



**UNITED STATES  
NUCLEAR REGULATORY COMMISSION  
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS  
WASHINGTON, DC 20555 - 0001**

May 23, 2007

The Honorable Dale E. Klein  
Chairman  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555-0001

**SUBJECT: PROPOSED TECHNICAL BASIS FOR THE REVISION TO 10 CFR 50.46 LOCA  
EMBRITTEMENT CRITERIA FOR FUEL CLADDING MATERIALS**

Dear Chairman Klein:

During the 542<sup>nd</sup> meeting of the Advisory Committee on Reactor Safeguards (ACRS), May 3-5, 2007, we completed our review of the proposed technical basis for a revision to the fuel cladding embrittlement criteria in 10 CFR 50.46. We heard presentations by and held discussions with representatives of the staff, the Electric Power Research Institute, Westinghouse, and AREVA regarding this matter during our 539<sup>th</sup> meeting, February 1-2, 2007. Our Subcommittee on Materials, Metallurgy, and Reactor Fuels also reviewed this matter during a meeting on January 19, 2007. We also had the benefit of the documents referenced.

#### RECOMMENDATIONS

1. The embrittlement criteria in 10 CFR 50.46 (a) and (b) should be revised to be technology-neutral and focus on preservation of core coolability following actuation of the emergency core cooling system in a design basis loss-of-coolant accident (LOCA).
2. Acceptable methodologies to analyze fuel and cladding behavior during a LOCA should be described in regulatory guides specific to zirconium-alloy-clad oxide fuels.
3. The staff should complete planned research needed to provide a sound basis for a regulatory guide applicable to current and future zirconium-based cladding alloys.

#### DISCUSSION

Zirconium alloy cladding used in current power reactors is embrittled by hydrogen absorption during normal operation and by oxidation and absorption of oxygen during the temperature transient associated with a LOCA. The requirements of 10 CFR 50.46 (a) and (b) limit the amount of embrittlement that may occur as result of a design basis accident. They specify limits for the peak clad temperature, the global oxidation of cladding, and the local oxidation of cladding. There are several deficiencies with the current regulations. The correlation specified for the rates of steam reaction with the cladding is viewed by the technical community as an anachronism. Cladding oxidation resulting from normal operation also contributes to embrittlement during a LOCA and can be significant in high-burnup fuel. Currently, not all licensees account for oxidation during normal operation in LOCA analyses. Also, since current requirements refer only to Zircaloy and ZIRLO cladding, the use of modern cladding alloys with superior performance requires regulatory exemptions.

The staff, in cooperation with the nuclear industry and others, has made significant progress in its research program to understand the behavior of fuel cladding at high-burnup. This research has resulted in the identification of several important new mechanisms of cladding embrittlement and has improved the understanding of embrittlement mechanisms not known at the time the current regulations were written. The new mechanisms include the deleterious roles of hydrogen pickup and fuel-clad bonding on the oxidation and embrittlement of high-burnup cladding. In addition, this research has identified the need to address the phenomenon of breakaway oxidation in the qualification of future cladding materials. Based on these research findings, the staff is proposing a revision to the current embrittlement criteria that would address all the mechanisms of embrittlement that are active during normal operation and during the LOCA event and would assure adequate cladding ductility.

Industry objections to the staff's proposal focus on the need to complete the research and analysis program. Specifically, key tests of high-burnup fuel rods with ZIRLO, M5, and Zircaloy-4 cladding have not been performed due to hot-cell unavailability. Industry representatives also argue that the quench temperatures and cooling rates used in the tests performed to date are not representative of those expected during LOCAs and result in excessive embrittlement of the cladding. The staff plans to address these issues in future tests.

The staff proposes that the methodology it has developed to deal with the LOCA embrittlement phenomena be incorporated in a revision to 10 CFR 50.46 (a) and (b) that would be applicable to high burnup, zirconium alloy-clad, fuel. We do not support this proposal. We anticipate that there will be continuing development of our understanding of the embrittlement of metal cladding and continued development of alloys with superior properties. It would be more efficient to revise the current regulations to be technology neutral and to focus on the preservation of core coolability following design basis accident events. Perhaps the revised regulations could go so far as to note that preservation of adequate residual ductility in metal-clad fuels can assure the core remains in a coolable configuration. Detailed methodologies acceptable to the NRC staff for demonstrating compliance with the requirements for specific fuel-cladding systems should be set forth in regulatory guides. The staff should complete its planned research to form a sound basis for a regulatory guide applicable to current and future zirconium-based cladding alloys. New or expanded guides can be developed readily as new knowledge on system performance develops or as new alloys for cladding are introduced.

Dr. Shack did not participate in the Committee's deliberations regarding this matter.

Sincerely,

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Mario V. Bonaca,  
Acting Chairman

## References:

1. Draft NUREG/CR-XXXX, "Cladding Embrittlement During Postulated Loss-of-Coolant Accidents", December 19, 2006
2. Revised Section 7, "Empirical Criteria for Embrittlement," for Reference 1, transmitted electronically to the ACRS on December 21, 2006

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Mario V. Bonaca,  
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**ADAMS:** ML071430639

<b>OFC</b>	ACRS	ACRS	ACRS	ACRS
<b>NAME</b>	RCaruso	CSantos	FGillespie	MVB
<b>DATE</b>	05/22/07	05/22/07	05/22/07	05/22/07

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