United States Nuclear Regulatory Commission

TECHNICAL BASIS FOR CURRENT NRC APPROACH TO LOCA RESEARCH

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THE PROBLEM

- Ductility of cladding is reduced by burnup and related corrosion. Because 50.46 uses embrittlement criteria, the adequacy of current licensing analyses should be confirmed for high-burnup fuel.

- Oxidation-related LOCA evaluation models might be affected by fuel burnup, and this needs to be checked out for high-burnup fuel.

- 50.46 is currently limited to two cladding alloys (Zircaloy and ZIRLO), and other alloys need to be accommodated.

BASIS FOR EMBRITTLEMENT CRITERIA IN 50.46

Maintain coolable geometry

➘

Keep fuel pellets inside the cladding

➘

Don’t let the cladding fragment or break in several pieces

➘

Retain some **ductility** in the cladding

➘

Limit cladding oxidation and temperature

CURRENT FORM OF EMBRITTLEMENT CRITERIA IN 50.46

(1) Peak cladding temperature shall not exceed 2200°F

(2) Maximum cladding oxidation shall nowhere exceed 17% of cladding thickness
- ! Includes ruptured cladding balloons, with double-sided oxidation
- ! Corrosion thickness should be subtracted from 17% (“total oxidation”)

These criteria only apply to Zircaloy and ZIRLO cladding.

TYPES OF DATA BEING GENERATED IN CURRENT PROGRAM AT ANL

! Ductility tests (ring-compression tests) to determine the dependence of ductility on burnup, corrosion, and alloy type — similar to original approach

! Integral tests, followed by 4-point bending, to confirm that application of ductility data to ballooned region achieves objective (Do you retain sufficient ductility if you follow directions in 50.46 and Appendix K?)

! Oxidation tests to see if burnup, corrosion, and alloy type affect kinetics correlations

! Current data base for resolution includes (a) high-burnup rods with Zircaloy cladding and (b) unirradiated M5 and ZIRLO cladding

! Future data base for confirming burnup behavior and developing a pre-hydrided surrogate will use high-burnup fuel with M5 and ZIRLO cladding, subject to the availability of fuel rods and the continued cooperation of the industry

DUCTILITY "SINGULARITIES"

- There are three local areas where we expect ductility to be lost even when applying the ductility criteria as intended:

  (1) Just above the balloon, where the hydrogen concentration is high
  (2) Around the rim of the burst opening where oxidation is 100%
  (3) Just below the balloon, where the hydrogen concentration is high

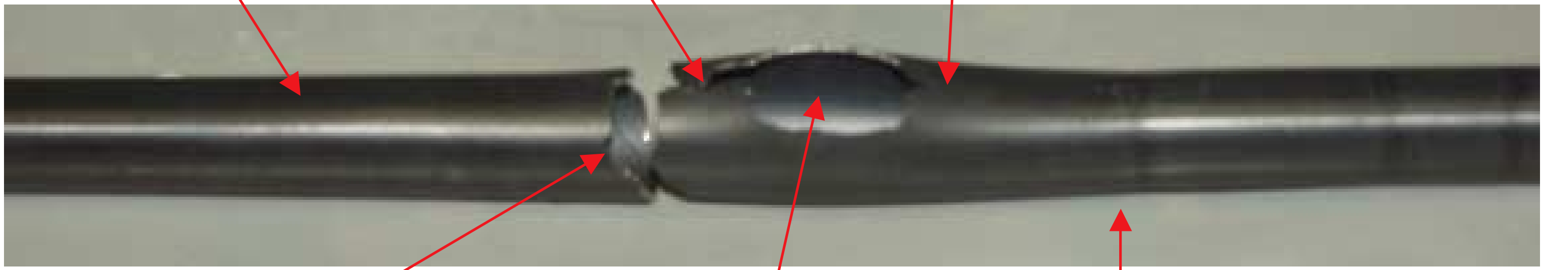
- We expect the integral tests to show that fuel loss will be minimal if the cladding cracks in one of these locations.

July 16, 2003 4-Point-Bend Demonstration Results

Axial Compression

Axial Crack

Axial Crack



Failure in Neck Region Lower ECR High H Content

Burst Midplane High ECR Region Low H Content

Axial Tension

PLAN FOR CONFIRMED AND GRANDFATHERED RULE

- Data are being generated for Zircaloy (high burnup and unirradiated), ZIRLO (unirradiated), and M5 (unirradiated) cladding to determine if sufficient ductility is retained in the ballooned region when the current embrittlement criteria (17%, 2200^{o}F) are applied (including the corrosion subtraction).

- Irradiation effects (largely due to corrosion) in ZIRLO and M5 will be assumed to be the same as in Zircaloy, for a given amount of corrosion.

- This determination would apply for burnups up to 62 GWd/t and corrosion up to 100µ. The burnup and corrosion limitations might be relaxed, depending on the data base.

- If the the current embrittlement criteria (including the corrosion subtraction) are confirmed to be adequate, these criteria could be grandfathered in the new rule.

- M5 could then be added to the grandfathered part of the rule, if that were desired, because equivalent data are being taken for M5 as for ZIRLO.

- Additional confirmation would be needed subsequently to make sure that high-burnup ZIRLO and M5 behave as assumed from current testing.

OPTIONAL PERFORMANCE-BASED EMBRITTLEMENT CRITERIA

! Ring-compression tests, which are being used for the confirmatory activity, are being qualified as a general test for all alloys, burnups, and corrosion thicknesses.

! Ring compression tests can be used to find the temperature and oxidation conditions corresponding to zero ductility.

! A test procedure could be specified in 50.46 instead of fixed values for temperature and oxidation limits (details in a Regulatory Guide).

! Appropriate temperature and oxidation limits could be determined from this performance-based procedure by the fuel manufacturer for use in LOCA safety analyses.

! These limits would be expected to be a function of burnup (or corrosion), and corrosion would not have to be subtracted as in the grandfathered part.

! Because this performance-based procedure would permit cladding temperatures above 2200^{o}F, an independent temperature limit might be needed to ensure against runaway temperatures from excessive metal-water reaction heat.

Note: Metal-water heat calculated by Baker-Just at 2200^{o}F equals metal-water heat calculated by Cathcart-Pawel at 2307^{o}F (discussion in RIL-0202).

DUCTILITY OR STRENGTH

- Ring-compression tests give an indication of ductility.
- Impact tests give an indication of toughness — related to strength.
- The intent of the original regulation was to ensure that some ductility would remain in the cladding as it goes through the quenching process.
- Measurement of strength and survival of thermal shock tests were found to be inadequate in the original finding of the Commission.

Our selection of the 2200°F limit results primarily from our belief that retention of ductility in the zircaloy is the best guarantee of its remaining intact during the hypothetical LOCA. The stress calculations, the measurements of strength and flexibility of oxidized rods, and the thermal shock tests all are reassuring, but their use for licensing purposes would involve an assumption of knowledge of the detailed process taking place in the core during a LOCA that we do not believe is justified.

Opinion of the Commission
December 28, 1973

Nuclear Regulatory Commission Issuances, p. 1098

OCTOBER 17, 1988, REVISION OF 10 CFR 50.46

- Chung & Kassner's impact tests of 1980 demonstrated that the original embrittlement criteria (17%, 2200 ^{o}F) would ensure quench survival with some <u>toughness</u> margin left over.

- This was significant inasmuch as the local regions of low (zero) ductility in or near the ballooned region had just been discovered.

- NUREG-1230 makes recommendations for ß-phase thicknesses that are equivalent to Chung & Kassner's 0.03J and 0.3J absorption energies, but these were not adopted.

- No changes regarding the embrittlement criteria were made in 10 CFR 50.46 relative to Chung & Kassner's tests.

9. *Acceptance Criteria.* The three comments received on this topic were all supportive of the existing criteria, as contained in § 50.46(b), and thus the Commission did not give consideration to altering them in the final rule.

Federal Register, Vol. 53, p. 35999
September 16, 1988

DUCTILITY OR STRENGTH (Contd.)

A new performance-based option in 10 CFR 50.46 could be based on strength rather than ductility, but the ductility approach has been taken for the following reasons:

! The ductility approach provides a seamless transition from the existing embrittlement criteria to the new performance-based criteria.

! It would be more expensive to perform enough impact tests on which to base criteria than to perform ring-compression tests.

! A change from ductility-based embrittlement criteria to toughness-based strength criteria — a fundamental change in the regulation — could result in a protracted hearing.

! NRC has not developed a data base or methodology for load analysis of fuel rods under LOCA conditions.

! These criteria are used in other accident analyses (e.g., BWR ATWS oscillations) where a load analysis might also be difficult.

IMPACT TESTS OR 4-POINT BEND TESTS

! Either impact tests or 4-point bend tests could be used to demonstrate remaining margin after quenching, such as done by Chung & Kassner in 1980.

! Impact loads might be more typical of loads from vibrations during quenching.

! Bending loads might be more typical of loads from core-plate acceleration.

! The failure location is pre-determined in an impact test.

! 4-point bend tests let the specimen break at its weakest location.

! 4-point bend tests provide more quantitative information than impact tests.

! The 4-point bend test appeared to have more advantages, but this could be negotiated.

SUMMARY

A change from ring-compression tests to impact tests would produce a fundamental change in the regulation — this is not just about test methods.

A change from 4-point bend tests to impact tests is a choice of test methods, but you can't perform both because they are destructive tests.