10.4, 10.4,
 10.4, 10.6,  9.5,  10.9,  11.,
 10.7, 10.2,  10.9  9.9,  9.9
 $end
```

IFA-513 Rod 6 Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out513r6.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plot513r6.n', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
         ifa 513 rod 6
 $frpcn
 im=30, na=5, nr=17,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.14, dco = 0.5035, thkcld = 0.0372,
 den = 95.5, thkgap = 0.00425, rc = 0.0345, dspg = 0.42,
 dspgw = 0.04, enrch = 9.9,fgpav = 14.7, hplt = 0.5, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 6,fa=1., pitch=0.56,
 amfhe=0.77, amfxe=0.23,nplot=1,
 iplant = -4, iq = 0,
 jdlpr = 0, jn(1) = 6,6,6,6,6,6,6,
 jst(1) = 10*1, 4*2, 4*3, 4*2, 4*4, 1*5,1*6,2*7,
 totl = 2.56, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,
 flux = 6*5.0e15, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
 qf(1)=1.16,1.16, 1.0, 1.0, 0.84, 0.84
 x(1)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(7)=1.13, 1.13, 1.0, 1.0, 0.87, 0.87,
 x(7)=0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(13)=1.07, 1.07, 1.0, 1.0, 0.93, 0.93,
 x(13)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(19)=1.05, 1.05, 1.0, 1.0, 0.95, 0.95,
 x(19)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56
 qf(25)=1.02, 1.02, 1.0, 1.0, 0.98, 0.98,
 x(25)= 0.0, 0.5, 1.0, 1.5, 2.0, 2.56,
 qf(31)=1.02, 1.02, 1.0, 1.0, 0.87, 0.87,
 x(31)= 0.0, 0.5,1.0,1.5,2.0,2.56,
 qf(37)=1.02,1.02,1.0, 1.0, 0.93, 0.93,
 x(37) = 0.0, 0.5,1.0,1.5,2.0,2.56,
 ProblemTime =
 0.01,0.1, 0.2, 0.3, 0.4,
 0.7, 3.1, 7., 15, 18,
 34, 37, 40, 45, 60,
 72, 77, 81, 83, 90.,
 100., 105, 110.,115.,120,
 139, 148, 158, 170., 176
 qmpy =
 1.,  3.,  5.,  7.,  9.0,
 11.06, 11.06, 12.2, 11.2, 9.1,
 10,   6.2,  10.4,  10.4, 10.3,
 10.3,  4.3,  8.7,  10.4, 10.4,
 10.4, 10.6,  9.5,  10.9,  11.,
 10.7, 10.2,  10.9  9.9,  9.9
 $end
```

A.3 Halden IFA-633 Rods

The IFA-633 test assembly consisted of six instrumented rods (three short binderless route (SBR) mixed oxide (MOX) fuel rods and three UO_2 rods) irradiated from beginning of life through a burnup of 31 gigawatt-days per metric ton of metal (GWd/MTM). Rod 6 (Wright, 2004) was the only MOX rod instrumented with both a fuel centerline thermocouple and a pressure transducer such that temperature and fission gas release (FGR) measurements can be compared. Rods 1, 3, and 5 (Rø and Rossiter, 2005) were UO_2 rods instrumented with centerline thermocouples and were used to assess the FRAPCON-3.4 predictions of temperature as a function of linear heat generation rate (LHGR) at BOL. This test assembly experienced a power ramp at a burnup of approximately 20 GWd/MTM to achieve fission gas bubble interlinkage. The MOX fuel was fabricated with the SBR process with a grain size of 7.5 microns and was typical of commercial fuel.

Rod 6 was used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup and the MOX FGR predictions. The input files used for the MOX temperature and FGR assessments are shown below. The input file that includes the central hole was used for the temperature assessment since the temperature was measured on hollow pellets. The input file that does not include the central hole was used for the FGR assessment since most of the FGR comes from solid pellets. Rods 1, 3, and 5 were used to assess the FRAPCON-3.4 temperature predictions for UO_2 as a function of LHGR at BOL. These input files are not included in this report due to the limited availablility and sensitivity of this information.

A.4 Halden IFA-677.1 Rods

The high initial rating test, IFA-677.1 (Thérache, 2005; Jošek, 2008), was loaded in the Halden reactor in December 2004 and had completed six cycles of irradiation under HBWR conditions as of September 2007, achieving a rig average burnup of 30 GWd/MTU. The single cluster contained six rods supplied by Westinghouse, Framatome ANP, and Global Nuclear Fuel (GNF), all fitted with pressure transducers, fuel centerline thermocouples in both ends, and fuel stack elongation detectors, and with a cladding extensometer for one of the rods. The experiment was aimed at investigating the performance of modern fuels subjected to high initial rating with respect to thermal behavior, dimensional changes (densification and swelling), FGR, and pellet/cladding mechanical interaction (PCMI).

Rod 2 (Framatome ANP), rod 3 (GNF), rod 4 (GNF), and rod 6 (Westinghouse) were all used to assess the BOL UO_2 temperature predictions of FRAPCON-3.4 as a function of LHGR. In addition, rod 2 was used to assess the UO_2 temperature predictions as a function of burnup up to 32 GWd/MTU. The input files used for these assessments are shown below.

IFA-677.1 Rod 2 BOL Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='677.1r2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='677.1r2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*********************************************************************
   IFA-677.1 Rod 2 BOL
 $frpcn
 im=40, nr=17, ngasr=45, na=10
 $end
 $frpcon
 dco=0.4232, thkcld=0.02854, thkgap=0.00335, totl=1.30906, cpl=1.1417
 dspg=0.315, dspgw=0.05, vs=10
 hplt=0.4331, rc=0.0354, hdish=0.0087, dishsd=0.0537
 enrch=4.935, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=27.5, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=195.8, idxgas=1, nunits=1
iplant=-4, pitch=1.811, icor=0, crdt=0, crdtr=0,
flux=11*5000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.05, 0.1, 0.15, 0.2, 0.25
 0.3, 0.35, 0.4, 0.45, 0.5
 0.55, 0.6, 0.65, 0.7, 0.75
 0.8, 0.85, 0.9, 0.95, 1
 1.05, 1.1, 1.15, 1.2, 1.25
 1.3, 1.35, 1.4, 1.45, 1.5
 1.55, 1.6, 1.65, 1.7, 1.75
 1.8, 1.85, 1.9, 1.95, 2
 qmpy=
```

```
 0.112, 0.312, 0.57, 0.884, 1.141
 1.399, 1.571, 1.913, 2.085, 2.627
 2.969, 3.312, 3.854, 4.228, 4.657
 5.113, 5.428, 5.826, 6.14, 6.397
 6.742, 7.17, 7.598, 8.143, 8.514
 9.198, 9.369, 9.57, 9.798, 10.17
 10.456, 10.828, 11.085, 11.54, 11.684
 11.942, 12.114, 12.343, 12.457, 13.716
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.14544, 0.29088, 0.43632, 0.58176
 0.7272, 0.87264, 1.01808, 1.16352, 1.30906
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 jn=10
 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
```

IFA-677.1 Rod 3 BOL Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='677.1r3.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='677.1r3.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*********************************************************************
   IFA-677.1 Rod 3 BOL
 $frpcn
 im=35, nr=17, ngasr=45, na=10
 $end
 $frpcon
 dco=0.4402, thkcld=0.02815, thkgap=0.00394, totl=1.31037, cpl=1.1969
 dspg=0.315, dspgw=0.05, vs=10
 hplt=0.4094, rc=0.0354, hdish=0, dishsd=0.188
 enrch=4.9, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.36, deng=0, roughf=0.0000787, rsntr=27.5, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=43.51, idxgas=1, nunits=1
 iplant=-4, pitch=1.811, icor=0, crdt=0, crdtr=0,
flux=11*5000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
```

```
 ProblemTime=
 0.05, 0.1, 0.15, 0.2, 0.25
 0.3, 0.35, 0.4, 0.45, 0.5
 0.55, 0.6, 0.65, 0.7, 0.75
 0.8, 0.85, 0.9, 0.95, 1
 1.05, 1.1, 1.15, 1.2, 1.25
 1.3, 1.35, 1.4, 1.45, 1.5
 1.55, 1.6, 1.65, 1.7, 1.75
 qmpy=
 0.11, 0.274, 0.548, 0.986, 1.205
 1.698, 2.356, 3.013, 3.671, 4.109
 4.492, 5.095, 5.807, 6.245, 6.684
 7.122, 7.396, 7.999, 8.327, 8.546
 8.93, 9.259, 9.916, 10.245, 10.793
 11.286, 11.669, 12.107, 12.381, 12.82
 13.094, 13.258, 13.313, 13.313, 13.716
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.14544, 0.29088, 0.43632, 0.58176
 0.7272, 0.87264, 1.01808, 1.16352, 1.31037
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 jn=10
 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
 $end
```

IFA-677.1 Rod 4 BOL Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='677.1r4.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='677.1r4.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
   IFA-677.1 Rod 4 BOL
 $frpcn
 im=40, nr=17, ngasr=45, na=10
 $end
 $frpcon
 dco=0.4402, thkcld=0.02815, thkgap=0.00394, totl=1.3143, cpl=1.189
 dspg=0.315, dspgw=0.05, vs=10
 hplt=0.4094, rc=0.0354, hdish=0, dishsd=0.188
 enrch=4.9, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
```

```
 den=96.36, deng=0, roughf=0.0000787, rsntr=27.5, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=195.8, idxgas=1, nunits=1
 iplant=-4, pitch=1.811, icor=0, crdt=0, crdtr=0,
flux=11*5000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.05, 0.1, 0.15, 0.2, 0.25
 0.3, 0.35, 0.4, 0.45, 0.5
 0.55, 0.6, 0.65, 0.7, 0.75
 0.8, 0.85, 0.9, 0.95, 1
 1.05, 1.1, 1.15, 1.2, 1.25
 1.3, 1.35, 1.4, 1.45, 1.5
 1.55, 1.6, 1.65, 1.7, 1.75
 1.8, 1.85, 1.9, 1.95, 2
 qmpy=
 0.055, 0.164, 0.383, 0.712, 1.15
 1.26, 1.644, 2.137, 2.411, 2.739
 3.068, 3.397, 3.561, 3.89, 3.999
 4.712, 5.205, 5.752, 6.081, 6.355
 6.958, 7.177, 7.56, 7.779, 8.108
 8.437, 8.82, 9.204, 9.587, 9.861
 10.3, 10.574, 11.012, 11.395, 11.724
 12.107, 12.491, 12.765, 13.368, 13.716
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.14603, 0.29206, 0.43809, 0.58412
 0.73015, 0.87618, 1.02221, 1.16824, 1.3143
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 jn=10
 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
```

IFA-677.1 Rod 6 BOL Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='677.1r6.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='677.1r6.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*********************************************************************
```

```
 IFA-677.1 rod 6 BOL
 $frpcn
 im=44, nr=17, ngasr=45, na=10
 $end
 $frpcon
 dco=0.4232, thkcld=0.02854, thkgap=0.00335, totl=1.31988, cpl=1.1417
 dspg=0.315, dspgw=0.05, vs=10
 hplt=0.4331, rc=0.0354, hdish=0.0118, dishsd=0.0813
 enrch=4.9, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=27.5, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=195.8, idxgas=1, nunits=1
 iplant=-4, pitch=1.811, icor=0, crdt=0, crdtr=0,
flux=11*5000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.05, 0.1, 0.15, 0.2, 0.25
 0.3, 0.35, 0.4, 0.45, 0.5
 0.55, 0.6, 0.65, 0.7, 0.75
 0.8, 0.85, 0.9, 0.95, 1
 1.05, 1.1, 1.15, 1.2, 1.25
 1.3, 1.35, 1.4, 1.45, 1.5
 1.55, 1.6, 1.65, 1.7, 1.75
 1.8, 1.85, 1.9, 1.95, 2
 2.05, 2.1, 2.15, 2.2
 qmpy=
 0, 0.219, 0.438, 0.986, 1.26
 1.698, 2.027, 2.356, 2.849, 3.342
 3.561, 3.835, 4.054, 4.273, 4.602
 4.931, 5.424, 6.081, 6.848, 7.122
 7.451, 7.615, 7.834, 7.999, 8.108
 8.218, 8.546, 8.766, 9.094, 9.368
 9.587, 9.971, 10.135, 10.519, 10.683
 10.793, 11.45, 11.834, 11.998, 12.217
 12.491, 12.655, 12.71, 13.716
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.14665, 0.29331, 0.43996, 0.58661
 0.73327, 0.87992, 1.02657, 1.17323, 1.31988
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 jn=10
 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
```

```
 $end
```

IFA-677.1 Rod 2 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IFA-677-2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IFA-677-2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
    IFA-677.1 Rod 2
 $frpcn
 im=101, nr=17, ngasr=45, na=10
 $end
 $frpcon
 dco=0.4232, thkcld=0.02854, thkgap=0.00335, totl=1.30906, cpl=1.7913
 dspg=0.315, dspgw=0.05, vs=10
 hplt=0.4331, rc=0.0354, hdish=0.0087, dishsd=0.0537
 enrch=4.935, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=27.5, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=195.8, idxgas=1, nunits=1
 iplant=-4, pitch=1.811, icor=0, crdt=0, crdtr=0,
flux=11*5000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 10.357, 19.186, 31.173, 40.642, 46.341
 53.277, 58.967, 66.547, 72.246, 74.118
 79.169, 84.202, 91.782, 96.201, 97.43
 103.999, 107.769, 111.549, 115.319, 120.37
 128.568, 132.906, 137.347, 147.447, 148.748
 154.464, 160.18, 163.29, 167.688, 172.747
 177.797, 182.216, 190.444, 192.304, 198.732
 202.537, 208.121, 214.34, 216.272, 221.378
 227.068, 233.991, 239.02, 244.715, 245.956
 250.422, 252.269, 255.447, 259.252, 261.777
 265.578, 270.637, 272.518, 284.961, 287.499
 293.829, 297.663, 303.324, 307.129, 312.84
 316.555, 320.356, 321.623, 329.199, 332.965
 334.885, 339.944, 343.727, 348.146, 355.261
 360.235, 361.476, 364.611, 366.458, 370.894
 375.331, 379.788, 384.173, 389.266, 398.143
 403.914, 407.629, 410.163, 413.29, 415.226
 419.027, 425.361, 428.471, 434.792, 444.271
 447.871, 452.26, 462.395, 470.623, 474.402
 478.856, 485.228, 488.974, 494.647, 499.646
 506.577
 qmpy=
 12.153, 12.258, 12.363, 12.365, 12.161
 12.265, 12.163, 12.113, 11.908, 12.166
 12.167, 12.374, 12.324, 12.325, 12.737
 9.65, 9.856, 9.96, 10.167, 10.168
```

```
10.272, 11.252, 10.995, 10.997, 10.534
10.123, 9.713, 10.28, 10.538, 10.436
10.437, 10.438, 10.182, 10.594, 9.206
9, 10.186, 11.32, 10.857, 10.189
10.087, 10.346, 10.604, 10.451, 10.708
10.143, 10.71, 10.453, 10.248, 10.248
10.095, 9.993, 10.148, 12.364, 12.21
12.006, 11.44, 11.699, 11.493, 11.134
12.01, 11.857, 11.805, 11.807, 12.065
11.757, 11.655, 11.707, 11.708, 9.65
10.578, 10.835, 11.093, 11.66, 11.455
11.25, 10.788, 11.2, 10.687, 10.225
9.145, 10.021, 9.919, 10.28, 9.765
9.611, 9.355, 9.922, 9.821, 9.72
11.986, 12.347, 11.937, 11.682, 11.785
11.374, 10.655, 11.17, 11.275, 11.893
 12.049
nsp=0
p2= 493.13, tw= 455, go= 0
iq=0, fa=1
x(1)=
0, 0.14544, 0.29088, 0.43632, 0.58176
0.7272, 0.87264, 1.01808, 1.16352, 1.30906
qf(1)=
1, 1, 1, 1, 1
1, 1, 1, 1, 1
jn=10
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, 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, 1, 1, 1, 1
      1
$end
```

A.5 Halden IFA-562 Rod

The Halden Ultra High Burnup (HUHB) test fuel assembly (IFA-562) (Wiesnack, 1992) was initiated by the Halden reactor project to demonstrate the effect of burnup on fuel thermal conductivity. The HUHB configuration of the assembly consisted of six rods, four of which were instrumented with centerline expansion thermometers and two with pressure transducers. The rods were under irradiation in the Halden reactor from September 1989 to 1997. Documented data for fuel center temperatures and linear heat ratings are available to a rod-average burnup of 76 megawatt-days per metric ton of uranium (MWd/MTU).

Four rods (rods 15, 16, 17, and 18) contained "expansion centerline thermometers." These are tungsten (1.8 percent ZrO) rods that run the full length of the rod on the inside of the pellets and gage the average center temperature of each rod via thermal expansion of the rod detected by resistance change. Two rods (rods 13 and 14) each contained a pressure transducer for measuring rod internal pressure. The assembly instrumentation included four SPNDs, three of which were located coplanar at the top of the assembly and one near the bottom to define the thermal neutron flux distribution within the assembly.

The behavior of LHGR and measured temperatures were very similar for all four rods with temperature sensors. One rod (number 18) was selected for comparison to FRAPCON-3 predictions. The input file used for the UO_2 temperature assessment as a function of burnup is shown below.

IFA-562 Rod 18 Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out562r18.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66= 'plot562r18.out', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
      IFA-562 rod 18 (ET4)
 $frpcn
 im=154, na=4,nr=20,
 mechan = 2, ngasr = 15,
 $end
 $frpcon
 cpl = 100.28, crdt = 0.0,pitch = 0.56,
 dco=0.2762, thkcld = 0.0197, thkgap= 0.002,
 den = 94., dspg = 0.236,
 dspgw = 0.04, enrch = 13., fa= 1.0, fgpav = 145,
 hplt = 0.295, hdish = 0.0, icm = 2,
 icor = 0, idxgas = 1, nplot = 1,
 iplant = -4, iq = 0, jdlpr = 0,
 totl = 1.45, jn = 5,5,5, jst = 12*1,40*2,102*3,
 rc = 0.0394, roughc = 1.97e-5,
 roughf = 2.36e-5, vs = 8.0,
 nunits = 1, rsntr = 150.,
 qf(1) = 0.807, 0.963, 1.025, 1.087, 1.118,
 qf(6) = 0.90, 1.00, 1.033, 1.033, 1.033,
 qf(11) = 0.903, 0.972, 1.042, 1.042, 1.042
 x(1) = 0.0, 0.38, 0.74, 1.10, 1.45,
 x(6) = 0.0, 0.38, 0.74, 1.10, 1.45,
```

```
x(11) = 0.0, 0.38, 0.74, 1.1, 1.45,
flux = 5*5.0e15, p2(1) = 500, tw(1) = 459.0, go(1) =  0.0,
ProblemTime=
0.43503 ,0.80173 ,1.38705 ,7.47071 ,9.7308 ,
10.9422 ,13.7663 ,19.2008 ,20.2054 ,22.9159 ,
32.7273 ,33.7323 ,34.5097 ,37.6132 ,41.7493 ,
64.8183 ,70.4971 ,73.3182 ,73.6958 ,77.6724 ,
79.0925 ,80.7099 ,91.4296 ,102.417 ,111.065 ,
112.673 ,113.386 ,114.295 ,120.388 ,125.329 ,
126.512 ,129.186 ,140.301 ,141.808 ,142.569 ,
143.636 ,144.535 ,144.723 ,157.737 ,158.367 ,
164.847 ,190.746 ,191.821 ,193.737 ,194.258 ,
217.31  ,218.421 ,219.156 ,220.116 ,220.973 ,
223.134 ,223.247 ,227.183 ,227.607 ,233.5   ,
233.951 ,236.331 ,249.877 ,267.158 ,268.924 ,
272.965 ,273.655 ,274.268 ,298.281 ,298.9   ,
319.631 ,325.674 ,328.984 ,329.303 ,331.248 ,
332.314 ,343.383 ,354.836 ,355.615 ,369.821 ,
381.793 ,386.584 ,390.518 ,401.779 ,402.37  ,
405.119 ,406.091 ,413.326 ,414.041 ,415.468 ,
417.273 ,418.598 ,421.171 ,431.288 ,432.362 ,
433.391 ,442.042 ,452.261 ,454.246 ,467.811 ,
469.596 ,483.766 ,488.786 ,491.259 ,499.438 ,
513.374 ,519.513 ,525.952 ,527.109 ,530.127 ,
530.654 ,531.389 ,534.611 ,555.952 ,601.893 ,
611.911 ,623.542 ,627.514 ,629.53  ,630.418 ,
641.244 ,645.96  ,648.069 ,653.543 ,659.318 ,
660.446 ,662.039 ,678.86  ,681.297 ,689.245 ,
691.947 ,693.958 ,696.915 ,713.772 ,714.411 ,
717.565 ,717.898 ,719.599 ,719.94  ,720.778 ,
722.409 ,728.508 ,732.685 ,741.803 ,743.816 ,
744.135 ,746.408 ,758.135 ,758.621 ,759.106 ,
759.724 ,771.859 ,774.897 ,776.758 ,777.903 ,
788.661 ,789.18  ,804.74 ,816.979
qmpy =6.28354 ,11.4634 ,9.94207 ,11.1311 ,9.96037 ,
9.41768 ,10.1402 ,10.5671 ,11.128  ,11.2713 ,
11.5579 ,7.00915 ,7.09146 ,8.26524 ,8.99695 ,
9.73171 ,9.57317 ,9.7439  ,10.3415 ,10.186  ,
10.2439 ,8.52134 ,8.5     ,9.7561  ,10.5366 ,
4.28659 ,5.36585 ,9.2622  ,10.3049 ,5.57927 ,
5.82622 ,8.01829 ,9.02439 ,4.06402 ,4.02134 ,
8.6128  ,7.67073 ,8.125   ,8.47256 ,8.50305 ,
8.27134 ,8.0122  ,7.83232 ,8.39329 ,8.80793 ,
7.90549 ,6.89329 ,4.16768 ,7.17378 ,8.04268 ,
8.14939 ,6.76524 ,7.39329 ,7.22561 ,8.05488 ,
8.5     ,8.3628  ,7.6311  ,8.06402 ,7.80488 ,
6.44207 ,6.65549 ,6.24695 ,6.95122 ,4.95122 ,
7.09146 ,6.33537 ,5.32012 ,4.80488 ,5.1189  ,
4.30793 ,5.32622 ,5.61585 ,5.89939 ,5.71341 ,
5.56402 ,5.27439 ,6.42378 ,6.32317 ,6.47866 ,
6.12805 ,4.72561 ,5.18598 ,5.35061 ,5.90244 ,
6.36585 ,6.35366 ,5.65549 ,5.60061 ,3.56402 ,
5.20732 ,5.92988 ,5.84451 ,5.78659 ,3.95122 ,
6.0061  ,5.67378 ,5.49085 ,4.02439 ,4.4939  ,
5       ,4.11585 ,4.04268 ,3.97256 ,3.80488 ,
4.36585 ,5.20427 ,5.70427 ,5.41768 ,5.25    ,
5.42683 ,5.66159 ,5.78354 ,4.17683 ,4.31402 ,
```

```
5.02134 ,3.08537 ,4.71951 ,4.47561 ,5.17073 ,
3.39634 ,4.32622 ,4.55183 ,4.39939 ,4.81707 ,
4.81707 ,4.94817 ,4.92073 ,4.90549 ,4.79878 ,
4.3689  ,4.60061 ,4.05183 ,4.4939  ,4.56707 ,
4.22561 ,4.89634 ,4.58232 ,4.78659 ,3.42378 ,
4.80793 ,5.05183 ,4.2439  ,4.72866 ,4.7378  ,
4.95732 ,4.35366 ,3.78049 ,4.11585 ,4.0122  ,
4.12805 ,4.42073 ,3.4939  ,3.12805
slim = .03,
$end
```

A.6 Halden IFA-597.3 Rod

The fuel segments for the high-burnup integral rod behavior test IFA-597 (Matsson and Turnbull, 1998) were refabricated from fuel rod 33-25065, which was irradiated in the Ringhals 1 BWR, Sweden, for approximately 12 years. The irradiation of this rod and its sibling rod 33-25046 was performed in two stages. During the first irradiation, 1980 to 1986, the rods were part of Ringhals assembly 6477 and an approximate rod-averaged burnup of 35 GWd/MTU was reached. The rods were then placed into fuel assembly 9902 for a second period of irradiation from 1986 to 1992 in Ringhals I. The locations of fuel rods 33-25065 and 33-25046 in this assembly were positions 9902/D5 and 9902/E4, respectively. A final rod-averaged burnup of 59 GWd/MTU was achieved. The burnup at the location of the Halden refabricated segments was estimated as 67 GWd/MTU.

Rods 8 and 9 were loaded into positions 2 and 5 in IFA-597.2 (second loading) and irradiated in Halden for some 20 days in July 1995. After a few power ramps, rod 9 failed and the assembly was withdrawn. During this time, useful data were generated on centerline temperature as a function of power.

Rod 9 was removed and replaced by rod 7. The assembly was returned to the reactor as IFA-597.3 (third loading); the irradiation started in January 1997 and continued to May of that year having accrued a further ~2 GWd/MTU. Data obtained included centerline temperature as a function of power and burnup, (rod 8), FGR estimated from the increase in rod internal pressure transducer (rod 8), and clad elongation (rod 7).

The assembly was discharged and transported to Kjeller for post-irradiation examination (PIE). FGRs of 12.6 percent and 15.8 percent were measured from puncturing and gas extraction from rods 7 and 8, respectively.

Rod 8 was used to assess the UO_2 temperature and FGR predictions of FRAPCON-3.4. The input files used for these assessments are shown below.

IFA-597.3 Rod 8 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out597~3notc.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66 = 'plot597~3notc.n', STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         ifa 597.3,Rod 8 FGR Case
 $frpcn
 im=71, na=3, nr=20,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 1.5, dco = 0.4809, thkcld = 0.0315,
 den = 95.5, thkgap = 0.0052, rc = 0.0, dspg = 0.39,
 dspgw = 0.04, enrch = 3.35, fgpav = 73, hplt = 0.5,
  hdish= 0.0,pitch=0.56,fa=1.0,
 icm = 2, icor = 0, idxgas = 1, iplant = -3, iq = 0,
 jdlpr = 1, jn(1) = 4, nplot =1,
 jst(1) = 71*1
```

```
 totl = 1.5, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 75.,
 flux = 4*0.25e16, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
 qf(1)= 1., 1., 1., 1.,
 x(1)= 0.0, 0.5, 1.0, 1.5,
 ProblemTime =
 0.1, 0.2, 0.3,
 100., 200., 300., 400., 500.,
 600., 700., 800., 900., 1000.,
 1100., 1200.,1300.,1400.,1500.,
 1600., 1700., 1800.,1900., 2000.,
 2100., 2200., 2300., 2400., 2500.,
 2600., 2700., 2800.,
 2803., 2805., 2807., 2809., 2811.,
 2811.2,2811.4,2811.6,2811.8,2812.,
 2812.1,2812.2,2812.3,2813.,2814.,
 2816.,2817.,2818.,2819.,2820.,
 2821.,2829.,2837.,2842.,2843.,
 2845.,2847.,2848.,2853.,2860.,
 2865.,2870.,2873.,2877.,2879.,
 2887.,2893.,2894.,2901.,2905.
 qmpy =
 1., 3., 5.,
 28*5.68,
 5., 4*7.62,
 6.,5.,4.,3.,2.,
 1.52,3.05,4.57,7.01,7.01,
 7.62,7.93,8.23,8.54,8.08,
 7.77,8.08,7.62,7.47,7.04,
 7.01,7.47,7.32,7.47,7.32,
 7.16,7.07,7.01,6.98,6.86,
 6.40,6.71,6.40,5.91,5.79
  $end
```

IFA-597.3 Rod 8 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out597r8.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plot597r8.out', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
         ifa 597.3 rod 8 temperature case
 $frpcn
 im=122, na=6, nr=20,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 2.0, dco = 0.4823, thkcld = 0.03150,
 den = 95.5, thkgap = 0.00413, rc = 0.049, dspg = 0.40,
 dspgw = 0.0030, enrch = 3.35,fgpav = 73.5,
 hplt = 0.4291, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1, iplant = -4, iq = 0,
 jdlpr = 0, jn(1) = 3,
 jst(1) = 122*1  nplot = 1,
 totl = 1.16, roughc = 2.5e-5, roughf = 8.5e-5, vs = 20.,
```

```
nunits = 1, rsntr = 75.,fa= 1.0, pitch=0.56,
flux = 7*1.78e16,
nsp =1,
p2(1)=75*1000.0, p2(76)=47*494.,
tw(1)=75*545, tw(76)=47*464.,
go(1) = 122*0.0,
qf(1)=1., 1., 1.
x(1)= 0.0, 0.58, 1.16
ProblemTime =
 0.1, 0.2, 0.3,
20.0, 45.3, 88.6, 125.4, 170.8,
210.1, 250.8, 297.2, 332.4, 350.,
376.9, 411.2, 453.3, 498.6, 532.2,
578.5, 622.9, 676.1, 720.4, 764.3,
802.2, 848.1, 992.7, 1045.2, 1092.1,
1130.1, 1170.3, 1210.3, 1250.7, 1290.9,
1350.5, 1390.1, 1432.8, 1470.4, 1518.2,
1552.6, 1590.5, 1639.7, 1688.9, 1721.4,
1767.8, 1800., 1850., 1900., 1950.,
2000., 2050., 2100., 2150., 2200.,
2250., 2300., 2350., 2400., 2450.,
2500., 2550., 2600., 2650., 2700.,
2750., 2800., 2850., 2900., 2950.,
3000., 3050., 3100., 3150., 3200.,
3250., 3290.,
3290.1,3290.2, 3290.3, 3290.4,
3291.,3292.,3293.,3294., 3295.,
3296., 3297.,3298., 3299.,
3299.2, 3299.4, 3299.5,
3300.1, 3300.2, 3300.3, 3300.4,
 3300.7, 3301.4, 3302.6,
3306.8, 3310.8, 3316.5, 3320.7, 3324.9,
3329.1, 3333.5, 3337.9, 3339.0, 3342.1,
3347.5, 3351.9, 3356.4, 3360.9, 3365.4,
3369.9, 3372.5, 3377.3, 3377.4,3382.2, 3387.0,
3392.3, 3397.6, 3398.3
qmpy =
1., 2., 3.,
40*4.57,
4.57, 4*5.5,
10*5.5,
2*1.22, 3*5.5
5*5.5
4*5.5, 1.22,
2*1.22,
2.,4.,6., 6.,
3*6, 6*7.5,
6., 4.,2.,
2.0, 3.0, 4.0, 5.0,
5.44, 4.77, 3.93,
7.05, 7.81, 7.53, 7.54, 7.60,
7.40, 7.26, 7.11, 7.1, 6.7,
7.15, 7.14, 6.99, 6.99, 6.94,
6.89, 6.89, 6.33, 6.33, 6.63, 6.63,
5.8, 5.80, 5.66,
slim= 0.05,
$end
```

A.7 Halden IFA-515.10 Rods

IFA-515.10 (Tverberg and Amaya, 2001) contained hollow rods with centerline thermocouples irradiated up to a burnup of greater than 80 GWd/MTU. Two of the rods contain UO_2 and two of the rods contain 8 percent gadolinia. However, the gadolinium used in these rods is composed of ^{160}Gd, which is a non-neutron absorbing isotope. In this way, the effect of the thermal conductivity degradation due to gadolinia can be separated from the power reduction that is typically seen in fuel containing gadolinia. For these rods, a special version of FRAPCON-3 was used that does not use the power profiles for neutron-absorbing gadolinia.

Rods A1 and A2 are sibling rods of UO_2 and urania-gadolinia (UO_2-Gd_2O_3), respectively, and experience very similar power histories. This is also true for rods B1 and B2. Halden has reported that the thermocouples failed in rods A1, A2, and B2 at the burnup indicated on Figures 3.10, 3.35, and 3.36. After this point, the temperature data are no longer valid.

These four rods were used to assess the FRAPCON-3.4 temperature predictions for UO_2 and UO_2-Gd_2O_3 fuel as a function of burnup. The input files used for the UO_2 and UO_2-Gd_2O_3 temperature assessment as a function of burnup are shown below.

IFA-515.10 Rod A1

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='515-A1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='515-A1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-515.10 Rod A1
 $frpcn
 im=90, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.2571, thkcld=0.01811, thkgap=0.00098, totl=0.72835, cpl=0.748
 dspg=0.2165, dspgw=0.0394, vs=10
 hplt=0.2362, rc=0.0354, hdish=0, dishsd=0.1094
 enrch=11.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.8, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1


 iplant=-4, pitch=0.2956, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 1.18, 11.73, 13.19, 27.93, 37.41
 45.21, 51.74, 78.47, 78.69, 96.25
 106.82, 125.58, 126.56, 152.61, 166.07
 177.89, 190.97, 202.55, 215.64, 220.93
```

```
224.22, 230.4, 240.83, 242.25, 245.67
255.47, 256.47, 261.76, 282.24, 283.15
291.49, 297.69, 302.76, 322.41, 332.27
338.27, 349.3, 358.32, 371.69, 386.09
397.55, 426.65, 440.79, 446.78, 452.81
455.22, 461.3, 461.98, 469.7, 474.48
481.8, 496.87, 498.51, 500.23, 509.87
516.56, 561.21, 575.09, 577.8, 592.04
594.86, 621.34, 622.36, 637.59, 656.08
681.83, 702.63, 706.25, 706.95, 717.24
741.76, 756.72, 766.41, 769.83, 792.76
792.78, 815.08, 825.37, 838.11, 879.09
899.46, 917.34, 919.05, 930.55, 972.14
1009.32, 1015.74, 1061.87, 1091.8, 1103.31
qmpy=
6.524, 3.197, 5.856, 6.236, 5.594
5.503, 5.83, 2.752, 5.346, 5.857
4.992, 5.176, 3.617, 3.29, 5.818
4.915, 4.941, 4.614, 5.413, 4.994
4.863, 5.308, 5.138, 6.173, 5.4
5.505, 6.383, 6.029, 6.043, 6.449
6.449, 7.065, 6.148, 6.017, 6.62
6.201, 6.358, 5.218, 5.232, 5.232
6.201, 6.87, 6.844, 6.163, 6.255
7.145, 7.067, 5.953, 6.333, 6.884
6.569, 6.413, 6.937, 4.762, 5.063
6.727, 5.758, 6.243, 5.732, 6.073
5.484, 5.274, 5.445, 5.288, 5.236
5.223, 5.171, 4.123, 4.49, 5.027
4.817, 5.053, 4.988, 4.595, 4.438
4.281, 4.347, 4.163, 3.299, 3.417
3.155, 2.998, 3.509, 3.247, 3.234
3.182, 3.392, 3.143, 3.052, 2.777
nsp=0
p2= 493.13, tw= 464, go= 0
iq=0, fa=1
x(1)=
0, 0.72835
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, 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
```

IFA-515.10 Rod A2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='515-A2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='515-A2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-515.10 Rod A2
 $frpcn
 im=92, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.2571, thkcld=0.01811, thkgap=0.00098, totl=0.72835, cpl=0.7362
 dspg=0.2165, dspgw=0.0394, vs=10
 hplt=0.2362, rc=0.0354, hdish=0, dishsd=0.1094
 enrch=13, imox=0, comp=0
 fotmtl=2, gadoln=0.08, ppmh2o=0, ppmn2=0
 den=97.3, deng=0, roughf=0.0000787, rsntr=0, tsint=2911
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1


 iplant=-4, pitch=0.2956, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.9257, 10.183, 14.0256, 26.4489, 27.4234
 56.6538, 64.4474, 83.8406, 92.5515, 121.1094
 124.0922, 127.9096, 127.9113, 146.9121, 148.9489
 155.0088, 157.8301, 168.9045, 171.0789, 186.0781
 195.2272, 206.6632, 211.8169, 212.8911, 219.4753
 221.4908, 236.411, 241.2181, 249.622, 251.2313
 253.7707, 275.9616, 277.5645, 289.4516, 294.4467
 305.2693, 314.5788, 323.1738, 325.646, 339.1863
 348.9701, 363.6806, 364.6428, 375.3528, 381.2033
 387.7418, 399.6896, 418.4637, 429.8751, 437.35
 441.7031, 452.9828, 462.4106, 472.3968, 485.9889
 489.1192, 490.2186, 496.6586, 498.3332, 503.1967
 507.507, 525.8332, 550.7197, 559.2848, 566.4029
 578.8926, 579.8727, 604.4594, 607.4282, 613.3801
 627.837, 658.8, 684.7323, 696.6081, 709.5151
 729.6179, 748.7744, 753.3161, 785.2378, 806.2351
 806.2365, 827.866, 869.8712, 902.2747, 914.6252
 954.8767, 993.2894, 996.4, 1043.3503, 1084.9598
 1096.8266, 1100.28
 qmpy=
```

```
 5.831, 2.916, 5.619, 6.083, 5.54
 5.54, 2.77, 5.567, 4.957, 5.104
 3.619, 4.242, 3.606, 3.421, 5.077
 5.382, 5.74, 5.356, 4.998, 5.038
 4.72, 4.72, 5.237, 5.025, 4.919
 5.356, 5.065, 3.369, 5.781, 6.709
 6.377, 6.325, 6.735, 7.266, 6.484
 6.484, 6.378, 6.908, 6.551, 6.379
 5.517, 5.504, 5.61, 5.544, 6.459
 6.605, 6.777, 7.188, 7.096, 6.499
 7.44, 6.221, 6.871, 6.487, 6.354
 6.898, 4.91, 5.029, 6.447, 6.659
 6.262, 5.891, 5.64, 6.302, 5.309
 6.051, 5.507, 5.269, 5.455, 5.442
 5.601, 5.23, 5.204, 4.091, 5.019
 4.833, 5.072, 4.754, 4.397, 4.37
 4.556, 3.244, 3.47, 3.165, 3.497
 3.219, 3.232, 3.471, 3.219, 3.114
 2.729, 1.563
 nsp=0
 p2= 493.13, tw= 464, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.72835
 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, 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
```

IFA-515.10 Rod B1

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='515-B1.out',
```

```
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='515-B1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-515.10 Rod B1
 $frpcn
 im=86, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.2571, thkcld=0.01811, thkgap=0.00098, totl=0.72835, cpl=0.7362
 dspg=0.2165, dspgw=0.0394, vs=10
 hplt=0.2362, rc=0.0354, hdish=0, dishsd=0.1094
 enrch=11.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.8, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1


 iplant=-4, pitch=0.2956, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 1.76, 7.17, 17.96, 20.77, 35.11
 41.35, 56.52, 62.89, 89.29, 107.35
 109.54, 142.21, 143.12, 176.3, 187.99
 200.79, 218.3, 224.35, 235.42, 240.14
 249.35, 261.35, 274.08, 281.12, 286.32
 287.95, 311.54, 314.11, 323.98, 327.96
 331.17, 349.94, 362.57, 382.06, 383.84
 411.15, 414.89, 422.56, 444.82, 455.78
 465.92, 474.32, 481.32, 481.84, 485.75
 488.92, 498.92, 514.6, 526.13, 528.87
 535.58, 542.84, 557.42, 582.73, 597.75
 603.54, 606.22, 615.16, 624.46, 630.27
 653.07, 653.13, 671.66, 691.14, 726.19
 742.76, 758.3, 776.17, 780.69, 793.63
 801.56, 836.08, 855.95, 866.82, 910.79
 949.19, 950.95, 970.41, 1019.38, 1034.07
 1049.63, 1070.37, 1097.05, 1123.91, 1127.49
 1143.52
 qmpy=
 6.048, 2.978, 2.991, 5.208, 5.681
 4.972, 4.959, 5.103, 2.689, 4.985
 4.644, 4.605, 3.24, 3.24, 5.379
 4.5, 4.618, 4.369, 4.369, 4.67
 4.67, 4.972, 4.592, 5.589, 6.533
 6.166, 6.153, 6.547, 6.533, 6.914
 6.455, 6.284, 6.402, 6.035, 5.313
 5.313, 6.166, 6.35, 6.271, 6.979
 6.874, 6.271, 6.402, 7.281, 7.281
 6.14, 6.52, 6.127, 6.599, 4.565
 4.893, 6.258, 5.851, 5.497, 4.539
 6.022, 6.022, 5.261, 5.904, 5.392
 5.169, 5.326, 5.208, 5.248, 5.051
 4.119, 4.933, 4.802, 4.723, 5.025
```

```
 4.67, 4.342, 4.329, 3.293, 3.555
 3.057, 3.542, 3.293, 3.293, 3.293
 3.477, 3.359, 3.214, 3.201, 2.821
   1.535
 nsp=0
 p2= 493.13, tw= 464, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.72835
 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, 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
```

IFA-515.10 Rod B2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='515-B2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='515-B2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
FA-515.10 Rod B2
 $frpcn
 im=96, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.2571, thkcld=0.01811, thkgap=0.00098, totl=0.72835, cpl=0.7362
 dspg=0.2165, dspgw=0.0394, vs=10
 hplt=0.2362, rc=0.0354, hdish=0, dishsd=0.1094
 enrch=13, imox=0, comp=0
 fotmtl=2, gadoln=0.08, ppmh2o=0, ppmn2=0
 den=97.3, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
```

```
 fgpav=145.04, idxgas=1


 iplant=-4, pitch=0.2956, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 3.629, 14.316, 16.074, 31.221, 36.942
 59.089, 74.677, 94.608, 97.581, 122.586
 122.587, 127.898, 149.027, 164.526, 178.859
 189.809, 197.874, 210.763, 218.538, 228.469
 232.669, 245.364, 258.361, 281.063, 286.275
 293.062, 297.892, 301.801, 302.475, 309.586
 324.349, 329.698, 335.655, 343.397, 351.191
 359.244, 376.36, 379.523, 387.927, 394.639
 403.664, 405.457, 412.875, 417.371, 430.584
 436.286, 446.856, 449.37, 458.493, 460.626
 465.489, 466.989, 476.784, 479.327, 489.859
 505.621, 506.511, 507.98, 513.343, 520.296
 545.235, 566.584, 574.138, 578.035, 585.869
 587.607, 597.493, 599.272, 626.589, 633.509
 640.52, 643.52, 653.393, 657.452, 671.273
 682.414, 698.83, 711.026, 729.349, 743.499
 750.118, 760.715, 773.449, 788.597, 802.385
 822.17, 825.969, 840.433, 886.682, 922.633
 929.29, 955.556, 1000.623, 1024.682, 1067.534
1095.709
 qmpy=
 5.799, 3.083, 5.497, 6.126, 5.444
 5.614, 2.794, 5.666, 5.115, 5.181
 5.181, 3.501, 3.58, 5.823, 4.76
 4.957, 4.603, 4.602, 4.93, 4.878
 5.324, 5.061, 5.927, 5.94, 6.346
 6.359, 6.897, 6.897, 6.215, 6.018
 5.821, 6.162, 6.411, 6.227, 6.227
 5.112, 5.033, 5.217, 5.112, 5.807
 6.017, 5.846, 5.807, 6.122, 6.594
 6.633, 6.633, 5.964, 6.095, 6.908
 6.974, 5.767, 6.121, 6.908, 6.606
 6.488, 6.921, 4.861, 5.11, 6.579
 6.015, 5.791, 4.755, 6.185, 6.198
 5.699, 6.067, 5.502, 5.318, 5.502
 5.344, 5.462, 5.462, 5.2, 5.501
 5.291, 5.252, 4.281, 5.081, 4.937
 4.871, 5.133, 4.582, 4.634, 4.254
 4.372, 4.162, 3.243, 3.387, 2.98
 3.334, 3.282, 3.229, 3.373, 3.136
   3.058
 nsp=0
 p2= 493.13, tw= 464, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.72835
 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, 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
```

A.8 Halden IFA-681 Rods

IFA-681 (Klecha, 2006) consists of six rods that had been irradiated for four cycles or 340 days as of 2006. Ongoing irradiation is currently underway in the Halden reactor. The input files for the UO_2 rods (rods 1 and 5) have been extended for six cycles to 507 days. All six of these rods were modeled using FRAPCON-3.4. Three of these rods contain solid pellets with hollow pellets at the top end and are equipped with centerline thermocouples in the top pellets. These three rods have UO_2 (rod 1), 2 percent Gd_2O_3 (rod 2), and 8 percent Gd_2O_3 (rod 3) pellets.

The other three rods contain all hollow pellets and are equipped with expansion thermometers. These three rods also have UO_2 (rod 5), 2 percent Gd_2O_3 (rod 4), and 8 percent Gd_2O_3 (rod 6) pellets, with rod 6 being filled with 50 percent argon and 50 percent helium.

For rod 3, there are some overpredictions (50 to 120°C) in the third and fourth cycles. This may be due to error in the temperature measurement or the estimation of the rod power level. This seems likely because the power level during these cycles is reported to increase from about 21 kW/m to about 25 kW/m, while the temperature is reported to remain constant at about 850°C. It also seems strange for the power level in this rod to increase during these cycles while the power level in the other rods is constant during these cycles.

These six rods were used to assess the FRAPCON-3.4 temperature predictions for UO_2 and UO_2-Gd_2O_3 fuel as a function of burnup. The input files used for the UO_2 and UO_2-Gd_2O_3 temperature assessment as a function of burnup are not included in this report due to the limited availablility and sensitivity of this information..

A.9 Halden IFA-558 Rods

IFA-558 (Turnbull and White, 2002) was an assembly commissioned by Central Electricity Generating Board in the UK (later Nuclear Electric) to investigate the effect of hydrostatic restraint on the onset of grain boundary interlinkage, and hence, FGR. The assembly comprised six identical, short boiling-water reactor (BWR) type rods, each fitted with a pressure transducer and upper and lower fuel centerline thermocouples. The rods contained 7 percent enriched hollow pellets supplied by British Nuclear Fuels, Ltd. (BNFL) with a 200 μm cold diametral fuel-to-clad gap. In this way, PCMI effects were minimized, which would otherwise have introduced unwanted uncertainty in the hydrostatic pressure in the fuel pellets.

The assembly was loaded in February 1986 and continued operation successfully until discharge at ~40 GWd/MTU in March 1992. The fuel rods were subsequently sent to AEA Technology for PIE.

During startup, the rods were filled with helium gas at 2 bar pressure. Once the temperatures had stabilized at the prescribed normal operating powers, the pressures of four rods were altered in pairs in such a way as to minimize the spread of temperatures. Subsequently, rods 1 and 2 were operated at the maximum internal pressure of 40 bar, rods 5 and 6 operated at 20 bar, while rods 3 and 4 remained at 2 bar. These pressures were maintained during all gas flow measurements and were only reduced at cold shutdown for safety reasons. The spread in fuel centerline temperatures during operation at around 35 kW/m for rods 2 through 6 was less than 60°C, but rod 1 was consistently some 50°C higher.

Radioactive FGR was measured frequently, particularly in rod 3, and the measurements were used to monitor the onset of grain boundary interlinkage. In addition, all gas swept out of the rods was retained in separate cold traps to measure the activity of ^{85}Kr, which was used to estimate the cumulative release of stable fission gas. This FGR data demonstrated that rod internal pressures up to 40 bar had little effect on FGR.

Rod 6 was used to assess the UO_2 temperature predictions of FRAPCON-3.4. The input file used for this assessment is shown below.

IFA-558 Rod 6

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='558r6.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='558r6.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-558 Rod 6 irradiation
 $frpcn
 im=193, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4921, thkcld=0.03346, thkgap=0.00374, totl=2.29199, cpl=11.811
 dspg=0.4173, dspgw=0.05, vs=10
 hplt=0.5, rc=0.0591, hdish=0, dishsd=0.2089
 enrch=7, imox=0, comp=0, ifba=0, b10=0, zrb2thick=0, zrb2den=90
```

```
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=144.31, idxgas=1, nunits=1, zr2vintage=1
 iplant=-2, pitch=0.6398, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3, ngasmod=2
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 9.23277, 12.23258, 20.25254, 24.40932, 28.72637
 34.768, 40.42194, 44.32893, 48.55906, 55.51768
 59.64239, 68.20546, 74.32519, 78.47402, 84.62798
 88.24684, 95.6484, 100.50419, 106.32257, 114.82881
 118.51141, 124.54594, 129.04444, 136.72156, 140.56233
 144.89259, 150.00987, 154.54799, 160.94651, 166.30838
 170.93386, 176.26077, 184.8945, 190.57191, 197.25675
 201.61126, 206.32171, 212.52209, 218.85836, 223.26032
 228.83212, 233.9859, 241.11864, 249.8468, 256.60391
 261.30265, 269.16482, 273.97563, 280.70497, 287.33455
 289.82212, 296.7486, 302.95525, 310.30827, 314.56541
 323.53245, 327.26102, 332.93171, 337.31804, 344.17256
 348.90749, 354.2508, 358.72474, 363.88811, 368.03597
 371.8751, 376.77339, 383.91072, 389.56532, 393.46927
 399.04503, 403.08011, 409.70497, 414.52919, 419.88375
 423.80971, 426.79297, 431.4387, 436.47212, 443.07496
 447.88108, 466.23778, 480.68577, 485.36219, 491.7528
 496.73538, 501.00872, 505.52374, 510.54838, 518.80825
 530.19591, 533.06147, 536.13293, 545.05715, 547.88801
 554.86373, 561.02342, 565.98276, 578.59922, 581.45446
 592.16728, 595.6572, 600.35405, 606.27069, 610.46307
 616.09411, 630.53679, 634.42474, 638.04933, 643.1219
 647.6596, 651.31326, 660.0665, 666.28907, 670.97384
 675.47866, 679.43225, 692.40404, 695.75451, 699.08706
 709.18153, 725.96888, 729.51359, 740.73953, 747.67087
 752.99773, 757.26213, 761.48233, 773.0368, 778.25786
 782.30132, 792.50097, 795.73564, 802.75115, 807.51425
 810.23594, 815.18606, 820.94155, 824.91883, 834.42957
 839.84713, 844.5573, 849.58192, 852.48086, 859.62617
 868.18102, 873.86181, 884.22251, 889.50111, 893.67731
 898.23305, 902.02999, 912.6552, 917.37526, 925.38504
 931.55281, 937.94774, 944.14235, 947.12677, 953.30263
 958.94313, 962.40706, 965.78039, 973.26748, 981.38116
 991.14259, 998.40849, 1017.67656, 1021.64171, 1029.65174
 1035.71158, 1042.83366, 1044.78228, 1049.8526, 1062.21505
 1070.41153, 1081.94888, 1084.68327, 1089.50856, 1101.53866
 1101.82959, 1109.63861, 1121.12679, 1127.0999, 1132.79787
 1142.44638, 1155.27866, 1163.14977, 1174.80284, 1183.2385
 1188.58508, 1193.60718, 1198.43247
 qmpy=
 8.927, 9.533, 7.333, 10.107, 10.043
 9.597, 8.991, 9.214, 10.139, 10.362
 10.49, 10.139, 10.585, 10.458, 10.553
 4.751, 3.954, 8.481, 7.524, 6.026
 9.374, 8.449, 8.066, 7.556, 7.524
 8.258, 8.449, 8.003, 7.907, 8.066
 9.246, 9.469, 9.214, 8.927, 7.652
 9.724, 9.246, 10.394, 10.266, 9.884
```

```
10.33, 9.852, 10.107, 5.229, 7.333
7.652, 7.365, 7.493, 8.513, 7.684
8.545, 8.353, 7.078, 6.887, 8.322
8.066, 9.501, 8.959, 9.788, 9.501
9.182, 9.437, 9.661, 4.655, 9.852
7.78, 4.719, 5.038, 6.281, 8.927
9.055, 8.959, 8.736, 8.959, 8.162
5.803, 9.15, 9.31, 9.979, 9.852
10.458, 10.617, 4.209, 8.8, 10.075
10.139, 10.139, 3.858, 4.272, 3.539
3.794, 11.35, 11.701, 4.432, 5.006
5.165, 3.635, 4.304, 4.017, 4.91
4.081, 9.597, 12.052, 11.063, 11.956
11.574, 4.24, 10.394, 10.011, 7.365
9.342, 9.82, 3.635, 6.727, 6.217
10.745, 10.936, 4.145, 8.066, 6.695
4.4, 4.304, 5.898, 4.559, 10.043
8.29, 8.449, 8.545, 9.342, 8.385
5.675, 3.635, 12.148, 12.339, 12.148
10.84, 10.266, 8.895, 10.681, 4.846
5.293, 10.235, 10.075, 9.979, 9.15
9.278, 8.927, 9.055, 9.533, 8.736
9.437, 9.501, 8.864, 9.15, 9.023
9.342, 9.055, 6.058, 9.182, 9.342
8.991, 8.417, 8.545, 8.672, 7.206
8.8, 8.003, 7.142, 7.269, 8.066
8.322, 7.174, 7.365, 7.142, 7.014
7.046, 3.284, 7.237, 7.461, 6.058
6.919, 7.078, 7.524, 6.153, 7.493
6.058, 6.185, 6.409, 9.182, 3.73
7.748, 7.237, 7.461
nsp=0
p2= 464.12, tw= 482, go= 0
iq=0, fa=1
x(1)=
0, 2.29199
qf(1)=
1, 1
jn=2
jst=1
$end
```

A.10 Halden IFA-629.1 Rods

The IFA-629.1 (White, 1999) test involved two MOX test rods (rods 1 and 2), but only rod 2 was punctured for FGR measurement such that only this rod will be used for FGR comparison. Both rods are used for the temperature comparison as a function of burnup. The MOX fuel was fabricated using the MIMAS-AUC process by Belgonucleaire (BN). The mother rod for the IFA-629.1 test rods was a full-length pressurized-water reactor (PWR) MOX rod irradiated for two cycles in the Saint-Laurent PWR, France, with rods 1 and 2 cut as segments from the full-length rod and refabricated into short segments. The rod 2 segment had a burnup of 29 GWd/MTM following commercial irradiation, which was extended to 40 GWd/MTM during the Halden irradiation. The maximum LHGRs in Halden were significant, at 35 to 40 kW/m.

These two rods were used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup. Rod 2 was used to assess the FRAPCON-3.4 MOX FGR predictions. The input files used for the MOX temperature and FGR assessments are shown below. Input files that include the central hole were used for the temperature assessment since the temperature was measured on hollow pellets. The input file for rod 2 does not include the central hole for the FGR assessment since most of the pellets were solid.

IFA-629.1 Rod 2 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa629-1notc.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa629-1notc.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         Refab.St Laurent PWR 2-Cycle Segment IFA-629.1 Rod 2
 $frpcn
 im=56, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 2., crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5,nplot=1,
 rc = 0.0, fotmtl = 1.997,dishsd=0.0652,
 den = 95.34, dspg = 0.3,fa = 1.,
 dspgw = 0.03, enrch = 0.253, fgpav = 382, hdish = 0.011,
 hplt = 0.5, icm = 4, imox = 1, comp = 5.931,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
 jn = 5,5,
 totl = 1.48, roughc = 3.94e-5, roughf = 7.9e-5, vs = 10.0,
 nunits = 1, rsntr = 70., nsp = 1,
 p2(1) = 25*2250., p2(26) = 31*500.,
 tw(1) = 25*570, tw(26) = 31*464.,
 go(1) = 56*0.0,
 jst = 25*1, 31*2,
 qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
 x(1) = 0.0, 0.37, 0.74, 1.11, 1.48
 qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
 x(6) = 0.0, 0.37, 0.74, 1.11, 1.48
 ProblemTime=
```

```
 0.1, 0.2, 0.3, 0.4, 0.5,
 0.6, 30., 60., 90., 120.,
 150., 180., 210., 240., 270.,
 300., 331., 360., 390., 420.,
 450., 490., 530., 560., 587.,
 588., 588.1, 588.2, 588.3, 588.4,
 588.5,588.6, 588.7, 588.8, 588.9,
 590., 591., 592., 593.,
 594., 595., 598., 602., 605.,
 638., 654., 674., 703., 703.1,
 703.2, 703.3, 703.4, 703.5, 703.6,
 703.7, 703.8
 qmpy =
 1,2,3,4,5,
 6., 4*7.3,
 10*7.3,
 5*7.3,
  5.0, 3.0, 2.0, 1.0, 2.0,
  3.0, 4.0, 5.0, 6.0, 7.0,
  8.0, 8.84, 9.14, 9.45,
  9.75,10.97,11.28,11.58,12.80,
  11.58, 9.14, 9.45, 9.14, 8.0,
  7.0, 6.0, 5.0, 4.0, 3.0,
  2.0, 1.0
 slim = .05,
 $end
 $frpmox
 enrpu39 = 61.47, enrpu40 = 24.67, enrpu41 = 9.06,
 enrpu42 = 4.80,
 $end
```

IFA-629.1 Rod 1 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa629-1r1tcextend.out',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='ifa629-1r1tcextend.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         Refab.St Laurent PWR 2-Cycle Segment IFA-629.1 Rod 1 with TC
 $frpcn
 im=62, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 2., crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5,nplot=1,
 rc = 0.0492, fotmtl = 1.997,dishsd=0.0652,
 den = 95.34, dspg = 0.3,fa = 1.,
 idxgas =6, amfhe = 0.60, amfxe = 0.40,
 dspgw = 0.03, enrch = 0.253, fgpav = 382, hdish = 0.011,
 hplt = 0.5, icm = 4, imox = 1, comp = 5.931,
 iplant =-2, iq = 0, jdlpr = 0,
 jn = 5,5,
```

```
 totl = 1.48, roughc = 3.94e-5, roughf = 7.9e-5, vs = 10.0,
 nunits = 1, rsntr = 70., nsp = 1,
 p2(1) = 25*2250., p2(26) = 37*500.,
 tw(1) = 25*570, tw(26) = 37*464.,
 go(1) = 62*0.0,
 jst = 62*1,
 qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
 x(1) = 0.0, 0.37, 0.74, 1.11, 1.48
 qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
 x(6) = 0.0, 0.37, 0.74, 1.11, 1.48
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 0.5,
 0.6, 30., 60., 90., 120.,
 150., 180., 210., 240., 270.,
 300., 331., 360., 390., 420.,
 450., 490., 530., 560., 587.,
 588.3, 590.4, 592.5, 593.5,
 594.6, 595.9, 596.6, 599,
 601.3, 604.3, 605.9, 607.1,
 609.2, 618.8, 627.3, 632.3,
 640.2, 641.9, 643, 651.5,
 658, 660.2, 669.8, 673.8,
 674.8, 678, 679.9, 686.6,
 690.4, 692.3, 693, 696.3,
 697.4, 699.3, 700.3, 704.3, 706.8
 qmpy =
 1,2,3,4,5,
 6., 4*6.6,
 10*6.6,
 5*6.6,
 6.55, 4.69, 7.96, 8.20, 8.41, 8.75, 9.83, 10.12,
 10.36, 10.27, 11.31, 11.27, 10.03, 9.94, 9.75,
 9.81, 9.66, 6.60, 7.82, 7.86, 7.83, 8.05, 8.11,
 7.92, 8.38, 8.32, 7.77, 8.08, 8.08, 7.82, 8.05,
 7.92, 7.65, 7.62, 7.86, 7.71, 7.25
slim = .05,
 $end
 $frpmox
 enrpu39 = 61.47, enrpu40 = 24.67, enrpu41 = 9.06,
 enrpu42 = 4.80,
 $end
```

IFA-629.1 Rod 2 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa629-1r2tcextend.out',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='ifa629-1r2tcextend.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*******************************************************************
         Refab.St Laurent PWR 2-Cycle Segment IFA-629.1 Rod 2 with TC
 $frpcn
 im=62, na=4,
 mechan = 2, ngasr = 45,
```

```
$end
$frpcon
cpl = 2., crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
dco = 0.374, pitch = 0.5,nplot=1,
rc = 0.0492, fotmtl = 1.997,dishsd=0.0652,
den = 95.34, dspg = 0.3,fa = 1.,
idxgas =1,
dspgw = 0.03, enrch = 0.253, fgpav = 382, hdish = 0.011,
hplt = 0.5, icm = 4, imox = 1, comp = 5.931,
iplant =-2, iq = 0, jdlpr = 0,
jn = 5,5,
totl = 1.48, roughc = 3.94e-5, roughf = 7.9e-5, vs = 10.0,
nunits = 1, rsntr = 70., nsp = 1,
p2(1) = 25*2250., p2(26) = 37*500.,
tw(1) = 25*570, tw(26) = 37*464.,
go(1) = 62*0.0,
jst = 62*1,
qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
x(1) = 0.0, 0.37, 0.74, 1.11, 1.48
qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
x(6) = 0.0, 0.37, 0.74, 1.11, 1.48
ProblemTime=
0.1, 0.2, 0.3, 0.4, 0.5,
0.6, 30., 60., 90., 120.,
150., 180., 210., 240., 270.,
300., 331., 360., 390., 420.,
450., 490., 530., 560., 587.,
588.3, 590.4, 592.5, 593.5, 594.6, 595.9, 596.6, 599,
601.3, 604.3, 605.9, 607.1, 609.2, 618.8, 627.3, 632.3,
640.2, 641.9, 643, 651.5, 658, 660.2, 669.8, 673.8, 674.8,
678, 679.9, 686.6, 690.4, 692.3, 693, 696.3, 697.4, 699.3,
700.3, 704.3, 706.8
qmpy =
1,2,3,4,5,
6., 4*6.6,
10*6.6,
5*6.6,
5.73, 3.90, 6.98, 7.21, 7.39, 7.59, 8.66, 9.01,
9.18, 9.14, 10.03, 9.97, 8.93, 8.84, 8.78, 8.78,
8.66, 6.00, 7.10, 7.10, 7.05, 7.27, 7.32, 7.19,
7.62, 7.56, 7.13, 7.35, 7.35, 7.10, 7.28, 7.19,
6.95, 6.95, 7.16, 6.98, 6.60,
slim = .05,
$end
$frpmox
enrpu39 = 61.47, enrpu40 = 24.67, enrpu41 = 9.06,
enrpu42 = 4.80,
$end
```

A.11 Halden IFA-610 Rods

One segment from four-cycle PWR MOX EdF rod N016 (which was base-irradiated for four cycles in the French Gravelines-4 reactors to a burnup of approximately 55 megawatt-days per kilogram of metal (MWd/kgM)) was re-fabricated and instrumented for use in the sequential IFA-610.2,4 cladding liftoff experiments (Beguin, 1999) (Fujii and Claudel, 2001). The rod was tested under simulated PWR conditions in a pressurized water loop within the Halden reactor. The rod was connected to a gas supply system, and temperature measurements were made in both helium and argon fill gases at varying pressures. Fuel temperature data from helium gas fill periods were used to assess the FRAPCON-3.4 temperature predictions.

The rod was base-irradiated at nominal LHGRs for ~1500 days. The final burnup for the segment was 54.5 MWd/kgM. The rod was instrumented with a fuel center thermocouple and a rod elongation sensor. Internal gas pressure was varied throughout the ~100 day IFA-610.2 test to investigate the threshold for cladding liftoff. The LHGR level during the IFA-610.2 test was steady at about 14 to 15 kW/m, and LHGR at the thermocouple was about 13.5 to 14 kW/m.

In IFA-610.4, the LHGRs were similar at the beginning and drifted downward to 12.5 and 12.0 kW/m for rod-average and thermocouple location, respectively (Fujii and Claudel, 2001). The test duration was similar to that of IFA-610.2 (100 days); however, after 50 days, questions of potential thermocouple degradation were raised, and code data comparison was only conducted over the first 50 days of the test.

These two experiments were used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup. The input files used for the MOX temperature assessments are shown below.

IFA-610.2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa610-2ext.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa610-2ext.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
   Refab.Gravelines PWR 4-Cycle Segment, extended history from HWR-603
 $frpcn
 im=66, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 2., crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5,nplot=1,
 rc = 0.0453, fotmtl = 1.997,dishsd=0.06488,
 den = 94.43, dspg = 0.3,fa = 1.,
 dspgw = 0.03, enrch = 0.229, fgpav = 382, hdish = 0.011,
 hplt = 0.5, icm = 4, imox = 1, comp = 5.945,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
 jn = 5,5,
 totl = 1.31, roughc = 3.94e-5, roughf = 7.9e-5, vs = 10.0,
 nunits = 1, rsntr = 52., nsp = 1,
```

```
 p2(1) = 44*2250., p2(45) = 22*2352,
 tw(1) = 44*570, tw(45) = 22*590
 go(1) = 66*2.0e6,
 jst =66*1
 qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
 x(1) = 0.0, 0.3275, 0.6650, 0.9925, 1.31
 qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
 x(6) = 0.0, 0.3275, 0.6650, 0.9925, 1.31
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 0.5,
 0.6, 30., 60., 90., 120.,
 150., 180., 210., 240., 270.,
 300., 331., 360., 390., 420.,
 450., 480., 510., 540., 570.,
 600., 625., 650., 700., 750.,
 800., 850., 900., 945., 990.,
 1000., 1050., 1100., 1150., 1200.,
 1250., 1300., 1350., 1400
 1401., 1402., 1403., 1404., 1405.,
 1406.
 1407., 1408., 1409., 1416.,1422.7,
 1422.8, 1424.8,1424.9, 1440., 1457.3,
 1460.2, 1468.5, 1472.7,1489.3, 1506.0,
 1516.4
 qmpy =
 0.9, 1.8, 2.7, 3.6, 4.5, 5.4, 6.03 6.3, 6.03, 6.03, 6.03,
 6.03, 6.03, 6.03, 6.03, 6.03, 6.03, 6.3, 6.3, 6.3, 6.3,
 6.3, 6.3, 6.3, 6.3, 6.3, 6.3, 6.3, 5.22, 5.22, 5.22, 5.22,
 5.22, 5.22, 5.22, 3.699, 3.699, 3.699, 3.699, 3.699, 3.699,
 3.699, 3.699, 3.699, 3.6, 3.15, 2.7, 2.25, 1.8, 1.35,
 2.5, 3.5, 4.11, 4.27,4.27
 4.57, 4.57,4.27, 4.27, 4.27,
 3.05, 4.42, 4.33, 4.24, 4.18,
 4.05
 slim = .05,
 $end
 $frpmox
 enrpu39 = 65.83, enrpu40 = 23.45, enrpu41 = 7.39,
 enrpu42 = 3.33
 $end
```

IFA-610.4

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa610-4ext.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa610-4ext.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
     Refab.Gravelines PWR 4-Cycle Segment, extended power history
 $frpcn
 im=65, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
```

```
cpl = 2., crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
dco = 0.374, pitch = 0.5,nplot=1,
rc = 0.0453, fotmtl = 1.997,dishsd=0.06488,
den = 94.43, dspg = 0.3,fa = 1.,
dspgw = 0.03, enrch = 0.229, fgpav = 382, hdish = 0.011,
hplt = 0.5, icm = 4, imox = 1, comp = 5.945,
idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
jn = 5,5,
totl = 1.31, roughc = 3.94e-5, roughf = 7.9e-5, vs = 10.0,
nunits = 1, rsntr = 52., nsp = 1,
p2(1) = 45*2250., p2(46) = 20*2352,
tw(1) = 45*570, tw(46) = 20*590
go(1) = 65*2.0e6,
jst = 65*1
qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
x(1) = 0.0, 0.3275, 0.6650, 0.9925, 1.31
qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
x(6) = 0.0, 0.3275, 0.6650, 0.9925, 1.31
ProblemTime=
0.1, 0.2, 0.3, 0.4, 0.5,
0.6, 30., 60., 90., 120.,
150., 180., 210., 240., 270.,
300., 331., 360., 390., 420.,
450., 480., 510., 540., 570.,
600., 625., 650., 700., 750.,
800., 850., 900., 945., 990.,
1000., 1050., 1100., 1150., 1200.,
1250., 1300., 1350., 1400., 1450.,
1451., 1452., 1453,
1454., 1455., 1456.
1456.42,  1457.25, 1458.29, 1460.17, 1462.46,
1465.58, 1471.83, 1476.83, 1485.17, 1495.68,
1495.79, 1497.67, 1501.83, 1506.0
qmpy =
1,2,3,4,5,
6., 6.7, 6.7, 6.7, 6.7,
5*6.7
6.7, 6.7, 7.0, 7.0, 7.0,
5*7.0,
7.0, 7.0, 7.0, 5.8, 5.8,
5*5.8,
5*4.11,
4.11, 4.11, 4.27, 4.27, 4.27,
4.0, 3.5, 3.0,
2.5, 2.0, 1.5,
2.59, 3.17, 3.48, 3.90, 4.33,
4.33, 4.12, 3.99, 3.87, 3.84,
3.96, 3.93, 3.81,3.81
slim = .05,
$end
$frpmox
enrpu39 = 65.83, enrpu40 = 23.45, enrpu41 = 7.39,
enrpu42 = 3.33,
$end
```

A.12 Halden IFA-648.1 Rods

The IFA-648.1 irradiation (Claudel and Huet, 2001) was simply a burnup extension at low LHGR for two refabricated instrumented segments from Gravelines-4 four-cycle PWR MOX rods, one segment each from rods N12 and P16. The irradiation was carried on at low LHGR under simulated PWR conditions in a pressurized water loop within the Halden reactor. The rods were then power-ramped in the follow-on IFA-629.3 test to investigate FGR and rod elongation behavior.

The mother rods were base-irradiated at nominal LHGRs for ~1200 days. The final burnup for the rods N12 and P16 were 57 and 53 MWd/kgM, respectively. The two rods were instrumented differently upon refabrication. Rod 1 carried a fuel center thermocouple and a rod elongation sensor. Rod 2 carried a fuel center thermocouple and a pressure transducer. The LHGRs were kept deliberately low to accumulate more burnup without inducing FGR.

These two rods were used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup. The input files used for the MOX temperature assessments are shown below.

IFA-648.1 Rod 1

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa648r1ext.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa648r1ext.plot', STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE
CONTROL='LIST'
/**********************************************************************
Refab.Gravelines PWR 4-Cycle Segment IFA-648.1 Rod 1 Extended Power
History
 $frpcn
 im= 63, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 5., crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5, dishsd = 0.0655,
 rc = 0.0492, fotmtl = 1.996,
 den = 94.72, dspg = 0.3,fa = 1.,
 dspgw = 0.03, enrch = 0.231, fgpav = 382, hdish = 0.0115,
 hplt = 0.4634, icm = 4, imox = 1, comp = 5.931,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
 jn = 5,5, nplot =1,
 totl = 1.49, roughc = 3.94e-5, roughf = 7.9e-5, vs = 10.0,
 nunits = 1, rsntr = 8.9, nsp = 1,
 p2(1) = 33*2250., p2(34) = 30*2350.,
 tw(1) = 33*580, tw(34) = 7*599.,
 tw(41)= 13*608., tw(54)= 10*617.,
 go(1) = 63*2.0E6,
 jst = 63*1,
 qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
 x(1) = 0.0, 0.37, 0.74, 1.11, 1.49
 qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
 x(6) = 0.0, 0.37, 0.74, 1.11, 1.49
```

```
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 0.5,
 0.6, 50., 100., 150., 200.,
 250., 300., 323., 350., 400.,
 450., 522., 550., 600., 623.,
 650., 700., 750., 792., 850.,
 900., 950., 1000., 1050., 1100.,
 1150., 1200., 1251., 1252., 1253.,
 1254., 1255., 1256.
 1260., 1265.5, 1273.8, 1281.0,1295.6,
 1310.1,1326.0, 1342., 1361., 1371.,
 1381., 1392., 1414., 1429., 1459.,
 1486., 1495., 1513., 1556., 1578.
 1579, 1580, 1581, 1582, 1583
 qmpy =
 1., 2., 3., 4., 6.,
 7., 4*7.01,
 3*7.01, 7.32, 7.32,
 5*7.32,
 5*6.10,
 2*6.10, 3*3.96,
 3*3.96, 3.5, 3.0,
 2.5, 2.0, 1.5,
 2.5, 3.14, 3.44,3.35, 3.11,
 3.18,2.80, 2.87, 2.93, 3.01,
 2.83, 2.74, 3.05, 2.98, 3.01,
 3.05, 3.14, 3.11, 3.14, 2.79,
 2.50, 2.25, 2.00, 1.75, 1.50
 slim = .05,
 $end
 $frpmox
 enrpu39 = 65.84, enrpu40 = 23.40, enrpu41 = 7.43,
 enrpu42 = 3.33,
 $end
```

IFA-648.1 Rod 2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa648r2tcext.out',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='ifa648r2tcext.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
 Refab.Gravelines PWR 4-Cycle Segment IFA-648rod 2(Mother Rod P16)
 $frpcn
 im=52, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 1.2, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5, dishsd = 0.0634,
 rc = 0.0492, fotmtl = 2.000,nplot=1,
 den = 94.62, dspg = 0.3, fa = 1.0,
 dspgw = 0.03, enrch = 0.225, fgpav = 382., hdish = 0.0115,
```

```
hplt = 0.4634, icm = 4, imox = 1, comp = 4.688,
idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
jn = 5,
totl = 1.49, roughc = 3.94e-5, roughf = 7.9e-5, vs = 10.0,
nunits = 1, rsntr = 40., nsp = 1,
p2(1) = 33*2250., p2(34) = 19*2350.,
tw(1) = 33*580., tw(34) = 7*599.,
tw(41) = 8*608., tw(49) = 4*617
go(1) = 33*2.0E6, go(34) = 19*0.0
jst = 52*1
qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
x(1) = 0.0, 0.37, 0.74, 1.11, 1.49
ProblemTime=
0.1, 0.2, 0.3, 0.4, 0.5,
0.6, 40., 80., 120., 160.,
210., 260., 306., 320., 340.,
380., 430., 480., 540., 608.,
650., 700., 750., 800., 850.,
900., 922., 970., 1020., 1070.,
1120., 1170., 1207.,
1216.5, 1224.8, 1232.0, 1246.6, 1261.1,
1277.0, 1293.0, 1312.0, 1322.0, 1332.0,
1343.0, 1365.0, 1380.0, 1410.0, 1437.0,
1447.0, 1464.0, 1507.0, 1529.0
qmpy =
1., 2., 3., 4., 6.,
7., 4*7.62,
3*7.62, 7.47, 7.47,
5*7.47,
5*6.10,
2*6.10, 3*4.57,
3*4.57,
2.88, 3.20, 3.14, 2.91, 2.97,
2.62, 2.68, 2.74, 2.81, 2.65,
2.55, 2.85, 2.77, 2.81, 2.86,
2.91, 2.88, 2.93, 2.59
slim = .05,
$end
$frpmox
enrpu39 = 65.99, enrpu40 = 23.45, enrpu41 = 7.08,
enrpu42 = 3.48,
$end
```

A.13 Halden IFA-629.3 Rods

Following base irradiation in a commercial PWR and further irradiation in Halden, two rods were further irradiated from 62 GWd/MTU to 68 to 72 GWd/MTU. The MOX fuel was fabricated using the MIMAS (micronized master blend) process. The documentation does not mention whether the UO_2 was fabricated using the ammonium diuranate (ADU) or ammonium uranyl carbonate (AUC) process, but it is likely that the AUC process was used because the fuel was fabricated in the early 1990s. The MOX rods in IFA-629.3 (Petiprez, 2002) were irradiated for four cycles in the Gravelines-4 PWR; after this period, two experimental rods were refabricated from the full-length rods, refilled with helium, and loaded in the IFA 648.1 rig to accumulate more burnup at low powers and no additional gas release. Following irradiation in IFA-648.1, rod 6 was punctured and refilled with helium and the two rods were irradiated in IFA-629.3. These rods were irradiated up to a final burnup of 68 and 72 GWd/MTM and discharged for PIE. The measured gas release values for these rods have been obtained by puncture measurement.

These two rods were used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup and the MOX FGR predictions. The input files used for the MOX temperature and FGR assessments are shown below. Input files that include the central hole were used for the temperature assessment since the temperature was measured on hollow pellets. Input files that do not include the central hole were used for the FGR assessment since most of the fuel column consisted of solid pellets.

IFA-629.3 Rod 5 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IFA-629-3R5.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IFA-629-3R5.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-629.3 Rod 5
 $frpcn
 im=99, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02244, thkgap=0.00329, totl=1.48819, cpl=2.1378
 dspg=0.315, dspgw=0.0394, vs=10, igas=40
 hplt=0.4685, rc=0, hdish=0.0114, dishsd=0.0648
 enrch=0.231, imox=1, comp=5.93
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.72, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
iplant=-2, pitch=0.3937, 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=0, nread=0, nrestr=0
 ProblemTime=
 16.92, 25.63, 48.38, 74.08, 98.39
 127.57, 151.7, 224.34, 244.61, 271.24
 293.58, 314.8, 330.71, 357.1, 391.25
```

419.43, 480.58, 521.01, 571.28, 597.8
614.33, 630.17, 647.82, 675.1, 762.99
793.5, 889.19, 910.83, 932.87, 941.53
950.68, 976.64, 1052.39, 1079.85, 1122.66
1185.71, 1209.33, 1222.23, 1230.37, 1234.4
1235.6, 1242.4, 1253.9, 1255.4, 1294.4
1299.4, 1354.9, 1372.4, 1380.6, 1395.6
1463.9, 1466.7, 1473.8, 1477.2, 1518.4
1520.6, 1529.4, 1530.9, 1552.9, 1566.9
1567.9, 1568.53, 1568.81, 1568.94, 1569.47
1570.88, 1571.47, 1572.66, 1573.8, 1574.59
1575.71, 1576.57, 1577.61, 1578.7, 1579
1579.45, 1579.75, 1580.63, 1581.39, 1582.12
1583.06, 1583.69, 1584.15, 1584.71, 1585.77
1586.8, 1587.18, 1590.4, 1598.39, 1613.84
1617.86, 1622.08, 1633.64, 1646.73, 1655.18
1658.08, 1659.36, 1679.17, 1681.19
qmpy=
4.42, 8.626, 8.443, 8.321, 8.321
8.23, 8.199, 8.153, 8.184, 7.651
7.163, 6.035, 4.023, 8.108, 8.138
8.108, 8.138, 8.169, 8.077, 7.681
7.041, 6.431, 3.627, 7.254, 7.285
7.01, 7.041, 6.858, 6.34, 6.218
2.225, 4.542, 4.648, 4.663, 4.724
4.755, 4.496, 4.176, 3.932, 2.134
1.737, 3.383, 3.566, 3.505, 3.322
2.499, 2.957, 2.85, 1.951, 3.216
3.124, 2.377, 3.383, 2.438, 3.353
2.682, 3.292, 2.987, 3.277, 3.048
1.615, 2.7, 2.792, 3.301, 2.184
2.143, 3.335, 1.334, 0.988, 3.713
4.263, 4.249, 4.734, 5.009, 1.954
3.799, 5.819, 5.938, 0.408, 2.327
0.13, 2.843, 4.653, 5.551, 5.856
6.458, 7.012, 6.894, 7.213, 5.383
6.625, 6.505, 5.765, 5.885, 5.544
3.173, 5.404, 5.047, 5.078
nsp=1
p2=
2250, 2250, 2250, 2250, 2250
2250, 2250, 2250, 2250, 2250
2250, 2250, 2250, 2250, 2250
2250, 2250, 2250, 2250, 2250
2250, 2250, 2250, 2250, 2250
2250, 2250, 2250, 2250, 2250
2250, 2250, 2250, 2250, 2250
2250, 2250, 2250, 2250, 2350
2350, 2350, 2350, 2350, 2350
2350, 2350, 2350, 2350, 2350
2350, 2350, 2350, 2350, 2350
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tw=
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2000000, 2000000, 2000000, 2000000, 2000000
2000000, 2000000, 2000000, 2000000, 2000000
2000000, 2000000, 2000000, 2000000, 2000000
2000000, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0
iq=0, fa=1
x(1)=
0, 0.08202, 0.24606, 0.4101, 0.57415
0.73819, 0.90223, 1.06627, 1.23031, 1.39436
1.48819
qf(1)=
1, 1, 1, 1, 1
1, 1, 1, 1, 1
      1
x(12)=
0, 0.08202, 0.24606, 0.4101, 0.57415
0.73819, 0.90223, 1.06627, 1.23031, 1.39436
```

```
 1.48819
 qf(12)=
 183.3, 185.9, 188.5, 192.2, 194
 194.4, 194.1, 193, 192.2, 190
   188.5
 jn=11,11
 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, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2
 $end
 $frpmox
 enrpu39=65.84, enrpu40=23.399, enrpu41=7.427, enrpu42=3.334
 $end
```

IFA-629.3 Rod 6 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IFA-629-3R6.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IFA-629-3R6.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-629.3 Rod 6
 $frpcn
 im=99, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02244, thkgap=0.00335, totl=1.48064, cpl=2.0866
 dspg=0.315, dspgw=0.0394, vs=10, igas=62
 hplt=0.4685, rc=0, hdish=0.0114, dishsd=0.0628
 enrch=0.225, imox=1, comp=4.69
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.62, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=319.08, idxgas=1
```

```
 iplant=-2, pitch=0.3937, 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=0, nread=0, nrestr=0
 ProblemTime=
 15.48, 26.04, 50.32, 78.34, 96.45
 126.1, 148.63, 185.75, 240.55, 270.24
 290.97, 314.17, 330.67, 357.73, 390.9
 418.83, 449.95, 476.91, 517.17, 569.5
 596.57, 629, 641.65, 669.6, 703.1
 723.23, 755.93, 786.15, 807.42, 881.54
 903.69, 923.5, 930.7, 949.98, 980.5
 1078.89, 1181.26, 1207.06, 1233.56, 1237.56
 1238.76, 1245.56, 1257.06, 1258.56, 1297.56
 1302.56, 1358.06, 1375.56, 1383.76, 1398.76
 1467.06, 1469.86, 1476.96, 1480.36, 1521.56
 1523.76, 1532.56, 1534.06, 1556.06, 1570.06
 1571.06, 1571.69, 1571.97, 1572.1, 1572.63
 1574.04, 1574.63, 1575.82, 1576.96, 1577.75
 1578.87, 1579.73, 1580.77, 1581.86, 1582.16
 1582.61, 1582.91, 1583.79, 1584.55, 1585.28
 1586.22, 1586.85, 1587.31, 1587.87, 1588.93
 1589.96, 1590.34, 1593.56, 1601.55, 1617
 1621.02, 1625.24, 1636.8, 1649.89, 1658.34
 1661.24, 1662.52, 1682.33, 1684.35
 qmpy=
 4.115, 8.077, 7.864, 7.772, 7.651
 7.681, 7.544, 7.468, 7.346, 7.559
 7.163, 6.401, 3.901, 7.803, 7.712
 7.62, 7.529, 7.468, 7.376, 7.315
 7.437, 6.919, 3.261, 6.492, 6.355
 6.309, 6.157, 6.005, 5.974, 5.944
 6.035, 5.913, 5.73, 2.225, 4.542
 4.511, 4.481, 4.542, 4.42, 1.829
 1.433, 3.139, 3.307, 3.231, 3.109
 2.042, 2.743, 2.652, 1.463, 2.972
 2.941, 1.89, 3.155, 2.134, 3.139
 2.438, 3.048, 2.804, 3.048, 2.804
 1.311, 2.435, 2.652, 3.121, 2.037
 2.006, 3.161, 1.316, 0.948, 3.52
 4.017, 4.061, 4.52, 4.782, 1.841
 3.618, 5.557, 5.661, 0.387, 2.222
 0.122, 2.765, 4.633, 5.56, 5.883
 6.639, 7.041, 6.864, 7.221, 5.31
 6.474, 6.349, 5.678, 5.81, 5.496
 3.183, 5.37, 4.977, 4.974
 nsp=1
 p2=
 2250, 2250, 2250, 2250, 2250
 2250, 2250, 2250, 2250, 2250
 2250, 2250, 2250, 2250, 2250
 2250, 2250, 2250, 2250, 2250
 2250, 2250, 2250, 2250, 2250
 2250, 2250, 2250, 2250, 2250
 2250, 2250, 2250, 2250, 2250
 2250, 2250, 2250, 2250, 2350
 2350, 2350, 2350, 2350, 2350
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tw=
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go=
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2000000, 2000000, 2000000, 2000000, 2000000
2000000, 2000000, 2000000, 2000000, 2000000
2000000, 2000000, 2000000, 2000000, 2000000
2000000, 2000000, 2000000, 2000000, 2000000
2000000, 2000000, 2000000, 2000000, 2000000
2000000, 2000000, 2000000, 2000000, 2000000
2000000, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0
iq=0, fa=1
x(1)=
0, 0.08202, 0.24606, 0.4101, 0.57415
0.73819, 0.90223, 1.06627, 1.23031, 1.39436
```

```
 1.48064
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 x(12)=
 0, 0.08202, 0.24606, 0.4101, 0.57415
 0.73819, 0.90223, 1.06627, 1.23031, 1.39436
 1.48064
 qf(12)=
 183.3, 185.9, 188.5, 192.2, 194
 194.4, 194.1, 193, 192.2, 190
   188.5
 jn=11,11
 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, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2
 $end
 $frpmox
 enrpu39=65.84, enrpu40=23.399, enrpu41=7.427, enrpu42=3.334
 $end
```

IFA-629.3 Rod 5 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa629-3r5ext.out',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='ifa629-3r5ext.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
    Refab.Gravelines PWR 4-Cycle Segment IFA-629.3rod 5(Mother Rod N12)
 $frpcn
 im=126, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
```

```
cpl = 1.5, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
dco = 0.374, pitch = 0.5, dishsd = 0.0655,
rc = 0.0492, fotmtl = 1.996,nplot=1,
den = 94.72, dspg = 0.3, fa = 1.0,
dspgw = 0.03, enrch = 0.231, fgpav = 382., hdish = 0.0115,
hplt = 0.4634, icm = 4, imox = 1, comp = 5.931,
idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
jn = 5,5, 5
totl = 1.49, roughc = 3.94e-5, roughf = 5.0e-5, vs = 10.0,
nunits = 1, rsntr = 8.9, nsp = 1,
p2(1) = 33*2250., p2(34) = 10*2350., p2(44) = 83*500.,
tw(1) = 33*580., tw(34) = 10*590., tw(44) = 83*464.,
go(1) = 43*2.0E6, go(44) = 83*0.0
jst = 33*1, 10*2, 83*3
qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
x(1) = 0.0, 0.37, 0.74, 1.11, 1.49
qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
x(6) = 0.0, 0.37, 0.74, 1.11, 1.49
qf(11) = 0.97, 1.0, 1.01, 1.0, 0.99
x(11) = 0.0, 0.37, 0.74, 1.11, 1.49
ProblemTime=
0.1, 0.2, 0.3, 0.4, 0.5,
0.6, 40., 80., 120., 160.,
200., 230., 293., 300., 340.,
380., 430., 480., 540., 587.,
630., 680., 720., 760., 800.,
840., 883., 920., 970., 1020.,
1070., 1120., 1175., 1200., 1233.6,
1280., 1312., 1360., 1400., 1430.,
1460., 1483., 1497.,
1497.53,1497.89,1498.42,1498.60,
1500.20,1500.30,1500.55,1501.97,
1502.86,1503.39,1504.46,1505.34,
1506.23,1507.65,1509.78,1510.49,
1510.85,1511.02,1511.20,1511.91,
1512.27,1512.62,1512.80,1513.33,
1513.86,1515.28,1515.99,1516.53,
1519.01,1520.61,1521.50,1524.16,
1526.64,1527.18,1530.91,1534.99,
1536.59,1540.85,1542.27,1543.69,
1544.22,1544.75,1545.99,1546.88,
1548.66,1551.14,1551.32,1551.85,
1552.03,1552.21,1552.56,1552.92,
1553.09,1554.51,1557.18,1558.78,
1561.44,1562.86,1565.52,1570.31,
1575.82,1576.70,1578.48,1580.61,
1584.51,1584.69,1585.58,1586.47,
1587.36,1587.71,1588.07,1588.60,
1590.37,1593.04,1596.41,1601.91,
1605.46,1607.95,1609.19,1609.60,
1609.72,1610.08,1610.61,1610.96
qmpy =
1., 2., 3., 4., 6.,
7., 4*8.53,
3*8.53, 8.23, 8.23,
5*8.23,
5*7.32,
```

```
 2*7.32, 3*3.96,
 3*3.96, 2.89, 2.89,
 2.49, 2.49, 2.63, 2.63, 2.63,
 2.63, 2.63, 2.36,
 2.48,2.57,3.30,2.07,1.87,
 3.00,3.13,1.30,0.85,3.56,
 3.74,4.09,4.33,4.57,5.53,
 0.89,0.80,2.24,1.61,0.94,
 0.02,1.98,2.96,4.50,5.13,
 5.48,6.11,6.57,6.48,6.77,
 6.94,6.81,6.75,6.77,5.11,
 5.00,4.90,4.98,4.88,5.25,
 5.74,6.16,6.05,5.96,6.16,
 6.05,0.33,1.37,1.61,5.79,
 5.40,5.22,5.64,5.46,5.37,
 5.33,5.25,5.42,5.55,5.51,
 5.48,4.66,5.18,5.24,5.14,
 1.78,0.50,2.87,4.87,5.25,
 5.16,4.98,4.87,4.87,4.85,
 4.83,4.76,4.66,0.00,1.28,
 4.22,4.55,4.72,2.16
 slim = .05,
 $end
 $frpmox
 enrpu39 = 65.84, enrpu40 = 23.40, enrpu41 = 7.43,
 enrpu42 = 3.33,
 $end
```

IFA-629.3 Rod 6 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa629-3r6ext.out',    STATUS='UNKNOWN', CARRIAGE
CONTROL='LIST'
FILE66='ifa629-3r6ext.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
  Refab.Gravelines PWR 4-Cycle Segment IFA-629.3rod 6 (Mother Rod P16)
 $frpcn
 im=126, na=9,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 1.5, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5, dishsd = 0.0634,
 rc = 0.0492, fotmtl = 1.996,
 nplot=1,
 den = 94.62, dspg = 0.3, fa = 1.0,
 dspgw = 0.03, enrch = 0.225, fgpav = 382., hdish = 0.0115,
 hplt = 0.4634, icm = 4, imox = 1, comp = 4.688,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
 jn = 5,5, 5
 totl = 1.49, roughc = 3.9e-5, roughf = 8.3e-5, vs = 10.0,
 nunits = 1, rsntr = 40., nsp = 1,
 p2(1) = 33*2250., p2(34) = 10*2350., p2(44) = 83*500.,
```

```
tw(1) = 33*580., tw(34) = 10*590., tw(44) = 83*464.,
go(1) = 43*2.0E6, go(44) = 83*0.0
jst = 33*1, 10*3, 83*3
qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
x(1) = 0.0, 0.37, 0.74, 1.11, 1.49
qf(6) = 0.9, 1.0, 1.1, 1.0, 0.9
x(6) = 0.0, 0.37, 0.74, 1.11, 1.49
qf(11) = 0.97, 1.0, 1.01, 1.0, 0.99
x(11) = 0.0, 0.37, 0.74, 1.11, 1.49
ProblemTime=
0.1, 0.2, 0.3, 0.4, 0.5,
0.6, 40., 80., 120., 160.,
210., 260., 306., 320., 340.,
380., 430., 480., 540., 608.,
650., 700., 750., 800., 850.,
900., 922., 970., 1020., 1070.,
1120., 1170., 1207., 1225., 1256.6,
1300., 1344., 1380., 1420., 1460.,
1500., 1515., 1529.,
1529.1,1529.18,1529.71,1530.07,1530.78,
1532.20,1532.55,1532.91,1533.97,1534.86,
1536.28,1537.52,1538.59,1540.72,1542.14,
1542.85,1543.38,1543.56,1543.91,1544.44,
1544.80,1545.33,1545.86,1546.93,1547.99,
1548.35,1551.37,1552.79,1554.92,1557.93,
1559.53,1562.91,1566.99,1568.41,1573.02,
1574.80,1575.69,1576.40,1576.75,1577.64,
1578.35,1580.30,1582.96,1584.03,1584.56,
1584.92,1585.45,1586.69,1589.18,1591.13,
1593.44,1594.86,1596.99,1599.12,1600.89,
1602.49,1604.09,1607.82,1609.06,1610.66,
1612.96,1614.74,1616.69,1616.87,1618.64,
1619.53,1619.89,1620.24,1620.60,1621.49,
1624.50,1629.30,1634.44,1637.99,1639.41,
1640.12,1641.37,1641.54,1641.72,1641.8,
1642.43,1642.96,1643.0
qmpy =
1., 2., 3., 4., 6.,
7., 4*7.62,
3*7.62, 7.47, 7.47,
5*7.47,
5*6.10,
2*6.10, 3*4.57,
3*4.57, 2.70, 2.70,
2.33, 2.33, 3*2.45,
2.45, 2.45, 2.21,
1.00, 2.33,2.57,2.98,1.96,
1.72,2.96,2.28,1.22,0.89,
3.57,3.90,4.16,4.46,5.27,
0.80,2.20,1.54,0.91,0.00,
2.94,4.51,5.18,5.48,6.11,
6.57,6.46,6.83,6.85,6.77,
6.79,4.96,4.92,4.87,4.96,
4.87,5.16,5.70,6.05,5.90,
5.81,6.01,5.92,5.66,5.38,
5.18,5.57,5.38,5.27,5.22,
5.22,5.37,5.55,5.51,5.48,
```

```
5.46,5.53,5.46,4.61,5.14,
5.18,5.09,5.13,1.74,2.81,
4.87,5.29,5.14,4.98,4.83,
4.81,4.77,4.77,4.64,4.66,
0.00,0.04,1.20,1.33,4.48,
4.48,4.59,2.15
slim = .05,
$end
$frpmox
enrpu39 = 65.99, enrpu40 = 23.45, enrpu41 = 7.08,
enrpu42 = 3.48,
$end
```

A.14 Halden IFA-606 Rod

The IFA-606 test assembly (Mertens et al., 1998; Mertens and Lippens, 2001) consisted of four refabricated rod segments from a full-length PWR MOX rod irradiated in the Beznau-1 reactor, Switzerland, at nominal LHGRs to a burnup of 50 MWd/kgM. The MOX fuel was fabricated using the MIMAS-AUC process by BN. Two test rods were instrumented with a fuel thermocouple and a pressure transducer, and irradiated under Halden conditions for approximately 30 days at elevated LHGR in "Phase 2" of the test, to determine FGR behavior. The code-data comparisons presented are for only rod 2 that measured FGR by rod puncture, with a 12.5 micron grain size.

The fuel rod segment was instrumented with a pressure transducer and a fuel centerline thermocouple. The rod was base-irradiated at nominal LHGRs for ~1500 days. The rod segment reached a burnup of 49.5 GWd/MTM during commercial operation, with additional 30 days of irradiation in Halden for a total burnup of 50.6 GWd/MTM.

This rod was used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup and the MOX FGR predictions. The input files used for the MOX temperature and FGR assessments are shown below. The input files that include the central hole were used for the temperature assessment since the temperature was measured on hollow pellets. The input file that does not include the central hole was used for the FGR assessment since most of the fuel column consists of solid pellets.

IFA-606 Phase 2 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa606notcP2.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa606notcP2.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         Refab.Beznau PWR 5-Cycle Segment for IFA-606 Phase 2
 $frpcn
 im=84, na=18,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 1.4, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0037,
 dco = 0.422, pitch = 0.5,nplot=1,
 rc = 0.0, fotmtl = 1.996,
 den = 95.585, rsntr = 68.0,
 dspg = 0.3, fa = 1., dspgw = 0.03,
 enrch = 0.278, fgpav = 74.11, hdish = 0.0115,
 dishsd = 0.0655
 hplt = 0.4943, icm = 4, imox = 1, comp = 5.970,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 1, fa = 1.0,
 jn = 5,6,
 totl = 1.31, roughc = 2.48e-5, roughf = 9.84e-5, vs = 10.0,
 nunits = 1, nsp = 1,
 p2(1) = 55*2277., p2(56) = 29*487.,
 tw(1) = 55*543, tw(56) = 29*464.0
 go(1) = 55*1.82e6, 29*0.0
```

```
 jst = 55*1, 29*2
 qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
 x(1) = 0.0, 0.3275, 0.6650, 0.9925, 1.31
 qf(6) = 0.9, 0.9995, 1.0445, 1.062, 0.9959,0.85
 x(6) = 0.0, 0.435794, 0.726312, 1.016831, 1.201444,1.31
 ProblemTime=
 1.5,4.,6.5,36.,88.,
 90.,120.,160.,194.5,220.,
 250.,280.,299.,302.5,304.5,
 306.5,309.,310.,312.5,334.6,
 360.,400.,440.,480.,506.,
 549.,580.,592.3,594.3,595.3,
 620.,650.,685.,706.8,720.,
 750.,783.,806.,840.,880.,
 898.,930.,970.,1000.,1050.,
 1110.,1150.,1200.,1230.,1260.,
 1300.,1340.,1390.,1440.,1469.,
 1471.5,1472.5,1472.7,1472.9,1473.1,
 1473.8,1474.3,1476.3,1477.1,1477.6,
 1478.6,1479.6,1480.6,1482.6,1483.6,
 1484.6,1486.6,1486.8,1487.3,1487.5,
 1488.5,1488.9,1489.2,1490.2,1491.2,
 1492.2,1495.0,1495.2,1496.8
 qmpy =
 1.75,3.65,4.36,4.99,4.93,
 3.72,4.85,4.85,4.85,4.82,
 4.82,4.82,4.82,3.81,4.43,
 5.02,3.68,4.32,4.98,4.94,
 4.82,4.82,4.82,4.82,4.82,
 4.37,4.45,3.55,5.37,7.25,
 7.22,7.22,7.22,7.22,7.27,
 7.27,7.27,7.22,7.32,7.32,
 7.02,7.31,7.42,7.35,7.35,
 7.35,7.2, 7.2, 7.26,7.26,
 6.39,6.35,6.01,6.01,6.01,
 1.07,4.63,0.85,2.77,7.16,
 5.33,5.49,6.95,7.50,6.86,
 7.47,7.50,6.77,8.81,8.72,
 8.66,9.69,9.60,9.54,9.42,
 9.45,9.75,9.91,9.81,9.75,
 9.69,6.40,6.40,6.34
 slim = .05,
 $end
 $frpmox
 enrpu39 = 65.86, enrpu40 = 23.43, enrpu41 = 7.38,
 enrpu42 = 3.33,
 $end
```

IFA-606 Phase 2 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa606tcP2.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa606tcP2.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
```

```
/*********************************************************************
        Refab.Beznau PWR 5-Cycle Segment for IFA-606 Phase 2
 $frpcn
 im=117, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 1.4, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0037,
 dco = 0.422, pitch = 0.5,nplot=1,
 rc = 0.049213, fotmtl = 1.996,
 den = 95.585, rsntr = 68.0,
 dspg = 0.3, fa = 1., dspgw = 0.03,
 enrch = 0.278, fgpav = 74.11, hdish = 0.0115,
 dishsd = 0.0655
 hplt = 0.4943, icm = 4, imox = 1, comp = 5.970,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0, fa = 1.0,
 jn = 5,6,
 totl = 1.31, roughc = 2.48e-5, roughf = 9.84e-5, vs = 10.0,
 nunits = 1, nsp = 1,
 p2(1) = 55*2277., p2(56) = 62*487.,
 tw(1) = 55*543, tw(56) = 62*428.0
 go(1) = 55*1.82e6, 62*0.0
 jst = 55*1, 62*1
 qf(1) = 1.0, 1.0, 1.0, 1.0, 1.0
 x(1) = 0.0, 0.3275, 0.6650, 0.9925, 1.31
 qf(6) = 0.9, 0.9995, 1.0445, 1.062, 0.9959,0.85
 x(6) = 0.0, 0.435794, 0.726312, 1.016831, 1.201444,1.31
 ProblemTime=
 1.5,4.,6.5,36.,88.,
 90.,120.,160.,194.5,220.,
 250.,280.,299.,302.5,304.5,
 306.5,309.,310.,312.5,334.6,
 360.,400.,440.,480.,506.,
 549.,580.,592.3,594.3,595.3,
 620.,650.,685.,706.8,720.,
 750.,783.,806.,840.,880.,
 898.,930.,970.,1000.,1050.,
 1110.,1150.,1200.,1230.,1260.,
 1300.,1340.,1390.,1440.,1469.,
 1469.33,1469.73,1471.83,1472.53,1473.83, 1475.93,
 1476.73,1476.78,1477.73,1478.60,1478.63,1478.78,
 1478.80, 1479.79, 1479.81,1479.83,
 1479.93,1480.23,1480.33,1480.73, 1480.75, 1481.70,
 1481.73, 1481.75, 1482.70, 1482.73,
 1483.63,1483.93, 1484.23,1484.73,1484.75, 1485.70,
 1485.73,1485.75, 1486.63, 1487.30,
 1487.33,1487.73,1487.75, 1488.90,
 1489.00, 1489.03,1489.73, 1490.70,1490.73,1490.80,
 1491.70, 1491.73,1491.83,
 1492.63,1492.68,1495.23, 1496.73,
 1498.33,
 1498.4, 1498.5, 1498.6, 1498.7, 1498.8,
 1498.9, 1499.0, 1499.1
 qmpy =
 1.75,3.65,4.36,4.99,4.93,
 3.72,4.85,4.85,4.85,4.82,
 4.82,4.82,4.82,3.81,4.43,
```

```
5.02,3.68,4.32,4.98,4.94,
4.82,4.82,4.82,4.82,4.82,
4.37,4.45,3.55,5.37,7.25,
7.22,7.22,7.22,7.22,7.27,
7.27,7.27,7.22,7.32,7.32,
7.02,7.31,7.42,7.35,7.35,
7.35,7.2, 7.2, 7.26,7.26,
6.39,6.35,6.01,6.01,6.01,
4.13,2.42, 6.45, 4.79, 6.26,
6.20, 6.17, 6.72, 6.17, 6.11,
6.75, 6.09, 6.75, 6.75, 6.11,
6.12, 7.82, 6.06, 7.90, 6.08,
7.90, 7.90, 6.03, 7.85, 7.85,
5.98, 7.79, 5.98, 8.73, 5.98,
8.7, 8.7, 5.92, 8.64, 8.64,
5.76, 8.45, 5.87, 8.70, 8.70,
5.87, 8.86, 5.84, 8.8, 5.51,
8.7, 8.7, 5.76, 8.7, 8.70,
5.73, 5.73, 4.94, 5.68,
5.00, 4.50, 4.00, 3.50,3.00,
2.50, 2.00, 1.50
slim = .05,
$end
$frpmox
enrpu39 = 65.86, enrpu40 = 23.43, enrpu41 = 7.38,
enrpu42 = 3.33,
$end
```

A.15 Halden IFA-636 Rods

IFA-636 (Tverberg et al., 2005) contained both hollow pellets with centerline thermocouples and solid pellets irradiated up to a burnup of 25 GWd/MTU. FRAPCON-3.4 was used to model two of the rods from this assembly. These rods contained 8 percent gadolinia of the type typically used in power reactors. Centerline temperature data from IFA-636 rod 2 (hollow pellets) was used to compare to FRAPCON-3.4 predictions.

Centerline temperature from IFA-636 rod 4 (solid rod) was estimated by Halden based on measurements from IFA-636 rod 2. These estimates were used to compare to FRAPCON-3.4 predictions. These estimates may have more error than those for rod 2 due to both power uncertainties and uncertainties in estimating rod 4 temperature from rod 2 data.

These two rods were used to assess the FRAPCON-3.4 temperature predictions for UO_2-Gd_2O_3 fuel as a function of burnup. The input files used for the UO_2-Gd_2O_3 temperature assessment as a function of burnup are shown below.

IFA-636 Rod 2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='636-2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='636-2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-636 rod 2
 $frpcn
 im=98, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02266, thkgap=0.00305, totl=1.28937, cpl=0.8031
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.3858, rc=0.0354, hdish=0.0094, dishsd=0.0639
 enrch=3.95, imox=0, comp=0
 fotmtl=2, gadoln=0.08, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1


 iplant=-4, pitch=0.4301, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 1, 2.69, 4, 16.94, 19.67
 29.2, 32.58, 61.13, 64.51, 88.29
 90.43, 94.4, 101.85, 116.11, 116.83
 131.05, 131.07, 141.92, 142.76, 146.69
 162.31, 162.36, 163, 199.66, 207.13
 209.29, 213.37, 216.63, 224.76, 233.59
 238.97, 241.03, 257.31, 265.47, 272.95
```

```
277.76, 283.9, 284.61, 307.03, 329.45
351.89, 352.12, 361.61, 366.27, 379.88
402.33, 405.18, 408.46, 447.21, 447.44
449.37, 456.16, 458.13, 467.66, 482.62
513.94, 513.98, 515.97, 524.14, 535.71
537.12, 539.13, 550.69, 551.63, 552.11
559.13, 561, 563.72, 571.11, 579.29
591.55, 599.25, 599.72, 613.3, 618.74
626.16, 636.38, 638.47, 645.88, 647.24
658.13, 658.16, 679.25, 694.89, 697.25
702.48, 705.13, 713.33, 725.61, 731.04
732.99, 739.1, 739.86, 760.27, 767.09
773.36, 775.95, 788.18
qmpy=
0.315, 0.363, 1.04, 0.962, 0.74
0.749, 0.977, 1.23, 1.593, 1.976
0.627, 2.117, 2.575, 2.859, 2.409
3.234, 3.053, 3.424, 1.308, 3.294
3.669, 3.083, 3.624, 4.606, 4.748
3.128, 3.343, 5.027, 5.485, 5.674
6.58, 6.312, 6.868, 6.876, 6.928
6.302, 6.083, 5.633, 6.15, 6.441
6.598, 3.343, 3.95, 5.396, 5.274
5.295, 3.496, 5.211, 5.473, 2.365
3.899, 4.04, 4.988, 4.997, 5.011
4.681, 4.096, 4.728, 4.691, 4.567
3.938, 4.435, 4.446, 0.888, 3.682
0.76, 3.014, 3.062, 4.24, 4.023
3.9, 0.934, 3.727, 4.101, 4.196
4.969, 4.753, 5.033, 4.08, 5.034
5.044, 4.549, 4.659, 4.674, 0.397
3.285, 4.188, 3.656, 3.262, 3.402
4.575, 4.807, 3.726, 3.746, 3.482
1.506, 3.22, 3.367
nsp=0
p2= 493.13, tw= 464, go= 0
iq=0, fa=1
x(1)=
0, 1.28937
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, 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, 1, 1
 $end
```

IFA-636 Rod 4

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='636-4.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='636-4.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-636 rod 4
 $frpcn
 im=98, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02266, thkgap=0.00305, totl=1.28937, cpl=0.7835
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.3858, rc=0, hdish=0.0094, dishsd=0.0639
 enrch=3.95, imox=0, comp=0
 fotmtl=2, gadoln=0.08, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1


 iplant=-4, pitch=0.4301, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 2.63, 4.75, 5.35, 16.7, 18.15
 28.67, 34.25, 65.11, 86.86, 90.59
 95.3, 107.91, 114.93, 120.54, 130.33
 140.86, 142.51, 142.92, 159.73, 160.52
 163.94, 205.97, 207.11, 211.78, 214.1
 214.52, 217.92, 219.44, 219.87, 220.71
 229.82, 231.04, 234.66, 245.12, 261.23
 268.26, 268.5, 272.1, 272.52, 273.91
 277.74, 282.38, 283.7, 318.12, 336.34
 349.66, 353.61, 355.46, 356.27, 360.61
 365.33, 380.82, 404.02, 404.29, 412.45
 444.03, 447.3, 458.88, 484.17, 508.11
 535.54, 535.71, 541.22, 554.57, 558.04
 562.21, 568.24, 572.77, 573.89, 579.05
 584.65, 584.81, 597.99, 601.76, 621.42
 623.39, 626.2, 629.72, 632.13, 640.98
 653.61, 656.8, 662.78, 694.44, 695.94
```

```
700.27, 707.19, 708.59, 714.28, 717.85
722.1, 729.13, 733.74, 738.8, 770.45
770.85, 774.69, 792.98
qmpy=
1.202, 1.785, 1.126, 1.131, 0.822
0.981, 1.294, 1.733, 2.014, 0.621
1.979, 2.294, 2.336, 2.455, 2.769
2.89, 1.263, 3.162, 3.596, 3.015
3.636, 4.623, 1.756, 3.386, 2.031
3.852, 4.628, 3.854, 5.637, 4.746
4.943, 6.184, 5.449, 5.996, 6.43
6.433, 4.844, 6.124, 4.264, 6.241
4.189, 6.594, 6.013, 6.764, 7.121
7.359, 4.532, 1.666, 5.541, 4.69
6.01, 5.9, 5.833, 4.09, 5.914
6.277, 3.295, 5.702, 5.829, 5.53
5.464, 4.341, 5.079, 5.163, 0.863
5.747, 3.076, 5.635, 2.924, 5.948
0.487, 6.106, 1.617, 4.524, 4.727
5.619, 5.62, 5.583, 3.608, 5.51
5.671, 3.192, 5.442, 5.301, 0.11
3.986, 4.687, 4.687, 4.302, 3.955
3.686, 3.689, 5.706, 4.817, 4.753
2.157, 4.561, 4.492
nsp=0
p2= 493.13, tw= 464, go= 0
iq=0, fa=1
x(1)=
0, 1.28937
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, 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, 1, 1
$end
```

A.16 BR-3 Rods

The DOE sponsored high-burnup irradiation of five well-characterized PWR-type test rods (Balfour, 1982; Balfour et al., 1982) in the BR-3 reactor, located in Mol, Belgium, to demonstrate the feasibility of extending commercial fuel rod burnup and thereby help to minimize radioactive waste disposal. These rods were fabricated by Westinghouse Corporation, whose staff also oversaw the PIEs. The PIE on the rods was carried out in the BR-2 hot cell facility at the Mol site. The rods were of basic PWR radial dimensions. Goal peak burnups exceeded 70 GWd/MTU.

The test rods were designed to simulate Westinghouse PWR (15 x 15) rod cladding type and radial dimensions, with variations in fuel enrichment and rod position providing variations in power history. The fuel rod length was much shorter than the full-length (~144-inch) commercial reactor rods and fit well within the short length of the BR-3 reactor core. The fuel rod overall length was 44 inches with an active fuel column length of 38.4 inches.

Six rods were selected for comparison with FRAPCON-3.4 FGR predictions: 24-I-6, 36-I-8, 111-I-5, 28-I-6, 30-I-8, and 332. Three of these rods were also selected for comparison with FRAPCON-3.4 void volume predictions: 24-I-6, 36-I-8, and 111-I-5. The input files used for the FGR and void volume assessments are shown below.

24-I-6 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out24I6.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='24i6.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         Westinghouse BR-3 Rod 24I6
 $frpcn
 im=54, na=9, nr=17,
 ngasr = 45,
 $end
 $frpcon
 nplot=1
 cpl = 4.0145, crdt = 1., crdtr = 0.0, thkcld=0.0243,
 dco = 0.4220, pitch = 0.505,crephr=10.0,
 den = 94.77, dishsd = 0.0504, thkgap=0.00375, dspg = 0.370,
 dspgw = 0.055, enrch = 6.42, fgpav = 200.01, hdish = 0.0135,
 hplt = 0.60, icm = 4,siggro=0.0
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 15,15,15,15,15,15,15,15
 totl = 3.2, roughc = 1.97e-5, roughf = 2.36e-5, vs = 8.0,
 nunits = 1, rsntr = 101.9,
 flux(1) = 10*0.21e17, p2(1) = 2199.0, tw(1) = 491, go(1) = 2.1e6,
 jst = 11*1, 13*2, 8*3, 2*4, 4*5, 5*6, 5*7, 6*8
 qf(1) =0.4556,0.6702,0.8718,1.0298,1.1801,1.2690,1.3377,1.3600,1.3300,
 1.2824,1.1686,1.0454,0.8680,0.6706,0.4610,
 x(1) =0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(16)  =0.5272,0.7170,0.8939,1.0269,1.1530,1.2297,1.2901,1.3100,1.2842,
 1.2431,1.1450,1.0389,0.8873,0.7191,0.5347,
```

```
 x(16) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(31) =
0.6247,0.7759,0.9171,1.0248,1.1267,1.1836,1.2256,1.2400,1.2232,
 1.1933,1.1140,1.0282,0.9100,0.7798,0.6330,
 x(31) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(46)  =0.5552,0.6963,0.8647,1.0320,1.1433,1.2192,1.2215,1.2356,1.2700,
 1.2552,1.2022,1.1037,0.9255,0.7322,0.5434,
 x(46) =  0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(61) =
0.5596,0.7407,0.9187,1.0442,1.1286,1.1877,1.1823,1.1865,1.2100,
 1.2070,1.1482,1.0821,0.9825,0.8038,0.6182,
 x(61) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(76) =
0.8368,0.9372,1.0473,1.0767,1.0800,1.0658,1.0271,1.0104,1.0124,
 1.0248,1.0420,1.0589,1.0367,0.9407,0.8033,
 x(76) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(91) =
0.5780,0.6795,0.8387,1.0024,1.1306,1.2171,1.2608,1.2616,1.2700,
 1.2418,1.1714,1.0831,0.9543,0.7516,0.5589,
 x(91) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(106) =
0.7999,0.8922,1.0090,1.0770,1.1000,1.0710,1.0406,1.0359,1.0462,
 1.0615,1.0863,1.0914,1.0176,0.9149,0.7565,
 x(106) =  0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 ProblemTime=
 0.1, 0.5, 1.0, 1.5, 6.25,
 13.33, 21.25, 52.25, 53.50, 69.50,
 81.25, 83.96, 87.71, 90.21, 96.21,
 97.00, 123.13, 124.00, 129.13, 135.63,
 137.0, 147.63, 149.00, 166.67, 182.04,
 183.0, 224.54, 226.00, 254.17, 255.00,
 257.71,276.13, 280.29, 286.13, 310.92,
 338.63,380.29, 442.79, 484.46, 526.13,
 609.46,692.79, 776.13, 779.88, 830.42,
 849.04,878.21, 932.38, 996.96, 999.96,
 1029.04, 1036.54, 1038.63, 1136.96,
 qmpy =
 2, 4, 6, 9.316, 10.915,
 11.473, 12.167, 10.846, 11.542,9.940,
 11.472,  9.734, 11.472, 10.429, 9.426,
 8.343,   7.095,  5.480,  7.300, 7.300,
 8.621,   8.621,  9.038,  9.038, 9.038,
 9.734,   9.734,  9.456,  9.456, 9.038,
 9.038,   9.038, 12.245, 13.324,12.468,
 12.468, 12.309, 12.055, 11.769,11.515,
 10.945, 10.437,  9.929,  6.760, 8.047,
 5.048,   8.013,  7.812,  7.297, 4.947,
 7.644,   8.013,  4.947,  7.879,
 slim = .05,
 $end
```

36-I-8 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out36I8.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='36i8.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*********************************************************************
         Westinghouse BR-3 Rod 36I8
 $frpcn
 im=43, na=6, nr=20,
 ngasr = 45,
 $end
 $frpcon
 nplot=1
 cpl = 4.0145, crdt = 1., thkcld = 0.0244,
 dco = 0.4220,pitch = 0.56
 den = 94.774, dishsd = 0.0504, thkgap=0.00375, dspg = 0.370,
 dspgw = 0.055, enrch = 8.53, fgpav = 214.4, hdish = 0.0135,
 hplt = 0.60, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 11,11,11,11,11,11,
 totl = 3.2, roughc = 1.97e-5, roughf = 2.36e-5, vs = 8.0,
 nunits = 1, rsntr = 101.9,
 flux = 7*0.21e17, p2(1) = 2199.0, tw(1) = 491, go(1) = 1.7e6,
 jst = 10*1, 3*2, 6*3, 4*4, 7*5, 5*6,8*5,
 qf(1) =0.34,0.67,0.96,1.18,1.31,1.36,1.31,1.19,0.98,0.70,0.35,
 x(1) = 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(12)=0.43,0.72,0.97,1.15,1.26,1.31,1.27,1.16,0.98,0.75,0.45,
 x(12)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(23)=0.46,0.70,0.95,1.14,1.22,1.23,1.27,1.21,1.03,0.75,0.45,
 x(23)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(34)=0.45,0.75,0.98,1.13,1.19,1.19,1.21,1.16,1.05,0.85,0.50,
 x(34)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(45)=0.78,0.94,1.07,1.08,1.05,1.01,1.02,1.04,1.06,0.96,0.72,
 x(45)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(56)=0.51,0.68,0.92,1.13,1.24,1.26,1.27,1.18,1.04,0.80,0.45,
 x(56)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 0.5,
 0.6, 1., 25., 52., 88.,
 96., 136., 148., 180., 224.,
 254., 274., 280., 286., 310.,
 350., 400., 450., 500., 526.,
 565., 609., 650., 700., 750.,
 800., 830., 882., 900., 932.,
 950., 997., 1029., 1037., 1062.,
 1087., 1112., 1137.
 qmpy =
 1.,  2.,  3.,  4.,  5.,
 6., 7.45, 7.45, 7.45, 7.00,
 6.60, 4.9, 5.7, 6.0, 6.5,
 6.3, 2.7, 11.7, 12.5, 11.8,
 5*12.6,
 12.2, 12.2, 11.8, 11.8, 11.4,
```

```
 9.4, 9.4, 9.7, 9.7, 9.7,
 9.5, 9.3, 9.8, 10.3, 10.2,
 10.2, 10.2, 10.2
 slim = .05,
 $end
```

111-I-5 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out111I5.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='111i5.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         Westinghouse BR-3 Rod 111I5
 $frpcn
 im=36, na=6, nr=15,
 ngasr = 45,
 $end
 $frpcon
 nplot=1
 cpl = 4.0145, crdt = 1., crdtr = 0.0, thkcld=0.0244,
 dco = 0.4220, pitch = 0.56,
 den = 94.77, dishsd = 0.0504, thkgap=0.00375, dspg = 0.358,
 dspgw = 0.055, enrch = 5.2, fgpav = 214.4, hdish = 0.014,
 hplt = 0.60, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 15,15,15,15,15,15,
 totl = 3.2, roughc = 1.97e-5, roughf = 2.36e-5, vs = 8.0,
 nunits = 1, rsntr = 101.9,
 flux = 7*0.21e17, p2(1) = 2199.0, tw(1) = 491, go(1) = 1.9e6,
 jst = 12*1, 4*2, 5*3, 2*4, 7*5, 6*6,
 qf(1) =0.7664,0.8658,0.9845,1.1023,1.1807,1.2342,1.2358,1.2457,1.2700,
 1.2596,0.5681,0.9040,0.8493,0.9745,0.7389,
 x(1) =0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(16)=0.5596,0.7407,0.9187,1.0442,1.1286,1.1877,1.1823,1.1865,1.2100,
 1.2070,1.1482,1.0821,0.9825,0.8038,0.6182,
 x(16)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(31)=0.8369,0.9372,1.0473,1.0767,1.0800,1.0658,1.0271,1.0104,1.0124,
 1.0248,1.0420,1.0589,1.0366,0.9407,0.8033,
 x(31)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(46)=0.6462,0.7377,0.8727,1.0046,1.1217,1.2000,1.2275,1.2397,1.2500,
 1.2296,1.1543,1.0474,0.8998,0.7382,0.6305,
 x(46)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(61)=0.6369,0.7298,0.8754,1.0251,1.1425,1.2217,1.2616,1.2623,1.2700,
 1.2442,1.1797,1.0990,0.9812,0.7957,0.2748,
 x(61)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(76)=0.7999,0.8922,1.0090,1.0770,1.1000,1.0710,1.0406,1.0359,1.0462,
 1.0615,1.0863,1.0914,1.0176,0.9149,0.7565,
```

```
 x(76)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 0.5,
 0.6, 0.7, 0.8, 0.9, 1.0,
 4.2, 10.0, 35.2, 62.5, 104.2,
 166.7, 208.3, 250.0, 333.3, 416.6,
 500.0, 500.2, 500.4, 500.6, 502., 503.8, 554.3, 572.9,
 602.1, 656.3, 720.8, 723.8, 752.9,
 760.4, 762.5, 860.8
 qmpy =
 1., 2., 3., 4., 5.0,
 6., 7., 8., 9., 10.0,
 13.138, 13.935, 12.724, 12.914, 12.914,
 12.914, 12.724, 12.372, 11.703, 11.097,
 10.491, 9., 7.5, 5., 4.232, 6.676, 8.131, 5.143,
 8.231, 8.131, 7.720, 5.243, 8.053,
 8.398, 5.143, 8.331
 slim = 0.05,
 $end
```

28-I-6 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out28I6.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='28i6.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*********************************************************************
Westinghouse BR-3 Rod 28I6
 $frpcn
 im=55, na=9, nr=17,
 ngasr = 45,
 $end
 $frpcon
 nplot=1
 cpl = 4.0145, crdt = 1., crdtr = 0.0, thkcld=0.0243,
 dco = 0.4220, pitch = 0.56,
 den = 94.70, dishsd = 0.0504, thkgap=0.00375, dspg = 0.370,
 dspgw = 0.055, enrch = 6.42, fgpav = 200.0, hdish = 0.0135,
 hplt = 0.60, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 1,fa = 1.0,
 jn = 15,15,15,15,15,15,15,15
 totl = 3.2, roughc = 1.97e-5, roughf = 2.36e-5, vs = 8.0,
 nunits = 1, rsntr = 101.9,
 flux(1) = 10*0.21e17, p2(1) = 2199.0, tw(1) = 491, go(1) = 2.1e6,
 jst = 11*1, 9*2, 6*3, 2*4, 4*5, 5*6, 6*7, 12*8
 qf(1) =0.4556,0.6702,0.8718,1.0298,1.1801,1.2690,1.3377,1.3600,1.3300,
 1.2824,1.1686,1.0454,0.8680,0.6706,0.4610,
 x(1) =0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(16)  =0.5272,0.7170,0.8939,1.0269,1.1530,1.2297,1.2901,1.3100,1.2842,
 1.2431,1.1450,1.0389,0.8873,0.7191,0.5347,
 x(16) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
```

```
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(31) =
0.6247,0.7759,0.9171,1.0248,1.1267,1.1836,1.2256,1.2400,1.2232,
 1.1933,1.1140,1.0282,0.9100,0.7798,0.6330,
 x(31) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(46)  =0.5552,0.6963,0.8647,1.0320,1.1433,1.2192,1.2215,1.2356,1.2700,
 1.2552,1.2022,1.1037,0.9255,0.7322,0.5434,
 x(46) =  0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(61) =
0.5596,0.7407,0.9187,1.0442,1.1286,1.1877,1.1823,1.1865,1.2100,
 1.2070,1.1482,1.0821,0.9825,0.8038,0.6182,
 x(61) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(76) =
0.8368,0.9372,1.0473,1.0767,1.0800,1.0658,1.0271,1.0104,1.0124,
 1.0248,1.0420,1.0589,1.0367,0.9407,0.8033,
 x(76) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(91) =
0.5780,0.6795,0.8387,1.0024,1.1306,1.2171,1.2608,1.2616,1.2700,
 1.2418,1.1714,1.0831,0.9543,0.7516,0.5589,
 x(91) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(106) =
0.7999,0.8922,1.0090,1.0770,1.1000,1.0710,1.0406,1.0359,1.0462,
 1.0615,1.0863,1.0914,1.0176,0.9149,0.7565,
 x(106) =  0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 6.3,
 13.3, 21.3, 52.3, 53.5, 69.5,
 81.3, 84.0, 87.7, 90.2, 96.2,
 123.1, 129.1, 135.6, 147.6, 166.7,
 182.0, 224.5, 254.2, 257.7, 258.7,
 274.2, 280.3, 286.1, 311.3, 338.6,
 380.3, 442.8, 484.5, 526.1, 609.5,
 692.8, 776.1, 777.4, 779.9, 830.4,
 849.0, 855.0, 863.0, 870.0, 878.2,
 932.4, 997.0, 1000.0, 1029.0, 1031.,
 1032., 1034. ,1036.5, 1038.6, 1137.0,

 qmpy =
  2., 4., 6., 7.78, 9.11,
  9.59, 10.46, 9.06, 9.64, 8.13,
  9.58, 8.13, 8.58, 8.71, 7.83,
  5.90, 6.10, 6.10,  7.20, 7.55,
  7.55, 8.03, 7.98, 7.55, 5.80,
  2.54, 9.90, 10.75, 10.09, 10.21,
  10.24, 10.21, 10.12, 9.99, 9.64,
  9.33, 8.98, 3.99, 6.41, 7.61,
  4.84, 5.0, 6.00, 7.00,  7.71,
  7.57, 7.19, 4.91, 5.0, 6.0,
  7.0, 7.61, 8.04, 7.84, 7.91
 slim = .05,
 $end
```

30-I-8 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out30I8.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='30i8.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/***********************************************************************
         Westinghouse BR-3 Rod 30I8
 $frpcn
 im=73, na=16, nr=20,
 ngasr = 45,
 $end
 $frpcon
 nplot=1
 dco = 0.4220, thkcld = 0.0243,thkgap=0.00375,
 totl = 3.2, cpl = 4.0145,
 dspg = 0.370, dspgw = 0.055, vs = 8.0,
 hplt = 0.60, hdish = 0.0135,dishsd = 0.0504,
 enrch = 8.53,
 den = 94.774,roughf = 2.36e-5,
 rsntr = 101.9,
 icm = 4,roughc = 1.97e-5,
 fgpav = 200.0, idxgas = 1,
 iplant = -2,nsp=1,
 p2(1) = 37*2000.0,20.0,18*2000.0,20.0,15*2000.0,15.0
 tw(1) = 37*491.0, 60.0,18*491.0, 60.0,15*491.0, 100.0,
 go(1) = 73*1.608e6, flux(1) = 17*0.21e17,  pitch = 0.56
 icor = 0, crdt = 1.,
 jdlpr = 0,nunits = 1,
 iq = 0, fa = 1.0,
 jn = 17,17,17,17,17,17,17,17,17,
 jst = 14*1,9*2,15*3,9*4,4*5,6*6,5*7,4*8,7*9,
 qf(1) =0.3483,0.4556,0.6702,0.8718,1.0298,1.1801,1.2690,
 1.3377,1.3600,1.3300,1.2824,1.1686,1.0454,0.8680,0.6706,
 0.4610,0.3562,
 x(1) = 0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
        2.027,2.240,2.453,2.667,2.880,3.093,3.200,
 qf(18)=0.4323,0.5272,0.7170,0.8939,1.0269,1.1530,1.2297,
 1.2901,1.3100,1.2842,1.2431,1.1450,1.0389,0.8873,0.7191,
 0.5347,0.4425,
 x(18)= 0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
        2.027,2.240,2.453,2.667,2.880,3.093,3.200,
 qf(35)=0.5364,0.6141,0.7695,0.9148,1.0255,1.1303,1.1888,
 1.2320,1.2468,1.2295,1.1988,1.1173,1.0290,0.9074,0.7736,
 0.6227,0.5473,
 x(35)= 0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
        2.027,2.240,2.453,2.667,2.880,3.093,3.200,
 qf(52)=0.4847,0.5552,0.6963,0.8647,1.0320,1.1433,1.2192,
 1.2215,1.2356,1.2700,1.2552,1.2022,1.1037,0.9255,0.7322,
 0.5434,0.4490,
 x(52)= 0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
        2.027,2.240,2.453,2.667,2.880,3.093,3.200,
 qf(69)=0.4691,0.5596,0.7407,0.9187,1.0442,1.1286,1.1877,
 1.1823,1.1865,1.2100,1.2070,1.1482,1.0821,0.9825,0.8038,
```

```
0.6182,0.5254,
x(69)= 0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
       2.027,2.240,2.453,2.667,2.880,3.093,3.200,
qf(86)=0.7987,0.8460,0.9407,1.0446,1.0724,1.0756,1.0621,
1.0256,1.0098,1.0117,1.0234,1.0397,1.0556,1.0346,0.9440,
0.8142,0.7493,
x(86)= 0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
       2.027,2.240,2.453,2.667,2.880,3.093,3.200,
qf(103)=0.6005,0.6462,0.7377,0.8727,1.0046,1.1217,1.2000,
 1.2275,1.2397,1.2500,1.2296,1.1543,1.0474,0.8998,0.7382,
 0.6305,0.5767,
x(103)=0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
       2.027,2.240,2.453,2.667,2.880,3.093,3.200,
qf(120)=0.5273,0.5780,0.6795,0.8387,1.0024,1.1306,1.2172,
 1.2608,1.2616,1.2700,1.2418,1.1714,1.0831,0.9543,0.7516,
 0.5589,0.4626,
x(120)=0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
       2.027,2.240,2.453,2.667,2.880,3.093,3.200,
qf(137)=0.7538,0.7999,0.8922,1.0090,1.0770,1.1000,1.0710,
 1.0406,1.0359,1.0462,1.0615,1.0863,1.0914,1.0176,0.9149,
 0.7565,0.6773,
x(137)=0.000,0.107,0.320,0.533,0.747,0.960,1.173,1.387,1.600,1.813
       2.027,2.240,2.453,2.667,2.880,3.093,3.200,
ProblemTime=
0.1000,0.2000,0.3000, 0.4000,0.5000,
0.6000,0.7000,6.2500,13.3333,21.2500,
52.2500,53.5000,69.5000,81.2500,83.9583,
87.7083,90.2083,96.2083,96.2088,123.1250,
123.1254,135.6250,147.6250,182.0417,224.5417,
254.1667,257.7083,257.7088,258.7083,258.7088,
258.7092,274.2083,274.2088,274.2092,274.2096,
274.2100,274.2104,276.1250,276.2000,276.3000,
276.4000,276.5000,276.6000,276.7000,276.8000,
280.2917,286.1250,310.9167,338.6250,380.2917,
442.7917,484.4583,526.1250,609.4583,692.7917,
776.1250,776.1254,777.3750,777.4000,777.5000,
777.6000,779.8750,830.4167,849.0417,878.2083,
932.3750,996.9583,999.9583,1029.0417,1036.5417,
1038.6250,1136.9583,1136.9588,
qmpy =
1.000,2.000,3.000,4.000,5.000,
6.000,6.975,8.173,8.589,9.109,
8.120,8.641,7.287,8.589,7.287,
8.589,7.808,7.062,6.247,5.321,
4.373,5.466,6.501,6.767,7.287,
7.079,6.767,5.998,5.206,4.353,
3.386,2.299,2.419,1.935,1.451,
0.967,0.484,0.010,1.000,2.500,
4.000,5.500,7.000,8.500,10.000,
10.711,11.590,11.024,11.276,11.496,
11.748,11.748,11.685,11.433,11.119,
10.837,0.010,1.745,3.000,4.500,
6.000,7.610,9.076,5.797,9.277,
9.244,8.908,6.110,9.378,9.859,
6.032,9.792,0.011,
slim = .05,
$end
```

24-I-6 Void Volume Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out24I6.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='24i6.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         Westinghouse BR-3 Rod 24I6
 $frpcn
 im=55, na=9, nr=17,
 ngasr = 45,
 $end
 $frpcon
 nplot=1
 cpl = 4.0145, crdt = 1., crdtr = 0.0, thkcld=0.0243,
 dco = 0.4220, pitch = 0.505,crephr=10.0,
 den = 94.77, dishsd = 0.0504, thkgap=0.00375, dspg = 0.370,
 dspgw = 0.055, enrch = 6.42, fgpav = 200.01, hdish = 0.0135,
 hplt = 0.60, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 15,15,15,15,15,15,15,15
 totl = 3.2, roughc = 1.97e-5, roughf = 2.36e-5, vs = 8.0,
 nunits = 1, rsntr = 101.9,nsp=1,
 flux(1) = 10*0.21e17, p2(1) = 54*2199.0,14.7
 tw(1) = 54*491,77.0 go(1) = 54*2.1e6,0.0
 jst = 11*1, 13*2, 8*3, 2*4, 4*5, 5*6, 5*7, 6*8,8
 qf(1) =0.4556,0.6702,0.8718,1.0298,1.1801,1.2690,1.3377,1.3600,1.3300,
 1.2824,1.1686,1.0454,0.8680,0.6706,0.4610,
 x(1) =0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(16)  =0.5272,0.7170,0.8939,1.0269,1.1530,1.2297,1.2901,1.3100,1.2842,
 1.2431,1.1450,1.0389,0.8873,0.7191,0.5347,
 x(16) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(31) =
0.6247,0.7759,0.9171,1.0248,1.1267,1.1836,1.2256,1.2400,1.2232,
 1.1933,1.1140,1.0282,0.9100,0.7798,0.6330,
 x(31) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(46)  =0.5552,0.6963,0.8647,1.0320,1.1433,1.2192,1.2215,1.2356,1.2700,
 1.2552,1.2022,1.1037,0.9255,0.7322,0.5434,
 x(46) =  0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(61) =
0.5596,0.7407,0.9187,1.0442,1.1286,1.1877,1.1823,1.1865,1.2100,
 1.2070,1.1482,1.0821,0.9825,0.8038,0.6182,
 x(61) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(76) =
0.8368,0.9372,1.0473,1.0767,1.0800,1.0658,1.0271,1.0104,1.0124,
 1.0248,1.0420,1.0589,1.0367,0.9407,0.8033,
 x(76) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
```

```
 qf(91) =
0.5780,0.6795,0.8387,1.0024,1.1306,1.2171,1.2608,1.2616,1.2700,
 1.2418,1.1714,1.0831,0.9543,0.7516,0.5589,
 x(91) = 0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 qf(106) =
0.7999,0.8922,1.0090,1.0770,1.1000,1.0710,1.0406,1.0359,1.0462,
 1.0615,1.0863,1.0914,1.0176,0.9149,0.7565,
 x(106) =  0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
 1.829,2.057,2.286,2.514,2.743,2.971,3.200,
 ProblemTime=
 0.1, 0.5, 1.0, 1.5, 6.25,
 13.33, 21.25, 52.25, 53.50, 69.50,
 81.25, 83.96, 87.71, 90.21, 96.21,
 97.00, 123.13, 124.00, 129.13, 135.63,
 137.0, 147.63, 149.00, 166.67, 182.04,
 183.0, 224.54, 226.00, 254.17, 255.00,
 257.71,276.13, 280.29, 286.13, 310.92,
 338.63,380.29, 442.79, 484.46, 526.13,
 609.46,692.79, 776.13, 779.88, 830.42,
 849.04,878.21, 932.38, 996.96, 999.96,
 1029.04, 1036.54, 1038.63, 1136.96,1137.96
 qmpy =
 2, 4, 6, 9.316, 10.915,
 11.473, 12.167, 10.846, 11.542,9.940,
 11.472,  9.734, 11.472, 10.429, 9.426,
 8.343,   7.095,  5.480,  7.300, 7.300,
 8.621,   8.621,  9.038,  9.038, 9.038,
 9.734,   9.734,  9.456,  9.456, 9.038,
 9.038,   9.038, 12.245, 13.324,12.468,
 12.468, 12.309, 12.055, 11.769,11.515,
 10.945, 10.437,  9.929,  6.760, 8.047,
 5.048,   8.013,  7.812,  7.297, 4.947,
 7.644,   8.013,  4.947,  7.879,0.0
 slim = .05,
 $end
```

36-I-8 Void Volume Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out36I8.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='36i8.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         Westinghouse BR-3 Rod 36I8
 $frpcn
 im=44, na=6, nr=20,
 ngasr = 45,
 $end
 $frpcon
 nplot=1
 cpl = 4.0145, crdt = 1., thkcld = 0.0244,
 dco = 0.4220,pitch = 0.56
 den = 94.774, dishsd = 0.0504, thkgap=0.00375, dspg = 0.370,
```

```
 dspgw = 0.055, enrch = 8.53, fgpav = 214.4, hdish = 0.0135,
 hplt = 0.60, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 11,11,11,11,11,11,
 totl = 3.2, roughc = 1.97e-5, roughf = 2.36e-5, vs = 8.0,
 nunits = 1, rsntr = 101.9,nsp=1
 flux = 7*0.21e17, p2(1) = 43*2199.0,14.7,
 tw(1) = 43*491,77.0 go(1) = 43*1.7e6,0.0
 jst = 10*1, 3*2, 6*3, 4*4, 7*5, 5*6,8*5,5
 qf(1) =0.34,0.67,0.96,1.18,1.31,1.36,1.31,1.19,0.98,0.70,0.35,
 x(1) = 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(12)=0.43,0.72,0.97,1.15,1.26,1.31,1.27,1.16,0.98,0.75,0.45,
 x(12)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(23)=0.46,0.70,0.95,1.14,1.22,1.23,1.27,1.21,1.03,0.75,0.45,
 x(23)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(34)=0.45,0.75,0.98,1.13,1.19,1.19,1.21,1.16,1.05,0.85,0.50,
 x(34)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(45)=0.78,0.94,1.07,1.08,1.05,1.01,1.02,1.04,1.06,0.96,0.72,
 x(45)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 qf(56)=0.51,0.68,0.92,1.13,1.24,1.26,1.27,1.18,1.04,0.80,0.45,
 x(56)= 0.00,0.32,0.64,0.96,1.28,1.60,1.92,2.24,2.56,2.88,3.20,
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 0.5,
 0.6, 1., 25., 52., 88.,
 96., 136., 148., 180., 224.,
 254., 274., 280., 286., 310.,
 350., 400., 450., 500., 526.,
 565., 609., 650., 700., 750.,
 800., 830., 882., 900., 932.,
 950., 997., 1029., 1037., 1062.,
 1087., 1112., 1137,1138
 qmpy =
 1.,  2.,  3.,  4.,  5.,
 6., 7.45, 7.45, 7.45, 7.00,
 6.60, 4.9, 5.7, 6.0, 6.5,
 6.3, 2.7, 11.7, 12.5, 11.8,
 5*12.6,
 12.2, 12.2, 11.8, 11.8, 11.4,
 9.4, 9.4, 9.7, 9.7, 9.7,
 9.5, 9.3, 9.8, 10.3, 10.2,
 10.2, 10.2, 10.2,0.0
 slim = .05,
 $end
```

111-I-5 Void Volume Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out111I5.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='111i5.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/***********************************************************************
******
         Westinghouse BR-3 Rod 111I5
 $frpcn
```

```
im=37, na=6, nr=15,
ngasr = 45,
$end
$frpcon
nplot=1
cpl = 4.0145, crdt = 1., crdtr = 0.0, thkcld=0.0244,
dco = 0.4220, pitch = 0.56,
den = 94.77, dishsd = 0.0504, thkgap=0.00375, dspg = 0.358,
dspgw = 0.055, enrch = 5.2, fgpav = 214.4, hdish = 0.014,
hplt = 0.60, icm = 4,
icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,fa = 1.0,
jn = 15,15,15,15,15,15,
totl = 3.2, roughc = 1.97e-5, roughf = 2.36e-5, vs = 8.0,
nunits = 1, rsntr = 101.9,nsp=1
flux = 7*0.21e17, p2(1) = 36*2199.0,14.7
tw(1) = 36*491,77.0 go(1) = 36*1.9e6,0.0
jst = 12*1, 4*2, 5*3, 2*4, 7*5, 6*6,6
qf(1) =0.7664,0.8658,0.9845,1.1023,1.1807,1.2342,1.2358,1.2457,1.2700,
1.2596,0.5681,0.9040,0.8493,0.9745,0.7389,
x(1) =0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
1.829,2.057,2.286,2.514,2.743,2.971,3.200,
qf(16)=0.5596,0.7407,0.9187,1.0442,1.1286,1.1877,1.1823,1.1865,1.2100,
1.2070,1.1482,1.0821,0.9825,0.8038,0.6182,
x(16)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
1.829,2.057,2.286,2.514,2.743,2.971,3.200,
qf(31)=0.8369,0.9372,1.0473,1.0767,1.0800,1.0658,1.0271,1.0104,1.0124,
1.0248,1.0420,1.0589,1.0366,0.9407,0.8033,
x(31)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
1.829,2.057,2.286,2.514,2.743,2.971,3.200,
qf(46)=0.6462,0.7377,0.8727,1.0046,1.1217,1.2000,1.2275,1.2397,1.2500,
1.2296,1.1543,1.0474,0.8998,0.7382,0.6305,
x(46)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
1.829,2.057,2.286,2.514,2.743,2.971,3.200,
qf(61)=0.6369,0.7298,0.8754,1.0251,1.1425,1.2217,1.2616,1.2623,1.2700,
1.2442,1.1797,1.0990,0.9812,0.7957,0.2748,
x(61)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
1.829,2.057,2.286,2.514,2.743,2.971,3.200,
qf(76)=0.7999,0.8922,1.0090,1.0770,1.1000,1.0710,1.0406,1.0359,1.0462,
1.0615,1.0863,1.0914,1.0176,0.9149,0.7565,
x(76)=0.000,0.229,0.457,0.686,0.914,1.143,1.371,1.600,
1.829,2.057,2.286,2.514,2.743,2.971,3.200,
ProblemTime=
0.1, 0.2, 0.3, 0.4, 0.5,
0.6, 0.7, 0.8, 0.9, 1.0,
4.2, 10.0, 35.2, 62.5, 104.2,
166.7, 208.3, 250.0, 333.3, 416.6,
500.0, 500.2, 500.4, 500.6, 502., 503.8, 554.3, 572.9,
602.1, 656.3, 720.8, 723.8, 752.9,
760.4, 762.5, 860.8,861.8
qmpy =
1., 2., 3., 4., 5.0,
6., 7., 8., 9., 10.0,
13.138, 13.935, 12.724, 12.914, 12.914,
12.914, 12.724, 12.372, 11.703, 11.097,
10.491, 9., 7.5, 5., 4.232, 6.676, 8.131, 5.143,
8.231, 8.131, 7.720, 5.243, 8.053,
8.398, 5.143, 8.331,0.0
```

```
slim = 0.05,
$end
```

A.17 Zorita Rod

Four fuel assemblies were initially irradiated in Zroita cycles 1 and 2. A total of 41 of the fuel rods in each assembly were removable, and 16 of these rods per assembly had high enrichment (4.08 to 6.6 wt% ^{235}U) to achieve high linear power levels and burnups. One of these rods, rod 332 (Balfour et al., 1982), with high enrichment that was irradiated up to 57 GWd/MTU, was selected as an FGR assessment case for FRAPCON-3.4. This case is shown below.

332 Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out332.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Zorita rod 332
 $frpcn
 im=36, na=8,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 15.618, crdt = 1., crdtr = 0.0, dco = 0.4229,
 thkcld = 0.0249, thkgap = 0.00315, pitch = 0.55,
 den = 93.8, dishsd = 0.050, dspg = 0.368,
 dspgw = 0.055, enrch = 6.60, fgpav = 500.0, hdish = 0.0135,
 hplt = 0.6122, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 1,fa = 1.0,
 jn = 15,15,15,15,15,15,15,15
 totl = 7.084, roughc = 2.e-5, roughf = 8.e-5, vs = 28.0,
 nunits = 1, rsntr = 150.,
 flux = 9*0.18e17, p2(1) = 1990.0, tw(1) = 533, go(1) = 19000000.0,
 jst = 3*1, 7*2, 6*3, 4, 5, 4*6, 7, 7*8, 6*7
 qf(1) = 0.285,0.520,0.719,0.863,1.085,1.204,1.204,1.305,1.341,
         1.294,1.278,1.205,1.065,0.906,0.729,0.727,
 x(1) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542,
         4.048,4.554,5.06,5.566,6.072,6.578,7.084,
 qf(16) =0.432,0.703,0.881,0.950,1.101,1.149,1.096,1.162,1.188,
         1.160,1.180,1.148,1.063,0.962,0.827,
 x(16) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542
          4.048,4.554,5.06,5.566,6.072,6.578,7.084,
 qf(31) =0.601,0.822,1.005,0.989,1.072,1.061,0.976,1.018,1.040,
         1.019,1.061,1.087,1.079,1.080,1.032,
 x(31) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542,
          4.048,4.554,5.06,5.566,6.072,6.578,7.084,
 qf(46) =0.700,0.878,0.955,0.973,1.029,1.044,1.034,1.057,1.059,
         1.051,1.079,1.072,1.049,1.031,0.988,
 x(46) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542,
          4.048,4.554,5.06,5.566,6.072,6.578,7.084,
 qf(61) =1.090,1.145,1.170,1.180,1.170,1.155,1.130,1.090,1.050,0.990,
         0.930,0.850,0.770,0.700,0.640,
 x(61) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542,
           4.048,4.554,5.06,5.566,6.072,6.578,7.084,
 qf(76) =0.689,0.926,1.010,1.012,1.066,1.066,1.031,1.045,1.046,
         1.027,1.053,1.048,1.018,1.003,0.961,
 x(76) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542,
```

```
         4.048,4.554,5.06,5.566,6.072,6.578,7.084,
qf(91) =0.754,0.942,1.037,1.002,1.079,1.071,0.985,1.014,1.022,
        0.990,1.043,1.050,1.013,1.010,0.937,
x(91) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542,
         4.048,4.554,5.06,5.566,6.072,6.578,7.084,
qf(106)=0.574,0.774,0.915,0.961,1.090,1.133,1.085,1.139,1.152,
        1.111,1.131,1.100,1.020,0.950,0.866,
x(106) = 0.0,0.506,1.012,1.518,2.024,2.53,3.036,3.542,
          4.048,4.554,5.06,5.566,6.072,6.578,7.084,
  ProblemTime=
0.1, 30.0, 69., 123., 165.,
232., 298., 322., 368., 400.,
472., 491., 509., 600., 697.,
720., 774, 774.33, 805., 820.,
900., 981., 994., 1007., 1032.,
1041., 1069., 1077., 1138., 1200.,
1264., 1295., 1302., 1312., 1320.,
1334.
 qmpy =
 3.0, 6.13, 6.13, 4.45, 4.75,
7.80, 8.38, 9.01, 6.05, 7.21,
8.90, 7.92, 3.26, 8.90, 6.28,
8.84, 9.89, 9.89, 9.29, 9.48,
9.04, 9.04, 3.91, 5.45, 7.23,
7.90, 9.21, 8.56, 8.92, 8.53,
8.53, 8.29, 5.47, 8.09, 5.34,
8.09,
slim = .05,
$end
```

A.18 BNFL BR-3 Rods

Battelle, Pacific Northwest Laboratories administered the international group-sponsored High Burnup Effects Program (HBEP), which continued from 1978 to 1990. The objective of the HBEP was to determine the effects of extended burnup on fuel rod performance, especially FGR. A variety of test rods and commercial power reactor rods were irradiated and examined under the HBEP, including two PWR assemblies (366 and 373) (Lanning et al., 1987; Barner et al., 1990) containing PWR-type test rods irradiated in a single assembly in the BR-3 test reactor in Mol, Belgium. Both of these assemblies experience high power, and the rods showed significant FGR.

One rod from each assembly (rod DE from 373 and rod 5-DH from 366) was selected to be part of the UO_2 FGR assessment cases for FRAPCON-3.4. These cases are shown below.

Rod DE from Assembly 373

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outBNFLDE.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='BNFLDE.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         BNFL BR-3 rod DE
 $frpcn
 im=36, na=10,
 ngasr = 45,
 $end
 $frpcon
 cpl = 3.8, crdt = 0.0, crdtr = 0.0, dco = 0.4244, pitch=0.556,
 den = 93.1, dishsd = 0.0456, dspg = 0.37,dspgw = 0.055,
 thkcld = 0.0246, thkgap=0.0052,fa=1.,
 enrch = 8.9, fgpav = 14.7, hdish = 0.015,
 hplt = 0.4488, icm = 4, nplot =1,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,
 jn = 11,11,11,11,11,11,11,11
 totl = 3.3, roughc = 1.e-5, roughf = 3.e-5, vs = 8.0,
 nunits = 1, rsntr = 75,
 flux = 11*0.16e17, p2(1) = 2230.0, tw(1) = 491, go(1) = 19000000.0,
 jst = 7*1,4*2,5*3,5*4,4*5,7*6,3*7,1*8
 qf(1) = 0.29, 0.49, 0.72, 0.90, 1.0, 1.0, 0.95, 0.86, 0.69, 0.49,0.31,
 x(1) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(12) =0.39, 0.57, 0.79, 0.93, 1.01 1.01 0.99, 0.94, 0.81, 0.61,0.44,
 x(12) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(23) =0.43, 0.60, 0.81, 0.94, 1.0, 1.0, 1.00, 0.96, 0.84, 0.65, 0.48,
 x(23) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(34) =0.46, 0.63, 0.83, 0.95, 1.0, 1.0, 1.00, 0.97, 0.87, 0.69,0.51,
 x(34) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(45) =0.55, 0.72, 0.89, 0.98, 1.0, 1.0, 1.01, 1.00, 0.93, 0.78,0.62,
 x(45) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(56) =0.47, 0.64, 0.84, 0.96, 1.0, 1.0, 1.00, 0.98, 0.87, 0.70,0.52,
 x(56) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(67) =0.57, 0.74, 0.91, 0.99, 1.0, 1.0, 1.01, 1.01, 0.95, 0.81,0.64,
 x(67) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(78) =0.69, 0.86, 0.99, 1.02, 1.0, 1.0, 1.02, 1.04, 1.03, 0.93, 0.78,
```

```
 x(78) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 ProblemTime=
   0.1,  27.0,  41.0, 101.5, 108.5,
 150.5, 216.5, 289.7, 339.7, 357.2,
 380.2, 394.7, 415.7, 488.5, 581.5,
 670.5, 740.9, 818.9, 877.9, 950.7,
 1014.7, 1073.3, 1119.5, 1165.0, 1233.5,
 1260.5, 1317.5, 1346.8, 1399.9, 1437.6,
 1471.6, 1505.9, 1547.3, 1554.8, 1602.0,
 1658.7
 qmpy =
  7.045, 7.045, 8.355, 8.939, 7.023
  9.894,10.567,11.224, 6.589,10.11
 10.942, 6.282, 3.319, 3.492, 2.84
  3.335, 2.772, 2.132, 3.977, 2.435
  3.749, 3.727, 3.442, 3.389, 2.926
  2.147, 4.005, 2.452, 3.776, 3.555
  3.284, 3.233, 3.520, 3.682, 3.637
  3.754
 slim = .05,
 $end
```

Rod 5-DH from Assembly 366

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outBNFLDH.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='BNFLDH.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
         BNFL BR-3 rod DH
 $frpcn
 im=31, na=10,
 ngasr = 45,
 $end
 $frpcon
 cpl = 3.8, crdt = 0.0, crdtr = 0.0, dco = 0.4244, pitch=0.556,
 den = 93.1, dishsd = 0.0456, dspg = 0.37,dspgw = 0.055,
 thkcld = 0.0246, thkgap=0.0042,
 enrch = 9.0, fgpav = 200.0, hdish = 0.015,
 hplt = 0.4488, icm = 4, nplot =1,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
 jn = 11,11,11, fa=1.0,
 totl = 3.3, roughc = 1.e-5, roughf = 3.e-5, vs = 8.0,
 nunits = 1, rsntr = 75,
 flux = 11*0.16e17, p2(1) = 2230.0, tw(1) = 491, go(1) = 19000000.0,
 jst = 11*1,7*2,13*3
 qf(1) = 0.29, 0.49, 0.72, 0.90, 1.0, 1.0, 0.95, 0.86, 0.69, 0.49,0.31,
 x(1) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(12) =0.39, 0.57, 0.79, 0.93, 1.01 1.01 0.99, 0.94, 0.81, 0.61,0.44,
 x(12) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 qf(23) =0.43, 0.60, 0.81, 0.94, 1.0, 1.0, 1.00, 0.96, 0.84, 0.65, 0.48,
 x(23) = 0,0.33,0.66,0.99,1.32,1.65,1.98,2.31,2.64,2.97,3.3,
 ProblemTime=
 0.1,  25., 45., 55., 70.,105.,150.,160.,180.,190.,215.,
```

```
270.,300.,310.,330.,350.,360.,380.,
400.,420.,460.,480.,500.,520.,530.,550.,580.,585.,595.,620.,670.,
qmpy =
 3.700, 8.140,10.286,11.026, 9.028
11.026,12.654,11.766,13.098,12.432
12.876,13.082,12.516, 7.914, 7.348
 8.156,11.305,12.032, 6.521, 9.328
10.071, 9.081, 7.017, 4.293, 4.788
 4.045, 4.540, 5.531, 4.540, 5.779
 5.531
slim = .05,
$end
```

A.19 DR-3 Rods

Test 022 comprised three UO_2-Zr test fuel pins which were irradiated in the DR-3 reactor at Risø, Denmark, at 7.2 MPa (70 atm) system pressure (Bagger et al., 1978). A burnup of approximately 42 GWd/MTU was accumulated at heat loads in the range of 35 to 53 kW/m. Fission gas analysis for two of the pins (PA29-4 and M2-2C) showed that the releases were 49 and 36 percent.

The three almost identical test fuel pins had 12.6 mm sintered $U0_2$ pellets of 2.28 percent enrichment in 128 mm long stacks. The cladding was cold-worked and stress-relieved Zr-2 tubing of approximately 0.55 mm wall thickness which had been autoclaved on both sides. The diametral pellet-clad clearance was 0.24 mm, and the pins were backfilled with 0.1 MPa (1 atm) helium.

These two rods were used to assess the FRAPCON-3.4 UO_2 FGR predictions. The input files used for the UO_2 FGR assessments are shown below.

PA29-4

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outPA29-4.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         RISO Rod PA29-4
 $frpcn
 im=133, na=10, nr=17,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 0.01544, thkcld=0.00059, dco = 0.01402, den = 94.7,
 pitch = 0.0128,fa = 1.0,iq=0,
 dishsd = 0.00071, thkgap=0.00012, enrch = 2.28, fgpav = 1.0134e5
 hplt = 0.0125, icm = 2,idxgas = 1, iplant = -3, jdlpr = 1,jn =8*11,
 nunits=0, p2=70.94e5, roughc = 8.9e-7, roughf = 8.9e-7, totl=0.128
 tw=554., rsntr = 110., hdish=0.00038,dspg=0.00889,
 jst(1) = 25*1, 11*2, 11*3, 19*4, 13*5, 14*6, 19*7, 21*8
 x(1)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(12)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(23)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(34)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(45)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(56)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(67)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(78)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 qf(1)=0.438,9*1.063,0.438,
 qf(12)=0.711,9*1.032,0.711,
 qf(23)=0.788,9*1.024,0.788,
 qf(34)=0.858,9*1.016,0.858,
 qf(45)=0.913,9*1.010,0.913,
 qf(56)=0.950,9*1.006,0.950,
 qf(67)=0.986,9*1.002,0.986,
 qf(78)=11*1.0,
 ProblemTime=
0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.1,5.,22.9,23.,34.,
```

```
 46.2,57.,69.6,69.7,78.,92.9,103.,116.3,125.,135.6,146.,
 159.1,170.,182.3,193.,205.3,205.4,216.,228.7,239.,251.9,
 262.,275.3,286.,298.7,309.,322.,332.,345.4,345.5,356.,
 361.8,361.9,372.,385.,395.,408.1,418.,431.3,431.4,442.,
 454.5,465.,477.8,488.,501.1,501.2,501.3,501.4,512.,524.5,
 524.6,535.,545.,555.,565.,575.,585.2,596.,608.5,619.,
 631.7,642.,654.8,665.,678.2,678.3,678.4,678.5,689.,701.4,
 701.5,701.6,707.7,712.,724.4,735.,747.7,758.,771.3,771.4,
 782.,794.6,806.,817.8,828.,840.9,851.,864.4,864.5,864.6,
 864.7,864.8,875.,886.1,896.,909.,919.,930.7,930.8,941.,
 954.,967.,982.9,993.,1005.8,1017.,1028.9,1030.,1041.,
 1052.,1063.,1079.8,1079.9,1080.,1080.1,1080.2,1080.3,
 qmpy = 5.,10.,15.,20.,25.,30.,35.,40.,45.,50.,3*53.4,55.4,2*57.4,
 2*55.7,53.,2*49.9,2*51.1,2*49.9,4*52.8,2*51.3,53.5,2*55.5,
 2*52.7,2*50.9,2*49.5,2*46.9,2*48.3,50.5,2*52.7,50.,2*46.9,
 2*45.1,2*44.0,41.5,2*39.1,2*40.8,2*41.4,43.5,45.5,47.5,
 2*49.5,51.7,3*54.2,3*51.3,2*50.4,2*47.5,2*46.6,2*49.8,52.,
 54.,56.,2*58.5,56.,53.,50.,2*46.9,2*45.5,2*48.4,46.,
 4*44.0,2*41.1,2*39.7,41.5,43.5,45.5,47.5,2*49.5,2*51.3,
  2*52.7,50.,2*46.9,2*46.6,4*48.1,49.5,2*51.0,2*48.1,40.,
  30.,20.,10.,0.1,
 $end
```

M2-2C

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outM2-2C.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         RISO Rod M2-2C
 $frpcn
 im=35, na=10, nr=17,
 mechan = 2, ngasr = 15,
 $end
 $frpcon
 cpl = 0.01544, thkcld=0.00053, dco = 0.01402, den = 94.7,
 dishsd = 0.00071, thkgap=0.00012, enrch = 2.28, fgpav = 1.0134e5
 hplt = 0.0125, icm = 2,idxgas = 1, iplant = -3, jdlpr = 1,jn =8*11,
 nunits=0, p2=70.94e5, roughc = 8.9e-7, roughf = 8.9e-7, totl=0.128
 tw=554., rsntr = 110., hdish=0.00038,dspg=0.00889,
 go=3.39e3, pitch = 0.016,
 iq=0, fa=1,
 jst(1) = 5*1,4*2,4*3,4*4,4*5,4*6,4*7,6*8,
 x(1)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(12)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(23)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(34)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(45)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(56)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(67)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 x(78)=0.,.0128,.0256,.0384,.0512,.0640,.0768,.0896,.1024,.1152,.1280,
 qf(1)=.287,.978,1.002,1.026,1.050,1.074,1.098,1.122,1.146,1.170,.386,
 qf(12)=.545,.948,.971,.995,1.018,1.041,1.064,1.088,1.111,1.134,.716,
 qf(23)=.646,.937,.960,.983,1.006,1.029,1.051,1.074,1.097,1.120,.841,
 qf(34)=.717,.930,.953,.975,.997,1.020,1.042,1.065,1.087,1.110,.925,
```

```
qf(45)=.780,.923,.945,.968,.990,1.012,1.034,1.056,1.079,1.101,1.006,
qf(56)=.815,.920,.942,.964,.986,1.008,1.029,1.052,1.074,1.095,1.048,
qf(67)=.846,.916,.938,.960,.982,1.004,1.026,1.048,1.070,1.092,1.089,
qf(78)=.880,.914,.936,.958,.980,1.001,1.023,1.045,1.067,1.008,1.097,
ProblemTime=
.1,22.92,46.17,69.58,135.58,182.33,205.33,228.67,251.88,275.29,
298.67,345.38,361.79,384.96,431.29,501.13,524.54,555.04,585.17,
608.46,654.75,678.17,701.38,724.40,747.67,771.29,817.75,864.38,
886.13,909.04,930.71,982.92,1028.92,1052.00,1079.79,
qmpy =
16.4,50.3,54.1,52.5,47.4,49.8,48.4,52.4,49.7,47.3,
46.7,44.9,49.7,44.2,42.0,38.1,45.1,51.1,48.0,44.8,
44.5,47.0,55.2,44.3,42.9,45.7,41.6,38.2,46.7,48.4,
49.7,44.1,45.4,48.1,45.4,
$end
```

A.20 NRX Rods

Several sets of UO_2 fuel rods were irradiated in a pressurized water loop in the NRX reactor in Chalk River, Canada (De Meulemeester et al., 1973; Notley et al., 1967). The goal of these tests was to measure the gas pressures inside the rods, with the following objectives:

- To determine the effects of fuel density on gas pressure and FGR.
- To determine the effects of element power output variations on gas pressure and FGR.
- To obtain data to test the predictions of a model for calculating the variation of gas pressure with power output.

After irradiation, the rods were dimensioned and punctured for fission gas analysis. Samples from the rods were also analyzed for chemical burnup. Five of these rods were selected as UO_2 FGR assessment cases for FRAPCON-3.4 because they provide FGR data at low burnups (< 11 GWd/MTU) while the other FGR assessment data were at burnups greater than 20 GWd/MTU. Rods CBR, CBY, and CBP were irradiated together to 2.7 GWd/MTU in 85 days. Rod LFF was irradiated to 3.3 GWd/MTU in 108 days. Rod EPL-4 was irradiated to 10.4 GWd/MTU in 100 days.

The input files used for the UO_2 FGR assessments are shown below.

CBY

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outCBY.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
   NRX test rod CBY
 $frpcn
 im=8, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 24.2, crdt = 1., crdtr = 0.0,
 thkgap = 0.01, thkcld = 0.02,
 dco = 0.6885, pitch = 0.9
 den = 95.0, dishsd = 0.18695, dspg = 0.64,
 dspgw = 0.055, enrch = 4.5, fgpav = 146.0, hdish = 0.01,
 hplt = 0.6043, icm = 2,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,fa = 1.0,
 jn = 4,
 totl = 0.798, roughc = 2.e-5, roughf = 5.e-5, vs = 2.0,
 nunits = 1, rsntr = 150.,
 flux = 5*0.18e17, p2(1) = 1178.0, tw(1) = 480, go(1) = 19000000.,
 jst = 8*1,
 qf(1) = 1,1,1,1,
 x(1) =0.0, 0.2295, 0.459, 0.798
 ProblemTime= 0.1,5, 17.2,34.3,51.5,68.7,85.9,89.6,
 qmpy= 5,7*16.55
 $end
```

CBR

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outCBR.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         NRX test rod CBR
 $frpcn
 im=8, na=4,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 24.2, crdt = 1., crdtr = 0.0,
 thkgap = 0.009, thkcld = 0.02,
 dco = 0.6885, pitch = 0.9
 den = 97.1, dishsd = 0.18695, dspg = 0.64,
 dspgw = 0.055, enrch = 4.5, fgpav = 146.0, hdish = 0.01,
 hplt = 0.6043, icm = 2,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 4,
 totl = 0.798, roughc = 2.e-5, roughf = 5.e-5, vs = 2.0,
 nunits = 1, rsntr = 150.,
 flux = 5*0.18e17, p2(1) = 1178.0, tw(1) = 480, go(1) = 19000000.,
 jst = 8*1,
 qf(1) = 1,1,1,1,
 x(1) =0.0, 0.2295, 0.459, 0.798
 ProblemTime= 0.1,5, 17.2,34.3,51.5,68.7,85.9,89.6,
 qmpy= 5,7*17.4
 $end
```

CBP

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outCBP.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         NRX test rod CBP
 $frpcn
 im=8, na=4,
 ngasr = 45,
 $end
 $frpcon
 cpl = 24.2, crdt = 1.0, crdtr = 0.0,
 thkgap = 0.009, thkcld = 0.02,
 dco = 0.6885, pitch = 0.9
 den = 97.2, dishsd = 0.18695, dspg = 0.64,
 dspgw = 0.055, enrch = 4.5, fgpav = 146.0, hdish = 0.01,
 hplt = 0.6043, icm = 2,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,fa = 1.0,
 jn = 4,
 totl = 0.798, roughc = 2.e-5, roughf = 5.e-5, vs = 2.0,
 nunits = 1, rsntr = 150.,
```

```
 flux(1) = 5*0.18e17, p2(1) = 1178.0, tw(1) = 480, go(1) = 19000000.,
 jst = 8*1,
 qf(1) = 1.0,1.0,1.0,1.0,
 x(1) =0.0, 0.2295, 0.459, 0.798,
 ProblemTime = 0.1,5, 17.2,34.3,51.5,68.7,85.9,89.6,
 qmpy= 5,7*16.8
 $end
```

LFF

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outLFF.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         NRX test rod LFF
 $frpcn
 im=12, na=4,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.1, crdt = 0, crdtr = 0.0, thkcld=0.030,
 dco = 0.8108, pitch = 0.90,
 den = 95.7, dishsd = 0.2466, thkgap=0.009, dspg = 0.72,
 dspgw = 0.055, enrch = 2.4, fgpav = 146.0, hdish = 0.02,
 hplt = 0.6043, icm = 4,fa=1.0,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,
 jn = 4,
 totl = 0.7975, roughc = 2.e-5, roughf = 5.e-5, vs = 8.0,
 nunits = 1, rsntr = 150.,
 flux(1) = 5*0.18e17, p2(1) = 1000.0, tw(1) = 550, go(1) = 19000000.0,
 jst = 12*1
 qf(1) = 1,1,1,1,
 x(1) =0.0, 0.2658, 0.5317, 0.7975
 ProblemTime=
 0.1, 0.2, 0.3, 0.4,
 5.0, 22.5, 44.9, 67.4, 89.9, 100.2,
 120., 140.
 qmpy=
 5, 8., 11., 14.,
 8*17.8
 $end
```

EPL-4

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outEPL-4.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         NRX test rod EPL-4
 $frpcn
 im=17, na=4,
 ngasr = 45, nr=17
```

```
$end
$frpcon
cpl = 1.1, crdt = 0, crdtr = 0.0, thkcld=0.030,
dco = 0.3621, pitch = 0.90,
den = 93.9, dishsd = 0.2466, thkgap=0.005, dspg = 0.29,
dspgw = 0.055, enrch = 2.4, fgpav = 146.0, hdish = 0.02,
hplt = 0.6043, icm = 4,
icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,
jn = 4, fa=1.0,
totl = 3.28, roughc = 2.e-5, roughf = 5.e-5, vs = 8.0,
nunits = 1, rsntr = 150.,
flux = 5*0.18e17, p2(1) = 1000.0, tw(1) = 550, go(1) = 19000000.0,
jst = 17*1
qf(1) = 1,1,1,1,
x(1) =0.0, 1.093, 2.187, 3.28
ProblemTime=
0.1,0.2,0.3,0.4,0.5,
0.6,0.7,0.8,0.9,1.,
1.1,1.2,
22.5, 44.9, 67.4, 89.9, 100.2
qmpy=
1.,2.,3.,4.,5.,
6.,7.,8.,9.,10.,
11.,12.,
5*12.3
$end
```

A.21 EL-3 Rods

Sixteen cartridges, each containing two rods, were irradiated in the EL-3 reactor, France, for a varying number of cycles to achieve burnups from 3 to 12 GWd/MTU. The aspects of the rods studied in this project were:

- Macroscopic appearances: crack network, material movement, and dimensional changes
- Microscopic appearances: recrystallization, pore redistribution, and new phases
- Migration of fission products: stable gases released by the fuel and distribution of solid fission products

Each cartridge was constructed of Zircaloy-2 and consisted of two separate stages, each containing a stack of UO_2 fuel 123 mm high at each end, and in the central joint, space was provided for cobalt flux indicators. Each stage contained a chromel-alumel thermocouple located in the center of the stack. The cartridges were then filled with helium.

After irradiation, the rods were dimensioned and punctured for fission gas analysis. Gamma scans were done as well as a radiochemical analysis. The rods 4110-AE2 and 4110-BE2 (Janvier et al., 1967) were used to assess the UO_2 FGR predictions of FRAPCON-3.4.

Both rods 4110-AE2 and 4110-BE2 contained fuel pellets with an as-fabricated density of 10.52 g/cm^3. AE2 ran at a power of 17.6 kW/ft while BE2 ran at a power of 17.8 kW/ft. Rods 4110-AE2 and 4110-BE2 were maintained throughout life at constant average LHGRs of 17.6 and 17.8 kW/ft, respectively. Both ran with a flat axial power profile. The input LHGRs were a flat 17.6 and 17.8 kW/ft, with a few steps to get up to power.

These two rods were used to assess the FRAPCON-3.4 UO_2 FGR predictions at burnups less than 15 GWd/MTU. The input files used for the UO_2 FGR assessments are shown below.

4110-AE2

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out4110-ae2.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
        EL-3 test rod number 4110-AE2
 $frpcn
 im=11, na=4,
 ngasr = 45,
 $end
 $frpcon
 cpl = 38.0, crdt = 0., crdtr = 0.0, dco = 0.5564,
 thkcld=0.020,
 pitch = 0.65,
 den = 96.0, dishsd = 0.1214, thkgap= 0.004, dspg = 0.51,
 dspgw = 0.055, enrch = 2.98, fgpav = 147.0, hdish = 0.0,
 hplt = 0.6043, icm = 2,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,fa = 1.0,
 jn = 4
 totl = 0.403, roughc = 2.e-5, roughf = 5.e-5, vs = 28.0,
 nunits = 1, rsntr = 150.
```

```
 flux = 5*0.18e17, p2(1) = 1000.0, tw(1) = 630, go(1)=19000000.0,
 jst = 11*1
 qf(1) = 1,1,1,1,
 x(1) =0.0, 0.134, 0.269, 0.403
 ProblemTime= 0.1, 0.2, 0.3,
 15.0, 25.2, 45.7, 66.2, 86.6, 107.1, 127.6, 132.5
 qmpy= 5., 9., 13.,8*17.6,
 slim = .05,
 $end
```

4110-BE2

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out4110-be2.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         EL-3 test rod number 4110-BE2
 $frpcn
 im=9, na=4,
 ngasr = 45,
 $end
 $frpcon
 cpl = 38.0, crdt = 0., crdtr = 0.0, dco = 0.5574,
 thkcld=0.020,
 pitch = 0.65,
 den = 96.0, dishsd = 0.1224, thkgap= 0.0035, dspg = 0.51,
 dspgw = 0.055, enrch = 2.98, fgpav = 147.0, hdish = 0.0,
 hplt = 0.6043, icm = 2,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,fa = 1.0,
 jn = 4
 totl = 0.403, roughc = 2.e-5, roughf = 5.e-5, vs = 28.0,
 nunits = 1, rsntr = 150.
 flux = 5*0.18e17, p2(1) = 1000.0, tw(1) = 630, go(1)=19000000.0,
 jst = 9*1
 qf(1) = 1,1,1,1,
 x(1) =0.0, 0.134, 0.269, 0.403
 ProblemTime= 0.1,15.1, 25.3, 45.7, 66.1, 86.5, 106.9, 127.3, 138.8
 qmpy= 5,12.,7*17.8,
 slim = .05,
 $end
```

A.22 FUMEX 6f and 6s Rods

Two rods were base-irradiated in the Halden HBWR at low power to 55 GWd/MTU. Each of these rods was then refabricated to include pressure transducers and run at higher power while the pressure was being monitored. These rods, FUMEX 6s and FUMEX 6f (Chantoin et al., 1997) were included as FRAPCON-3.4 UO_2 FGR assessment cases.

The input files used for the FGR assessment are shown below.

FUMEX 6f

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outfumex6f.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
FUMEX Case 6f - fast EOL Ramp
 $frpcn
 im=72, na=4, nr=17,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 8.0, dco = 0.4929, thkcld = 0.0339,
 den = 94.7, thkgap = 0.00512, rc = 0.0, dspg = 0.42,
 dspgw = 0.04, enrch = 9.88,fgpav = 370, hplt = 0.41, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1, iplant = -4, iq = 0, fa = 1.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,
 jst(1) = 8*1,11*2, 5*3, 3*2, 1*4, 1*2, 8*5, 2*3, 7*5, 2*3, 15*6, 9*7,
 totl = 1.53, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 100.,pitch =0.56, crephr=1.0,
 flux(1) = 5*.05e17, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
  qf(1) =
 1.42, 1.26, 1.01,0.749,0.545,
 1.22, 1.14, 1.01, 0.87, 0.73,
 1.31, 1.19, 1.01, 0.81, 0.64,
 1.37, 1.24, 1.01, 0.77, 0.58,
 1.12, 1.09, 1.01, 0.92, 0.82,
 1.18, 1.13, 1.01, 0.88, 0.77,
 0.70, 0.84, 1.00, 1.16, 1.28,
 x(1) =
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
  ProblemTime =
  0.10, 0.20, 0.30, 0.40, 0.50,
    3.5, 15.,   50.,   59., 61., 100.,
  150.,  156.,  200.,  250.,
  260.,  275.,  280.,  310.,  350.,  360.,  370.,  400.,
  425.,  450.,
  490.,  500.,  550.,  600.,  650.,  685.,
```

```
  700.,  710.,  750.,  780.,  800.,  810.,  850.,  890.,
  940.,  950., 1000., 1010., 1050., 1065., 1100., 1160.,
  1200., 1250.,
  1300., 1325., 1350., 1400., 1450., 1500.,
  1550., 1600., 1660., 1695., 1702., 1745., 1755., 1800.
  1800.2, 1800.4, 1800.6, 1800.8, 1801.,
  1817. 1854., 1882., 1902.,
  qmpy =
  2.,  4.,  6.,  8.,  10. ,10.  ,
  7.  , 7.  , 10.,11.9, 10.5 ,10.87, 8.5 , 8.5 , 7.93,
  6.12, 8.  , 6.  , 5.87, 6.1 , 7.71, 6.1 , 6.25,
  8.  , 6.25, 6.5 , 7.05, 5.69, 6.31, 6.96, 7.  ,
  8.98, 7.  , 6.1 , 7.  , 9.  , 6.74, 6.74, 4.86,
  6.13, 8.98, 8.25, 4.46, 7.71, 9.75, 8.15, 8.33,
  7.58, 8.72, 8.45, 7.25, 8.25, 6.66, 4.69, 4.38,
  4.47, 4.  , 5.  , 4.5 , 4.25, 4.5 , 5.4 , 5.5
  6.,  8.,  9.,   10.,  11.,
 13., 12.3, 11.8,  11.5,
  $end
```

FUMEX 6s

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outfumex6s.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
   FUMEX Case 6s - Slow EOL Ramp
 $frpcn
 im=80, na=4, nr=17,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 8.0, dco = 0.4929, thkcld = 0.0339, pitch = 0.56,
 den = 94.7, thkgap = 0.00512, rc = 0.0, dspg = 0.42,
 dspgw = 0.04, enrch = 9.88,fgpav = 370., hplt = 0.41, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1, iplant = -4, iq = 0, fa = 1.0,
 jdlpr = 0, jn(1) = 5,5,5,5,5,5,
 jst(1) = 8*1,11*2, 5*3, 3*2, 1*4, 1*2, 8*5, 2*3, 7*5, 2*3, 15*6, 17*7,
 totl = 1.53, roughc = 2.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, rsntr = 100.,
 flux(1) = 5*.05e17, p2(1) = 500., tw(1) = 459., go(1) = 0.0,
  qf(1) =
 1.42, 1.26, 1.01, 0.749, 0.545,
 1.22, 1.14, 1.01, 0.87, 0.73,
 1.31, 1.19, 1.01, 0.81, 0.64,
 1.37, 1.24, 1.01, 0.77, 0.58,
 1.12, 1.09, 1.01, 0.92, 0.82,
 1.18, 1.13, 1.01, 0.88, 0.77,
 0.71, 0.84, 1.01, 1.16, 1.26,
 x(1) =
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
 0.0, 0.382, 0.765, 1.1475, 1.53,
```

```
0.0, 0.382, 0.765, 1.1475, 1.53,
0.0, 0.382, 0.765, 1.1475, 1.53,
 ProblemTime =
0.10, 0.20, 0.30, 0.40, 0.50,
   3.5, 15.,   50.,   59.,61.,100.,
 150.,  156.,  200.,  250.,
 260.,  275.,  280.,  310.,  350.,  360.,  370.,  400.,
 425.,  450.,
 490.,  500.,  550.,  600.,  650.,  685.,
 700.,  710.,  750.,  780.,  800.,  810.,  850.,  890.,
 940.,  950., 1000., 1010., 1050., 1065., 1100., 1160.,
 1200., 1250.,
 1300., 1325., 1350., 1400., 1450., 1500.,
 1550., 1600., 1660., 1695., 1702., 1745., 1755., 1800.
1800.1, 1800.2, 1800.3, 1802., 1804.,
1805., 1806., 1807, 1810., 1810.25, 1810.5, 1810.75, 1811.,
1812., 1832., 1866., 1885.,
 qmpy =
2.,  4.,  6.,  8.,  10. ,10.  ,
 7.  , 7.  , 10.,11.9, 10.5 ,10.87, 8.5 , 8.5 , 7.93,
 6.12, 8.  , 6.  , 5.87, 6.1 , 7.71, 6.1 , 6.25,
 8.  , 6.25, 6.5 , 7.05, 5.69, 6.31, 6.96, 7.  ,
 8.98, 7.  , 6.1 , 7.  , 9.  , 6.74, 6.74, 4.86,
 6.13, 8.98, 8.25, 4.46, 7.71, 9.75, 8.15, 8.33,
 7.58, 8.72, 8.45, 7.25, 8.25, 6.66, 4.69, 4.38,
 4.47, 4.  , 5.  , 4.5 , 4.25, 4.5 , 5.4 , 5.5
5., 6., 7., 8., 9.,
11., 12., 13., 13., 14., 14.5, 15.,  16.,
16., 15., 15., 13.
$end
```

A.23 Halden IFA-429 Rod

The IFA-429 test fuel assembly (Turnbull, 2001) was initiated by NRC-Research and designed and fabricated by Idaho National Laboratory (with fuel pellet fabrication by PNNL) to demonstrate the effect of burnup, power level, and fuel grain size on fuel thermal behavior and FGR. The assembly consisted of 18 original short rods, arranged in three clusters of 6 rods each, and 15 noninstrumented spare and replacement rods. Rod DH is a replacement rod that was re-instrumented with a pressure transducer after it had attained about 30 GWd/MTU burnup at relatively low LHGR; the rod was then irradiated in IFA-519 at much higher and variable LHGR as part of a load-follow test, and eventually attained a peak burnup of 99 GWd/MTU. The FGR for this rod was obtained by puncture during PIE. It should be noted that the puncture data provided much higher release values than were estimated from the pressure transducer measurements because the rod pressures had exceeded the measurement capabilities of the pressure transducer.

The input file used for the FGR assessment is shown below.

IFA-513 Rod 6 Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='429-DH.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='429-DH.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
******
Base Irradiation
 $frpcn
 im=224, nr=17, ngasr=45, na=5
 $end
 $frpcon
 dco=0.422, thkcld=0.024, thkgap=0.00394, totl=0.8005, cpl=4.9
 dspg=0.358, dspgw=0.055, vs=10
 hplt=0.5984, rc=0, hdish=0.013, dishsd=0.122
 enrch=13, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.00008, rsntr=75, tsint=2911
 icm=4, cldwks=0.5, roughc=0.00001, catexf=0.05, chorg=10
 fgpav=375.6, idxgas=1
 iplant=-4, pitch=0.56, icor=0, crdt=0, crdtr=0,
 flux=6*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.107, 52.666, 98.375, 140.122, 186.152
 247.275, 292.02, 328.522, 367.058, 388.468
 406.665, 468.109, 501.293, 556.315, 612.942
 694.617, 764.625, 802.519, 821.038, 871.884
 899.181, 944.889, 973.363, 1008.581, 1050.65
 1076.127, 1083.484, 1092.917, 1095.322, 1096.736
 1102.202, 1106.118, 1112.926, 1114.494, 1122.588
```

1124.846, 1127.706, 1129.905, 1133.554, 1138.839
1140.901, 1156.586, 1156.899, 1166.598, 1174.076
1177.247, 1177.896, 1188.702, 1193.167, 1196.827
1201.568, 1204.695, 1208.179, 1213.462, 1214.348
1220.713, 1222.388, 1228.393, 1228.52, 1234.654
1234.776, 1237.137, 1242.143, 1242.723, 1248.617
1250.83, 1252.786, 1256.383, 1261.73, 1271.233
1274.658, 1279.632, 1287.232, 1287.607, 1292.604
1296.517, 1308.795, 1311.263, 1319.303, 1324.69
1327.568, 1335.828, 1338.234, 1342.781, 1348.062
1357.185, 1363.576, 1374.935, 1381.616, 1388.955
1392.641, 1399.322, 1402.213, 1409.1, 1416.818
1420.249, 1424.529, 1427.328, 1429.139, 1434.281
1447.456, 1453.785, 1478.063, 1483.68, 1495.168
1507.311, 1513.647, 1514.144, 1523.431, 1529.12
1537.496, 1553.678, 1557.822, 1574.023, 1577.104
1583.743, 1588.679, 1597.283, 1598.01, 1602.52
1603.81, 1621.357, 1626.793, 1630.935, 1656.04
1661.731, 1678.402, 1681.153, 1685.674, 1701.61
1707.839, 1707.91, 1712.024, 1716.861, 1721.106
1721.821, 1725.39, 1728.832, 1731.344, 1731.472
1744.411, 1750.486, 1792.74, 1802.71, 1805.017
1806.129, 1818.219, 1818.389, 1830.079, 1832.081
1832.918, 1849.596, 1853.814, 1873.91, 1874.796
1900, 1903.009, 1914.922, 1922.959, 1923.484
1930.055, 1935.636, 1938.468, 1949.727, 1949.953
1957.606, 1971.239, 1974.114, 1979.215, 1981.361
1997.831, 1999.49, 2007.921, 2019.334, 2030.442
2071.124, 2071.296, 2088.608, 2092.605, 2101.635
2111.086, 2114.178, 2122.165, 2126.12, 2128.571
2151.032, 2151.235, 2154.715, 2158.033, 2165.988
2173.162, 2181.591, 2183.74, 2190.745, 2203.826
2207.841, 2210.694, 2212.49, 2306.431, 2312.752
2316.966, 2328.726, 2351.996, 2359.229, 2366.216
2379.106, 2380.726, 2410.946, 2416.25, 2419.379
2429.008, 2440.578, 2441.865, 2464.408, 2484.045
2488.399, 2506.505, 2539.723, 2548.695, 2550.965
2561.464, 2564.636, 2594.665, 2615.101
qmpy=
4.27, 4.27, 4.88, 5.34, 4.88
5.49, 5.03, 6.1, 5.79, 5.34
6.1, 5.49, 6.71, 6.1, 5.95
5.49, 3.18, 5.95, 5.95, 4.42
4.12, 4.88, 3.96, 4.42, 4.27
4.42, 10.933, 10.983, 11.547, 11.09
10.953, 11.355, 11.433, 11.809, 11.644
12.02, 11.83, 11.964, 9.785, 9.784
11.987, 11.417, 9.777, 9.774, 10.873
10.872, 7.162, 7.187, 9.416, 9.442
8.204, 7.424, 7.369, 9.572, 9.518
9.435, 8.601, 8.627, 10.347, 10.855
11.258, 11.956, 12.25, 11.712, 11.683
11.682, 9.585, 9.584, 9.824, 10.063
10.491, 10.194, 10.218, 8.632, 8.604
10.162, 9.701, 7.631, 7.414, 8.998
9.078, 7.839, 9.478, 9.476, 10.362
10.412, 11.216, 11.454, 11.774, 11.717

```
11.42, 9.187, 10.584, 11.925, 12.567
12.028, 12.295, 12.186, 9.793, 10.571
10.432, 8.495, 8.112, 10.879, 11.412
12.321, 12.157, 11.27, 9.6, 8.335
9.891, 10.182, 11.39, 11.115, 10.388
10.386, 10.68, 11.241, 12.021, 12.045
11.238, 11.312, 10.746, 8.863, 8.936
9.311, 9.306, 8.902, 11.427, 11.34
10.746, 8.381, 8.38, 10.152, 10.151
9.64, 10.015, 10.283, 10.255, 9.879
9.767, 10.141, 7.765, 7.789, 8.46
8.809, 8.457, 7.812, 7.808, 6.652
8.829, 8.126, 8.366, 4.493, 9.519
3.656, 9.837, 8.221, 5.129, 8.947
9.32, 9.184, 9.452, 9.072, 3.508
8.774, 3.827, 8.422, 8.501, 9.307
10.108, 4.866, 6.988, 6.716, 8.218
7.805, 8.048, 8.525, 9.196, 8.226
8.197, 6.476, 6.474, 6.93, 6.661
6.951, 7.866, 7.81, 8.669, 8.667
8.181, 8.179, 8.447, 8.768, 8.495
9.085, 9.192, 8.735, 8.145, 8.224
8.007, 8.085, 5.124, 4.451, 5.391
5.335, 9.528, 8.068, 8.227, 7.797
8.197, 8.194, 9.107, 7.838, 7.914
7.939, 8.714, 1.321, 5.378, 8.576
8.035, 6.368, 6.308, 6.331
nsp=0
p2= 500, tw= 464, go= 0
iq=0, fa=1
x(1)=
0, 0.13342, 0.26683, 0.40025, 0.53367
0.66708, 0.8005
qf(1)=
0.8, 0.68, 0.78, 0.89, 1.11
1.27, 1.85
x(8)=
0, 0.13342, 0.26683, 0.40025, 0.53367
0.66708, 0.8005
qf(8)=
1.045, 1.075, 1.05, 1.2, 0.98
0.94, 0.855
jn=7,7
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, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
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2, 2, 2, 2, 2
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2, 2, 2, 2, 2
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2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2
$end
```

A.24 Arkansas Nuclear PWR Rod

DOE sponsored a program with ABB Combustion Engineering and Energy Operations, Inc. to improve the use of PWR fuel. The scope of this project was to develop more efficient fuel management concepts and an increase in the burnup of discharged fuel.

Two 16 x 16 lead test assemblies were irradiated in the Arkansas Nuclear One-Unit 2 reactor (ANO-2). This is a PWR that operates at 2815 MW thermal. One of the assemblies, D039, was irradiated for three cycles and achieved a burnup of 33 GWd/MTU. The other assembly, number D040, was irradiated for five cycles and achieved a burnup of 52 GWd/MTU.

Rod TSQ002 (Smith et al., 1994), irradiated in assembly D040, was of standard CE 16 x 16 design and contained solid UO_2. Assembly D040 was irradiated from 1979 to 1988 in ANO-2, cycles two through six. It accumulated 52 GWd/MTU assembly-average burnup. Rod TSQ002 accumulated an end-of-life (EOL) rod-average burnup of 56.1 GWd/MTU. The rod-average LHGR varied from 2.75 to 6.95 kW/ft, with the higher values near BOL.

This rod was used to assess the FRAPCON-3.4 UO_2 FGR predictions, the EOL void volume predictions and the Zircaloy-4 corrosion predictions. The input files used for these assessments are shown below. The input for the EOL void volume contains one extra time step at room temperature and zero power so the room temperature void volume is calculated for comparison to the PIE measured volume.

ANO-2 Rods TSQ002 Case for FGR and Corrosion

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outTSQ002.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plotTSQ002.n', STATUS = 'UNKNOWN', FORM = 'FORMATTED'
/**********************************************************************
         ANO-2 Assembly D040 rod TSQ002
 $frpcn
 im = 70, na = 12, nr = 17,
 ngasr = 45,
 $end
 $frpcon
 cpl = 10.7, crdt = 0.2, crdtr = 0.0, dco = 0.382,
 thkcld = 0.025, thkgap = 0.0035,
 den = 95.0, dishsd = 0.1, dspg = 0.33,
 dspgw = 0.055, enrch = 3.48, fgpav = 380.0, hdish = 0.0135,
 hplt = 0.390, icm = 4,pitch = 0.50,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0, fa = 1.0,
 jn = 25,25,25,24,24,
 totl = 12.5, roughc = 2e-5, roughf = 3e-5, vs = 8.0,
 nunits = 1, rsntr = 150., nplot = 1,
 flux(1) = 13*0.26e17, p2 = 70*2250.0,tw = 70*554.,
 go = 70*4.35e6,nsp=1,
 jst = 9*1,11*2,17*3,14*4,19*5,
 qf(1) = 0.54,0.83,1.03,1.10,1.14,1.14,1.12,1.11,1.10,1.08,1.07,
 1.06,1.06,1.06,1.05,1.05,1.06,1.07,1.07,1.07,1.06,1.00,0.93,0.73,0.46,
 x(1) = 0,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,
 6.25,6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12.5,
```

```
 qf(26) = 0.58,0.86,1.02,1.06,1.09,1.10,1.09,1.09,1.09,
 1.08,1.08,1.07,1.07,1.07,1.07,1.06,1.06,1.06,1.06,1.05,1.04,
 1.00,0.95,0.87,0.52,
 x(26) = 0,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,
 6.25,6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12.5,
 qf(51) = 0.63,0.90,1.04,1.07,1.09,1.08,1.07,1.07,1.06,
 1.05,1.04,1.04,1.04,1.04,1.03,1.04,1.04,1.04,1.05,1.05,1.04,
 1.02,0.97,0.83,0.56,
 x(51) = 0,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,
 6.25,6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12.5,
 qf(76) = 0.61,0.81,0.95,1.02,1.06,1.07,1.06,1.06,1.06,
 1.05,1.06,1.06,1.06,1.07,1.08,1.08,1.10,1.11,1.13,1.12,1.07,
 0.99,0.84,0.61,
 x(76) = 0,0.52,0.83,1.16,1.65,2.28,2.87,3.50,4.15,

4.78,5.37,6.00,6.65,7.28,7.87,8.50,9.15,9.78,10.37,11.00,11.82,12.13,12
.5,
 qf(100) = 0.69,0.82,0.94,1.00,1.03,1.04,1.04,1.04,1.04,

1.05,1.05,1.05,1.05,1.06,1.06,1.07,1.08,1.09,1.09,1.09,1.06,1.01,0.88,0
.75,
 x(100) = 0,0.52,0.83,1.16,1.65,2.28,2.87,3.50,4.15,

4.78,5.37,6.00,6.65,7.28,7.87,8.50,9.15,9.78,10.37,11.00,11.82,12.13,12
.5,
 ProblemTime= 9.8,68.7,91.5,139.6,187.7,209.8,236.6,263.0,292.3,
 307.2,321.0,334.7,362.2,389.7,417.0,444.4,471.7,499.0,526.2,548.7,
 553.3,561.3,570.7,586.2,605.9,621.4,639.0,668.9,696.3,726.5,
 756.4,786.2,813.9,843.2,886.4,905.4,919.8,

926.6,933.5,947.2,974.9,1002,1030,1057,1085,1112,1140,1168,1196,1223,12
43,
 1249,1256,1270,1296,1322,1350,1376,1403,1430,1456,1483,1510,1537,
 1563,1590,1617,1644,1670,1697,
 qmpy =3.28,4.34,4.31,4.3,4.32,4.29,4.32,4.35,2.88,
 6.95,6.95,6.91,6.84,6.8,6.76,6.73,6.7,6.68,6.65,6.62,
 5.95,5.95,5.76,5.78,5.86,5.87,5.81,5.79,5.77,5.75,
 5.72,5.68,5.68,5.62,4.8,5.05,5.62,
 4.37,4.41,4.4,4.37,4.38,4.39,4.4,4.42,4.43,4.4,4.4,4.4,4.4,4.4,
 2.75,2.97,2.82,2.88,2.92,3.01,3.09,3.14,3.21,3.27,
 3.33,3.39,3.46,3.52,3.59,3.66,3.69,3.82,3.89,
 slim = .05,
 $end
```

ANO-2 Rods TSQ002 Case for EOL Void Volume

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outTSQ002.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plotTSQ002.n', STATUS = 'UNKNOWN', FORM = 'FORMATTED'
/**********************************************************************
         ANO-2 Assembly D040 rod TSQ002
 $frpcn
 im = 71, na = 12, nr = 17,
 ngasr = 45,
```

```
 $end
 $frpcon
 cpl = 10.7, crdt = 0.2, crdtr = 0.0, dco = 0.382,
 thkcld = 0.025, thkgap = 0.0035,
 den = 95.0, dishsd = 0.1, dspg = 0.33,
 dspgw = 0.055, enrch = 3.48, fgpav = 380.0, hdish = 0.0135,
 hplt = 0.390, icm = 4,pitch = 0.50,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0, fa = 1.0,
 jn = 25,25,25,24,24,
 totl = 12.5, roughc = 2e-5, roughf = 3e-5, vs = 8.0,
 nunits = 1, rsntr = 150., nplot = 1,
 flux(1) = 13*0.26e17, p2 = 70*2250.0,14.7,tw = 70*554.,77.0
 go = 70*4.35e6,0.0,nsp=1,
 jst = 9*1,11*2,17*3,14*4,19*5,
 qf(1) = 0.54,0.83,1.03,1.10,1.14,1.14,1.12,1.11,1.10,1.08,1.07,
 1.06,1.06,1.06,1.05,1.05,1.06,1.07,1.07,1.07,1.06,1.00,0.93,0.73,0.46,
 x(1) = 0,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,
 6.25,6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12.5,
 qf(26) = 0.58,0.86,1.02,1.06,1.09,1.10,1.09,1.09,1.09,
 1.08,1.08,1.07,1.07,1.07,1.07,1.06,1.06,1.06,1.06,1.05,1.04,
 1.00,0.95,0.87,0.52,
 x(26) = 0,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,
 6.25,6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12.5,
 qf(51) = 0.63,0.90,1.04,1.07,1.09,1.08,1.07,1.07,1.06,
 1.05,1.04,1.04,1.04,1.04,1.03,1.04,1.04,1.04,1.05,1.05,1.04,
 1.02,0.97,0.83,0.56,
 x(51) = 0,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,
 6.25,6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12.5,
 qf(76) = 0.61,0.81,0.95,1.02,1.06,1.07,1.06,1.06,1.06,
 1.05,1.06,1.06,1.06,1.07,1.08,1.08,1.10,1.11,1.13,1.12,1.07,
 0.99,0.84,0.61,
 x(76) = 0,0.52,0.83,1.16,1.65,2.28,2.87,3.50,4.15,
 .78,5.37,6.00,6.65,7.28,7.87,8.50,9.15,9.78,10.37,11.00,11.82,12.13,12
.5,
 qf(100) = 0.69,0.82,0.94,1.00,1.03,1.04,1.04,1.04,1.04,
 .05,1.05,1.05,1.05,1.06,1.06,1.07,1.08,1.09,1.09,1.09,1.06,1.01,0.88,0
.75,
 x(100) = 0,0.52,0.83,1.16,1.65,2.28,2.87,3.50,4.15,
 .78,5.37,6.00,6.65,7.28,7.87,8.50,9.15,9.78,10.37,11.00,11.82,12.13,12
.5,
 ProblemTime= 9.8,68.7,91.5,139.6,187.7,209.8,236.6,263.0,292.3,
 307.2,321.0,334.7,362.2,389.7,417.0,444.4,471.7,499.0,526.2,548.7,
 553.3,561.3,570.7,586.2,605.9,621.4,639.0,668.9,696.3,726.5,
 756.4,786.2,813.9,843.2,886.4,905.4,919.8,
926.6,933.5,947.2,974.9,1002,1030,1057,1085,1112,1140,1168,1196,1223,12
43,
 1249,1256,1270,1296,1322,1350,1376,1403,1430,1456,1483,1510,1537,
 1563,1590,1617,1644,1670,1697,1698
 qmpy =3.28,4.34,4.31,4.3,4.32,4.29,4.32,4.35,2.88,
 6.95,6.95,6.91,6.84,6.8,6.76,6.73,6.7,6.68,6.65,6.62,
 5.95,5.95,5.76,5.78,5.86,5.87,5.81,5.79,5.77,5.75,
 5.72,5.68,5.68,5.62,4.8,5.05,5.62,
 4.37,4.41,4.4,4.37,4.38,4.39,4.4,4.42,4.43,4.4,4.4,4.4,4.4,4.4,
 2.75,2.97,2.82,2.88,2.92,3.01,3.09,3.14,3.21,3.27,
 3.33,3.39,3.46,3.52,3.59,3.66,3.69,3.82,3.89,0.0
 slim = .05,
 $end
```

A.25 Oconee PWR Rod

DOE sponsored a long-term, multi-organizational program on the performance of light-water reactor (LWR) fuel rods during operation to extend burnups. As part of that program, Babcock and Wilcox (B&W) 15 x 15-type PWR fuel assemblies were irradiated to 3, 4, and 5 cycles in the Oconee PWR, operated by Duke Power Company. One assembly, 1D45, completed five cycles of irradiation in June 1983, having achieved an assembly average burnup of 50 GWd/MTU during 1553 effective full-power days.

Several rods from the assembly were nondestructively and destructively examined in the B&W hot cells. This document summarizes the design and operating parameters for one rod, number 15309 (Newman, 1986). Fuel density and microstructure, rod growth, cladding oxidation/hydriding, and diametral strain data are available for this rod together with FGR measurement via rod puncture and plenum gas analysis. The FGR for this low-powered rod was < 1 percent; but the cladding oxidation, growth, and diametral strain were significant.

The rods were standard 15 x 15 full-length PWR rods. The rod initially had a rod-average LHGR of 7 to 8 kW/ft; however, this decreased to ~4 kW/ft by EOL. The axial power profile flattened early and remained relatively flat throughout life.

This rod was used to assess the FRAPCON-3.4 UO_2 FGR predictions, the EOL void volume predictions and the Zircaloy-4 corrosion predictions. The input files used for these assessments are shown below. The input for the EOL void volume contains one extra time step at room temperature and zero power so the room temperature volid volume is calculated for comparison to the PIE measured volume.

Oconee Rods 15309 Case for FGR and Corrosion

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out15309.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plot15309.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/*******************************************************************
         Oconee rod 15309
 $frpcn
 im=34, na=12,
 ngasr = 45,
 $end
 $frpcon
 cpl = 10.5, crdt = 0.2, crdtr = 0.0, thkcld = 0.0265,
 dco = 0.430, pitch = 0.56,
 den = 95., thkgap=0.0050, dishsd = 0.050,dspg = 0.37,
 dspgw = 0.055, enrch = 3., fa= 1.0, fgpav = 480,
 hplt = 0.70, hdish = 0.014, icm = 4,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
 totl = 11.75, jn = 13,13,13,13,13, jst = 7*1,10*2,2*3,5*4,10*5
 rc = 0.0, roughc = 1.97e-5, nplot = 1,
 roughf = 2.36e-5, vs = 20.0,
 nunits = 1, rsntr = 150.,
 qf(1)=0.2,1.0,1.2,1.25,1.25,1.22,1.2,1.16,1.14,1.06,.78,.3,.15,
 qf(14)=0.2,1.08,1.18,1.12,1.04,0.97,0.97,1.00,1.03,1.05,1.10,0.97,0.2,
```

```
 qf(27)=0.2,0.82,1.02,1.11,1.13,1.08,1.04,1.05,1.14,1.19,1.13,0.9,0.2,
 qf(40)=0.2,0.95,1.05,1.03,1.03,1.08,1.12,1.12,1.1,1.05,1.0,0.81,0.4,
 qf(53)=0.45,0.94,1.02,1.05,1.07,1.10,1.12,1.11,1.10,1.06,1.02,0.95,0.5
 x(1)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 x(14)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 x(27)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 x(40)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 x(53)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 flux = 13*0.25e17, p2(1) = 2200.0, tw(1) = 555.0, go(1) = 2.6e6,
 ProblemTime= 0.1,65,125,185,210,235,295,
 325,350,360,370,500,510,535,540,560,600,
 615,850,
 890,905, 920,1130,1150,
 1160,1205,1220,1240,1400,1445,1490,1510,1535,1550,
 qmpy = 5.8,5.8,7.9,7.5,7.3,6.8,6.6,
 7.9,7.6,7.4,6.9,6.6,6.1,6.7,6.0,6.6,6.1,
 4.1, 5.4,
 5.1,4.7,5.4,5.0,4.5,
 4.3,4.4,4.3,4.4,4.5,4.55,4.6,4.65,4.7,3.6,
 slim = .05,
 $end
```

Oconee rods 15309 Case for EOL Void Volume

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='out15309.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plot15309.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Oconee rod 15309
 $frpcn
 im=35, na=12,
 ngasr = 45,
 $end
 $frpcon
 cpl = 10.5, crdt = 0.2, crdtr = 0.0, thkcld = 0.0265,
 dco = 0.430, pitch = 0.56,
 den = 95., thkgap=0.0050, dishsd = 0.050,dspg = 0.37,
 dspgw = 0.055, enrch = 3., fa= 1.0, fgpav = 480,
 hplt = 0.70, hdish = 0.014, icm = 4,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,
 totl = 11.75, jn = 13,13,13,13,13, jst = 7*1,10*2,2*3,5*4,10*5,10
 rc = 0.0, roughc = 1.97e-5, nplot = 1,
 roughf = 2.36e-5, vs = 20.0,
 nunits = 1, rsntr = 150.,
 qf(1)=0.2,1.0,1.2,1.25,1.25,1.22,1.2,1.16,1.14,1.06,.78,.3,.15,
 qf(14)=0.2,1.08,1.18,1.12,1.04,0.97,0.97,1.00,1.03,1.05,1.10,0.97,0.2,
 qf(27)=0.2,0.82,1.02,1.11,1.13,1.08,1.04,1.05,1.14,1.19,1.13,0.9,0.2,
 qf(40)=0.2,0.95,1.05,1.03,1.03,1.08,1.12,1.12,1.1,1.05,1.0,0.81,0.4,
 qf(53)=0.45,0.94,1.02,1.05,1.07,1.10,1.12,1.11,1.10,1.06,1.02,0.95,0.5
 x(1)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 x(14)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 x(27)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
 x(40)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
```

```
x(53)=0,1,2,3,4,5,6,7,8,9,10,11,11.75
nsp=1
flux = 13*0.25e17, p2(1) = 34*2200.0,14.7, tw(1) = 34*555.0,77
go(1) = 34*2.6e6,,0.0
ProblemTime= 0.1,65,125,185,210,235,295,
325,350,360,370,500,510,535,540,560,600,
615,850,
890,905, 920,1130,1150,
1160,1205,1220,1240,1400,1445,1490,1510,1535,1550,1551
qmpy = 5.8,5.8,7.9,7.5,7.3,6.8,6.6,
7.9,7.6,7.4,6.9,6.6,6.1,6.7,6.0,6.6,6.1,
4.1, 5.4,
5.1,4.7,5.4,5.0,4.5,
4.3,4.4,4.3,4.4,4.5,4.55,4.6,4.65,4.7,3.6,0.0
slim = .05,
$end
```

A.26 Halden IFA-651 Rods

The IFA-651.1 rig (Blair and Wright, 2004) contained six fuel rod segments. Three of these rod segments contained inert matrix fuel and three rod segments contained MOX fuel. The MOX rods (rods 1, 3, and 6) were modeled with FRAPCON-3.4. Rod 1 MOX fuel was fabricated using an SBR that results in a relatively homogenous distribution of the PuO_2 compared to MOX fabricated using the MIMAS process. Rods 3 and 6 were fabricated at Paul Scherrer Institute using a two-stage attrition milling process developed by the Korean Atomic Energy Research Institute. Micrographs provided appear to demonstrate that this process provides a homogenous distribution of PuO_2 similar to that observed in the SBR process.

These rods were irradiated for four cycles in the Halden reactor to a rod-average burnup between 20 and 23 GWd/MTM. PIE showed that the fuel in rods 1 and 6 had an in-reactor densification of 2 percent, while the fuel in rod 3 had an in-reactor densification of 1 percent. These values have been entered into the code as input parameters. The measured gas release values used for model verification have been estimated from pressure measurements and are subject to greater uncertainty than measurements made by rod puncture.

These three rods were used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup and the MOX FGR predictions. The input files used for the MOX temperature and FGR assessments are shown below. Input files that include the central hole were used for the temperature assessment since the temperature was measured on hollow pellets. Input files that do not include the central hole were used for the FGR assessment since most of the fuel column consists of solid pellets.

IFA-651 Rod 1 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa-651-1r1tc.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa-651-1r1tc.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-651 Rod 1 Temperature Case
 $frpcn
 im=92, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3741, thkcld=0.02254, thkgap=0.00311, totl=1.63615, cpl=5.1969
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.4764, rc=0.0354, hdish=0.0075, dishsd=0.0354
 enrch=0.225, imox=1, comp=8.18
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.6, deng=0, roughf=0.0000787, rsntr=220, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1
iplant=-4, pitch=0.3937, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
```

```
ProblemTime=
1.8, 4.2, 10.4, 11.9, 55.1
89.6, 103.9, 105.1, 106.3, 110.8
111.8, 113.6, 114.8, 115.3, 116.3
119.2, 120.2, 121.1, 122, 124.3
124.8, 127, 127.7, 129.7, 130.6
131.1, 132.8, 133.4, 135, 136.5
138.7, 141.1, 145.8, 147, 149.7
150.6, 152.6, 153.8, 167, 173.6
174.1, 179.6, 183.3, 186.7, 187.2
187.9, 196.2, 196.7, 206.3, 208.1
209.9, 210.4, 212.3, 221, 222.8
226.7, 234.2, 238.6, 239.1, 247.2
247.7, 249.4, 253.7, 256.7, 264.8
268.5, 271.9, 280.1, 283.5, 288.6
291.8, 300.6, 312.8, 321.6, 323.9
325.3, 345.7, 347.2, 349.1, 350.5
351.9, 353.1, 367, 369, 384.9
393.8, 404.8, 406.5, 430.4, 446.9
481.8, 484.4
qmpy=
2.743, 4.572, 5.304, 5.639, 7.651
7.559, 7.163, 1.829, 4.145, 6.706
2.896, 0.975, 1.067, 1.25, 4.115
7.986, 3.353, 1.981, 3.597, 8.23
3.81, 7.681, 4.206, 8.047, 1.798
3.962, 8.077, 2.286, 3.048, 5.334
2.682, 8.047, 7.559, 3.322, 5.029
2.499, 4.694, 0.823, 5.669, 6.005
3.2, 6.645, 6.675, 5.029, 6.309
3.079, 6.828, 3.627, 6.584, 6.462
4.907, 6.553, 7.01, 6.95, 6.797
6.95, 6.37, 6.706, 5.913, 6.736
3.383, 0.853, 3.871, 3.292, 6.98
4.755, 3.871, 3.17, 8.687, 9.906
3.444, 6.828, 7.102, 6.157, 3.079
3.048, 5.456, 2.743, 2.621, 2.621
1.524, 5.09, 10.028, 8.382, 8.108
7.468, 8.291, 4.206, 8.382, 8.656
8.352, 4.023
nsp=0
p2= 493.13, tw= 455, go= 0
iq=0, fa=1
x(1)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.63615
qf(1)=
102.6, 104.2, 104.9, 105.1, 104.6
103.2, 100.8, 96.8, 92.6, 88.8
     85
x(12)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.63615
qf(12)=
88.6, 91.4, 94.6, 97.4, 99.3
```

```
 100.8, 101.5, 101.3, 100.5, 99.6
    98.4
 x(23)=
 0, 0.16404, 0.32808, 0.49213, 0.65617
 0.82021, 0.98425, 1.14829, 1.31234, 1.47638
 1.63615
 qf(23)=
 97.9, 100, 100.8, 101.5, 101.5
 101.3, 100.2, 99, 97.4, 96.4
      94
 x(34)=
 0, 0.16404, 0.32808, 0.49213, 0.65617
 0.82021, 0.98425, 1.14829, 1.31234, 1.47638
 1.63615
 qf(34)=
 137.7, 140, 141.6, 142.7, 142.3
 141.6, 140.6, 138.7, 136, 133.7
   130.6
 jn=11,11,11,11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 4, 4
 4, 4, 4, 4, 4
 4, 4, 4, 4, 4
 4, 4
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

IFA-651 Rod 3 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa-651-1r3tc.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa-651-1r3tc.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-651 rod 3 Temperature Case
 $frpcn
```

```
im=92, nr=17, ngasr=45, na=9
$end
$frpcon
dco=0.3743, thkcld=0.0228, thkgap=0.00311, totl=1.64206, cpl=5.1181
dspg=0.315, dspgw=0.0394, vs=10
hplt=0.3858, rc=0.0394, hdish=0.0094, dishsd=0.0638
enrch=0.225, imox=1, comp=8.01
fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
den=94.6, deng=0, roughf=0.0000787, rsntr=110, tsint=2911
icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
fgpav=145.04, idxgas=1


iplant=-4, pitch=0.3937, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
crephr=10, sgapf=31, slim=0.05, qend=0.3
jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
ProblemTime=
1.8, 4.2, 10.4, 11.9, 55.1
89.6, 103.9, 105.1, 106.3, 110.8
111.8, 113.6, 114.8, 115.3, 116.3
119.2, 120.2, 121.1, 122, 124.3
124.8, 127, 127.7, 129.7, 130.6
131.1, 132.8, 133.4, 135, 136.5
138.7, 141.1, 145.8, 147, 149.7
150.6, 152.6, 153.8, 167, 173.6
174.1, 179.6, 183.3, 186.7, 187.2
187.9, 196.2, 196.7, 206.3, 208.1
209.9, 210.4, 212.3, 221, 222.8
226.7, 234.2, 238.6, 239.1, 247.2
247.7, 249.4, 253.7, 256.7, 264.8
268.5, 271.9, 280.1, 283.5, 288.6
291.8, 300.6, 312.8, 321.6, 323.9
325.3, 345.7, 347.2, 349.1, 350.5
351.9, 353.1, 367, 369, 384.9
393.8, 404.8, 406.5, 430.4, 446.9
481.8, 484.4
qmpy=
2.438, 4.206, 4.877, 5.029, 6.828
6.675, 6.431, 1.737, 4.267, 6.858
3.048, 1.067, 1.189, 1.372, 4.267
8.23, 3.505, 2.134, 3.841, 8.535
4.267, 7.925, 4.359, 8.382, 1.89
4.115, 8.291, 2.438, 3.353, 5.547
2.804, 8.382, 7.864, 3.475, 5.243
2.591, 4.877, 0.914, 5.669, 6.005
3.2, 6.736, 6.767, 5.334, 6.431
3.2, 7.01, 3.719, 6.675, 6.614
4.999, 6.858, 7.071, 7.01, 6.889
7.01, 6.462, 6.889, 6.005, 6.889
3.444, 0.945, 4.145, 3.383, 6.98
4.968, 3.932, 3.292, 8.9, 10.119
3.627, 7.041, 7.224, 6.37, 3.2
3.2, 5.639, 2.835, 2.743, 2.317
1.737, 4.542, 8.961, 7.772, 7.62
7.132, 7.864, 3.993, 8.077, 8.321
8.047, 3.901
```

```
nsp=0
p2= 493.13, tw= 455, go= 0
iq=0, fa=1
x(1)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(1)=
102.6, 104.2, 104.9, 105.1, 104.6
103.2, 100.8, 96.8, 92.6, 88.8
     85
x(12)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(12)=
88.6, 91.4, 94.6, 97.4, 99.3
100.8, 101.5, 101.3, 100.5, 99.6
   98.4
x(23)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(23)=
97.9, 100, 100.8, 101.5, 101.5
101.3, 100.2, 99, 97.4, 96.4
     94
x(34)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(34)=
137.7, 140, 141.6, 142.7, 142.3
141.6, 140.6, 138.7, 136, 133.7
  130.6
jn=11,11,11,11
jst=
1, 1, 1, 1, 1
1, 1, 1, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 3, 3, 3, 3
3, 3, 3, 3, 3
3, 3, 3, 3, 3
3, 3, 3, 4, 4
4, 4, 4, 4, 4
4, 4, 4, 4, 4
4, 4
$end
```

```
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

IFA-651 Rod 6 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa-651-1r6tc.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa-651-1r6tc.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/***********************************************************************
IFA-651 rod 6 Temperature Case
 $frpcn
 im=92, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3743, thkcld=0.0227, thkgap=0.00319, totl=1.64206, cpl=5.2362
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.3858, rc=0.0354, hdish=0.0094, dishsd=0.0638
 enrch=0.255, imox=1, comp=8.01
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.9, deng=0, roughf=0.0000787, rsntr=220, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1
iplant=-4, pitch=0.3937, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 1.8, 4.2, 10.4, 11.9, 55.1
 89.6, 103.9, 105.1, 106.3, 110.8
 111.8, 113.6, 114.8, 115.3, 116.3
 119.2, 120.2, 121.1, 122, 124.3
 124.8, 127, 127.7, 129.7, 130.6
 131.1, 132.8, 133.4, 135, 136.5
 138.7, 141.1, 145.8, 147, 149.7
 150.6, 152.6, 153.8, 167, 173.6
 174.1, 179.6, 183.3, 186.7, 187.2
 187.9, 196.2, 196.7, 206.3, 208.1
 209.9, 210.4, 212.3, 221, 222.8
 226.7, 234.2, 238.6, 239.1, 247.2
 247.7, 249.4, 253.7, 256.7, 264.8
 268.5, 271.9, 280.1, 283.5, 288.6
 291.8, 300.6, 312.8, 321.6, 323.9
 325.3, 345.7, 347.2, 349.1, 350.5
 351.9, 353.1, 367, 369, 384.9
 393.8, 404.8, 406.5, 430.4, 446.9
 481.8, 484.4
 qmpy=
 2.591, 4.42, 5.182, 5.395, 7.437
 7.315, 6.95, 1.585, 3.962, 6.309
 2.743, 0.823, 0.914, 1.067, 3.841
```

```
7.376, 2.896, 1.585, 3.231, 7.62
3.658, 7.254, 3.688, 7.559, 1.676
3.719, 7.62, 1.524, 2.743, 4.877
2.469, 7.559, 7.01, 2.804, 4.45
1.981, 3.962, 0.61, 4.724, 5.212
2.713, 5.517, 5.517, 4.267, 5.212
2.469, 5.608, 2.926, 5.578, 5.426
4.115, 5.883, 6.035, 5.913, 5.73
5.944, 5.395, 5.73, 4.816, 5.791
2.896, 0.64, 3.17, 3.17, 6.34
4.054, 3.383, 2.896, 7.285, 8.291
3.048, 5.822, 6.157, 5.334, 2.682
5.395, 4.633, 2.317, 2.286, 1.829
1.219, 4.389, 8.656, 7.559, 7.559
6.95, 7.59, 3.81, 7.712, 7.894
7.681, 3.78
nsp=0
p2= 493.13, tw= 455, go= 0
iq=0, fa=1
x(1)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(1)=
102.6, 104.2, 104.9, 105.1, 104.6
103.2, 100.8, 96.8, 92.6, 88.8
     85
x(12)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(12)=
88.6, 91.4, 94.6, 97.4, 99.3
100.8, 101.5, 101.3, 100.5, 99.6
   98.4
x(23)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(23)=
97.9, 100, 100.8, 101.5, 101.5
101.3, 100.2, 99, 97.4, 96.4
     94
x(34)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(34)=
137.7, 140, 141.6, 142.7, 142.3
141.6, 140.6, 138.7, 136, 133.7
  130.6
jn=11,11,11,11
jst=
1, 1, 1, 1, 1
1, 1, 1, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
```

```
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 4, 4
 4, 4, 4, 4, 4
 4, 4, 4, 4, 4
 4, 4
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

IFA-651 Rod 1 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa-651-1r1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa-651-1r1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-651 rod 1 FGR case
 $frpcn
 im=92, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3741, thkcld=0.02254, thkgap=0.00311, totl=1.63615, cpl=5.1969
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.4764, rc=0, hdish=0.0075, dishsd=0.0354
 enrch=0.225, imox=1, comp=8.18
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.6, deng=0, roughf=0.0000787, rsntr=220, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1
 iplant=-4, pitch=0.3937, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 1.8, 4.2, 10.4, 11.9, 55.1
 89.6, 103.9, 105.1, 106.3, 110.8
 111.8, 113.6, 114.8, 115.3, 116.3
 119.2, 120.2, 121.1, 122, 124.3
 124.8, 127, 127.7, 129.7, 130.6
 131.1, 132.8, 133.4, 135, 136.5
 138.7, 141.1, 145.8, 147, 149.7
 150.6, 152.6, 153.8, 167, 173.6
```

```
174.1, 179.6, 183.3, 186.7, 187.2
187.9, 196.2, 196.7, 206.3, 208.1
209.9, 210.4, 212.3, 221, 222.8
226.7, 234.2, 238.6, 239.1, 247.2
247.7, 249.4, 253.7, 256.7, 264.8
268.5, 271.9, 280.1, 283.5, 288.6
291.8, 300.6, 312.8, 321.6, 323.9
325.3, 345.7, 347.2, 349.1, 350.5
351.9, 353.1, 367, 369, 384.9
393.8, 404.8, 406.5, 430.4, 446.9
481.8, 484.4
qmpy=
2.743, 4.572, 5.304, 5.639, 7.651
7.559, 7.163, 1.829, 4.145, 6.706
2.896, 0.975, 1.067, 1.25, 4.115
7.986, 3.353, 1.981, 3.597, 8.23
3.81, 7.681, 4.206, 8.047, 1.798
3.962, 8.077, 2.286, 3.048, 5.334
2.682, 8.047, 7.559, 3.322, 5.029
2.499, 4.694, 0.823, 5.669, 6.005
3.2, 6.645, 6.675, 5.029, 6.309
3.079, 6.828, 3.627, 6.584, 6.462
4.907, 6.553, 7.01, 6.95, 6.797
6.95, 6.37, 6.706, 5.913, 6.736
3.383, 0.853, 3.871, 3.292, 6.98
4.755, 3.871, 3.17, 8.687, 9.906
3.444, 6.828, 7.102, 6.157, 3.079
3.048, 5.456, 2.743, 2.621, 2.621
1.524, 5.09, 10.028, 8.382, 8.108
7.468, 8.291, 4.206, 8.382, 8.656
8.352, 4.023
nsp=0
p2= 493.13, tw= 455, go= 0
iq=0, fa=1
x(1)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.63615
qf(1)=
102.6, 104.2, 104.9, 105.1, 104.6
103.2, 100.8, 96.8, 92.6, 88.8
     85
x(12)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.63615
qf(12)=
88.6, 91.4, 94.6, 97.4, 99.3
100.8, 101.5, 101.3, 100.5, 99.6
   98.4
x(23)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.63615
qf(23)=
97.9, 100, 100.8, 101.5, 101.5
101.3, 100.2, 99, 97.4, 96.4
```

```
      94
 x(34)=
 0, 0.16404, 0.32808, 0.49213, 0.65617
 0.82021, 0.98425, 1.14829, 1.31234, 1.47638
 1.63615
 qf(34)=
 137.7, 140, 141.6, 142.7, 142.3
 141.6, 140.6, 138.7, 136, 133.7
   130.6
 jn=11,11,11,11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 4, 4
 4, 4, 4, 4, 4
 4, 4, 4, 4, 4
 4, 4
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

IFA-651 Rod 3 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='ifa-651-1r3.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa-651-1r3.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-651 rod 3 FGR case
 $frpcn
 im=92, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3743, thkcld=0.0228, thkgap=0.00311, totl=1.64206, cpl=5.1181
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.3858, rc=0.0, hdish=0.0094, dishsd=0.0638
 enrch=0.225, imox=1, comp=8.01
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
```

```
 den=94.6, deng=0, roughf=0.0000787, rsntr=110, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1
iplant=-4, pitch=0.3937, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 1.8, 4.2, 10.4, 11.9, 55.1
 89.6, 103.9, 105.1, 106.3, 110.8
 111.8, 113.6, 114.8, 115.3, 116.3
 119.2, 120.2, 121.1, 122, 124.3
 124.8, 127, 127.7, 129.7, 130.6
 131.1, 132.8, 133.4, 135, 136.5
 138.7, 141.1, 145.8, 147, 149.7
 150.6, 152.6, 153.8, 167, 173.6
 174.1, 179.6, 183.3, 186.7, 187.2
 187.9, 196.2, 196.7, 206.3, 208.1
 209.9, 210.4, 212.3, 221, 222.8
 226.7, 234.2, 238.6, 239.1, 247.2
 247.7, 249.4, 253.7, 256.7, 264.8
 268.5, 271.9, 280.1, 283.5, 288.6
 291.8, 300.6, 312.8, 321.6, 323.9
 325.3, 345.7, 347.2, 349.1, 350.5
 351.9, 353.1, 367, 369, 384.9
 393.8, 404.8, 406.5, 430.4, 446.9
 481.8, 484.4
 qmpy=
 2.438, 4.206, 4.877, 5.029, 6.828
 6.675, 6.431, 1.737, 4.267, 6.858
 3.048, 1.067, 1.189, 1.372, 4.267
 8.23, 3.505, 2.134, 3.841, 8.535
 4.267, 7.925, 4.359, 8.382, 1.89
 4.115, 8.291, 2.438, 3.353, 5.547
 2.804, 8.382, 7.864, 3.475, 5.243
 2.591, 4.877, 0.914, 5.669, 6.005
 3.2, 6.736, 6.767, 5.334, 6.431
 3.2, 7.01, 3.719, 6.675, 6.614
 4.999, 6.858, 7.071, 7.01, 6.889
 7.01, 6.462, 6.889, 6.005, 6.889
 3.444, 0.945, 4.145, 3.383, 6.98
 4.968, 3.932, 3.292, 8.9, 10.119
 3.627, 7.041, 7.224, 6.37, 3.2
 3.2, 5.639, 2.835, 2.743, 2.317
 1.737, 4.542, 8.961, 7.772, 7.62
 7.132, 7.864, 3.993, 8.077, 8.321
 8.047, 3.901
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.16404, 0.32808, 0.49213, 0.65617
 0.82021, 0.98425, 1.14829, 1.31234, 1.47638
 1.64206
 qf(1)=
 102.6, 104.2, 104.9, 105.1, 104.6
 103.2, 100.8, 96.8, 92.6, 88.8
```

```
      85
 x(12)=
 0, 0.16404, 0.32808, 0.49213, 0.65617
 0.82021, 0.98425, 1.14829, 1.31234, 1.47638
 1.64206
 qf(12)=
 88.6, 91.4, 94.6, 97.4, 99.3
 100.8, 101.5, 101.3, 100.5, 99.6
    98.4
 x(23)=
 0, 0.16404, 0.32808, 0.49213, 0.65617
 0.82021, 0.98425, 1.14829, 1.31234, 1.47638
 1.64206
 qf(23)=
 97.9, 100, 100.8, 101.5, 101.5
 101.3, 100.2, 99, 97.4, 96.4
      94
 x(34)=
 0, 0.16404, 0.32808, 0.49213, 0.65617
 0.82021, 0.98425, 1.14829, 1.31234, 1.47638
 1.64206
 qf(34)=
 137.7, 140, 141.6, 142.7, 142.3
 141.6, 140.6, 138.7, 136, 133.7
   130.6
 jn=11,11,11,11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 4, 4
 4, 4, 4, 4, 4
 4, 4, 4, 4, 4
 4, 4
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

IFA-651 Rod 6 FGR Case

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

```
* GOESOUTS:
FILE06='ifa-651-1r6.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ifa-651-1r6.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/************************************************************************
IFA-651 rod 6 FGR case
 $frpcn
 im=92, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.3743, thkcld=0.0227, thkgap=0.00319, totl=1.64206, cpl=5.2362
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.3858, rc=0, hdish=0.0094, dishsd=0.0638
 enrch=0.255, imox=1, comp=8.01
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.9, deng=0, roughf=0.0000787, rsntr=220, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=145.04, idxgas=1
iplant=-4, pitch=0.3937, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 1.8, 4.2, 10.4, 11.9, 55.1
 89.6, 103.9, 105.1, 106.3, 110.8
 111.8, 113.6, 114.8, 115.3, 116.3
 119.2, 120.2, 121.1, 122, 124.3
 124.8, 127, 127.7, 129.7, 130.6
 131.1, 132.8, 133.4, 135, 136.5
 138.7, 141.1, 145.8, 147, 149.7
 150.6, 152.6, 153.8, 167, 173.6
 174.1, 179.6, 183.3, 186.7, 187.2
 187.9, 196.2, 196.7, 206.3, 208.1
 209.9, 210.4, 212.3, 221, 222.8
 226.7, 234.2, 238.6, 239.1, 247.2
 247.7, 249.4, 253.7, 256.7, 264.8
 268.5, 271.9, 280.1, 283.5, 288.6
 291.8, 300.6, 312.8, 321.6, 323.9
 325.3, 345.7, 347.2, 349.1, 350.5
 351.9, 353.1, 367, 369, 384.9
 393.8, 404.8, 406.5, 430.4, 446.9
 481.8, 484.4
 qmpy=
 2.591, 4.42, 5.182, 5.395, 7.437
 7.315, 6.95, 1.585, 3.962, 6.309
 2.743, 0.823, 0.914, 1.067, 3.841
 7.376, 2.896, 1.585, 3.231, 7.62
 3.658, 7.254, 3.688, 7.559, 1.676
 3.719, 7.62, 1.524, 2.743, 4.877
 2.469, 7.559, 7.01, 2.804, 4.45
 1.981, 3.962, 0.61, 4.724, 5.212
 2.713, 5.517, 5.517, 4.267, 5.212
 2.469, 5.608, 2.926, 5.578, 5.426
 4.115, 5.883, 6.035, 5.913, 5.73
 5.944, 5.395, 5.73, 4.816, 5.791
 2.896, 0.64, 3.17, 3.17, 6.34
```

```
4.054, 3.383, 2.896, 7.285, 8.291
3.048, 5.822, 6.157, 5.334, 2.682
5.395, 4.633, 2.317, 2.286, 1.829
1.219, 4.389, 8.656, 7.559, 7.559
6.95, 7.59, 3.81, 7.712, 7.894
7.681, 3.78
nsp=0
p2= 493.13, tw= 455, go= 0
iq=0, fa=1
x(1)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(1)=
102.6, 104.2, 104.9, 105.1, 104.6
103.2, 100.8, 96.8, 92.6, 88.8
     85
x(12)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(12)=
88.6, 91.4, 94.6, 97.4, 99.3
100.8, 101.5, 101.3, 100.5, 99.6
   98.4
x(23)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(23)=
97.9, 100, 100.8, 101.5, 101.5
101.3, 100.2, 99, 97.4, 96.4
     94
x(34)=
0, 0.16404, 0.32808, 0.49213, 0.65617
0.82021, 0.98425, 1.14829, 1.31234, 1.47638
1.64206
qf(34)=
137.7, 140, 141.6, 142.7, 142.3
141.6, 140.6, 138.7, 136, 133.7
  130.6
jn=11,11,11,11
jst=
1, 1, 1, 1, 1
1, 1, 1, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 3, 3, 3, 3
3, 3, 3, 3, 3
```

```
3, 3, 3, 3, 3
3, 3, 3, 4, 4
4, 4, 4, 4, 4
4, 4, 4, 4, 4
4, 4
$end
$frpmox
enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
$end
```

A.27 Advanced Test Reactor WG-MOX Rods

Oak Ridge National Laboratory has reported base-irradiation LHGR histories and post-irradiation FGR for seven fuel pins irradiated in the ATR (Morris et al., 2000, 2001, 2005; Hodge et al., 2002, 2003). These pins were irradiated in stainless steel capsules. Several pins were withdrawn for PIE after Phases II, III, and IV, after the pins had accumulated 21, 30, and 40 to 50 GWd/MTM, respectively. The fuel used in these pins was fabricated using weapons-grade (WG) plutonium with a process similar to MIMAS. Fuel produced from WG plutonium differs from commercial MOX fuel in two ways. First, the WG MOX has greater amounts of ^{239}Pu, and second, WG MOX contains small amounts of gallium.

The measured gas release values for these rods have been obtained by puncture measurement.

These three rods were used to assess the FRAPCON-3.4 MOX FGR predictions. The input files used for the MOX FGR assessments are shown below.

ATR Phase II, Capsule 2, Pin 5

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='outapt2_2.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.2_2', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
     ATR MOX Experiment: Phase II, Capsule 2 / Fuel Pin 5 (March 2005)
 $frpcn
   im=50,
   na=15,
   ngasr=45,
   nr=17,
 $end
 $frpcon
   crephr=10.0,
   catexf=0.05,
   cldwks=0.2,
   comp=5.0037,
   cpl=0.796,
   crdt = 0.0,
   crdtr=0.0,
   dco=0.38065,
   den=94.5,
   deng=0.5,
   dishsd=0.0491,
   dspg=0.30,
   dspgw=0.030,
   enrch=0.266457,
   fa=1.0,
   fgpav=11.1,
   flux(1)=16*0.5e12,
   fotmtl=2.0,
   gadoln=0.0,
   go(1)=50*0.0,
   hdish=0.0082,
```

```
   hplt=0.388867,
   icm=4,
   icor=1,
   idxgas=1,
   imox=1,
   imswch=0,
   iplant=-2,
   iq=0,
   jdlpr=0,
   jn=14*16,
   jst=10*1,2*2,2*3,2*4,3*5,4*6,2*7,2*8,4*9,3*10,2*11,2*12,4*13,8*14,
   nplot=1,
   nsp=1,
   nunits=1,
   p2(1)=50*12.5,
   pitch=0.38135,
   ppmh2o=1.0,
   ppmn2=40.0,
   qend=0.1,
   qf(1)=
1.17414,0.97912,0.94777,0.94028,0.94496,0.95150,0.95711,0.96507,

0.97396,0.98238,0.99174,1.00203,1.01466,1.03898,1.09184,1.26306,
   qf(17)=
1.14085,0.97201,0.94596,0.94211,0.94745,0.95373,0.95988,0.96719,

0.97582,0.98360,0.99206,1.00171,1.01461,1.03974,1.09330,1.28081,
   qf(33)=
1.13291,0.97032,0.94553,0.94255,0.94804,0.95426,0.96053,0.96769,

0.97627,0.98389,0.99214,1.00164,1.01460,1.03992,1.09365,1.28504,
   qf(49)=
1.11777,0.96708,0.94471,0.94338,0.94917,0.95527,0.96179,0.96866,

0.97712,0.98445,0.99228,1.00149,1.01458,1.04026,1.09432,1.29312,
   qf(65)=
1.10923,0.96526,0.94424,0.94385,0.94981,0.95584,0.96250,0.96920,

0.97759,0.98476,0.99237,1.00141,1.01457,1.04046,1.09469,1.29767,
   qf(81)=
1.07437,0.95781,0.94235,0.94577,0.95242,0.95818,0.96539,0.97141,

0.97955,0.98604,0.99270,1.00108,1.01452,1.04125,1.09622,1.31626,
   qf(97)=
1.05352,0.95348,0.94134,0.94697,0.95401,0.95960,0.96713,0.97276,

0.98073,0.98683,0.99294,1.00094,1.01454,1.04174,1.09705,1.32636,

qf(113)=1.04096,0.95447,0.94421,0.94940,0.95606,0.96141,0.96855,0.97405,

0.98184,0.98787,0.99424,1.00261,1.01602,1.04247,1.09515,1.30231,

qf(129)=1.01962,0.95615,0.94909,0.95353,0.95955,0.96448,0.97098,0.97626,

0.98373,0.98965,0.99645,1.00545,1.01855,1.04371,1.09191,1.26144,

qf(145)=1.01210,0.95674,0.95081,0.95499,0.96078,0.96556,0.97183,0.97704,
```

```
0.98439,0.99028,0.99722,1.00645,1.01943,1.04415,1.09076,1.24703,

qf(161)=1.01077,0.95685,0.95111,0.95524,0.96099,0.96575,0.97198,0.97718,

0.98451,0.99039,0.99736,1.00663,1.01959,1.04423,1.09056,1.24449,

qf(177)=0.99922,0.95776,0.95375,0.95748,0.96288,0.96741,0.97329,0.97837,

0.98553,0.99136,0.99855,1.00817,1.02096,1.04490,1.08881,1.22237,

qf(193)=0.97768,0.95945,0.95867,0.96164,0.96640,0.97050,0.97573,0.98060,

0.98744,0.99315,1.00078,1.01103,1.02350,1.04615,1.08554,1.18114,

qf(209)=0.95523,0.95912,0.96227,0.96550,0.97006,0.97419,0.97901,0.98382,

0.99036,0.99607,1.00400,1.01449,1.02640,1.04688,1.08026,1.13993,
   x(1)=
0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.16202778,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
         0.38886667,0.42127222,0.45367778,0.48608333,

x(17)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.16202778,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
         0.38886667,0.42127222,0.45367778,0.48608333,

x(33)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.16202778,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
         0.38886667,0.42127222,0.45367778,0.48608333,

x(49)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.16202778,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
         0.38886667,0.42127222,0.45367778,0.48608333,

x(65)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.16202778,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
         0.38886667,0.42127222,0.45367778,0.48608333,

x(81)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.16202778,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
         0.38886667,0.42127222,0.45367778,0.48608333,

x(97)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.16202778,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
         0.38886667,0.42127222,0.45367778,0.48608333,

x(113)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.1620277
8,
```

```
0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
          0.38886667,0.42127222,0.45367778,0.48608333,

x(129)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.1620277
8,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
          0.38886667,0.42127222,0.45367778,0.48608333,

x(145)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.1620277
8,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
          0.38886667,0.42127222,0.45367778,0.48608333,

x(161)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.1620277
8,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
          0.38886667,0.42127222,0.45367778,0.48608333,

x(177)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.1620277
8,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
          0.38886667,0.42127222,0.45367778,0.48608333,

x(193)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.1620277
8,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
          0.38886667,0.42127222,0.45367778,0.48608333,

x(209)=0.00000000,0.03240556,0.06481111,0.09721667,0.12962222,0.1620277
8,

0.19443333,0.22683889,0.25924444,0.29165000,0.32405556,0.35646111,
          0.38886667,0.42127222,0.45367778,0.48608333,
   qmpy(1)=1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,8.472,8.472,
           7.633,7.633,
           8.402,8.402,
           7.454,7.454,
           3*7.479,
           8.451,3*9.422,
           9.418,9.418,
           9.232,9.232,
           8.000,7.000,6.168,6.168,
           7.259,8.349,8.349,
           7.945,7.945,
           8.052,8.052,
           7.700,3*7.349,
           6.000,5.000,4.000,3.000,2.000,1.000,0.004,0.004,
   rc=0.0,
   roughc=26.0e-6,
   roughf=72.4e-6,
   rsntr=220.0,
```

```
   sgapf=31.0,
   slim=0.10,
   thkcld=0.025725,
   thkgap=0.001475,
   ProblemTime=0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,48.4,
           48.5,61.2,
           61.3,83.4,
           83.5,97.5,
           97.6,126.0,154.9,
           155.0,155.1,169.2,182.3,
           182.4,203.3,
           203.4,239.7,
           239.8,239.9,240.0,258.9,
           259.0,259.1,261.4,
           261.5,284.3,
           284.4,326.4,
           326.5,326.6,354.6,382.6,
           382.7,382.8,382.9,383.0,383.1,383.2,383.3,390.0,
   tsint=3227.0,
   totl=0.48608333,
   tw(1)=209.5,263.8,318.1,372.4,426.6,480.9,535.2,589.5,2*617.6,
         2*575.6,
         2*612.1,
         2*565.6,
         3*564.7,
         610.6,3*656.4,
         2*655.4,
         2*645.3,
         585.2,536.5,2*495.9,
         548.6,2*601.3,
         2*582.1,
         2*585.5,
         567.8,3*550.1,
         480.9,426.6,372.4,318.1,263.8,209.5,2*110.2,
   vs=8.5,
 $end
 $frpmox
   enrpu39=93.845367,
   enrpu40= 6.009014,
   enrpu41= 0.122010,
   enrpu42= 0.023609,
 $end
```

ATR Phase III, Capsule 3, Pin 6

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='outapt3_3.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.3_3', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
    ATR MOX Experiment: Phase III, Capsule 3 / Fuel Pin 6 (March 2005)
 $frpcn
   im=63,
   na=15,
```

```
   ngasr=45,
   nr=17,
 $end
 $frpcon
   crephr=10.0,
   catexf=0.05,
   cldwks=0.2,
   comp=5.0037,
   cpl=0.770,
   crdt = 0.0,
   crdtr=0.0,
   dco=0.38065,
   den=94.5,
   deng=0.5,
   dishsd=0.0491,
   dspg=0.30,
   dspgw=0.030,
   enrch=0.266457,
   fa=1.0,
   fgpav=11.1,
   flux(1)=16*0.5e12,
   fotmtl=2.0,
   gadoln=0.0,
   go(1)=63*0.0,
   hdish=0.0082,
   hplt=0.390600,
   icm=4,
   icor=1,
   idxgas=1,
   imox=1,
   imswch=0,
   iplant=-2,
   iq=0,
   jdlpr=0,
   jn=21*16,
   jst=10*1,2*2,2*3,2*4,3*5,4*6,2*7,2*8,4*9,3*10,2*11,2*12,
       4*13,2*14,3*15,2*16,2*17,2*18,2*19,2*20,6*21,
   nplot=1,
   nsp=1,
   nunits=1,
   p2(1)=63*12.5,
   pitch=0.38135,
   ppmh2o=1.0,
   ppmn2=40.0,
   qend=0.1,
   qf(1)=
1.38500,1.08265,1.04509,1.01927,1.00283,0.99109,0.98077,0.97231,

0.96433,0.95823,0.95024,0.94180,0.93241,0.92443,0.93288,1.21833,
   qf(17)=
1.35352,1.08353,1.04738,1.02330,1.00731,0.99485,0.98367,0.97437,

0.96542,0.95836,0.95020,0.94144,0.93254,0.92598,0.94088,1.18802,
   qf(33)=
1.34608,1.08373,1.04792,1.02425,1.00837,0.99574,0.98436,0.97486,

0.96568,0.95839,0.95019,0.94136,0.93257,0.92635,0.94277,1.18085,
```

```
   qf(49)=
1.33198,1.08413,1.04895,1.02605,1.01038,0.99742,0.98566,0.97579,

0.96617,0.95844,0.95017,0.94119,0.93263,0.92705,0.94636,1.16727,
   qf(65)=
1.32397,1.08435,1.04953,1.02708,1.01152,0.99837,0.98640,0.97631,

0.96644,0.95847,0.95015,0.94110,0.93266,0.92744,0.94839,1.15956,
   qf(81)=
1.29069,1.08528,1.05195,1.03134,1.01626,1.00235,0.98947,0.97849,

0.96759,0.95861,0.95011,0.94072,0.93279,0.92909,0.95685,1.12751,
   qf(97)=
1.27003,1.08591,1.05356,1.03397,1.01915,1.00478,0.99142,0.97992,

0.96844,0.95887,0.95024,0.94063,0.93293,0.93009,0.96129,1.10761,

qf(113)=1.25211,1.08685,1.05574,1.03618,1.02125,1.00665,0.99344,0.98170,

0.97018,0.96042,0.95154,0.94156,0.93341,0.93078,0.95911,1.09029,

qf(129)=1.22244,1.08842,1.05934,1.03984,1.02473,1.00974,0.99678,0.98464,

0.97304,0.96299,0.95371,0.94310,0.93422,0.93192,0.95551,1.06163,

qf(145)=1.21225,1.08895,1.06057,1.04109,1.02593,1.01080,0.99793,0.98565,

0.97403,0.96387,0.95445,0.94363,0.93450,0.93231,0.95428,1.05178,

qf(161)=1.21051,1.08904,1.06078,1.04131,1.02613,1.01098,0.99813,0.98582,

0.97420,0.96402,0.95457,0.94372,0.93455,0.93237,0.95407,1.05010,

qf(177)=1.19433,1.08990,1.06275,1.04330,1.02803,1.01266,0.99995,0.98743,

0.97576,0.96543,0.95575,0.94456,0.93499,0.93300,0.95210,1.03447,

qf(193)=1.16532,1.09142,1.06627,1.04687,1.03143,1.01569,1.00322,0.99031,

0.97857,0.96794,0.95787,0.94607,0.93578,0.93411,0.94858,1.00644,

qf(209)=1.13350,1.08848,1.06700,1.04915,1.03459,1.01947,1.00758,0.99476,

0.98306,0.97232,0.96180,0.94939,0.93840,0.93570,0.94377,0.97556,

qf(225)=1.12024,1.08249,1.06408,1.04840,1.03531,1.02152,1.01021,0.99795,

0.98641,0.97581,0.96510,0.95249,0.94131,0.93674,0.94078,0.96255,

qf(241)=1.11612,1.08062,1.06317,1.04817,1.03554,1.02216,1.01102,0.99895,

0.98745,0.97690,0.96612,0.95346,0.94222,0.93706,0.93985,0.95850,

qf(257)=1.10995,1.07783,1.06182,1.04782,1.03587,1.02312,1.01224,1.00043,

0.98901,0.97853,0.96766,0.95490,0.94357,0.93754,0.93846,0.95245,
```

```
qf(273)=1.10025,1.07345,1.05968,1.04727,1.03640,1.02462,1.01416,1.00277,

0.99145,0.98108,0.97007,0.95717,0.94570,0.93830,0.93627,0.94293,

qf(289)=1.08466,1.06639,1.05625,1.04639,1.03725,1.02704,1.01725,1.00653,

0.99539,0.98520,0.97395,0.96083,0.94912,0.93953,0.93275,0.92762,

qf(305)=1.07175,1.06056,1.05340,1.04566,1.03796,1.02904,1.01981,1.00964,

0.99865,0.98860,0.97716,0.96385,0.95195,0.94054,0.92984,0.91496,

qf(321)=1.05607,1.05346,1.04995,1.04477,1.03881,1.03147,1.02291,1.01342,

1.00260,0.99274,0.98107,0.96752,0.95539,0.94177,0.92630,0.89956,
   x(1)=
0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.16275000,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
         0.39060000,0.42315000,0.45570000,0.48825000,

x(17)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.16275000,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
         0.39060000,0.42315000,0.45570000,0.48825000,

x(33)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.16275000,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
         0.39060000,0.42315000,0.45570000,0.48825000,

x(49)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.16275000,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
         0.39060000,0.42315000,0.45570000,0.48825000,

x(65)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.16275000,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
         0.39060000,0.42315000,0.45570000,0.48825000,

x(81)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.16275000,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
         0.39060000,0.42315000,0.45570000,0.48825000,

x(97)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.16275000,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
         0.39060000,0.42315000,0.45570000,0.48825000,

x(113)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
```

```
x(129)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(145)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(161)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(177)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(193)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(209)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(225)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(241)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(257)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
x(273)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,
```

```
0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,

x(289)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,

x(305)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,

x(321)=0.00000000,0.03255000,0.06510000,0.09765000,0.13020000,0.1627500
0,

0.19530000,0.22785000,0.26040000,0.29295000,0.32550000,0.35805000,
          0.39060000,0.42315000,0.45570000,0.48825000,
   qmpy(1)=1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,8.379,8.379,
           7.495,7.495,
           8.184,8.184,
           7.319,7.319,
           3*7.470,
           8.526,3*9.581,
           9.580,9.580,
           9.145,9.145,
           8.000,7.000,5.958,5.958,
           6.875,7.791,7.791,
           7.928,7.928,
           7.734,7.734,
           7.449,3*7.164,
           6.327,6.327,
           5.552,4.776,4.776,
           5.128,5.128,
           5.868,5.868,
           5.347,5.347,
           5.118,5.118,
           5.098,5.098,
           4.0,3.0,2.0,1.0,0.004,0.004,
   rc=0.0,
   roughc=26.0e-6,
   roughf=72.4e-6,
   rsntr=220.0,
   sgapf=31.0,
   slim=0.10,
   thkcld=0.025725,
   thkgap=0.001475,
   ProblemTime=0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,48.4,
           48.5,61.2,
           61.3,83.4,
           83.5,97.5,
           97.6,126.2,154.9,
           155.0,155.1,169.2,182.3,
           182.4,203.3,
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           203.4,239.7,
           239.8,239.9,240.0,258.9,
           259.0,259.1,261.4,
           261.5,284.3,
           284.4,326.4,
           326.5,326.6,354.5,382.6,
           382.7,416.6,
           416.7,416.8,430.6,
           430.7,450.1,
           450.2,476.9,
           477.0,524.2,
           524.3,565.1,
           565.2,615.0,
           615.1,615.2,615.3,615.4,615.5,615.6,
   tsint=3227.0,
   totl=0.48825000,
   tw(1)=209.5,263.8,318.1,372.4,426.6,480.9,535.2,589.5,2*613.0,
         2*569.0,
         2*601.5,
         2*558.9,
         3*564.7,
         614.3,3*663.9,
         2*662.9,
         2*641.0,
         585.1,536.2,2*485.3,
         529.9,2*574.5,
         2*580.7,
         2*570.3,
         555.7,3*541.1,
         2*498.2,
         459.0,2*419.8,
         2*436.3,
         2*471.8,
         2*444.4,
         2*431.0,
         2*427.8,
         372.4,318.1,263.8,209.5,2*110.2,
   vs=8.5,
 $end
 $frpmox
   enrpu39=93.845367,
   enrpu40= 6.009014,
   enrpu41= 0.122010,
   enrpu42= 0.023609,
 $end
```

ATR Phase III, Capsule 10, Pin 13

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='outapt3_10.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.310', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
 ATR MOX Experiment: Phase III, Capsule 10 / Fuel Pin 13 (March 2005)
```

```
 $frpcn
   im=62,
   na=15,
   ngasr=45,
   nr=17,
 $end
 $frpcon
   crephr=10.0,
   catexf=0.05,
   cldwks=0.2,
   comp=5.0037,
   cpl=0.816,
   crdt = 0.0,
   crdtr=0.0,
   dco=0.38065,
   den=95.2,
   deng=0.5,
   dishsd=0.0496,
   dspg=0.30,
   dspgw=0.030,
   enrch=0.266457,
   fa=1.0,
   fgpav=11.1,
   flux(1)=16*0.5e12,
   fotmtl=2.0,
   gadoln=0.0,
   go(1)=62*0.0,
   hdish=0.0063,
   hplt=0.387533,
   icm=4,
   icor=1,
   idxgas=1,
   imox=1,
   imswch=0,
   iplant=-2,
   iq=0,
   jdlpr=0,
   jn=21*16,
   jst=10*1,2*2,2*3,2*4,3*5,4*6,2*7,2*8,4*9,3*10,2*11,2*12,
       4*13,2*14,2*15,2*16,2*17,2*18,2*19,2*20,6*21,
   nplot=1,
   nsp=1,
   nunits=1,
   p2(1)=62*12.5,
   pitch=0.38135,
   ppmh2o=1.0,
   ppmn2=40.0,
   qend=0.1,
   qf(1)=
1.38500,1.08265,1.04509,1.01927,1.00283,0.99109,0.98077,0.97231,

0.96433,0.95823,0.95024,0.94180,0.93241,0.92443,0.93288,1.21833,
   qf(17)=
1.35375,1.08352,1.04736,1.02327,1.00728,0.99482,0.98365,0.97436,

0.96541,0.95836,0.95020,0.94144,0.93254,0.92597,0.94082,1.18824,
```

```
   qf(33)=
1.34619,1.08373,1.04791,1.02424,1.00836,0.99572,0.98435,0.97485,

0.96567,0.95839,0.95019,0.94136,0.93257,0.92635,0.94274,1.18096,
   qf(49)=
1.33209,1.08412,1.04894,1.02604,1.01037,0.99741,0.98565,0.97578,

0.96616,0.95844,0.95017,0.94120,0.93263,0.92704,0.94633,1.16738,
   qf(65)=
1.32408,1.08435,1.04952,1.02707,1.01151,0.99836,0.98639,0.97630,

0.96644,0.95847,0.95016,0.94110,0.93266,0.92744,0.94836,1.15966,
   qf(81)=
1.29080,1.08528,1.05194,1.03133,1.01625,1.00233,0.98946,0.97848,

0.96759,0.95861,0.95011,0.94073,0.93279,0.92909,0.95682,1.12762,
   qf(97)=
1.27024,1.08590,1.05353,1.03395,1.01912,1.00476,0.99139,0.97990,

0.96842,0.95885,0.95022,0.94062,0.93292,0.93008,0.96131,1.10781,

qf(113)=1.25236,1.08684,1.05570,1.03615,1.02122,1.00662,0.99341,0.98167,

0.97015,0.96040,0.95152,0.94154,0.93341,0.93077,0.95915,1.09054,

qf(129)=1.22270,1.08840,1.05930,1.03980,1.02470,1.00971,0.99675,0.98461,

0.97302,0.96297,0.95369,0.94309,0.93421,0.93191,0.95555,1.06188,

qf(145)=1.21247,1.08894,1.06055,1.04107,1.02590,1.01077,0.99790,0.98563,

0.97401,0.96385,0.95443,0.94362,0.93449,0.93230,0.95430,1.05199,

qf(161)=1.21072,1.08903,1.06076,1.04128,1.02611,1.01096,0.99810,0.98580,

0.97418,0.96401,0.95456,0.94371,0.93454,0.93237,0.95409,1.05031,

qf(177)=1.19446,1.08989,1.06273,1.04328,1.02801,1.01265,0.99993,0.98741,

0.97575,0.96541,0.95574,0.94455,0.93498,0.93299,0.95212,1.03460,

qf(193)=1.16570,1.09140,1.06622,1.04683,1.03139,1.01565,1.00317,0.99027,

0.97853,0.96791,0.95784,0.94605,0.93577,0.93409,0.94863,1.00681,

qf(209)=1.13395,1.08869,1.06710,1.04917,1.03457,1.01940,1.00749,0.99465,

0.98295,0.97220,0.96169,0.94928,0.93830,0.93566,0.94387,0.97600,

qf(225)=1.12078,1.08273,1.06420,1.04843,1.03528,1.02144,1.01010,0.99782,

0.98628,0.97567,0.96496,0.95237,0.94119,0.93669,0.94090,0.96307,

qf(241)=1.11657,1.08082,1.06327,1.04819,1.03551,1.02209,1.01094,0.99884,

0.98734,0.97678,0.96601,0.95335,0.94212,0.93702,0.93995,0.95894,
```

```
qf(257)=1.11038,1.07803,1.06191,1.04784,1.03585,1.02305,1.01216,1.00033,

0.98890,0.97841,0.96755,0.95480,0.94347,0.93751,0.93855,0.95287,

qf(273)=1.10070,1.07365,1.05978,1.04729,1.03638,1.02455,1.01408,1.00266,

0.99134,0.98097,0.96996,0.95707,0.94560,0.93827,0.93637,0.94337,

qf(289)=1.08511,1.06660,1.05634,1.04641,1.03723,1.02697,1.01716,1.00642,

0.99528,0.98508,0.97384,0.96072,0.94902,0.93949,0.93285,0.92806,

qf(305)=1.07220,1.06076,1.05350,1.04568,1.03793,1.02897,1.01972,1.00953,

0.99853,0.98848,0.97705,0.96375,0.95185,0.94050,0.92994,0.91540,

qf(321)=1.05652,1.05367,1.05005,1.04479,1.03879,1.03140,1.02282,1.01331,

1.00249,0.99262,0.98096,0.96742,0.95530,0.94173,0.92640,0.90000,
    x(1)=
0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.16147222,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
         0.38753333,0.41982778,0.45212222,0.48441667,

x(17)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.16147222,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
         0.38753333,0.41982778,0.45212222,0.48441667,

x(33)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.16147222,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
         0.38753333,0.41982778,0.45212222,0.48441667,

x(49)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.16147222,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
         0.38753333,0.41982778,0.45212222,0.48441667,

x(65)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.16147222,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
         0.38753333,0.41982778,0.45212222,0.48441667,

x(81)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.16147222,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
         0.38753333,0.41982778,0.45212222,0.48441667,

x(97)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.16147222,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
         0.38753333,0.41982778,0.45212222,0.48441667,
```

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x(113)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(129)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(145)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(161)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(177)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(193)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(209)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(225)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(241)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(257)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,
```

```
0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(273)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(289)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(305)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,

x(321)=0.00000000,0.03229444,0.06458889,0.09688333,0.12917778,0.1614722
2,

0.19376667,0.22606111,0.25835556,0.29065000,0.32294444,0.35523889,
          0.38753333,0.41982778,0.45212222,0.48441667,
   qmpy(1)=1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,8.570,8.570,
           7.838,7.838,
           8.432,8.432,
           7.540,7.540,
           3*7.696,
           8.767,3*9.837,
           9.840,9.840,
           9.421,9.421,
           8.000,7.000,6.161,6.161,
           7.124,8.086,8.086,
           8.207,8.207,
           7.896,7.896,
           7.612,3*7.327,
           6.474,6.474,
           5.027,5.027,
           5.299,5.299,
           6.034,6.034,
           5.509,5.509,
           5.272,5.272,
           5.252,5.252,
           4.0,3.0,2.0,1.0,0.004,0.004,
   rc=0.0,
   roughc=26.0e-6,
   roughf=72.4e-6,
   rsntr=220.0,
   sgapf=31.0,
   slim=0.10,
   thkcld=0.025725,
   thkgap=0.001475,
   ProblemTime=0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,48.4,
```

```
          48.5,61.2,
          61.3,83.4,
          83.5,97.5,
          97.6,126.2,154.9,
          155.0,155.1,169.2,182.3,
          182.4,203.3,
          203.4,239.7,
          239.8,239.9,240.0,258.9,
          259.0,259.1,261.4,
          261.5,284.3,
          284.4,326.4,
          326.5,326.6,354.5,382.6,
          382.7,416.6,
          416.7,430.6,
          430.7,450.1,
          450.2,476.9,
          477.0,524.2,
          524.3,565.1,
          565.2,615.0,
          615.1,615.2,615.3,615.4,615.5,615.6,
  tsint=3227.0,
  totl=0.48441667,
  tw(1)=209.5,263.8,318.1,372.4,426.6,480.9,535.2,589.5,2*621.5,
        2*584.0,
        2*611.3,
        2*567.2,
        3*572.1,
        621.2,3*670.3,
        2*668.3,
        2*646.3,
        577.7,529.5,2*489.0,
        534.9,2*580.7,
        2*585.6,
        2*569.1,
        554.1,3*539.0,
        2*495.8,
        2*424.2,
        2*436.6,
        2*470.5,
        2*443.8,
        2*430.1,
        2*427.0,
        372.4,318.1,263.8,209.5,2*110.2,
  vs=8.5,
 $end
 $frpmox
  enrpu39=93.845367,
  enrpu40= 6.009014,
  enrpu41= 0.122010,
  enrpu42= 0.023609,
 $end
```

ATR Phase IV, Capsule 4, Pin 7

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

```
* GOESOUTS:
FILE06='outapt4_4.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.4_4', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
  ATR MOX Experiment: Phase IV, Capsule 4 / Fuel Pin 7 (March 2005)
 $frpcn
   im=89,
   na=15,
   ngasr=45,
   nr=17,
 $end
 $frpcon
   crephr=10.0,
   catexf=0.05,
   cldwks=0.2,
   comp=5.0037,
   cpl=0.813,
   crdt = 0.0,
   crdtr=0.0,
   dco=0.38065,
   den=94.5,
   deng=0.5,
   dishsd=0.0491,
   dspg=0.30,
   dspgw=0.030,
   enrch=0.266457,
   fa=1.0,
   fgpav=11.1,
   flux(1)=16*0.5e12,
   fotmtl=2.0,
   gadoln=0.0,
   go(1)=89*0.0,
   hdish=0.0082,
   hplt=0.387733,
   icm=4,
   icor=1,
   idxgas=1,
   imox=1,
   imswch=0,
   iplant=-2,
   iq=0,
   jdlpr=0,
   jn=22*16,
   jst=7*1,6*2,3*3,8*4,2*5,10*6,2*7,3*8,3*9,3*10,4*11,2*12,
       2*13,3*14,8*15,2*16,2*17,3*18,2*19,4*20,3*21,7*22,
   nplot=1,
   nsp=1,
   nunits=1,
   p2(1)=89*12.5,
   pitch=0.38135,
   ppmh2o=1.0,
   ppmn2=40.0,
   qend=0.1,
   qf(1)=
1.38500,1.08265,1.04509,1.01927,1.00283,0.99109,0.98077,0.97231,
```

```
0.96433,0.95823,0.95024,0.94180,0.93241,0.92443,0.93288,1.21833,
   qf(17)=
1.35713,1.08343,1.04712,1.02283,1.00680,0.99442,0.98334,0.97414,

0.96530,0.95834,0.95020,0.94148,0.93252,0.92580,0.93996,1.19150,
   qf(33)=
1.34089,1.08388,1.04830,1.02491,1.00911,0.99636,0.98484,0.97520,

0.96586,0.95841,0.95018,0.94130,0.93259,0.92661,0.94409,1.17585,
   qf(49)=
1.22019,1.01715,0.98447,0.97655,0.97360,0.97231,0.97213,0.97213,

0.97249,0.97268,0.97305,0.97360,0.97902,0.99289,1.03847,1.23877,
   qf(65)=
1.17472,1.01240,0.98010,0.97495,0.97464,0.97451,0.97449,0.97449,

0.97453,0.97455,0.97458,0.97464,0.98124,0.99649,1.04093,1.26022,
   qf(81)=
1.13476,1.00986,0.98359,0.97964,0.97964,0.97964,0.97964,0.97964,

0.97964,0.97964,0.97964,0.97964,0.98441,0.99627,1.03449,1.21447,
   qf(97)=
1.11682,1.00883,0.98568,0.98217,0.98217,0.98217,0.98217,0.98217,

0.98217,0.98217,0.98217,0.98217,0.98592,0.99594,1.03100,1.18941,

qf(113)=1.08737,1.00713,0.98910,0.98632,0.98632,0.98632,0.98632,0.98632,

0.98632,0.98632,0.98632,0.98632,0.98839,0.99540,1.02527,1.14827,

qf(129)=0.96029,0.96082,0.96265,0.96501,0.96924,0.97300,0.97771,0.98239,

0.98898,0.99460,1.00257,1.01335,1.02556,1.04716,1.08290,1.14783,

qf(145)=0.95221,0.95800,0.96197,0.96577,0.97055,0.97492,0.97983,0.98472,

0.99122,0.99699,1.00489,1.01520,1.02691,1.04669,1.07860,1.13529,

qf(161)=0.94971,0.95708,0.96172,0.96599,0.97095,0.97553,0.98050,0.98546,

0.99194,0.99775,1.00564,1.01578,1.02734,1.04652,1.07722,1.13146,

qf(177)=0.94018,0.95356,0.96077,0.96685,0.97249,0.97784,0.98307,0.98829,

0.99468,1.00066,1.00846,1.01800,1.02895,1.04591,1.07197,1.11685,

qf(193)=0.93091,0.95013,0.95985,0.96768,0.97398,0.98009,0.98556,0.99103,

0.99734,1.00349,1.01121,1.02016,1.03053,1.04531,1.06686,1.10264,

qf(209)=0.92325,0.94730,0.95908,0.96836,0.97522,0.98194,0.98763,0.99330,

0.99954,1.00583,1.01347,1.02195,1.03183,1.04482,1.06264,1.09091,

qf(225)=0.97908,0.98804,0.99605,0.99974,1.00103,1.00103,1.00103,1.00103,
```

```
1.00103,1.00103,1.00103,1.00103,1.00103,1.00131,1.00502,1.02204,

qf(241)=0.97218,0.98634,0.99623,1.00049,1.00194,1.00200,1.00203,1.00205,

1.00205,1.00204,1.00202,1.00199,1.00193,1.00188,1.00362,1.01461,

qf(257)=0.97054,0.98546,0.99571,1.00032,1.00208,1.00260,1.00277,1.00295,

1.00295,1.00289,1.00272,1.00248,1.00202,1.00162,1.00239,1.01155,

qf(273)=0.96941,0.98486,0.99535,1.00021,1.00218,1.00301,1.00329,1.00357,

1.00357,1.00348,1.00320,1.00283,1.00208,1.00143,1.00153,1.00942,

qf(289)=0.96712,0.98363,0.99462,0.99997,1.00237,1.00385,1.00434,1.00483,

1.00483,1.00467,1.00417,1.00352,1.00220,1.00105,0.99981,1.00513,

qf(305)=0.96530,0.98266,0.99404,0.99979,1.00252,1.00451,1.00517,1.00584,

1.00584,1.00562,1.00495,1.00407,1.00230,1.00076,0.99843,1.00172,

qf(321)=0.96206,0.98093,0.99300,0.99946,1.00280,1.00569,1.00665,1.00762,

1.00762,1.00730,1.00633,1.00505,1.00247,1.00022,0.99599,0.99566,

qf(337)=0.95898,0.97928,0.99202,0.99915,1.00306,1.00681,1.00807,1.00932,

1.00932,1.00890,1.00765,1.00598,1.00264,0.99972,0.99367,0.98987,
   x(1)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(17)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(33)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(49)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(65)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(81)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,
```

```
0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(97)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(113)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(129)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(145)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(161)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(177)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(193)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(209)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(225)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
```

```
x(241)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(257)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(273)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(289)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(305)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(321)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(337)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   qmpy(1)=1.0,2.0,3.0,4.0,5.0,6.118,6.118,
           5.436,5.436,
           6.069,6.069,
           5.565,5.565,
           3*5.726,
           7.0,8.0,9.0,10.0,2*10.644,
           10.504,10.504,
           10.046,10.046,
           9.0,8.0,6.654,6.654,
           7.0,8.0,8.646,8.646,
           8.864,8.864,
           8.756,8.756,
           3*7.982,
           7.301,6.619,6.619,
           5.848,5.076,5.076,
```

```
        5.246,5.246,
        6.292,6.292,
        5.571,5.571,
        5.321,5.321,
        3*5.400,
        5.152,5.152,
        5.095,5.095,
        4.671,4.671,
        4.658,4.658,
        4.966,4.966,
        5.292,5.292,
        3*4.450,
        4.475,4.475,
        5.478,3*6.383,
        3*5.658,
        5.0,4.0,3.0,2.0,1.0,0.004,0.004,
rc=0.0,
roughc=26.0e-6,
roughf=72.4e-6,
rsntr=220.0,
sgapf=31.0,
slim=0.10,
thkcld=0.025725,
thkgap=0.001475,
ProblemTime=0.1,0.2,0.3,0.4,0.5,0.6,48.4,
        48.5,61.2,
        61.3,83.4,
        83.5,97.5,
        97.6,126.2,154.9,
        155.0,155.1,155.2,155.3,155.4,182.3,
        182.4,203.3,
        203.4,239.7,
        239.8,239.9,240.0,258.9,
        259.0,259.1,259.2,261.4,
        261.5,284.3,
        284.4,326.4,
        326.5,354.5,382.6,
        382.7,382.8,416.6,
        416.7,416.8,430.6,
        430.7,450.1,
        450.2,476.9,
        477.0,524.2,
        524.3,565.1,
        565.2,590.1,615.0,
        615.1,620.0,
        620.1,623.4,
        623.5,642.1,
        642.2,655.1,
        655.2,687.0,
        687.1,709.1,
        709.2,734.1,759.0,
        759.1,798.7,
        798.8,798.9,823.3,848.1,
        848.2,876.5,904.1,
        904.2,904.3,904.4,904.5,904.6,904.7,904.8,
tsint=3227.0,
totl=0.48466667,
```

```
  tw(1)=209.5,263.8,318.1,372.4,426.6,2*501.1,
        2*465.6,
        2*497.4,
        2*471.6,
        3*478.8,
        540.2,588.3,636.5,684.7,2*715.7,
        2*708.0,
        2*685.0,
        634.4,586.1,2*521.0,
        537.6,585.5,2*616.5,
        2*626.4,
        2*620.0,
        3*581.2,
        547.5,2*513.7,
        474.9,2*436.1,
        2*443.3,
        2*493.6,
        2*456.8,
        2*441.9,
        3*443.3,
        2*430.0,
        2*426.9,
        2*405.7,
        2*404.0,
        2*416.8,
        2*429.8,
        3*386.6,
        2*384.1,
        427.8,3*467.2,
        3*428.3,
        426.6,372.4,318.1,263.8,209.5,2*110.2,
  vs=8.5,
 $end
 $frpmox
  enrpu39=93.845367,
  enrpu40= 6.009014,
  enrpu41= 0.122010,
  enrpu42= 0.023609,
 $end
```

ATR Phase IV, Capsule 5, Pin 8

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='outapt4_5.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.4_5', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
  ATR MOX Experiment: Phase IV, Capsule 5/ Fuel Pin 8 (March 2005)
 $frpcn
  im=114,
  na=15,
  ngasr=45,
  nr=17,
 $end
```

```
 $frpcon
   crephr=10.0,
   catexf=0.05,
   cldwks=0.2,
   comp=5.0037,
   cpl=0.813,
   crdt = 0.0,
   crdtr=0.0,
   dco=0.38065,
   den=94.5,
   deng=0.5,
   dishsd=0.0491,
   dspg=0.30,
   dspgw=0.030,
   enrch=0.266457,
   fa=1.0,
   fgpav=11.1,
   flux(1)=16*0.5e12,
   fotmtl=2.0,
   gadoln=0.0,
   go(1)=114*0.0,
   hdish=0.0082,
   hplt=0.387733,
   icm=4,
   icor=1,
   idxgas=1,
   imox=1,
   imswch=0,
   iplant=-2,
   iq=0,
   jdlpr=0,
   jn=22*16,
   jst=11*1,5*2,7*3,10*4,3*5,6*6,4*7,5*8,4*9,3*10,10*11,5*12,
       2*13,4*14,3*15,3*16,3*17,3*18,4*19,6*20,4*21,9*22,
   nplot=1,
   nsp=1,
   nunits=1,
   p2(1)=114*12.5,
   pitch=0.38135,
   ppmh2o=1.0,
   ppmn2=40.0,
   qend=0.1,
   qf(1)
=1.27328,1.02268,0.98958,0.97840,0.97238,0.96974,0.96937,0.96937,

0.97012,0.97050,0.97125,0.97238,0.97643,0.98868,1.03560,1.21372,

qf(17)=1.24673,1.01992,0.98703,0.97747,0.97299,0.97103,0.97075,0.97075,

0.97131,0.97159,0.97215,0.97299,0.97773,0.99079,1.03704,1.22625,

qf(33)=1.19758,1.01479,0.98230,0.97576,0.97412,0.97340,0.97330,0.97330,

0.97350,0.97361,0.97381,0.97412,0.98013,0.99468,1.03969,1.24943,

qf(49)=1.13645,1.00995,0.98340,0.97940,0.97940,0.97940,0.97940,0.97940,
```

0.97940,0.97940,0.97940,0.97940,0.98427,0.99630,1.03482,1.21683,

qf(65)=1.11315,1.00862,0.98610,0.98269,0.98269,0.98269,0.98269,0.98269,

0.98269,0.98269,0.98269,0.98269,0.98622,0.99587,1.03028,1.18429,

qf(81)=1.06691,1.00596,0.99148,0.98921,0.98921,0.98921,0.98921,0.98921,

0.98921,0.98921,0.98921,0.98921,0.99011,0.99502,1.02128,1.11969,

qf(97)=1.04414,1.00341,0.99358,0.99224,0.99236,0.99236,0.99236,0.99236,

0.99236,0.99236,0.99236,0.99236,0.99236,0.99536,1.01693,1.09029,

qf(113)=1.01960,0.99761,0.99451,0.99507,0.99563,0.99563,0.99563,0.99563,

0.99563,0.99563,0.99563,0.99563,0.99563,0.99760,1.01244,1.06455,

qf(129)=1.00568,0.99432,0.99504,0.99667,0.99749,0.99749,0.99749,0.99749,

0.99749,0.99749,0.99749,0.99749,0.99749,0.99888,1.00989,1.04994,

qf(145)=0.99364,0.99148,0.99549,0.99806,0.99909,0.99909,0.99909,0.99909,

0.99909,0.99909,0.99909,0.99909,0.99909,0.99998,1.00768,1.03732,

qf(161)=0.97358,0.98674,0.99626,1.00038,1.00176,1.00176,1.00176,1.00176,

1.00176,1.00176,1.00176,1.00176,1.00176,1.00181,1.00401,1.01627,

qf(177)=0.97049,0.98544,0.99569,1.00032,1.00208,1.00262,1.00280,1.00298,

1.00298,1.00292,1.00274,1.00250,1.00202,1.00161,1.00235,1.01145,

qf(193)=0.96872,0.98449,0.99512,1.00014,1.00223,1.00326,1.00361,1.00395,

1.00395,1.00384,1.00349,1.00304,1.00212,1.00132,1.00101,1.00812,

qf(209)=0.96729,0.98372,0.99467,0.99999,1.00236,1.00378,1.00426,1.00474,

1.00474,1.00458,1.00410,1.00347,1.00220,1.00108,0.99993,1.00544,

qf(225)=0.96464,0.98230,0.99382,0.99972,1.00258,1.00475,1.00548,1.00620,

1.00620,1.00596,1.00523,1.00427,1.00234,1.00065,0.99793,1.00048,

qf(241)=1.06545,1.06131,1.05661,1.05037,1.04353,1.03497,1.02568,1.01449,

1.00287,0.99121,0.97834,0.96395,0.94933,0.93351,0.91569,0.89082,

qf(257)=1.06881,1.06381,1.05859,1.05193,1.04476,1.03579,1.02626,1.01458,

1.00273,0.99059,0.97740,0.96279,0.94751,0.93121,0.91301,0.88926,

qf(273)=1.07167,1.06584,1.06002,1.05286,1.04526,1.03594,1.02610,1.01418,

```
1.00220,0.98979,0.97651,0.96186,0.94649,0.93013,0.91212,0.88974,

qf(289)=1.07349,1.06698,1.06047,1.05279,1.04466,1.03512,1.02490,1.01314,

1.00116,0.98884,0.97580,0.96139,0.94671,0.93089,0.91388,0.89304,

qf(305)=1.07640,1.06880,1.06120,1.05268,1.04370,1.03380,1.02298,1.01148,

0.99951,0.98732,0.97466,0.96063,0.94706,0.93211,0.91670,0.89832,

qf(321)=1.07764,1.06958,1.06151,1.05263,1.04329,1.03324,1.02216,1.01077,

0.99881,0.98667,0.97418,0.96030,0.94721,0.93263,0.91791,0.90057,

qf(337)=1.07999,1.07105,1.06210,1.05254,1.04251,1.03217,1.02062,1.00943,

0.99748,0.98545,0.97326,0.95969,0.94749,0.93362,0.92018,0.90483,
   x(1)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(17)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(33)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(49)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(65)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(81)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   x(97)=
0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.16155556,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(113)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,
```

```
0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(129)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(145)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(161)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(177)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(193)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(209)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(225)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(241)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(257)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
```

```
x(273)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(289)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(305)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(321)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,

x(337)=0.00000000,0.03231111,0.06462222,0.09693333,0.12924444,0.1615555
6,

0.19386667,0.22617778,0.25848889,0.29080000,0.32311111,0.35542222,
          0.38773333,0.42004444,0.45235556,0.48466667,
   qmpy(1)=1.0,2.0,3.0,4.0,5.0,6.386,6.386,
           5.892,5.892,
           6.328,6.328,
           5.873,5.873,
           3*5.823,
           7.0,2*7.988,
           7.887,7.887,
           7.719,7.719,
           6.5,5.338,5.338,
           6.0,6.921,6.921,
           7.104,7.104,
           6.920,6.920,
           3*6.500,
           6.263,6.263,
           5.070,5.070,
           5.187,5.187,
           5.827,5.827,
           5.346,5.346,
           5.098,5.098,
           3*5.246,
           4.170,4.170,
           3.752,3.752,
           3*4.038,
           3.815,3.815,
           3.784,3.784,
           3.606,3.606,
           3.504,3.504,
```

```
        3.755,3.755,
        4.082,4.082,
        3*3.497,
        3.539,3.539,
        4.5,3*5.269,
        3*4.753,
        3*5.527,
        3*4.641,
        3*4.748,
        4.491,4.491,
        3.878,3.878,
        3.743,3.743,
        3.776,3.776,
        3.712,3.712,
        3.476,3.476,
        3.350,3.350,
        3.429,3.429,
        3*3.352,
        2.0,1.0,0.004,0.004,
rc=0.0,
roughc=26.0e-6,
roughf=72.4e-6,
rsntr=220.0,
sgapf=31.0,
slim=0.10,
thkcld=0.025725,
thkgap=0.001475,
ProblemTime=0.1,0.2,0.3,0.4,0.5,0.6,48.4,
        48.5,61.2,
        61.3,83.4,
        83.5,97.5,
        97.6,126.2,154.9,
        155.0,155.1,182.3,
        182.4,203.3,
        203.4,239.7,
        239.8,239.9,258.9,
        259.0,259.1,261.4,
        261.5,284.3,
        284.4,326.4,
        326.5,354.5,382.6,
        382.7,416.6,
        416.7,430.6,
        430.7,450.1,
        450.2,476.9,
        477.0,524.2,
        524.3,565.1,
        565.2,590.1,615.0,
        615.1,657.2,
        657.3,670.6,
        670.7,699.4,728.1,
        728.2,733.1,
        733.2,736.5,
        736.6,755.2,
        755.3,768.2,
        768.3,800.1,
        800.2,822.2,
        822.3,847.3,872.1,
```

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          872.2,911.8,
          911.9,912.0,936.8,961.2,
          961.3,989.2,1017.2,
          1017.3,1042.2,1067.5,
          1067.6,1097.5,1127.4,
          1127.5,1152.4,1179.1,
          1179.2,1222.9,
          1223.0,1240.9,
          1241.0,1274.4,
          1274.5,1304.4,
          1304.5,1318.9,
          1319.0,1367.4,
          1367.5,1390.8,
          1390.9,1411.5,
          1411.6,1436.8,1461.8,
          1461.9,1462.0,1462.1,1465.0,
tsint=3227.0,
totl=0.48466667,
tw(1)=209.5,263.8,318.1,372.4,426.6,2*515.1,
      2*490.1,
      2*511.8,
      2*488.7,
      3*485.8,
      544.1,2*593.1,
      2*588.2,
      2*579.5,
      518.1,2*459.6,
      492.8,2*539.0,
      2*548.1,
      2*538.7,
      3*516.7,
      2*503.8,
      2*442.7,
      2*448.1,
      2*480.1,
      2*455.0,
      2*441.1,
      3*446.8,
      2*390.7,
      2*368.0,
      3*381.6,
      2*369.6,
      2*367.9,
      2*358.2,
      2*352.4,
      2*364.7,
      2*380.8,
      3*350.0,
      2*350.8,
      398.0,3*435.8,
      3*409.4,
      3*444.8,
      3*400.5,
      3*403.9,
      2*389.6,
      2*359.7,
      2*352.6,
```

```
         2*353.4,
         2*350.0,
         2*337.9,
         2*331.0,
         2*334.5,
         3*330.3,
         263.8,209.5,2*110.2,
   vs=8.5,
 $end
 $frpmox
   enrpu39=93.845367,
   enrpu40= 6.009014,
   enrpu41= 0.122010,
   enrpu42= 0.023609,
 $end
```

ATR Phase IV, Capsule 6, Pin 9

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='outapt4_6.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.4_6', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
   ATR MOX Experiment: Phase IV, Capsule 6 / Fuel Pin 9 (March 2005)
 $frpcn
   im=107,
   na=15,
   ngasr=45,
   nr=17,
 $end
 $frpcon
   crephr=10.0,
   catexf=0.05,
   cldwks=0.2,
   comp=5.0037,
   cpl=0.800,
   crdt = 0.0,
   crdtr=0.0,
   dco=0.38065,
   den=94.5,
   deng=0.5,
   dishsd=0.0491,
   dspg=0.30,
   dspgw=0.030,
   enrch=0.266457,
   fa=1.0,
   fgpav=11.1,
   flux(1)=16*0.5e12,
   fotmtl=2.0,
   gadoln=0.0,
   go(1)=107*0.0,
   hdish=0.0082,
   hplt=0.3886,
   icm=4,
```

```
    icor=1,
    idxgas=1,
    imox=1,
    imswch=0,
    iplant=-2,
    iq=0,
    jdlpr=0,
    jn=22*16,
    jst=12*1,9*2,4*3,3*4,8*5,2*6,2*7,3*8,4*9,3*10,10*11,5*12,
        2*13,4*14,3*15,3*16,3*17,3*18,4*19,6*20,4*21,10*22,
    nplot=1,
    nsp=1,
    nunits=1,
    p2(1)=107*12.5,
    pitch=0.38135,
    ppmh2o=1.0,
    ppmn2=40.0,
    qend=0.1,
    qf(1)
=1.38500,1.08265,1.04509,1.01927,1.00283,0.99109,0.98077,0.97231,

0.96433,0.95823,0.95024,0.94180,0.93241,0.92443,0.93288,1.21833,

qf(17)=1.32995,1.08418,1.04909,1.02631,1.01067,0.99766,0.98585,0.97592,

0.96624,0.95845,0.95016,0.94117,0.93263,0.92715,0.94687,1.16531,

qf(33)=1.30682,1.08483,1.05078,1.02928,1.01396,1.00042,0.98798,0.97743,

0.96704,0.95854,0.95013,0.94091,0.93273,0.92829,0.95275,1.14304,

qf(49)=1.28313,1.08549,1.05250,1.03231,1.01734,1.00325,0.99017,0.97899,

0.96786,0.95864,0.95009,0.94064,0.93282,0.92947,0.95877,1.12023,

qf(65)=1.23086,1.08797,1.05831,1.03880,1.02374,1.00886,0.99583,0.98380,

0.97223,0.96226,0.95309,0.94266,0.93399,0.93159,0.95654,1.06977,

qf(81)=1.20081,1.08956,1.06196,1.04250,1.02727,1.01199,0.99922,0.98678,

0.97513,0.96486,0.95528,0.94422,0.93481,0.93275,0.95289,1.04073,

qf(97)=1.17723,1.09080,1.06482,1.04541,1.03004,1.01445,1.00187,0.98912,

0.97741,0.96691,0.95700,0.94545,0.93545,0.93365,0.95003,1.01795,

qf(113)=1.15728,1.09185,1.06724,1.04786,1.03238,1.01652,1.00412,0.99110,

0.97934,0.96864,0.95846,0.94649,0.93599,0.93442,0.94761,0.99868,

qf(129)=1.04493,1.00360,0.99355,0.99215,0.99226,0.99226,0.99226,0.99226,

0.99226,0.99226,0.99226,0.99226,0.99226,0.99528,1.01708,1.09112,

qf(145)=1.02558,0.99903,0.99428,0.99438,0.99484,0.99484,0.99484,0.99484,
```

```
0.99484,0.99484,0.99484,0.99484,0.99484,0.99706,1.01353,1.07082,
qf(161)=1.08360,1.06592,1.05601,1.04633,1.03731,1.02720,1.01746,1.00678,
0.99566,0.98548,0.97422,0.96108,0.94935,0.93961,0.93251,0.92658,
qf(177)=1.06172,1.05602,1.05119,1.04509,1.03850,1.03060,1.02179,1.01206,
1.00118,0.99125,0.97966,0.96620,0.95416,0.94133,0.92757,0.90510,
qf(193)=1.05415,1.05292,1.04994,1.04512,1.03939,1.03222,1.02371,1.01418,
1.00333,0.99333,0.98151,0.96785,0.95545,0.94124,0.92471,0.89605,
qf(209)=1.05642,1.05461,1.05128,1.04617,1.04022,1.03277,1.02411,1.01424,
1.00323,0.99291,0.98087,0.96707,0.95423,0.93969,0.92290,0.89500,
qf(225)=1.06017,1.05739,1.05349,1.04792,1.04160,1.03369,1.02476,1.01434,
1.00308,0.99220,0.97982,0.96577,0.95219,0.93712,0.91991,0.89326,
qf(241)=0.96309,0.98147,0.99333,0.99956,1.00271,1.00531,1.00619,1.00706,
1.00706,1.00677,1.00589,1.00474,1.00242,1.00039,0.99677,0.99757,
qf(257)=0.95972,0.97967,0.99225,0.99922,1.00300,1.00654,1.00773,1.00892,
1.00892,1.00852,1.00733,1.00576,1.00260,0.99984,0.99422,0.99126,
qf(273)=0.95887,0.97926,0.99187,0.99900,1.00300,1.00699,1.00833,1.00967,
1.00967,1.00922,1.00789,1.00611,1.00255,0.99944,0.99278,0.98955,
qf(289)=0.96461,0.98252,0.99325,0.99905,1.00225,1.00545,1.00652,1.00759,
1.00759,1.00723,1.00616,1.00474,1.00190,0.99941,0.99408,0.99990,
qf(305)=0.97332,0.98745,0.99536,0.99913,1.00112,1.00311,1.00377,1.00444,
1.00444,1.00421,1.00355,1.00267,1.00090,0.99935,0.99605,1.01558,
qf(321)=0.97702,0.98954,0.99625,0.99917,1.00064,1.00211,1.00261,1.00310,
1.00310,1.00294,1.00244,1.00179,1.00048,0.99933,0.99688,1.02223,
qf(337)=0.98382,0.99339,0.99789,0.99923,0.99976,1.00028,1.00046,1.00064,
1.00064,1.00058,1.00040,1.00017,0.99970,0.99929,0.99841,1.03448,
    x(1)=
0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.16191667,
0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
    x(17)=
0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.16191667,
```

```
0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
   x(33)=
0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.16191667,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
   x(49)=
0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.16191667,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
   x(65)=
0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.16191667,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
   x(81)=
0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.16191667,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
   x(97)=
0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.16191667,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(113)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(129)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(145)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(161)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(177)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
```

```
          0.38860000,0.42098333,0.45336667,0.48575000,

x(193)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(209)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(225)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(241)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(257)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(273)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(289)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(305)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,

x(321)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
```

```
x(337)=0.00000000,0.03238333,0.06476667,0.09715000,0.12953333,0.1619166
7,

0.19430000,0.22668333,0.25906667,0.29145000,0.32383333,0.35621667,
          0.38860000,0.42098333,0.45336667,0.48575000,
   qmpy(1)=1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,2*8.653,
           8.539,8.539,
           8.427,8.427,
           7.5,6.6,5.742,5.742,
           6.6,7.469,7.469,
           7.636,7.636,
           7.392,7.392,
           3*7.040,
           6.494,6.494,
           5.081,5.081,
           5.487,5.487,
           6.182,6.182,
           5.702,5.702,
           5.580,5.580,
           3*5.672,
           6.672,6.672,
           6.193,6.193,
           3*6.134,
           5.572,5.572,
           5.492,5.492,
           5.183,5.183,
           5.038,5.038,
           5.342,5.342,
           5.700,5.700,
           3*4.752,
           4.741,4.741,
           5.4,3*6.300,
           3*5.795,
           3*6.599,
           3*5.121,
           3*5.446,
           4.940,4.940,
           4.281,4.281,
           3.981,3.981,
           4.154,4.154,
           3.873,3.873,
           3.605,3.605,
           3.610,3.610,
           3.508,3.508,
           3*3.594,
           3.0,2.0,1.0,0.004,0.004,
   rc=0.0,
   roughc=26.0e-6,
   roughf=72.4e-6,
   rsntr=220.0,
   sgapf=31.0,
   slim=0.10,
   thkcld=0.025725,
   thkgap=0.001475,
   ProblemTime=0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,27.4,
           27.5,48.4,
```

```
         48.5,84.8,
         84.9,85.0,85.1,104.0,
         104.1,104.2,106.5,
         106.6,129.4,
         129.5,171.5,
         171.6,199.6,227.7,
         227.8,261.7,
         261.8,275.7,
         275.8,295.2,
         295.3,322.0,
         322.1,369.3,
         369.4,410.2,
         410.3,435.3,460.1,
         460.2,502.3,
         502.4,515.7,
         515.8,544.5,573.2,
         573.3,578.2,
         578.3,581.6,
         581.7,600.3,
         600.4,613.3,
         613.4,645.2,
         645.3,667.3,
         667.4,692.3,717.2,
         717.3,756.9,
         757.0,757.1,781.9,806.3,
         806.4,834.3,862.3,
         862.4,887.3,912.6,
         912.7,942.6,972.5,
         972.6,998.5,1024.2,
         1024.3,1068.0,
         1068.1,1086.0,
         1086.1,1119.5,
         1119.6,1149.5,
         1149.6,1164.0,
         1164.1,1212.5,
         1212.6,1235.9,
         1236.0,1256.6,
         1256.7,1281.8,1306.9,
         1307.0,1307.1,1307.2,1307.3,1310.0,
tsint=3227.0,
totl=0.48575,
tw(1)=209.5,263.8,318.1,372.4,426.6,480.9,535.2,589.5,2*627.2,
      2*621.4,
      2*615.6,
      569.3,519.4,2*481.7,
      524.5,2*568.0,
      2*576.3,
      2*563.7,
      3*545.3,
      2*517.0,
      2*444.6,
      2*464.8,
      2*499.3,
      2*473.8,
      2*466.0,
      3*468.7,
      2*515.8,
```

```
         2*490.9,
         3*485.8,
         2*456.5,
         2*452.2,
         2*436.4,
         2*428.4,
         2*442.1,
         2*458.0,
         3*409.8,
         2*407.3,
         437.9,3*479.8,
         3*453.6,
         3*488.4,
         3*417.3,
         3*430.6,
         2*405.5,
         2*373.6,
         2*358.7,
         2*366.0,
         2*352.1,
         2*338.6,
         2*338.0,
         2*332.6,
         3*335.8,
         318.1,263.8,209.5,2*110.2,
   vs=8.5,
 $end
 $frpmox
   enrpu39=93.845367,
   enrpu40= 6.009014,
   enrpu41= 0.122010,
   enrpu42= 0.023609,
 $end
```

ATR Phase IV, Capsule 12, Pin 15

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='outapt4_12.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='stripf.412', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*********************************************************************
  ATR MOX Experiment: Phase IV, Capsule 12 / Fuel Pin 15 (March 2005)
 $frpcn
   im=107,
   na=15,
   ngasr=45,
   nr=17,
 $end
 $frpcon
   crephr=10.0,
   catexf=0.05,
   cldwks=0.2,
   comp=5.0037,
   cpl=0.834,
```

```
   crdt = 0.0,
   crdtr=0.0,
   dco=0.38065,
   den=95.2,
   deng=0.5,
   dishsd=0.0496,
   dspg=0.30,
   dspgw=0.030,
   enrch=0.266457,
   fa=1.0,
   fgpav=11.1,
   flux(1)=16*0.5e12,
   fotmtl=2.0,
   gadoln=0.0,
   go(1)=107*0.0,
   hdish=0.0063,
   hplt=0.386333,
   icm=4,
   icor=1,
   idxgas=1,
   imox=1,
   imswch=0,
   iplant=-2,
   iq=0,
   jdlpr=0,
   jn=22*16,
   jst=12*1,9*2,4*3,3*4,8*5,2*6,2*7,3*8,4*9,3*10,10*11,5*12,
       2*13,4*14,3*15,3*16,3*17,3*18,4*19,6*20,4*21,10*22,
   nplot=1,
   nsp=1,
   nunits=1,
   p2(1)=107*12.5,
   pitch=0.38135,
   ppmh2o=1.0,
   ppmn2=40.0,
   qend=0.1,
  qf(1)
=1.17414,0.97912,0.94777,0.94028,0.94496,0.95150,0.95711,0.96507,

0.97396,0.98238,0.99174,1.00203,1.01466,1.03898,1.09184,1.26306,
  qf(17)
=1.11572,0.96664,0.94460,0.94350,0.94932,0.95541,0.96196,0.96879,

0.97723,0.98452,0.99230,1.00147,1.01458,1.04031,1.09441,1.29421,
  qf(33)
=1.09120,0.96140,0.94327,0.94484,0.95116,0.95705,0.96399,0.97034,

0.97860,0.98542,0.99254,1.00124,1.01454,1.04087,1.09548,1.30728,
  qf(49)
=1.06548,0.95591,0.94187,0.94626,0.95308,0.95877,0.96613,0.97198,

0.98005,0.98637,0.99279,1.00099,1.01451,1.04146,1.09661,1.32100,
  qf(65)
=1.02357,0.95584,0.94819,0.95277,0.95890,0.96391,0.97053,0.97585,

0.98338,0.98932,0.99604,1.00492,1.01808,1.04348,1.09251,1.26900,
```

```
  qf(81)
=1.00185,0.95755,0.95315,0.95697,0.96245,0.96703,0.97299,0.97810,

0.98530,0.99114,0.99828,1.00782,1.02065,1.04474,1.08921,1.22741,
  qf(97)
=0.98474,0.95890,0.95706,0.96028,0.96525,0.96949,0.97493,0.97987,

0.98681,0.99256,1.00005,1.01010,1.02267,1.04574,1.08661,1.19464,

qf(113)=0.97016,0.96005,0.96039,0.96310,0.96763,0.97158,0.97659,0.98137,

0.98810,0.99378,1.00155,1.01204,1.02439,1.04659,1.08440,1.16673,

qf(129)=1.04454,1.00351,0.99356,0.99219,0.99231,0.99231,0.99231,0.99231,

0.99231,0.99231,0.99231,0.99231,0.99231,0.99532,1.01700,1.09070,

qf(145)=1.02519,0.99893,0.99430,0.99442,0.99489,0.99489,0.99489,0.99489,

0.99489,0.99489,0.99489,0.99489,0.99489,0.99709,1.01346,1.07041,

qf(161)=1.08268,1.06550,1.05581,1.04627,1.03736,1.02735,1.01764,1.00700,

0.99589,0.98572,0.97445,0.96129,0.94955,0.93968,0.93230,0.92568,

qf(177)=1.06091,1.05565,1.05101,1.04504,1.03855,1.03072,1.02195,1.01225,

1.00138,0.99146,0.97986,0.96639,0.95433,0.94139,0.92739,0.90431,

qf(193)=1.05431,1.05304,1.05004,1.04519,1.03945,1.03226,1.02374,1.01419,

1.00332,0.99330,0.98146,0.96779,0.95537,0.94113,0.92458,0.89598,

qf(209)=1.05659,1.05474,1.05139,1.04626,1.04029,1.03281,1.02414,1.01425,

1.00323,0.99287,0.98082,0.96700,0.95413,0.93956,0.92276,0.89492,

qf(225)=1.06031,1.05750,1.05358,1.04798,1.04165,1.03372,1.02478,1.01435,

1.00308,0.99218,0.97978,0.96572,0.95212,0.93702,0.91979,0.89320,

qf(241)=0.96295,0.98140,0.99329,0.99955,1.00272,1.00536,1.00625,1.00713,

1.00713,1.00684,1.00595,1.00478,1.00243,1.00037,0.99666,0.99732,

qf(257)=0.95958,0.97960,0.99221,0.99921,1.00301,1.00659,1.00779,1.00899,

1.00899,1.00859,1.00739,1.00580,1.00261,0.99982,0.99412,0.99100,

qf(273)=0.95917,0.97943,0.99194,0.99900,1.00296,1.00691,1.00824,1.00956,

1.00956,1.00912,1.00780,1.00604,1.00252,0.99944,0.99285,0.99009,

qf(289)=0.96492,0.98269,0.99333,0.99905,1.00221,1.00537,1.00642,1.00748,

1.00748,1.00713,1.00607,1.00467,1.00186,0.99941,0.99415,1.00044,
```

```
qf(305)=0.97378,0.98771,0.99547,0.99914,1.00106,1.00298,1.00363,1.00427,

1.00427,1.00406,1.00341,1.00256,1.00085,0.99935,0.99615,1.01640,

qf(321)=0.97759,0.98986,0.99639,0.99917,1.00057,1.00196,1.00243,1.00289,

1.00289,1.00274,1.00227,1.00165,1.00041,0.99933,0.99701,1.02326,

qf(337)=0.98452,0.99379,0.99806,0.99924,0.99967,1.00010,1.00024,1.00038,

1.00038,1.00034,1.00019,1.00000,0.99962,0.99929,0.99857,1.03573,
   x(1)=
0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.16097222,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
   x(17)=
0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.16097222,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
   x(33)=
0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.16097222,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
   x(49)=
0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.16097222,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
   x(65)=
0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.16097222,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
   x(81)=
0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.16097222,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
   x(97)=
0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.16097222,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(113)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(129)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,
```

```
0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(145)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(161)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(177)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(193)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(209)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(225)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(241)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(257)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(273)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
```

```
x(289)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(305)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(321)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,

x(337)=0.00000000,0.03219444,0.06438889,0.09658333,0.12877778,0.1609722
2,

0.19316667,0.22536111,0.25755556,0.28975000,0.32194444,0.35413889,
          0.38633333,0.41852778,0.45072222,0.48291667,
   qmpy(1)=1.0,2.0,3.0,4.0,5.0,6.0,7.0,8.0,2*8.713,
           8.589,8.589,
           8.471,8.471,
           7.5,6.6,5.769,5.769,
           6.6,7.544,7.544,
           7.674,7.674,
           7.608,7.608,
           3*7.164,
           6.604,6.604,
           5.239,5.239,
           5.458,5.458,
           6.194,6.194,
           5.759,5.759,
           5.672,5.672,
           3*5.759,
           6.775,6.775,
           6.144,6.144,
           3*6.326,
           5.628,5.628,
           5.591,5.591,
           5.251,5.251,
           5.170,5.170,
           5.349,5.349,
           5.689,5.689,
           3*4.799,
           4.826,4.826,
           5.4,3*6.302,
           3*5.880,
           3*6.666,
           3*5.198,
           3*5.501,
           5.058,5.058,
           4.399,4.399,
```

```
        4.115,4.115,
        4.296,4.296,
        4.119,4.119,
        3.765,3.765,
        3.646,3.646,
        3.615,3.615,
        3*3.660,
        3.0,2.0,1.0,0.004,0.004,
rc=0.0,
roughc=26.0e-6,
roughf=72.4e-6,
rsntr=220.0,
sgapf=31.0,
slim=0.10,
thkcld=0.025725,
thkgap=0.001475,
ProblemTime=0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,27.4,
        27.5,48.4,
        48.5,84.8,
        84.9,85.0,85.1,104.0,
        104.1,104.2,106.5,
        106.6,129.4,
        129.5,171.5,
        171.6,199.6,227.7,
        227.8,261.7,
        261.8,275.7,
        275.8,295.2,
        295.3,322.0,
        322.1,369.3,
        369.4,410.2,
        410.3,435.3,460.1,
        460.2,502.3,
        502.4,515.7,
        515.8,544.5,573.2,
        573.3,578.2,
        578.3,581.6,
        581.7,600.3,
        600.4,613.3,
        613.4,645.2,
        645.3,667.3,
        667.4,692.3,717.2,
        717.3,756.9,
        757.0,757.1,781.9,806.3,
        806.4,834.3,862.3,
        862.4,887.3,912.6,
        912.7,942.6,972.5,
        972.6,998.5,1024.2,
        1024.3,1068.0,
        1068.1,1086.0,
        1086.1,1119.5,
        1119.6,1149.5,
        1149.6,1164.0,
        1164.1,1212.5,
        1212.6,1235.9,
        1236.0,1256.6,
        1256.7,1281.8,1306.9,
        1307.0,1307.1,1307.2,1307.3,1310.0,
```

```
  tsint=3227.0,
  totl=0.48291667,
  tw(1)=209.5,263.8,318.1,372.4,426.6,480.9,535.2,589.5,2*630.1,
        2*623.9,
        2*617.8,
        569.4,524.5,2*483.1,
        524.5,2*571.5,
        2*578.2,
        2*574.5,
        3*551.3,
        2*522.2,
        2*452.3,
        2*463.0,
        2*499.4,
        2*476.1,
        2*469.8,
        3*471.9,
        2*519.1,
        2*486.8,
        3*493.1,
        2*457.3,
        2*455.1,
        2*437.8,
        2*433.0,
        2*440.3,
        2*455.1,
        3*410.0,
        2*409.3,
        435.7,3*477.3,
        3*455.2,
        3*489.1,
        3*418.9,
        3*431.2,
        2*409.1,
        2*377.4,
        2*363.1,
        2*370.7,
        2*362.6,
        2*344.3,
        2*337.6,
        2*335.6,
        3*336.5,
        318.1,263.8,209.5,2*110.2,
  vs=8.5,
$end
$frpmox
  enrpu39=93.845367,
  enrpu40= 6.009014,
  enrpu41= 0.122010,
  enrpu42= 0.023609,
$end
```

A.28 Gravelines-4 PWR Rods

Halden Project has reported base-irradiation LHGR histories and post-irradiation (rod puncture) FGR for three full-length PWR MOX rods from Gravelines-4 reactor, France, which were subsequently sectioned to produce test rods for various instrumented tests (Beguin, 1999; Fujii and Claudel, 2001; Claudel and Huet, 2001; Petiprez, 2002). These commercial rods did not experience LHGRs in excess of 25 kW/m or temperatures in excess of 1500K, resulting in measured FGR below 5 percent.

These three full-length commercial rods were used to assess the FRAPCON-3.4 MOX FGR predictions. The input files used for the MOX FGR assessments are shown below.

Gravelines-4 Rod N06

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='GraveRodN06.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='GraveRodN06.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*********************************************************************
      Full-Length Gravelines-4 4-Cycle PWR MOX rod N06
 $frpcn
 im=58, na=12,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 7.2, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5,nplot=1,
 rc = 0.0, fotmtl = 1.997,
 den = 94.43, rsntr = 52.,
 dspg = 0.3, fa = 1., dspgw = 0.03,
 enrch = 0.229, fgpav = 382.0, hdish = 0.0115,
 dishsd = 0.0649
 hplt = 0.4634, icm = 4, imox = 1, comp = 5.945,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0, fa = 1.0,
 totl = 12.0, roughc = 2.5e-5, roughf = 8.54e-5, vs = 10.0,
 nunits = 1,
 p2(1) = 2250., tw(1) = 548, go(1) = 2.8e6
 jn = 13, 13, 13, 13, 13,
 jst = 16*1, 10*2, 10*3, 10*4, 12*5
 qf(1) =
 0.4823, 0.8646, 1.116, 1.198, 1.206,
 1.189, 1.1678, 1.1374, 1.1089, 1.0318,
 0.8738, 0.4437, 0.2306
 x(1) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
 qf(14) =
 0.5614, 0.8883, 1.0116, 1.0231, 1.03371,
 1.0594, 1.0718, 1.117, 1.1534, 1.1933,
 1.1418, 0.6498, 0.3528
 x(14) =
```

```
0.000, 1.053, 2.105, 3.158, 4.211,
5.263, 6.316, 7.579, 8.421, 9.474,
10.526, 11.578, 12.000
qf(27) =
0.5661, 0.9515, 1.0570, 1.0553, 1.0536,
1.0536, 1.0712, 1.0737, 1.0896, 1.108,
1.0568, 0.6466, 0.5017,
x(27) =
0.000, 1.053, 2.105, 3.158, 4.211,
5.263, 6.316, 7.579, 8.421, 9.474,
10.526, 11.578, 12.000
qf(40) =
0.4364, 0.9766, 1.1449, 1.1631, 1.1510,
1.1348, 1.0986, 1.0925, 1.067, 1.0482,
0.9111, 0.4979, 0.3850
x(40) =
0.000, 1.053, 2.105, 3.158, 4.211,
5.263, 6.316, 7.579, 8.421, 9.474,
10.526, 11.578, 12.000
qf(53) =
0.3459, 0.9048, 1.1217, 1.1804, 1.1902,
1.1765, 1.1745, 1.1511, 1.1393, 1.0826,
0.8521, 0.3576, 0.2697
x(53) =
0.000, 1.053, 2.105, 3.158, 4.211,
5.263, 6.316, 7.579, 8.421, 9.474,
10.526, 11.578, 12.000
ProblemTime=
1.0 2.0, 3.0, 4.0, 5.0,
14.3, 24.6, 47.8, 74.7, 96.8,
124.1, 147.8, 185.5, 219.1, 239.2,
267.6, 289.1, 309.0, 313.2, 325.5,
353.0, 386.3, 413.9, 444.7, 472.5,
511.9, 544.4, 562.7, 589.4, 609.3,
621.1, 623.1, 637.1, 665.2, 697.1,
717.9, 751.8, 783.0, 804.7, 835.3,
865.8, 879.6, 903.7, 924.4, 932.1,
944.5, 976.2, 1006.8, 1034.1, 1044.5,
1074.2, 1091.6, 1114.4, 1176.9, 1201.7,
1218.7, 1225.4, 1226.6
 qmpy =
1.2, 2.4, 3.6, 4.8, 6.0,
7.14, 6.83, 6.89, 6.83, 6.86,
6.83, 6.83, 6.83, 6.83, 6.83, 6.74,
6.22, 5.33, 5.33, 7.07, 7.13,
7.16, 7.19, 7.19, 7.22, 7.25,
7.28, 7.25, 7.25, 6.68, 6.31,
6.31, 5.97, 5.97, 6.00, 5.97,
5.94, 5.85, 5.94, 5.94, 5.94,
5.97, 5.97, 5.70, 5.70, 3.78,
4*3.93, 4.02,
3.99, 4.05, 4.15, 4.11, 3.87,
3.75, 3.75
slim = .05,
$end
$frpmox
enrpu39 = 65.83, enrpu40 = 23.45, enrpu41 = 7.39,
```

```
 enrpu42 = 3.33,
 $end
```

Gravelines-4 Rod N12

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='GraveRodN12.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='GraveRodN12.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
      Full-Length Gravelines-4 4-Cycle PWR MOX rod N12
 $frpcn
 im=58, na=12,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 7.2, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5,nplot=1,
 rc = 0.0, fotmtl = 1.996,
 den = 94.72, rsntr = 8.9,
 dspg = 0.3, fa = 1., dspgw = 0.03,
 enrch = 0.231, fgpav = 382.0, hdish = 0.0115,
 dishsd = 0.0655
 hplt = 0.4634, icm = 4, imox = 1, comp = 5.931,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0, fa = 1.0,
 totl = 12.0, roughc = 2.5e-5, roughf = 8.54e-5, vs = 10.0,
 nunits = 1,
 p2(1) = 2250., tw(1) = 548, go(1) = 2.8e6
 jn = 13, 13, 13, 13, 13,
 jst = 16*1, 10*2, 10*3, 10*4, 12*5
 qf(1) =
 0.4823, 0.8646, 1.116, 1.198, 1.206,
 1.189, 1.1678, 1.1374, 1.1089, 1.0318,
 0.8738, 0.4437, 0.2306
 x(1) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
 qf(14) =
 0.5614, 0.8883, 1.0116, 1.0231, 1.03371,
 1.0594, 1.0718, 1.117, 1.1534, 1.1933,
 1.1418, 0.6498, 0.3528
 x(14) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
 qf(27) =
 0.5661, 0.9515, 1.0570, 1.0553, 1.0536,
 1.0536, 1.0712, 1.0737, 1.0896, 1.108,
 1.0568, 0.6466, 0.5017,
 x(27) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
```

```
qf(40) =
0.4364, 0.9766, 1.1449, 1.1631, 1.1510,
1.1348, 1.0986, 1.0925, 1.067, 1.0482,
0.9111, 0.4979, 0.3850
x(40) =
0.000, 1.053, 2.105, 3.158, 4.211,
5.263, 6.316, 7.579, 8.421, 9.474,
10.526, 11.578, 12.000
qf(53) =
0.3459, 0.9048, 1.1217, 1.1804, 1.1902,
1.1765, 1.1745, 1.1511, 1.1393, 1.0826,
0.8521, 0.3576, 0.2697
x(53) =
0.000, 1.053, 2.105, 3.158, 4.211,
5.263, 6.316, 7.579, 8.421, 9.474,
10.526, 11.578, 12.000
ProblemTime=
1.0 2.0, 3.0, 4.0, 5.0,
14.3, 24.6, 47.8, 74.7, 96.8,
124.1, 147.8, 185.5, 219.1, 239.2,
267.6, 289.1, 309.0, 313.2, 325.5,
353.0, 386.3, 413.9, 444.7, 472.5,
511.9, 544.4, 562.7, 589.4, 609.3,
621.1, 623.1, 637.1, 665.2, 697.1,
717.9, 751.8, 783.0, 804.7, 835.3,
865.8, 879.6, 903.7, 924.4, 932.1,
944.5, 976.2, 1006.8, 1034.1, 1044.5,
1074.2, 1091.6, 1114.4, 1176.9, 1201.7,
1218.7, 1225.4, 1226.6
qmpy =
1.2, 2.4, 3.6, 4.8, 6.0,
7.38, 7.07, 7.10, 7.04, 7.07,
7.04, 7.04, 7.01, 7.01, 7.01, 6.92,
6.37, 5.47, 5.47, 7.13, 7.22,
7.22, 7.25, 7.25, 7.28, 7.28,
7.28, 7.25, 7.28, 6.71, 6.34,
6.34, 6.22, 6.19, 6.19, 6.19,
6.10, 6.00, 6.10, 6.10, 6.07,
6.13, 6.10, 5.79, 5.79, 3.75,
3.90, 3.90, 3.93, 3.90, 3.99,
3.96, 4.02, 4.11, 4.08, 3.84,
4.05, 3.81
slim = .05,
$end
$frpmox
enrpu39 = 65.84, enrpu40 = 23.40, enrpu41 = 7.43,
enrpu42 = 3.33
$end
```

Gravelines-4 Rod P16

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='GraveRodP16.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='GraveRodP16.plot', STATUS='UNKNOWN', FORM='FORMATTED',
```

```
        CARRIAGE CONTROL='LIST'
/**********************************************************************
      Full-Length Gravelines-4 4-Cycle PWR MOX rod P16
 $frpcn
 im=58, na=12,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 7.2, crdt = 0.0, thkcld = 0.0224, thkgap = 0.0033,
 dco = 0.374, pitch = 0.5,nplot=1,
 rc = 0.0, fotmtl = 2.000,
 den = 94.62, rsntr = 40.,
 dspg = 0.3, fa = 1., dspgw = 0.03,
 enrch = 0.225, fgpav = 382.0, hdish = 0.0115,
 dishsd = 0.0634
 hplt = 0.4634, icm = 4, imox = 1, comp = 4.688,
 idxgas = 1, iplant =-2, iq = 0, jdlpr = 0, fa = 1.0,
 totl = 12.0, roughc = 2.5e-5, roughf = 8.54e-5, vs = 10.0,
 nunits = 1,
 p2(1) = 2250., tw(1) = 548, go(1) = 2.8e6
 jn = 13, 13, 13, 13, 13,
 jst = 16*1, 10*2, 10*3, 10*4, 12*5
 qf(1) =
 0.4823, 0.8646, 1.116, 1.198, 1.206,
 1.189, 1.1678, 1.1374, 1.1089, 1.0318,
 0.8738, 0.4437, 0.2306
 x(1) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
 qf(14) =
 0.5614, 0.8883, 1.0116, 1.0231, 1.03371,
 1.0594, 1.0718, 1.117, 1.1534, 1.1933,
 1.1418, 0.6498, 0.3528
 x(14) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
 qf(27) =
 0.5661, 0.9515, 1.0570, 1.0553, 1.0536,
 1.0536, 1.0712, 1.0737, 1.0896, 1.108,
 1.0568, 0.6466, 0.5017,
 x(27) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
 qf(40) =
 0.4364, 0.9766, 1.1449, 1.1631, 1.1510,
 1.1348, 1.0986, 1.0925, 1.067, 1.0482,
 0.9111, 0.4979, 0.3850
 x(40) =
 0.000, 1.053, 2.105, 3.158, 4.211,
 5.263, 6.316, 7.579, 8.421, 9.474,
 10.526, 11.578, 12.000
 qf(53) =
 0.3459, 0.9048, 1.1217, 1.1804, 1.1902,
 1.1765, 1.1745, 1.1511, 1.1393, 1.0826,
```

```
0.8521, 0.3576, 0.2697
x(53) =
0.000, 1.053, 2.105, 3.158, 4.211,
5.263, 6.316, 7.579, 8.421, 9.474,
10.526, 11.578, 12.000
ProblemTime=
1.0 2.0, 3.0, 4.0, 5.0,
14.3, 24.6, 47.8, 74.7, 96.8,
124.1, 147.8, 185.5, 219.1, 239.2,
267.6, 289.1, 309.0, 313.2, 325.5,
353.0, 386.3, 413.9, 444.7, 472.5,
511.9, 544.4, 562.7, 589.4, 609.3,
621.1, 623.1, 637.1, 665.2, 697.1,
717.9, 751.8, 783.0, 804.7, 835.3,
865.8, 879.6, 903.7, 924.4, 932.1,
944.5, 976.2, 1006.8, 1034.1, 1044.5,
1074.2, 1091.6, 1114.4, 1176.9, 1201.7,
1218.7, 1225.4, 1226.6
qmpy =
1.2, 2.4, 3.6, 4.8, 6.0,
6.64, 6.36, 6.39, 6.34, 6.36,
6.34, 6.34, 6.31, 6.31, 6.31, 6.23,
5.73, 4.92, 4.92, 6.56, 6.65,
6.65, 6.67, 6.67, 6.70, 6.70,
6.70, 6.67, 6.70, 6.17, 5.39,
5.39, 5.29, 5.26, 5.26, 5.26,
5.18, 5.10, 6.18, 5.18, 5.16,
5.21, 5.18, 4.92, 4.92, 3.64,
3.78, 3.78, 3.81, 3.78, 3.87,
3.84, 3.90, 3.99, 3.96, 3.73,
3.93, 3.70
slim = .05,
$end
$frpmox
enrpu39 = 65.99, enrpu40 = 23.45, enrpu41 = 7.08,
enrpu42 = 3.48,
$end
```

A.29 Beznau-1 M504 Rods

The M504 program (Cook et al., 2003, 2004) consisted of four MOX rods irradiated in assembly M504 for four cycles in the Beznau-1 PWR reactor. The MOX fuel was fabricated using the SBR process, which results in a relatively homogenous distribution of the PuO_2. These rods were irradiated up to a burnup between 37 and 43 GWd/MTM. The measured gas release values are relatively low and have been obtained from puncture measurements that have less uncertainty than those estimated from pressure measurements.

These four rods were used to assess the FRAPCON-3.4 MOX FGR predictions. The input files used for the MOX FGR assessments are provided below.

M504 Rod H8

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M504-H8.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M504-H8.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Test M504 Rod H8
 $frpcn
 im=13, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=11.41732, cpl=10
 dspg=0.374, dspgw=0.05, vs=34
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.235, imox=1, comp=5.54
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=99, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=349.54, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 334.82, 353.49, 677.07, 706.5, 726.96
 1031.11, 1071.72, 1140.9, 1144.47, 1164.61
 1653.98, 1693.76, 1716.98
 qmpy=
 5.218, 5.041, 6.127, 5.77, 2.701
 5.691, 5.541, 5.264, 5.154, 1.829
 2.295, 2.057, 0.881
 nsp=0
 p2= 2248.08, tw= 550, go= 2650000
 iq=0, fa=1
 x(1)=
 0, 1.14167, 2.28333, 3.425, 4.56667
 5.70833, 6.85, 7.99167, 9.13333, 10.275
11.41732
```

```
 qf(1)=
 0.5, 1, 1, 1, 1
 1, 1, 1, 1, 1
     0.5
 jn=11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

M504 Rod I2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M504-I2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M504-I2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Test M504 Rod I2
 $frpcn
 im=13, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=11.41732, cpl=10
 dspg=0.374, dspgw=0.05, vs=34
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.235, imox=1, comp=5.54
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=99, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=349.54, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 334.29, 351.03, 677.47, 705.8, 717.85
 1021.77, 1065.36, 1133.34, 1138.29, 1164.62
 1660.3, 1699.27, 1724.7
 qmpy=
 4.67, 4.523, 6.806, 6.425, 3.057
 6.456, 6.242, 5.928, 5.791, 2.408
 3.834, 3.307, 0.805
 nsp=0
 p2= 2248.08, tw= 550, go= 2650000
 iq=0, fa=1
 x(1)=
 0, 1.14167, 2.28333, 3.425, 4.56667
 5.70833, 6.85, 7.99167, 9.13333, 10.275
11.41732
```

```
 qf(1)=
 0.5, 1, 1, 1, 1
 1, 1, 1, 1, 1
     0.5
 jn=11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

M504 Rod K9

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M504-K9.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M504-K9.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Test M504 Rod K9
 $frpcn
 im=13, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=11.41732, cpl=10
 dspg=0.374, dspgw=0.05, vs=34
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.235, imox=1, comp=5.54
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=99, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=349.54, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 331.42, 353.84, 679.98, 710.47, 719.92
 1026.15, 1065.77, 1131.74, 1138.24, 1169.64
 1656.16, 1703.43, 1720.25
 qmpy=
 5.618, 5.383, 6.913, 6.441, 3.033
 6.373, 6.145, 5.831, 5.666, 2.085
 2.847, 1.948, 1.094
 nsp=0
 p2= 2248.08, tw= 550, go= 2650000
 iq=0, fa=1
 x(1)=
 0, 1.14167, 2.28333, 3.425, 4.56667
 5.70833, 6.85, 7.99167, 9.13333, 10.275
11.41732
```

```
 qf(1)=
 0.5, 1, 1, 1, 1
 1, 1, 1, 1, 1
     0.5
 jn=11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

M504 Rod M9

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M504-M9.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M504-M9.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Test M504 Rod M9
 $frpcn
 im=13, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=11.41732, cpl=10
 dspg=0.374, dspgw=0.05, vs=34
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.235, imox=1, comp=5.54
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=99, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=349.54, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 335.61, 355.01, 677.9, 705.85, 721.76
 1030.13, 1067.69, 1133.11, 1140.94, 1165.64
 1650.06, 1694.53, 1709.3
 qmpy=
 5.346, 5.166, 7.078, 6.733, 3.472
 6.761, 6.483, 6.13, 6.005, 2.32
 3.341, 2.944, 1.247
 nsp=0
 p2= 2248.08, tw= 550, go= 2650000
 iq=0, fa=1
 x(1)=
 0, 1.14167, 2.28333, 3.425, 4.56667
```

```
 5.70833, 6.85, 7.99167, 9.13333, 10.275
11.41732
 qf(1)=
 0.5, 1, 1, 1, 1
 1, 1, 1, 1, 1
     0.5
 jn=11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1
 $end
 $frpmox
 enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
 $end
```

A.30 Beznau-1 M308 Rod

In the M308 program (Boulanger et al., 2004), segmented MOX rods were irradiated in the Beznau reactor up to peak burnups of 55 to 60 GWd/MTM. The MOX fuel was fabricated using the MIMAS–AUC process by BN, which results in larger PuO_2 particle sizes than the SBR process. Sufficient detail on the power history and measured FGR was provided for Segment 2, such that this segment was modeled using FRAPCON-3.4. Only the cladding inner and outer diameters were provided for this segment; however, since these values were identical to the cladding inner and outer diameters for a Westinghouse 15 x 15 fuel rod, it was assumed the rest of the rod dimensions were the same as for a Westinghouse 15 x 15 fuel rod.

This rod was used to assess the FRAPCON-3.4 MOX FGR predictions. The input file used for the MOX FGR assessment is shown below.

M308 Segment 2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M308-2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M308-2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Assembly M308, segment 2 of a PWR segmented Rod
 $frpcn
 im=29, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.422, thkcld=0.02441, thkgap=0.00374, totl=1.39108, cpl=3.937
 dspg=0.3583, dspgw=0.05, vs=33
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0939
 enrch=0.235, imox=1, comp=5.94
 fotmtl=1.996, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=99, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=333.59, idxgas=1
 iplant=-2, pitch=0.563, 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=0, nread=0, nrestr=0
 ProblemTime=
 109.7, 188, 212.3, 301.1, 351.6
 426.4, 563.9, 644, 711.9, 776.3
 856.3, 983.4, 1079, 1086, 1152
 1166, 1399, 1420, 1469, 1728
 1786, 1794, 1831, 1890, 1956
 2005, 2061, 2127, 2158
 qmpy=
 5.989, 6.017, 5.852, 5.822, 0
 4.785, 5.06, 5.06, 5.121, 0
 5.822, 5.547, 0, 3.505, 7.376
 3.749, 7.224, 5.639, 0, 6.34
 6.005, 5.913, 0, 4.968, 5.182
```

```
5.486, 5.395, 5.334, 5.09
nsp=0
p2= 2248.08, tw= 550, go= 2610000
iq=0, fa=1
x(1)=
0, 0.13911, 0.27822, 0.41732, 0.55643
0.69554, 0.83465, 0.97375, 1.11286, 1.25197
1.39108
qf(1)=
1, 1, 1, 1, 1
1, 1, 1, 1, 1
       1
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
$end
$frpmox
enrpu39=65.99, enrpu40=23.45, enrpu41=7.08, enrpu42=3.48
$end
```

A.31 Halden IFA-597.4/.5/.6/.7 Rods

IFA-597.4, 5, 6, and 7 (Koike, 2004) contained two MOX rods, containing fuel that was fabricated with the MIMAS-ADU process. Rod 10 contained mostly solid pellets, with a few hollow pellets at the top of the stack to accommodate the fuel centerline thermocouple. Rod 11 contained all hollow pellets. These rods were irradiated for four cycles in the Halden reactor to a burnup between 35 and 37 GWd/MTM. The power history at the thermocouple position was provided for both rod 10 and rod 11. To determine the rod-average LHGR, for rod 10, the power history was increased by the ratio of average power to power at the top of the rod, and the ratio of the volume of a solid pellet to the volume of a hollow pellet. For rod 11, the power history was increased by only the ratio of average power to power at the top of the rod. For these pellets, the out-of-pile re-sintering tests of 24 hours at 1700°C showed a density increase of 0.46 percent. However, based on in-pile free volume and pressure measurements, it was determined that the maximum densification was 0.8 percent for rod 10 and 1.4 percent for rod 11. These measured values were used in the FRAPCON input files.

The measured gas release values used for the FRAPCON-3.4 assessment have been estimated from pressure measurements and are subject to greater uncertainty than measurements made by rod puncture.

These two rods were used to assess the FRAPCON-3.4 temperature predictions for MOX as a function of burnup and the MOX FGR predictions. The input files used for the MOX temperature and FGR assessments are shown below. Input files that include the central hole were used for the temperature assessment on rod 10 since the temperature was measured on hollow pellets. Input files that do not include the central hole were used for the FGR assessment on rod 10 since most of the pellets consist are solid. The rod 11 input file is the same for the temperature and FGR assessment since all the pellets in rod 11 are hollow.

IFA-597.4/.5/.6/.7 Rod 10 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IFA-597-4-5-6-7R10.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IFA-597-4-5-6-7R10.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-597.4/.5/.6/.7 Rod 10
 $frpcn
 im=36, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.025, thkgap=0.00374, totl=0.73491, cpl=1.878
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.4213, rc=0, hdish=0.0102, dishsd=0.0795
 enrch=0.252, imox=1, comp=7.42
 fotmtl=1.999, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.86, deng=0, roughf=0.0000787, rsntr=88, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000394, catexf=0.05, chorg=0.3
 fgpav=72.52, idxgas=1
```

```
 iplant=-4, pitch=0.4724, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 13.27, 18.51, 27, 30.44, 41.1
 48.27, 89.48, 97.14, 108.18, 163.14
 174.36, 182.65, 220.76, 239.01, 257.34
 261.43, 283.02, 287.63, 305.73, 352.38
 356.87, 420.32, 429.47, 512.27, 517.97
 520.23, 559.52, 594.2, 608.3, 633.09
 644.8, 662.27, 667.64, 687.04, 697.41
  736.77
 qmpy=
 11.041, 10.303, 10.72, 11.169, 10.271
 10.913, 10.11, 10.206, 9.404, 9.34
 9.632, 8.923, 9.179, 2.728, 6.515
 5.906, 6.259, 5.553, 5.264, 4.846
 4.75, 5.2, 4.044, 3.916, 8.73
 8.184, 8.505, 8.57, 8.57, 4.59
 5.585, 5.456, 5.553, 5.938, 6.034
   5.745
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.04429, 0.12631, 0.20833, 0.29035
 0.37238, 0.4544, 0.53642, 0.61844, 0.70046
 0.73491
 qf(1)=
 157.8, 158.5, 159.4, 160.1, 160.7
 161.2, 161.6, 161.7, 161.6, 161.4
   161.2
 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
 $end
 $frpmox
 enrpu39=65.95, enrpu40=23.9, enrpu41=6.63, enrpu42=3.52
 $end
```

IFA-597.4/.5/.6/.7 Rod 11 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IFA-597-4-5-6-7R11.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IFA-597-4-5-6-7R11.plot',
```

```
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-597.4/.5/.6/.7 Rod 11
 $frpcn
 im=30, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.025, thkgap=0.00374, totl=0.72178, cpl=1.7165
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.4134, rc=0.0354, hdish=0.0102, dishsd=0.0795
 enrch=0.252, imox=1, comp=7.42
 fotmtl=1.999, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.86, deng=0, roughf=0.0000787, rsntr=153, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000394, catexf=0.05, chorg=0.3
 fgpav=72.52, idxgas=1
 iplant=-4, pitch=0.4724, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 14.08, 19.64, 29.66, 32.16, 42.4
 49.61, 94.84, 100.71, 113.82, 171.92
 177.52, 182.35, 192.66, 231.13, 253.87
 273.41, 278.26, 303.35, 325.26, 335.66
 448.44, 542.09, 640.7, 662.73, 675.31
 697.11, 704.71, 731.55, 737.53, 772.26
 qmpy=
 10.577, 9.723, 10.272, 10.79, 9.784
 10.516, 9.754, 10.15, 9.083, 8.992
 9.662, 8.961, 8.535, 8.9, 2.499
 6.096, 5.304, 6.096, 4.816, 4.298
 4.572, 3.627, 7.864, 4.054, 5.06
 5.09, 5.517, 5.547, 4.526, 5.456
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.04429, 0.12631, 0.20833, 0.29035
 0.37238, 0.4544, 0.53642, 0.61844, 0.70046
 0.72178
 qf(1)=
 157.8, 158.5, 159.4, 160.1, 160.7
 161.2, 161.6, 161.7, 161.6, 161.4
   161.3
 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
 $end
 $frpmox
 enrpu39=65.95, enrpu40=23.9, enrpu41=6.63, enrpu42=3.52
 $end
```

IFA-597.4/.5/.6/.7 Rod 10 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IFA-597-4-5-6-7R10tc.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IFA-597-4-5-6-7R10tc.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-597.4/.5/.6/.7 Rod 10
 $frpcn
 im=36, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.025, thkgap=0.00374, totl=0.73491, cpl=1.878
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.4213, rc=0.0354, hdish=0.0102, dishsd=0.0795
 enrch=0.252, imox=1, comp=7.42
 fotmtl=1.999, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.86, deng=0, roughf=0.0000787, rsntr=55.0, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000394, catexf=0.05, chorg=0.3
 fgpav=72.52, idxgas=1
 iplant=-4, pitch=0.4724, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 13.27, 18.51, 27, 30.44, 41.1
 48.27, 89.48, 97.14, 108.18, 163.14
 174.36, 182.65, 220.76, 239.01, 257.34
 261.43, 283.02, 287.63, 305.73, 352.38
 356.87, 420.32, 429.47, 512.27, 517.97
 520.23, 559.52, 594.2, 608.3, 633.09
 644.8, 662.27, 667.64, 687.04, 697.41
  736.77
 qmpy=
 11.041, 10.303, 10.72, 11.169, 10.271
 10.913, 10.11, 10.206, 9.404, 9.34
 9.632, 8.923, 9.179, 2.728, 6.515
 5.906, 6.259, 5.553, 5.264, 4.846
 4.75, 5.2, 4.044, 3.916, 8.73
 8.184, 8.505, 8.57, 8.57, 4.59
 5.585, 5.456, 5.553, 5.938, 6.034
   5.745
 nsp=0
 p2= 493.13, tw= 455, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.04429, 0.12631, 0.20833, 0.29035
 0.37238, 0.4544, 0.53642, 0.61844, 0.70046
 0.73491
 qf(1)=
 157.8, 158.5, 159.4, 160.1, 160.7
 161.2, 161.6, 161.7, 161.6, 161.4
   161.2
```

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

IFA-597.4/.5/.6/.7 Rod 11 Temperature Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IFA-597-4-5-6-7R11.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IFA-597-4-5-6-7R11.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
IFA-597.4/.5/.6/.7 Rod 11
 $frpcn
 im=30, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.025, thkgap=0.00374, totl=0.72178, cpl=1.7165
 dspg=0.315, dspgw=0.0394, vs=10
 hplt=0.4134, rc=0.0354, hdish=0.0102, dishsd=0.0795
 enrch=0.252, imox=1, comp=7.42
 fotmtl=1.999, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.86, deng=0, roughf=0.0000787, rsntr=66.0, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000394, catexf=0.05, chorg=0.3
 fgpav=72.52, idxgas=1
 iplant=-4, pitch=0.4724, icor=0, crdt=0, crdtr=0,
flux=10*5000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 14.08, 19.64, 29.66, 32.16, 42.4
 49.61, 94.84, 100.71, 113.82, 171.92
 177.52, 182.35, 192.66, 231.13, 253.87
 273.41, 278.26, 303.35, 325.26, 335.66
 448.44, 542.09, 640.7, 662.73, 675.31
 697.11, 704.71, 731.55, 737.53, 772.26
 qmpy=
 10.577, 9.723, 10.272, 10.79, 9.784
 10.516, 9.754, 10.15, 9.083, 8.992
 9.662, 8.961, 8.535, 8.9, 2.499
 6.096, 5.304, 6.096, 4.816, 4.298
 4.572, 3.627, 7.864, 4.054, 5.06
 5.09, 5.517, 5.547, 4.526, 5.456
```

```
nsp=0
p2= 493.13, tw= 455, go= 0
iq=0, fa=1
x(1)=
0, 0.04429, 0.12631, 0.20833, 0.29035
0.37238, 0.4544, 0.53642, 0.61844, 0.70046
0.72178
qf(1)=
157.8, 158.5, 159.4, 160.1, 160.7
161.2, 161.6, 161.7, 161.6, 161.4
  161.3
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
$end
$frpmox
enrpu39=65.95, enrpu40=23.9, enrpu41=6.63, enrpu42=3.52
$end
```

A.32 FUGEN Rods

The MOX fuel assembly, E09 (Ozawa, 2004), was irradiated for 10 cycles in the Japanese advanced thermal reactor, Fugen. This assembly reached the highest assembly average burnup of 38 GWd/MTM. The rods in this assembly were arranged in a circular pattern consisting of three concentric rings. The power history was approximately the same for all rods in a given ring. However, the power histories given for each ring did not provide the rod-average burnup that was measured in the pellets via gamma scanning. This discrepancy is most likely due to uncertainty in the linear heat rates that were provided. To model these cases, the power histories that were supplied were increased by a factor so the burnup calculated using these histories would be equivalent to the measured burnup.

The pellet stack consisted of pellets with varying plutonium concentration in different axial regions. The top and bottom areas contained more plutonium than the central region. Since it is not possible to specify the plutonium concentration at various axial regions along the pellet stack in FRAPCON, two cases were run. In the first case, the plutonium concentration for the middle section was used for the entire rod, and in the second case, the plutonium concentration for the top and bottom sections was used for the entire rod. This allowed the effect of plutonium concentration on FGR to be seen. Plutonium concentration had very little impact on the predicted FGR (< 5 percent relative).

The measured gas release values for these rods have been obtained by puncture measurement on several rods from each ring.

These three rods were used to assess the FRAPCON-3.4 MOX FGR predictions. The input files used for the MOX FGR assessment are shown below.

FUGEN Assembly E09 Inner Rod

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='E09-inner.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='E09-inner.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Inner Rod of Japanese ATR Assembly E09
 $frpcn
 im=78, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.5693, thkcld=0.03484, thkgap=0.00571, totl=11.9416, cpl=15.252
 dspg=0.4724, dspgw=0.0394, vs=10
 hplt=0.5138, rc=0, hdish=0.0079, dishsd=0.1033
 enrch=, imox=1, comp=4.77
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.76, deng=0, roughf=0.0000787, rsntr=100, tsint=3092
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=42.68, idxgas=1
iplant=-3, pitch=0.6016, 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=0, nread=0, nrestr=0
ProblemTime=
6.7, 26.7, 61, 89.2, 103.2
118.7, 141, 153.7, 176.5, 178.5
185.3, 219.2, 247.2, 282.2, 309.3
335.4, 356.3, 358.3, 364.2, 398
426.1, 454.1, 480.9, 486.9, 493.6
512.6, 542.7, 578.2, 605.3, 640.3
668.3, 676.3, 682.4, 716.3, 744.3
779.4, 807.5, 835.6, 844.6, 850.6
862.2, 874.5, 901.3, 936, 963.8
991.7, 1019.6, 1022.4, 1028.3, 1059.2
1087.4, 1122.6, 1150.7, 1185.7, 1211
1216.8, 1236.8, 1272.8, 1300, 1335.1
1364.2, 1398.3, 1401, 1405.8, 1431.7
1459.6, 1494.3, 1522.3, 1546.2, 1548.9
1555.5, 1582.7, 1617.7, 1645.6, 1680.5
1704.4, 1725.3, 1728.1
qmpy=
4.611, 4.616, 4.651, 4.7, 5.734
5.745, 5.794, 5.902, 5.949, 0
6.036, 6.199, 6.255, 6.314, 6.313
6.322, 6.332, 0, 5.995, 5.961
5.969, 5.964, 5.937, 0, 7.135
7.086, 7.052, 6.911, 6.825, 6.702
6.622, 0, 6.639, 6.535, 6.481
6.412, 6.319, 6.28, 0, 6.94
6.921, 6.878, 6.844, 6.788, 6.7
6.659, 6.607, 0, 4.963, 5.006
5.028, 5.056, 5.07, 5.099, 0
6.308, 6.234, 6.15, 6.078, 6.003
5.937, 5.874, 0, 5.757, 5.734
5.7, 5.669, 5.616, 5.587, 0
5.391, 5.361, 5.351, 5.331, 5.313
5.292, 5.3, 0
nsp=0
p2= 1024.3, tw= 534.2, go= 2757000
iq=0, fa=1
x(1)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(1)=
0.546379310344828, 0.705, 1.073, 1.338, 1.375
1.386, 1.303, 1.187, 1.056, 0.942
0.95, 0.953, 0.913, 0.858, 0.815
0.657, 0.46, 0.351427149321267
x(19)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(19)=
0.442310344827586, 0.563, 0.843, 1.031, 1.08
1.134, 1.178, 1.192, 1.168, 1.13
```

```
1.177, 1.205, 1.154, 1.029, 0.92
0.707, 0.479, 0.353342081447964
x(37)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(37)=
0.390103448275862, 0.497, 0.745, 0.918, 0.973
1.04, 1.093, 1.121, 1.115, 1.1
1.15, 1.183, 1.176, 1.133, 1.117
0.924, 0.623, 0.457109502262443
x(55)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(55)=
0.467965517241379, 0.574, 0.82, 0.931, 1.01
1.064, 1.106, 1.126, 1.117, 1.078
1.113, 1.142, 1.132, 1.088, 1.084
0.92, 0.668, 0.529114932126697
x(73)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(73)=
0.483, 0.583, 0.815, 0.969, 1.012
1.069, 1.11, 1.132, 1.122, 1.084
1.126, 1.146, 1.132, 1.084, 1.06
0.894, 0.666, 0.540342081447964
x(91)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(91)=
0.524206896551724, 0.613, 0.819, 0.953, 0.99
1.043, 1.082, 1.102, 1.095, 1.08
1.115, 1.126, 1.121, 1.084, 1.062
0.924, 0.705, 0.584302262443439
x(109)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(109)=
0.526637931034483, 0.615, 0.82, 0.944, 0.99
1.051, 1.093, 1.11, 1.109, 1.088
1.121, 1.143, 1.121, 1.086, 1.057
0.918, 0.69, 0.564342081447963
x(127)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
```

```
qf(127)=
0.515465517241379, 0.609, 0.826, 0.942, 0.99
1.051, 1.097, 1.113, 1.117, 1.104
1.108, 1.123, 1.106, 1.069, 1.061
0.929, 0.759, 0.665307692307692
x(145)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(145)=
0.54248275862069, 0.633, 0.843, 0.936, 0.991
1.044, 1.081, 1.11, 1.103, 1.088
1.123, 1.141, 1.128, 1.093, 1.067
0.923, 0.659, 0.513501357466063
x(163)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(163)=
0.576155172413793, 0.649, 0.818, 0.921, 0.97
1.027, 1.073, 1.092, 1.087, 1.079
1.109, 1.13, 1.126, 1.097, 1.081
0.95, 0.762, 0.658387330316742
x(181)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(181)=
0.570293103448276, 0.644, 0.815, 0.914, 0.979
1.039, 1.091, 1.123, 1.118, 1.099
1.127, 1.134, 1.121, 1.074, 1.052
0.921, 0.745, 0.648000904977375
jn=18,18,18,18,18,18,18,18,18,18,18
jst=
1, 1, 1, 1, 2
2, 2, 2, 2, 2
3, 3, 3, 3, 3
3, 3, 3, 4, 4
4, 4, 4, 4, 5
5, 5, 5, 5, 5
5, 5, 6, 6, 6
6, 6, 6, 6, 7
7, 7, 7, 7, 7
7, 7, 7, 8, 8
8, 8, 8, 8, 8
9, 9, 9, 9, 9
9, 9, 9, 10, 10
10, 10, 10, 10, 10
11, 11, 11, 11, 11
11, 11, 11
$end
$frpmox
enrpu39=65, enrpu40=24, enrpu41=7, enrpu42=4
$end
```

FUGEN Assembly E09 Intermediate Rod

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='E09-intermediate.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='E09-intermediate.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/************************************************************************
Intermediate Rod of Japanese ATR Assembly E09
 $frpcn
 im=78, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.5693, thkcld=0.03484, thkgap=0.00571, totl=11.9416, cpl=15.252
 dspg=0.4724, dspgw=0.0394, vs=10
 hplt=0.5138, rc=0, hdish=0.0079, dishsd=0.1033
 enrch=, imox=1, comp=4.77
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.76, deng=0, roughf=0.0000787, rsntr=100, tsint=3092
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=42.68, idxgas=1
iplant=-3, pitch=0.6016, 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=0, nread=0, nrestr=0
 ProblemTime=
 6.7, 26.7, 61, 89.2, 103.2
 118.7, 141, 153.7, 176.5, 178.5
 185.3, 219.2, 247.2, 282.2, 309.3
 335.4, 356.3, 358.3, 364.2, 398
 426.1, 454.1, 480.9, 486.9, 493.6
 512.6, 542.7, 578.2, 605.3, 640.3
 668.3, 676.3, 682.4, 716.3, 744.3
 779.4, 807.5, 835.6, 844.6, 850.6
 862.2, 874.5, 901.3, 936, 963.8
 991.7, 1019.6, 1022.4, 1028.3, 1059.2
 1087.4, 1122.6, 1150.7, 1185.7, 1211
 1216.8, 1236.8, 1272.8, 1300, 1335.1
 1364.2, 1398.3, 1401, 1405.8, 1431.7
 1459.6, 1494.3, 1522.3, 1546.2, 1548.9
 1555.5, 1582.7, 1617.7, 1645.6, 1680.5
 1704.4, 1725.3, 1728.1
 qmpy=
 6.966, 6.971, 7.015, 7.079, 8.633
 8.626, 8.672, 8.819, 8.86, 0
 8.845, 9.045, 9.089, 9.135, 9.109
 9.104, 9.105, 0, 8.537, 8.476
 8.478, 8.462, 8.415, 0, 9.921
 9.845, 9.788, 9.569, 9.432, 9.238
 9.108, 0, 8.999, 8.846, 8.755
 8.638, 8.492, 8.418, 0, 9.12
 9.088, 9.023, 8.957, 8.858, 8.72
 8.636, 8.543, 0, 6.353, 6.4
```

```
6.415, 6.435, 6.44, 6.461, 0
7.817, 7.716, 7.588, 7.482, 7.364
7.264, 7.164, 0, 6.934, 6.894
6.838, 6.782, 6.703, 6.655, 0
6.333, 6.29, 6.265, 6.232, 6.195
6.159, 6.159, 0
nsp=0
p2= 1024.3, tw= 534.2, go= 2757000
iq=0, fa=1
x(1)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(1)=
0.546379310344828, 0.705, 1.073, 1.338, 1.375
1.386, 1.303, 1.187, 1.056, 0.942
0.95, 0.953, 0.913, 0.858, 0.815
0.657, 0.46, 0.351427149321267
x(19)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(19)=
0.442310344827586, 0.563, 0.843, 1.031, 1.08
1.134, 1.178, 1.192, 1.168, 1.13
1.177, 1.205, 1.154, 1.029, 0.92
0.707, 0.479, 0.353342081447964
x(37)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(37)=
0.390103448275862, 0.497, 0.745, 0.918, 0.973
1.04, 1.093, 1.121, 1.115, 1.1
1.15, 1.183, 1.176, 1.133, 1.117
0.924, 0.623, 0.457109502262443
x(55)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(55)=
0.467965517241379, 0.574, 0.82, 0.931, 1.01
1.064, 1.106, 1.126, 1.117, 1.078
1.113, 1.142, 1.132, 1.088, 1.084
0.92, 0.668, 0.529114932126697
x(73)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(73)=
0.483, 0.583, 0.815, 0.969, 1.012
1.069, 1.11, 1.132, 1.122, 1.084
```

```
1.126, 1.146, 1.132, 1.084, 1.06
0.894, 0.666, 0.540342081447964
x(91)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(91)=
0.524206896551724, 0.613, 0.819, 0.953, 0.99
1.043, 1.082, 1.102, 1.095, 1.08
1.115, 1.126, 1.121, 1.084, 1.062
0.924, 0.705, 0.584302262443439
x(109)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(109)=
0.526637931034483, 0.615, 0.82, 0.944, 0.99
1.051, 1.093, 1.11, 1.109, 1.088
1.121, 1.143, 1.121, 1.086, 1.057
0.918, 0.69, 0.564342081447963
x(127)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(127)=
0.515465517241379, 0.609, 0.826, 0.942, 0.99
1.051, 1.097, 1.113, 1.117, 1.104
1.108, 1.123, 1.106, 1.069, 1.061
0.929, 0.759, 0.665307692307692
x(145)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(145)=
0.54248275862069, 0.633, 0.843, 0.936, 0.991
1.044, 1.081, 1.11, 1.103, 1.088
1.123, 1.141, 1.128, 1.093, 1.067
0.923, 0.659, 0.513501357466063
x(163)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(163)=
0.576155172413793, 0.649, 0.818, 0.921, 0.97
1.027, 1.073, 1.092, 1.087, 1.079
1.109, 1.13, 1.126, 1.097, 1.081
0.95, 0.762, 0.658387330316742
x(181)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
```

```
 qf(181)=
 0.570293103448276, 0.644, 0.815, 0.914, 0.979
 1.039, 1.091, 1.123, 1.118, 1.099
 1.127, 1.134, 1.121, 1.074, 1.052
 0.921, 0.745, 0.648000904977375
 jn=18,18,18,18,18,18,18,18,18,18,18
 jst=
 1, 1, 1, 1, 2
 2, 2, 2, 2, 2
 3, 3, 3, 3, 3
 3, 3, 3, 4, 4
 4, 4, 4, 4, 5
 5, 5, 5, 5, 5
 5, 5, 6, 6, 6
 6, 6, 6, 6, 7
 7, 7, 7, 7, 7
 7, 7, 7, 8, 8
 8, 8, 8, 8, 8
 9, 9, 9, 9, 9
 9, 9, 9, 10, 10
 10, 10, 10, 10, 10
 11, 11, 11, 11, 11
 11, 11, 11
 $end
 $frpmox
 enrpu39=65, enrpu40=24, enrpu41=7, enrpu42=4
 $end
```

FUGEN Assembly E09 Outer Rod

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='E09-outer.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='E09-outer.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Outer Rod of Japanese ATR Assembly E09
 $frpcn
 im=78, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.5693, thkcld=0.03484, thkgap=0.00571, totl=11.9416, cpl=15.252
 dspg=0.4724, dspgw=0.0394, vs=10
 hplt=0.5138, rc=0, hdish=0.0079, dishsd=0.1033
 enrch=0.711, imox=1, comp=2.6
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.76, deng=0, roughf=0.0000787, rsntr=100, tsint=3092
 icm=2, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=42.68, idxgas=1
 iplant=-3, pitch=0.6016, 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=0, nread=0, nrestr=0
 ProblemTime=
```

```
6.7, 26.7, 61, 89.2, 103.2
118.7, 141, 153.7, 176.5, 178.5
185.3, 219.2, 247.2, 282.2, 309.3
335.4, 356.3, 358.3, 364.2, 398
426.1, 454.1, 480.9, 486.9, 493.6
512.6, 542.7, 578.2, 605.3, 640.3
668.3, 676.3, 682.4, 716.3, 744.3
779.4, 807.5, 835.6, 844.6, 850.6
862.2, 874.5, 901.3, 936, 963.8
991.7, 1019.6, 1022.4, 1028.3, 1059.2
1087.4, 1122.6, 1150.7, 1185.7, 1211
1216.8, 1236.8, 1272.8, 1300, 1335.1
1364.2, 1398.3, 1401, 1405.8, 1431.7
1459.6, 1494.3, 1522.3, 1546.2, 1548.9
1555.5, 1582.7, 1617.7, 1645.6, 1680.5
1704.4, 1725.3, 1728.1
qmpy=
10.787, 10.665, 10.503, 10.41, 12.45
12.283, 12.121, 12.193, 12.03, 0
11.78, 11.747, 11.567, 11.354, 11.144
10.976, 10.859, 0, 10.062, 9.866
9.759, 9.639, 9.492, 0, 10.88
10.723, 10.548, 10.209, 9.986, 9.687
9.468, 0, 9.212, 8.996, 8.848
8.666, 8.481, 8.36, 0, 8.883
8.842, 8.771, 8.675, 8.535, 8.371
8.258, 8.14, 0, 6.057, 6.099
6.11, 6.118, 6.107, 6.103, 0
7.239, 7.154, 7.04, 6.943, 6.822
6.722, 6.616, 0, 6.38, 6.349
6.301, 6.244, 6.171, 6.122, 0
5.804, 5.779, 5.769, 5.745, 5.706
5.67, 5.664, 0
nsp=0
p2= 1024.3, tw= 534.2, go= 2757000
iq=0, fa=1
x(1)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(1)=
0.546379310344828, 0.705, 1.073, 1.338, 1.375
1.386, 1.303, 1.187, 1.056, 0.942
0.95, 0.953, 0.913, 0.858, 0.815
0.657, 0.46, 0.351427149321267
x(19)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(19)=
0.442310344827586, 0.563, 0.843, 1.031, 1.08
1.134, 1.178, 1.192, 1.168, 1.13
1.177, 1.205, 1.154, 1.029, 0.92
0.707, 0.479, 0.353342081447964
x(37)=
```

```
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(37)=
0.390103448275862, 0.497, 0.745, 0.918, 0.973
1.04, 1.093, 1.121, 1.115, 1.1
1.15, 1.183, 1.176, 1.133, 1.117
0.924, 0.623, 0.457109502262443
x(55)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(55)=
0.467965517241379, 0.574, 0.82, 0.931, 1.01
1.064, 1.106, 1.126, 1.117, 1.078
1.113, 1.142, 1.132, 1.088, 1.084
0.92, 0.668, 0.529114932126697
x(73)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(73)=
0.483, 0.583, 0.815, 0.969, 1.012
1.069, 1.11, 1.132, 1.122, 1.084
1.126, 1.146, 1.132, 1.084, 1.06
0.894, 0.666, 0.540342081447964
x(91)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(91)=
0.524206896551724, 0.613, 0.819, 0.953, 0.99
1.043, 1.082, 1.102, 1.095, 1.08
1.115, 1.126, 1.121, 1.084, 1.062
0.924, 0.705, 0.584302262443439
x(109)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(109)=
0.526637931034483, 0.615, 0.82, 0.944, 0.99
1.051, 1.093, 1.11, 1.109, 1.088
1.121, 1.143, 1.121, 1.086, 1.057
0.918, 0.69, 0.564342081447963
x(127)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(127)=
0.515465517241379, 0.609, 0.826, 0.942, 0.99
1.051, 1.097, 1.113, 1.117, 1.104
```

```
1.108, 1.123, 1.106, 1.069, 1.061
0.929, 0.759, 0.665307692307692
x(145)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(145)=
0.54248275862069, 0.633, 0.843, 0.936, 0.991
1.044, 1.081, 1.11, 1.103, 1.088
1.123, 1.141, 1.128, 1.093, 1.067
0.923, 0.659, 0.513501357466063
x(163)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(163)=
0.576155172413793, 0.649, 0.818, 0.921, 0.97
1.027, 1.073, 1.092, 1.087, 1.079
1.109, 1.13, 1.126, 1.097, 1.081
0.95, 0.762, 0.658387330316742
x(181)=
0, 0.32808, 1.08924, 1.83071, 2.58858
3.34646, 4.08465, 4.83924, 5.56759, 6.3189
7.07677, 7.81496, 8.56955, 9.30118, 10.05906
10.81693, 11.54199, 11.9416
qf(181)=
0.570293103448276, 0.644, 0.815, 0.914, 0.979
1.039, 1.091, 1.123, 1.118, 1.099
1.127, 1.134, 1.121, 1.074, 1.052
0.921, 0.745, 0.648000904977375
jn=18,18,18,18,18,18,18,18,18,18,18
jst=
1, 1, 1, 1, 2
2, 2, 2, 2, 2
3, 3, 3, 3, 3
3, 3, 3, 4, 4
4, 4, 4, 4, 5
5, 5, 5, 5, 5
5, 5, 6, 6, 6
6, 6, 6, 6, 7
7, 7, 7, 7, 7
7, 7, 7, 8, 8
8, 8, 8, 8, 8
9, 9, 9, 9, 9
9, 9, 9, 10, 10
10, 10, 10, 10, 10
11, 11, 11, 11, 11
11, 11, 11
$end
$frpmox
enrpu39=65, enrpu40=24, enrpu41=7, enrpu42=4
$end
```

A.33 Monticello BWR Rod

A DOE program was completed in 1985 in which nine 8 x 8 fuel assemblies in the Monticello BWR were taken to high burnup (up to 45.6 MWd/MTM assembly average), and the rods were periodically examined nondestructively and sampled for destructive examinations (Baumgartner, 1984). Four of the assemblies went for the "full term" from cycle 3 through cycle 9 from May 1974 to September 1982.

All of these rods have fully annealed Zircaloy-2 cladding. One of these rods, rod A1 from assembly MTB99 was used in the Zircaloy-2 corrosion assessment for FRAPCON-3.4. The input file used for the Zircaloy-2 corrosion assessment is shown below.

Monticello Rod A1 from MTB99

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='geA1.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         GE Monticello rod A1 (Assembly MTB099,Rod BNA-0208)
 $frpcn
   im=72, na=12,
   mechan = 2, ngasr = 45,
 $end
 $frpcon
   cpl = 11.24, crdt = 0.0, thkcld = 0.034, thkgap = 0.0045,
   dco = 0.493, pitch = 0.64,
   den = 95., dspg = 0.4,fa = 1.,
   dspgw = 0.04, enrch = 1.45, fgpav = 14.7, hdish = 0.0,
   hplt = 0.5, icm = 5,
   icor = 1, idxgas = 1, iplant =-3, iq = 0, jdlpr = 0,
   jn = 26,26,26,26,26,26,26,
   totl = 12.0, roughc = 1.97e-5, roughf = 8.3e-5, vs = 100.0,
   nunits = 1, rsntr = 150.,
   p2(1) = 1037.0, tw(1) = 516, go(1) = 9.92e5,
   flux=1.95e16,1.95e16,2.20e16,2.40e16,2.50e16,2.60e16,2.80e16,
        2.95e16,3.08e16,
        3.17e16,3.21e16,3.15e16,2.95e16,
   jst = 6*1,3*2,8*1,5*3,1,2*4,1,4,1,2*5,5*1,5*6,3*1,10*7,1*3,18*7
   qf(1) =
0.02,0.24,0.47,0.66,0.83,0.93,0.96,0.99,0.97,0.94,0.89,0.83,0.78,

0.73,0.68,0.64,0.61,0.59,0.66,2.41,2.36,2.14,1.81,1.35,0.74,0.24,
   qf(27)=
0.07,0.12,0.16,0.20,0.27,1.21,1.33,1.33,1.29,1.24,1.20,1.17,1.16,

1.15,1.15,1.16,1.19,1.23,1.26,1.24,1.24,1.21,1.19,0.89,0.50,0.13,
   qf(53)=
0.13,0.43,0.77,1.02,1.21,1.28,1.30,1.36,1.45,1.47,1.45,1.41,1.35,

1.28,1.21,1.12,1.03,0.94,0.85,0.75,0.67,0.60,0.53,0.41,0.23,0.03,
   qf(79)=
0.15,0.64,1.10,1.40,1.47,1.38,1.25,1.15,1.09,1.05,1.03,1.03,1.03,
```

```
1.03,1.03,1.03,1.01,1.00,0.97,0.95,0.91,0.86,0.78,0.62,0.36,0.09,

qf(105)=0.57,0.99,1.40,1.42,1.30,1.17,1.07,1.02,0.99,1.01,1.03,1.06,1.0
8,

1.10,1.07,1.11,1.10,1.06,1.01,0.94,0.87,0.78,0.68,0.53,0.31,0.08,

qf(131)=0.27,0.50,0.75,0.90,1.02,1.11,1.19,1.27,1.33,1.35,1.36,1.34,1.2
0,

1.31,1.28,1.25,1.22,1.17,1.11,1.02,0.93,0.83,0.70,0.53,0.32,0.08,

qf(157)=0.12,0.43,0.73,0.93,1.06,1.12,1.15,1.17,1.18,1.19,1.20,1.21,1.2
1,
1.21,1.21,1.20,1.19,1.17,1.14,1.09,1.12,0.92,0.78,0.59,0.35,0.07,
   x(1)=
0,0.25,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,6.25,
          6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12,
   x(27)=
0,0.25,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,6.25,
          6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12,
   x(53)=
0,0.25,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,6.25,
          6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12,
   x(79)=
0,0.25,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,6.25,
          6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12,
   x(105)=
0,0.25,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,6.25,

6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12,
   x(131)=
0,0.25,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,6.25,

6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12,
   x(157)=
0,0.25,0.75,1.25,1.75,2.25,2.75,3.25,3.75,4.25,4.75,5.25,5.75,6.25,
    6.75,7.25,7.75,8.25,8.75,9.25,9.75,10.25,10.75,11.25,11.75,12,
   ProblemTime=6.5,12.9,31.1,52.3,71.4,105.2,118.3,129,144,149,
        172, 200, 222, 243, 262, 332, 368, 404, 443, 486,
        506, 543, 572, 603, 642, 673, 711, 743, 769, 800,
        971, 999,1010,1031,1071,1083,1109,1135,1157,1200,
        1228,1250,1273,1298,1323,1350,1375,1398,1420,1432,
        1443,1457,1532,1536,1558,1584,1602,1628,1653,1672,1696,
        1709,
        1754,1799,1844,1889,1934,1979,2024,2069,2114,2159,
   qmpy =3.56,3.01,2.65,3.41,6.89,6.92,6.40,6.37,6.37,3.44,
         3.54,3.75,6.34,6.06,6.03,2.62,2.74,6.10,6.08,5.85,
         6.00,6.10,2.96,5.85,5.76,6.04,6.04,5.21,5.94,5.88,
         2.01,2.03,2.10,4.66,5.09,4.97,5.15,5.06,5.12,5.03,
         3.96,2.87,5.77,4.94,5.03,5.06,5.09,5.06,5.03,5.03,
         5.02,4.88,4.97,6.5,4.97,4.88,4.88,4.88,4.80,4.80,4.80,
         4.80,10*4.8
   slim = .05,
 $end
```

A.34 TVO-1 BWR Rod

Battelle, Pacific Northwest Laboratories administered the international group-sponsored HBEP, which continued from 1978 to 1990. The objectives of the HBEP were to determine the effects of extended burnup on fuel rod performance, especially FGR. A variety of test rods and commercial power reactor rods were irradiated and examined under the HBEP, including nine full-length 5- and 6-cycle rods from the TVO-1 BWR in Finland (Barner et al., 1990). One of these rods was used to assess the corrosion performance of FRAPCON-3.4 for Zircaloy-2: rod number H8/36-6 from 5-cycle fuel assembly 6116.

The rod occupied position H8, which was the control blade corner position. The rod-average burnup at EOL was 44.6 GWd/MTU, with a peak value (confirmed by chemical burnup analysis) of 50.9 GWd/MTU. The rod-average LHGR varied between 12 and 24 kW/m (3.3 to 7.6 kW/ft), but large variations in the peak-to-average LHGR ratio occurred due to control blade movements.

The input file used for the Zircaloy-2 corrosion assessment is shown below.

TVO-1 Rod H8/36-6

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outH8-36-6.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
******
         TVO-1 rod H8/36-6
 $frpcn
 im=37, na=12,nr=20,
 ngasr = 45,
 $end
 $frpcon
 cpl = 7.03, crdt = 1., dco = 0.4626, thkcld=0.0315,
 den = 95.5, dishsd = 0.097 dspg = 0.395, thkgap=0.004135,
 dspgw = 0.039, enrch = 1.38, fgpav = 56.6, hdish = 0.0135,
 hplt = 0.390, icm = 2,pitch = 0.56,
 icor = 2, idxgas =1,  iplant =-3, iq = 0, jdlpr = 1, fa = 1.0,
 jn = 13,13,13,13,13,13,
 totl = 12.075, roughc = 1.978e-5, roughf = 8.5e-5, vs = 20,
 nunits = 1, rsntr = 47,nsp=0
 flux = 0.18e17, p2(1) = 1015.0, tw(1) = 523.,
 go(1) = 1.14e6,
 jst = 6*1,6*2,6*3,6*4,6*5,7*6
 qf(1) =
0.33,0.84,1.03,1.06,1.10,1.23,1.27,1.19,1.13,1.09,1.00,0.74,0.30,
 x(1) = 0,1.006,2.0125,3.01875,4.025,5.03125,6.0375,
 7.04375,8.05,9.05625,10.0625,11.06875,12.075,
 qf(14) =
0.47,1.02,1.11,1.10,1.11,1.12,1.13,1.12,1.10,1.07,0.98,0.74,0.31,
 x(14) = 0,1.006,2.0125,3.01875,4.025,5.03125,6.0375,
 7.04375,8.05,9.05625,10.0625,11.06875,12.075,
 qf(27) =
0.46,0.90,1.04,1.06,1.07,1.08,1.10,1.13,1.15,1.13,1.05,0.85,0.41,
 x(27) = 0,1.006,2.0125,3.01875,4.025,5.03125,6.0375,
 7.04375,8.05,9.05625,10.0625,11.06875,12.075,
```

```
 qf(40) =
0.37,0.68,0.83,0.98,1.10,1.16,1.18,1.19,1.19,1.19,1.15,0.94,0.45,
 x(40) = 0,1.006,2.0125,3.01875,4.025,5.03125,6.0375,
 7.04375,8.05,9.05625,10.0625,11.06875,12.075,
 qf(53) =
0.38,0.73,0.98,1.17,1.25,1.27,1.26,1.21,1.17,1.04,0.91,0.69,0.34,
 x(53) = 0,1.006,2.0125,3.01875,4.025,5.03125,6.0375,
 7.04375,8.05,9.05625,10.0625,11.06875,12.075,
 qf(66) =
0.40,0.74,0.90,1.00,1.06,1.09,1.11,1.12,1.15,1.22,1.20,1.06,0.49,
 x(66) = 0,1.006,2.0125,3.01875,4.025,5.03125,6.0375,
 7.04375,8.05,9.05625,10.0625,11.06875,12.075,
 ProblemTime = 0.1, 6.5, 23.6, 68.0, 109.2, 160.3, 187.0, 220.0,
 267.9,  312.6, 380.1,
 432.3,  466.3, 522.1, 593.7, 647.1, 694.7, 748.6, 785.6, 820.1, 849.4,
 869.2, 912.9, 934.2, 957.4, 1005.0, 1038.6, 1100.8, 1158.4, 1216.8,
 1275.7, 1324.5, 1383.1, 1451.8, 1502.8, 1538.5, 1598.2,
 qmpy =
 5.701, 5.701, 6.595, 7.098, 7.143,
 7.107, 7.040, 6.790, 6.387, 3.774,
 4.354, 4.302, 4.155, 3.811, 6.585,
 6.021, 5.811, 5.579, 5.558, 5.759,
 5.665, 5.314, 4.564, 5.274, 4.460,
 5.610, 5.613, 5.476, 5.445, 5.131,
 4.802, 5.085, 4.970, 4.817, 4.933,
 5.058, 4.360
 slim = .05,
 $end
```

A.35 Vandellos PWR ZIRLO Rods

A joint Spanish and Japanese effort irradiated a large number of full-length fuel rods for five cycles in the Spanish PWR Vandellos 2 (CSN, ENUSA, 2002). The rods were clad with ZIRLO and Mitsubishi Developed Alloy (MDA). Two of the ZIRLO rods (A06 and A12) have been modeled with FRAPCON-3.4 to assess the performance of the ZIRLO corrosion model to high burnup.

The input files used for the ZIRLO corrosion assessment are shown below.

Vandellos Rod A06

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='A06.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='A06.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/************************************************************************
Spanish Rods WZR 0067 A-06 with ZIRLO cladding
 $frpcn
 im=46, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.0225, thkgap=0.00325, totl=12, cpl=6.3386
 dspg=0.3189, dspgw=0.0394, vs=30
 hplt=0.387, rc=0, hdish=0.0094, dishsd=0.064
 enrch=4.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.5, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=6, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=340.84, idxgas=1
 iplant=-2, pitch=0.4291, 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=0, nread=0, nrestr=0
 ProblemTime=
 50, 100, 150, 200, 250
 300, 350, 351, 400, 450
 500, 550, 600, 650, 672
 700, 750, 800, 850, 900
 950, 1000, 1050, 1065, 1100
 1150, 1200, 1250, 1300, 1350
 1400, 1450, 1500, 1550, 1587
 1600, 1650, 1700, 1750, 1800
 1850, 1900, 1950, 2000, 2050
    2078
 qmpy=
 5.608, 5.608, 5.608, 5.608, 5.608
 5.608, 5.608, 5.608, 6.184, 6.184
 6.184, 6.184, 6.184, 6.184, 6.184
 6.148, 6.148, 6.148, 6.148, 6.148
 6.148, 6.148, 6.148, 6.148, 1.39
```

```
1.39, 1.39, 1.39, 1.39, 1.39
1.39, 1.39, 1.39, 1.39, 1.39
5.258, 5.258, 5.258, 5.258, 5.258
5.258, 5.258, 5.258, 5.258, 5.258
  5.258
nsp=0
p2= 2250, tw= 550, go= 2550000
iq=0, fa=1
x(1)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(1)=
2, 6, 7, 7.1, 7
6.8, 6.6, 6.65, 6.5, 5.4
    2.5
x(12)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(12)=
2, 5.2, 6, 6.2, 6.05
6, 5.8, 5.8, 5.7, 4.7
    2.2
x(23)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(23)=
2.2, 6, 7, 7, 7
6.8, 6.7, 6.7, 6.5, 5.5
    2.8
x(34)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(34)=
0.5, 1.8, 2.2, 2.3, 2.2
2.2, 2.2, 2.2, 2.2, 1.9
    0.8
x(45)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(45)=
2.3, 6.2, 7, 7.1, 6.9
6.7, 6.6, 6.5, 6.4, 5.2
      3
jn=11,11,11,11,11
jst=
1, 1, 1, 1, 1
1, 1, 1, 2, 2
2, 2, 2, 2, 2
3, 3, 3, 3, 3
3, 3, 3, 3, 4
4, 4, 4, 4, 4
4, 4, 4, 4, 4
```

```
 5, 5, 5, 5, 5
 5, 5, 5, 5, 5
       5
 $end
```

Vandellos Rod A12

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='A12.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='A12.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/***********************************************************************
Spanish Rods WZR 0058 A-12 with ZIRLO cladding
 $frpcn
 im=46, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.0225, thkgap=0.00325, totl=12, cpl=6.6142
 dspg=0.3189, dspgw=0.0394, vs=30
 hplt=0.387, rc=0, hdish=0.0094, dishsd=0.064
 enrch=4.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.5, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=6, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=340.84, idxgas=1
 iplant=-2, pitch=0.4291, 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=0, nread=0, nrestr=0
 ProblemTime=
 50, 100, 150, 200, 250
 300, 350, 351, 400, 450
 500, 550, 600, 650, 672
 700, 750, 800, 850, 900
 950, 1000, 1050, 1065, 1100
 1150, 1200, 1250, 1300, 1350
 1400, 1450, 1500, 1550, 1587
 1600, 1650, 1700, 1750, 1800
 1850, 1900, 1950, 2000, 2050
    2078
 qmpy=
 7.053, 7.053, 7.053, 7.053, 7.053
 7.053, 7.053, 7.053, 3.895, 3.895
 3.895, 3.895, 3.895, 3.895, 3.895
 6.404, 6.404, 6.404, 6.404, 6.404
 6.404, 6.404, 6.404, 6.404, 1.64
 1.64, 1.64, 1.64, 1.64, 1.64
 1.64, 1.64, 1.64, 1.64, 1.64
 5.395, 5.395, 5.395, 5.395, 5.395
 5.395, 5.395, 5.395, 5.395, 5.395
   5.395
 nsp=1
 p2=
```

```
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54, 2249.54, 2249.54, 2249.54, 2249.54
2249.54
tw=
558.3, 558.3, 558.3, 558.3, 558.3
558.3, 558.3, 558.3, 558.3, 558.3
558.3, 558.3, 558.3, 558.3, 558.3
558.3, 558.3, 558.3, 558.3, 558.3
558.3, 558.3, 558.3, 558.3, 558.3
558.3, 558.3, 558.3, 558.3, 558.3
558.3, 558.3, 558.3, 558.3, 558.3
554.9, 554.9, 554.9, 554.9, 554.9
554.9, 554.9, 554.9, 554.9, 554.9
  554.9
go=
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000, 2550000, 2550000, 2550000, 2550000
2550000
iq=0, fa=1
x(1)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(1)=
2, 6, 7, 7.1, 7
6.8, 6.6, 6.65, 6.5, 5.4
    2.5
x(12)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(12)=
2, 5.2, 6, 6.2, 6.05
6, 5.8, 5.8, 5.7, 4.7
    2.2
x(23)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(23)=
2.2, 6, 7, 7, 7
6.8, 6.7, 6.7, 6.5, 5.5
    2.8
```

```
x(34)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(34)=
0.5, 1.8, 2.2, 2.3, 2.2
2.2, 2.2, 2.2, 2.2, 1.9
    0.8
x(45)=
0, 1.2, 2.4, 3.6, 4.8
6, 7.2, 8.4, 9.6, 10.8
     12
qf(45)=
2.3, 6.2, 7, 7.1, 6.9
6.7, 6.6, 6.5, 6.4, 5.2
      3
jn=11,11,11,11,11
jst=
1, 1, 1, 1, 1
1, 1, 1, 2, 2
2, 2, 2, 2, 2
3, 3, 3, 3, 3
3, 3, 3, 3, 4
4, 4, 4, 4, 4
4, 4, 4, 4, 4
5, 5, 5, 5, 5
5, 5, 5, 5, 5
      5
$end
```

A.36 Gravelines-5 PWR M5 Rod

One high-burnup rod was taken from the French reactor Gravelines-5 and refabricated for the reactivity-initiated accident (RIA) test CIP0-1, performed in the CABRI reactor, France (Segura and Bernaudat, 2002). This rod, N05, was clad with M5. Before refabrication, rod N05 was examined and the oxide layer thickness was measured. This full-length commercial rod has been modeled with FRAPCON-3.4 to assess the performance of the M5 corrosion model to high burnup.

The input file used for the M5 corrosion assessment is shown below.

Gravelines-5 Rod N05

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='N05.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='N05.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
French Rod 4021 N05 with M5 cladding
 $frpcn
 im=94, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.374, thkcld=0.02461, thkgap=0.00323, totl=11.98727, cpl=6.8311
 dspg=0.311, dspgw=0.0571, vs=43
 hplt=0.5374, rc=0, hdish=0.0122, dishsd=0.0411
 enrch=4.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.31, deng=0, roughf=0.0000787, rsntr=71, tsint=2911
 icm=5, cldwks=0, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=217.56, idxgas=1
iplant=-2, pitch=0.4291, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 8, 64.2, 104.5, 137.7, 166.7
 196.9, 225.5, 253.1, 270.2, 302.4
 330.6, 353.4, 371.3, 372.8, 384.8
 399.9, 414.7, 427.7, 441.6, 454.9
 467.4, 489, 514.3, 536.4, 569.4
 600.4, 614.7, 621, 628.7, 649.9
 651.7, 670.6, 685.9, 704.1, 715.8
 728.1, 740.5, 754.3, 777.8, 800.8
 833.4, 863.9, 889.6, 912.7, 936.4
 957.6, 982.1, 982.9, 993.8, 1028.5
 1052.8, 1079.2, 1096.1, 1135.6, 1156.2
 1185.7, 1214.2, 1240, 1259.4, 1278.4
 1298.4, 1313.7, 1315.4, 1332.6, 1360
 1386.1, 1414.1, 1443.5, 1464.3, 1490.1
 1518, 1540.3, 1567, 1594, 1611.9
```

```
 1626.6, 1641.8, 1656.3, 1657.3, 1674.3
 1701.9, 1727.3, 1750.5, 1774.8, 1800.1
 1825.3, 1850.6, 1869.2, 1894.9, 1911.2
 1932.4, 1952.6, 1973.6, 1976.1
 qmpy=
 0.047, 4.716, 4.716, 4.774, 4.744
 4.846, 4.842, 4.924, 4.932, 4.923
 4.916, 4.926, 4.711, 4.419, 0
 5.174, 5.174, 5.163, 5.202, 5.198
 5.271, 5.3, 5.264, 5.274, 5.321
 5.325, 5.347, 5.397, 5.267, 5.105
 4.688, 0.059, 5.879, 5.97, 5.959
 5.924, 5.939, 5.903, 5.85, 5.838
 5.797, 5.782, 5.769, 5.745, 5.785
 5.466, 5.002, 3.879, 0.053, 5.313
 5.364, 5.419, 5.449, 5.454, 5.495
 5.528, 5.542, 5.591, 5.621, 5.594
 5.453, 4.988, 4.395, 0.044, 4.388
 4.415, 4.451, 4.492, 4.653, 4.637
 4.671, 4.753, 4.794, 4.799, 4.874
 4.685, 4.353, 3.903, 3.481, 0.05
 4.993, 5.004, 4.988, 5.005, 5.009
 5.033, 5.042, 5.073, 5.08, 5.1
 5.101, 4.904, 4.447, 3.706
 nsp=0
 p2= 2249.54, tw= 558.32, go= 2550000
 iq=0, fa=1
 x(1)=
 0, 0.86732, 1.71532, 2.66152, 3.45171
 5.03281, 6.48783, 8.10121, 9.30446, 10.38422
 11.11811, 11.98727
 qf(1)=
 0.4227, 0.8016, 1.0596, 1.1694, 1.1859
 1.1859, 1.1694, 1.142, 1.0706, 0.8675
 0.5765, 0.269
 x(13)=
 0, 0.60082, 1.54951, 2.87766, 4.74337
 6.45102, 8.06375, 9.32864, 10.27733, 10.75167
11.98727
 qf(13)=
 0.4741, 0.7443, 0.9928, 1.0209, 1.0272
 1.0555, 1.1388, 1.1834, 1.2059, 1.0959
  0.5616
 x(24)=
 0, 1.03287, 1.95144, 3.02687, 4.6085
 6.31663, 7.96299, 9.67201, 10.33596, 10.93383
 11.49521, 11.99524
 qf(24)=
 0.4558, 0.9283, 0.9945, 1.006, 1.0286
 1.0513, 1.1398, 1.2009, 1.1957, 1.0642
 0.7185, 0.4552
 x(36)=
 0, 0.55249, 1.30466, 1.4937, 2.78625
 4.77306, 6.38018, 8.01814, 9.49836, 10.22257
 10.82405, 11.27152, 11.99524
 qf(36)=
 0.4118, 0.6808, 0.9004, 0.9114, 0.9498
```

```
 0.9773, 1.0541, 1.1639, 1.2737, 1.3341
 1.2408, 0.9827, 0.4447
 x(49)=
 0, 0.67585, 1.52831, 2.7937, 4.50056
 6.17533, 7.62874, 9.30161, 10.21706, 10.85026
11.99524
 qf(49)=
 0.4667, 0.8784, 0.9388, 0.9169, 0.9498
 1.0047, 1.0596, 1.1969, 1.2682, 1.2353
  0.7467
 x(60)=
 0, 0.49275, 1.95738, 2.9731, 4.65427
 6.36627, 7.98192, 9.37444, 10.3228, 11.0792
11.99524
 qf(60)=
 0.4282, 0.7631, 1.0486, 1.109, 1.1584
 1.1694, 1.1255, 1.0267, 0.9114, 0.7192
  0.4502
 jn=12,11,12,13,11,11
 jst=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 3, 3
 3, 3, 3, 3, 4
 4, 4, 4, 4, 4
 4, 4, 4, 4, 4
 4, 4, 4, 4, 5
 5, 5, 5, 5, 5
 5, 5, 5, 5, 5
 5, 5, 5, 5, 5
 6, 6, 6, 6, 6
 6, 6, 6, 6, 6
 6, 6, 6, 6
 $end
```

Power-Ramp Assessment Cases

A.37 Ramped HBEP Obrigheim/Petten Rods

The HBEP was an international, group-sponsored program administrated by Battelle Pacific Northwest Laboratory from 1979 to 1989 (Barner et al., 1990). The objective was to investigate the impact of extended burnup on fuel rod performance, especially FGR. A total of 81 rods of both BWR and PWR types were irradiated and examined under the program, with rod-average burnups ranging up to 69 GWd/MTU and peak pellet burnups up to 83 GWd/MTU.

Under Task 2 of the program, full-length segmented rods were irradiated in commercial power reactors and then subjected to power ramps in test reactors. The rod segments comprised “rodlets” that were individual short-length fuel rods, mated end-to-end to form the full-length rods. Following irradiation to a variety of burnup levels, the rods were disassembled into the individual rodlets, and the rodlets were ramp-tested in test reactors. The peak LHGRs in these ramps ranged from 35 to 50 kW/m, and hold times ranged from 48 to 196 hours. The FGR during bumping was a function of the peak LHGRs and ranged from 10 to 45 percent. The pre-bump LHGRs ranged from 15 to 35 kW/m, as confirmed by calibrated nondestructive ^{85}Kr activity determinations for the plenum gas, and the pre-bump FGRs were generally low (1 to 5 percent).

Two PWR-type ramped rodlets were chosen for comparison to FRAPCON-3.4 predictions. Both were fabricated by Kraftwerk Union (KWU), irradiated in the same fuel assembly in the Obrigheim PWR, Germany, and then power-ramped to approximately the same peak LHGR (41 to 43 kW/m) in the JRC-Petten test reactor, the Netherlands. Rodlet D200 attained 25 GWd/MTU burnup in one reactor cycle at LHGRs of 25 ± 2 kW/m. Rodlet D226 attained 45 GWd/MTU by further irradiation in the same assembly for two more cycles, with LHGR generally decreasing with time from 25 kW/m at BOL to ~17 kW/m during the final cycle. The fuel in these rods resulted in high fuel densification > 2.5 percent TD and high open porosity that is atypical of today’s fuel. Comparisons of the FGR data from these power-ramped rods to other power-ramped data with lower densification and open porosity fuel typical of today’s fuel suggests that these FGR data are higher than observed from today’s fuel. As a result, the FRAPCON-3.4 code tended to underpredict this data, which is not surprising.

The post-bump FGR is greater for the higher-burnup rodlet D226 than for rodlet D200 (44 vs. 38 percent), despite D226 having a smaller as-fabricated fuel cladding gap. The pre-ramp FGRs, based on ^{85}Kr activity in the plenums, were very similar: 4.2 and 6.6 percent, respectively. Therefore, the net FGR during ramping is greater for rodlet D226, and this was attributed to burnup effects. This rodlet pair thus provides a test of the burnup effects inherent in the FRAPCON-3.4

The input files used for the UO_2 FGR assessment are shown below.

Ramped Rodlet D200

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outd200.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
```

```
         HBEP Ramped Rodlet d200
 $frpcn
 im=29, na=5,nr=20
 ngasr = 45,
 $end
 $frpcon
 cpl = 0.974, crdt = 0.,dco = 0.4236,
 thkcld = 0.02905, thkgap = 0.004, pitch = 0.56,
 den = 94.3, dishsd = 0.02185, dspg = 0.36,
 dspgw = 0.02, enrch = 3.20, fa= 1.0, fgpav = 304.6,
 hplt = 0.3588, hdish = 0.0284, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,
 jn = 6,6, jst = 17*1,12*2, nsp = 1,
 go(1) = 29*0.0, tw(1) = 17*580.,12*611., p2(1) = 29*2106.,
 totl = 1.0417, rsntr = 150.,
 rc = 0.0, roughc = 2.5e-5,
 roughf = 4.5e-5, vs = 8.0,
 nunits = 1,
 flux = 6*0.18e17,
 qf(1) = 1.,1.,0.99,0.98,0.97,0.96,
 x(1) = 0.0, 0.20834, 0.41668, 0.62502, 0.83336, 1.0417,
 qf(7) = 0.96,0.96,0.97,0.98,0.99,1,
 x(7) = 0.0, 0.20834, 0.41668, 0.62502, 0.83336, 1.0417,
 ProblemTime= 0.1,43.8, 73.7, 101.8, 132.0, 157.4, 188.3, 247.0,
 293.9, 295.7, 318.0, 346.4, 376.8, 406.4, 460.5, 488.0,
 548.1, 571.4, 571.41, 571.42, 571.43, 571.7, 572.1, 572.6,
 573.0, 573.5, 574.0, 574.5, 575.0
 qmpy = 7.89, 7.89, 8.05, 8.53, 8.26, 8.02, 7.80, 8.11,
 7.50, 7.35, 8.05, 7.89, 7.65, 7.53, 7.38, 7.25,
 7.13, 6.64, 0.30, 1.68, 5.12, 7.01, 7.80, 9.36,
 5*13.8,
 slim = .05,
 $end
```

Ramped Rodlet D226

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outd226.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plotd226.out', STATUS = 'UNKNOWN', FORM = 'FORMATTED'
/**********************************************************************
       HBEP Ramped Rodlet d226
 $frpcn
 im=45, na=3, nr=20
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.05, crdt = 0., pitch = 0.55,
 dco = 0.4240, thkcld = 0.02925, thkgap = 0.00335,
 den = 94.3, dishsd = 0.02185,  dspg = 0.36,
 dspgw = 0.02, enrch = 3.20, fa= 1.0, fgpav = 304.6,
 hplt = 0.3588, hdish = 0.0284, icm = 4,
 icor = 0, idxgas = 1, iplant = -2, iq = 0, jdlpr = 0,
 jn = 6, jst = 45*1, nsp = 1,crephr=1.0,
```

```
go(1) = 45*0.0, tw(1) = 30*580., 15*611., p2(1) = 45*2106.,
totl = 1.0417, rsntr = 250.,
rc = 0.0, roughc = 2.5e-5,
roughf = 8.5e-5, vs = 8.0,
nunits = 1, nplot=1,
flux = 4*0.18e17,
qf(1) = 6*1.0
x(1) = 0.0, 0.20834, 0.41668, 0.62502, 0.83336, 1.0417,
ProblemTime=
0.1,    43.8,  73.7, 101.8, 132.0,
157.4, 188.3, 247.0, 293.9, 295.7,
318.0, 346.4, 376.8, 406.4, 460.5,
488.0, 548.1, 571.4, 621.1, 681.0,
711.9, 760.6, 790.9, 850.5, 872.0,
925.5, 985.7, 1044.0, 1100.8, 1161.0,
1185.8, 1185.9, 1186.0, 1186.2, 1186.7,
1187.2,
1187.8, 1188.05, 1188.3, 1188.55, 1188.8,
1189.05,  1189.3, 1189.55, 1189.8
qmpy =
7.28, 7.28, 7.92, 8.32, 8.05,
7.89, 7.71, 7.56, 7.41, 8.08,
7.86, 7.59, 7.38, 7.22, 7.07,
6.98, 6.92, 6.43, 7.04, 6.64,
6.49, 6.40, 6.25, 6.04, 4.36,
5.27, 5.27, 5.24, 5.27, 5.24,
4.27, 3.00, 3.54, 7.07, 7.92,
9.60,
9*13.10,
slim = .05,
$end
```

A.38 Super-Ramp Rods

The Super-Ramp Project was an international, group-sponsored program involving base-irradiation of segmented full-length BWR and PWR rods in various power reactors, followed by ramp-testing of the rod segments in the Studsvik R-2 test reactor, Sweden (Djurle, 1985). The project's purpose was to establish the failure threshold for rods of varying types and burnup, and some rod segments did fail during high-power ramp testing. Rod segments that did not fail, however, gave data on FGR and cladding permanent hoop strain during EOL power transients.

Three rod segments were selected as FGR assessment cases and nine rod segments were selected as cladding hoop strain assessment cases. These were all non-failed PWR rod segments, which had been base-irradiated in the Obrigheim PWR for three cycles up to a burnup of 34 to 37 GWd/MTU. The segments were then ramp-tested in the Studsvik reactor to ramp terminal levels as high as 43 kW/m. The FGRs and residual cladding hoop strain were measured following the ramp test.

The segmented PWR rods were designed in basic conformance with KWU's 15 x 15 PWR fuel design. The general design specifications are given in Table A15.1. The fuel segment length was short, 39 cm overall and 31.5 cm active fuel length, to match well within the ~1 meter active length of the Studsvik reactor core. The diametral fuel-cladding gap was 145 microns (5.7 mils). The fuel pellet density is 95 percent TD, and the standard KWU densification test is only 2.2 hours at 1700°C rather than the 24 hour densification test at 1700°C required by the NRC as a measure of maximum densification. Therefore, the quoted maximum densification for this fuel "none" may be low, and it may be as great as 1 percent TD—the latter figure is used as FRAPCON-3.4 input.

The input files used for the UO_2 FGR assessments and cladding hoop strain assessments are shown below.

PK1/1 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK1-1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK1-1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/************************************************************************
Super Ramp Rod PK1-1
 $frpcn
 im=40, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4237, thkcld=0.0286, thkgap=0.00394, totl=1.02067, cpl=1.2598
 dspg=0.3587, dspgw=0.0394, vs=10
 hplt=0.4484, rc=0, hdish=0.0098, dishsd=0.022
 enrch=3.2, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.5, deng=0, roughf=0.0000787, rsntr=41.44, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
```

```
 iplant=-2, pitch=0.5509, icor=0, crdt=0, crdtr=0,
flux=10*2210000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.063, 0.125, 0.25, 24.875, 54.542
 84.458, 111.583, 134.792, 165.5, 193.833
 223.208, 253.667, 277.75, 296.083, 328.167
 356.75, 386.875, 419.792, 438.75, 469.833
 499.708, 525.708, 533.417, 588.542, 616.417
 645.458, 675.583, 707.333, 737.708, 763.917
 793.75, 826.333, 831.708, 874.75, 876.25
 876.75, 877.75, 878.251, 878.501, 886.38
 qmpy=
 0.792, 2.377, 4.755, 6.943, 8.272
 8.211, 8.211, 8.178, 8.053, 7.797
 7.797, 8.083, 7.925, 6.815, 6.943
 6.846, 6.91, 6.864, 6.687, 6.642
 6.642, 6.642, 6.608, 5.349, 6.815
 6.91, 6.895, 6.785, 6.815, 6.767
 6.815, 6.846, 6.578, 5.508, 0
 3.417, 6.836, 11.345, 5.672, 5.445
 nsp=1
 p2=
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 tw=
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 597.2, 597.2, 597.2, 597.2, 597.2
 go=
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 0, 0, 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.1706, 0.47244, 0.81365, 1.02067
 qf(1)=
 1, 1, 1, 1, 1
 x(6)=
 0, 0.1706, 0.47244, 0.81365, 1.02067
```

```
 qf(6)=
 34, 37.35, 41.5, 34.44, 29
 jn=5,5
 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
 2, 2, 2, 2, 2
 $end
```

PK1/3 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK1-3.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK1-3.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Super Ramp Rod PK1-3
 $frpcn
 im=39, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4237, thkcld=0.02862, thkgap=0.0039, totl=1.01706, cpl=1.2756
 dspg=0.3587, dspgw=0.0394, vs=10
 hplt=0.4484, rc=0, hdish=0.0098, dishsd=0.0236
 enrch=3.2, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.5255474452555, deng=0, roughf=0.0000787, rsntr=41.44,
tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5508, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.063, 0.125, 0.25, 24.875, 54.542
 84.458, 111.625, 134.833, 165.542, 193.875
 223.292, 253.708, 277.792, 296.125, 328.208
 356.792, 386.917, 419.833, 438.792, 469.875
 499.792, 525.833, 533.583, 588.708, 616.583
 645.625, 675.75, 707.5, 737.875, 764.083
 793.917, 826.5, 831.875, 874.917, 876.417
 876.917, 877.917, 878.418, 878.668
 qmpy=
 0.792, 2.377, 4.755, 6.943, 8.495
 8.306, 8.178, 8.053, 7.989, 7.83
 7.736, 7.736, 7.227, 7.163, 7.212
 6.959, 6.974, 6.91, 6.895, 6.989
```

```
6.879, 6.657, 6.578, 5.349, 6.974
6.721, 6.593, 6.562, 6.434, 6.404
6.34, 6.325, 6.419, 5.429, 0
3.417, 6.835, 12.985, 6.492
nsp=1
p2=
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
tw=
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
597.2, 597.2, 597.2, 597.2, 597.2
go=
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
0, 0, 0, 0, 0
iq=0, fa=1
x(1)=
0, 0.1706, 0.47244, 0.81365, 1.01706
qf(1)=
1, 1, 1, 1, 1
x(6)=
0, 0.1706, 0.47244, 0.81365, 1.01706
qf(6)=
40, 42.74, 47.5, 39.43, 35
jn=5,5
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
2, 2, 2, 2
$end
```

PK2/1 Cladding Hoop Strain Case

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

```
*
* GOESOUTS:
FILE06='PK2-1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK2-1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Super Ramp Rod PK2-1
 $frpcn
 im=50, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4233, thkcld=0.02894, thkgap=0.00285, totl=1.04134, cpl=1.2835
 dspg=0.3587, dspgw=0.0394, vs=10
 hplt=0.4461, rc=0, hdish=0.0098, dishsd=0.0236
 enrch=3.21, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.3430656934306, deng=0, roughf=0.0000787, rsntr=72.38,
tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5504, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.063, 0.125, 0.25, 45.667, 74.792
 106.333, 132.417, 158.5, 187.708, 215
 246.542, 278.083, 294.75, 319.375, 349
 378.917, 406.083, 429.292, 460, 488.333
 517.75, 548.208, 572.292, 590.625, 622.708
 651.292, 681.417, 714.333, 733.292, 764.375
 794.25, 820.25, 827.958, 883.083, 910.958
 940, 970.125, 1001.875, 1032.25, 1058.458
 1088.292, 1120.875, 1126.208, 1169.25, 1169.5
 1170.75, 1171.25, 1172.25, 1172.751, 1173.001
 qmpy=
 0.796, 2.387, 3.978, 5.115, 6.858
 6.953, 6.904, 6.843, 6.764, 6.651
 6.587, 5.983, 5.983, 7.047, 8.114
 8.068, 7.986, 7.925, 7.827, 7.605
 7.638, 7.733, 7.891, 7.254, 7.303
 7.129, 7.081, 6.937, 6.843, 6.62
 6.62, 6.62, 6.62, 5.377, 6.127
 6.206, 6.191, 6.093, 6.142, 6.078
 6.127, 6.172, 6.172, 5.313, 2.228
 0, 3.418, 6.835, 11.208, 5.605
 nsp=1
 p2=
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
```

```
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05
tw=
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
597.2, 597.2, 597.2, 597.2
go=
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
0, 0, 0, 0
iq=0, fa=1
x(1)=
0, 0.1706, 0.47244, 0.81365, 1.04134
qf(1)=
1, 1, 1, 1, 1
x(6)=
0, 0.1706, 0.47244, 0.81365, 1.04134
qf(6)=
34, 36.89, 41, 34.03, 29
jn=5,5
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, 2, 2, 2, 2
$end
```

PK2/3 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK2-3.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK2-3.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
```

```
/*********************************************************************
Super Ramp Rod PK2-3
 $frpcn
 im=50, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4233, thkcld=0.02892, thkgap=0.00285, totl=1.01378, cpl=1.2795
 dspg=0.3587, dspgw=0.0394, vs=10
 hplt=0.4461, rc=0, hdish=0.0098, dishsd=0.0236
 enrch=3.21, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.3430656934306, deng=0, roughf=0.0000787, rsntr=72.38,
tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5503, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.063, 0.125, 0.25, 45.667, 74.792
 106.333, 132.417, 158.5, 187.708, 215
 246.542, 278.083, 294.75, 319.375, 349
 378.917, 406.083, 429.292, 460, 488.333
 517.75, 548.208, 572.292, 590.625, 622.708
 651.292, 681.417, 714.333, 733.292, 764.375
 794.292, 820.333, 828.042, 883.167, 911.042
 940.083, 970.208, 1001.958, 1032.333, 1058.542
 1088.375, 1120.958, 1126.292, 1169.333, 1169.583
 1170.833, 1171.333, 1172.333, 1172.835, 1173.085
 qmpy=
 0.796, 2.387, 3.978, 5.435, 6.73
 6.858, 6.794, 6.764, 6.7, 6.602
 6.538, 6.191, 6.166, 7.175, 8.211
 8.068, 8.178, 7.669, 7.638, 7.541
 7.477, 7.477, 6.986, 7.541, 7.51
 7.129, 7.081, 6.937, 6.843, 6.873
 6.764, 6.602, 6.532, 5.297, 6.221
 6.047, 5.904, 5.791, 5.776, 5.697
 5.697, 5.697, 5.697, 5.075, 2.228
 0, 3.418, 6.835, 13.398, 6.699
 nsp=1
 p2=
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 tw=
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
```

```
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 597.2, 597.2, 597.2, 597.2
 go=
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 0, 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.1706, 0.47244, 0.81365, 1.01378
 qf(1)=
 1, 1, 1, 1, 1
 x(6)=
 0, 0.1706, 0.47244, 0.81365, 1.01378
 qf(6)=
 41, 44.11, 49.01, 40.67, 35.5
 jn=5,5
 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, 2, 2, 2, 2
 $end
```

PK2/S Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK2-S.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK2-S.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Super Ramp Rod PK2-S
 $frpcn
 im=50, nr=17, ngasr=45, na=9
 $end
 $frpcon
```

```
 dco=0.4234, thkcld=0.02896, thkgap=0.00285, totl=1.04134, cpl=1.2913
 dspg=0.3587, dspgw=0.0394, vs=10
 hplt=0.4461, rc=0, hdish=0.0098, dishsd=0.0236
 enrch=3.21, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.3430656934306, deng=0, roughf=0.0000787, rsntr=72.38,
tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5504, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=0.1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.063, 0.125, 0.25, 45.667, 74.792
 106.333, 132.417, 158.5, 187.708, 215
 246.542, 278.083, 294.75, 319.375, 349
 378.917, 406.083, 429.292, 460, 488.333
 517.75, 548.208, 572.292, 590.625, 622.708
 651.292, 681.417, 714.333, 733.292, 764.375
 794.292, 820.333, 828.042, 883.167, 911.042
 940.083, 970.208, 1001.958, 1032.333, 1058.542
 1088.375, 1120.958, 1126.292, 1169.333, 1169.583
 1170.833, 1171.333, 1172.333, 1172.835, 1173.085
 qmpy=
 0.796, 2.387, 3.978, 5.435, 6.73
 6.858, 6.794, 6.764, 6.7, 6.602
 6.538, 6.191, 6.166, 7.175, 8.211
 8.068, 8.178, 7.669, 7.638, 7.541
 7.477, 7.477, 6.986, 7.541, 7.51
 7.129, 7.081, 6.937, 6.843, 6.873
 6.764, 6.602, 6.532, 5.297, 6.221
 6.047, 5.904, 5.791, 5.776, 5.697
 5.697, 5.697, 5.697, 5.075, 2.228
 0, 3.418, 6.835, 13.398, 6.699
 nsp=1
 p2=
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 tw=
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
```

```
 541.4, 507.2, 507.2, 507.2, 507.2
 go=
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 0, 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.1706, 0.47244, 0.81365, 1.04134
 qf(1)=
 1, 1, 1, 1, 1
 x(6)=
 0, 0.1706, 0.47244, 0.81365, 1.04134
 qf(6)=
 36, 39.6, 44, 36.52, 32
 jn=5,5
 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, 2, 2, 2, 2
 $end
```

PK4/1 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK4-1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK4-1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Super Ramp Rod PK4-1
 $frpcn
 im=41, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4239, thkcld=0.02935, thkgap=0.00329, totl=1.03117, cpl=1.2756
 dspg=0.3587, dspgw=0.0394, vs=10
 hplt=0.4268, rc=0, hdish=0.0098, dishsd=0.0236
 enrch=3.19, imox=0, comp=0
 fotmtl=2, gadoln=0.0409, ppmh2o=0, ppmn2=0
 den=93.978, deng=0, roughf=0.0000787, rsntr=72.1, tsint=2911
```

```
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5511, icor=0, crdt=0, crdtr=0,
flux=10*2210000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 8.25, 16.5, 43.8, 73.7, 101.8
 132, 157.4, 188.3, 216.2, 247
 275.9, 293.9, 295.7, 318, 346.4
 376.8, 406.4, 429.917, 460.5, 488
 518.583, 548.083, 571.417, 591.417, 621.083
 651.083, 681, 711.917, 742.708, 770.583
 800.917, 830.708, 860.5, 865.875, 871.25
 876.625, 882, 883, 884, 884.501
 885.501
 qmpy=
 1.659, 3.26, 2.946, 3.861, 5.005
 5.548, 6.007, 6.379, 7.151, 7.007
 7.036, 7.036, 6.979, 7.036, 7.178
 7.151, 7.122, 7.064, 7.007, 6.864
 6.893, 7.007, 7.122, 5.978, 6.063
 5.978, 6.007, 5.95, 5.777, 5.692
 5.663, 5.663, 5.577, 6.264, 5.749
 5.52, 5.005, 0, 6.721, 10.468
       0
 nsp=1
 p2=
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05
 tw=
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 597.2, 597.2, 597.2
   597.2
 go=
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 0, 0, 0
       0
```

```
 iq=0, fa=1
 x(1)=
 0, 0.17186, 0.51558, 0.85931, 1.03117
 qf(1)=
 1, 1, 1, 1, 1
 x(6)=
 0, 0.17186, 0.51558, 0.85931, 1.03117
 qf(6)=
 32.25, 33.67, 36.6, 32.76, 31
 jn=5,5
 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, 2, 2, 2
       2
 $end
```

PK4/2 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK4-2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK4-2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*********************************************************************
Super Ramp Rod PK4-2
 $frpcn
 im=41, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4239, thkcld=0.02933, thkgap=0.00333, totl=1.02822, cpl=1.2913
 dspg=0.3587, dspgw=0.0394, vs=10
 hplt=0.4268, rc=0, hdish=0.0098, dishsd=0.0236
 enrch=3.19, imox=0, comp=0
 fotmtl=2, gadoln=0.0409, ppmh2o=0, ppmn2=0
 den=93.9781, deng=0, roughf=0.0000787, rsntr=72.1, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5511, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 8.25, 16.5, 43.8, 73.7, 101.8
 132, 157.4, 188.3, 216.2, 247
 275.9, 293.9, 295.7, 318, 346.4
 376.8, 406.4, 429.917, 460.5, 488
 518.583, 548.083, 571.417, 591.417, 621.083
 651.083, 681, 711.917, 742.708, 770.583
```

```
800.917, 830.708, 860.5, 865.875, 871.25
876.625, 882, 883, 883.979, 884.502
885.502
qmpy=
1.63, 3.232, 2.946, 3.861, 5.033
5.548, 5.978, 6.379, 7.122, 6.951
6.979, 7.007, 7.493, 7.408, 7.379
7.35, 7.178, 7.122, 7.064, 6.979
6.893, 6.749, 6.321, 6.206, 6.149
6.206, 6.12, 6.063, 5.863, 5.863
5.663, 5.491, 5.406, 6.12, 5.72
5.378, 4.863, 0, 6.721, 11.955
      0
nsp=1
p2=
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05, 2103.05, 2103.05, 2103.05, 2103.05
2103.05
tw=
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 541.4, 541.4, 541.4
541.4, 541.4, 597.2, 597.2, 597.2
  597.2
go=
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 2100000, 2100000, 2100000
2100000, 2100000, 0, 0, 0
      0
iq=0, fa=1
x(1)=
0, 0.17186, 0.51558, 0.85931, 1.02822
qf(1)=
1, 1, 1, 1, 1
x(6)=
0, 0.17186, 0.51558, 0.85931, 1.02822
qf(6)=
36.75, 38.46, 41.8, 37.41, 35.4
jn=5,5
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, 2, 2, 2
       2
 $end
```

PK6/1 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK6-1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK6-1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Super Ramp Rod PK6-1
 $frpcn
 im=40, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.423, thkcld=0.02852, thkgap=0.00285, totl=1.03379, cpl=1.3031
 dspg=0.36, dspgw=0.0394, vs=10
 hplt=0.437, rc=0, hdish=0.0228, dishsd=0.0512
 enrch=2.99, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.0729927007299, deng=0, roughf=0.0000787, rsntr=0, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5499, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.063, 0.125, 0.25, 26.25, 54.292
 84.333, 112.875, 142.917, 167.458, 198.5
 226.542, 257.583, 287.625, 310.167, 334.208
 363.25, 394.292, 424.333, 448.375, 479.417
 538.458, 568.5, 593.042, 614.083, 644.125
 674.167, 704.208, 735.25, 766.292, 794.333
 825.375, 855.417, 886.458, 916.5, 917.504
 917.754, 918.754, 918.756, 918.794, 919.044
 qmpy=
 0.868, 2.601, 5.201, 6.934, 6.876
 7.539, 7.882, 7.623, 7.336, 7.134
 7.106, 7.019, 6.934, 6.846, 6.905
 7.077, 7.019, 6.99, 6.934, 6.849
 6.731, 6.818, 6.934, 6.358, 6.388
 6.243, 6.214, 6.1, 5.897, 5.812
 5.782, 5.753, 5.667, 5.725, 0
 3.532, 7.068, 9.894, 12.72, 6.36
 nsp=1
 p2=
```

```
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 tw=
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 597.2, 597.2, 597.2, 597.2, 597.2
 go=
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 0, 0, 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.14764, 0.42651, 0.7956, 1.03379
 qf(1)=
 1, 1, 1, 1, 1
 x(6)=
 0, 0.14764, 0.42651, 0.7956, 1.03379
 qf(6)=
 39, 41.05, 44.98, 40.36, 37.5
 jn=5,5
 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
 2, 2, 2, 2, 2
 $end
```

PK6/2 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='PK6-2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='PK6-2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
```

```
/*********************************************************************
Super Ramp Rod PK6-2
 $frpcn
 im=40, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.423, thkcld=0.0286, thkgap=0.00287, totl=1.0351, cpl=1.2795
 dspg=0.3601, dspgw=0.0394, vs=10
 hplt=0.4358, rc=0, hdish=0.0228, dishsd=0.0512
 enrch=2.99, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.073, deng=0, roughf=0.0000787, rsntr=0, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=326.34, idxgas=1
 iplant=-2, pitch=0.5499, icor=0, crdt=0, crdtr=0,
flux=10*2210000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.063, 0.125, 0.25, 0.292, 45.708
 74.833, 106.375, 132.458, 158.542, 187.75
 215.042, 246.583, 278.125, 294.833, 319.5
 349.167, 379.083, 406.25, 429.458, 460.167
 488.5, 517.917, 548.375, 572.458, 590.792
 622.875, 651.458, 681.583, 714.5, 733.458
 764.542, 794.458, 820.5, 828.208, 883.333
 884.338, 884.629, 885.629, 886.13, 886.38
 qmpy=
 0.792, 2.371, 3.953, 5.535, 6.962
 8.352, 8.669, 8.4, 8.083, 7.83
 7.8, 7.705, 7.245, 7.196, 7.989
 7.958, 7.815, 7.721, 7.608, 7.529
 7.419, 7.294, 7.294, 6.818, 7.276
 7.181, 7.166, 7.007, 6.864, 6.803
 6.581, 6.358, 6.184, 6.178, 5.142
 0, 3.471, 6.941, 10.892, 5.445
 nsp=1
 p2=
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 2103.05, 2103.05, 2103.05, 2103.05, 2103.05
 tw=
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 541.4, 541.4, 541.4, 541.4, 541.4
 597.2, 597.2, 597.2, 597.2, 597.2
 go=
 2100000, 2100000, 2100000, 2100000, 2100000
```

```
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 2100000, 2100000, 2100000, 2100000, 2100000
 0, 0, 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.14764, 0.42651, 0.7956, 1.0351
 qf(1)=
 1, 1, 1, 1, 1
 x(6)=
 0, 0.14764, 0.42651, 0.7956, 1.0351
 qf(6)=
 33.5, 36.01, 40, 33.21, 29
 jn=5,5
 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
 2, 2, 2, 2, 2
 $end
```

PK6/2 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outpk6-2.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Super Ramp Rod pk6-2
 $frpcn
 im=34, na=8,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.28, crdt = 1., crdtr = 0.0,
 dco = 0.4230,pitch = 0.56,
 thkgap = 0.00285, thkcld = 0.0286,
 den = 95., dishsd = 0.0732, dspg = 0.35,
 dspgw = 0.03, enrch = 2.98, fa= 1.0, fgpav = 326,
 hplt = 0.437, hdish = 0.0228, icm = 4,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,
 jn = 9,9, jst = 19*1, 15*2, nsp = 0,
 go(1) = 0.0, tw(1) = 580., p2(1) = 2106.,
 totl = 1.022,
 rc = 0.0, roughc = 3.e-5,
 roughf = 8.e-5, vs = 8.0,
 nunits = 1, rsntr = 100.,
 flux = 9*0.18e17,
 qf(1) = 9*1.0
```

```
 x(1) = 0.0,0.1277,0.2556,0.3831,0.5108,0.6385,0.7663,
 0.8940, 1.022,
 qf(10) = 0.89,0.999,1.065,1.092,1.092,1.038,0.92,0.901,0.792,
 x(10) = 0.0,0.1277,0.2556,0.3831,0.5108,0.6385,0.7663,
 0.8940, 1.022,
 ProblemTime=0.1, 50., 100., 150., 200.,
 250., 300., 350., 400., 450.,
 500., 550., 600., 650., 700.,
 750., 800., 850., 900., 901.,
 901.2, 901.4, 901.6, 901.8, 901.9,
 902.1,902.15,902.2,902.25, 902.3, 902.35,902.4,902.45, 902.5
 qmpy =7.2, 7.2, 8.2, 8.2, 7.9,
 7.3, 6.9, 6.9, 7.8, 7.3,
 7.0, 6.9, 6.7, 6.9, 6.5,
 6.3, 6.1, 5.3, 4.6, 6.96,
 8.0, 9.0, 10., 11.0, 12.0,
 9*12.2
 slim = .05,
 $end
```

PK6/3 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outpk6-3.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Super Ramp Rod pk6-3
 $frpcn
 im=32, na=8,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.28, crdt = 1., crdtr = 0.0,
 dco = 0.4230,pitch = 0.56,
 thkgap = 0.00285, thkcld = 0.0286
 den = 95., dishsd = 0.0732, dspg = 0.35,
 dspgw = 0.03, enrch = 2.98, fa= 1.0, fgpav = 326,
 hplt = 0.437, hdish = 0.0228, icm = 4,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,
 jn = 9,9, jst = 19*1, 13*2, nsp = 0,
 go(1) = 0.0, tw(1) = 580., p2(1) = 2106.,
 totl = 1.022,
 rc = 0.0, roughc = 3.e-5,
 roughf = 8.e-5, vs = 8.0,
 nunits = 1, rsntr = 100.,
 flux = 9*0.18e17,
 qf(1) = 9*1.0,
 x(1) = 0.0,0.1277,0.2556,0.3831,0.5108,0.6385,0.7663, 0.8940, 1.022,
 qf(10) = 0.89,0.999,1.065,1.092,1.092,1.038,0.92,0.901,0.792,
 x(10) = 0.0,0.1277,0.2556,0.3831,0.5108,0.6385,0.7663,0.8940, 1.022,
 ProblemTime=0.1,    50., 100., 150., 200.,
 250.,300., 350., 400., 450.,
 500., 550., 600., 650., 700.,
 750., 800., 850., 900., 901.,901.03,901.06,901.09,
 901.1,901.15,901.2,901.25, 901.3, 901.35,901.4,901.45, 901.5,
```

```
 qmpy =7.2, 7.2, 8.2, 8.2, 7.9,
 7.3, 6.9, 6.9, 7.8, 7.3,
 7.0, 6.9, 6.7, 6.9, 6.5,
 6.3, 6.1, 5.3, 4.6, 6.96,9.0,11.0,12.5,
 9*13.19,
 slim = .05,
 $end
```

PK6/S FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outpk6-S.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Super Ramp Rod pk6-S
 $frpcn
 im=34, na=8,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.28, crdt = 1., crdtr = 0.0,
 dco = 0.4230,pitch = 0.56,
 thkgap = 0.00285, thkcld = 0.0286,
 den = 95., dishsd = 0.0732, dspg = 0.35,
 dspgw = 0.03, enrch = 2.98, fa= 1.0 fgpav = 326,
 hplt = 0.437, hdish = 0.0228, icm = 4,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 1,
 jn = 9,9, jst = 19*1, 15*2, nsp = 0,
 go(1) = 0.0, tw(1) = 580., p2(1) = 2106.,
 totl = 1.022,
 rc = 0.0 roughc = 3.e-5,
 roughf = 8.e-5, vs = 8.0,
 nunits = 1, rsntr = 100.,
 flux = 9*0.18e17,
 qf(1) = 9*1.0
 x(1) = 0.0,0.1277,0.2556,0.3831,0.5108,0.6385,0.7663,
 0.8940, 1.022,
 qf(10) = 0.89,0.999,1.065,1.092,1.092,1.038,0.92,0.901,0.792,
 x(10) = 0.0,0.1277,0.2556,0.3831,0.5108,0.6385,0.7663,
 0.8940, 1.022,
 ProblemTime=0.1,50., 100., 150., 200.,
 250., 300., 350., 400., 450.,
 500., 550., 600., 650., 700.,
 750., 800., 850., 900., 901.,
 901.2, 901.4, 901.6, 901.8, 901.9,
 902.1,902.15,902.2,902.25, 902.3, 902.35,902.4,902.45,
 902.5,
 qmpy =7.2, 7.2, 8.2, 8.2, 7.9,
 7.3, 6.9, 6.9, 7.8, 7.3,
 7.0, 6.9, 6.7, 6.9, 6.5,
 6.3, 6.1, 5.3, 4.6, 6.96,
 8.0, 9.0, 10., 11.0, 12.0,
 9*12.5,
 slim = .05,
 $end
```

A.39 Inter-Ramp Rods

The Studsvik Inter-Ramp Project objective was to investigate the mechanical failure threshold for BWR 8 x 8 type fuel rods. Short rodlets with standard BWR 8 x 8 dimensions and components were fabricated by ABB/Atom specifically for the project and were base-irradiated to ~20 GWd/MTU at low LHGRs before EOL ramping at rapid rate to high LHGRs to probe for cladding failure. Hold times at the ramp terminal (LHGR) level were 24 hours for non-failed rods. For the non-failed rods, post-ramp FGR was determined by rod puncture.

Two of the non-failed, ramp-tested Inter-Ramp rods, numbers 16 and 18 (Mogard et al., 1979; Lysell and Birath, 1979), were selected for FGR and cladding permanent hoop strain assessment.

Twenty short 21-inch rodlets were fabricated for the test, with nominal 8 x 8 BWR fuel rod characteristics, and there were some departures from these characteristics. Rods 16 and 18 were both "nominal rods" with 6-mil diametral gaps, 1 atm helium fill, and 95 percent TD solid, dished fuel pellets. The rods were irradiated in approximate BWR coolant conditions in pressurized loops within the Studsvik reactor. Rods 16 and 18 operated for ~550 days at LHGRs ranging from 20 to 40 kW/m and achieved burnups of 21 and 18 GWd/MTU, respectively.

Rods 16 and 18 were then preconditioned for 24 hours at 29 and 25 kW/m, respectively, and then ramped at a rate of ~70 W/m per second to terminal levels (maximum peak LHGR values) of 48 and 41 kW/m, respectively, where they were each held for 24 hours, during which the coolant was monitored for added radioactivity (indicating rod failure). Neither rod failed. Therefore, puncture and FGR determinations were feasible, and were performed.

The input files used for the UO_2 FGR assessments and cladding hoop strain assessments are shown below.

Inter-Ramp Rod 16 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='IRRMP-16.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IRRMP-16.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
Inter-Ramp Rod 16
 $frpcn
 im=54, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4935, thkcld=0.03514, thkgap=0.00217, totl=1.31529, cpl=1.6535
 dspg=0.4189, dspgw=0.0394, vs=10
 hplt=0.5118, rc=0, hdish=0.0102, dishsd=0.048
 enrch=3.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.4, deng=0, roughf=0.0000787, rsntr=120, tsint=2911
 icm=2, cldwks=0, roughc=0.0000315, catexf=0.05, chorg=10
 fgpav=14.7, idxgas=1
```

```
 iplant=-3, pitch=0.5413, icor=0, crdt=0, crdtr=0,
flux=10*2210000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 18.271, 34.204, 52.521, 62.996, 69.804
 73.088, 85.813, 98.604, 102.604, 118.3
 137.971, 150.704, 154.625, 172.321, 187.754
 203.971, 205.6, 216.492, 224.879, 241.929
 243.592, 253.108, 270.908, 276.471, 286.467
 302.171, 319.908, 332.604, 337.217, 343.496
 347.538, 362.746, 375.508, 378.433, 384.683
 397.046, 413.175, 430.808, 443.158, 456.992
 467.013, 468.375, 472.517, 488.017, 494.642
 508.163, 522.092, 539.775, 540.775, 541.275
 541.779, 542.28, 542.783, 543.033
 qmpy=
 5.859, 11.223, 10.788, 10.846, 10.967
 9.075, 7.068, 7.241, 7.446, 7.378
 7.475, 9.139, 10.443, 10.385, 10.705
 10.747, 9.172, 7.74, 7.734, 7.65
 7.585, 7.851, 7.832, 9.082, 10.872
 11.093, 10.736, 10.36, 9.088, 7.783
 7.814, 7.814, 7.873, 7.74, 7.686
 7.869, 9.216, 10.059, 9.936, 10.211
 10.115, 10.209, 10.308, 9.263, 8.288
 8.025, 7.76, 7.76, 0, 8.074
 8.074, 13.335, 13.335, 6.667
 nsp=0
 p2= 1035.57, tw= 554, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.1644, 0.49321, 0.82201, 1.15082
 1.31529
 qf(1)=
 22, 27.06, 32.82, 32.82, 26.39
      22
 jn=6
 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, 1, 1
 1, 1, 1, 1
 $end
```

Inter-Ramp Rod 18 Cladding Hoop Strain Case

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

```
*
* GOESOUTS:
FILE06='IRRMP-18.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='IRRMP-18.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
******
Inter-Ramp Rod 18
 $frpcn
 im=54, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4934, thkcld=0.03411, thkgap=0.00311, totl=1.30906, cpl=1.7323
 dspg=0.419, dspgw=0.0394, vs=10
 hplt=0.5118, rc=0, hdish=0.0102, dishsd=0.0481
 enrch=3.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.3, deng=0, roughf=0.0000787, rsntr=120, tsint=2911
 icm=2, cldwks=0.5, roughc=0.0000315, catexf=0.05, chorg=10
 fgpav=14.7, idxgas=1


 iplant=-3, pitch=0.5413, icor=0, crdt=0, crdtr=0,
flux=10*2210000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.25, 3.533, 16.263, 29.058, 33.067
 48.767, 68.442, 81.179, 85.104, 102.808
 118.246, 134.467, 136.1, 146.996, 155.388
 172.442, 174.108, 183.629, 201.433, 207
 217, 232.708, 250.45, 263.15, 267.767
 274.05, 289.263, 302.029, 304.958, 311.213
 323.579, 339.713, 357.35, 369.704, 383.542
 393.567, 394.933, 399.079, 414.583, 430.558
 444.083, 458.017, 475.704, 479.117, 486.983
 502.708, 519.721, 532.017, 533.021, 533.271
 533.77, 534.271, 534.315, 534.565
 qmpy=
 4.836, 9.675, 9.594, 9.768, 9.321
 9.085, 9.318, 6.637, 6.08, 6.08
 5.928, 6.054, 8.819, 9.45, 9.109
 9.583, 8.739, 9.636, 9.056, 6.409
 6.287, 6.795, 6.314, 7.176, 8.979
 9.322, 9.667, 9.296, 9.85, 9.405
 9.163, 6.742, 6.565, 6.489, 6.742
 7.202, 6.719, 6.312, 9.268, 9.002
 9.295, 9.242, 9.482, 6.916, 6.838
 6.709, 6.736, 6.812, 0, 3.482
 6.966, 6.966, 11.517, 5.758
 nsp=0
 p2= 1035.57, tw= 554, go= 0
 iq=0, fa=1
 x(1)=
 0, 0.16363, 0.4909, 0.81816, 1.14542
 1.30906
```

```
 qf(1)=
 33, 35.73, 41, 40.58, 33.83
      30
 jn=6
 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, 1, 1
 1, 1, 1, 1
 $end
```

Inter-Ramp Rod 16 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outirmp16.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='irrmp16.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
         Inter-Ramp Rod 16
 $frpcn
 im=25, na=6,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.93, crdt = 0., dco = 0.4929, thkcld = 0.034,
 den = 95., thkgap=0.0025, dishsd = 0.049, dspg = 0.42,
 dspgw = 0.055, enrch = 3.5, fa= 1.146, fgpav = 14.7,
 hplt = 0.51, hdish = 0.0102, icm = 2,
 icor = 0, idxgas = 1, iplant =-3, iq = 1, jdlpr = 1,
 totl = 1.322,pitch = 0.56,crephr=1.0,nplot=1,
 rc = 0.0, roughc = 3.1e-5,
 roughf = 5.96e-5, vs = 8,
 nunits = 1, rsntr = 120.,
 flux = 7*0.18e17, p2(1) = 1068, tw(1) = 500.0, go(1) = 6E5,
 ProblemTime =
 1., 16.6, 60., 70.,  85.,
 116, 136, 202, 242, 250,
 268, 285, 300, 331, 360,
 395, 412, 430, 473, 495,
 525, 550, 551, 551.5, 552
 qmpy =
 13.1, 13.1, 12.2, 12.7, 7.96,
 8.08, 8.5,  12.2,  8.6,  9.1,
 8.2,  12.2, 12.5, 11.6, 8.7,
 8.7, 11.7, 10.9,  11.3, 9.1,
 8.6, 8.6,  8.8,   14.6, 14.6
 slim = .05,
```

 ```
 $end
```

Inter-Ramp Rod 18 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outirmp18.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Inter-Ramp Rod 18
 $frpcn
 im=25, na=6,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.93, crdt = 0., dco = 0.4929, thkcld = 0.034,
 den = 95., thkgap=0.0025, dishsd = 0.049, dspg = 0.42,
 dspgw = 0.055, enrch = 3.5, fa= 1.146, fgpav = 14.7,
 hplt = 0.51, hdish = 0.0102, icm = 2,
 icor = 0, idxgas = 1, iplant =-3, iq = 1, jdlpr = 1,
 totl = 1.322,pitch = 0.56,
 rc = 0.0, roughc = 3.1e-5,
 roughf = 5.96e-5, vs = 8,
 nunits = 1, rsntr = 120.,
 flux = 7*0.18e17, p2(1) = 1068, tw(1) = 500.0, go(1) = 6E5,
 ProblemTime =
 1.,   28,  46,  68,  100,
 135, 155, 185, 200,  250, 262,
 272, 300, 301, 324, 360,
 402, 430, 461, 478, 514,
 550, 551, 551.5, 552
 qmpy =
  10.7, 10.7,10.06,10.36, 6.9,
   6.9,10.45, 10.7,10.06, 7.16,
  8.00, 9.90,10.50,10.97,10.36,
  7.38, 7.38, 10.2, 10.2,10.36,
  7.47, 7.47, 7.60, 12.5,12.5,
 slim = .05,
 $end
```

A.40 Ramped Halden/DR-2 Rods

The Risø Fission Gas Release Project was an international, group-sponsored program administrated by Risø Laboratories, Denmark, from 1980 to 1981. The objective was to investigate the impact of extended burnup and EOL power ramping on FGR in BWR-type fuel rods. This was done by performing power-bumping tests in the DR-2 reactor (Denmark) on 9 of the 14 rods irradiated in test fuel assembly IFA-148. This assembly was operated in the Halden reactor, Norway, from 1968 to 1979. The power ramps featured 24-hour hold periods at the peak power level, with the peak power level varied among the tests. These tests were supplemented by nondestructive examinations before and after the bumping irradiations, rod puncturing/gas analysis on all tested rods, and detailed destructive examinations on selected rods.

Three of the bumped rods were selected as FRAPCON-3.4 FGR assessment cases: rods F7-3, F9-3, and F14-6 (Knudson et al., 1983), which had rod-average burnups of 35, 33, and 27 GWd/MTU, respectively. The analyses of plenum gas ^{85}Kr activity before and after bumping were performed, and these were calibrated against the post-bump rod puncture results to yield an estimate of the net FGR caused by the power bumping. Thus, these cases provide the opportunity to assess the transient power induced short-term FGR predictions of the FRAPCON-3.4 FGR model.

The IFA-148 assembly contained a total of 14 short BWR-type test rodlets, with 7 rods each in two clusters (upper and lower clusters). The fuel pellets were 5 percent enriched sintered urania, with some variations in density and grain size. These two assessment cases, the nominal grain size and the fuel pellet densities, are equal (13 to 16 micron grain size and density of 93.4 percent TD, with a 0.6 percent increase upon resinter). The rods were initially filled with 1 atm helium fill gas.

The input files used for the UO_2 FGR assessments are shown below.

F14-6 Ramped Rod

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outF14-6.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
  Riso FGP Rod F14-6
 $frpcn
 im=31,
 na =5, ngasr = 45,
 $end
 $frpcon
 cpl = 1.79, crdt = 0.0, thkcld = 0.0205, dco = 0.5472,
 pitch = 0.6,fa=1.,
 den = 93.4, thkgap = 0.00355, dspg = 0.5, dspgw = 0.03,
 enrch = 5.0, fgpav = 14.7,
 hplt = 0.51, icm = 2, icor = 0,
 idxgas = 1, iplant = -4, iq = 0, jdlpr = 1,
 totl = 2.627,
  roughc = 2.5e-5, roughf =2.5e-5, vs = 8.0,
 nunits = 1, rsntr = 66., nsp =1,
 flux = 6*5.E15, p2(1) = 21*500, 10*1030.,
```

```
 tw(1) = 21*464, 10*500.,
 go(1) = 31*0.0, jn = 7,7,7,7,7,
 jst = 1,1,2, 5*3, 3*4, 5*3, 4, 1,1,2,3,10*5
  ProblemTime=
   1.0,   28.,   40.,  140.,  240.,
  340.,  440.,  556.,  656.,  756.,
  808.,  908., 1008., 1108., 1208.,
 1304., 1351., 1451., 1587., 1613.,
 1702.
 1702.5,1702.55, 1702.6, 1702.65,
 1703.0, 1703.5,1704.0,1704.5,
 1705.0, 1705.65
  qmpy =
  3.5, 7.29, 10.43, 7.22, 7.22,
 7.22, 7.22, 7.22, 6.01, 6.01,
 6.01, 4.60, 4.60, 4.60, 4.60,
 4.60, 5.38, 3.81, 3.81, 4.68,
 2.97,
 5.4, 6.4, 7.4, 8.4,
 6*8.76
 x(1) =
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0,  1.5, 2.0, 2.267
 qf(1) =
 1.29, 1.27,1.26, 1.16, 1.0, 0.79, 0.47,
 1.0,  1.0, 1.0,  1.0,  1.0, 1.0,  1.0,
 1.16, 1.13, 1.14, 1.09, 1.0, 0.88, 0.69,
 1.09, 1.08, 1.08, 1.05, 0.999, 0.93, 0.818
 1.54, 1.54, 1.54, 1.41, 0.975, 0.53, 0.30
  slim = .05,
  $end
```

F7-3 Ramped Rod

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outF7-3.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/*****************************************************************
  Riso FGP Rod F7-3
 $frpcn
 im=38,na =5,
 ngasr = 45,
 $end
 $frpcon
 cpl = 1.79, crdt = 0.0, thkcld = 0.0213, dco = 0.5472,
 pitch = 0.6,fa = 1.,
 den = 93.4, thkgap = 0.00355, dspg = 0.5, dspgw = 0.03,
 enrch = 5.0, fgpav = 14.7,crephr=1.0,
 hplt = 0.51, icm = 2, icor = 0,
 idxgas = 1, iplant = -4, iq = 0, jdlpr = 1,
 totl = 2.627,
  roughc = 2.5e-5, roughf =2.5e-5, vs = 8.0,
```

```
 nunits = 1, rsntr = 66., nsp =1,
 flux = 6*5.E15, p2(1) = 21*500, 17*1030.,
 tw(1) = 21*464, 17*500.,
 go(1) = 0.0, jn = 7,7,7,7,7,
 jst = 1,1,2, 5*3, 3*4, 5*3, 4, 1,1,2,3,17*5
  ProblemTime=
   1.0,   28.,   40.,  140.,  240.,
  340.,  440.,  556.,  656.,  756.,
  808.,  908., 1008., 1108., 1208.,
 1304., 1351., 1451., 1587., 1613.,
 1702.
 1702.3, 1702.35,1702.4,1702.45,
 1702.8, 1703.3,
 1703.35,1703.4,1703.45,1703.6,
 1703.7,1703.75,1703.8,1703.85,
 1703.9,1704.1, 1704.6
  qmpy =
  4.5, 9.33,13.33, 9.24, 9.24,
 9.24, 9.24, 9.24, 7.68, 7.68,
 7.68, 5.89, 5.89, 5.89, 5.89,
 5.89, 6.88, 4.87, 4.87, 5.98,
 3.8,
 3.6, 4.5,5.5,6.5,6.98, 6.98,
 6.5,5.5,4.5,3.6,
 4.5,5.5,6.5,7.5,8.5,9.2,
 9.2,
 x(1) =
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
 0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627
 qf(1) =
 1.29, 1.27,1.26, 1.16, 1.0, 0.79, 0.47,
 1.0,  1.0, 1.0,  1.0,  1.0, 1.0,  1.0,
 1.16, 1.13, 1.14, 1.09, 1.0, 0.88, 0.69,
 1.09, 1.08, 1.08, 1.05, 0.999, 0.93, 0.818
 1.47, 1.47, 1.47, 1.33, 0.922, 0.51, 0.28
  slim = .05,
  $end
```

F9-3 Ramped Rod

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outF9-3.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
  Riso FGP Rod F9-3
 $frpcn
 im=27,
 na =5, ngasr = 45,
 $end
 $frpcon
 cpl = 1.79, crdt = 0.0, thkcld = 0.0213, dco = 0.5472,
 pitch = 0.6,fa = 1.,
```

```
den = 93.4, thkgap = 0.00355, dspg = 0.5, dspgw = 0.03,
enrch = 5.0, fgpav = 14.7,
hplt = 0.51, icm = 2, icor = 0,
idxgas = 1, iplant = -4, iq = 0, jdlpr = 1,
totl = 2.627,
 roughc = 2.5e-5, roughf =2.5e-5, vs = 8.0,
nunits = 1, rsntr = 66., nsp =1,
flux = 6*5.E15, p2(1) = 21*500, 6*1030.,
tw(1) = 21*464, 6*500.,
go(1) = 27*0.0, jn = 7,7,7,7,7,
jst = 1,1,2, 5*3, 3*4, 5*3, 4, 1,1,2,3,6*5
 ProblemTime=
  1.0,   28.,   40.,  140.,  240.,
 340.,  440.,  556.,  656.,  756.,
 808.,  908., 1008., 1108., 1208.,
1304., 1351., 1451., 1587., 1613.,
1702.,
1702.4,
1703.25,1703.667,1704.5,1704.83
1704.9
 qmpy =
 4.5, 9.33,13.33, 9.24, 9.24,
9.24, 9.24, 9.24, 7.68, 7.68,
7.68, 5.89, 5.89, 5.89, 5.89,
5.89, 6.88, 4.87, 4.87, 5.98,
4.5,5.64,6.8,7.9,3*9.05,
 x(1) =
0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
0.,  0.5, 0.85, 1.0, 1.5, 2.0, 2.627,
0.,  0.5, 0.85, 1.0,  1.5, 2.0, 2.267
qf(1) =
1.29, 1.27,1.26, 1.16, 1.0, 0.79, 0.47,
1.0,  1.0, 1.0,  1.0,  1.0, 1.0,  1.0,
1.16, 1.13, 1.14, 1.09, 1.0, 0.88, 0.69,
1.09, 1.11, 1.09, 1.05, 0.999, 0.93, 0.818
1.53, 1.53, 1.53, 1.43, 0.991, 0.535, 0.310
 slim = .05,
 $end
```

A.41 Risø-3 Ramped Rods

The Risø National Laboratory in Denmark has carried out three irradiation programs of slow ramp and hold tests, so called "bump tests," to investigate FGR and fuel microstructural changes. The third and final project, which took place between 1986 and 1990, bump-tested fuel re-instrumented with both pressure transducers and fuel centerline thermocouples.

The innovative technique used for refabrication involved freezing the fuel rod to hold the fuel fragments in position before cutting and drilling away the center part of the solid pellets to accommodate the new thermocouple.

The fuel used in the project was from IFA-161 irradiated in the Halden BWR to 52 GWd/MTU, GE BWR fuel irradiated in Quad Cities 1 and Millstone 1 from 23 to 45 GWd/MTU, and ANF PWR fuel irradiated in Biblis A (Germany) to 43 GWd/MTU. All these rods were subsequently ramped in the DR-3 reactor.

Four of the GE BWR rods (GE2, GE4, GE6, and GE7) (Chantoin et al., 1997) and two of the ANF rods (AN1 and AN8) (Chantoin et al., 1997) were selected to assess the FRAPCON-3.4 predictions of UO_2 FGR and cladding hoop strain. The input files used for the UO_2 FGR assessments and cladding hoop strain assessments are shown below.

GE-2 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outge2notc.n'
',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Riso3 bumped rod GE-2
 $frpcn
 im=54, na=12, nr=17,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 3.0, dco = 0.4827, thkcld = 0.0321,
  idxgas = 1,
 den = 95.2, rsntr = 44,
 thkgap = 0.00433, rc = 0.0, dspg = 0.39,
 dspgw = 0.04, enrch = 3.0,pitch=0.56, fa=1.0,
 fgpav = 104.5, hplt = 0.41, hdish= 0.0,
 icm = 2, icor = 0,crephr=1.0,
 iq = 0,iplant=-3,
 jdlpr = 0, jn(1) = 5,5,
 jst(1) = 40*1,14*2,
 totl = 0.882, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, nsp = 1,
 p2(1) = 54*1000, tw(1) = 40*570., tw(41)=14*550.,go(1) = 54*0.0,
 qf(1)=1.,1.,1.,1.,1.,
 qf(6)=0.915, 0.982, 1.035, 1.05, 0.975,
 x(1)= 0.0,0.2205, 0.441, 0.6615, 0.882,
 x(6)= 0.0,0.2205, 0.441, 0.6615, 0.882,
  ProblemTime =
```

```
 0.1, 0.2, 0.3,
  50.,100.,150.,200.,
 250.,300.,350.,400.,
 450.,500.,550.,600.,
 650.,700.,750.,800.,
 850. 900.,950.,1000.,
 1050.,1100.,1150.,1200.,
 1250.,1300.,1350.,1400.,
 1450.,1500.,
 1550.,1600.,1650.,1700.,
 1750.,1800.,1850.,
 1850.05,1850.10,1850.15,1850.20,1850.25,
 1850.30,1850.40,1850.60,1850.80,1851.00,
 1851.4,1851.8,1852.2,1852.6
 qmpy =
 2.,4.,6.,
 4*7.5,
 4*5.5,
 16*4.8,
 4*5.35,
 2*4.3,
 7*5.6,
 2.,3.,4.,5.,6.,
 7.,8.,10.5,11.2,11.7,
 12.35,12.35,12.35,12.35
 $end
```

GE-4 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outge4notc.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Riso3 bumped rod GE-4
 $frpcn
 im=46, na=12, nr=17,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 2.8, dco = 0.48307, thkcld = 0.032,
 den = 96.2, rsntr = 33,
 thkgap = 0.00464, rc = 0.0, dspg = 0.39,
 dspgw = 0.04, enrch = 2.6,pitch = 0.56, fa=1.,
 fgpav = 104.5, hplt = 0.41, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1,
 iq = 0,iplant=-3,
 jdlpr = 0, jn(1) = 5,5,
 jst(1) = 20*1,26*2,
 totl = 0.8825, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, nsp = 1,
 p2(1) = 46*1000, tw(1) = 20*570., tw(21)= 26*552., go(1) = 46*0.0,
 qf(1)=1.,1.,1.,1.,1.,
 qf(6) = 0.984,1.006,1.025,1.017,0.968,
 x(1)= 0.0, 0.2205, 0.441, 0.6615, 0.8825,
 x(6)= 0.0, 0.2205, 0.441, 0.6615, 0.8825,
```

```
  ProblemTime =
 0.1, 0.2, 0.3,
  50.,100.,150.,200.,
 250.,300.,350.,400.,
 450.,500.,550.,600.,
 650.,700.,750.,800.,
 850.,
 850.05, 850.10, 850.15, 850.20, 850.25,
 850.30, 850.40, 850.50, 850.70, 850.9,
 851.10, 851.30, 851.50,
 851.90, 852.30, 852.90,
 852.91, 852.92, 852.93, 852.94, 852.95,
 852.96, 852.97, 852.98, 852.99, 853.00
 qmpy =
 2.,4.,6.,
 8*8.0,
 6*6.0,
 3*7.0,
 2.,3.,4.,5.,6.,
 7.,8.,9.,10.6,11.2,
 11.6, 12.2, 12.6,
 3*13.2,
 12., 11., 10., 9.,   8.,
  7.,  8., 9., 11.5, 13.2
 4*13.2
 $end
```

GE-6 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outge6notc.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/**********************************************************************
         Riso3 bumped rod GE-6
 $frpcn
 im=72, na=5, nr=17,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 2.9, dco = 0.48268, thkcld = 0.03209,
 den = 95.2, rsntr = 44.0,pitch=0.56, fa=1.0,
 thkgap = 0.00435, rc = 0.0, dspg = 0.39,
 dspgw = 0.04, enrch = 3.037,
 fgpav =  104.5, hplt = 0.41, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1,
 iq = 0,iplant=-3,
 jdlpr = 0, jn(1) = 5,5
 jst(1) = 40*1, 32*2
 totl = 0.961, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, nsp =1,
 p2(1) = 72*1000, tw(1) =40*570., 32*552., go(1) = 72*0.0,
 qf(1)=1., 1., 1.,1.,1.,
 qf(6) = 1.004, 1.002, 1.019, 1.023, 0.952,
 x(1)= 0.0, 0.24025, 0.4805, 0.72075, 0.961,
 x(6)= 0.0, 0.24025, 0.4805, 0.72075, 0.961,
```

```
  ProblemTime =
 0.1, 0.2, 0.3,
  50.,100.,150.,200.,
 250.,300.,350.,400.,
 450.,500.,550.,600.,
 650.,700.,750.,800.,
 850. 900.,950.,1000.,
 1050.,1100.,1150.,1200.,
 1250.,1300.,1350.,1400.,
 1450.,1500.,
 1550.,1600.,1650.,1700.,
 1750.,1800.,1850.,
 1850.1, 1850.2, 1850.3, 1850.4, 1850.45,
 1850.5, 1851.0, 1851.2, 1851.3, 1851.5,
 1851.7, 1851.9, 1852.0, 1852.2, 1852.4,
 1852.6, 1852.8, 1853.0, 1853.2, 1853.4,
 1853.6, 1853.8, 1854.0, 1854.2, 1854.4,
 1854.6, 1854.8, 1855.0, 1855.2, 1855.4,
 1855.6, 1855.8
  qmpy =
 2.0, 4.0, 6.0,
 7.5, 8.0, 9.0, 9.5,
 9.0, 8.0, 7.0, 6.0,
 5.0, 3.5, 7.0, 8.0,
 7.0, 8.5, 7.75, 7.0,
 5.5, 4.0, 3.0, 2.0,
 6.0, 6.5, 6.75, 7.0,
 6.5, 5.75, 5.0, 4.0,
 4.0, 4.0,
 4.0, 4.0, 4.5, 4.75,
 4.5, 4.5, 4.5,
 2., 4., 6., 8., 10.,
 11.7,11.8,11.6,11.2,11.3,
 11.4,11.5,11.6,10.8,10.85,
 10.9,10.95,11.,11.,11.05,
 11.1,11.15,11.2,11.25,11.3,
 11.3,11.35,11.4,11.4,11.45
 11.5,11.5
  $end
```

GE-7 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outge7.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='ge7.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/*********************************************************************
         Riso3 bumped rod GE-7
 $frpcn
 im=50, na=10, nr=17,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 cpl = 5.63, thkcld = 0.03209,
```

```
 den = 95.2, rsntr = 44.0,dco=0.48268,
 thkgap = 0.00435, rc = 0.0, dspg = 0.39,
 dspgw = 0.04, enrch = 3.0,
 fgpav = 42.06, hplt = 0.41, hdish= 0.0,
 icm = 2, icor = 0, idxgas = 1,
 iq = 0,fa=1.0,crephr=1.0,nplot=1
 jdlpr = 0, jn(1) = 3,12,
 jst(1) = 41*1, 9*2
 totl = 2.47, roughc = 4.5e-5, roughf = 8.5e-5, vs = 5.0,
 nunits = 1, nsp = 1,iplant=-3,pitch=0.56,
 p2(1) = 50*1000, tw(1) = 41*570., tw(42)=9*552., go(1) = 50*0.0,
 qf(1)=0.98, 1.02, 0.98,
 qf(4) =
 1.313,1.351, 1.427, 1.421, 1.366, 1.242,
 1.064,0.872, 0.657, 0.400, 0.201, 0.1015
 x(1)= 0.0,1.25, 2.47
 X(4) = 0.0,0.1235,0.370,0.6175,
 0.8645,1.1115,1.3585,1.6055,1.8525,
 2.0995,2.3465,2.47
  ProblemTime =
 0.1, 0.2, 0.3,
  50.,100.,150.,200.,
 250.,300.,350.,400.,
 450.,500.,550.,600.,
 650.,700.,750.,800.,
 850. 900.,950.,1000.,
 1050.,1100.,1150.,1200.,
 1250.,1300.,1350.,1400.,
 1450.,1500.,
 1550.,1600.,1650.,1700.,
 1750.,1800.,1850.,1900.,
 1900.2, 1900.4, 1900.6, 1900.85,
 1900.87, 1900.89, 1900.91,
 1900.93, 1901.08
   qmpy =
 2.0, 4.0, 6.0,
 8.5, 7.5, 7.5, 6.5,
 6.0, 6.0, 6.0, 6.0,
 5.0, 4.0, 6.0, 6.0,
 6.5, 6.5, 5.25, 5.25,
 5.25,4.5, 3.5, 2.5,
 2.5, 5.0, 5.0, 5.0,
 4*5.0,
 7*4.0, 4.5,
 5.0, 4.0,
 2.0, 4.0, 6.0, 7.0,
 8.0, 9.0, 10.0,
 10.8, 10.8
   $end
```

AN1 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='AN1.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
```

```
FILE66='AN1.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/*********************************************************************
RISO3 bump test AN1 (cb9) with 42 hour hold time
 $frpcn
 im=96 , na=12,nr=25,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.4256, thkcld=0.03055, thkgap=0.00405, totl=0.9678, cpl=3.4,
 dspg=0.350, dspgw=0.050, vs=10,
 hplt=0.2720, rc=0.0, hdish=4.887e-3, dishsd=0.0473,
 enrch=2.95, fotmtl=2.0,
 den=93.74, roughf=8.5e-5, rsntr=98.64,
 icm=4, cldwks=0.5, roughc=2.5e-5,
 idxgas=1, fgpav=187.0,igas=55,
 iplant=-2,nsp=1, p2=54*2251.0,42*2219 tw=54*544.5,42*622.9,
 go=54*2.61e6,42*2.0e7 pitch=0.568,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1,
 jn=5,5, jst=54*1,42*2,iq=0, fa=1,
 qf(1) = 1.0,1.0,1.0,1.0,1.0
 x(1) =  0.000,0.24195,0.4839,0.72585,0.9678,
 qf(6)= 0.983,1.031,1.059,0.995,0.933,
 x(6) =  0.000,0.24195,0.4839,0.72585,0.9678,
 ProblemTime =
    0.100,   0.200,   0.300,   4.375,
   14.583,  29.167,  58.333,  87.500, 116.667,
  145.833, 175.000, 204.167, 233.333, 262.500,
  273.500, 277.875, 288.083, 302.667, 331.833,
  361.000, 390.167, 419.333, 448.500, 477.667,
  506.833, 536.000, 565.167, 594.333, 623.500,
  636.583, 640.958, 651.167, 665.750, 694.917,
  724.083, 753.250, 782.375, 811.542, 840.708,
  869.875, 899.042, 917.375, 921.750, 931.958,
  946.583, 975.750,1004.958,1034.125,1063.333,
 1092.542,1121.708,1150.917,1180.083,1198.250,
 1198.264,1198.265,1198.278,1198.347,1198.349,
 1198.358,1198.520,1198.525,1198.699,1198.861,
 1199.024,1199.027,1199.191,1199.358,1199.360,
 1200.234,1200.235,1200.245,1200.247,1200.255,
 1200.265,1200.266,1200.274,1200.276,1200.285,
 1200.296,1201.170,1201.172,1201.173,1201.180,
 1201.182,1201.193,1201.202,1201.213,1201.222,
 1201.233,1201.234,1201.244,1201.245,1201.247,
 1201.249,1201.256,
 qmpy =
 1.000,2.000,3.000,3.962,3.780,
 3.719,3.749,3.871,3.962,4.023,
 4.054,4.084,4.084,4.115,4.115,
 7.590,7.468,7.468,7.407,7.224,
 7.071,6.949,6.828,6.736,6.645,
 6.614,6.584,6.553,6.523,6.523,
 6.066,5.913,5.852,5.852,5.791,
 5.830,5.730,5.669,5.669,5.700,
 5.730,5.730,7.193,6.736,6.706,
 6.645,6.462,6.309,6.157,6.005,
 5.883,5.791,5.730,5.700,
```

```
 1.280,
 2.377,4.054,5.791,6.066,6.828,
 7.620,8.352,9.144,9.632,10.150,
 10.546,10.851,11.460,11.796,12.131,
 10.119,8.809,6.675,6.035,7.193,
 7.742,8.748,9.144,10.150,11.186,
 12.101,11.887,9.906,8.717,8.138,
 6.035,6.980,8.412,9.936,11.064,
 11.460,12.283,9.540,4.420,1.463,
 0.366,
 slim = .05,
 $end
```

AN8 FGR Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='AN8.out',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='AN8.plot', STATUS='UNKNOWN', FORM='FORMATTED',
        CARRIAGE CONTROL='LIST'
/**********************************************************************
RISO3 bump test AN8 (cb10) with 4 hour hold time
 $frpcn
 im=72 , na=12,nr=25,
 mechan = 2, ngasr = 45,
 $end
 $frpcon
 dco=0.4256, thkcld=0.0305, thkgap=0.0041, totl=1.778, cpl=2.40,
 dspg=0.350, dspgw=0.050, vs=10,
 hplt=0.2720, rc=0.0, hdish=4.887e-3, dishsd=0.0473,
 enrch=2.95, fotmtl=2.0,
 den=93.74, roughf=8.5e-5, rsntr=98.64,
 icm=4, cldwks=0.5, roughc=2.5e-5,
 idxgas=1, fgpav=335.0,
 iplant=-2,nsp=1, p2=55*2251.0,17*2219 tw=55*544.5,17*622.9,
 go=55*2.61e6,17*2.0e7, pitch=0.568,
 nunits=1, crephr=10.0, jdlpr=0, nplot=1,
 jn=10,10, jst=55*1,17*2, iq=0, fa=1,
 qf(1) = 1.012,1.004,1.004,0.995,0.974,
         0.996,1.007,1.007,0.999,1.003,
 qf(11)= 1.547,1.585,1.469,1.337,1.188,
         0.968,0.751,0.558,0.377,0.217,
 x(1) =  0.000,0.198,0.395,0.593,0.790,
         0.988,1.185,1.383,1.580,1.778,
 x(11)=  0.000,0.198,0.395,0.593,0.790,
         0.988,1.185,1.383,1.580,1.778,
 ProblemTime =
    0.100,   0.200,   0.300,   0.400,   4.375,
   14.583,  29.167,  58.333,  87.500, 116.667,
  145.833, 175.000, 204.167, 233.333, 262.500,
  273.500, 277.875, 288.083, 302.667, 331.833,
  361.000, 390.167, 419.333, 448.500, 477.667,
  506.833, 536.000, 565.167, 594.333, 623.500,
  636.583, 640.958, 651.167, 665.750, 694.917,
  724.083, 753.250, 782.375, 811.542, 840.708,
```

```
 869.875, 899.042, 917.375, 921.750, 931.958,
 946.583, 975.750,1004.958,1034.125,1063.333,
1092.542,1121.708,1150.917,1180.083,1198.250,
1198.258,1198.279,1198.284,1198.294,1198.324,
1198.330,1198.339,1198.347,1198.356,1198.617,
1198.620,1198.625,1198.793,1198.795,1198.796,
1198.797,1198.804,
qmpy =
1.000,2.000,3.000,4.000,4.907,
4.633,4.542,4.572,4.694,4.755,
4.785,4.785,4.755,4.724,4.724,
4.724,7.224,7.041,7.010,6.980,
6.858,6.736,6.645,6.553,6.462,
6.370,6.340,6.309,6.309,6.248,
6.248,6.309,6.126,6.066,6.005,
5.944,5.883,5.852,5.822,5.791,
5.822,5.822,5.822,6.888,6.462,
6.431,6.340,6.126,5.944,5.761,
5.608,5.486,5.364,5.304,5.304,
0.549,2.377,2.865,3.536,4.328,
4.785,5.182,5.639,6.035,6.584,
7.681,8.534,9.083,7.285,3.536,
1.1676,0.518,
slim = .05,
$end
```

GE-2 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='GE2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='GE2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
RISO-3 Rod GE2 Refabricated from segment ZX114
 $frpcn
 im=267, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4827, thkcld=0.03209, thkgap=0.00433, totl=0.95144, cpl=3.478
 dspg=0.4098, dspgw=0.0394, vs=10
 hplt=0.4098, rc=0, hdish=0, dishsd=0.2049
 enrch=3, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=43.8, tsint=2911
 icm=2, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=95.73, idxgas=1
 iplant=-3, pitch=0.6417, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 4.673, 13.57, 26.584, 41.469, 49.029
```

54.848, 63.814, 73.828, 76.925, 86.29
92.61, 105.303, 114.861, 124.58, 134.816
145.097, 151.89, 162.126, 172.737, 176.149
183.821, 188.012, 192.202, 196.304, 204.506
208.543, 224.608, 229.064, 237.827, 242.158
246.466, 250.774, 254.311, 258.524, 263.435
267.09, 270.744, 278.123, 281.812, 289.226
303.639, 310.845, 318.331, 325.605, 334.318
337.972, 345.532, 349.446, 361.07, 369.06
377.22, 389.59, 398.453, 407.687, 416.977
426.496, 431.315, 436.195, 441.138, 451.218
456.358, 466.849, 477.709, 488.724, 494.353
499.054, 508.344, 518.104, 527.565, 537.026
546.605, 551.335, 556.125, 565.763, 585.161
590.041, 599.331, 604.033, 618.4, 627.015
635.728, 644.591, 649.698, 660.117, 666.386
679.131, 684.271, 693.561, 702.965, 707.666
726.705, 731.378, 736.023, 746.169, 761.19
770.889, 780.408, 785.383, 795.205, 800.085
814.543, 819.245, 833.013, 842.36, 846.977
854.251, 858.465, 867.644, 876.934, 886.168
900.626, 905.569, 915.518, 925.597, 941.019
951.581, 956.899, 967.836, 978.93, 996.323
1008.278, 1026.492, 1039.237, 1056.183, 1064.657
1077.437, 1090.36, 1099.82, 1112.743, 1125.887
1130.37, 1138.89, 1152.261, 1161.44, 1166.685
1176.831, 1186.977, 1198.071, 1203.783, 1215.04
1226.548, 1236.562, 1251.681, 1257.073, 1268.581
1273.064, 1281.927, 1290.841, 1295.784, 1304.75
1313.086, 1317.165, 1329.213, 1333.188, 1341.097
1345.071, 1352.899, 1360.688, 1368.72, 1381.938
1386.27, 1390.554, 1394.838, 1399.194, 1408.108
1417.233, 1422.144, 1434.192, 1441.398, 1447.24
1458.496, 1469.671, 1475.743, 1482.063, 1487.775
1499.198, 1511.153, 1518.292, 1530.246, 1535.715
1546.499, 1551.78, 1557.173, 1566.995, 1572.205
1582.219, 1587.13, 1596.89, 1601.297, 1605.806
1610.315, 1614.824, 1623.895, 1628.458, 1637.583
1647.344, 1656.982, 1661.742, 1671.203, 1676.114
1681.088, 1685.878, 1690.789, 1704.808, 1709.51
1714.183, 1723.586, 1733.936, 1739.111, 1744.286
1754.849, 1763.23, 1771.611, 1776.094, 1785.008
1789.389, 1793.77, 1807.219, 1816.344, 1820.801
1829.98, 1835.912, 1841.157, 1850.175, 1865.1
1870.607, 1870.675, 1870.677, 1870.698, 1870.717
1870.753, 1870.754, 1870.769, 1870.942, 1870.943
1871.108, 1871.118, 1871.278, 1871.443, 1871.611
1871.776, 1871.781, 1872.691, 1872.693, 1872.703
1872.714, 1872.723, 1872.734, 1872.745, 1872.754
1872.756, 1873.547, 1873.548, 1873.556, 1873.558
1873.568, 1873.579, 1873.588, 1873.589, 1873.599
1873.609, 1873.62, 1873.622, 1873.623, 1873.624
1873.629, 1873.641
qmpy=
5.974, 8.87, 8.077, 8.931, 7.102
9.297, 9.053, 8.016, 8.352, 8.291
8.26, 8.291, 8.26, 8.108, 7.62

```
7.62, 7.62, 7.59, 7.224, 7.498
6.309, 6.066, 6.005, 5.974, 5.944
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qf(1)=
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x(6)=
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qf(6)=
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GE-4 Cladding Hoop Strain Case

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* GOESOUTS:
FILE06='GE4.out',
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FILE66='GE4.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
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 dspg=0.4098, dspgw=0.0394, vs=10
 hplt=0.4098, rc=0, hdish=0, dishsd=0.2049
 enrch=2.6, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=96.2, deng=0, roughf=0.0000787, rsntr=32.9, tsint=2911
 icm=2, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=95.73, idxgas=1
 iplant=-3, pitch=0.6417, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
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iq=0, fa=1
x(1)=
0, 0.22064, 0.44127, 0.66191, 0.88255
qf(1)=
1.002, 1.004, 1.002, 0.998, 0.994
x(6)=
0, 0.22064, 0.44127, 0.66191, 0.88255
qf(6)=
0.984, 1.006, 1.025, 1.017, 0.968
jn=5,5
jst=
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GE-6 Cladding Hoop Strain Case

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* GOESOUTS:
FILE06='GE6.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='GE6.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
RISO-3 Rod GE6 Refabricated from segment ZX113
 $frpcn
 im=298, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4827, thkcld=0.03209, thkgap=0.00433, totl=0.96129, cpl=3.4071
 dspg=0.4098, dspgw=0.0394, vs=10
 hplt=0.4098, rc=0, hdish=0, dishsd=0.2049
 enrch=3, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=44, tsint=2911
 icm=2, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=95.73, idxgas=1
 iplant=-3, pitch=0.6417, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 6.174, 14.846, 29.227, 41.81, 51.458
 55.794, 64.665, 75.743, 79.401, 86.822
 94.035, 104.512, 114.535, 124.263, 134.884
 145.457, 152.256, 162.547, 172.93, 176.33
 179.886, 187.033, 190.071, 196.124, 199.224
 205.423, 211.698, 225.004, 231.409, 238.091
 241.521, 248.538, 252.849, 256.89, 260.066
 263.984, 267.108, 270.271, 280.082, 283.528
 290.674, 305.588, 313.463, 318.057, 325.203
 333.638, 341.554, 345.703, 349.681, 362.13
 371.209, 380.738, 390.893, 395.904, 406.55
 417.654, 430.003, 436.329, 443.475, 450.968
 459.008, 467.879, 477.178, 487.072, 495.843
 500.464, 511.158, 519.35, 528.354, 539.93
 545.9, 552.611, 556.806, 624.669, 628.647
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1691.76, 1698.841, 1705.732, 1712.328, 1719.04
1725.693, 1732.124, 1744.988, 1751.262, 1757.436
1763.815, 1770.193, 1775.953, 1781.844, 1787.827
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1886.035, 1894.074, 1907.155, 1914.505, 1914.566
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1914.887, 1914.891, 1915.095, 1915.716, 1915.717
1915.726, 1915.727, 1915.728, 1915.736, 1915.737
1915.746, 1915.748, 1915.757, 1915.768, 1915.777
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iq=0, fa=1
x(1)=
0, 0.24032, 0.48064, 0.72096, 0.96129
qf(1)=
0.944, 0.992, 1.013, 1.023, 1.028
x(6)=
0, 0.24032, 0.48064, 0.72096, 0.96129
qf(6)=
1.004, 1.002, 1.019, 1.023, 0.952
jn=5,5
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GE-7 Cladding Hoop Strain Case

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* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='GE7.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='GE7.plot',
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/**********************************************************************
RISO-3 Rod GE7 Tested on segment ZX115 w/o refabrication
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 im=249, nr=17, ngasr=45, na=9
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 dco=0.4827, thkcld=0.03209, thkgap=0.00433, totl=2.50033, cpl=5.6417
 dspg=0.4098, dspgw=0.0394, vs=15
 hplt=0.4098, rc=0, hdish=0, dishsd=0.2049
 enrch=3, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95.2, deng=0, roughf=0.0000787, rsntr=44, tsint=2911
 icm=2, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=42.06, idxgas=1
iplant=-3, pitch=0.6417, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
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1.38907, 1.66689, 1.9447, 2.22252, 2.50033
qf(1)=
0.983, 1.014, 1.027, 1.027, 1.025
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x(11)=
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AN1 Cladding Hoop Strain Case

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         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
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        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='AN1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
RISO-3 Rod AN1 refabricated from segment CB9
 $frpcn
 im=93, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4256, thkcld=0.03055, thkgap=0.00404, totl=0.96785, cpl=3.515
 dspg=0.3564, dspgw=0.0394, vs=10
 hplt=0.272, rc=0, hdish=0.0113, dishsd=0.0892
 enrch=2.95, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=93.74, deng=0, roughf=0.0000787, rsntr=20, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=192.9, idxgas=1
 iplant=-2, pitch=0.5512, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
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549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6
go=
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0
iq=0, fa=1
x(1)=
0, 0.24196, 0.48392, 0.72589, 0.96785
qf(1)=
1.009, 0.997, 0.983, 1.001, 1.01
x(6)=
0, 0.24196, 0.48392, 0.72589, 0.96785
qf(6)=
0.983, 1.031, 1.059, 0.995, 0.933
jn=5,5
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, 1, 1
 1, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
```

AN8 Cladding Hoop Strain Case

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='AN8.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='AN8.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
RISO-3 Rod AN8 tests on the segment CB10
 $frpcn
 im=68, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4256, thkcld=0.03049, thkgap=0.00409, totl=1.77756, cpl=2.4
 dspg=0.3564, dspgw=0.0394, vs=10
 hplt=0.272, rc=0, hdish=0.0113, dishsd=0.0892
 enrch=2.95, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=93.74, deng=0, roughf=0.0000787, rsntr=20, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=335.04, idxgas=1
 iplant=-2, pitch=0.5512, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=0, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 4.375, 14.583, 29.167, 58.333, 87.5
 116.667, 145.833, 175, 204.167, 233.333
 262.5, 273.5, 277.875, 288.083, 302.667
 331.833, 361, 390.167, 419.333, 448.5
 477.667, 506.833, 536, 565.167, 594.333
 623.5, 636.583, 640.958, 651.167, 665.75
 694.917, 724.083, 753.25, 782.375, 811.542
 840.708, 869.875, 899.042, 917.375, 921.75
```

```
931.958, 946.583, 975.75, 1004.958, 1034.125
1063.333, 1092.542, 1121.708, 1150.917, 1180.083
1198.25, 1198.32, 1198.341, 1198.346, 1198.356
1198.386, 1198.392, 1198.401, 1198.409, 1198.418
1198.679, 1198.683, 1198.687, 1198.856, 1198.857
1198.858, 1198.859, 1198.866
qmpy=
4.907, 4.633, 4.542, 4.572, 4.694
4.755, 4.785, 4.785, 4.755, 4.724
4.724, 4.724, 7.224, 7.041, 7.01
6.98, 6.858, 6.736, 6.645, 6.553
6.462, 6.37, 6.34, 6.309, 6.309
6.248, 6.248, 6.309, 6.127, 6.066
6.005, 5.944, 5.883, 5.852, 5.822
5.791, 5.822, 5.822, 5.822, 6.889
6.462, 6.431, 6.34, 6.127, 5.944
5.761, 5.608, 5.486, 5.365, 5.304
5.304, 0.555, 2.411, 2.893, 3.572
4.377, 4.84, 5.24, 5.7, 6.102
6.654, 7.763, 8.626, 9.178, 7.361
3.572, 1.695, 0.521
nsp=1
p2=
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2250.99, 2250.99, 2250.99, 2250.99
2250.99, 2219.08, 2219.08, 2219.08, 2219.08
2219.08, 2219.08, 2219.08, 2219.08, 2219.08
2219.08, 2219.08, 2219.08, 2219.08, 2219.08
2219.08, 2219.08, 2219.08
tw=
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 549.9, 549.9, 549.9, 549.9
549.9, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6, 638.6, 638.6
638.6, 638.6, 638.6
go=
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
2610000, 2610000, 2610000, 2610000, 2610000
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 2610000, 2610000, 2610000, 2610000, 2610000
 2610000, 2610000, 2610000, 2610000, 2610000
 2610000, 2610000, 2610000, 2610000, 2610000
 2610000, 2610000, 2610000, 2610000, 2610000
 2610000, 2610000, 2610000, 2610000, 2610000
 2610000, 2610000, 2610000, 2610000, 2610000
 2610000, 0, 0, 0, 0
 0, 0, 0, 0, 0
 0, 0, 0, 0, 0
 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.19751, 0.39501, 0.59252, 0.79003
 0.98753, 1.18504, 1.38255, 1.58005, 1.77756
 qf(1)=
 1.012, 1.004, 1.004, 0.995, 0.974
 0.996, 1.007, 1.007, 0.999, 1.003
 x(11)=
 0, 0.19751, 0.39501, 0.59252, 0.79003
 0.98753, 1.18504, 1.38255, 1.58005, 1.77756
 qf(11)=
 1.53105280637662, 1.56758551976088, 1.4546662238459, 1.43141813351046,
1.17568913982066
 0.956492859515111, 0.743938890733975, 0.551311856526071,
0.371969445366988, 0.215875124543341
 jn=10,10
 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, 1, 1
 1, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
```

A.42 B&W Rods Ramped at Studsvik

Three well-characterized 1.10 m long rodlets that had been irradiated to burnups slightly greater than 62 GWd/MTU in ANO-1 were ramp tested in the Studsvik R2 experimental reactor (Wesley et al., 1994). Peak power levels of 39.5, 42.0, and 44.0 kW/m and a 12 hour hold time were selected for these tests. No failures were experienced during testing and no incipient cracks were detected in the cladding during the post-ramp examinations. The FGR after the ramp was measured. Two of these rods (rods 1 and 3) were used in the assessment of the FRAPCON-3.4 UO_2 FGR predictions.

The input files for these two rods are shown below.

B&W Rod 1 Ramped at Studsvik

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outBWstudR1.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='plotBWstudr1.out', STATUS='UNKNOWN', FORM='FORMATTED'
/**********************************************************************
B&W Rod 14334L (C13) Rod 1
 $frpcn
 im=37, na=10, nr = 25,
 mechan = 2,ngasr = 45
 $end
 $frpcon
 cpl = 8.55, crdt = 1., crdtr = 0.0, dco = 0.430,
 thkcld = 0.030, thkgap = 0.0037,
 den = 95.0, dishsd = 0.05, dspg = 0.33,
 dspgw = 0.055, enrch = 2.95, fgpav = 400.0, hdish = 0.0135,
 hplt = 0.418, icm = 4,pitch = 0.56,
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 5,9, crephr = 1.0,
 totl = 2.90, roughc = 2e-5, roughf = 3e-5, vs = 8.0,
 nunits = 1, rsntr = 150.,nsp=0, nplot = 1,
 flux(1) = 11*0.26e17, p2(1) = 2200.0, tw(1) = 555.,
 go(1) = 3.e6,
 jst = 31*1,6*2,
 qf(1) = 1.00,1.00,1.00,1.00,1.00,
  x(1) = 0.000,0.725,1.450,2.175,2.900,
 qf(6) = 0.36,1.41,1.75,1.79,1.71,1.61,1.25,0.46,0.05,
  x(6) = 0.00,0.57,0.90,1.07,1.23,1.48,1.64,2.21,2.90,
 ProblemTime=
 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7,
 52.9, 150.0, 248.3, 358.9, 482.0, 544.7,
  561.8, 677.5, 777.9, 913.6, 966.5, 995.6,1016.9,
 1084.9,1182.0,1354.2,1471.9,1567.1,1604.9,1770.1,
 1872.2,2032.5,2083.3,2138.5, 2138.75, 2139.0, 2140.0,
 2140.5, 2140.75, 2141.0
 qmpy =
  1., 2., 3., 4., 5., 6., 7.,
  7.60, 8.01, 7.60, 6.21, 6.16, 4.93, 7.36,
  7.41, 7.42, 6.58, 6.16, 5.55, 5.52, 5.44, 5.49,
  5.16, 4.57, 4.06, 4.12, 3.23, 3.40, 3.25, 3.22,
```

```
  2.75, 2.73, 3.6, 4.61, 5.6, 6.74, 6.74
 slim = .05, nplot =1,
 $end
```

B&W Rod 3 Ramped at Studsvik

```
* GOESINS:
FILE05='nullfile', STATUS='scratch', FORM='FORMATTED',
         CARRIAGE CONTROL='LIST'
*
* GOESOUTS:
FILE06='outBWstudR3.n',    STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
/*****************************************************************
B&W Rod 14334L (N3) Rod 3
 $frpcn
 im=30, na=15,
 mechan = 2,ngasr = 45
 $end
 $frpcon
 cpl = 8.55, crdt = 1., crdtr = 0.0, dco = 0.430,
 thkcld = 0.030, thkgap = 0.0037,
 den = 95.0, dishsd = 0.05, dspg = 0.33,
 dspgw = 0.055, enrch = 2.95, fgpav = 400.0, hdish = 0.0135,
 hplt = 0.418, icm = 4,pitch = 0.56,crephr=1.0
 icor = 0, idxgas = 1, iplant =-2, iq = 0, jdlpr = 0,fa = 1.0,
 jn = 5,9,
 totl = 2.90, roughc = 2e-5, roughf = 3e-5, vs = 8.0,
 nunits = 1, rsntr = 150.,nsp=0,
 flux(1) = 16*0.26e17, p2(1) = 2200.0, tw(1) = 555.,
 go(1) = 3.e6,
 jst = 24*1, 6*2,
 qf(1) = 1.00,1.00,1.00,1.00,1.00,
  x(1) = 0.000,0.725,1.450,2.175,2.900,
 qf(6) = 0.36,1.41,1.75,1.79,1.71,1.61,1.25,0.46,0.05,
  x(6) = 0.00,0.57,0.90,1.07,1.23,1.48,1.64,2.21,2.90,
 ProblemTime=    52.9, 150.0, 248.3, 358.9, 482.0, 544.7,
  561.8, 677.5, 777.9, 913.6, 966.5, 995.6,1016.9,
 1084.9,1182.0,1354.2,1471.9,1567.1,1604.9,1770.1,
 1872.2,2032.5,2083.3,2138.5,2140.30,2140.35,2140.4,
 2140.45, 2140.5, 2140.75, 2141.0
 qmpy = 8.23, 7.64, 6.89, 6.27, 7.39, 5.13, 7.16,
  7.35, 7.23, 6.83, 6.12, 6.20, 5.93, 4.97, 5.39,
  5.17, 4.52, 4.05, 4.09, 3.34, 3.18, 3.32, 3.37,
  2.69, 2.73, 3.50, 4.61, 5.50, 6.50, 7.52, 7.52
 slim = .05,
 $end
```

A.43 Regate Rod

This Regate experiment (Struzik, 2004) deals with the study of FGR and fuel swelling during power transient at medium burnup. The rod was base-irradiated in the Gravelines-5 PWR and then re-irradiated in the test reactor SILOE in Grenoble, France. Since the rod was initially a segmented rod, the refabrication process prior to loading in the test is minor. In particular, the rod was not purged of its fission gases following refabrication.

The segmented rod consisted of UO_2 fuel with 4.5 percent enrichment. It was irradiated up to 47 GWd/MTU. In the SILOE reactor, the rod was given a conditioning power step of 195 W/cm for 48 hours and then was ramped at 10W/cm/min and held at 385 W/cm for 90 minutes. This rod is particularly valuable for examining FGR for power ramps of short time duration because the other power ramped UO_2 rods used for FRAPCON-3.4 assessment were for hold times of 4) hours or greater.

This rod was used as part of the FRAPCON-3.4 UO_2 FGR assessment. The input file used for the UO_2 FGR assessment is shown below.

Regate Rod

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='REGATE.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='regate.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
REGATE L10
 $frpcn
 im=65, nr=17, ngasr=45, na=7
 $end
 $frpcon
 dco=0.374, thkcld=0.02244, thkgap=0.00331, totl=1.43045, cpl=1.8504
 dspg=0.319, dspgw=0.04, vs=4
 hplt=0.5512, rc=0, hdish=0.0126, dishsd=0.0431
 enrch=4.5, imox=0, comp=0
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=94.75, deng=0.57, roughf=0.000025, rsntr=74, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=377.1, idxgas=1
iplant=-2, pitch=0.496, icor=0, crdt=0, crdtr=0,
flux=8*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 0.5, 21.18, 53.8, 83.45, 116.39
 147.97, 176.44, 204.92, 240.66, 271.29
 274.29, 283.13, 316.4, 346.61, 375.68
 407.7, 439.54, 470.84, 503.33, 560.24
 588.37, 590.57, 600.54, 632.65, 659.29
 684.85, 714.43, 742.4, 768.6, 796.83
 823.73, 850.63, 857.97, 868.32, 897.7
```

```
926.16, 957.52, 1039.06, 1067.15, 1099.1
1135.84, 1138.97, 1139.03, 1139.04, 1139.73
1139.74, 1145.75, 1145.753, 1145.76, 1145.77
1145.78, 1145.79, 1145.793, 1147.78, 1147.8
1147.86, 1147.87, 1150.86, 1150.862, 1152.49
1152.5, 1152.51, 1152.511, 1152.53, 1152.531
qmpy=
1.524, 3.444, 6.706, 6.584, 6.462
6.248, 6.248, 6.096, 6.127, 5.791
5.791, 4.054, 7.864, 7.712, 7.529
7.529, 7.468, 7.254, 7.163, 6.614
5.639, 5.029, 3.444, 6.675, 6.584
6.431, 6.309, 6.37, 6.309, 6.37
6.37, 6.188, 6.188, 3.109, 6.096
6.096, 5.944, 5.791, 5.73, 5.639
5.669, 5.669, 2.399, 3.277, 4.176
2.088, 4.176, 2.088, 1.158, 2.286
2.481, 2.649, 4.033, 5.416, 8.032
10.732, 8.032, 5.416, 3.837, 2.344
2.173, 2.003, 1.835, 1.664, 0.82
nsp=1
p2=
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 1885.2, 1885.2, 1885.2
1885.2, 1885.2, 1885.2, 1885.2, 1885.2
1885.2, 1885.2, 1885.2, 1885.2, 1885.2
1885.2, 1885.2, 1885.2, 1885.2, 1885.2
1885.2, 1885.2, 1885.2, 1885.2, 1885.2
tw=
608, 608, 608, 608, 608
608, 608, 608, 608, 608
608, 608, 608, 608, 608
608, 608, 608, 608, 608
608, 608, 608, 608, 608
608, 608, 608, 608, 608
608, 608, 608, 608, 608
608, 608, 608, 608, 608
608, 608, 368.6, 446, 514.4
338, 514.4, 338, 233.6, 356
374, 392, 505.4, 588.2, 636.8
640.4, 636.8, 588.2, 492.8, 361.4
345.2, 329, 311, 293, 194
go=
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
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2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
2653331, 2653331, 2653331, 2653331, 2653331
iq=0, fa=1
x(1)=
0, 0.20433, 0.40866, 0.61299, 0.81729
1.02162, 1.22595, 1.43045
qf(1)=
1, 1, 1, 1, 1
1, 1, 1
x(9)=
0, 0.20433, 0.40866, 0.61299, 0.81729
1.02162, 1.22595, 1.43045
qf(9)=
0.727, 0.854, 1.017, 1.068, 1.079
1.085, 1.037, 0.952
jn=8,8
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, 1, 1
1, 1, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2, 2, 2
$end
```

A.44 Beznau-1 M501 Rods

Two MOX rods were irradiated for three cycles in the Beznau-1 PWR up to a rod-average burnup between 34 and 37 GWd/MTM. The MOX fuel was fabricated using SBR that results in a relatively homogenous distribution of the PuO_2. One of these rods had a high plutonium enrichment (5.54 wt%) and one had a medium plutonium enrichment (3.72 wt%). After this, eight rodlets were refabricated from these two rods. Rodlets HR-1 to HR-4 (White et al., 2001; Cook et al., 2000, 2003, 2004) were refabricated from the high-enrichment rod, number 4463, and rodlets MR-1 to MR-4 (White et al., 2001; Cook et al., 2000, 2003, 2004) were refabricated from the medium enrichment rod, number 7612. These rodlets were ramp tested in the Petten high flux reactor. The ramp consisted of a 60 hour hold time at a preconditioning level followed by a ramp to a higher level with a hold of 12 hours for all the rodlets except MR-4, which was only held at the higher level for 20 minutes. It should be noted that the preconditioning and ramp power levels listed in the documents are the peak node powers. These values have been divided by the peak-to-average ratio to determine the rod-average power levels for these ramp tests.

These eight rodlets were used to assess the FRAPCON-3.4 MOX FGR predictions. The input files used for the MOX temperature and FGR assessments are shown below.

M501 Rod HR1

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M501-HR1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-HR1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet HR-1
 $frpcn
 im=48, nr=17, ngasr=45, na=10
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.6732
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.3, imox=1, comp=5.54
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=340.84, idxgas=1
iplant=-2, pitch=0.5799, icor=0, crdt=0, crdtr=0,
flux=11*221000000000000000
 crephr=10, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 36.9, 75.2, 110.7, 144.9, 181.8
 215.9, 252.8, 291.1, 311.6, 319.8
 330.7, 363.5, 399.8, 436, 474.2
 509.8, 545.3, 583.8, 620.5, 657.4
 673.8, 684.7, 694.3, 740.8, 774.9
 810.5, 833.7, 882.9, 918.4, 953.9
```

```
990.9, 1026.4, 1072.9, 1089.3, 1123.4
1133, 1141.6, 1142.1, 1142.6, 1143.1
1143.6, 1144.1, 1144.6, 1145.1, 1145.6
1146.1, 1146.6, 1147.1
qmpy=
6.569, 6.508, 6.514, 6.517, 6.526
6.544, 6.562, 6.581, 6.593, 6.599
6.633, 7.041, 7.254, 7.254, 7.285
7.315, 7.331, 7.346, 7.376, 7.391
7.391, 7.391, 7.407, 7.163, 6.828
6.919, 6.98, 7.01, 7.01, 7.041
7.071, 7.071, 7.102, 7.132, 7.132
7.102, 7.102, 7.09, 7.09, 7.09
7.09, 7.09, 7.09, 7.09, 7.09
7.09, 7.09, 11.625
nsp=1
p2=
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08
tw=
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 632.1, 632.1, 632.1
632.1, 632.1, 632.1, 632.1, 632.1
632.1, 632.1, 644
go=
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0
iq=0, fa=1
x(1)=
0, 0.09843, 0.19685, 0.29528, 0.3937
0.49213, 0.59055, 0.68898, 0.7874, 0.88583
0.98425
qf(1)=
1, 1, 1, 1, 1
1, 1, 1, 1, 1
```

```
       1
 x(12)=
 0, 0.04921, 0.14764, 0.24606, 0.34449
 0.44291, 0.54134, 0.63976, 0.73819, 0.83661
 0.93504, 0.98425
 qf(12)=
 29.875, 31.27, 34.06, 36.81, 39.03
 40.42, 41, 40.92, 40.26, 39.36
 38.29, 37.755
 jn=11,12
 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, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
 $frpmox
 enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
 $end
```

M501 Rod HR2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M501-HR2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-HR2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet HR-2
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.689
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.3, imox=1, comp=5.54
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=335.04, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 36.9, 75.2, 110.7, 144.9, 181.8
 215.9, 252.8, 291.1, 311.6, 319.8
```

```
330.7, 363.5, 399.8, 436, 474.2
509.8, 545.3, 583.8, 620.5, 657.4
673.8, 684.7, 694.3, 740.8, 774.9
810.5, 833.7, 882.9, 918.4, 953.9
990.9, 1026.4, 1072.9, 1089.3, 1123.4
1133, 1141.6, 1142.1, 1142.6, 1143.1
1143.6, 1144.1, 1144.6, 1145.1, 1145.6
1146.1, 1146.6, 1147.1
qmpy=
6.569, 6.508, 6.514, 6.517, 6.526
6.544, 6.562, 6.581, 6.593, 6.599
6.633, 7.041, 7.254, 7.254, 7.285
7.315, 7.331, 7.346, 7.376, 7.391
7.391, 7.391, 7.407, 7.163, 6.828
6.919, 6.98, 7.01, 7.01, 7.041
7.071, 7.071, 7.102, 7.132, 7.132
7.102, 7.102, 8.382, 8.382, 8.382
8.382, 8.382, 8.382, 8.382, 8.382
8.382, 8.382, 10.872
nsp=1
p2=
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08
tw=
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 644, 644, 644
644, 644, 644, 644, 644
644, 644, 644
go=
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0
iq=0, fa=1
x(1)=
0, 0.09843, 0.19685, 0.29528, 0.3937
0.49213, 0.59055, 0.68898, 0.7874, 0.88583
```

```
 0.98425
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 x(12)=
 0, 0.04921, 0.14764, 0.24606, 0.34449
 0.44291, 0.54134, 0.63976, 0.73819, 0.83661
 0.93504, 0.98425
 qf(12)=
 26.7, 28.02, 30.66, 33.46, 35.87
 37.54, 38.51, 38.86, 38.7, 38.08
 36.99, 36.445
 jn=11,12
 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, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
 $frpmox
 enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
 $end
```

M501 Rod HR3

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M501-HR3.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-HR3.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet HR-3
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.6772
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.3, imox=1, comp=5.54
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=336.49, idxgas=1
iplant=-2, pitch=0.5799, icor=0, crdt=0, crdtr=0,
flux=10*221000000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
```

```
jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
ProblemTime=
36.9, 75.2, 110.7, 144.9, 181.8
215.9, 252.8, 291.1, 311.6, 319.8
330.7, 363.5, 399.8, 436, 474.2
509.8, 545.3, 583.8, 620.5, 657.4
673.8, 684.7, 694.3, 740.8, 774.9
810.5, 833.7, 882.9, 918.4, 953.9
990.9, 1026.4, 1072.9, 1089.3, 1123.4
1133, 1141.6, 1142.1, 1142.6, 1143.1
1143.6, 1144.1, 1144.6, 1145.1, 1145.6
1146.1, 1146.6, 1147.1
qmpy=
6.569, 6.508, 6.514, 6.517, 6.526
6.544, 6.562, 6.581, 6.593, 6.599
6.633, 7.041, 7.254, 7.254, 7.285
7.315, 7.331, 7.346, 7.376, 7.391
7.391, 7.391, 7.407, 7.163, 6.828
6.919, 6.98, 7.01, 7.01, 7.041
7.071, 7.071, 7.102, 7.132, 7.132
7.102, 7.102, 5.855, 5.855, 5.855
5.855, 5.855, 5.855, 5.855, 5.855
5.855, 5.855, 14.073
nsp=1
p2=
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08, 2248.08, 2248.08
2248.08, 2248.08, 2248.08
tw=
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 578.3, 578.3, 578.3
578.3, 578.3, 578.3, 578.3, 578.3
578.3, 578.3, 644
go=
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0
```

```
 iq=0, fa=1
 x(1)=
 0, 0.09843, 0.19685, 0.29528, 0.3937
 0.49213, 0.59055, 0.68898, 0.7874, 0.88583
 0.98425
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 x(12)=
 0, 0.04921, 0.14764, 0.24606, 0.34449
 0.44291, 0.54134, 0.63976, 0.73819, 0.83661
 0.93504, 0.98425
 qf(12)=
 35.3, 36.94, 40.22, 43.61, 46.53
 48.75, 50.07, 50.47, 50.02, 48.65
 46.43, 45.32
 jn=11,12
 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, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
 $frpmox
 enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
 $end
```

M501 Rod HR4

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M501-HR4.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-HR4.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet HR-4
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.6732
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.3, imox=1, comp=5.54
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
```

```
 fgpav=333.59, idxgas=1
 iplant=-2, pitch=0.5799, icor=0, crdt=0, crdtr=0,
flux=10*22100000000000000
 crephr=1, sgapf=31, slim=0.05, qend=0.3
 jdlpr=1, nopt=0, nplot=1, ntape=0, nread=0, nrestr=0
 ProblemTime=
 36.9, 75.2, 110.7, 144.9, 181.8
 215.9, 252.8, 291.1, 311.6, 319.8
 330.7, 363.5, 399.8, 436, 474.2
 509.8, 545.3, 583.8, 620.5, 657.4
 673.8, 684.7, 694.3, 740.8, 774.9
 810.5, 833.7, 882.9, 918.4, 953.9
 990.9, 1026.4, 1072.9, 1089.3, 1123.4
 1133, 1141.6, 1142.1, 1142.6, 1143.1
 1143.6, 1144.1, 1144.6, 1145.1, 1145.6
 1146.1, 1146.6, 1147.1
 qmpy=
 6.569, 6.508, 6.514, 6.517, 6.526
 6.544, 6.562, 6.581, 6.593, 6.599
 6.633, 7.041, 7.254, 7.254, 7.285
 7.315, 7.331, 7.346, 7.376, 7.391
 7.391, 7.391, 7.407, 7.163, 6.828
 6.919, 6.98, 7.01, 7.01, 7.041
 7.071, 7.071, 7.102, 7.132, 7.132
 7.102, 7.102, 7.014, 7.014, 7.014
 7.014, 7.014, 7.014, 7.014, 7.014
 7.014, 7.014, 14.32
 nsp=1
 p2=
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08
 tw=
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 629.4, 629.4, 629.4
 629.4, 629.4, 629.4, 629.4, 629.4
 629.4, 629.4, 644
 go=
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
```

```
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 0, 0, 0
 0, 0, 0, 0, 0
 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.09843, 0.19685, 0.29528, 0.3937
 0.49213, 0.59055, 0.68898, 0.7874, 0.88583
 0.98425
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 x(12)=
 0, 0.04921, 0.14764, 0.24606, 0.34449
 0.44291, 0.54134, 0.63976, 0.73819, 0.83661
 0.93504, 0.98425
 qf(12)=
 35.605, 37.65, 41.74, 45.32, 48.13
 50.02, 50.99, 51.04, 50.17, 48.54
 46.24, 45.09
 jn=11,12
 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, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
 $frpmox
 enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
 $end
```

M501 Rod MR1

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M501-MR1.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-MR1.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet MR-1
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.6654
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
```

```
 enrch=0.3, imox=1, comp=3.72
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=336.49, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 36.9, 75.2, 110.7, 144.9, 181.8
 215.9, 252.8, 291.1, 311.6, 319.8
 330.7, 363.5, 399.8, 436, 474.2
 509.8, 545.3, 583.8, 620.5, 657.4
 673.8, 684.7, 694.3, 740.8, 774.9
 810.5, 833.7, 882.9, 918.4, 953.9
 990.9, 1026.4, 1072.9, 1089.3, 1123.4
 1133, 1141.6, 1142.1, 1142.6, 1143.1
 1143.6, 1144.1, 1144.6, 1145.1, 1145.6
 1146.1, 1146.6, 1147.1
 qmpy=
 4.7, 4.682, 4.703, 4.731, 4.755
 4.788, 4.801, 4.825, 4.849, 4.859
 4.868, 5.98, 6.895, 6.895, 6.87
 6.867, 6.867, 6.867, 6.855, 6.855
 6.837, 6.828, 6.837, 6.907, 6.946
 6.937, 6.898, 6.898, 6.898, 6.757
 6.733, 6.69, 6.672, 6.648, 6.617
 6.59, 6.593, 5.618, 5.618, 5.618
 5.618, 5.618, 5.618, 5.618, 5.618
 5.618, 5.618, 11.622
 nsp=1
 p2=
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08
 tw=
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 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 566.2, 566.2, 566.2
 566.2, 566.2, 566.2, 566.2, 566.2
 566.2, 566.2, 644
 go=
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
```

```
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 0, 0, 0
 0, 0, 0, 0, 0
 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.09843, 0.19685, 0.29528, 0.3937
 0.49213, 0.59055, 0.68898, 0.7874, 0.88583
 0.98425
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 x(12)=
 0, 0.04921, 0.14764, 0.24606, 0.34449
 0.44291, 0.54134, 0.63976, 0.73819, 0.83661
 0.93504, 0.98425
 qf(12)=
 29.64, 31.13, 34.11, 36.88, 39.11
 40.64, 41.35, 41.27, 40.48, 39.11
 37.21, 36.26
 jn=11,12
 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, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
 $frpmox
 enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
 $end
```

M501 Rod MR2

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M501-MR2.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-MR2.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet MR-2
 $frpcn
 im=48, nr=17, ngasr=45, na=9
```

```
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.6732
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.3, imox=1, comp=3.72
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=339.39, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 36.9, 75.2, 110.7, 144.9, 181.8
 215.9, 252.8, 291.1, 311.6, 319.8
 330.7, 363.5, 399.8, 436, 474.2
 509.8, 545.3, 583.8, 620.5, 657.4
 673.8, 684.7, 694.3, 740.8, 774.9
 810.5, 833.7, 882.9, 918.4, 953.9
 990.9, 1026.4, 1072.9, 1089.3, 1123.4
 1133, 1141.6, 1142.1, 1142.6, 1143.1
 1143.6, 1144.1, 1144.6, 1145.1, 1145.6
 1146.1, 1146.6, 1147.1
 qmpy=
 4.7, 4.682, 4.703, 4.731, 4.755
 4.788, 4.801, 4.825, 4.849, 4.859
 4.868, 5.98, 6.895, 6.895, 6.87
 6.867, 6.867, 6.867, 6.855, 6.855
 6.837, 6.828, 6.837, 6.907, 6.946
 6.937, 6.898, 6.898, 6.898, 6.757
 6.733, 6.69, 6.672, 6.648, 6.617
 6.59, 6.593, 6.986, 6.986, 6.986
 6.986, 6.986, 6.986, 6.986, 6.986
 6.986, 6.986, 12.762
 nsp=1
 p2=
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08
 tw=
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 628.5, 628.5, 628.5
```

```
 628.5, 628.5, 628.5, 628.5, 628.5
 628.5, 628.5, 644
 go=
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 2650000, 2650000, 2650000
 2650000, 2650000, 0, 0, 0
 0, 0, 0, 0, 0
 0, 0, 0
 iq=0, fa=1
 x(1)=
 0, 0.09843, 0.19685, 0.29528, 0.3937
 0.49213, 0.59055, 0.68898, 0.7874, 0.88583
 0.98425
 qf(1)=
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
       1
 x(12)=
 0, 0.04921, 0.14764, 0.24606, 0.34449
 0.44291, 0.54134, 0.63976, 0.73819, 0.83661
 0.93504, 0.98425
 qf(12)=
 31.515, 34.25, 39.72, 42.46, 44.29
 45.66, 45.66, 44.75, 43.38, 41.09
 37.44, 35.615
 jn=11,12
 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, 1
 1, 1, 1, 1, 1
 1, 1, 1, 1, 1
 1, 1, 2, 2, 2
 2, 2, 2, 2, 2
 2, 2, 2
 $end
 $frpmox
 enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
 $end
```

M501 Rod MR3

```
* GOESINS:
FILE05='nullfile', STATUS='UNKNOWN', FORM='FORMATTED',
         CARRIAGE CONTROL='NONE'
*
* GOESOUTS:
FILE06='M501-MR3.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-MR3.plot',
```

```
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet MR-3
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.6063
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.3, imox=1, comp=3.72
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=336.49, idxgas=1
iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 36.9, 75.2, 110.7, 144.9, 181.8
 215.9, 252.8, 291.1, 311.6, 319.8
 330.7, 363.5, 399.8, 436, 474.2
 509.8, 545.3, 583.8, 620.5, 657.4
 673.8, 684.7, 694.3, 740.8, 774.9
 810.5, 833.7, 882.9, 918.4, 953.9
 990.9, 1026.4, 1072.9, 1089.3, 1123.4
 1133, 1141.6, 1142.1, 1142.6, 1143.1
 1143.6, 1144.1, 1144.6, 1145.1, 1145.6
 1146.1, 1146.6, 1147.1
 qmpy=
 4.7, 4.682, 4.703, 4.731, 4.755
 4.788, 4.801, 4.825, 4.849, 4.859
 4.868, 5.98, 6.895, 6.895, 6.87
 6.867, 6.867, 6.867, 6.855, 6.855
 6.837, 6.828, 6.837, 6.907, 6.946
 6.937, 6.898, 6.898, 6.898, 6.757
 6.733, 6.69, 6.672, 6.648, 6.617
 6.59, 6.593, 8.47, 8.47, 8.47
 8.47, 8.47, 8.47, 8.47, 8.47
 8.47, 8.47, 12.351
 nsp=1
 p2=
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
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 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
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 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08
 tw=
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
 550, 550, 550, 550, 550
```

```
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 644, 644, 644
644, 644, 644, 644, 644
644, 644, 644
go=
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
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2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0
iq=0, fa=1
x(1)=
0, 0.09843, 0.19685, 0.29528, 0.3937
0.49213, 0.59055, 0.68898, 0.7874, 0.88583
0.98425
qf(1)=
1, 1, 1, 1, 1
1, 1, 1, 1, 1
      1
x(12)=
0, 0.04921, 0.14764, 0.24606, 0.34449
0.44291, 0.54134, 0.63976, 0.73819, 0.83661
0.93504, 0.98425
qf(12)=
33.775, 35.11, 37.78, 40.5, 42.51
43.6, 43.74, 43.04, 41.68, 39.84
37.43, 36.225
jn=11,12
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, 1
1, 1, 1, 1, 1
1, 1, 1, 1, 1
1, 1, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2
$end
$frpmox
enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
$end
```

M501 Rod MR4

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

```
*
* GOESOUTS:
FILE06='M501-MR4.out',
        STATUS='UNKNOWN', CARRIAGE CONTROL='LIST'
FILE66='M501-MR4.plot',
        STATUS='UNKNOWN', FORM='FORMATTED',CARRIAGE CONTROL='LIST'
/**********************************************************************
M501 ramp tested rodlet MR-4
 $frpcn
 im=48, nr=17, ngasr=45, na=9
 $end
 $frpcon
 dco=0.4398, thkcld=0.02598, thkgap=0.00335, totl=0.98425, cpl=0.6575
 dspg=0.374, dspgw=0.05, vs=2
 hplt=0.6, rc=0, hdish=0.0113, dishsd=0.0969
 enrch=0.3, imox=1, comp=3.72
 fotmtl=2, gadoln=0, ppmh2o=0, ppmn2=0
 den=95, deng=0, roughf=0.0000787, rsntr=100, tsint=2911
 icm=4, cldwks=0.5, roughc=0.0000197, catexf=0.05, chorg=10
 fgpav=336.49, idxgas=1
 iplant=-2, pitch=0.5799, 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=0, nread=0, nrestr=0
 ProblemTime=
 36.9, 75.2, 110.7, 144.9, 181.8
 215.9, 252.8, 291.1, 311.6, 319.8
 330.7, 363.5, 399.8, 436, 474.2
 509.8, 545.3, 583.8, 620.5, 657.4
 673.8, 684.7, 694.3, 740.8, 774.9
 810.5, 833.7, 882.9, 918.4, 953.9
 990.9, 1026.4, 1072.9, 1089.3, 1123.4
 1133, 1141.6, 1142.1, 1142.6, 1143.1
 1143.6, 1144.1, 1144.6, 1145.1, 1145.6
 1146.1, 1146.6, 1146.61
 qmpy=
 4.7, 4.682, 4.703, 4.731, 4.755
 4.788, 4.801, 4.825, 4.849, 4.859
 4.868, 5.98, 6.895, 6.895, 6.87
 6.867, 6.867, 6.867, 6.855, 6.855
 6.837, 6.828, 6.837, 6.907, 6.946
 6.937, 6.898, 6.898, 6.898, 6.757
 6.733, 6.69, 6.672, 6.648, 6.617
 6.59, 6.593, 5.618, 5.618, 5.618
 5.618, 5.618, 5.618, 5.618, 5.618
 5.618, 5.618, 12.71
 nsp=1
 p2=
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 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
 2248.08, 2248.08, 2248.08, 2248.08, 2248.08
```

```
2248.08, 2248.08, 2248.08
tw=
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 550, 550, 550
550, 550, 566.2, 566.2, 566.2
566.2, 566.2, 566.2, 566.2, 566.2
566.2, 566.2, 644
go=
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 2650000, 2650000, 2650000
2650000, 2650000, 0, 0, 0
0, 0, 0, 0, 0
0, 0, 0
iq=0, fa=1
x(1)=
0, 0.09843, 0.19685, 0.29528, 0.3937
0.49213, 0.59055, 0.68898, 0.7874, 0.88583
0.98425
qf(1)=
1, 1, 1, 1, 1
1, 1, 1, 1, 1
      1
x(12)=
0, 0.04921, 0.14764, 0.24606, 0.34449
0.44291, 0.54134, 0.63976, 0.73819, 0.83661
0.93504, 0.98425
qf(12)=
32.495, 33.94, 36.83, 39.68, 42.08
43.89, 44.93, 45.25, 44.84, 43.71
41.8, 40.845
jn=11,12
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, 1
1, 1, 1, 1, 1
1, 1, 1, 1, 1
1, 1, 2, 2, 2
2, 2, 2, 2, 2
2, 2, 2
$end
$frpmox
enrpu39=70, enrpu40=25, enrpu41=5, enrpu42=0
$end
```

A.45 Studsvik Cladding Integrity Project Ramped Rods

The Studsvik Cladding Integrity Program (SCIP) has subjected 10 test rods to power ramp testing (Kallstrom, 2005). Each test rod was subjected to a designated type of ramp test, which included staircase, short hold, long hold, and two-step power ramp tests. Each test rod was fabricated from a rodlet sectioned from a previously irradiated father rod.

Four ramp test rods were made by refabricating rodlets from BWR father rods that had been irradiated in Kernkraftwerk, Leibstadt. These test rods were labeled KKL-1, KKL-2, KKL-3, and KKL-4 and were irradiated to approximately 63, 67, 56, and 40 megawatt-days per metric ton of uranium (MWd/kgU) average rodlet burnup, respectively. Before ramp testing, each rod was conditioned for a designated period of time and LHR. The first ramp test, KKL-1, was aimed at defining the ramp terminal level where rod failure would occur. The rod was subjected to a staircase ramp, and after six steps of 5 kW/m with a 1 hour hold time between steps, the rodlet failed after 40 minutes at an LHR of 42 kW/m. To determine if the failure, which was caused by an outside-in crack, was dependent on burnup, a similar test was performed on KKL-3. A staircase ramp consisting of eight steps at 5 kW/m with a 1 hour hold time between steps was performed up to 52 kW/m. After holding for 12 hours at 52 kW/m, no failure was observed in KKL-3. Ramp tests of the other two rods, KKL-2 and KKL-4, were aimed at studying the geometric changes during a power transient and their dependence on burnup. The rods, KKL-2 and KKL-4, were held at 41 and 45 kW/m for 30 and 5 seconds, respectively. Neither KKL-2 or KKL-4 failed during ramp testing.

Two ramp test rods, M5-H1 and M5-H2, were fabricated from the same father rod, which had been irradiated in Ringhals 4 PWR and used to study the influence of holding time on geometric changes. The rods, M5-H1 and M5-H2, had been irradiated to a rodlet-average burnup of 67 and 68 MWd/kgU, respectively, and conditioned for a designated period of time and LHR prior to ramp testing. During the short hold and long hold ramp tests, holding times of 5 seconds and 12 hours were used on M5-H1 and M5-H2, respectively, at an LHGR of 40 kW/m. Neither rod failed during the ramp test.

Ramp testing was performed on rod O2 (55 MWd/kgU burnup) to study geometric changes and PCI. Rod O2 had been previously irradiated in the BWR Oskarshamn 2 (Sweden) to an average rodlet burnup of 55 MWd/kgU. A short hold ramp test was performed by holding rod O2 at an LHR of 45 kW/m for 30 seconds. Rod O2 did not fail during the ramp test.

Ramp test rods Z-2, Z-3, and Z-4 had each been irradiated to 76 MWd/kgU. Rods Z-3 and Z-4 were irradiated in the PWR North Anna while rod Z-2 was irradiated in the PWR Vandellos. Rod Z-3 was intended to study the hydrogen embrittlement by ramping the rod to an LHR of 40 kW/m for a 5 second hold. However, failure occurred at an LHR of 39 kW/M, which prevented the short hold ramp test from being completed. Rods Z-2 and Z-4 were intended to study delayed hydrogen cracking (DHC), and were subjected to two-step power ramp tests. Rod Z-2 was initially ramped to an LHR of 35 kW/m and held for 6 hours before being ramped to an LHR of 40 kW/m and held for an additional 6 hours. Rod Z-4 was initially ramped to 33 kW/m and held for 6 hours before being ramped to 38 kW/m and held for an additional 6 hours. The rods, Z-2 and Z-4, did not fail during the two-step power ramp.

These 10 rods were used to assess the FRAPCON-3.4 predictions of cladding hoop strain. The input files used for these cases are not included in this report due to the limited availablility and sensitivity of this information.

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11. ABSTRACT *(200 words or less)*

An integral assessment has been performed for the U.S. Nuclear Regulatory Commission by Pacific Northwest National Laboratory to quantify the predictive capabilities of FRAPCON-3, a steady-state fuel behavior code designed to analyze fuel behavior from beginning-of-life to rod-average burnup levels of 62 gigawatt-days per metric ton of uranium. FRAPCON-3 code calculations are shown to compare satisfactorily to a preselected set of experimental data with steady-state operating conditions.

This document describes the assessment of FRAPCON-3.4a, which is the latest version of FRAPCON-3, released April 13, 2010.

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