Out-of-Pile Furnace Tests on Fast Reactor Metallic Fuels Conducted at the AGHCF

Nuclear Science & Engineering Division

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Summary

Summary for Out-of-Pile Furnace Tests on Fast Reactor Metallic Fuels Conducted at the AGHCF

An extensive out-of-pile furnace test program was conducted at Argonne's Alpha-Gamma Hot Cell Facility (AGHCF) from 1987-1994 to evaluate the fuel/clad compatibility and performance of fast reactor metallic fuels. This test program included over 150 tests on irradiated fuels conducted in two furnace apparatuses. The available records of these tests have been preserved with the support of the Advanced Reactor Technology program and organized in the OPTD (Out-of-Pile Transient Database). This report provides at-a-glance summary information for each of the out-of-pile furnace tests, including information about the tested fuel samples, test conditions, purpose of the tests, and key results. It is intended for open and unlimited distribution to allow all interested persons to view key information about the out-of-pile tests.

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1 INTRODUCTION

The Out-of-Pile Furnace Tests on metallic fuels were conducted at the Alpha-Gamma Hot Cell Facility (AGHCF) at Argonne National Laboratory as part of the IFR metallic fuel compatibility testing program. Records and results from these legacy tests support advanced nuclear fuels and materials R&D by demonstrating the safety performance of the tested fuels, providing a basis for code development and validation, and informing future testing. An extensive effort was made to collect and digitally preserve all available test records, organizing them in the web-accessible Out-of-Pile Transient Database (OPTD) [1]. This report provides summary information about each of the out-of-pile tests for a high-level review of the entire test program.

A brief overview of the IFR Metallic Fuel Compatibility Testing Program and the Out-of-Pile Furnace Tests is provided in Section 0. Sections 3 and 4 provide summary information for each of the tests conducted in the Fuel Behavior Test Apparatus (FBTA) and the Whole Pin Furnace (WPF), respectively. Collections of highly related FBTA tests are presented together in subsections 3.1 through 3.21. Each WPF test is presented individually in subsections 4.1 through 4.7. Each subsection includes a brief description of the test or test set to provide introduction and context, indicating its purpose or key objectives. For each individual test, an at-a-glance summary sheet follows with the following information:

- test identifying information (apparatus, name, date),
- tested material (pin/subassembly, fuel, cladding, peak burnup of the pin, axial location of the tested segment for FBTA tests, plenum-to-fuel volume ratio for WPF tests),
- test parameters (temperature, duration),
- test and sample examination records available, and
- test results.

Informal notes have been made on the summary sheets to indicate the relative expected reliability of the included quantitative results. Tests results with a status label of “GOOD” have been reported publicly and exhibit good agreement between original test records and later published values. These tests appear in bold font in the test group summary tables. Test results that were discarded because of unfavorable or unanticipated test conditions are labeled as “DISCARDED.” Those with unresolved discrepancies between original test records and published results or other deviations are noted as “QUESTIONABLE” with explanatory notes included in the key test information. Finally, many test results were not previously reported; those results were transcribed from various preliminary and unpublished records and are noted in the summary sheets as “PRELIMINARY.”

2 METALLIC FUEL COMPATIBILITY TESTING

The Integral Fast Reactor (IFR) program, active from 1984 to 1994, produced a large collection of data relating to the performance of metallic fuels in sodium-cooled fast reactors (SFRs). The metallurgical reaction between metallic fuel forms and their cladding was examined through an extensive program of fuel/cladding compatibility tests conducted under both steady-state and transient conditions. During steady-state irradiation, contact between the fuel and cladding allows solid-state interdiffusion of the cladding and fuel constituents (including lanthanide fission products) across the fuel-cladding interface. The resulting reacted zone in the cladding is considered normal cladding wastage due to formation of the thin layer of low-melting point eutectic. The extent of this fuel/cladding interaction is highly dependent on the local power, temperature, and burnup of the fuel, making the cladding more vulnerable to liquefaction during some elevated-temperature off-normal events (e.g., loss of coolant flow, loss of a heat sink, or transient overpower events).

Transient tests are used to evaluate fuel performance during these off-normal events since, when subjected to an elevated-temperature transient, the fuel and cladding materials may undergo additional interdiffusion. If the temperature rises above the liquefaction threshold, a two-phase solid/liquid eutectic mixture may form at the fuel-cladding surface, penetrating the pre-existing solid-state interdiffusion band in the cladding and, in the case of a prolonged transient, progressing into previously unaffected depths of the cladding.

While these off-normal events can be simulated in-pile (e.g., in the TREAT reactor), they can also be simulated out-of-pile by raising the previously irradiated fuel samples rapidly to high temperatures representative of these accident scenarios. The furnace transient testing program conducted in the Alpha-Gamma Hot Cell Facility (AGHCF) heat-tested irradiated fuel samples mostly from EBR-II under the anticipated aggressive loss-of-flow and loss-of-heat sink accident conditions.

The findings of the out-of-pile furnace tests contribute to the safety case for metallic fuels in fast reactor applications, as they demonstrate good fuel survivability under the design basis conditions. During most transient events, eutectic formation affected only already wasted cladding. Only when the transient was particularly prolonged did the eutectic reaction progress into previously unaffected cladding. The mode, extent, and rate of cladding wastage induced by the out-of-pile furnace transients varied with fuel and cladding composition and condition as well as transient temperature and duration.

In the one-page test summary sheets that follow, the recorded post-transient cladding “penetration depth” generally represents the difference between the original cladding thickness and the thinnest area of remaining unaffected cladding. The reduction in unaffected cladding thickness may be due to solid-state diffusional attack, liquid-phase boundary penetration, and/or liquid-phase matrix dissolution. Unless otherwise indicated, the penetration depths referred to herein represent the deepest penetration into the cladding. This was not always the eutectic front; in the case of some high-burnup pins, a lanthanide-rich band extended deeper into the cladding than the eutectic.

2.1 IFR Fuel Compatibility Test Program

For a clearer picture of where the AGHCF furnace transient tests fit in the larger landscape of IFR fuel compatibility testing, they can be compared to both the transient over-power testing conducted in TREAT and the steady-state testing conducted in EBR-II. The tests of metallic fuels conducted in EBR-II were lower temperature, steady-state tests to demonstrate the performance of the fuel under normal operating conditions. Records of these EBR-II tests are being archived in other online databases. An extensive long-duration transient testing program was also conducted at EBR-II. The transient tests conducted on metallic fuels in the TREAT reactor were high temperature, short burst tests to demonstrate the fuel behavior under rapid transient-overpower conditions. The AGHCF furnace tests bridge the gap between the EBR-II and TREAT testing conditions by exposing irradiated fuel samples to higher accident-scenario temperatures for longer durations ranging from minutes to hours, as shown in Figure 1.

Figure 1: Testing regimes for in-reactor and out-of-pile tests on metallic fuels [2].

2.2 Out-of-Pile Furnace Test Methodology

The out-of-pile furnace transient tests were conducted in two different furnace apparatuses at the Alpha-Gamma Hot Cell Facility at Argonne National Laboratory: The Whole Pin Furnace (WPF) and the Fuel Behavior Test Apparatus (FBTA). These furnace apparatuses heat-tested fuel pins or fuel pin segments. Prior to furnace testing the samples, pre-test examinations of the fuel and cladding were made to characterize the as-irradiated structure. To begin the temperature transient test, the sample was installed in the furnace and slowly ramped to a pre-test, priming temperature. The prescribed furnace transient routine then began by increasing the temperature at a predetermined rate (ramp rate) to a peak target temperature. A representative furnace testing

routine is shown in Figure 2. The sample was held at the target temperature for a designated period of time or until pin failure. The furnace was scrammed when the test end condition was met (either at the end of the test time, or when pin failure was detected by a pressure spike), and the pin was then allowed to cool by convective heat loss. Following each test, data was collected and post-test examinations were made of the sample.

Figure 2: Furnace testing routine [3].

The FBTA tests were conducted on more than 140 fuel pin segments extracted from EBR-II fuel pins (and one pin from FFTF) at constant temperatures from 625 to 850°C for durations from a few minutes up to 36 hours, although most had a 1 hour duration. Fuels tested were binary (U-10Zr) and ternary fuels (up to U-26Pu-10Zr), with claddings composed of HT9, D9, or 316 stainless steel and peak burnups from 2.3 to 17 at.%. A few tests were also conducted on ternary fuels with varying Zr content. The results of the FBTA tests established the time- and temperature-dependence of eutectic cladding penetration in the metallic fuel samples as well as rough threshold temperatures for liquefaction. The Whole Pin Furnace (WPF) tests were conducted on *intact* fuel pins from EBR-II, rather than segments, to study synergistic effects of fission gas pressure loading and fuel-cladding interaction. Seven WPF tests determined modes of pin failure, established safety margins and fuel failure thresholds, and examined fuel motion within the pin.

3 FBTA TESTS

Tests conducted in the FBTA utilized small segments cut from various axial locations of irradiated fuel pins. A complete description of the Fuel Behavior Test Apparatus can be found in [4]. Published reports of FBTA test results can be found in [5], [6], and [7]. Each section that follows presents a set of related tests; the tested pin(s) are indicated in the section headings.

3.1 U-10Zr/HT9 at 3 at.% burnup (T-437/X425)

This group of tests was conducted on segments taken from fuel pin T-437 from EBR-II subassembly X425 (U-10Zr/HT9 at 3 at.% burnup). Together, tests 88-04, 88-05, 88-06, and 88-13 established a rough threshold temperature for fuel liquefaction (725-750°C for a 1-hour test) and measured the cladding penetration rate as a function of temperature. The initial tests (88-01 through 88-03) conducted on segments from the upper portion of the fuel pin ($x/L > 0.8$) were discarded on account of the samples exhibiting an open fuel-cladding gap. Segments were thereafter selected from near the fuel midplane where there was a closed fuel-cladding gap (x/L near 0.5). Test 88-10 was conducted at 800°C for 1 hour in order to create SEM samples to examine the resulting phases in the reacted cladding zones.

Test	Temperature	Duration	Note
88-01	800°C	1 hour	Open fuel-cladding gap - discarded
88-02	850°C	1 hour	Open fuel-cladding gap - questionable
88-03	750°C	1 hour	Open fuel-cladding gap - discarded
88-04	800°C	1 hour	
88-05	750°C	1 hour	
88-06	700°C	1 hour	
88-10	800°C	1 hour	For SEM
88-13	725°C	1 hour	

FBTA Test 88-01

Conducted ~12 October 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.85
Segment ID (AGHCF)	341C10

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	DISCARDED (Open Fuel-Cladding Gap)
Max. Depth of Penetration	NA
Penetration Rate	NA

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	Macrophotos [2]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 88-01 Test Notes (*unpublished information*)

KEY TEST INFORMATION
The tested fuel segment in test 88-01 had a posttest residual fuel-cladding gap of ~1 mil maximum and showed essentially no cladding attack. The results (no FCCI observed) were attributed to the observed open fuel-cladding gap; the test was repeated with a new fuel pin segment with a closed fuel-cladding gap (test 80-04).

FBTA Test 88-02

Conducted ~14 October 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.87
Segment ID (AGHCF)	341C14

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	850°C
Duration	1 hour

RESULTS	
Status	QUESTIONABLE (Open Fuel-Cladding Gap)
Max. Depth of Penetration	175 μm
Penetration Rate	$4.9 \times 10^{-2} \mu\text{m/s}$
% Liquefaction	~80%

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	Macrophotos [2]
During Transient	none
Post-Transient	Cross-section microphotos, Microprobe examination records [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 88-02 Test Notes (*unpublished information*)

KEY TEST INFORMATION
The tested segment in test 88-02 showed a posttest residual fuel-cladding gap (as for test 88-01), but unlike the 88-01 test (at 800°C), this test at 850°C showed extensive fuel melting & FCCI. Roughly 80% of the fuel melted (20% was left intact). Microprobe examination confirmed that the unaffected fuel contained 9 a/o Zr (balance U) but no Fe and that the once-molten fuel had a two-phase structure (high-Z and low-Z) containing Fe. Melting was promoted by the Fe & Cr diffused away from the HT9 cladding. Microprobe examination confirmed compositional changes at the reacted cladding ID (presence of lanthanides, depletion of Fe, Cr, C). These results were unpublished.

FBTA Test 88-03

Conducted ~19 October 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.89
Segment ID (AGHCF)	341C15

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	DISCARDED (Open Fuel-Cladding Gap)
Max. Depth of Penetration	NA
Penetration Rate	NA

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	Macrophotos, weight [2]
During Transient	none
Post-Transient	Cross-section microphoto, weight [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 88-03 Test Notes (*unpublished information*)

KEY TEST INFORMATION
The tested fuel segment in test 88-03 had a posttest residual fuel-cladding gap of ~1 mil maximum and showed essentially no cladding attack. The test was repeated with a new fuel pin segment with a closed fuel-cladding gap (test 80-05).

FBTA Test 88-04

Conducted 12 November 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.46
Segment ID (AGHCF)	341C18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	164 μm
Penetration Rate	$4.56 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	Macrophotos, weight [2]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 88-04 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Test 88-04 is a repeat of test 88-01 (the tested specimen in 88-01 was found to have an open fuel-cladding gap and showed essentially no cladding attack). This test, 88-04, utilized a specimen from near the midplane of the pin with a closed fuel-cladding gap.

FBTA Test 88-05

Conducted 17 November 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.48
Segment ID (AGHCF)	341C19

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	67 μm
Penetration Rate	$1.87 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	Macrophotos, weight [2]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 88-05 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Test 88-05 is a repeat of 88-03 (which was conducted on a specimen with an open fuel-cladding gap). Test 88-05 was conducted on a segment taken from near the midplane region of the pin, with a closed fuel-cladding gap. Apparent liquefaction and fuel-cladding interaction was observed, necessitating a lower temperature run at 700°C to determine the threshold temperature for fuel surface liquefaction (test 88-06).

FBTA Test 88-06

Conducted 24 November 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.52
Segment ID (AGHCF)	341C20

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 μm
Penetration Rate	0 $\mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	Macrophotos, weight [2]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 88-06 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Test 88-06 was conducted to determine the threshold temperature for FCCI (because interaction was seen in test 88-05 at 750°C). It was conducted on a segment taken from near the midplane region of the pin, with a closed fuel-cladding gap. No fuel liquefaction was observed in test 88-06.

FBTA Test 88-10

Conducted 16 December 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	~0.54
Segment ID (AGHCF)	341C21

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour*

*test conducted in 2 parts – 6 min. hold on 12/15/87, 54 min. on 12/16/87.

RESULTS	
Status	NONE – created SEM samples
Max. Depth of Penetration	NA
Penetration Rate	NA

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	none
During Transient	Temperature [2]
Post-Transient	SEM-BSE imaging, microphotos, SEM/EDX composition [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-10 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Test 88-10 was conducted using the same conditions as test 88-04 in order to produce samples for SEM examination to determine the phase structures in the reacted cladding zones (extent of fuel-cladding interaction was approximately the same as in the 88-04 test). Three phases were found in the reaction zone between the fuel and cladding. Fuel-cladding interaction between the U-10Zr fuel and HT9 cladding at 800°C was determined to be a liquid-alloy attack of the cladding. The boundary observed in optical photomicrographs was determined to be a good indicator of the extent of cladding penetration.

FBTA Test 88-13

Conducted 5 April 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-437 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.56
Segment ID (AGHCF)	341C23

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 μm
Penetration Rate	0 $\mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	HFEF bow and length measurements, isotopic gamma scans [1]
(segment)	Macrophotos [2]
During Transient	Temperature [2]
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-13 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Test 88-13 was conducted because tests on this material at 800°C and 750°C both showed FCCI, but the test conducted at 700°C did not. This test was conducted to determine if there was FCCI at 725°C to support EBR-II Mk-IV fuel qualification. No FCCI was observed.

3.2 U-10Zr/HT9 at 8 at.% burnup (T-619/X429), G-series

FBTA tests 88-17, 88-18, 88-19, 88-20, and 88-21 comprise the G-series tests which examined cladding penetration kinetics as a function of time in pin T-619 from EBR-II subassembly X429 (U-10Zr/HT9 at 8 at.% burnup). All tests were conducted at 800°C. FBTA tests 88-15 & 88-16 were intended to be the first in the series but were discarded on account of a suspected open fuel/cladding gap. The G-series tests demonstrated that after the initial rapid reaction, the liquid-phase penetration into the cladding occurred at a constant rate. Rapid penetration at the onset of heating was attributed to the fuel/cladding diffusional interaction that occurred during the steady-state irradiation of the fuel pin in EBR-II, which left interdiffusion layers on the fuel and cladding surfaces that liquefied quickly after reaching the test temperature. After the interdiffusion layers were consumed, further penetration into the cladding was then driven by diffusion across the liquid/solid boundaries and proceeded at a constant rate (up to the 2-hour duration tested).

Test	Temperature	Duration	Note
88-15	800°C	1 hour	Open fuel-cladding gap - discarded
88-16	800°C	30 mins	Open fuel-cladding gap - discarded
88-17	800°C	2 hours	
88-18	800°C	1 hour	
88-19	800°C	30 minutes	
88-20	800°C	7.5 minutes	
88-21	800°C	15 minutes	

FBTA Test 88-15

Conducted 6 July 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-619 (X429)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	8 a/o
Segment Axial Location (x/L)	0.46
Segment ID (AGHCF)	365B4

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	DISCARDED (Open Fuel-Cladding Gap)
Max. Depth of Penetration	NA
Penetration Rate	NA

DATA AVAILABLE	
Pre-Transient (whole pin)	Weight and length measurements [1]
(segment)	Macrophotos, length, weight [2]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-15 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Test 88-15 was intended to be the first in the G-series to examine cladding penetration kinetics, but metallographic data showed a possible open fuel-cladding gap, so the results were discarded and the experiment repeated with a new segment in test 88-18.

FBTA Test 88-16

Conducted 6 July 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-619 (X429)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	8 a/o
Segment Axial Location (x/L)	0.55
Segment ID (AGHCF)	365B8

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	0.5 hour

RESULTS	
Status	DISCARDED (Open Fuel-Cladding Gap)
Max. Depth of Penetration	NA
Penetration Rate	NA

DATA AVAILABLE	
Pre-Transient (whole pin)	Weight and length measurements [1]
(segment)	Macrophotos, length, weight [2]
During Transient	none
Post-Transient	none

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-16 Test Notes (*unpublished information*)

KEY TEST INFORMATION	
Test 88-16 was intended to be the second in the G-series to examine cladding penetration kinetics, but the sample appeared to have an open fuel-cladding gap, so the results were discarded and the experiment repeated with a new segment in test 88-19.	

FBTA Test 88-17

Conducted 21 July 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-619 (X429)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	8 a/o
Segment Axial Location (x/L)	0.23
Segment ID (AGHCF)	365B15

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	234 μm
Penetration Rate	$3.25 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Weight and length measurements [1]
(segment)	Macrophotos, length, weight [2], microprobe analysis of sibling segment [3]
During Transient	Temperature, FG detector output, LVDT extension [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-17 Test Notes (*unpublished information*), [3] FBTA Book #2: Metallography and Microprobe Analysis of Steady-State Sibling to G-series FBTA Tests (*unpublished information*)

KEY TEST INFORMATION
The LVDT extension indicated sample shrinkage in the latter part of the 88-17 test.

FBTA Test 88-18

Conducted 21 July 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-619 (X429)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	8 a/o
Segment Axial Location (x/L)	0.20
Segment ID (AGHCF)	365B14

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	145 μm
Penetration Rate	$4.03 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Weight and length measurements [1]
(segment)	Macrophotos, length, weight [2], microprobe analysis of sibling segment [3]
During Transient	Temperature, FG detector output, LVDT extension [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-18 Test Notes (*unpublished information*), [3] FBTA Book #2: Metallography and Microprobe Analysis of Steady-State Sibling to G-series FBTA Tests (*unpublished information*)

KEY TEST INFORMATION
The LVDT extension indicated sample shrinkage during the latter part of the 88-18 test.

FBTA Test 88-19

Conducted 25 July 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-619 (X429)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	8 a/o
Segment Axial Location (x/L)	0.25
Segment ID (AGHCF)	365B16

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	30 mins (0.5 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	81 μm
Penetration Rate	$4.5 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Weight and length measurements [1]
(segment)	Macrophotos, length, weight [2], microprobe analysis of sibling segment [3]
During Transient	Temperature, FG detector output, LVDT extension [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-19 Test Notes (*unpublished information*), [3] FBTA Book #2: Metallography and Microprobe Analysis of Steady-State Sibling to G-series FBTA Tests (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 88-20

Conducted 25 July 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-619 (X429)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	8 a/o
Segment Axial Location (x/L)	0.27
Segment ID (AGHCF)	365B17

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	7.5 mins (0.125 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	53 μm
Penetration Rate	$1.18 \times 10^{-1} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Weight and length measurements [1]
(segment)	Macrophotos, length, weight [2], microprobe analysis of sibling segment [3]
During Transient	Temperature, FG detector output, LVDT extension [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-20 Test Notes (*unpublished information*), [3] FBTA Book #2: Metallography and Microprobe Analysis of Steady-State Sibling to G-series FBTA Tests (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 88-21

Conducted 25 July 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-619 (X429)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	8 a/o
Segment Axial Location (x/L)	0.30
Segment ID (AGHCF)	365B18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	15 mins (0.25 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	69 μm
Penetration Rate	$7.67 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Weight and length measurements [1]
(segment)	Macrophotos, length, weight [2], microprobe analysis of sibling segment [3]
During Transient	Temperature, FG detector output, LVDT extension [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-21 Test Notes (*unpublished information*), [3] FBTA Book #2: Metallography and Microprobe Analysis of Steady-State Sibling to G-series FBTA Tests (*unpublished information*)

KEY TEST INFORMATION

3.3 U-10Zr/D9 at 6 at.% burnup (T-224/X420)

FBTA tests 88-07, 88-08, and 88-09 were conducted on segments taken from near the top (x/L ~ 0.9) of pin T-224 from EBR-II subassembly X420 (U-10Zr/D9 at 6 at.% burnup) to examine the threshold temperature for fuel-cladding chemical interaction (FCCI). FCCI was evident in the first two tests at 800°C and 750°C (88-07 and 88-08, respectively) with only a slight amount seen in the last test at 725°C (88-09). The fuel/cladding interaction seen in the 725°C test was attributed to solid-state interdiffusion rather than liquid-phase cladding attack. The fuel liquefaction threshold temperature (for a 1 hr test) was 725-750°C.

Test	Temperature	Duration	Note
88-07	800°C	1 hour	
88-08	750°C	1 hour	
88-09	725°C	1 hour	FCCI due to solid-state interdiffusion

FBTA Test 88-07

Conducted 9 December 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-224 (X420)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	6 a/o
Segment Axial Location (x/L)	0.93
Segment ID (AGHCF)	333A16

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	177.7 μm
Penetration Rate	$4.94 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and bow measurements, fission gas analysis, gamma scans, metallography [1]
(segment)	Macrophotos, weight [2], metallography of sibling [1]
During Transient	none
Post-Transient	Cross-section (transverse) and longitudinal microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-07 Test Notes (*unpublished information*)

KEY TEST INFORMATION
The sample used for FBTA test 88-07 could not be readily removed from the Ta holder after the test, so the holder was made part of the posttest metallographic examination mount. Extensive FCCI was observed. No fully intact cladding was found on the examined section of the sample, so a metallographic standard was photographed and measured to represent the original cladding thickness (15 mils) for the purposes of calculating the penetration depth into the cladding. The longitudinal metallography showed nearly uniform fuel-cladding interaction over the length of the specimen, indicating no appreciable temperature gradients in the axial direction during the test.

FBTA Test 88-08

Conducted 10 December 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-224 (X420)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	6 a/o
Segment Axial Location (x/L)	0.91
Segment ID (AGHCF)	333A17

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	19.9 μm
Penetration Rate	$5.53 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and bow measurements, fission gas analysis, gamma scans, metallography [1]
(segment)	Macrophotos, weight [2], metallography of sibling [1]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-08 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Only minor FCCI was observed.

FBTA Test 88-09

Conducted 14 December 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-224 (X420)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	6 a/o
Segment Axial Location (x/L)	0.89
Segment ID (AGHCF)	333A18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	7.2 μm (solid-state interdiffusion, not eutectic penetration)
Penetration Rate	$2.0 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and bow measurements, fission gas analysis, gamma scans, metallography [1]
(segment)	Macrophotos, weight [2], metallography of sibling [1]
During Transient	none
Post-Transient	Cross-section microphoto, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-09 Test Notes (*unpublished information*)

KEY TEST INFORMATION
The experimenter's note indicates there was evidence of a slight amount of fuel-cladding interaction in the sample tested in FBTA test 88-09. Some slight cladding reaction was noted in the as-irradiated steady state sibling specimen examined near the same axial location along the pin. The later published reports indicate no liquid-phase cladding penetration for this test, attributing the observed FCCI to solid-state interdiffusion.

3.4 U-10Zr/D9 at 10 at.% burnup (T-248/X421)

FBTA tests 88-11, 88-12, and 88-14 were conducted on segments taken from the upper portion of pin T-248 from EBR-II subassembly X421 (U-10Zr/D9 at 10 at.% burnup). The samples were held for one hour at 750°C and 800°C, respectively, to examine cladding attack. Test 88-14 was conducted to repeat test 88-12 in which less-than-expected FCCI occurred. Test 88-14 saw slightly more FCCI, but still much less than expected (far more FCCI was seen in test 88-07, conducted on the same fuel composition but at lower burnup). A thick Zr-rich layer found on the surface of the fuel from pin T-248 may have slowed the fuel-cladding interaction in these tests.

Test	Temperature	Duration	Note
88-11	750°C	1 hour	
88-12	800°C	1 hour	
88-14	800°C	1 hour	Repeat of 88-12 to confirm results

FBTA Test 88-11

Conducted 1 April 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-248 (X421)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.76*
Segment ID (AGHCF)	353C12

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	16.3 μm
Penetration Rate	$4.53 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and bow measurements, fission gas analysis, gamma scans, contact and laser profilometry, weight [1]
(segment)	Macrophotos, weight [2], metallography of sibling [1], [3]
During Transient	none
Post-Transient	Cross-section microphoto, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-11 Test Notes (*unpublished information*), [3] A/G Databook 353C (*unpublished information*)

KEY TEST INFORMATION
Test 88-11 showed minimal FCCI that experimenters initially noted appeared to be a diffusional attack, not necessarily liquid-attack wastage. The resulting calculated penetration rate was reported as liquid-phase cladding penetration in later publications. A thick Zr-rich layer was found on the surface of the fuel (attributed to the fuel casting process), which may have retarded fuel-cladding interaction during the test.
*Experimenter's notes indicate axial location of segment as x/L ~ 0.82, the sectioning diagram indicates x/L ~ 0.84, but the compatibility test summary table in later FBTA records indicates x/L = 0.76.

FBTA Test 88-12

Conducted 4 April 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-248 (X421)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.78*
Segment ID (AGHCF)	353C13

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	51 μm
Penetration Rate	$1.42 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and bow measurements, fission gas analysis, gamma scans, contact and laser profilometry, weight [1]
(segment)	Macrophotos, weight [2], metallography of sibling [1], [3]
During Transient	Temperature [2]
Post-Transient	Cross-section microphoto, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-12 Test Notes (*unpublished information*), [3] A/G Databook 353C (*unpublished information*)

KEY TEST INFORMATION
Test 88-12 showed less than expected cladding penetration (test 88-07, which was conducted at the same temperature on a lower burnup sample of the same composition, exhibited 3x the cladding penetration). A thick Zr-rich layer found on the surface of the 88-12 fuel, thought to be due to the casting process, may have retarded the fuel-cladding interaction for this test (the lower burnup sample used in 88-07 had a thinner surface layer). Test 88-12 was repeated as FBTA test 88-14.
*Experimenter's notes indicate axial location of segment as x/L ~ 0.84, the sectioning diagram indicates x/L ~ 0.86, but the compatibility test summary table in later FBTA records indicates x/L = 0.78.

FBTA Test 88-14

Conducted 7 April 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-248 (X421)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.74*
Segment ID (AGHCF)	353C11

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	70.2 μm
Penetration Rate	$1.95 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and bow measurements, fission gas analysis, gamma scans, contact and laser profilometry, weight [1]
(segment)	Macrophotos, weight [2], metallography of sibling [1], [3]
During Transient	none
Post-Transient	Cross-section microphoto, macrophotos, electron microprobe examination [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #2: 88-14 Test Notes (*unpublished information*), [3] A/G Databook 353C (*unpublished information*)

KEY TEST INFORMATION
Test 88-14 was a repeat of test 88-12, which showed less than expected cladding penetration. Slightly more penetration was seen in the repeat test, but still far less than expected (test 88-07, which was conducted at the same temperature on a lower burnup sample of the same composition, exhibited over 2x the cladding penetration). A thick Zr-rich layer found on the surface of the 88-14 fuel, thought to be due to the casting process, may have retarded the fuel-cladding interaction for this test (the lower burnup sample used in 88-07 had a thinner surface layer).
*The sectioning diagram indicates x/L ~ 0.82, but the compatibility test summary table in later FBTA records indicates x/L = 0.74.

3.5 U-10Zr/D9 at 17 at.% burnup (T-227/X421A)

FBTA tests 90-04 through 90-16 were conducted on segments taken from various locations along the length of pin T-227 from EBR-II subassembly X421A (U-10Zr/D9 at 17 at.% burnup) to determine which portion of the fuel pin was more susceptible to FCCI in the high burnup Mk-III-type pin. The experiment set was also conducted to determine the onset-of-melting temperature (~725-750°C) and temperature-dependent cladding penetration rate. The examination of this high burnup pin was intended to support the EBR-II Mk-III burnup extension and safety case. Some of the reported cladding penetration results in this set should be considered preliminary. The calculation methods varied as compared with previous tests and many results were not formally reported (only preliminary data is available). Explanatory notes are included with the individual test summaries (under “key test information”).

Test	Temperature	Duration	Note
90-04	800°C	1 hour	wide fuel-cladding gap - discarded
90-05	800°C	1 hour	
90-06	800°C	1 hour	wide fuel-cladding gap - discarded
90-07	750°C	1 hour	erratic TC reading, unreported/preliminary
90-08	725°C	1 hour	
90-09	800°C	30 mins	unreported/preliminary
90-10	725°C	7 hours	unreported/preliminary
90-11	750°C	5 mins	unreported/preliminary
90-12	800°C	1 hour	
90-13	800°C	5 mins	unreported/preliminary
90-14	850°C	5 mins	unreported/preliminary
90-15	800°C	2 hours	unreported/preliminary
90-16	800°C	30 mins	unreported/preliminary

FBTA Test 90-04

Conducted 22 February 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.51
Segment ID (AGHCF)	395C12

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	DISCARDED (open fuel-cladding gap)
Max. Depth of Penetration	N/A
Penetration Rate	N/A

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	~length [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-04 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A) (*unpublished information*)

KEY TEST INFORMATION
Test 90-04 used a segment from the midplane of the fuel pin where there was a very wide fuel-cladding gap. No further post-test examination was completed on account of the large gap.

FBTA Test 90-05

Conducted ~7 March 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.87
Segment ID (AGHCF)	395C13

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	98 μm
Penetration Rate	$2.72 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	~length [2], sibling segment cross-section microphotos [3]
During Transient	Temperature, FG Detector Output
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-05 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A) (*unpublished information*)

KEY TEST INFORMATION
Experimenter notes indicate that the thinned cladding after test 90-05 was mostly due to diffusional and liquid-phase grain boundary penetration attack. Note that the experimenters calculated resulting cladding penetration using the as-tested cladding thickness rather than the original cladding thickness.

FBTA Test 90-06

Conducted 8 March 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.53
Segment ID (AGHCF)	395C14

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	DISCARDED (open fuel-cladding gap)
Max. Depth of Penetration	N/A
Penetration Rate	N/A

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	~length [2], sibling segment cross-section microphotos [2, 3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-06 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A) (*unpublished information*)

KEY TEST INFORMATION
Test 90-06 used a segment from near the midplane of the fuel pin where there was a very wide fuel-cladding gap. No further post-test examination was completed on account of the large gap.

FBTA Test 90-07

Conducted 16 March 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.82
Segment ID (AGHCF)	395C16

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	QUESTIONABLE (see key test information)
Max. Depth of Penetration	106 μm
Penetration Rate	$2.94 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos, macrophotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-07 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
Experimenter notes indicate erratic thermocouple behavior during test 90-07 (within +/- 10°C). The measured penetration results were not included in later publications. The measured penetration depth and effective rate were greater for this test than for tests 90-05 and 90-12 (conducted on segments from slightly higher on along the fuel pin axis at a higher temperature of 800°C). Experimenters also calculated resulting cladding penetration using the as-tested cladding thickness rather than the original thickness.

FBTA Test 90-08

Conducted 20 March 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.78
Segment ID (AGHCF)	395C15

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 µm
Penetration Rate	0 µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos, macrophotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-08 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
No liquid-phase cladding penetration was observed in test 90-08.

FBTA Test 90-09

Conducted 5 April 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.75
Segment ID (AGHCF)	395C18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	30 mins (0.5 hr)

RESULTS	
Status	QUESTIONABLE (see key test information)
Max. Depth of Penetration	117 μm
Penetration Rate	$6.5 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos, macrophotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-09 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
The results of test 90-09 were not included in later publications. Note that the recorded maximum depth of penetration for test 90-09 (of 30 minute duration) was greater than for the 1 hour tests (90-05 and 90-12). This variance in cladding penetration rate may be attributable to the changing microstructure along the axis of this fuel pin (note that this segment was from x/L ~ 0.75, while the longer duration 800°C tests were conducted on segments nearer the fuel top). Experimenters also calculated resulting cladding penetration using the as-tested cladding thickness rather than the original thickness.

FBTA Test 90-10

Conducted 6 April 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.73
Segment ID (AGHCF)	395C19

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	7 hours

RESULTS	
Status	QUESTIONABLE (see key test information)
Max. Depth of Penetration	249 μm
Penetration Rate	$9.88 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos, macrophotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-10 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
The results of test 90-10 were not included in later publications. Experimenters also calculated resulting cladding penetration using the as-tested cladding thickness rather than the original thickness.

FBTA Test 90-11

Conducted 26 April 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.71
Segment ID (AGHCF)	395C20

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	QUESTIONABLE (see key test information)
Max. Depth of Penetration	27 μm^*
Penetration Rate	$9.0 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos, macrophotos [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-11 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
The results of test 90-11 were not included in later publications. Experimenter notes indicate that the accuracy of the measurement dropped as the thickness decreased.
*Penetration was measured only up to the porosity front, not including the 16 μm -thick diffusion zone.

FBTA Test 90-12

Conducted 3 May 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.89
Segment ID (AGHCF)	395C22

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	77 μm
Penetration Rate	$2.14 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-12 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
Test 90-12 was a repeat of test 90-05. Results were consistent. Note that experimenters calculated the resulting cladding penetration using the as-tested cladding thickness rather than the original thickness.

FBTA Test 90-13

Conducted 3 May 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.69
Segment ID (AGHCF)	395C23

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	QUESTIONABLE (see key test information)
Max. Depth of Penetration	45 μm
Penetration Rate	$1.5 \times 10^{-1} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-13 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
Results of test 90-13 were not included in later publications. Penetration results for test 90-13 were calculated based on the as-tested cladding thickness, rather than the original cladding thickness. Note that results for test 90-14 (at 850°C), however, were reported based on the original cladding thickness.

FBTA Test 90-14

Conducted 10 May 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.91
Segment ID (AGHCF)	395C21

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	850°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	39 μm
Penetration Rate	$1.3 \times 10^{-1} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	sibling segment cross-section microphotos [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-14 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
Results of test 90-14 were not included in later publications. When comparing results, note that the cladding penetration for test 90-13 (at 800°C) was measured based on the as-tested cladding thickness, rather than the original cladding thickness (This test, 90-14, used the original cladding thickness for calculation).

FBTA Test 90-15

Conducted 16 May 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.92
Segment ID (AGHCF)	395C8

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	120 μm
Penetration Rate	$1.67 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	Length [2], sibling segment cross-section microphotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-15 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 90-16

Conducted 17 May 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-227 (X421A)
Fuel	U-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.67
Segment ID (AGHCF)	395C24

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	30 mins (0.5 hr)

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	117 μm
Penetration Rate	$6.5 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, contact profilometry [1]
(segment)	Length [2], sibling segment cross-section microphotos [3]
During Transient	None
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-16 Test Notes (*unpublished information*), [3] A/G Databook 395C (Binder 448A & 448B) (*unpublished information*)

KEY TEST INFORMATION
The results of test 90-16 were not included in later publications. Note that the recorded maximum depth of penetration for test 90-16 (of 30 minute duration) was greater than for the 1 hour tests (90-05 and 90-12). This variance in cladding penetration rate may be attributable to the changing microstructure along the axis of this fuel pin (note that this segment was from x/L ~ 0.67, while the longer duration 800°C tests were conducted on segments nearer the fuel top). Experimenters calculated resulting cladding penetration using the original cladding thickness (consistent with the method used for most previous tests), noting the as-tested cladding thickness was 5 μm thinner.

3.6 U-10Zr/316SS at 9.3 at.% burnup (T-536/X421A)

FBTA tests 89-02 through 89-04 were conducted on segments taken from near the midline of pin T-536 from EBR-II subassembly X421A (U-10Zr/N-lot 316SS at 9.3 at.% burnup) to examine the extent of cladding attack. Examined together with the results of the 89-05 through 89-08 tests, this test set established penetration rate as a function of temperature and burnup in binary fuel with 316SS cladding.

Test	Temperature	Duration	Note
89-02	800°C	1 hour	
89-03	850°C	1 hour	
89-04	750°C	1 hour	

FBTA Test 89-02

Conducted 22 February 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-536 (X421A)
Fuel	U-10Zr
Cladding	316SS (N-lot)
Peak Burnup in Pin	9.3 a/o
Segment Axial Location (x/L)	0.48
Segment ID (AGHCF)	379B3

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	116.8 μm
Penetration Rate	$3.25 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and weight, fission gas release and chemistry [1]
(segment)	Length & weight, macrophotos [2], sibling segment cross-section microphotos [3], microprobe & chemical analysis of sibling segment [4]
During Transient	Temperature [2]
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-02 Test Notes (*unpublished information*), [3] A/G Databook 379B (Binder 441) (*unpublished information*), [4] FBTA Book #4: Metallography and Chemical Analysis of Sibling Segment A/G 379B4 (*unpublished information*)

KEY TEST INFORMATION
Note that the calculations for penetration depth and rate into the cladding are not included in the experimenter's notes, but they are reported consistently in later records.

FBTA Test 89-03

Conducted 22 February 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-536 (X421A)
Fuel	U-10Zr
Cladding	316SS (N-lot)
Peak Burnup in Pin	9.3 a/o
Segment Axial Location (x/L)	0.52
Segment ID (AGHCF)	379B5

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	850°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	155 μm
Penetration Rate	$4.31 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and weight, fission gas release and chemistry [1]
(segment)	Length & weight, macrophotos [2], sibling segment cross-section microphotos [3], microprobe & chemical analysis of sibling segment [4]
During Transient	Temperature [2], table of FG and LVDT output for first 1120 s of test [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-03 Test Notes (*unpublished information*), [3] A/G Databook 379B (Binder 441) (*unpublished information*), [4] FBTA Book #4: Metallography and Chemical Analysis of Sibling Segment A/G 379B4 (*unpublished information*)

KEY TEST INFORMATION
Test 89-03 exhibited a slight temperature perturbation (cause unknown) at 320 seconds into the test (dipping to a temperature of 842°C) but recovered within 20 seconds and maintained test temperature of 850°C for the remainder of the test (+/- 4°C).

FBTA Test 89-04

Conducted ~ March 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-536 (X421A)
Fuel	U-10Zr
Cladding	316SS (N-lot)
Peak Burnup in Pin	9.3 a/o
Segment Axial Location (x/L)	0.45
Segment ID (AGHCF)	379B2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	49 μm
Penetration Rate	$1.36 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and weight, fission gas release and chemistry [1]
(segment)	Length & weight [2], microphotos, microprobe & chemical analysis of sibling segment [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-04 Test Notes (*unpublished information*), [3] FBTA Book #4: Metallography and Chemical Analysis of Sibling Segment A/G 379B4 (*unpublished information*)

KEY TEST INFORMATION
Test 89-04 was conducted at 750°C because test 89-02, conducted for 1 hour at 800°C, showed fuel liquefaction. This test at a lower temperature also showed noticeable cladding penetration (though less than the higher temperature test).

3.7 U-10Zr/316SS at 4.6 at.% burnup (T-323/X423C), Temperature-dependence

FBTA tests 89-05 through 89-08 were conducted on segments taken from near the middle of pin T-323 from EBR-II subassembly X423C (U-10Zr/1st core 316SS at 4.6 at.% BU). Because prior tests on U-10Zr/N-lot 316SS (89-02 through 89-04) showed inferior fuel-cladding compatibility compared with tests on U-26Pu-10Zr/1st core 316SS (88-22 through 89-01), this set of tests was run on a sister to the ternary pin (from the same subassembly X423C, with the same 1st core cladding lot) to determine whether the cladding lot was a factor contributing to the compatibility difference (N-lot vs 1st core 316SS). Together with tests 89-02 through 89-04, this test set examines penetration rate as a function of burnup and temperature as well as onset-of-melting temperature for binary fuel with 316SS cladding.

Test	Temperature	Duration	Note
89-05	800°C	1 hour	
89-06	750°C	1 hour	
89-07	850°C	1 hour	Discarded (Ta hold-down rod in fuel)
89-08	850°C	1 hour	

FBTA Test 89-05

Conducted ~ March 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.55
Segment ID (AGHCF)	379A6

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	86.5 µm
Penetration Rate	2.40×10^{-2} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight [2], length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	Temperature [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-05 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 89-06

Conducted ~7 March 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.52
Segment ID (AGHCF)	379A5

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	84 μm
Penetration Rate	$2.33 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, macrophotos [2], length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	Temperature [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-06 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 89-07

Conducted 16 March 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.48
Segment ID (AGHCF)	379A3

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	850°C
Duration	1 hour

RESULTS	
Status	DISCARDED
Max. Depth of Penetration	N/A
Penetration Rate	N/A

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight [2], length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-07 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
Posttest examination of FBTA test 89-07 was aborted because the Ta hold-down rod sunk into the once-molten fuel (the hold-down rod was narrower than the inner diameter of the cladding). The test was re-run as FBTA test 89-08.

FBTA Test 89-08

Conducted ~16 March 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.45
Segment ID (AGHCF)	379A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	850°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	244 µm
Penetration Rate	6.78×10^{-2} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, macrophotos [2], length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	Temperature [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-08 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
Test 89-08 is a repeat of failed test 89-07.

3.8 U-10Zr/316SS at 4.6 at.% burnup (T-323/X423C), Time-dependence

FBTA Tests 89-13 through 89-16 were conducted on segments taken from near the midline of pin T-323 from EBR-II subassembly X423C (U-10Zr/316SS at 4.6 at.% burnup). Together with test 89-05, they investigated the time-dependent cladding penetration rate for U-10Zr/316SS fuel for comparison with that seen in U-26Pu-10Zr/316SS fuel (FBTA tests 89-09 through 89-12). Tests were conducted at 800°C for varying times. Penetration rate into the 316SS cladding decreased with time, with little incremental cladding penetration after 2 hrs.

Test	Temperature	Duration	Note
89-05	800 °C	1 hour	
89-13	800°C	24 min (0.4 hr)	
89-14	800°C	12 min (0.2 hr)	unreported/preliminary
89-15	800°C	2 hrs	
89-16	800°C	4 hrs	

FBTA Test 89-13

Conducted 10 May 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.58
Segment ID (AGHCF)	379A8

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	24 mins (0.4 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	59 µm
Penetration Rate	4.1×10^{-2} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight [2], length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-13 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 89-14

Conducted 11 May 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.61
Segment ID (AGHCF)	379A9

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	12 mins (0.2 hr)

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	69 µm
Penetration Rate	9.58×10^{-2} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-14 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
FBTA test 89-14 experimenter notes include calculation of maximum penetration depth and penetration rate, but these results were not reported in later publications. Note that the cladding penetration observed following this 12 min test was greater than it was for the longer-duration 24 min test (89-13).

FBTA Test 89-15

Conducted 15 May 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.64
Segment ID (AGHCF)	379A10

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	99 µm
Penetration Rate	1.38×10^{-2} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight [2], length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-15 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 89-16

Conducted 26 May 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-323 (X423C)
Fuel	U-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.6 a/o
Segment Axial Location (x/L)	0.67
Segment ID (AGHCF)	379A11

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	4 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	109 µm
Penetration Rate	$7.57 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas release and chemistry, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight [2], length, sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-16 Test Notes (*unpublished information*), [3] A/G Databook 379A (Binder 440) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

3.9 U-19Pu-10Zr/HT9 at 3 at.% burnup (T-459/X425)

FBTA tests 87-70 through 87-73 were conducted on segments taken from near the top of the fuel column of pin T-459 from EBR-II subassembly X425 (U-19Pu-10Zr/HT9 at 3 at.% burnup). These were early screening tests conducted to provide data on compatibility between irradiated high-Pu fuel and HT9 cladding for direct comparison with similar tests conducted on high-Pu fuel with D9 cladding (at 2 at.% burnup). The tests indicated that HT9 cladding offers reduced compatibility with U-19Pu-10Zr fuel as compared with D9 cladding at comparable high temperatures, with onset-of-melting appearing at a temperature over 100°C lower and cladding penetration occurring at a greater rate in the HT9-clad fuel pins.

Test	Temperature	Duration	Note
87-70	800°C	5 mins	Some fuel-clad interaction
87-71	880°C	5 mins	Extensive fuel-clad interaction, melting
87-72	700°C	5 mins	
87-73	750°C	5 mins	

FBTA Test 87-70

Conducted 28 April 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-459 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.93
Segment ID (AGHCF)	341B20

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	~25.4 μm (reported as ~1 mil max)
Penetration Rate	~0.1 $\mu\text{m/s}$ (estimated, not reported)

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas analysis, gamma scans, neutron radiography [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos, microprobe [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 87-70 Test Notes (*unpublished information*), [3] A/G Databook 341B (Binder 370A) (*unpublished information*)

KEY TEST INFORMATION
Some early stage fuel-cladding interaction was seen in FBTA test 87-70, resulting in nearly-uniform cladding penetration of ~1 mil maximum and a porous fuel ring at the fuel periphery. X-ray microprobe examination verified iron and chromium within the porous ring. Penetration depth and rate values were not recorded explicitly in the experimenter's notes and are estimated here. The test results indicate HT9 has inferior compatibility with U-19Pu-10Zr at this temperature, exhibiting a greater reaction rate between the metal fuel and cladding (a comparable test on D9-clad fuel showed essentially no cladding attack). The experimenters theorized that the more open BCC lattice structure of (tempered martensitic) HT9 enhanced the self-diffusion of iron and other components, resulting in an increased reaction rate between the fuel and cladding as compared with the close-packed FCC lattice structure of (austenitic) D9.

FBTA Test 87-71

Conducted 29 April 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-459 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.91
Segment ID (AGHCF)	341B19

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	880°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	~63.5 μm (reported as ~2.5 mils max)
Penetration Rate	~0.21 $\mu\text{m/s}$ (estimated, not reported)

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas analysis, gamma scans, neutron radiography [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 87-71 Test Notes (*unpublished information*), [3] A/G Databook 341B (Binder 370A) (*unpublished information*)

KEY TEST INFORMATION
Test 87-71 had a target temp of 850°C. However, because of an overshoot due to manual power control, 880°C was first reached and held. Extensive melting and fuel-cladding interaction was observed. Penetration depth and rate values were not recorded explicitly in the experimenter's notes and are estimated here. The test results indicate HT9 has inferior compatibility with U-19Pu-10Zr at this temperature, exhibiting a greater reaction rate between the metal fuel and cladding (a comparable test on D9-clad fuel at 920°C showed very minor fuel-cladding interaction). The experimenters theorized that the more open BCC lattice structure of (tempered martensitic) HT9 enhanced the self-diffusion of iron and other components, resulting in an increased reaction rate between the fuel and cladding as compared with the close-packed FCC lattice structure of (austenitic) D9.

FBTA Test 87-72

Conducted 4 May 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-459 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.88
Segment ID (AGHCF)	341B18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	None measured
Penetration Rate	None measured

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas analysis, gamma scans, neutron radiography [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 87-72 Test Notes (*unpublished information*), [3] A/G Databook 341B (Binder 370A) (*unpublished information*)

KEY TEST INFORMATION
Test 87-72 showed no apparent interaction between the fuel and cladding as a result of the furnace test and no fuel melting. The condition of the cladding ID and fuel surface appeared the same as for a steady-state sibling segment, with no apparent changes in microstructure or morphology resulting from the furnace test.

FBTA Test 87-73

Conducted 5 May 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-459 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.86
Segment ID (AGHCF)	341B17

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	None measured
Penetration Rate	None measured

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas analysis, gamma scans, neutron radiography [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 87-73 Test Notes (*unpublished information*), [3] A/G Databook 341B (Binder 370A) (*unpublished information*)

KEY TEST INFORMATION
Test 87-73 showed no apparent interaction between the fuel and cladding as a result of the furnace test (same as for the 700°C test), and no fuel melting was observed. The condition of the cladding ID and fuel surface appeared the same as for a steady-state sibling segment, with no apparent changes in microstructure or morphology resulting from the furnace test.

3.10 U-19Pu-10Zr/HT9 at 3 at.% burnup (T-459/X425)

FBTA tests 87-74 through 87-76 were conducted on segments taken from pin T-459 from EBR-II subassembly X425 (U-19Pu-10Zr/HT9 at 3 at.% burnup) to determine the depth and effective rate of liquid-phase cladding penetration as a function of temperature.

Test	Temperature	Duration	Note
87-74	700°C	1 hour	FCCI due to solid-state interdiffusion
87-75	750°C	1 hour	
87-76	780°C	1 hour	

FBTA Test 87-74

Conducted 4 September 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-459 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.69
Segment ID (AGHCF)	341B21

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	31.4 μm (solid-state interdiffusion, no eutectic penetration)
Penetration Rate	$8.72 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas analysis, gamma scans, neutron radiography [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3]
During Transient	Temperature
Post-Transient	Weight, Cross-section microphotos, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 87-74 Test Notes (*unpublished information*), [3] A/G Databook 341B (Binder 370A) (*unpublished information*)

KEY TEST INFORMATION
Test 87-74 experimenter's notes recorded a maximum depth of cladding attack of 31.4 μm . Later published reports indicate no liquid-phase cladding penetration for this test. The initially recorded reduced cladding thickness was later attributed to solid-state interdiffusion.

FBTA Test 87-75

Conducted ~8 September 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-459 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.71
Segment ID (AGHCF)	341B22

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	49.8 μm
Penetration Rate	$1.38 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas analysis, gamma scans, neutron radiography [1]
(segment)	Weight, macrophotos [2], length, sibling segment cross-section microphotos [3]
During Transient	Temperature
Post-Transient	Cross-section microphotos, macrophotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 87-75 Test Notes (*unpublished information*), [3] A/G Databook 341B (Binder 370A) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 87-76

Conducted ~14 September 1987

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-459 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3 a/o
Segment Axial Location (x/L)	0.74
Segment ID (AGHCF)	341B23

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	780°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	62.7 μm
Penetration Rate	$1.74 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, fission gas analysis, gamma scans, neutron radiography [1]
(segment)	Weight, macrophotos [2], length, sibling segment cross-section microphotos [3]
During Transient	Temperature
Post-Transient	Weight, Cross-section microphotos, macrophotos, microprobe, microhardness [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #1: 87-76 Test Notes (*unpublished information*), [3] A/G Databook 341B (Binder 370A) (*unpublished information*)

KEY TEST INFORMATION

3.11 U-26Pu-10Zr/316SS at 4.7 at.% burnup (T-326/X423C), Onset-of-melting

FBTA tests 88-22 through 89-01 were conducted on segments taken from pin T-326 of EBR-II subassembly X423C (U-26Pu-10Zr/1st core 316SS at 4.7 at.% burnup) to determine the onset-of-melting temperature of the U-26Pu-10Zr/316SS system. Fuel liquefaction was only seen in the 88-24 and 88-26 tests (at 800°C and 850°C), establishing the onset-of-melting temperature as somewhere between 770°C and 800°C. Some evidence of diffusional cladding attack was observed in 88-27 and 89-01 tests.

Test	Temperature	Duration	Note
88-22	700°C	1 hour	
88-23	750°C	1 hour	
88-24	800°C	1 hour	Liquefaction observed
88-26	850°C	1 hour	Liquefaction observed
88-25	670°C	7 hours	
88-27	740°C	7 hours	
88-28	710°C	7 hours	
89-01	770°C	7 hours	

FBTA Test 88-22

Conducted 12 September 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.54
Segment ID (AGHCF)	369C8

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 µm
Penetration Rate	0 µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 88-22 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
No fuel-cladding interaction observed.

FBTA Test 88-23

Conducted 12 September 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.60
Segment ID (AGHCF)	369C10

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 µm
Penetration Rate	0 µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, macrophotos [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	FG detector output [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 88-23 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
No fuel-cladding interaction observed.

FBTA Test 88-24

Conducted 12 September 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.57
Segment ID (AGHCF)	369C9

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	32.5 μm
Penetration Rate	$9.03 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, macrophotos [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 88-24 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
Fuel liquefaction was observed in this test, placing the onset-of-melting temperature somewhere between 770°C (sample was held for 7 hours at this temperature with no reaction seen in test 89-01) and 800°C (test temperature of this test).

FBTA Test 88-25

Conducted 19 September 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.48
Segment ID (AGHCF)	369C6

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	670°C
Duration	7 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 µm
Penetration Rate	0 µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 88-25 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
No fuel-cladding interaction observed.

FBTA Test 88-26

Conducted 19 September 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.63
Segment ID (AGHCF)	369C11

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	850°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	75 µm
Penetration Rate	2.08×10^{-2} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos, SEM/EDX composition of reaction zones [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 88-26 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 88-27

Conducted 21 September 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.48
Segment ID (AGHCF)	369C7

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	740°C
Duration	7 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 μm^*
Penetration Rate	0 $\mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos, microhardness, microprobe composition [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 88-27 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
No liquid-phase attack was seen in this test.
*Some evidence of diffusional attack of cladding was found during post-test examination. The extent was not measured.

FBTA Test 88-28

Conducted 27 September 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.4
Segment ID (AGHCF)	369C4

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	710°C
Duration	7 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 µm
Penetration Rate	0 µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length, macrophotos [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 88-28 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
No liquid-phase attack was seen in this test.

FBTA Test 89-01

Conducted 21 October 1988

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.42
Segment ID (AGHCF)	369C5

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	770°C
Duration	7 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 μm^*
Penetration Rate	0 $\mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	Temperature
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #3: 89-01 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION
No liquid-phase attack was seen in this test. Because there was no evidence of fuel liquefaction after 7 hours at 770°C, the onset-of-melting temperature for this pin was thought to be somewhere between 770°C and 800°C (liquefaction was seen in test 88-24 at 800°C).
*Some evidence of diffusional attack of cladding was found during post-test examination. The extent was not measured.

3.12 U-26Pu-10Zr/316SS at 4.7 at.% burnup (T-326/X423C), Time-dependence

FBTA tests 89-09 through 89-12 were conducted on segments taken from above the midplane of pin T-326 from EBR-II subassembly X423 (U-26Pu-10Zr/1st core 316SS at 4.7 at.% burnup). Tests were conducted at 800°C for varying times to investigate the time dependence of cladding penetration rate. These results were compared with the time-dependent cladding penetration rate seen in U-10Zr/316SS fuel (tests 89-13 through 89-16 and 89-05). There was less cladding penetration seen in these high-Pu fuel tests, but the time-dependence of the cladding penetration rate was similar; the penetration rate decreased with time.

Test	Temperature	Duration	Note
89-09	800°C	1 hour	
89-10	800°C	2 hours	
89-11	800°C	4 hours	
89-12	800°C	24 mins	

FBTA Test 89-09

Conducted 27 April 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.7
Segment ID (AGHCF)	369C14

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	36.5 µm
Penetration Rate	1.01×10^{-2} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-09 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 89-10

Conducted 27 April 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.73
Segment ID (AGHCF)	369C15

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	56.5 µm
Penetration Rate	7.85×10^{-3} µm/s

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-10 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 89-11

Conducted 28 April 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.78
Segment ID (AGHCF)	369C17

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	4 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	74 µm
Penetration Rate	$5.14 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-11 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 89-12

Conducted 2 May 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-326 (X423C)
Fuel	U-26Pu-10Zr
Cladding	316SS (1 st core)
Peak Burnup in Pin	4.7 a/o
Segment Axial Location (x/L)	0.8
Segment ID (AGHCF)	369C18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	24 mins (0.4 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	24 µm
Penetration Rate	$1.67 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Bow & length measurements, gamma scans, neutron radiography, contact profilometry [1]
(segment)	Weight, length [2], sibling segment cross-section microphotos [3], sibling pin micrographs [4]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #4: 89-12 Test Notes (*unpublished information*), [3] A/G Databook 369C (Binders 401A and 401B) (*unpublished information*), [4] Metallographic Examination of Three Elements from S/A X423C (*unpublished information*)

KEY TEST INFORMATION

3.13 U-19Pu-10Zr/D9 at 17 at.% (T-106/X421A)

FBTA tests 90-01 through 90-03 and 92-01 were conducted to investigate the effects of fission products on fuel/cladding compatibility, using segments from pin T-106 of EBR-II subassembly X421A (U-19Pu-10Zr/D9 at 17 at.% burnup). This was the highest burnup tested during the out-of-pile test program. The purpose of the test set was to determine the onset-of-melting temperature and the cladding penetration rate as a function of temperature. The first test was conducted on a segment from the midplane of the fuel pin, where there was incomplete fuel-cladding gap closure. The remaining two tests were conducted on segments take from near the top of the pin where the gap closure was more complete. Results were also intended for comparison with the tests conducted on the high burnup binary fuel sibling pin (90-04 through 90-16). Test 92-01 was conducted to evaluate the effect of a low-temperature/long-duration excursion on the D9 cladding.

Test	Temperature	Duration	Note
90-01	750°C	1 hour	Midplane segment
90-02	750°C	1 hour	Near top of pin
90-03	800°C	1 hour	Near top of pin
92-01	660°C	12 hours	Preliminary/unpublished

FBTA Test 90-01

Conducted 11 December 1989

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-106 (X421A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.5
Segment ID (AGHCF)	395B6

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	187 μm
Penetration Rate	$5.19 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, laser profilometry [1]
(segment)	~length [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos, microhardness [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-01 Test Notes (*unpublished information*), [3] FBTA Book #5: Sibling Segment (*unpublished information*)

KEY TEST INFORMATION
Test 90-01 used a segment from the midplane of the fuel pin where there was incomplete fuel-cladding gap closure. Measured thinning of the cladding following the test was attributed to liquid-phase grain-boundary penetration.

FBTA Test 90-02

Conducted 10 January 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-106 (X421A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.87
Segment ID (AGHCF)	395B17

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	46 μm
Penetration Rate	$1.28 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, laser profilometry [1]
(segment)	~length [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-01 Test Notes (*unpublished information*), [3] FBTA Book #5: Sibling Segment (*unpublished information*)

KEY TEST INFORMATION
The segment used for test 90-02 was taken from the top area of the fuel pin which had more complete fuel-cladding gap closure than the segment used for test 90-01 (from the midplane).

FBTA Test 90-03

Conducted 11 January 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-106 (X421A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.84
Segment ID (AGHCF)	395B18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	83 μm
Penetration Rate	$2.31 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, laser profilometry [1]
(segment)	sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #5: 90-03 Test Notes (*unpublished information*), [3] FBTA Book #5: Sibling Segment (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 92-01

Conducted 25 February 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-106 (X421A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	17 a/o
Segment Axial Location (x/L)	0.91
Segment ID (AGHCF)	395B14B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	660°C
Duration	12 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	88 μm
Penetration Rate	$2.04 \times 10^{-3} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, bow & weight measurements, fission gas analysis & chemistry data, gamma scans, laser profilometry [1]
(segment)	sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 92-01 Test Notes (*unpublished information*), [3] FBTA Book #5: Sibling Segment (*unpublished information*)

KEY TEST INFORMATION
The results of test 92-01 were not published and should be considered preliminary.

3.14 U-26Pu-10Zr/HT9 at 2.3 at.% (T-678/X430A)

FBTA tests 90-17, 90-18, 90-19, and 90-21 were conducted on segments taken from fuel pin T-678 from EBR-II subassembly X430A (U-26Pu-10Zr/HT9 at 2.3 at.% burnup). The constant-temperature, fixed-duration tests were designed to compare the compatibility performance of the U-26Pu-10Zr/HT9 PRISM-type fuel with the broader IFR data base, providing comparison of time-dependent cladding penetration rates. The initial rapid penetration of the cladding seen in test 90-19 was probably caused by the rapid melting of a pre-existing interdiffusional layer that had formed during the steady-state irradiation of the fuel pin. After the initial rapid reaction, the cladding penetration rate leveled off with time (seen in tests 90-17 and 90-21), indicating that the reaction rate was likely determined by diffusion processes across the reaction layer. The time-dependent cladding penetration behavior for this low-burnup U-26Pu-10Zr/HT9 fuel was comparable to that for the 316SS-clad fuel examined in tests 89-09 to 89-12 and superior to that seen in binary fuels (clad with D9, HT9, and 316SS as seen in tests 90-04 to 90-16, 88-17 to 88-21, and 89-13 to 89-16, respectively). The Pu content did not have a negative effect on the fuel behavior. This test set also provided scoping information to aid in the design of whole pin furnace test FM-3 (on sister pin T-680) and investigated the onset-of-liquid-phase-formation temperature (determined to be between 750°C and 800°C based on the results of tests 90-18 and 90-17).

Test	Temperature	Duration	Note
90-17	800°C	1 hour	
90-18	750°C	1 hour	
90-19	800°C	5 mins	
90-21	800°C	2 hours	

FBTA Test 90-17

Conducted 11 June 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.79
Segment ID (AGHCF)	409A11

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	55.1 μm
Penetration Rate	$1.53 \times 10^{-2} \mu\text{m/s}$
% Liquefaction (areal)	70%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	length [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-17 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*)

KEY TEST INFORMATION
Posttest examination of the 90-17 test segment revealed extensive liquefaction of the fuel extending from roughly mid-radius to the cladding ID.

FBTA Test 90-18

Conducted 12 June 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.82
Segment ID (AGHCF)	409A12

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 μm
Penetration Rate	0 $\mu\text{m/s}$
% Liquefaction (areal)	0%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	length [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-18 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*)

KEY TEST INFORMATION
No observed fuel liquefaction after test 90-18.

FBTA Test 90-19

Conducted 12 June 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.84
Segment ID (AGHCF)	409A13

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	23.6 μm
Penetration Rate	$7.9 \times 10^{-2} \mu\text{m/s}$
% Liquefaction (areal)	8%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	length [2], sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-19 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 90-21

Conducted 14 June 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.88
Segment ID (AGHCF)	409A7

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	65 μm
Penetration Rate	$9.03 \times 10^{-3} \mu\text{m/s}$
% Liquefaction (areal)	100%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-21 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*)

KEY TEST INFORMATION

3.15 U-26Pu-10Zr/HT9 at 2.3 at.% (T-678/X430A), Simulated UTOP & LOHS

FBTA tests 90-20 and 90-22 through 90-24 simulated unprotected transient overpower (UTOP) and loss of heat sink (LOHS) events on segments from pin T-678 from EBR-II subassembly X430A (U-26Pu-10Zr/HT9 at 2.3 at.% burnup). Test 90-22 simulated a 0.40\$ UTOP event in PRISM. Tests 90-20, 90-23, and 90-24 were conducted to evaluate the effects of the most severe unscrammed transient for the ALMR (NRC bounding event 1B). This event consists of a 0.40\$ UTOP followed by a loss of IHTS cooling. It was simulated in the FBTA by a sudden rise to 815°C held for 2 minutes followed by a rapid cool to 700°C (held for 36 hours). Tests 90-20 and 90-23 were terminated early due to unexpected power failures and their results should be considered preliminary. Test 90-24 completed the prescribed transient routine to simulate the 1B event. Limited fuel surface liquefaction was observed in all tests. Very minor cladding penetration was seen as a result of the UTOP test (90-22) and modest cladding wastage of only 28% of the original cladding thickness was the result of the most severe UTOP and LOHS simulation (90-24).

Test	Transient Routine	Note
90-22	2 mins at 815°C	UTOP
90-20	2 mins at 815°C, 9.3 hrs at 700°C	UTOP & LOHS (preliminary/unpublished)
90-23	2 mins at 815°C, 16.6 hrs at 700°C	UTOP & LOHS (preliminary/unpublished)
90-24	2 mins at 815°C, 36 hrs at 700°C	Bounding Event 1B (UTOP & LOHS)

FBTA Test 90-20

Conducted 13 June 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.86
Segment ID (AGHCF)	409A14

TEST CONDITIONS	
Test Type	Shaped
Transient Routine	815°C for 2 mins, then 700°C for 9.3 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	64.6 µm

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	Sibling segment cross-section microphotos [3]
During Transient	Temperature
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-20 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*)

KEY TEST INFORMATION
Test 90-20, intended to run for 36 hours, was terminated at 9.3 hours due to an unexpected power trip. Minimal fuel surface liquefaction and cladding penetration was observed. The penetration depth was not published and only recorded in preliminary notes and internal memos.

FBTA Test 90-22

Conducted 20 June 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.66
Segment ID (AGHCF)	409A18

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	815°C
Duration	2 mins (0.033 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	19 μm
Penetration Rate	$1.58 \times 10^{-1} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	sibling segment cross-section microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-22 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*)

KEY TEST INFORMATION
Fuel surface liquefaction and cladding interaction was minimal following test 90-22.

FBTA Test 90-23

Conducted 25 June 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.69
Segment ID (AGHCF)	409A17

TEST CONDITIONS	
Test Type	Shaped
Transient Routine	815°C for 2 mins, then 700°C for 16.6 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	49.3 μm

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	Length [2], sibling segment cross-section microphotos [3]
During Transient	Temperature
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-23 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*)

KEY TEST INFORMATION
Test 90-23, intended to run for 36 hours, was unexpectedly interrupted at 16.6 hours. Minimal fuel surface liquefaction and cladding penetration was observed. The penetration depth was not published and only recorded in preliminary notes and internal memos.

FBTA Test 90-24

Conducted 16 July 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-678 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.3 a/o
Segment Axial Location (x/L)	0.74
Segment ID (AGHCF)	409A15

TEST CONDITIONS	
Test Type	Shaped
Transient Routine	815°C for 2 mins, then 700°C for 36 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	121 μ m

DATA AVAILABLE	
Pre-Transient (whole pin)	Length & weight measurements, fission gas chemistry data, photos [1]
(segment)	Length [2], sibling segment cross-section microphotos [3]
During Transient	Temperature
Post-Transient	Cross-section microphotos [2], SEM/EDX [4]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #6: 90-24 Test Notes (*unpublished information*), [3] A/G Databook 409A (Binder 460A) (*unpublished information*), [4] FBTA Book #6: 90-24 SEM (*unpublished information*)

KEY TEST INFORMATION
Test 90-24 simulated the NRC bounding event 1B, a 0.40\$ UTOP followed by a loss of IHTS cooling. The FBTA transient envelope for the simulation was defined by General Electric, based on their calculation of peak cladding temperature history for this event. There was not substantial additional fuel surface liquefaction as compared with test 90-22 (2 minute 815°C flattop), but there was more cladding wastage (~28% of the total cladding thickness). Considering the extreme severity of the transient event, the resulting cladding wastage was modest.

3.16 U-19Pu-xZr/HT9 at ~5 at.% burnup (DP-17, DP-27, DP-32/X441), Zr effect

FBTA tests 91-01 through 91-10 were conducted on medium-burnup U-19Pu-xZr/HT9 fuels with varying Zr content, where $x = 6, 10$, and 14 . To examine the effects of Zr-content on fuel-cladding interaction, the tests were conducted on segments from pins DP-17 (U-19Pu-10Zr/HT9 at 5.6 at.% burnup), DP-27 (U-19Pu-6Zr/HT9 at 4.9 at.% burnup), and DP-32 (U-19Pu-14Zr/HT9 at 6.2 at.% burnup) from EBR-II subassembly X441. The results of tests 91-02, 91-04, and 91-10 should be considered preliminary (unpublished). While the fuel liquefaction fraction increased notably with decreasing Zr-content during the 1 hour/800°C tests, the measured cladding penetration rates were comparable.

Test	Zr (wt%)	Temperature	Duration	Note
91-01	10	800°C	1 hour	
91-02	6	792°C	1 hour	Preliminary/unpublished
91-03	10	738°C	1 hour	
91-04	14	800°C	1 hour	Preliminary/unpublished
91-05	10	725°C	7 hours	
91-06	10	800°C	2 hours	
91-07	10	800°C	30 mins	
91-08	10	800°C	6.5 mins (0.1 hr)	
91-09	10	770°C	1 hour	
91-10	6	800°C	1 hour	Preliminary/unpublished

To examine the compatibility of U-19Pu-10Zr fuel with HT9 cladding, the results of the tests on segments from DP-17 (U-19Pu-10Zr/HT9 at 5.6 at.% burnup) were examined together with the results of tests 91-11 through 91-19 and 91-28 on segments from pin DP-21 (U-19Pu-10Zr/HT9 at 11 at.% burnup) and tests 91-29 through 91-36 on segments from pin DP-16 (U-19Pu-10Zr/HT9 at 11.3 at.% burnup). Together, these tests established a temperature range for onset of liquefaction and its variation with burnup as well as the variation of cladding penetration rate with burnup, test temperature, and test duration. The temperature for onset-of-liquefaction in a 1-hour test was found to be between 738°C and 770°C for the 5.6 at.% burnup DP-17 pin (test 92-18 later narrowed the range to 738-750°C). The furthest penetration observed into the cladding following the furnace tests on these DP-17 segments consisted of a two-phase region similar to the structure seen in previously tested low-burnup samples (in e.g. tests 87-75 and 87-76).

FBTA Test 91-01

Conducted 16 November 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.55
Segment ID (AGHCF)	378A5

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	114 μm
Penetration Rate	$3.17 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	34%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	~Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-01 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-02

Conducted 21 November 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-27 (X441)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	4.9 a/o
Segment Axial Location (x/L)	0.53
Segment ID (AGHCF)	378C7

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	792°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	85 μm
Penetration Rate	$2.36 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	68%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	none
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-02 Test Notes (*unpublished information*)

KEY TEST INFORMATION
Test 90-02 did not reach the target temperature of 800°C and was repeated as test 90-10. The results were not published and should be considered preliminary.

FBTA Test 91-03

Conducted 27 November 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.57
Segment ID (AGHCF)	378A6

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	738°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	0 µm
Penetration Rate	0 µm/s
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	~Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-03 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-04

Conducted 4 December 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-32 (X441)
Fuel	U-19Pu-14Zr
Cladding	HT9
Peak Burnup in Pin	6.2 a/o
Segment Axial Location (x/L)	0.53
Segment ID (AGHCF)	378D6

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	94 μm
Penetration Rate	$2.61 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	13%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	none
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-04 Test Notes (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-04 were not published and should be considered preliminary.

FBTA Test 91-05

Conducted 8 January 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.48
Segment ID (AGHCF)	378A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	7 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	74 μm
Penetration Rate	$2.94 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	4%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	~Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-05 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-06

Conducted 9 January 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.5
Segment ID (AGHCF)	378A3

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	142 μm
Penetration Rate	$1.97 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	26%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	Sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-06 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-07

Conducted 21 January 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.45
Segment ID (AGHCF)	378A12

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	30 mins (0.5 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	78 μm
Penetration Rate	$4.33 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	33%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	~Length, sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-07 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-08

Conducted 21 January 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.42
Segment ID (AGHCF)	378A13

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	6 mins, 30 s (0.1 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	18 μm
Penetration Rate	$5.0 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	9%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	~Length, sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-08 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-09

Conducted 22 January 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.39
Segment ID (AGHCF)	378A14

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	770°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	27 μm
Penetration Rate	$7.5 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	10%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	Sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-09 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-10

Conducted 15 February 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-27 (X441)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	4.9 a/o
Segment Axial Location (x/L)	0.55
Segment ID (AGHCF)	378C8

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	98 μm
Penetration Rate	$2.72 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	100%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	none
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #7: 91-10 Test Notes (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-04 were not published and should be considered preliminary.

3.17 U-19Pu-10Zr/HT9 at 11 at.% burnup (DP-21/X441A)

FBTA tests 91-11 through 91-19 and 91-28 were conducted on segments taken from pin DP-21 from EBR-II subassembly X441A (U-19Pu-10Zr/HT9 at 11 at.% burnup) to examine onset-of-liquefaction temperature and the time- and temperature-dependence of cladding penetration rate. It should be noted that some internal, preliminary reports of these test results present smaller cladding penetration depths. The reason for this difference is unclear. It is possible that what was recorded in these internal reports was not a maximum cladding penetration depth but an estimated “net” transient penetration depth (after subtracting an estimate of the steady state irradiation-induced cladding wastage based on that seen in a steady-state sibling) or that the values quoted were meant to represent only eutectic penetration into the cladding (and not lanthanide penetration). The cladding penetration values included on summary sheets herein and in OPTD are those that were recorded in the original experimenter’s notes and subsequently published in conference proceedings; they represent the maximum cladding penetration depth following each test (measured as the original cladding thickness minus the thinnest area of remaining unaffected cladding).

Test	Temperature	Duration	Note
91-11	800°C	1 hour	Discrepancy in preliminary records
91-12	800°C	5 mins	
91-13	800°C	30 mins	
91-14	800°C	2 hours	Discrepancy in preliminary records
91-15	740°C	1 hour	Discrepancy in preliminary records
91-16	770°C	1 hour	Discrepancy in preliminary records
91-17	700°C	1 hour	Discrepancy in preliminary records
91-18	740°C	1 hour	Discrepancy in preliminary records
91-19	650°C	1 hour	Discrepancy in preliminary records
91-28	800°C	30 mins	

In the tests conducted at 800°C, cladding penetration rate dropped off and areal fraction of fuel liquefaction increased with longer test durations. Test 91-17 and 91-19 found the threshold temperature for liquefaction in the U-19Pu-10Zr/HT9 fuel at 11 at.% burnup to be between 650°C and 700°C for a 1-hour test (this range would later be narrowed to 650-675°C by test 91-31 on pin DP-16). Notably, while a two-phase cladding penetration band (like that seen in lower-burnup samples) was evident following the furnace tests, the furthest penetration into the cladding was a lanthanide-rich band not seen in the lower burnup samples.

FBTA Test 91-11

Conducted 19 March 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.8
Segment ID (AGHCF)	427F5E

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	100 μm
Penetration Rate	$2.78 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	100%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	~Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-11 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-12

Conducted 28 March 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.68
Segment ID (AGHCF)	427F3D

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	5 mins (0.083 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	42 μm
Penetration Rate	$1.42 \times 10^{-1} \mu\text{m/s}$
% liquefaction (areal)	27%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	~Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-12 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION
Experimenters noted that the initial temperature overshoot for test 91-12 was larger than usual ($\sim 23^\circ\text{C}$).

FBTA Test 91-13

Conducted 28 March 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.72
Segment ID (AGHCF)	427F3C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	30 mins (0.5 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	79 μm
Penetration Rate	$4.41 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	63%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	~Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-13 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-14

Conducted 1 April 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.73
Segment ID (AGHCF)	427F3B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	104 μm
Penetration Rate	$1.45 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	100%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos, microhardness [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-14 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION
Experimenters noted that ~45% of the cladding circumference could not be examined for attack due to fuel spillover which caused a "two front" attack. The remaining 55% was fairly uniform, and it was therefore assumed that the maximum penetration measured there was the maximum for the whole piece.

FBTA Test 91-15

Conducted 4 April 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.89
Segment ID (AGHCF)	427F5B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	740°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	87 μm
Penetration Rate	$2.41 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	18%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-15 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION
The initial temperature overshoot for test 91-15 was $\sim 20^\circ\text{C}$.

FBTA Test 91-16

Conducted 4 April 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.85
Segment ID (AGHCF)	427F5C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	770°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	80 μm
Penetration Rate	$2.23 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	66%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-16 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-17

Conducted 11 April 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.83
Segment ID (AGHCF)	427F5D

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	76 μm
Penetration Rate	$2.12 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	13%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	Temperature [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-17 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-18

Conducted 11 April 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.54
Segment ID (AGHCF)	427F3E

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	740°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	58 μm
Penetration Rate	$1.6 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	12%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	Temperature [2]
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-18 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION
Test 91-18 was conducted to see if the interaction at 740°C is dependent on axial height along the pin x/L (and therefore steady-state irradiation temperature) or due to the transient test temperature (test 91-15 was conducted on a segment from near the fuel top, at x/L = 0.89, while this test was conducted on a segment from near the fuel midplane at x/L = 0.54).

FBTA Test 91-19

Conducted 19 April 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.88
Segment ID (AGHCF)	427F5A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	650°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	29 μm^* (diffusional attack)
Penetration Rate	$8.1 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-19 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION
*The interaction on the cladding in test 91-19 appears to be diffusional.

FBTA Test 91-28

Conducted 7 October 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-21 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.1 a/o
Segment Axial Location (x/L)	0.52
Segment ID (AGHCF)	427F3F

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	30 mins (0.5 hr)

RESULTS	
Status	GOOD
Max. Depth of Penetration	37 μm
Penetration Rate	$2.06 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	58%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section & longitudinal microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-28 Test Notes (*unpublished information*), [3] A/G Databook 427F (Binders 471A and 471B) (*unpublished information*)

KEY TEST INFORMATION
Test 91-28 posttest cross-section and longitudinal microphotos showed the liquefaction front was cylindrical, moving inward from the cladding.

3.18 U-19Pu-10Zr/HT9 at 11 at.% burnup (DP-16/X441A), low temp

FBTA tests 91-29 through 91-36 and 92-02 were a series of lower-temperature tests on segments taken from pin DP-16 of EBR-II subassembly X441A (U-19Pu-10Zr/HT9 at 11.3 at.% burnup). Together with tests 91-17 and 91-19, they established the fuel liquefaction threshold temperature for the high-burnup U-19Pu-10Zr/HT9 pins. It should be noted that some preliminary, internal records of these test results recorded smaller cladding penetration depths. The reason for this difference is unclear. It is possible that what was recorded in these preliminary reports was not a maximum cladding penetration depth but a “net” transient penetration depth (subtracting an estimate of the pre-existing cladding wastage seen in a steady-state sibling) or that the values quoted were meant to represent only eutectic penetration into the cladding (and not lanthanide penetration). The cladding penetration values included on summary sheets herein are those that were recorded in the original experimenter’s notes and subsequently published in conference proceedings, which represent the maximum cladding penetration depth following each test (measured as the original cladding thickness minus the thinnest area of remaining unaffected cladding). Test 92-02 was later conducted on a segment from the lower portion of the fuel pin (that therefore experienced lower cladding temperature during the steady-state irradiation). Peak cladding temperature during steady-state irradiation of the 92-02 segment taken from $x/L = 0.25$ was 475°C (vs 600°C for the 91-31 test segment from $x/L = 0.72$). Results for test 92-02 should be considered preliminary. While there was some fuel liquefaction in test 91-31, no liquefaction was found in test 92-02, suggesting that the lower cladding irradiation temperature with reduced steady-state fuel/cladding chemical interaction and Fe diffusion into the fuel resulted in a higher fuel liquefaction threshold temperature.

Test	Temperature	Duration	Note
91-29	700°C	1 hour	Discrepancy in preliminary records
91-30	650°C	1 hour	Discrepancy in preliminary records
91-31	675°C	1 hour	Discrepancy in preliminary records
91-32	650°C	12 hours	Discrepancy in preliminary records
91-33	625°C	1 hour	Discrepancy in preliminary records
91-34	675°C	12 hours	Discrepancy in preliminary records
91-35	650°C	36 hours	Discrepancy in preliminary records
91-36	660°C	12 hours	Discrepancy in preliminary records
92-02	675°C	1 hour	Preliminary/unpublished

Test 91-30 and 91-31 found the threshold temperature for liquefaction in U-19Pu-10Zr/HT9 fuel at 11 at.% burnup to be between 650°C and 675°C for a 1-hour test and tests 91-32 and 91-36 placed it between 650°C and 660°C for a 12-hour test. Notably, while a two-phase cladding penetration band like that seen in the lower-burnup samples was present following the furnace tests on the 11 at.% burnup samples, extending further into the cladding was a lanthanide-rich band which was responsible for the deepest penetration into the cladding. This lanthanide-rich band was not seen in the lower burnup samples.

FBTA Test 91-29

Conducted 6 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.83
Segment ID (AGHCF)	427E11

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	58 μm
Penetration Rate	$1.6 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	9%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-29 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION
Posttest examination of the fuel/clad interface for test 91-29 revealed a clear boundary of 2-phase eutectic penetration into the cladding with lanthanide diffusional attack of the cladding extending beyond it.

FBTA Test 91-30

Conducted 6 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.75
Segment ID (AGHCF)	427E9

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	650°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	46 μm
Penetration Rate	$1.28 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-30 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-31

Conducted 9 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.72
Segment ID (AGHCF)	427E8

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	59 μm
Penetration Rate	$1.64 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	5%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-31 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-32

Conducted 9 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.61
Segment ID (AGHCF)	427E4

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	650°C
Duration	12 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	36 μm
Penetration Rate	$8.33 \times 10^{-4} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-32 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-33

Conducted 10 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.69
Segment ID (AGHCF)	427E7

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	625°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	34 μm
Penetration Rate	$9.44 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-33 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-34

Conducted 12 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.67
Segment ID (AGHCF)	427E6

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	12 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	140 μm
Penetration Rate	$3.24 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	31%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-34 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-35

Conducted 16 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.59
Segment ID (AGHCF)	427E3

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	650°C
Duration	36 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	75 μm
Penetration Rate	$5.79 \times 10^{-4} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos, microhardness [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-35 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 91-36

Conducted 19 December 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.64
Segment ID (AGHCF)	427E5

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	660°C
Duration	12 hours

RESULTS	
Status	GOOD
Max. Depth of Penetration	81 μm
Penetration Rate	$1.88 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	12%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #9: 91-36 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

FBTA Test 92-02

Conducted 1 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-16 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Segment Axial Location (x/L)	0.25
Segment ID (AGHCF)	427E1C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	GOOD
Max. Depth of Penetration	29 μm
Penetration Rate	$8.06 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, gamma scans, and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-02 Test Notes (*unpublished information*), [3] A/G Databook 427E (Binder 470) (*unpublished information*)

KEY TEST INFORMATION

3.19 U-19Pu-xZr/HT9 at ~11 at.% (DP-24, DP-29, DP-45, DP-61/X441A), Zr effect

FBTA tests 91-20 through 91-27 examined U-19Pu pins with varying Zr content (6, 10, and 14 wt. %) at high temperature to examine the effect of Zr content on fuel/cladding compatibility. Test segments were taken from pins DP-24 (U-19Pu-6Zr/HT9 at 10 at.% burnup), DP-29 (U-19Pu-14Zr/HT9 at 12.3 at.% burnup), DP-45 (U-19Pu-10Zr/HT9 at 9.8 at.% burnup, 85% TD), and DP-61 (U-19Pu-10Zr/HT9 at 11.9 at.% burnup, 70% TD) of EBR-II subassembly X441A. The results of these tests were not published and should be considered preliminary. Tests 91-22 and 91-23 were conducted on U-19Pu-10Zr/HT9 pins with higher (85%) and lower (70%) fuel smeared density, for comparison with test 91-16, on U-19Pu-10Zr/HT9 with 75% TD, but no quantitative penetration results were recorded and only a 75x magnification composite microphoto is available in the records. Summary notes indicated that the 91-22 test on the high smear density (85% TD) sample showed considerably less fuel surface liquefaction and cladding penetration than was seen in tests 91-16 and 91-23 on sibling pins with 75% and 70% TD. The steady-state cladding wastage of the high smear-density fuel was also noticeably smaller. Fuel surface liquefaction was seen in all specimens (of 6, 10, and 14 Zr) after the 770°C and 800°C tests at one hour; no differentiation of Zr-content effect was possible.

Test	Zr (wt%)	Temperature	Duration	Note
91-20	6	770°C	1 hour	Preliminary/unpublished
91-21	14	770°C	1 hour	Preliminary/unpublished
91-22	10	770°C	1 hour	No results, only one composite
91-23	10	770°C	1 hour	No results, only one composite
91-24	6	800°C	1 hour	Preliminary/unpublished
91-25	6	700°C	1 hour	Preliminary/unpublished
91-26	6	800°C	2 hours	Fuel spillover, preliminary
91-27	6	800°C	30 mins	Preliminary/unpublished

FBTA Test 91-20

Conducted 10 June 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-24 (X441A)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.8
Segment ID (AGHCF)	427G5B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	770°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	73 μm
Penetration Rate	$2.03 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	47%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-20 Test Notes (*unpublished information*), [3] A/G Databook 427G (Binder 472) (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-20 were not published and should be considered preliminary.

FBTA Test 91-21

Conducted 10 June 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-29 (X441A)
Fuel	U-19Pu-14Zr
Cladding	HT9
Peak Burnup in Pin	12.3 a/o
Segment Axial Location (x/L)	0.8
Segment ID (AGHCF)	427H5B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	770°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	55 μm
Penetration Rate	$1.51 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	69%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-21 Test Notes (*unpublished information*), [3] A/G Databook 427H (Binder 473) (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-21 were not published and should be considered preliminary.

FBTA Test 91-22

Conducted 11 June 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-45 (X441A)
Fuel	U-19Pu-10Zr, 85% TD
Cladding	HT9
Peak Burnup in Pin	9.8 a/o
Segment Axial Location (x/L)	0.8
Segment ID (AGHCF)	427J5B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	770°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	36 μm
Penetration Rate	$1.0 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	2%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-22 Test Notes (*unpublished information*), [3] A/G Databook 427J (Binder 474) (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-22 were not published and should be considered preliminary. Fuel surface liquefaction was minimal and penetration was only seen in one area ~45° of the arc.

FBTA Test 91-23

Conducted 11 June 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-61 (X441A)
Fuel	U-19Pu-10Zr, 70% TD
Cladding	HT9
Peak Burnup in Pin	11.9 a/o
Segment Axial Location (x/L)	0.8
Segment ID (AGHCF)	427K5B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	770°C
Duration	1 hour

RESULTS	
Status	UNAVAILABLE
Max. Depth of Penetration	Not measured
Penetration Rate	Not measured

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-23 Test Notes (*unpublished information*), [3] A/G Databook 427K (Binder 475) (*unpublished information*)

KEY TEST INFORMATION
No results were reported for test 91-23. A single composite cross-section posttest microphoto at 75x magnification is available for comparison with the steady-state sibling segment microstructure. Fuel liquefaction is apparent. No high-magnification microphotos are available for measurement of cladding penetration depth.

FBTA Test 91-24

Conducted 1 October 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-24 (X441A)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.76
Segment ID (AGHCF)	427G3B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	116 μm
Penetration Rate	$3.22 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	100%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-24 Test Notes (*unpublished information*), [3] A/G Databook 427G (Binder 472) (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-24 were not published and should be considered preliminary.

FBTA Test 91-25

Conducted 2 October 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-24 (X441A)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.83
Segment ID (AGHCF)	427G5C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	36 μm
Penetration Rate	$1.0 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	9%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-25 Test Notes (*unpublished information*), [3] A/G Databook 427G (Binder 472) (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-25 were not published and should be considered preliminary. No penetration depths were recorded in the initial test notes. Those quoted here are from later summary notes (<i>also preliminary</i>).

FBTA Test 91-26

Conducted 2 October 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-24 (X441A)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.73
Segment ID (AGHCF)	427G3C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	2 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	Not recorded
Penetration Rate	Not recorded

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-26 Test Notes (*unpublished information*), [3] A/G Databook 427G (Binder 472) (*unpublished information*)

KEY TEST INFORMATION
Test 91-26 resulted in a massive fuel spillover due to liquefaction. No further posttest measurements were made. Results were not published and should be considered preliminary.

FBTA Test 91-27

Conducted 2 October 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-24 (X441A)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.71
Segment ID (AGHCF)	427G3D

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	800°C
Duration	30 mins (0.5 hr)

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	70 μm
Penetration Rate	$3.89 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	72%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #8: 91-27 Test Notes (*unpublished information*), [3] A/G Databook 427G (Binder 472) (*unpublished information*)

KEY TEST INFORMATION
The results of test 91-27 were not published and should be considered preliminary.

3.20 U-19Pu-xZr/various at ~12 at.% Burnup (DP-29, DP-24, DP-45, DP-17, A850, T581, and T608)

FBTA tests 92-03 through 93-01 were conducted to better define the fuel/cladding liquefaction threshold temperatures for high-burnup U-19Pu-10Zr pins and the fuel operating conditions and design parameters that influence those temperatures (including Zr content, cladding material, fuel smear density, and burnup). Test segments were taken from several different U-19Pu-10Zr fuel pins from EBR-II, as listed in the table below. Previous tests on pins DP-16 and DP-21 (U-19Pu-10Zr/HT9 at 11 at.% burnup), 91-11 through 91-19 and 91-28 through 91-36, can be used for reference and comparison. All of the results of the tests in this set are unpublished and preliminary.

Tests 92-03 and 92-05 were conducted to examine the effect of varying Zr content. Tests 92-04, 92-09, and 92-12 found the liquefaction threshold temperature for a 1-hour test in a high smear density sample (85% TD) was 675-700°C, higher than the threshold temperature of 650-675°C found in tests 91-30 and 91-31 for pin DP-16 (75% TD). Tests 91-03 and 92-18 determined the liquefaction threshold temperature for a 1-hour test in a medium burnup pin (5.6 at.%) was 738-750°C, higher than in the high burnup pins. Tests 92-08 and 92-10 determined the threshold temperature for D9-clad pin A850 was 675-700°C, slightly higher than for the comparable HT9-clad pin. Test 92-16 and 92-17 found a higher fuel liquefaction threshold of 700-725°C for a pin that experienced lower linear pin power during steady state irradiation.

Test	Pin	Fuel	Clad	B/U (a/o)	Temp	Duration
<i>Reference Test</i>						
91-31	DP-16	U-19Pu-10Zr	HT9	11	675 °C	1 hour
Zr content:						
92-03	DP-29	U-19Pu-14Zr	HT9	12.3	675 °C	1 hour
92-05	DP-24	U-19Pu-6Zr	HT9	10	675 °C	1 hour
Fuel smear density:						
92-04	DP-45	U-19Pu-10Zr (85% TD)	HT9	9.8	675 °C	1 hour
92-09	DP-45	U-19Pu-10Zr (85% TD)	HT9	9.8	740 °C	1 hour
92-12	DP-45	U-19Pu-10Zr (85% TD)	HT9	9.8	700 °C	1 hour
Medium Burnup:						
91-03	DP-17	U-19Pu-10Zr	HT9	5.6	738 °C	1 hour
92-18	DP-17	U-19Pu-10Zr	HT9	5.6	750 °C	1 hour
D9 Cladding:						
92-07	A850	U-19Pu-10Zr	D9	11.2	675 °C	1 hour
92-08	A850	U-19Pu-10Zr	D9	11.2	660 °C	12 hours
92-10	A850	U-19Pu-10Zr	D9	11.2	700 °C	1 hour
92-13	A850	U-19Pu-10Zr	D9	11.2	725 °C	1 hour
92-14	A850	U-19Pu-10Zr	D9	11.2	700 °C	12 hours
Lower pin power (13kW/ft) and 316SS vs HT9 Cladding:						
92-06	T581	U-19Pu-10Zr	316SS	13.5	675 °C	1 hour
92-19	T581	U-19Pu-10Zr	316SS	13.5	650 °C	7 hours
93-01	T581	U-19Pu-10Zr	316SS	13.5	750 °C	2 hours
92-11	T608	U-19Pu-10Zr	HT9	13.5	675 °C	1 hour
92-15	T608	U-19Pu-10Zr	HT9	13.5	660 °C	12 hours
92-16	T608	U-19Pu-10Zr	HT9	13.5	700 °C	1 hour
92-17	T608	U-19Pu-10Zr	HT9	13.5	725 °C	1 hour

FBTA Test 92-03

Conducted 2 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-29 (X441A)
Fuel	U-19Pu-14Zr
Cladding	HT9
Peak Burnup in Pin	12.3 a/o
Segment Axial Location (x/L)	0.76
Segment ID (AGHCF)	427H3B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	82 μm
Penetration Rate	$2.28 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	Not measured; possible liquefaction on several fronts.

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-03 Test Notes (*unpublished information*), [3] A/G Databook 427H (Binder 473) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-04

Conducted 2 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-45 (X441A)
Fuel	U-19Pu-10Zr, 85% TD
Cladding	HT9
Peak Burnup in Pin	9.8 a/o
Segment Axial Location (x/L)	0.76
Segment ID (AGHCF)	427J3B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	0 µm
Penetration Rate	0 µm/s
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-04 Test Notes (*unpublished information*), [3] A/G Databook 427J (Binder 474) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-05

Conducted 9 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-24 (X441A)
Fuel	U-19Pu-6Zr
Cladding	HT9
Peak Burnup in Pin	10 a/o
Segment Axial Location (x/L)	0.68
Segment ID (AGHCF)	427G3E

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	38 μm
Penetration Rate	$1.06 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-05 Test Notes (*unpublished information*), [3] A/G Databook 427G (Binder 472) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-06

Conducted 9 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-581 (X429B)
Fuel	U-19Pu-10Zr
Cladding	316SS
Peak Burnup in Pin	13.5 a/o
Segment Axial Location (x/L)	0.76
Segment ID (AGHCF)	434A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	68 μm
Penetration Rate	$1.89 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, weight, fission gas analysis [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-06 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binder 482) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-07

Conducted 13 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	A850 (X441A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	11.2 a/o
Segment Axial Location (x/L)	0.76
Segment ID (AGHCF)	446A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	88 μm
Penetration Rate	$2.44 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, contact and laser profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-07 Test Notes (*unpublished information*), [3] A/G Databook 446A (Binders 486A and 486B) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-08

Conducted 13 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	A850 (X441A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	11.2 a/o
Segment Axial Location (x/L)	0.81
Segment ID (AGHCF)	446A4

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	660°C
Duration	12 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	113 μm
Penetration Rate	$2.61 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, contact and laser profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphoto [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-08 Test Notes (*unpublished information*), [3] A/G Databook 446A (Binders 486A and 486B) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-09

Conducted 27 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-45 (X441A)
Fuel	U-19Pu-10Zr, 85% TD
Cladding	HT9
Peak Burnup in Pin	9.8 a/o
Segment Axial Location (x/L)	0.82
Segment ID (AGHCF)	427J5C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	740°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	35 μm
Penetration Rate	$9.72 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	1%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-09 Test Notes (*unpublished information*), [3] A/G Databook 427J (Binder 474) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-10

Conducted 27 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	A850 (X441A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	11.2 a/o
Segment Axial Location (x/L)	0.83
Segment ID (AGHCF)	446A5

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	107 μm
Penetration Rate	$2.97 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	4%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, contact and laser profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-10 Test Notes (*unpublished information*), [3] A/G Databook 446A (Binders 486A and 486B) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-11

Conducted 27 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T608 (X429B)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	13.5 a/o
Segment Axial Location (x/L)	0.76
Segment ID (AGHCF)	447A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	16 μm
Penetration Rate	$4.44 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and weight, fission gas analysis and chemistry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-11 Test Notes (*unpublished information*), [3] A/G Databook 447A (Binder 487) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-12

Conducted 28 May 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-45 (X441A)
Fuel	U-19Pu-10Zr, 85% TD
Cladding	HT9
Peak Burnup in Pin	9.8 a/o
Segment Axial Location (x/L)	0.72
Segment ID (AGHCF)	427J3A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	48 μm
Penetration Rate	$1.33 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0.77%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, laser and contact profilometry [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-12 Test Notes (*unpublished information*), [3] A/G Databook 427J (Binder 474) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary. Experimenter notes indicate the fuel was coming out of the cladding following the test (protruding from the top of the segment).

FBTA Test 92-13

Conducted 8 June 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	A850 (X441A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	11.2 a/o
Segment Axial Location (x/L)	0.73
Segment ID (AGHCF)	446A1C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	108 μm
Penetration Rate	$3.0 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	7%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, contact and laser profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-13 Test Notes (*unpublished information*), [3] A/G Databook 446A (Binders 486A and 486B) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-14

Conducted 8 June 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	A850 (X441A)
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	11.2 a/o
Segment Axial Location (x/L)	0.71
Segment ID (AGHCF)	446A1B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	12 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	178 μm
Penetration Rate	$4.12 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	57%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, fission gas analysis and chemistry, gamma scans, contact and laser profilometry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-14 Test Notes (*unpublished information*), [3] A/G Databook 446A (Binders 486A and 486B) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-15

Conducted 18 June 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T608 (X429B)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	13.5 a/o
Segment Axial Location (x/L)	0.69
Segment ID (AGHCF)	447A1B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	660°C
Duration	12 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	108 μm
Penetration Rate	$2.5 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and weight, fission gas analysis and chemistry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-15 Test Notes (*unpublished information*), [3] A/G Databook 447A (Binder 487) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-16

Conducted 19 June 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T608 (X429B)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	13.5 a/o
Segment Axial Location (x/L)	0.71
Segment ID (AGHCF)	447A1C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	53 μm
Penetration Rate	$1.47 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and weight, fission gas analysis and chemistry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-16 Test Notes (*unpublished information*), [3] A/G Databook 447A (Binder 487) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-17

Conducted 19 June 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T608 (X429B)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	13.5 a/o
Segment Axial Location (x/L)	0.73
Segment ID (AGHCF)	447A1D

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	32 μm
Penetration Rate	$8.89 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	2.5%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length and weight, fission gas analysis and chemistry [1]
(segment)	Length [2], sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-17 Test Notes (*unpublished information*), [3] A/G Databook 447A (Binder 487) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-18

Conducted 21 October 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-17 (X441)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	5.6 a/o
Segment Axial Location (x/L)	0.76
Segment ID (AGHCF)	378A7B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY
Max. Depth of Penetration	37 μm
Penetration Rate	$1.03 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	16%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, Fission gas analysis and chemistry, Gamma scans, Laser and contact profilometry, Neutron radiography [1]
(segment)	Sibling segment microphotos and microhardness measurements [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-18 Test Notes (*unpublished information*), [3] A/G Databook 378A (Binder 437) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 92-19

Conducted 22 December 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-581 (X429B)
Fuel	U-19Pu-10Zr
Cladding	316SS
Peak Burnup in Pin	13.5 a/o
Segment Axial Location (x/L)	0.91
Segment ID (AGHCF)	434A4C

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	650°C
Duration	7 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	65 μm
Penetration Rate	$1.81 \times 10^{-2} \mu\text{m/s}$

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, weight, fission gas analysis [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 92-19 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binder 482) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-01

Conducted 7 January 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-581 (X429B)
Fuel	U-19Pu-10Zr
Cladding	316SS
Peak Burnup in Pin	13.5 a/o
Segment Axial Location (x/L)	0.89
Segment ID (AGHCF)	434A4H

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	2 hours

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	119 μm
Penetration Rate	$1.65 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	19%

DATA AVAILABLE	
Pre-Transient (whole pin)	Length, weight, fission gas analysis [1]
(segment)	Length, sibling segment microphotos [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] EBR-II Post-Irradiation Records, [2] FBTA Book #10: 93-01 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binder 482) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

3.21 U-19Pu-10Zr/D9 at 9.4 at.% burnup (181193/IFR-1 FFTF)

Tests 93-02 through 94-06 were FBTA tests on IFR-1 fuel pin 181193 that was irradiated as part of the IFR-1 experiment in FFTF. Pin 181193 was a U-19Pu-10Zr/D9 pin irradiated to ~9.4 at.% burnup. This test set allowed for comparison of the resulting cladding wastage and eutectic formation to the results of previous FBTA tests on EBR-II pin A850 (tests 92-07, 92-08, 92-10, 92-13, 92-14). The two pins had the same fuel composition and cladding. While they had different dimensions (cladding thicknesses and fuel column lengths) and irradiation temperatures, a key difference in pin 181193 was that high power and high irradiation temperature conditions did not occur at the same elevation along the pin (as was the case for EBR-II pins like A850, wherein segments from axial locations $x/L \sim 0.6$ to 0.95 were subjected to both peak linear power and high irradiation temperatures due to the flatter power profile).

In pin 181193 from FFTF, high power occurred near the fuel midplane, while high temperature occurred near the top of the fuel. Segments from axial elevations near $x/L = 0.7$ represent the worst combination of linear power and temperature in pin 181193, with peak linear power of ~13 kW/ft and PICT ~590°C (at BOL). Segments from near the midplane ($x/L = 0.5$) were subjected to the highest linear power (~15.7 kW/ft) but with PICT closer to 565°C at BOL. Segments from near $x/L = 0.9$ experienced higher irradiation temperatures of about 600°C, but with significantly lower linear power (~8.5 kW/ft) than segments from A850 (15 kW/ft). All tests in this set were conducted for durations of 1 hour. The results of this test set are preliminary.

The highest fuel liquefaction threshold of 725-750°C was found in the low power / high irradiation temperature segments near $x/L = 0.9$. The threshold temperature for the “worst case” pins near $x/L = 0.7$ was 700-725°C. The highest-power, lower irradiation temperature segments near $x/L = 0.5$ had the lowest liquefaction threshold of 675-700°C, comparable to pin A850 of EBR-II.

Test	x/L	PICT (BOL)	Linear Power (BOL)	Temperature	Melting?
93-05	0.52	564°C	15.7 kW/ft	725°C	Yes
93-04	0.53	566°C	15.7 kW/ft	750°C	Yes
94-01	0.55	568°C	15.7 kW/ft	700°C	Yes
94-06	0.56	569°C	15.7 kW/ft	700°C	Yes
94-02	0.57	571°C	15.7 kW/ft	675°C	No
93-02	0.71	591°C	13.3 kW/ft	725°C	Yes
93-03	0.72	591°C	13.1 kW/ft	750°C	Yes
93-08	0.73	592°C	12.9 kW/ft	775°C	Yes
93-09	0.74	592°C	12.6 kW/ft	700°C	No
93-10	0.75	593°C	12.4 kW/ft	725°C	Yes
93-06	0.92	601°C	8.5 kW/ft	725°C	No
93-07	0.93	602°C	8.3 kW/ft	750°C	Yes

FBTA Test 93-02

Conducted 17 November 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Assembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.71
Segment ID (AGHCF)	436A16A1

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	80 μm
Penetration Rate	$2.22 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	3%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-02 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary. Note that test was run in three separate time intervals due to unanticipated interruptions, total run time was ~1 hour.

FBTA Test 93-03

Conducted 18 November 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.72
Segment ID (AGHCF)	436A16A2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	66 μm
Penetration Rate	$1.83 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	4%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,
[2] FBTA Book #11: 93-03 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-04

Conducted 3 December 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.53
Segment ID (AGHCF)	436A12B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	97 μm
Penetration Rate	$2.70 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	11%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-04 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-05

Conducted 3 December 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.52
Segment ID (AGHCF)	436A12A

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	95 μm
Penetration Rate	$2.60 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	9%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-05 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-06

Conducted 6 December 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.92
Segment ID (AGHCF)	436A19A

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	46 μm
Penetration Rate	$1.28 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-06 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-07

Conducted 6 December 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.93
Segment ID (AGHCF)	436A19B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	750°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	13 μm
Penetration Rate	$3.61 \times 10^{-3} \mu\text{m/s}$
% liquefaction (areal)	1%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-07 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-08

Conducted 6 December 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.73
Segment ID (AGHCF)	436A16A3

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	775°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	85 μm
Penetration Rate	$2.36 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	18%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	none
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-08 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-09

Conducted 9 December 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.74
Segment ID (AGHCF)	436A16A4

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	41 μm
Penetration Rate	$1.14 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-09 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 93-10

Conducted 9 December 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.75
Segment ID (AGHCF)	436A16A5

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	725°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	48 μm
Penetration Rate	$1.33 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	2%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 93-10 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 94-01

Conducted 4 March 1994

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.55
Segment ID (AGHCF)	436A12C1

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	61 μm
Penetration Rate	$1.68 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	1%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 94-01 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 94-02

Conducted 4 March 1994

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.57
Segment ID (AGHCF)	436A12C3

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	675°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	41 μm
Penetration Rate	$1.13 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	0% (none)

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 94-02 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary.

FBTA Test 94-06

Conducted 5 March 1994

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	181193 (IFR-1) from FFTF
Fuel	U-19Pu-10Zr
Cladding	D9
Peak Burnup in Pin	9.4 a/o
Segment Axial Location (x/L)	0.56
Segment ID (AGHCF)	436A12C2

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	700°C
Duration	1 hour

RESULTS	
Status	PRELIMINARY (unpublished)
Max. Depth of Penetration	40 μm
Penetration Rate	$1.11 \times 10^{-2} \mu\text{m/s}$
% liquefaction (areal)	1%

DATA AVAILABLE	
Pre-Transient (whole pin)	Fission density profile (^{106}Ru scan), cladding strain profile, fission gas collection results are summarized in [1]
(segment)	Length [2], sibling segment microphotos [1], [3]
During Transient	Temperature, FG Detector Output [2]
Post-Transient	Cross-section microphotos [2]

[1] H. Tsai and L. A. Neimark, "Irradiation Performance of Full-Length Metallic IFR Fuels," July 1992,

[2] FBTA Book #11: 94-06 Test Notes (*unpublished information*), [3] A/G Databook 434A (Binders 494A, 494B, and 494C) (*unpublished information*)

KEY TEST INFORMATION
Results were not published and should be considered preliminary. Test 94-06 was a repeat of 94-01 to verify results.

4 WPF TESTS

The whole pin furnace tests were conducted on whole, intact fuel pins inside an evacuated, sealed test section. Pressure transducers at the top of the test section provided means to detect pin breach by measuring the pressure rise due to fission gas release. A fuller description of the Whole Pin Furnace can be found in [3]. Published reports of WPF test results can be found in [8] and [9].

FM-1 through FM-3 were ramp-and-hold tests to examine failure modes in pins of varying fuel composition, plenum-to-fuel-volume, and burnup. The cladding temperature was ramped from a pretest priming temperature of 500°C up to the test temperature at a rate of 6°C/s, then held at the test temperature until fuel pin failure was detected. The test temperature of 820°C for tests FM-1 through FM-3 was selected to be higher than temperatures for a wide range of theoretical reactor transient events. A cladding integrity margin for these events could therefore be established by the difference in time between the duration of the reactor event and the breach time of the test pin. The resulting fuel pin breaches in tests FM-1 through FM-3 were benign axial cladding cracks with small strains at the crack tips. These breaches were the result of the coupled effects of cladding thinning due to fuel/cladding interaction and fission gas pressure loading.

Test FM-4 was a ramp-and-hold test conducted at lower temperature on a pin with much higher burnup and plenum pressure than the previous tests, resulting in pin failure in the plenum due to mechanical deformation of the cladding. The breach in test FM-4 was a much larger rupture with significant cladding deformation. Test FM-4 demonstrated the large safety margin of a high burnup, Mark-V-type fuel pin in a simulated LOF event by holding the pin at the peak cladding temperature of the worst-case UN-1 LOF event and measuring time to failure. Test FM-5 was a complementary proof test that demonstrated a high-burnup Mark-V-type fuel pin could endure a bounding UN-1 LOF event with only minor incremental cladding strain and wastage and no cladding breach.

Tests FM-6 and FM-7 were extended duration, intermediate-temperature tests of 36 hours conducted to determine the survivability, cladding strain, eutectic formation, and fuel-cladding interaction in Mk-V/MK-VA type fuel. No eutectic formation was found in either test, but FCCI-induced cladding wastage was found to be greater in the 316SS-clad FM-7 pin.

Test	Fuel	Clad	Plenum/Fuel Vol. Ratio	Burnup	Temp	Duration (*failure)
FM-1	U-10Zr	HT9	1.0	3.0 at. %	820°C	67 mins*
FM-2	U-19Pu-10Zr	HT9	1.0	3.0 at. %	820°C	112 mins*
FM-3	U-26Pu-10Zr	HT9	1.4	2.2 at. %	820°C	146 mins*
FM-4	U-19Pu-10Zr	HT9	1.5	11.4 at. %	770°C	68 mins*
FM-5	U-19Pu-10Zr	HT9	1.5	11.4 at. %	4°C/s ramp to 780°C; cool	3 mins
FM-6	U-19Pu-10Zr	HT9	1.0	11.3 at. %	650-670°C	36 hours
FM-7	U-19Pu-10Zr	316SS	1.0	13.5 at. %	650-670°C	36 hours

4.1 FM-1: U-10Zr/HT9 at 3.0 at.% burnup (T-418/X425)

Test FM-1, the first Whole Pin Furnace test on irradiated fuel, served to provide an in-cell checkout of the WPF system. It investigated the behavior of a low burnup (3.0 at.%) U-10Zr/HT9 fuel pin (pin T-418 from EBR-II subassembly X425) by heating it to a peak cladding temperature of 820°C and holding it constant until cladding breach was detected. The pin breached 67 minutes into the constant-temperature hold and the breach was successfully detected by the pressure transducers. The pin breach axial location was along the fuel column at $x/L = 0.7$. The pin likely didn't breach at the fuel top because the fuel/cladding gap was open at the fuel top following the steady-state irradiation in EBR-II, which prevented fuel-cladding interaction.

4.2 FM-2: U-19Pu-10Zr/HT9 at 3.0 at.% burnup (T-461/X425)

The FM-2 test was conducted on a low burnup (3.0 at.%) U-19Pu-10Zr/HT9 fuel pin (pin T461 from EBR-II subassembly X425). The pin was heated and run until cladding breach was detected 112 mins into the constant temperature hold at 820°C. This served as an over-test for a low-burnup Mk-V fuel undergoing a worst-case anticipated LOF event in EBR-II (UN-1). The fuel pin breached at $x/L = 1.0$. During the test, fuel/cladding metallurgical interaction reduced the cladding to a thin membrane near the crack tip (cladding thinning was evident at other locations in the pin as well); fission-gas pressure loading apparently caused the final rupture of the thinned membrane.

4.3 FM-3: U-26Pu-10Zr/HT9 at 2.2 at.% burnup (T-680/X430A)

Test FM-3 was conducted on a low-burnup (2.2 at.%) U-26Pu-10Zr/HT9 fuel pin (pin T-680 from EBR-II subassembly X430A). This was the first test on a pin with fuel/cladding prototypical to that of the PRISM design. The test pin breached 146 minutes into the constant temperature hold at 820°C. The pin breached at $x/L = 1.0$. Fuel/cladding interaction caused thinning of the cladding (penetration was nonuniform around the fuel perimeter); final rupture of the thinned cladding was the result of fission-gas pressure loading.

4.4 FM-4: U-19Pu-10Zr/HT9 at 11.4 at.% burnup (DP-22/X441A), heat to failure

Test FM-4 was conducted to evaluate the temporal safety margin for high-burnup Mk-V fuel pins undergoing a worst-case anticipated LOF event in EBR-II (the UN-1 transient). A U-19Pu-10Zr/HT9 fuel pin at burnup of 11.4 at.% (pin DP-22 from EBR-II subassembly X441A) was held at the peak temperature of the UN-1 transient until failure occurred. Cladding failure was detected 68 mins into the constant temperature hold at 770°C. The test demonstrated a large failure margin, as the UN-1 event is under 2 minutes in duration.

4.5 FM-5: U-19-Pu-10Zr/HT9 at 11.4 at.% burnup (DP-15/X441A), UN-1 simulation

Test FM-5 was conducted on a high-burnup (11.4 at.%) U-19-Pu-10Zr/HT9 fuel pin (DP-15, a corner pin from EBR-II subassembly X441A) to support the Mk-V safety case. It demonstrated survivability of a high-burnup Mk-V-type pin subject to a simulated, umbrella design thermal transient bounding the UN-1 loss-of-flow event in EBR-II. The pin exhibited only minor

incremental cladding strain and no cladding breach. There was no evidence of any fuel surface liquefaction or fuel/cladding eutectic interaction. The measured posttest cladding wastage was comparable to that seen in steady-state sibling fuel pins, indicating there was no incremental wastage as a result of the transient. Detailed thermal analysis indicated that the top portion of the fuel pin ($x/L = 0.86 - 1.0$) was heated above 660°C for ~40 seconds during the test, more than twice as long as it would be during the UN-1 event.

4.6 FM-6: U-19Pu-10Zr/HT9 at 11.3 at.% burnup (DP-39/X441A)

Test FM-6 was conducted to determine the survivability of a high-burnup Mk-V/VA-type fuel element in an extended-duration test at a Mk-V limiting cladding temperature. The test pin, U-19Pu-10Zr/HT9 at 11.3 at.% burnup (pin DP-39 from EBR-II subassembly X441A), was subject to a 36-hr heating at 650°C (at fuel top, 670°C in plenum) without any cladding breach. The test was run in two stages (12 hrs, then 24 hrs) with interim non-destructive examination (contact profilometry and gamma scanning) of the fuel element to check for premature breach. No fuel/cladding eutectic formation was observed. Four narrow transverse cracks present in the fuel before the test all maintained their location and widths following the test, indicating minimal disturbance of the fuel column.

4.7 FM-7: U-19Pu-10Zr/HT9 at 13.5 at.% burnup (T-539/X429B)

Test FM-7, like test FM-6, was conducted to determine the survivability of a high-burnup Mk-V/VA-type fuel element in an extended-duration test at a Mk-V limiting cladding temperature. The test pin, U-19Pu-10Zr/HT9 at 13.5 at.% burnup (pin T-539 from EBR-II subassembly X429B) was subject to a 36-hr heating at 650°C (at fuel top, 670°C in plenum). This test was run in one 36 hour stage (unlike FM-6, which was run in two stages). The test pin apparently experienced a pinhole breach near the end of the test (a small amount of sodium was found to have exited the cladding, but there was no indication of fission gas release). There was no evidence of fuel-cladding eutectic formation and no axial expansion of the fuel column, but cladding wastage in this fuel element was found to be greater than that observed in the HT9-clad FM-6 test pin. The posttest examination results of test FM-7 are unpublished and should be considered preliminary.

WPF Test FM-1

Conducted 8 February 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-418 (X425)
Fuel	U-10Zr
Cladding	HT9
Peak Burnup in Pin	3.0 a/o
Plenum-to-Fuel Volume Ratio	1.0
AGHCF Records Databook	365C

TEST CONDITIONS	
Test Type	Ramp and Hold, Run to Breach
Temperature	820°C (in plenum)

RESULTS	
Status	GOOD
Time of Breach	67 minutes
Location of Breach	x/L = 0.7

DATA AVAILABLE	
Pre-Transient (NDE)	Macrophotos, Diametral Profilometry, Gamma Scans [1]
During Transient	Thermocouple Locations [1], Temperatures along length of fuel pin [2], Pressure in test section (for breach detection) [2]
Post-Transient	Gamma scans, Diameter measurements (with micrometer), Macrophotos, Microphotos, Analysis of collected FG [1]

[1] A/G 365C Databook (Binders 465A, 465B, and 465C) (*unpublished information*), [2] A. E. Wright, Technical Memorandum, 1991

KEY TEST INFORMATION
<p>An earlier attempt to run test FM-1 (on Feb 5, 1990) was terminated 74 seconds into the test due to an unexpected temperature overshoot (>30°C). Because the time at high temperature was so brief, this first heating was not thought to affect the results when the same pin was re-tested on Feb 8. The test routine ramped the sample up from a priming temperature of 500°C at 6°C/s to the test temperature of 820°C (in plenum). The FM-1 test pin breached 67 minutes into the constant-temperature hold (detected by the pressure transducers). Posttest examination of the failed pin revealed that much of the fuel was solid at the location of the breach (at x/L = 0.7). The breach was caused by the coupled effect of cladding wall thinning and fission-gas pressure loading. Adjacent to the failure site, there was significant eutectic penetration through 64% of the cladding thickness. The breach was a benign axial crack ~ 1500 µm long and 75 µm wide with a peak cladding plastic strain of 3.3% near the crack tip. Note that the cladding test temperature of 820°C occurred at ~75mm above the fuel top, with lower temperature at the fuel top (~810°C) and at the fuel failure height.</p>

WPF Test FM-2

Conducted 23 May 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-461 (X425)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	3.0 a/o
Plenum-to-Fuel Volume Ratio	1.0
AGHCF Records Databook	377B

TEST CONDITIONS	
Test Type	Ramp and Hold, Run to Breach
Temperature	820°C (in plenum)

RESULTS	
Status	GOOD
Time of Breach	112 minutes
Location of Breach	x/L = 1.0

DATA AVAILABLE	
Pre-Transient (NDE)	Macrophotos, Diametral Profilometry, Gamma Scans [1]
During Transient	Thermocouple Locations [2], Temperatures along length of fuel pin [2], Pressure in test section (for breach detection) [2]
Post-Transient	Gamma scans, Diameter measurements (with micrometer), Macrophotos, Microphotos, Analysis of collected FG [1]

[1] A/G 377B Databook (Binders 466A, 466B, and 466C) (*unpublished information*), [2] Y. Y. Liu, Internal Memorandum, 1991

KEY TEST INFORMATION
<p>The FM-2 test routine ramped the sample up from a priming temperature of 500°C at 6°C/s to the test temperature of 820°C (in plenum). The test pin was breached at 112 minutes into the constant temperature hold (detected by the pressure transducers). The breach occurred at the top of the pin, where the fuel was porous foam. The breach was caused by the coupled effect of fuel/cladding interaction-induced cladding thinning and fission gas pressure loading. At the failure site, eutectic penetrated up to 67% of the total cladding thickness. The breach was a benign axial crack ~2 mm long with a maximum width of 0.9mm and small cladding strains of 2.3-4.3% near the crack tip. Significant axial fuel expansion, the mechanism for which was apparently fuel foaming, occurred during the FM-2 test. There was upward in-pin fuel motion up to 1.4-5 cm into the plenum (preliminary measurements on top of the fuel column indicated expansion as much as ~5cm, but subsequent metallographic examination could only confirm ~1.4cm above the top of the as-irradiated fuel column). Note that the test temperature of 820°C occurred in the plenum region; the temperature was 810°C at the fuel top. Fuel liquefaction was evident down to approximately the fuel midplane, where the temperature reached 760°C during the test. The areal fuel liquefaction fraction was 11% at x/L = 0.54 and 100% at x/L = 0.68 and above.</p>

WPF Test FM-3

Conducted 31 August 1990

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-680 (X430A)
Fuel	U-26Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	2.2 a/o
Plenum-to-Fuel Volume Ratio	1.4
AGHCF Records Databook	409B

TEST CONDITIONS	
Test Type	Ramp and Hold, Run to Breach
Temperature	820°C

RESULTS	
Status	GOOD
Time of Breach	146 minutes
Location of Breach	x/L = 1.0

DATA AVAILABLE	
Pre-Transient (NDE)	Radiographs, Gamma Scans [1], Diametral Profilometry [2]
During Transient	Peak Cladding Temperature history, Pressure in test section (for breach detection) [3]
Post-Transient	Gamma scans, Radiographs, Diameter measurements (with micrometer), Macrophotos, Microphotos, Analysis of collected FG [1]

[1] A/G 409B Databook (Binders 467A and 467B) (*unpublished information*), [2] FM-3 Posttest Pin Diameter Measurements (*unpublished information*), [3] H. C. Tsai, Presentation Material, 1991

KEY TEST INFORMATION
The FM-3 test routine ramped the sample up from a priming temperature of 500°C at 6°C/s to the test temperature of 820°C. The test pin was breached at 146 minutes into the constant temperature hold (detected by the pressure transducers). The breach occurred at the top of the pin. It was caused by the coupled effect of cladding penetration due to fuel/cladding interaction and fission gas pressure loading. At the failure site, eutectic penetration extended through 65% of the total cladding thickness. The breach was a benign axial crack with a length < 1mm and a width of 0.25mm at maximum and small cladding strain of 1.2% near the crack tip. The fuel at the breach location was porous foam. There was upward in-pin fuel motion of ~1.6 cm into the plenum.

WPF Test FM-4

Conducted 12 April 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-22 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.4 a/o
Plenum-to-Fuel Volume Ratio	1.5
AGHCF Records Databook	427A

TEST CONDITIONS	
Test Type	Ramp and Hold, Run to Breach
Temperature	770°C (in plenum)

RESULTS	
Status	GOOD
Time of Breach	68 minutes
Location of Breach	In plenum, 15 cm above fuel top (creep rupture)

DATA AVAILABLE	
Pre-Transient (NDE)	Gamma scans, Diameter measurements (with micrometer) [1]
During Transient	Peak Cladding Temperature history, Pressure in test section (for breach detection) [2]
Post-Transient	Gamma scans, Diameter measurements (with micrometer), Macrophotos, Microphotos, analysis of collected FG, Microhardness [1]

[1] A/G 427A Databook (Binder 468A) (*unpublished information*), [2] J. M. Kramer, Internal Memo, 1991

KEY TEST INFORMATION
The FM-4 test pin breached 68 minutes into the constant temperature hold. The breach occurred by creep rupture due to fission-gas pressure loading in the plenum ~15cm above the fuel top. The large rupture was 12.5mm long and 3.5 mm wide and significant cladding deformation was evident near the breach (peak strains of 10-15%). There was no evidence of fuel at the breach location and therefore no fuel/cladding metallurgical interaction contribution to the breach. There was much less fuel-cladding interaction seen in this test than in the longer and higher temperature FM-2 test. At the fuel top, eutectic penetration extended through 24% of cladding thickness. Fuel surface liquefaction was evident down to approximately the fuel midplane, where the temperature was 675°C during the test. At $x/L = 0.96$, where the test temperature was 750°C, the areal fraction of fuel liquefaction was ~20% and the cladding penetration extended through 13.3% of the original cladding thickness. The test resulted in modest upward motion of foamed fuel into the plenum (~3mm).

WPF Test FM-5

Conducted 27 June 1991

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-15 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.4 a/o
Plenum-to-Fuel Volume Ratio	1.5
AGHCF Records Databook	427B

TEST CONDITIONS	
Test Type	Shaped (UN-1 LOF simulation)
Routine	Heat sample at 4°C /s up to 780°C, then cool.
Temperature	Peak Temp of 780°C at the fuel top (870°C in plenum)*
Duration	~3 minutes

RESULTS	
Status	GOOD
Time of Breach	N/A (no cladding breach)

DATA AVAILABLE	
Pre-Transient (whole pin)	Gamma scans, Diameter measurements (with micrometer) [1]
During Transient	Temperature history at fuel top [2], All Thermocouple history [3]*
Post-Transient	Gamma scans, Diametral profilometry, Microphotos, Microhardness [1]

[1] A/G 427B Databook (Binders 469A and 469B) (*unpublished information*), [2] J. M. Kramer, Technical Report, 1991, [3] Y. Y. Liu, Internal Memo, 1991

KEY TEST INFORMATION
<p>The FM-5 temperature history at the fuel top effectively enveloped the cladding temperature history in a UN-1 LOF event. Following the FM-5 test, there was no noticeable damage to the fuel element. Posttest examination at a number of axial locations above the midplane of the fuel column showed no fuel surface liquefaction and very minimal cladding wastage (small or comparable to that seen in the steady-state irradiated sibling pin). Posttest profilometry showed peak incremental cladding strain of < 0.1% throughout the fuel region (where peak test temperature was ~780°C) and 2.7% in the upper plenum (where peak test temperature was ~870°C).</p> <p>* The WPF was designed for steady or slowly varying overtemperature tests, not the rapidly changing temperature transient performed in test FM-5. The measured TC histories may not be representative of the actual pin temperature history, because the thermal time constants were non-negligible. A thermal analysis with a lumped parameter model estimated that peak cladding ID temperatures lag the thermocouple temperatures by 10 to 50 s in the plenum and fuel regions, respectively; the peak cladding ID temperatures may be 10 to 30°C lower than measured. (Bauer, Internal Memo, 1992).</p>

WPF Test FM-6

Conducted 19 and 29 June 1992

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	DP-39 (X441A)
Fuel	U-19Pu-10Zr
Cladding	HT9
Peak Burnup in Pin	11.3 a/o
Plenum-to-Fuel Volume Ratio	1.0
AGHCF Records Databook	435A

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	670°C in plenum, 650°C near fuel top
Duration	36 hours (in two stages, 12 hrs + 24 hrs)

RESULTS	
Status	GOOD
Time of Breach	N/A (no cladding breach)

DATA AVAILABLE	
Pre-Transient (NDE)	Gamma Scans [1], Diametral Profilometry [2]
During Transient	Thermocouple locations [1], Temperature histories [2] (between 1 st and 2 nd test stage): Gamma Scans [1], Diametral Profilometry [2]
Post-Transient	Gamma scans, Radiographs, Microphotos, Analysis of collected FG [1], Diametral Profilometry [2]

[1] A/G 435A Databook (Binder 524) (*unpublished information*), [2] Y. Y. Liu, Presentation Material, 1993

KEY TEST INFORMATION
Posttest metallography revealed no evidence of eutectic formation, but some FCCI was evident in the cladding. After 12 hours of heating, the incremental cladding strain at the fuel top (test temperature ~650°C) was 0.33% and in 0.31% in plenum. After 36 hours of heating (12 hours in first stage + 24 hours in the second stage), the incremental cladding strain was 0.5% near the fuel top and 0.9% in the plenum. Posttest radiography indicated no axial expansion of the fuel.

WPF Test FM-7

Conducted 28 January 1993

TEST SAMPLE (Fuel Pin Segment)	
Pin ID (Subassembly)	T-539 (X429B)
Fuel	U-19Pu-10Zr
Cladding	316SS
Peak Burnup in Pin	13.5 a/o
Plenum-to-Fuel Volume Ratio	1.0
AGHCF Records Databook	434B

TEST CONDITIONS	
Test Type	Ramp and Hold
Temperature	670°C in plenum, 650°C near fuel top
Duration	36 hours

RESULTS	
Status	PRELIMINARY
Time of Breach	N/A (no cladding breach)

DATA AVAILABLE	
Pre-Transient (NDE)	Gamma scans [1], Diametral Profilometry and cladding average strain profile [2]
During Transient	none
Post-Transient	Gamma scans, Macrophotos, Microphotos, analysis of collected FG [1], Cladding average strain profile [2]

[1] A/G 434B Databook (Binder 525) (*unpublished information*), [2] FM-7 Supplemental Notes from AGHCF (*unpublished information*)

KEY TEST INFORMATION
<p>There was no evidence of fuel/cladding eutectic formation, but some FCCI was evident. There was no evidence of axial expansion of the fuel. The incremental cladding strain caused by the test was ~0.15% in the fuel region and 0.18% in the plenum region, substantially smaller than the 6.1% total strain resulting from the steady-state irradiation in EBR-II. While there was no indication of a breach during the test (no FG release was detected), a small accumulation of bond sodium was found on the outside of the cladding when the fuel pin was removed from the test capsule. A small pin hole was found when the sodium was removed, but extensive metallography found no additional evidence of cladding breach. It was assumed that this pin hole formed late in the test. The posttest examination results are unpublished and preliminary.</p>

5 CONCLUSIONS

The 150+ out-of-pile furnace tests conducted in the FBTA and WPF apparatuses at the AGHCF from 1987-1994 establish a knowledge base on fuel/clad compatibility and performance for a variety of fast reactor metallic fuel compositions and conditions. The results of the legacy testing program provide support for advanced nuclear fuels and materials R&D. This open report provided summary information on all tests comprising the out-of-pile furnace testing program, the records of which are now preserved and organized in a database. Stakeholders are invited to review the test summary information to determine which tests are of interest and request additional records depending on their availability.

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