Global Nuclear Fuel

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MFN 16-044
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Director, Division of Safety Systems
U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

Subject: Information Regarding the Formation of a Eutectic Between Zircaloy and Inconel Fuel Bundle Components in a LOCA Environment

Global Nuclear Fuel – Americas, LLC (GNF) has become aware of a Petition for Rulemaking (Reference 1) making the assertion that fuel rod failures due to eutectic reactions may occur between Inconel grid material and Zircaloy cladding during Loss-of-Coolant Accident (LOCA) conditions. There have also been a substantial number of comments submitted in relation to this petition, for example Reference 2. While a eutectic reaction is possible from a metallurgy standpoint, the geometry of the contact and the environment during the temperature excursion have a substantial effect on the potential for a meaningful reaction.

GNF performed simulated LOCA testing in 1978 to investigate the significance of a eutectic reaction between a Zircaloy fuel rod and an Inconel spacer spring. The 1978 report has poor image quality so it is difficult to make independent assessments of the general conclusions. Therefore, GNF has performed additional simulated LOCA testing using the current design geometry and materials. The current testing apparatus was designed and used to support the 10 CFR 50.46c rulemaking oxidation testing.

A summary of the results from these tests is provided for your consideration and use in the NRC response to the referenced Petition for Rulemaking.

If you have questions regarding the information provided here, please contact me or Jim Harrison at (910) 620-1826.

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Project No. 712

References:

1. Petition for Rulemaking-50-95, Letter from Mark E. Leyse to R. William Borchardt, Executive Director for Operations, U.S. Nuclear Regulatory Commission, Subject: 10 C.F.R. § 2.206 Request to Lower the Licensing Basis Peak Cladding Temperature of Vermont Yankee Nuclear Power Station (Docket-50-271) in Order to Provide a Necessary Margin of Safety-to Help Prevent a Meltdown-in the Event of a Loss-of-Coolant Accident, June 7, 2010, Docketed September 30, 2010, ML102770018.

2. Rulemaking Comments PRM-50-95 (75FR66007), E-Mail from Mark Leyse to Rulemaking Comments, Ms. Vietti-Cook, Subject: NRC-2009-0554, Dated November 23, 2010, Docketed November 24, 2010, ML103340249.

Enclosure:

1. Summary of Testing of a Prototypical Fuel Assembly Grid and Cladding Design for Eutectic Reactions during Accident Conditions – Non-Proprietary Information – Class I (Public)

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P Clifford, USNRC
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PLM Specification 003N7782

ENCLOSURE 1

MFN 16-044

Summary of Testing of a Prototypical Fuel Assembly Grid and Cladding Design for Eutectic Reactions during Accident Conditions

Non-Proprietary Information – Class I (Public)

Summary of Testing of a Prototypical Fuel Assembly Grid and Cladding Design for Eutectic Reactions during Accident Conditions

Introduction

Global Nuclear Fuel – Americas, LLC (GNF) has become aware of a Petition for Rulemaking (Reference 1) making the assertion that fuel rod failures due to eutectic reactions may occur between Inconel grid material and Zircaloy cladding during Loss-of-Coolant Accident (LOCA) conditions. There have also been a substantial number of comments submitted in relation to this petition, for example Reference 2. While theoretically possible from a metallurgy standpoint, the geometry of the point of contact and the environment during the temperature excursion have a substantial effect on the potential for a meaningful reaction.

GNF performed simulated LOCA testing in 1978 to investigate the significance of a eutectic reaction between a Zircaloy fuel rod and an Inconel spacer spring. The tests were performed using an egg crate type Zircaloy spacer with X-750 Inconel spacer cells and a Zircaloy cladding tube which were prototypical of fuel assembly designs at that time. The cladding was electrically heated and the test environment was 1205°C steam for 10 minutes or less.

The testing concluded that eutectic reactions will occur in postulated LOCA conditions. Further, the zirconium oxide film might reduce the reaction rate, but does not prevent the reaction from taking place at ~1200°C. The 1978 investigation concluded that pinhole failures in both fuel cladding and Inconel spring are expected to occur. The 1978 report has poor image quality so it is difficult to make independent assessments of the general conclusions. Therefore, GNF has performed additional simulated LOCA testing using the current design geometry and materials.

Test Apparatus

The testing apparatus was designed to support the 10 CFR 50.46c rulemaking oxidation testing, and therefore is appropriate for this application. It is a vertical clamshell furnace with a quartz test chamber. In the test assembly, steam flows from the bottom to the top. The furnace is pre-heated and the test sample is inserted from the top. The assembly uses a Type S thermocouple to monitor the temperature near the sample.

Testing

An as-fabricated Inconel X-750 GNF2 spacer cell with a thin age-hardening oxide and bare unoxidized Zircaloy-2 cladding were used for the tests.

Two tests were performed:

- 1200°C/10 minutes in steam
  This test duration is quite conservative because worst case calculated LOCA cladding temperature transients are only momentarily near 1200°C.
- 1000°C/5000 seconds in steam
  This test duration is designed to represent very conservative longer term conditions. Again, long-term behavior would be expected to decline to less than 1000°C over the 5000 second period.

The number of tests conducted weren't meant to form a statistically significant design basis. While repeatability tests were also not performed, it should be noted that the temperature imposed on the test specimens and the duration of the tests were conditions that are extremely conservative relative to those expected in LOCA scenarios.

Results

1200°C/10 minutes in steam

The pre-test appearance of the sample configuration used in the 1200°C/10 minute test is shown in Figure 1. The configuration consists of a single X-750 cell placed onto a slightly longer section of open-ended cladding. The X-750 cell was obtained from a full-size spacer assembly using a slow-speed saw. The cell was held in place by the contact force from the cell's springs. The post-test appearance is shown in Figure 2 for two orientations with the original cell configuration intact, and in Figure 3 with the cladding removed from the cell. Black pen markings were applied post-test to identify the top end of the cell and the relative orientation between the cell and cladding prior to disassembly.

Results show that the original cell configuration was maintained, and that the interaction between the cell and cladding was mild and localized to a nearly invisible spot around each contact point. The cladding has a lustrous black appearance.

One of the contact points was evaluated using a Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray (EDX) microanalyzer. The contact point was imaged using Secondary Electrons (SEI) and Backscattered Electrons (BSE), which highlight topographical and compositional characteristics, respectively. SEM results shown in Figure 4 reveal a localized contact feature about 300 microns across. A thin outer layer of the cladding layer has been pulled off, which created a shallow crater that contains a columnar oxide layer. The BSE images show little compositional variation within or around the crater except for a dark intermittent ring around the crater. Because X-750 contains about 70% nickel and lesser alloying amounts of chromium, iron, titanium, and aluminum, the extent of interaction between the X-750 and the cladding is indicated by elevated levels of these elements in and around the

crater. An EDX of the area in and around the crater shows that the extent of compositional interaction is localized consistent with the visual appearance (Figure 5). The highest nickel content is in the thin black layer that encircles the crater, which appears to be a thin remnant of the cell material that interacted with the cladding. The black layer also contains chromium, iron, titanium and aluminum, whereas these elements are not detected in the other locations that were interrogated outside of the crater. The nickel content diminishes about one crater length away from the contact center (Figure 5, Points 1 and 7) at locations that do not contain cell contact scrapes (Figure 5, Point 6).

Figure 1. Pre-test Sample Configuration Used for 1200°C/10 Minute Test

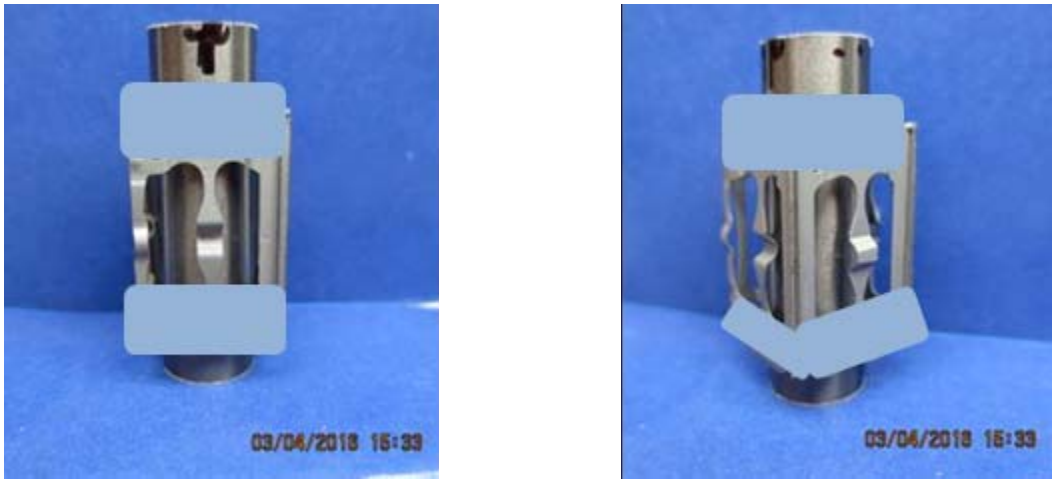


Figure 2. Post-Test Sample Appearance from 1200°C/10 Minute Test (Assembled Configuration)

Figure 3. Post-Test Sample Appearance from 1200°C/10 Minute Test (Disassembled Configuration)

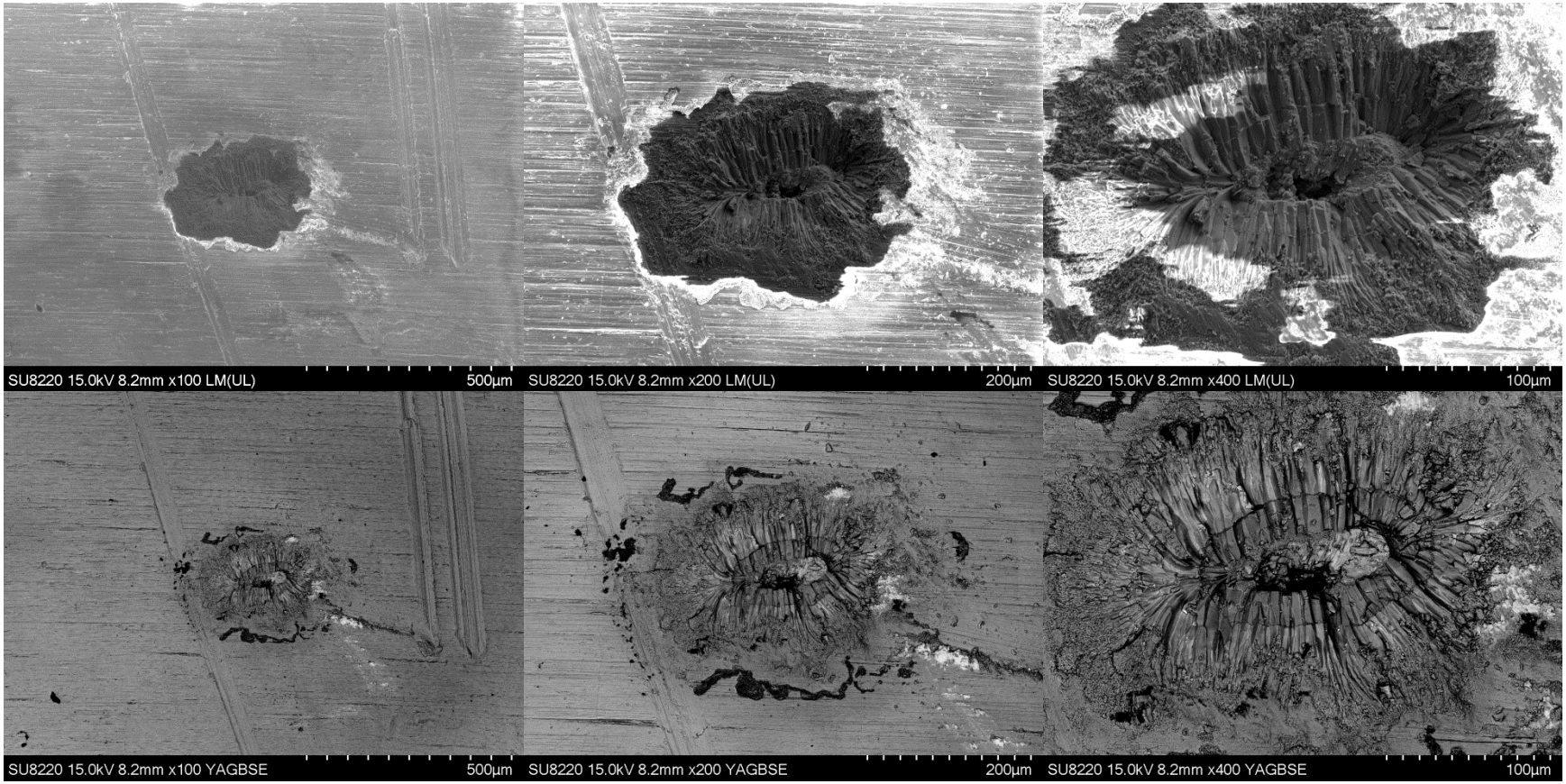
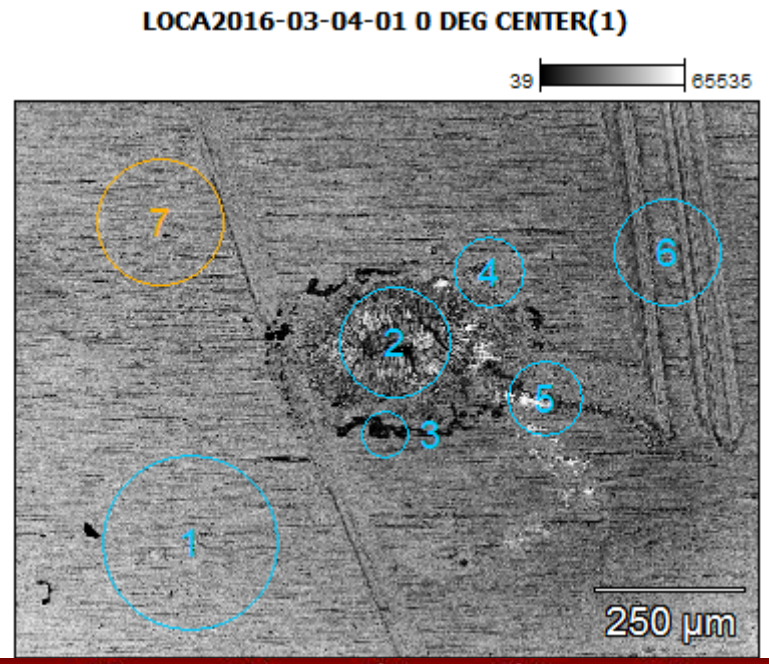


Figure 4. Backscattered and Secondary Electron Images of Localized X-750 Contact Point on Cladding from 1200°C/10 Minute Test (100X, 200X, and 400X Magnifications)



Wt%	C-K	O-K	Al-K	Ti-K	Cr-K	Fe-K	Ni-K	Zr-L
LOCA2016-03-04-01 0 DEG CENTER(1)_pt1	0.00	27.13					2.04	70.84
LOCA2016-03-04-01 0 DEG CENTER(1)_pt2	7.20	27.30			0.98		4.30	60.22
LOCA2016-03-04-01 0 DEG CENTER(1)_pt3	10.17	0.00	0.49	2.50	6.84	2.97	12.37	64.66
LOCA2016-03-04-01 0 DEG CENTER(1)_pt4	0.00	28.76					1.89	69.35
LOCA2016-03-04-01 0 DEG CENTER(1)_pt5		25.23					4.77	70.01
LOCA2016-03-04-01 0 DEG CENTER(1)_pt6		28.31					5.11	66.58
LOCA2016-03-04-01 0 DEG CENTER(1)_pt7		27.01					1.84	71.16

Figure 5. X-Ray Microanalysis of Localized X-750 Contact Point on Cladding from 1200°C/10 Minute Test

1000°C/5000 seconds in steam

The sample preparation and test configuration used for the 1000°C/5000 second test are the same as those used for the 1200°C/10 minute test. The post-test appearance is shown in Figure 6 with the original cell configuration intact, and in Figure 7 with the cladding removed from the cell. Black pen markings were applied post-test to identify the top end of the cell prior to disassembly.

Results show that the original cell configuration was maintained and that the interaction between the cell and cladding was mild and localized to a nearly invisible spot around each contact point. The cladding is transitioning from a lustrous black appearance to a lighter, opaque appearance for reasons unrelated to the interaction between the spacer cell and cladding.

One of the contact points was evaluated by SEM and EDX. SEM results shown in Figure 8 reveal a localized contact feature about 100 microns across. A similar pull-out feature does not exist but the conditions for it appear to be developing. The BSE images show little compositional variation within or around the contact's center except for a patch of dark spots away from the center. The extent of interaction between the X-750 and the cladding is indicated by the nickel, chromium, iron, titanium, and aluminum content in and around the contact area. EDX of the area shows that the extent of compositional interaction is minor and localized (Figure 9). No elevated nickel, chromium, iron, titanium or aluminum levels were detected in the contact area. The only notable compositional feature is elevated chromium content in the dark spots a short distance away from the contact's center, which appears to be a thin remnant of the broader contact area of the cell material that interacted with the cladding (Figure 9, Point 2).

Figure 6. Post-Test Sample Appearance from 1000°C/5000 Second Test (Assembled Configuration)

Figure 7. Post-Test Sample Appearance from 1000°C/5000 Second Test (Disassembled Configuration)

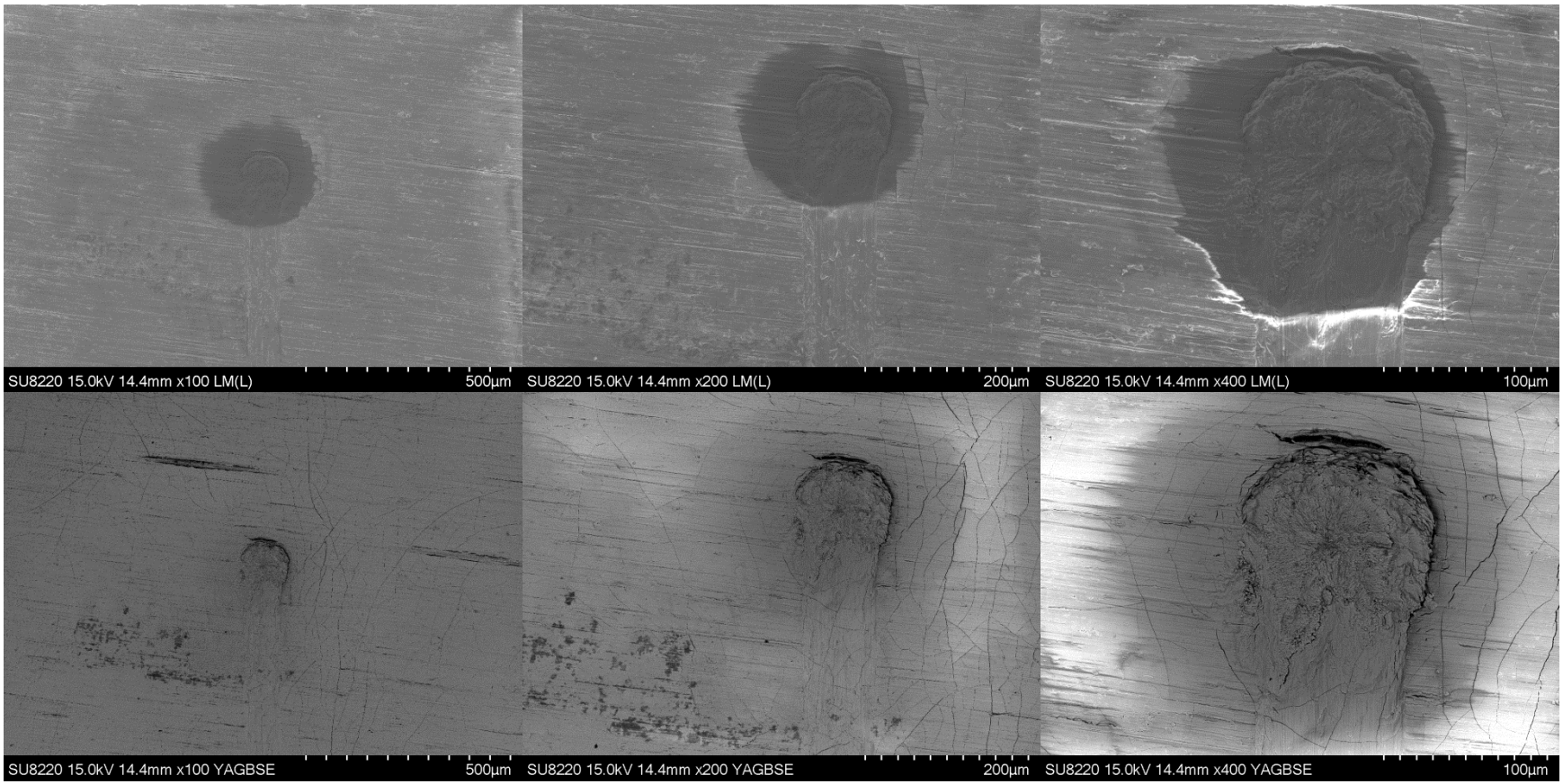
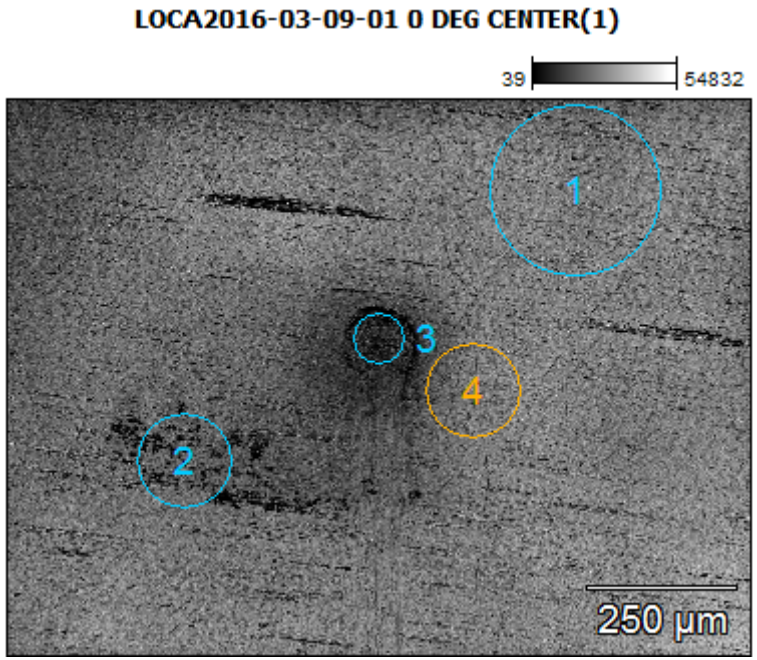


Figure 8. Backscattered and Secondary Electron Images of Localized X-750 Contact Point on Cladding from 1000°C/5000 Second Test (100X, 200X, and 400X Magnifications)



Weight %	C-K	O-K	Ti-K	Cr-K	Zr-L
LOCA2016-03-09-01 0 DEG CENTER(1)_pt1	0.00	34.03			65.97
LOCA2016-03-09-01 0 DEG CENTER(1)_pt2	5.90	38.20	3.49	1.22	51.20
LOCA2016-03-09-01 0 DEG CENTER(1)_pt3	8.04	26.54			65.43
LOCA2016-03-09-01 0 DEG CENTER(1)_pt4	0.00	38.58			61.42

Figure 9. X-Ray Microanalysis of Localized X-750 Contact Point on Cladding from 1000°C/5000 Second Test

Summary

Testing was performed to evaluate the eutectic interaction between modern production cladding and modern spacer materials using conservatively applied time at temperature assumptions to represent bounding LOCA scenarios. This testing confirmed our understanding, consistent with the 1978 report, that interaction can occur under LOCA conditions. However, the extent of the eutectic reaction is very localized and controlled due to oxidation during testing and its consequences are insignificant.

References

1 Petition for Rulemaking-50-95, Letter from Mark E. Leyse to R. William Borchardt, Executive Director for Operations, U.S. Nuclear Regulatory Commission, Subject: 10 C.F.R. § 2.206 Request to Lower the Licensing Basis Peak Cladding Temperature of Vermont Yankee Nuclear Power Station (Docket-50-271) in Order to Provide a Necessary Margin of Safety-to Help Prevent a Meltdown-in the Event of a Loss-of-Coolant Accident, June 7, 2010, Docketed September 30, 2010, ML102770018.

2 Rulemaking Comments PRM-50-95 (75FR66007), E-Mail from Mark Leyse to Rulemaking Comments, Ms. Vietti-Cook, Subject: NRC-2009-0554, Dated November 23, 2010, Docketed November 24, 2010, ML103340249.