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U.S. Nuclear Regulatory Commission
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Comments on the Report PNNL-28437, "Degradation and Failure Phenomena of Accident Tolerant Fuel Concepts Chromium Coated Zirconium Alloy Cladding"

Ref. 1: PNNL-28437, "Degradation and Failure Phenomena of Accident Tolerant Fuel Concepts Chromium Coated Zirconium Alloy Cladding," January 2019.

Framatome is providing comments on Reference 1 to support the NRC meeting "Phenomenon Identification and Ranking Table (PIRT) Panel Discussion on Degradation and Failure Phenomena of Chrome Coated Zirconium Alloy Cladding," which is to be held on April 23, 2019 at the PNNL offices in Richland, Washington.

The comments are presented in the enclosed table.

There are no commitments within this letter or its enclosures.

If you have any questions related to this information, please contact Ms. Gayle Elliott, Deputy Director, Licensing & Regulatory Affairs, by telephone at (434) 832-3347, or by e-mail at Gayle.Elliott@framatome.com.

Sincerely,

Gary Peters, Director
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Framatome Inc.

cc: M. Gavrilas
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Enclosure:
1. Table - Comments on PNNL-28437

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Framatome Inc. Comments on PNNL-28437

Comment No.	Section Number and Page Number in PNNL-28437	Text in PNNL-28437 or subject identification	Framatome Comment
1	Section 5.1.3 – Page 5.4	"Because the current coatings are on the outer surface it would be acceptable to retain the emissivity used for an uncoated Zr alloy tube for thermal-mechanical analysis, but it may be necessary to revise the outer surface emissivity for accident analyses. This would apply equally to metallic and ceramic coatings."	Emissivity is strongly correlated to oxide thickness, increasing with increased oxide until reaching a stable level consistent with an 'opaque' surface. As chromium coatings exhibit a significantly reduced oxidation rate, the resulting impact on emissivity values should be assessed and accounted for in accident analyses.
2	Section 5.1.3 – Page 5.4	emissivity	See comment No. 1. Radiative heat transfer is part of cladding heat removal to the coolant for any LOCA. The current text connotation is that it is dominant in the very high temperature range, while it is also a dominant component of steam-only heat transfer characteristic of SBLOCAs. Emissivity is strongly correlated to oxide thickness, increasing with increased oxide until reaching a stable level consistent with an 'opaque' surface. Current claddings are very similar with respect to the emissivity-relevant oxide development, but this should be evaluated for coatings highly resistant to oxidation. But, since chromium coatings exhibit a significantly reduced oxidation rate, the resulting impact on emissivity values should be assessed and accounted for in accident analyses.
3	Section 5.1.6-Page 5.5	Yield Stress	The evaluation of cladding can be based on either yield stress or ultimate tensile stress (UTS) per ASME BP&VC methods.

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4	Section 5.1.7– Page 5.6	"Recent data on unirradiated Cr-coated Zr indicate the thermal creep behavior of a coated part will be the same as that of an uncoated part (Brachet, et al., 2017)"	Framatome's experience is that there may be a difference in the creep behavior between the coated cladding and the base cladding material.
5	Section 5.1.9- Page 5.6	"...should not be used to develop corrosion correlations for coated parts. Additionally, the corrosion behavior of non-fueled cladding segments may also not be representative of fueled cladding corrosion as the surface heat flux in the fueled cladding seems to strongly impact oxidation rate ...".	Framatome's experience is that it is the cladding surface temperature, not the applied heat flux that governs the corrosion rate. Fueled samples typically have a rod surface temperature ~20C+ higher than the surrounding coolant, which dictates the higher corrosion rates. However, Framatome's experience is that unfueled/unheated samples can be used for developing corrosion correlations, as long as the surface temperature is taken into account as a model variable, as is the case in Framatome's existing cladding corrosion models.
6	Section 5.1.9– Page 5.7	"Some in-reactor data from fueled rods under prototypical coolant conditions are recommended to demonstrate the oxidation rate or lack of one."	See comment No. 5
7	Section 5.1.12 - Page 5.8, Table 5.1	Tables with recommended tests	Table 5.1 provides a column labeled recommended tests but it is clear from the detailed discussion sections that tests are not always required or recommended. This inconsistency could lead to future confusion. This comment applies to some degree to all of the tables in the report.
8	Section 5.1.12- Page 5.8, Table 5.1	The table states that no testing is needed for emissivity.	See comment No. 1

Comment No.	Section Number and Page Number in PNNL-28437	Text in PNNL-28437 or subject identification	Framatome Comment
9	Section 5.2 – Page 5.10, Table 5.2	"Prevent cladding failure from chemically assisted cracking"	The purpose of the limit is to prevent failure from both mechanical interactions and chemical interactions.
10	Section 5.2.1.2 - Page 5.12	Irradiation growth	The change in the irradiation induced growth for fuel rods may also impact the irradiation induced growth for fuel assemblies through the change in slip load.
11	Section 5.1.12 - Page 5.8	high temperature steam oxidation rate	While thinning of the cladding is important, high temperature steam oxidation results in diffusion of oxygen into the beta-substrate which is the primary mechanism for clad embrittlement.
12	Table 5.1 - Page 5.8	emissivity	See comment No. 1
13	Section 5.2.2.2 - Page 5.13	"...when performed at the maximum expected fast neutron fluence."	The reduction in ductility typically saturates with fluence and thus the tests do not need to be performed at the maximum expected fluence.
14	Section 5.2.2.2 - Page 5.13	"...there is the additional concern that large strains in the cladding may lead to cracking of the coating (See Section 6.1.3). The authors propose adding crack detection criteria so that there is no visual cracking or microcracking of the coating."	Detection of coated cladding cracks during poolside exams is not a viable approach. By the time cracks are visible during poolside exams, they are probably large enough to impact performance. A better approach would be to generically assess performance and properties with coatings cracked to an anticipated degree to ensure other properties are not impacted.
15	Section 5.2.2.3 - Page 5.13	"... Cr-coated Zr where the fatigue life went down with the application of a coating (Sevecek, et al., 2018)."	Fatigue performance of a coated cladding is expected to be very dependent upon the coating application method. The testing cited here was on cold spray coating, results were attributed to microstructural damage produced during cold spray.

Comment No.	Section Number and Page Number in PNNL-28437	Text in PNNL-28437 or subject identification	Framatome Comment
16	Section 5.2.2.3 - Page 5.13	"Because of this, fatigue data from irradiated cladding that was produced using a representative process for the applicant in question is recommended to either confirm the O'Donnell and Langer irradiated fatigue design curve or to develop a new fatigue design curve."	The O'Donnell-Langer correlation was developed for Zr-2 and did include some irradiated material. The advanced alloys primarily rely on this and the similarity to Zr-2. The fatigue limits are generally not challenged; large margins exist to the criterion. Tests on irradiated cladding are not necessary.
17	Section 5.2.2.4 - Page 5.13	"Limits should be proposed that preclude environmental damage to the protective Cr2O3 layer and embrittlement of the cladding. As with Zr-alloy cladding, the CRUD should be monitored in plants and be explicitly considered if it is present and modeled as an insulating layer around the fuel rod."	This can be accomplished by defining the model applicability within operating regimes (temperatures, RCS chemistry, etc.)
18	Section 5.2.3.1 - Page 5.15	"If the coating results in a significantly different surface roughness or cladding outer diameter ..."	Since the surface roughness is not the only surface condition that could trigger the need for CHF testing it is suggested that the word roughness be replaced by the word condition.
19	Section 5.2.3.2 - Page 5.16	Third paragraph	If the alternate approach is followed and the current limits are concluded to be acceptable then RIA testing on irradiated material or a commitment to do so should not be required.
20	Section 5.2.3.9 - Page 5.19, Table 5.3	"Ex-reactor tests on irradiated tubes to establish fatigue design curve"	See comment No. 16
21	Section 5.2.4.2 - Page 5.20	"Local coating delamination could create a local cool spot on the cladding which is a sink for hydrogen diffusion."	The key is that delamination is not acceptable and it should be shown to not occur.

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22	Section 5.2.4.4 - Page 5.22	"A second concern is what the impact of fast neutron irradiation on Cr metal and other Cr containing compounds will be."	Cr is already throughout the core in nickel-based metals and as Cr-plated on certain fuel components. This has previously been shown to not be a problem.
23	Section 5.3.1 - Page 5.22	"This approach could also attempt to make an argument to ignore the coating in the analyses and rely on existing cladding properties."	This approach only works when the existing cladding properties are conservative for a specific analysis, which is not the case for all coated cladding properties.
24	Section 5.3.1.2 - Page 5.23	"An ongoing surveillance plan with the goal of continuing to obtain more fission gas release data would provide additional assessment data."	Since the coated cladding has limited impact on fuel temperatures there does not appear to be a need to collect fission gas release data specific to coated claddings.
25	Section 5.3.1.4 - Page 5.24	"...a surveillance plan to monitor the oxide thickness on Cr-coated Zr cladding would be useful as it may give an early indication of a process change that is causing a problem."	There are already controls in place in the manufacturing facilities to control process changes. In-reactor experience feedback is not available until at least 2 years after cladding manufacture - too late to be an effective indicator of manufacturing process changes. Cladding specifications establish the required tests in order to identify performance changes resulting from process drifts. Qualification requirements establish the required tests in order to confirm performance following a manufacturing process change.
26	Section 6.1 – Page 6.1	in-reactor data	Fuel centerline temperature and fission gas release data are not needed for chromium coated cladding.

Comment No.	Section Number and Page Number in PNNL-28437	Text in PNNL-28437 or subject identification	Framatome Comment
27	Section 6.1.1 - Page 6.2	"It should be noted that because these samples did not contain fuel or have prototypical surface heat flux, these samples will have limited value for determining oxide thickness but will be useful for determining mechanical properties."	See comment No. 5
28	Section 6.2.5 – Page 6.8	"No data has been found in the literature from Cr-coated Zr cladding for different thermal limits."	Framatome has examined other sources of measured CHF performance for coated rods: • Kam, Lee, Lee, Jeon, "Critical heat flux for SiC and Cr coated plates under atmospheric condition", Annals of Nuclear Energy, 2015. • Son, Seo, Jeong, Shin, Kim, "Capillary wicking effect of a Cr-sputtered super hydrophilic surface on enhancement of pool boiling critical heat flux", International Journal of Heat and Mass Transfer, 2016. • Lee, Chi Young, Wang Kee In, and Yang Hyun Koo, "Transient pool boiling heat transfer during rapid cooling under saturated water condition." Journal of Nuclear Science and Technology (2015): 1-9. The data presented in these articles relates to investigations on flat samples in static horizontal regime which is not representative of the cylindrical geometry in a dynamic vertical regime at high pressure, temperature, and water flow rate.

Comment No.	Section Number and Page Number in PNNL-28437	Text in PNNL-28437 or subject identification	Framatome Comment
29	Section 6.3 – Page 6.12	"Elastic modulus"	The elastic modulus can be determined from unirradiated data. The elastic modulus for current cladding is from unirradiated data.
30	Section 6.3.2 – Page 6.13	"These data indicate a critical need to an applicant to provide fatigue data from irradiated cladding ..."	See comment No. 16
31	Section 6.2.6 - Page 6.8	LOCA post quench ductility	The existing LOCA limits of 2200 and 17% are associated with cladding embrittlement and could be shown to be conservative. However, ECR is surrogate metric for the diffusion of oxygen and its impact on retention of ductility. The value of 17% was calculated from the time-at-temperature of uncoated cladding testing with a specific correlation (Baker-Just). The diffusion processes (i.e. weight gain) and material-specific correlations are different though. Coated claddings do delay the diffusion of oxygen and for the same time-at-temperature would inherently have a greater retained ductility than uncoated claddings (i.e. greater margin to safety). Failure ECR values cannot be compared unless the basis is provided and consistent.
32	Section 6.4.1 - Page 6.14	LOCA post quench ductility	See comment No. 7
33	Section 6.4.2 - Page 6.15	LOCA post quench ductility	See comment No. 31
34	Section 6.4.2 - Page 6.15	Cladding fatigue life	See comment No. 16

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