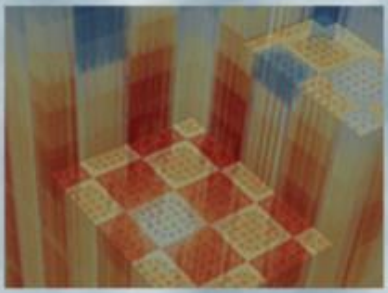
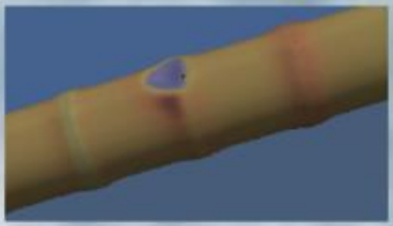
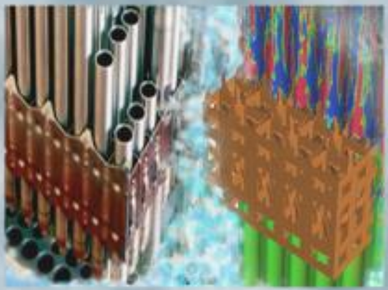
CASL-U-2018-1663-000

RIA Experimentation Benchmark L3:FMC.FUEL.P17.03







C.P. Folsom[1]
W. Liu[2]
R.L. Williamson[1]

[1]Idaho National Laboratory
[2]Structural Integrity Associates, Inc.

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RIA Experimentation Benchmark CASL FY18 Milestone Report L3:FMC.FUEL.P17.03

C. P. Folsom[1], W. Liu[2], R. L. Williamson[1]

[1]Fuels Modeling and Simulation
Idaho National Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-3840

[2]Structural Integrity Associates, Inc.

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Introduction

The CASL Reactivity Initiated Accident (RIA) Challenge Problem Charter [1] states, "The Pressurized Water Reactor (PWR) Rod Ejection Accident (REA) and Boiling Water Reactor (BWR) Control Rod Drop Accident (CRDA) are postulated accidents with consequences that are important to nuclear safety (fuel rod integrity and core coolability). Currently each reload core design must be analyzed to meet regulatory acceptance criteria. The goal of CASLs Mod-Sim capability for RIA is to model the event at a higher fidelity, with validation to existing tests, to better model the transient neutronics and the progression of the fuel and cladding thermal-mechanical behavior. These improved analytical capabilities can be used to better inform reload core design, limits on fuel assembly discharge burnup, restrictions on placement of fuel in the reactor, control rod insertion limits, operating margin, and performance sensitivities." In support of that charter, Bison, the fuel performance code used within CASL has been selected to demonstrate the thermal-mechanical behavior of the fuel and the cladding during a reactivity initiated accident.

Bison [2] is a modern finite-element based, multidimensional fuel performance code which has been under development at Idaho National Laboratory (INL) since 2009. In addition to being the fuel performance code adopted by CASL, Bison is also being used by multiple DOE NE programs as well as by both industry and universities. Bison has been demonstrated through recent work that it is capable of both simulating LWR fuel under normal operating conditions [3] and special conditions such as a missing pellet surface case [4]. More recently, Bison has been demonstrated in transient analyses such as Loss-Of-Coolant Accident (LOCA) [5,6] and RIAs [7,8].

CASL has identified a Bison RIA milestone to demonstrate PWR RIA fuel performance capability. The milestone identifies a series of experimental comparisons to validate Bison RIA capability. Previously a RIA experimental benchmark was established including a set of high priority integral experiments. This task will enlarge the benchmark by completing additional high priority validation cases in the implementation plan and revisiting the previously completed cases to incorporate improved code capabilities.

1 RIA Tests Overview

1.1 CABRI Tests

The CABRI test reactor is a pool-type Light Water Reactor (LWR) designed with a central area that can accept the insertion of a test device. The central area was originally designed to study fast reactor transients and contains a sodium coolant loop. During the experiment, the test rod is placed inside a test capsule which contains the in-pile instrumentation. Due to the sodium coolant loop, the test capsule temperature and pressure are different from LWR conditions, but the tests are considered appropriate to study the response of the rodlet up to the departure from nucleate boiling point. Under these conditions the effects of pellet cladding mechanical interaction (PCMI) can be tested.

The RIA tests at the CABRI reactor facility began in 1992 by the Institut de Protection et de Sûreté Nucléaire (IPSN which is now IRSN) in collaboration with Electricité de France (EDF), Framatome, CEA, and with participation of the US NRC. A total of twelve tests were performed within the CABRI REP sodium loop using pre-irradiated fuel rods having burnups ranging between 33 and 65 GWd/tU. Of the twelve, eight contained UO2 fuel and four were MOX. The cladding for all tests was Zircaloy 4 except test 11 which was M5. Following the CABRI REP tests the CABRI International Program (CIP) was created in 2000, two tests were run with the previous sodium loop capabilities and more are scheduled in the future with the new water loop.

The tests chosen for evaluation in this study were identified as priority cases in the CASL RIA Challenge Problem Implementation Plan [9] and include the CABRI REP Na-2, 3, 5, and 10 cases with UO2 fuel and Zircaloy-4 cladding tested in sodium coolant. The CIP3-1 case with UO2 fuel and ZIRLO^{TM} cladding was selected even though the experiment has not been run. The CIP3-1 case is scheduled to be completed in the future with the new CABRI water loop capabilities. The results from this test will be a code comparison with a number of codes that participated in an Organization for Economic Co-operation and Development (OECD)/Nuclear Energy Agency (NEA)/Committee on the Safety of Nuclear Installations (CSNI)/ Working Group on Fuel Safety (WGFS) RIA Fuel Codes Benchmark in 2013 [10]. Additionally the CABRI REP Na-4 case was completed under a NEAMS subcontract and will be included here for completeness. As part of a collaboration with the IRSN a SCANAIR/Bison comparison benchmark was completed on the CIP0-1 case [7]. The CIP0-1 case was a UO2 fuel with ZIRLO cladding performed in sodium coolant. Details of each test are summarized in Table 1.

Table 1: CABRI REP and CIP Test Summary [11–13]

Test	REP Na-2	REP Na-3	REP Na-4	REP Na-5	REP Na-10	CIP0-1	CIP3-1
Fuel Type	17x17 UO_2	17x17 UO_2	17x17 UO_2	17x17 UO_2	17x17 UO_2	17x17 UO_2	17x17 UO_2
Cladding Type	Std Zry-4	Std Zry-4	Std Zry-4	Std Zry-4	Std Zry-4	ZIRLO	ZIRLO
Initial enrichment (^{235}U/U %)	6.85	4.5	4.5	4.5	4.5	4.5	4.5
Internal gas pressure (MPa, 20°C)	0.101	0.31	0.301	0.302	0.301	0.304	2.35
Active length (mm)	1004.9	440.8	563	563.5	559	540.7	540.7
Max. burnup (GWd/tU)	33	53.8	62	64	63	75	72
Corrosion thickness (μm)	10	35-60	60-80	15-25	60-100	70-90	60-110
Pulse width FWHM (ms)	9.6	9.5	76.4	8.8	31	32.4	9
Energy deposit (cal/g)	207	122.2	95	104	108.3	99	115
Cladding OD (mm)	9.51	9.55	9.51	9.51	9.51	9.50	9.50
Cladding thickness (mm)	0.637	0.596	0.578	0.578	0.575	0.5715	0.5715
Pellet OD (mm)	8.05	8.19	8.19	8.19	8.19	8.192	8.192
Pellet height (mm)	11.99	13.69	13.74	13.74	14.25	9.83	9.83
Diametral fuel-cladding gap (μm)	186	164	164	164	164	165	165
Coolant Type	Sodium	Sodium	Sodium	Sodium	Sodium	Sodium	Water
Coolant Pressure (MPa)	0.5	0.5	0.5	0.5	0.5	0.5	15.5
Coolant Temp. (°C)	280	280	280	280	280	280	280

1.2 NSRR Tests

NSRR is a modified TRIGA (Training, Research, Isotopes, General Atomics) ACPR (Annular Core Pulse Reactor) with a dry space located in the center of the core. In a simulated RIA test for an irradiated fuel, a single instrumented fuel rod in a water-filled capsule is placed in the center of the core, and is pulse irradiated. A large number of experiments on simulated RIAs have been performed at the test facility of NSRR to evaluate fuel rod behavior and failures at different energy deposition, burnup, fuel design, and coolant condition. Since 1989, tests on medium and high burnup fuels in NSRR have been started and continued; recent experiments have moved towards testing on high burnup fuel with advanced corrosion resistant cladding alloys such as MDA and ZIRLO [14]. Pulse irradiation tests were normally performed in stagnant coolant water at room temperature (∼20°C) and atmospheric pressure (∼0.1 MPa) under a narrow power pulse with Full Width at Half Maximum (FWHM) of approximately 5 ms. Recent tests were performed at high coolant temperature (280°C) and high pressure (up to 6.4 MPa) to provide measurements on fuel failures close to Hot Zero Power (HZP) condition.

The cases selected for Bison evaluation in this study are the LS-1 and LS-2 cases (summarized in Table 2). In previous work a number of tests on BWR type fuels with burnup from 41 to 61 GWd/tU (three and four cycles) have been selected for validation of Bison based on published information from JAEA (formerly known as JAERI) [15,16]. These initially include cases FK-1 through FK-9 which include four tests (FK-3, FK-6, FK-8, FK-10) identified as priority cases in the CASL RIA Challenge Problem Implementation Plan [9]. Three NSRR tests VA-3, VA-4, and RH-2, conducted at high temperatures (249-285°C), were selected to validate the CSED failure model. The FK, VA, and RH tests were performed by Structural Integrity Associates (Anatech) under subcontracts from CASL and NEAMS. Many of these results will not be included in this report as they can be found elsewhere [8,17,18], but they will be introduced to provide an overview of the entire suite of RIA cases that have been evaluated using Bison (summarized in Table 3).

Table 2: NSRR LS-1 and LS-2 Test Summary [9]

Test	Assembly Type	Cladding	Fuel	Burnup (GWd/t)	Hydrogen (ppm)	Initial Enthalpy (cal/g)	Max Increase in Fuel Enthalpy (cal/g)	Fuel Enthalpy at Failure (cal/g)	Fuel Dispersal
LS-1	BWR 10x10	Zry-2	UO2	69	300	0	112	53	Yes
LS-2	BWR 10x10	Zry-2	UO2	69	290	17	89	No Failure	-

Table 3: NSRR FK, VA, and RH Test Summary [15,16]

Test	FK1	FK2	FK3	FK4	FK5	FK6	FK7	FK8	FK9	VA-3	VA-4	RH-2
Cladding Type	Zry-2	Zry-2	Zry-2	Zry-2	Zry-2	Zry-2	Zry-2	Zry-2	Zry-2	ZIRLO	MDA	M5
Coolant Type	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Coolant Temp. (°C)	20	20	20	20	20	20	20	20	20	285	249	278
Coolant Pressure (MPa)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	6.8	4.0	6.4
Clad thickness (mm)	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.57	0.57	0.57
Fuel density (%TD)	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
U235 enrichment (%)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	5.0	5.0	5.0
Burnup (GWd/tU)	45	45	41	56	56	61	61	61	61	71	77	67
Pre-test fill gas pressure (MPa)	0.3	0.3	0.3	0.5	0.5	0.1	1.5	1.5	1.5	0.1	0.1	0.1
Peak linear heat rate (W/cm)	228	228	209	350	350	350	350	350	350	-	-	-
Energy deposit (cal/g)	167	95	186	180	100	168	166	90	119	-	-	-
Peak fuel enthalpy (cal/g)	129.52	69.8	144.5	139.5	69.8	130.5	128.6	64.8	89.8	108	109	90
Power Pulse width (ms)	4.5	7	4.5	4.3	7.3	4.3	4.3	7.3	5.7	4.4	4.4	4.4
Failure enthalpy (cal/g)	-	-	-	-	-	70	62		86	99	-	-

2 Modeling Options

Only the modeling options for the CABRI cases will be discussed in this report. The fuel rods were modeled using a 2-D radial axisymmetric geometry with eight-node quadratic elements. A biased 15 element radial mesh is used to model the fuel column with a finer mesh at the pellet rim and a coarser mesh at the central region to capture the edge-peaked radial power/burnup profiles indicative of high burnup fuels. In the radial direction, four elements are used for meshing the cladding to capture the steep temperature gradient in the fast transient. Four axial elements per pellet were used in the fuel with a similar element height used for the cladding. A schematic of the mesh used for RIA test case is shown in Figure 1 below.

When data were not available for the RIA pulse, a Gaussian shaped power pulse was assumed with the corresponding full-width-at-half-max (FWHM) specified for the test. The magnitude of the rod linear power is defined according to the energy deposition in cal/g specified in Table 1. Figure 2 illustrates the input linear power for test case CABRI REP Na-10 and the resulting energy deposition into the fuel. The fuel enthalpy calculation in Bison uses a MATPRO model. Key input parameters for modeling Bison code are listed in Table 4 below.

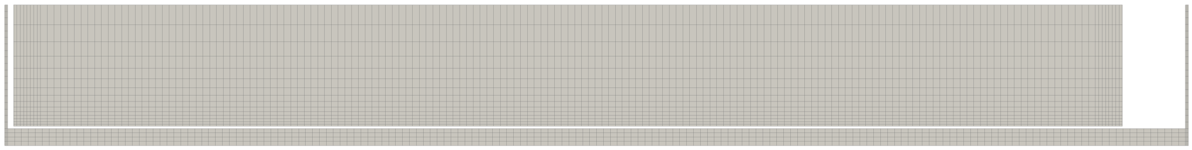


Figure 1: Mesh file for Bison RIA test case (scaled 10x in radial direction)

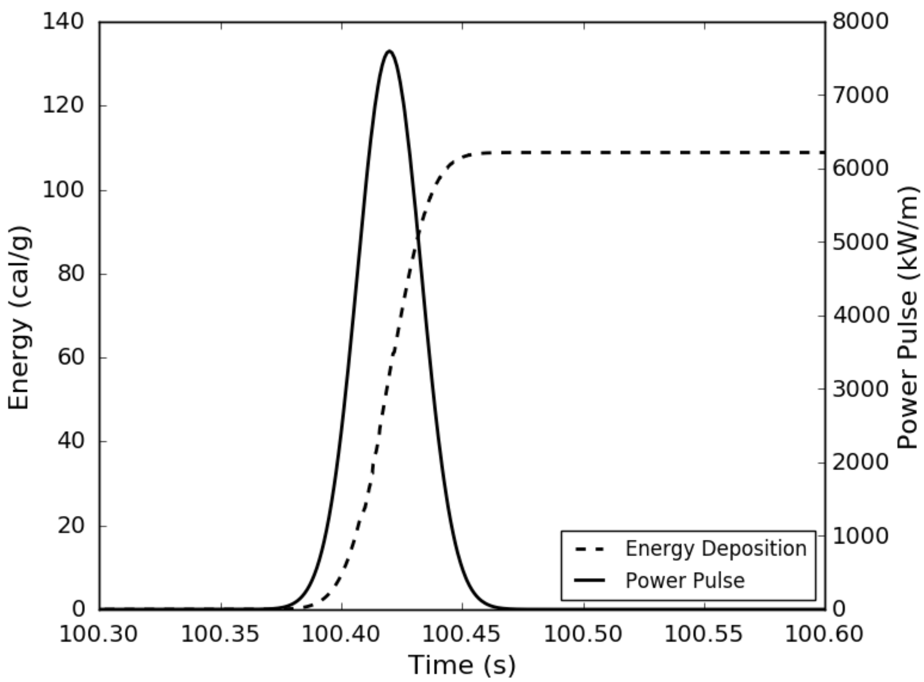


Figure 2: Input linear power and resulting energy deposition for RIA test case (CABRI REP Na-10)

3 Modeling Results

In this work only the CABRI REP and CIP cases have been completed. The NSRR LS-1 and LS-2 cases were selected as part of this benchmark but were not completed. After performing a literature search not enough information on fuel rod geometry, base irradiation operating conditions, RIA operating conditions, and experimental results were found to provide adequate benchmarking capabilities. The remaining NSRR cases completed by Anatech can be found in other reports [8,17,18].

Without membership in the CABRI International Program there is limited access to the CABRI REP and CIP experimental data. So to the extent possible, Bison results are compared against those CABRI REP experimental data reported in the open literature [11–13]. To provide more detailed comparisons, Bison results are also compared against Falcon calculations for the same cases, as extracted from two EPRI reports [20,21].

3.1 CABRI REP Na Cases

The results for the CABRI REP Na-2,3,5, and 10 were previously reported in a FY17 CASL report [8], and the efforts for this year were to improve upon the results by incorporating new code capabilities. For all the cases the models have been upgraded to use the tensor mechanics modules, incorporate frictional contact between the fuel and cladding, and Strain Energy Density (SED) calculations to compare against the CSED failure model recently developed [17]. Highlights of the results will be presented here.

One of the primary regulatory acceptance criteria for the RIA is that the fuel temperature and radial average

Table 4: Summary of Bison input models and parameters

Model	Parameters
Fuel thermal conductivity	NFIR
Fuel mechanical model	Elastic model with temperature dependent properties
Clad mechanical model	Creep and Plasticity models
Clad material type	SRA Zry-4 (CABRI REP Na cases) ZIRLO with temperature dependent yield stress defined by Prometra [19]
Contact algorithm	Frictional with Augmented Lagrange
Fission gas release and swelling model	Sifgrs model with transient option enabled during RIA
Thermal hydraulic model	Bison coolant channel correlations (Sodium for all cases but CIP3-1)
Geometry	2-D Radial axisymmetric
Mesh Fuel Clad	 15 (radial) x 4 per pellet (axial) 4 (radial)
Element Type	Quad-8

enthalpy (RAE) response remains below established limits. Bison is able to calculate both these parameters to demonstrate acceptable fuel performance during RIA transients. The Gaussian shaped power pulse, energy deposited into the fuel and calculated fuel RAE along with comparisons to Falcon are shown in Figure 3 for case REP Na-5. The Bison, Falcon, and reported values for peak fuel radial average enthalpy increase from 20°C are summarized in Table 5 for all five cases and the Bison and Falcon peak fuel centerline and max fuel temperatures are tabulated in Table 6. The energy and RAE comparison with Falcon and the experimental/reported values show excellent agreement for this case with the resulting max increase in radial averaged enthalpy calculated in Bison was 117.6 cal/g compared to 115 cal/g from Falcon and 108 cal/g reported from IRSN. For the REP Na-2 case the calculated maximum change in radial averaged fuel enthalpy from 20°C is 209 cal/g compared to 200 cal/g calculated by Falcon and 199 cal/g reported by IRSN which agree within 5%.

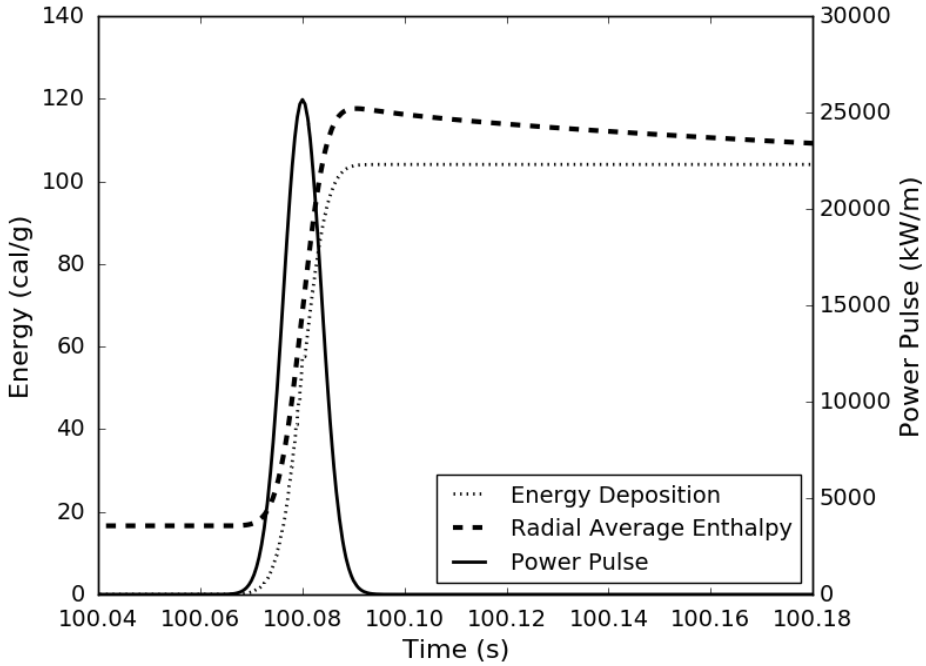
Table 5: Comparison of peak fuel radial average enthalpy (cal/g) increase from 20°C

Case	Bison	Falcon	Reported Value
REP Na-2	209	200	199
REP Na-3	136.7	118	123.5
REP Na-4	87.7	71.9	85.9
REP Na-5	117.6	115	108
REP Na-10	119	109	98

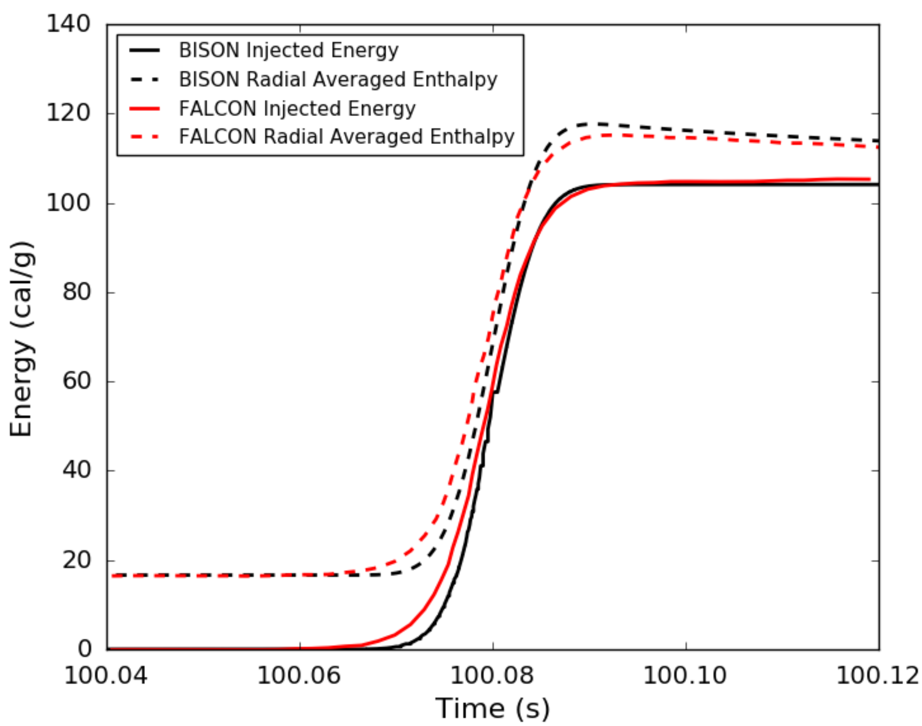
Table 6: Comparison of peak fuel temperatures (K)

Case	Bison		Falcon	
	Centerline	Max	Centerline	Max
REP Na-2	2647	3134	2775	2948
REP Na-3	1965	2643	1960	2480
REP Na-4	1671	-	1625	-
REP Na-5	1770	2300	1757	2387
REP Na-10	1820	2114	1662	2046

Figure 4 and Figure 5 show the calculated fuel and cladding temperatures from Bison as well as comparisons



(a) Bison Energy and Power Calculations



(b) Bison and Falcon Comparison

Figure 3: REP Na-5 a) Bison power pulse, energy deposited, and radial average enthalpy calculations b) Bison and Falcon comparison for energy deposited and radial average enthalpy.

between Bison and Falcon. Figure 4b shows very good agreement between Bison and Falcon on the fuel centerline and cladding inside surfaces for REP Na-2 and Figure 5b shows similar agreement for the cladding inner and outer surface temperatures for REP Na-10. For all cases the agreement between Bison and Falcon for the fuel centerline temperature was within 5% and the maximum fuel temperature was within 10%. Similar results were found for the maximum cladding inner temperature with agreement typically well under 10%.

While Bison compared very well with Falcon on thermal results, the previous mechanical results showed greater deviation from both Falcon and measured values (Figures 4 and 5 in [8]).The updated results with tensor mechanics modules and frictional contact show better agreement with Falcon calculations (Figure 6), but there are still differences: Falcon appears to compute higher clad hoop strains than Bison. Even with better agreement between the cladding hoop strain calculations the final residual clad diameter or clad displacement still shows a large deviation from measured results shown in Figure 7 (Note: oscillations in the post-test measurements in Figure 7a are due to cladding ridging at the pellet-pellet interfaces, and are not seen in the Bison results due to the smeared fuel approximation).

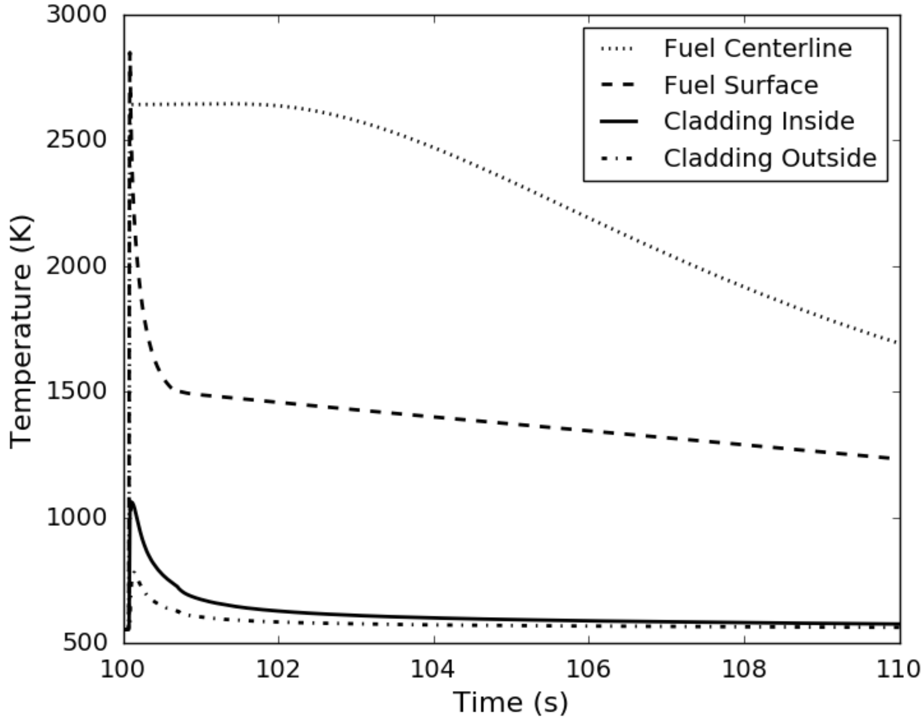
There are a number of postulated reasons for the discrepancies in the residual mechanical results. Likely the most significant factor influencing the calculated hoop strain and residual hoop strain is the initial fuel-to-clad gap width prior to the RIA [22]. Bison calculates this gap based on results from the base irradiation simulation, which indicate a gap opens between the fuel and cladding during cooling from operational conditions. Both Falcon and SCANAIR assume small or no initial fuel-to-cladding gap in their respective analyses depending on burnup conditions since the bonding formed at clad and pellet interface in high burnup fuel would eliminate the pellet-clad gap.

The updates using frictional contact allows for clad elongation and SED comparisons with Falcon and the measured results. An overview of the mechanical results with comparisons to Falcon and measured values is shown in Table 7, with a plot of the Bison and Falcon calculated cladding axial elongation for REP Na-5 in Figure 8. The Bison calculations appear to be in good agreement with measurement, which also shows the successful modeling of the frictional contact between pellet and cladding for RIAs. The max SEDs computed by Bison and Falcon are in close agreement, with Bison accurately predicting the failure of REP Na-10 (see Figure 3 in [18]). The CSED for REP Na-10 is $\sim$4.75 MPa and based upon the calculated Bison SED, the increase in fuel radial average enthalpy at failure is 83.2 cal/g with the reported enthalpy at failure of 81 cal/g [19].

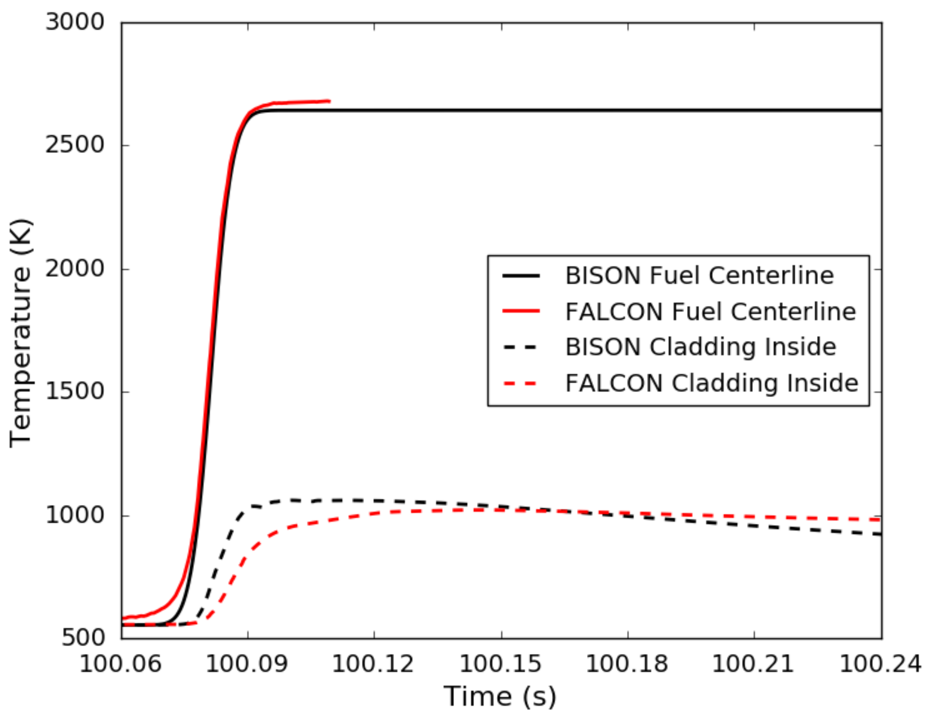
Table 7: Summary of the Bison calculated characteristics for the CABRI cases in comparison with measurements and Falcon calculations

Test Case	REP Na-2	REP Na-3	REP Na-4	REP Na-5	REP Na-10
Permanent Hoop Strain (%)	1.28	0.62	0.06	0.57	0.52
Peak Hoop Strain (%)	1.75	0.97	0.82	1.18	1.12
Peak Clad Elongation (mm)	13.83	5.88	3.37	6.22	5.95
Measured Clad Peak Elongation (mm)	11	6	4	7	NM
Falcon Peak Clad Elongation (mm)	6.68	4.81	3.28	5.24	5.06
Max SED (MPa)	25.58	14.42	5.83	13.07	9.57
Measured Peak Cladding Permanent Hoop Strain (%)	3.5	2.2	0.4	1.1	NM
Falcon Calc. Perm Hoop Strain (%)	2.13	0.995	0.233	0.718	0.637
Falcon Calc. SED (MPa)	28.2	16.6	5.2	12.5	10.9

The predictions for fission gas release (FGR) during the transient are in good agreement with measurements. Bison predicted a final FGR of 6.7% compared to the measured value of 5.5% for REP Na-2, and 10.3% compared to 13.7% for REP Na-3. A plot of the FGR history for REP Na-2 is shown in Figure 9a along with the fuel centerline temperature plotted on the right ordinate. The inset shows the FGR and fuel temperature during the time period of the pulse. Figure 9b shows similar results for REP Na-4 with Bison predicting 5.2% compared to the measured 8.3%. In both these figures the initial large increase in FGR is highly correlated to the fast increase in fuel temperature resulting in micro-cracking and a burst release of fission gas. Note that diffusion-based FGR without accounting for this mechanism will thus tend to strongly under-predict FGR during the short duration of a RIA event. This is demonstrated in Figure 9 by comparison with the results from a purely diffusion based model that differs from the original Bison model only in that the specific transient (micro-cracking) capability is deactivated. In the REP Na-2 case the FGR still increases due to diffusion based FGR because of the very high temperatures in the fuel reaching between 2700-3000 K. Hence, the recently developed transient release capability of the Bison model may represent an important step towards better capturing FGR during fast transient such as RIAs. Comparisons of fission gas release are not reported for the REP Na-10 case since the rod failed during the experiment.

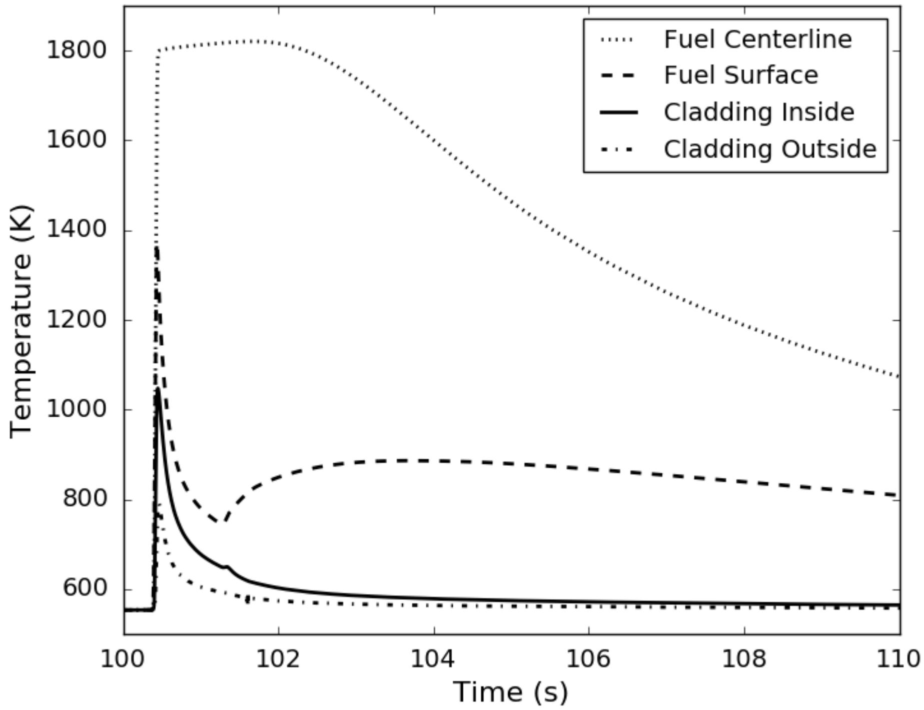


(a) REP Na-2 Bison temperature calculations

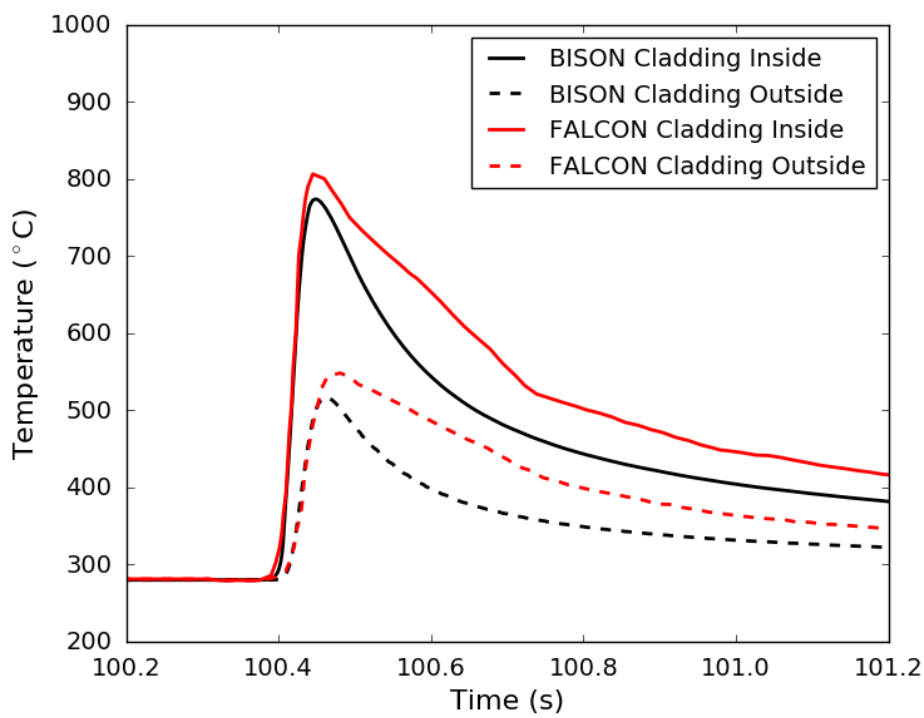


(b) REP Na-2 Bison and Falcon temperature comparisons

Figure 4: Temperature calculations and comparisons to Falcon for REP Na-2

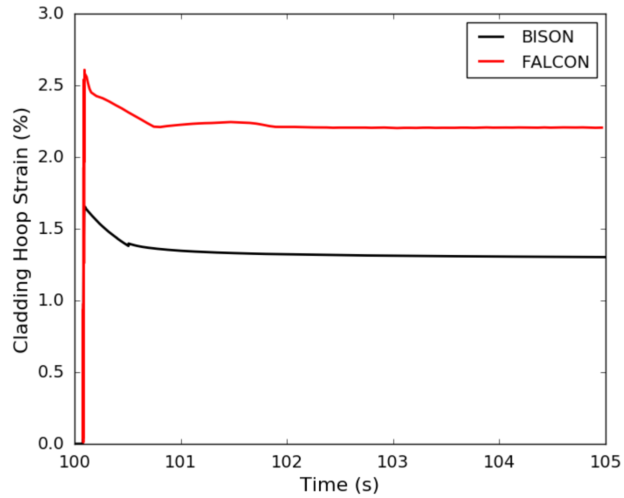


(a) REP Na-10 Bison temperature calculations

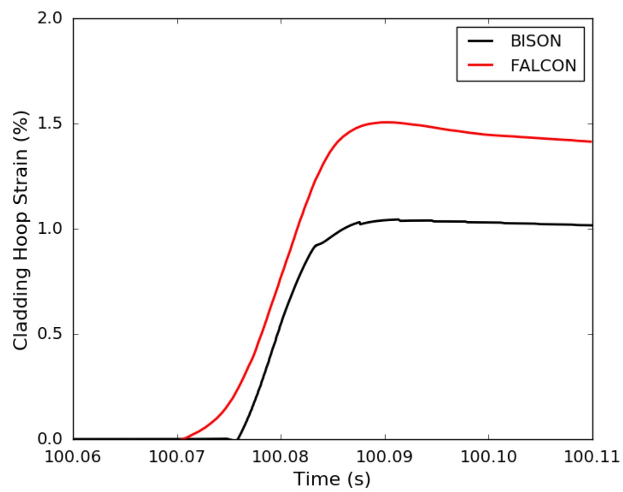


(b) REP Na-10 Bison and Falcon temperature comparisons

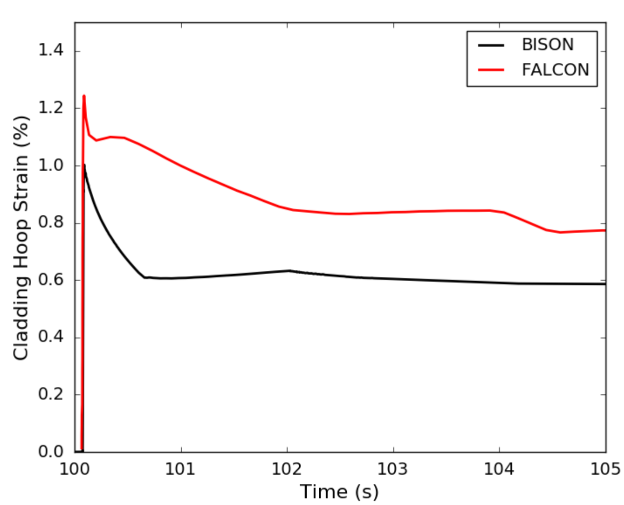
Figure 5: Temperature calculations and comparisons to Falcon for REP Na-10



(a) REP Na-2

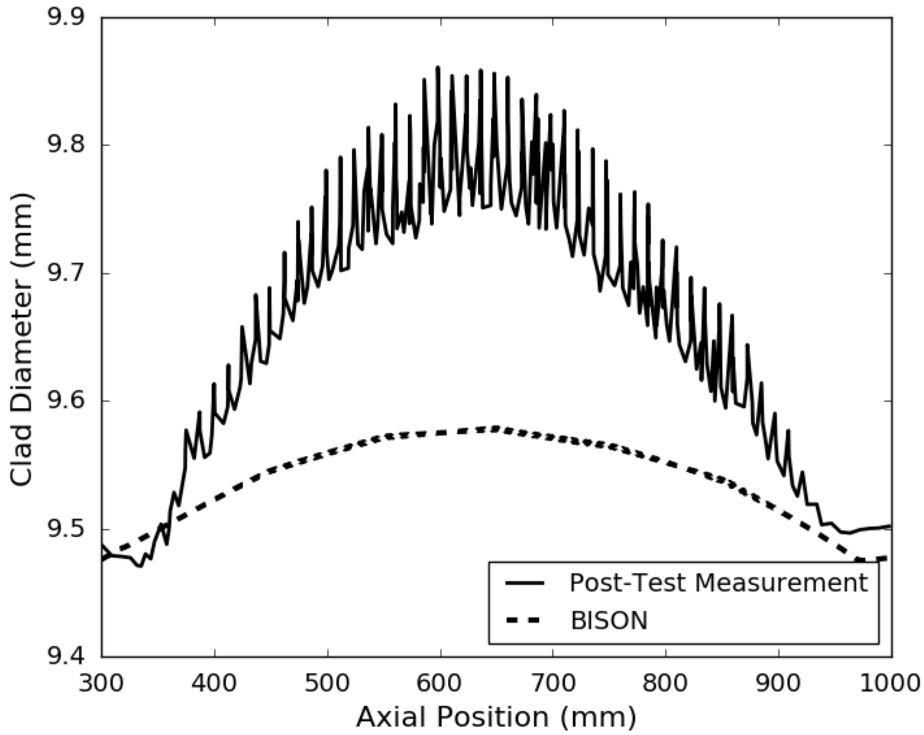


(b) REP Na-3

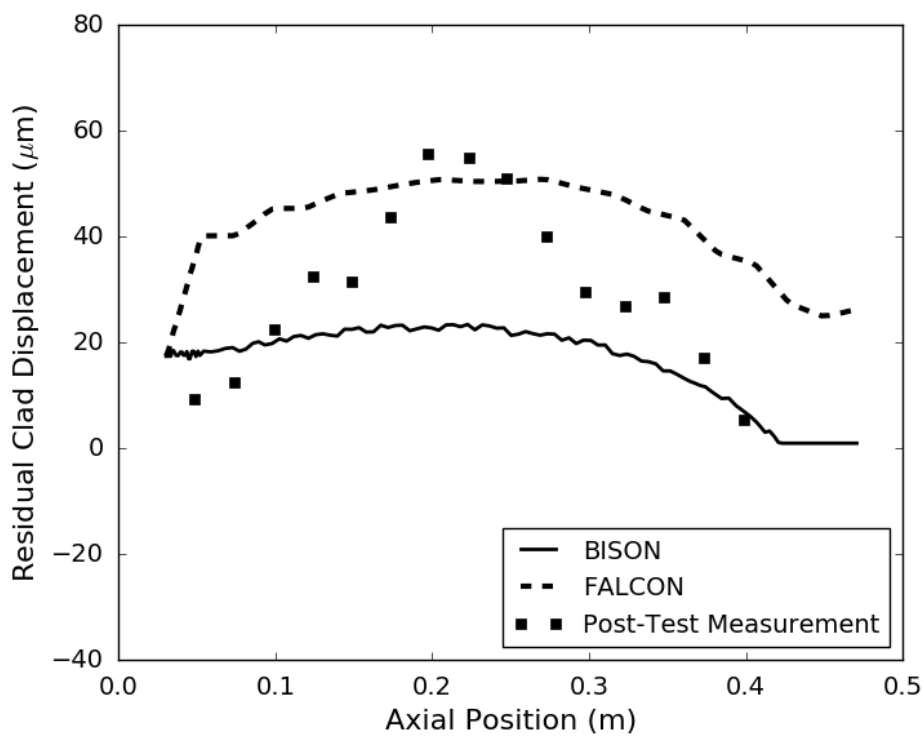


(c) REP Na-5

Figure 6: Cladding hoop strain comparisons with Falcon



(a) REP Na-2 post RIA clad diameter



(b) REP Na-3 post RIA cladding displacements

Figure 7: Bison mechanical calculations and comparisons to Falcon and measured results for post-RIA clad dimensions

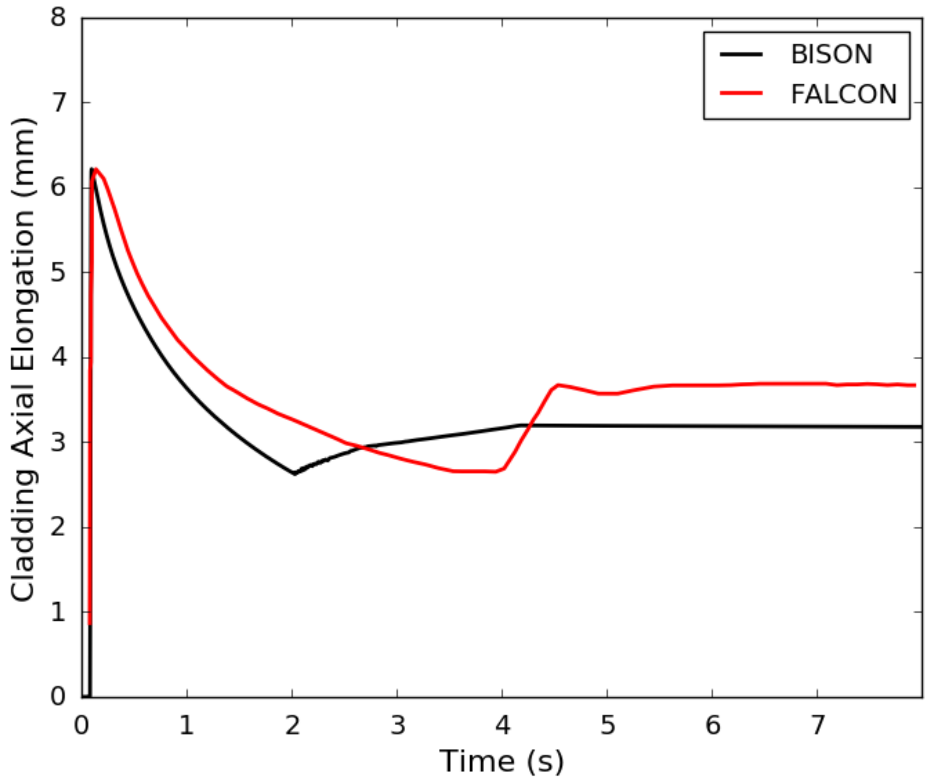
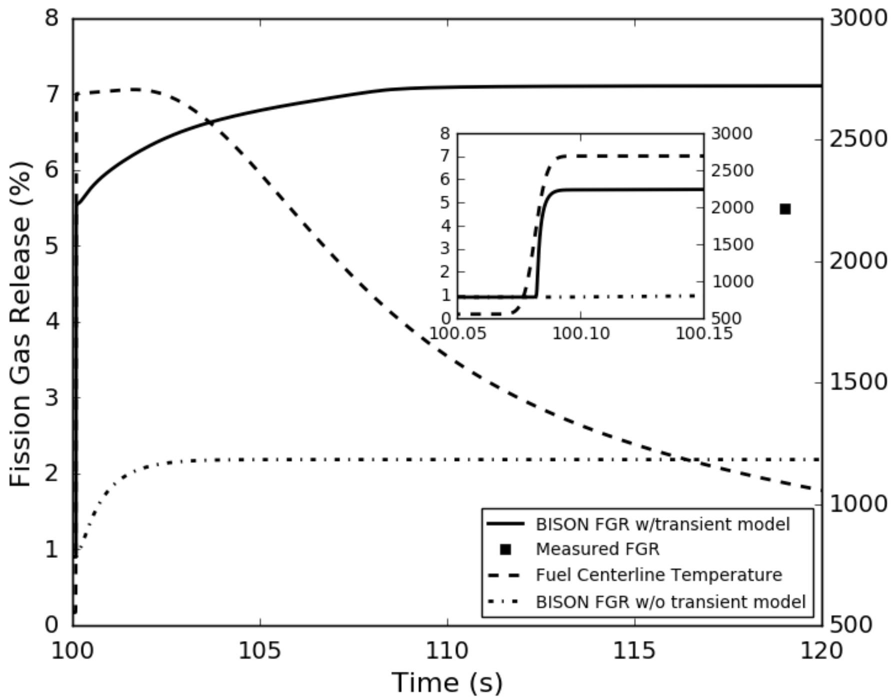
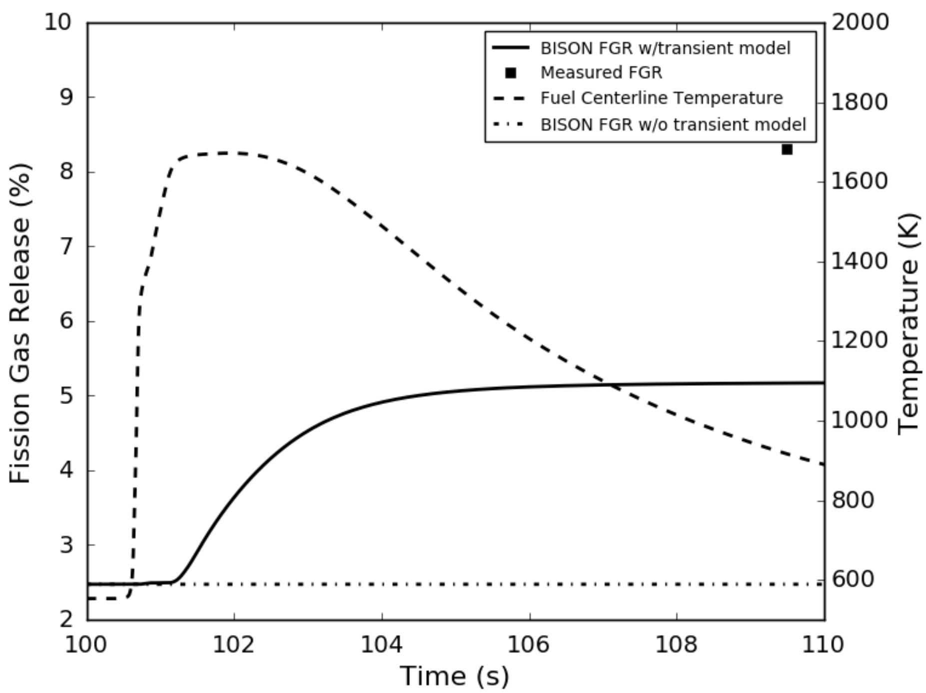


Figure 8: REP Na-5 clad axial elongation comparison with Falcon



(a) REP Na-2



(b) REP Na-4

Figure 9: Fission gas release results plotted with fuel centerline temperature compared against measured FGR results post-RIA. Plotted for comparison is the Bison FGR results during the RIA with the transient FGR model turned off.

3.2 CIP0-1

Detailed results for the Bison/SCANAIR benchmark for the CIP0-1 simulation have been documented in literature and will not be repeated here. These results can be found in the following locations [7,23].

3.3 CIP3-1

The CIP3-1 case is different from the CIP0-1 case in that it is planned for a future test in CABRI with a water coolant loop instead of the sodium coolant loop. Since this experiment has not been run yet there is no experimental data to compare the results against, instead this case will be used to compare against other transient fuel performance codes. The OECD/NEA/CSNI/WGFS performed a RIA fuel codes benchmark to compare multiple codes to a selected number of cases. The full details of this benchmark can be found in the final report [10]. Currently only comparisons to other codes can be made to the clad permanent hoop strain profile at the moment since it is the only parameter discussed in the report for the CIP3-1 case. These results are shown in Figure 10. Access to all the various output parameters will require permission from each of the participating organizations.

Until further notice of access to other data a few parameters of interest for the CIP3-1 case will be shown. Figure 11 shows the 9 ms FWHM pulse depositing a rodlet averaged 99.4 cal/g of energy into the fuel. The energy deposited at the peak power node in the fuel was 113.4 cal/g. The resulting fuel radial average enthalpy increase from hot-zero power conditions was 103 cal/g. Under these conditions the peak fuel centerline temperature reached 1879 K and the maximum fuel temperature reached 2244 K. During the test the cladding experienced departure from nucleate boiling resulting in elevated cladding temperatures reaching 1120 K on the surface with a max cladding temperature of 1175 K. All the temperature profiles are shown in Figure 12.

The mechanical results such as the cladding hoop stress and strain are plotted in Figure 13 with a peak cladding hoop strain of 1.2% and a corresponding peak hoop stress of 560 MPa. The elevated cladding temperatures and large stresses resulted in 0.59% of plastic strain which shows up in Figure 10 as the permanent hoop strain after the RIA.

Bison calculated a final 10.3% fission gas release at the end of the RIA for the CIP3-1 case. The fission gas and fuel centerline temperature are plotted in Figure 14.

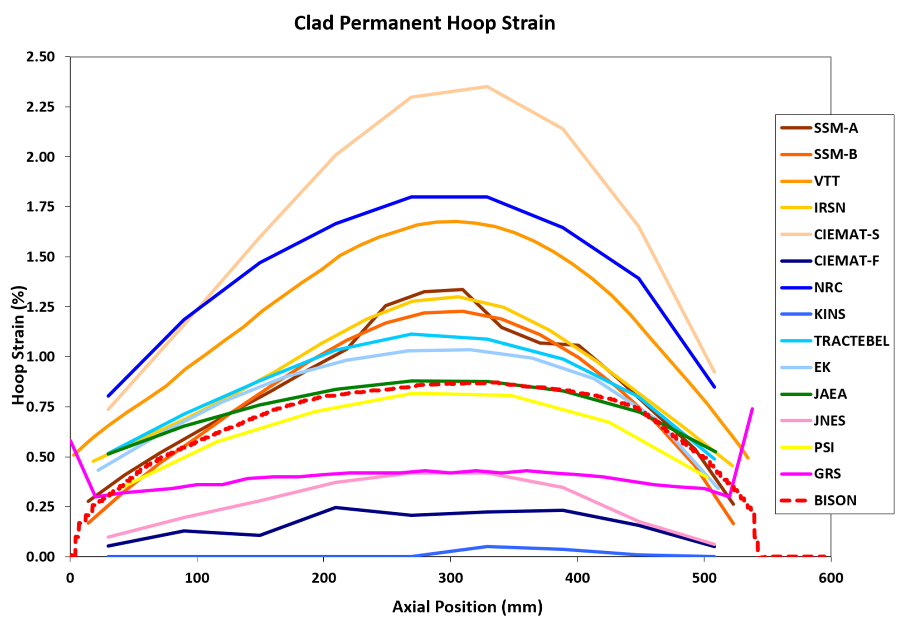


Figure 10: CIP3-1 clad permanent hoop strain profile

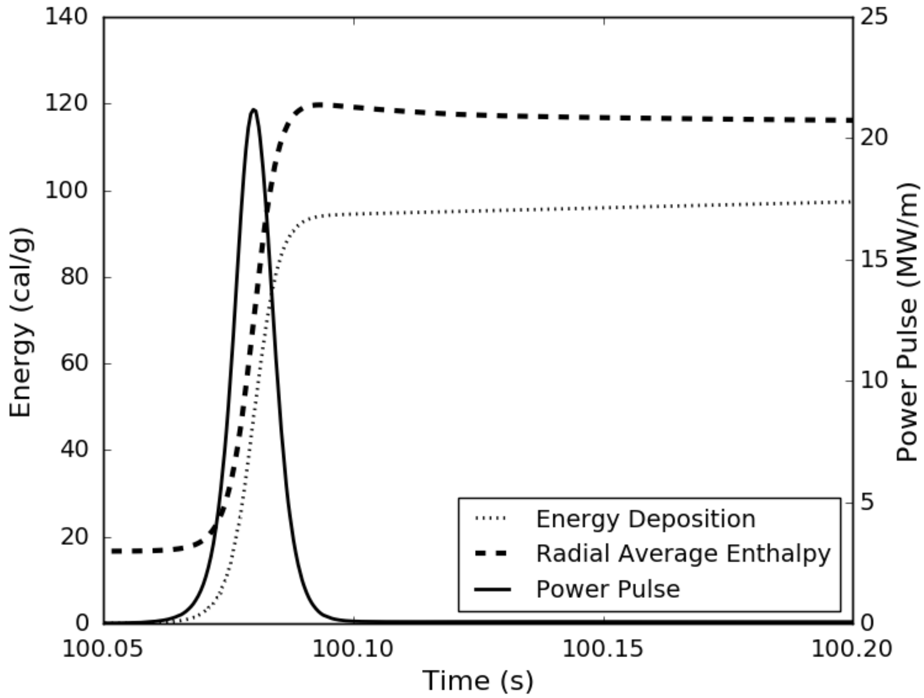


Figure 11: CIP3-1 Power pulse, energy deposited, and calculated fuel radial average enthalpy

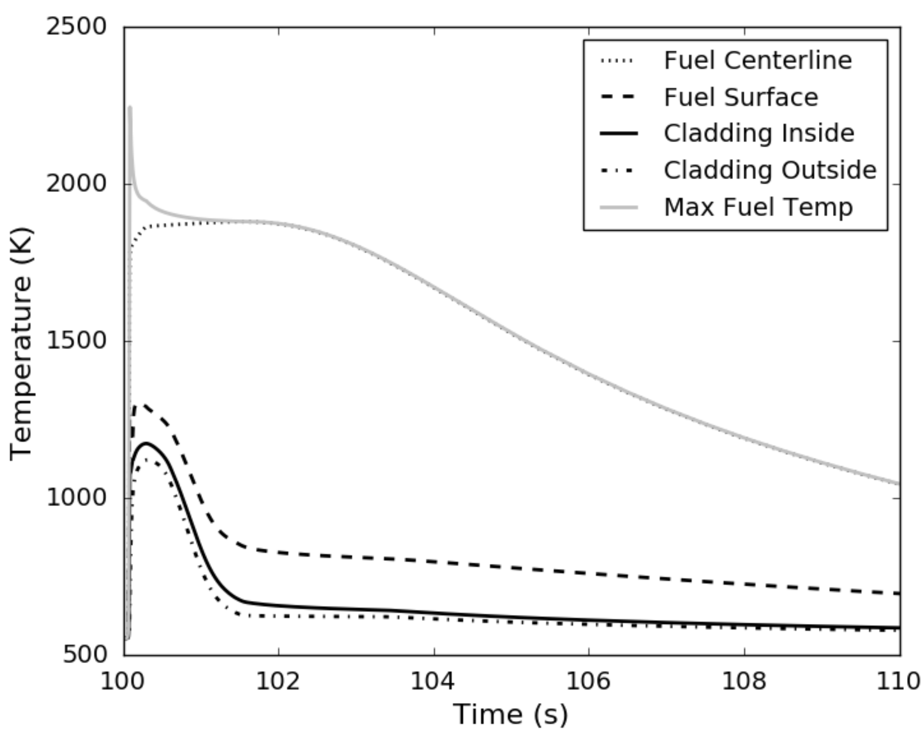


Figure 12: CIP3-1 fuel and cladding temperatures

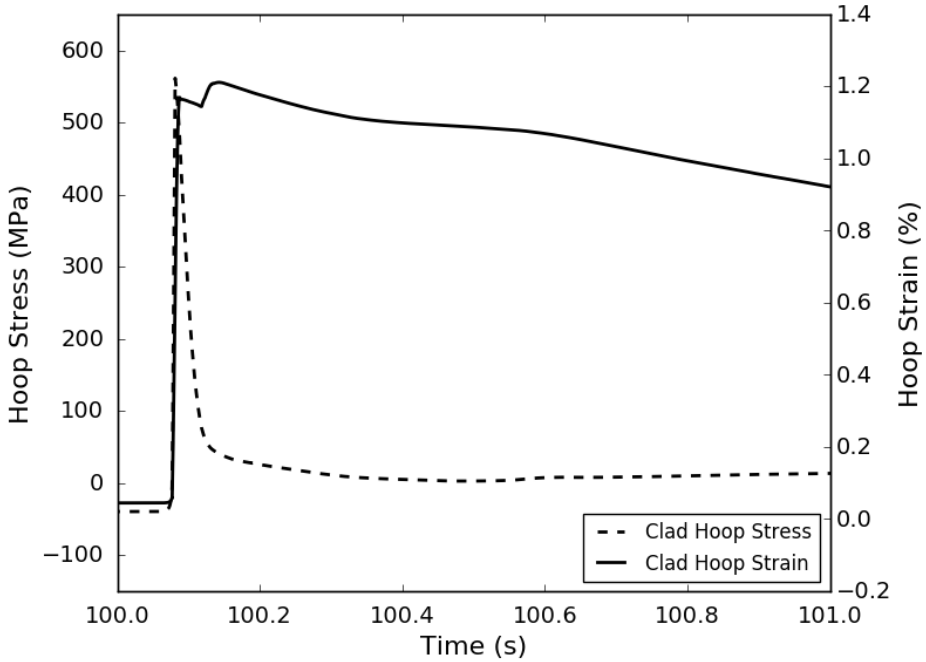


Figure 13: CIP3-1 cladding hoop stress and strain

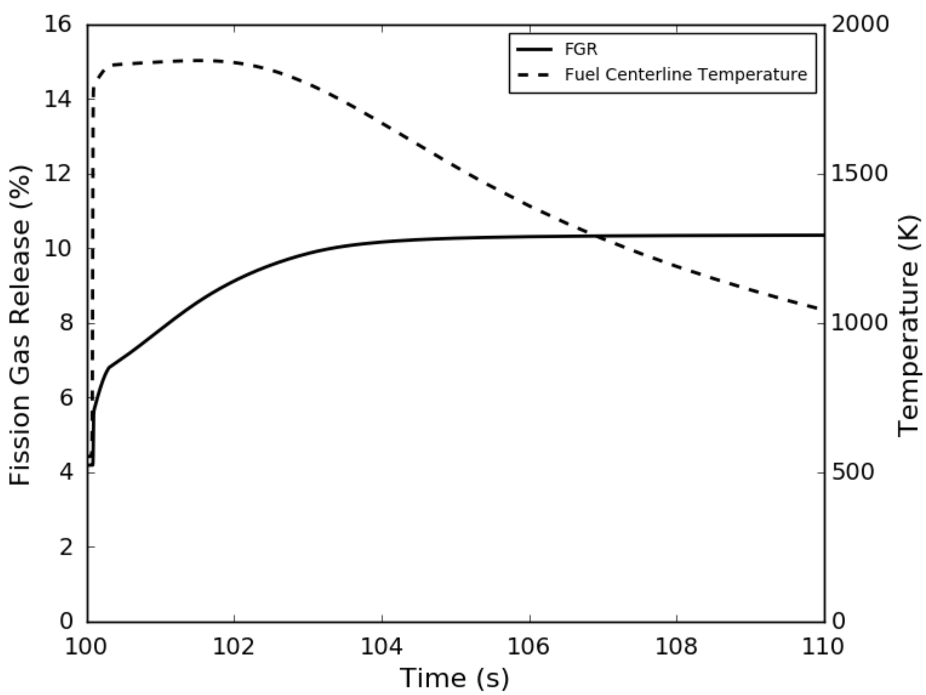


Figure 14: CIP3-1 fission gas release and fuel centerline temperature

4 Summary

Bison has been shown it is capable of simulating reactivity-initiated accidents with reasonable accuracy in comparison to other codes and experimental results. A total of five CABRI REP Na cases and two CABRI CIP cases have been completed as well as nine NSRR FK, two NSRR VA, and an NSRR RH case have been completed by Anatech for Bison validation on RIA modeling.

In general Bison provides good results for both fuel radial average enthalpy and fuel temperature predictions which are both used as regulatory acceptance criteria for RIA transients. Bison shows reasonable agreement with Falcon on predicted mechanical results such as cladding hoop strain. Considerable improvement can be seen over previous results when implementing the tensor mechanics modules and frictional contact. The frictional contact modeling allows for comparisons with clad elongation which shows very good agreement with measured and Falcon results. Additionally, friction allows for accurate calculations of SED that can be used for failure predictions where Bison successfully predicted the non-failed rods (REP Na-2,3,4, and 5) and the failed rod (REP Na-10). The addition of the transient fission gas release model [24] shows very promising results for predicting fission gas release following fast transients such as RIAs.

Bison still under predicts the residual cladding displacement at the end of the RIA when compared against experimental results. This can be explained in part to the initial fuel-to-cladding gap prior to the RIA, but additional work and development needs to be implemented to improve these results.

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