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A Comparative Study of the Mechanical Test Metrics for Fuel Cladding after Simulated LOCA Test

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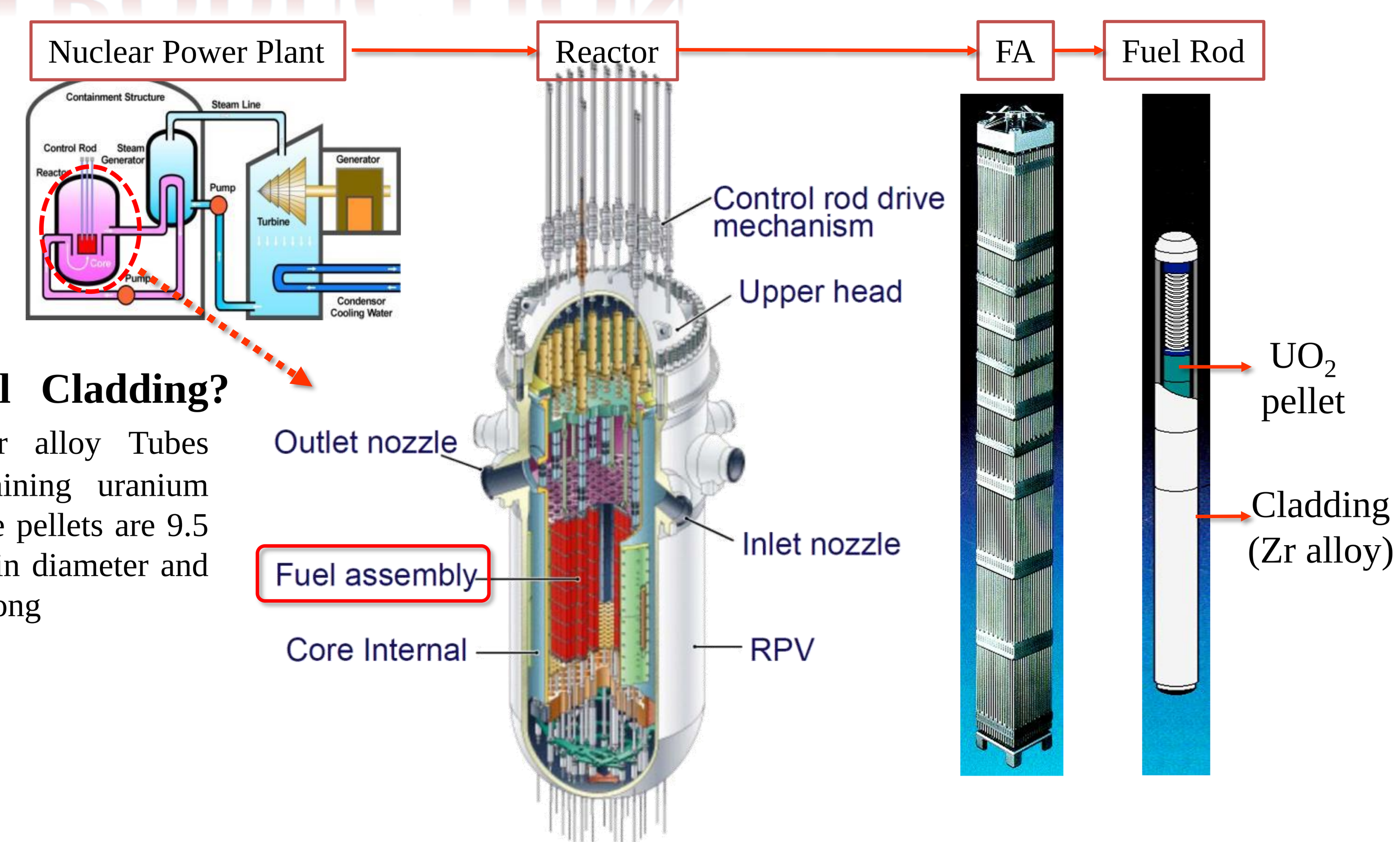
ABSTRACT

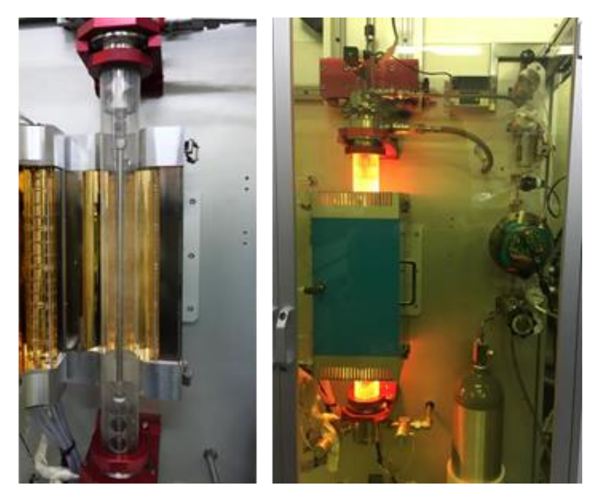
Ballooning and rupture phenomenon of fuel cladding during loss-of-coolant accident(LOCA) scenarios occurs due to pressure difference between inner and outer cladding at high temperature. These phenomena have a significant impact on the integrity of nuclear fuel. Ballooning may cause the fuel relocation and fuel dispersal can occur due to its rupture opening during accidents. However, a current LOCA criterion is based on the results obtained from non-pressurized and relatively short claddings specimens under simulated LOCA condition. In this study, the mechanical properties of ballooned and ruptured cladding were evaluated and its applicability to existing LOCA criteria was also investigated.

INTRODUCTION



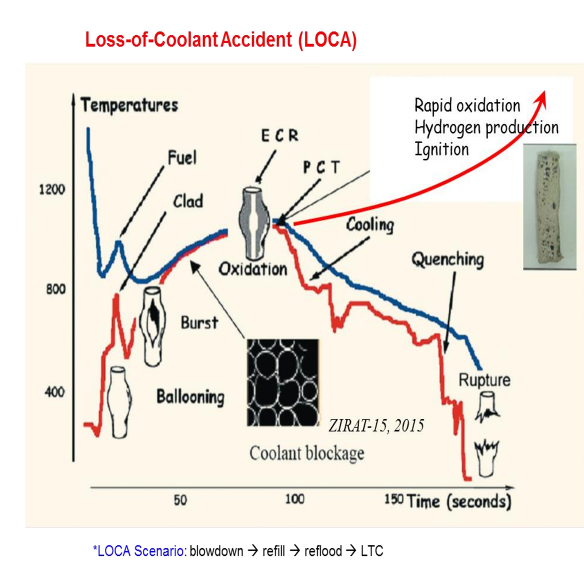
Fuel Cladding?

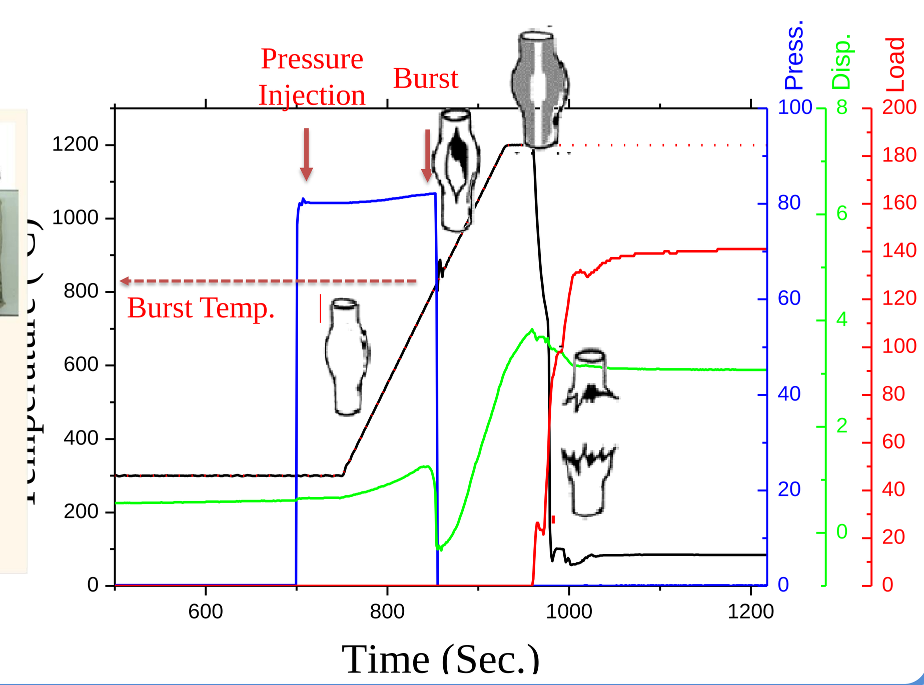
: Zr alloy Tubes containing uranium oxide pellets are 9.5 mm in diameter and 4m long



- LOCA test apparatus at KAERI
  - Test temperature up to 1400°C by IR lamp
  - Internal pressure up to 20 MPa
  - Various test environments (Steam, Air, Ar, mixture)
  - Temperature measurement by type-R TC.
  - Introduction of steam and quench water at bottom.
  - Automated test process with computer system UI.

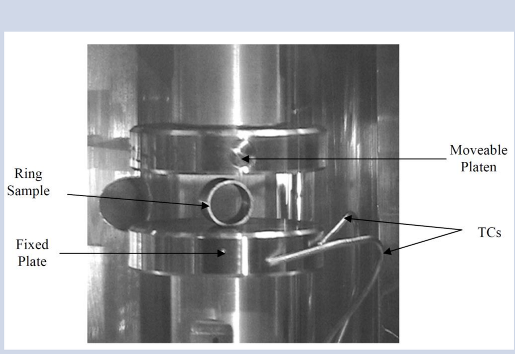
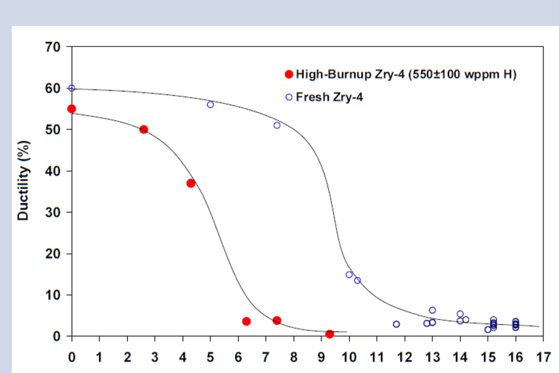
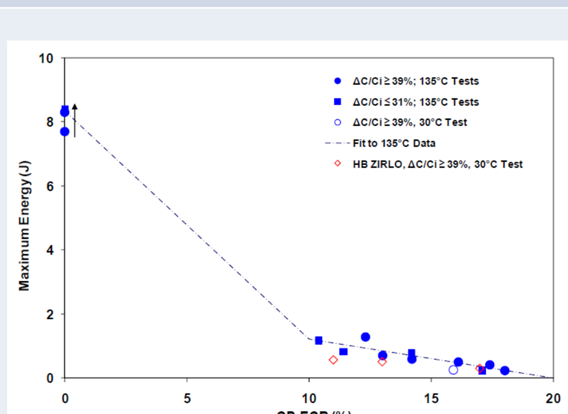
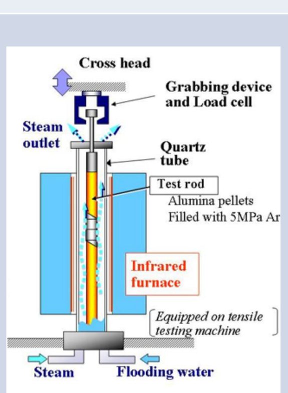
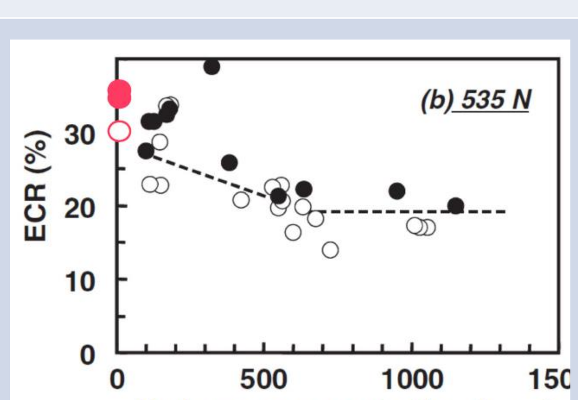
- High temperature ballooning test
  - 400 mm long Zr based alloy claddings
  - Pressure injection(1-8 MPa) before fast heating phase.
  - Heating rate 1-28°C/s up to 1200°C.
  - Determination of burst temperature at the point of pressure drop.



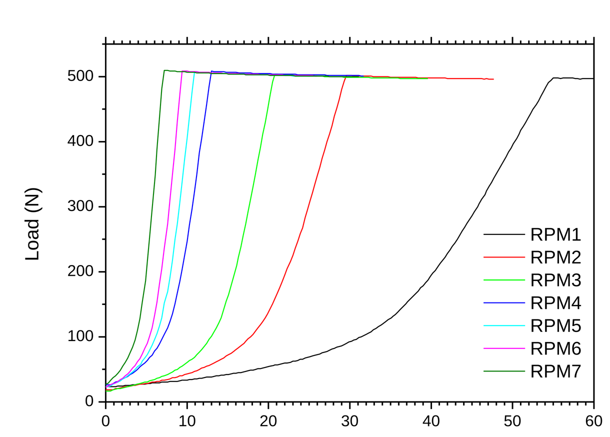


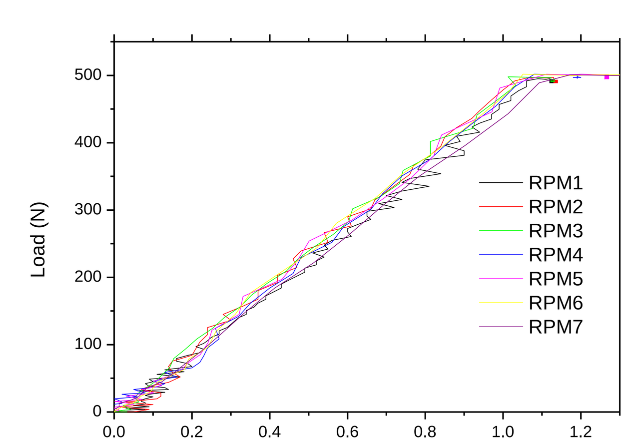
RESULTS

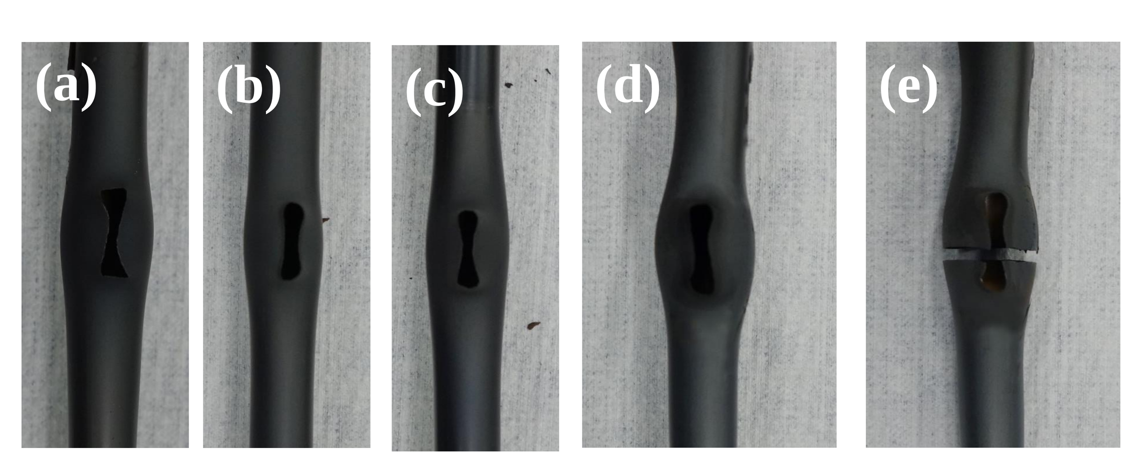
- **Mechanical evaluation for LOCA simulated cladding**
  - ✓ Ring compression test
  - ✓ 4-point bend test
  - ✓ Axial tensile test

Test methods	Evaluation
	
	
	

- **A new LOCA test equipment has been developed and constructed.**
  - ✓ Validate the functionality of the new test equipment.
- **The new equipment has the ability to apply an axial load on test specimens. The load can be applied instantly or under a controlled load rate**
  - ✓ Perform a number of LOCA transients with different ECR and instant axial load applied at quench.
  - ✓ Perform a number of load ramps applied after a LOCA transient with a certain ECR
  - ✓ Up to 67N/s (9, 16, 25, 38, 45, 52 N/s)

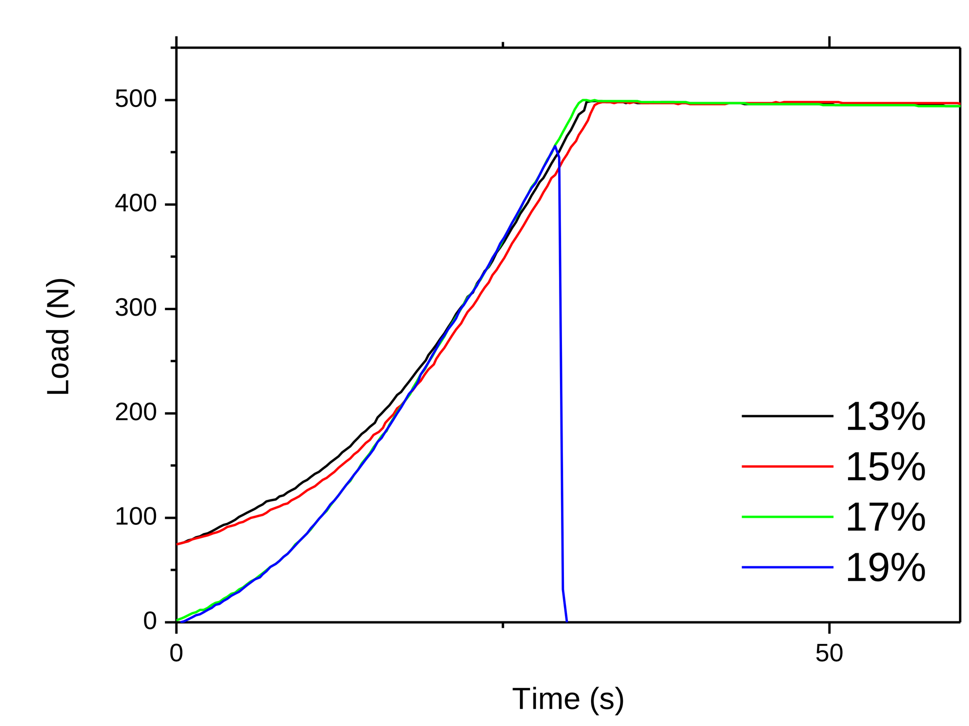






W/O oxidation | 13% ECR | 15% ECR | 17% ECR | 19% ECR

- **LOCA transient with controlled axial load rate**



- ✓ Rods were supposed to be tested with burst (inner pressure) → two sided oxidation.
- ✓ The same inner pressure as in the previous tests were used (8 MPa at 300°C)
- ✓ Zircaloy-4 claddings were used and an ECR of 13, 15, 17, 19 % was chosen
- ✓ All the tensile test were conducted with maximum loads of 500 N.
- ✓ Under maximum load of 500N, all samples with 13, 15, and 17 %ECR were survived without failure after axial tensile test. However ballooned and ruptured sample with 19% ECR was failed under a load of less than 500N. It is noteworthy that the abrupt change of mechanical property is similar to the existing criteria based on the ring compression test. However, it is necessary to confirm it through more repeated tests.

CONCLUSIONS

- Post transient axial tensile tests were performed using ballooned and ruptured claddings. Zircaloy 4 fuel claddings under 17% ECR did not fail at a maximum load of 500 N but cladding specimen with 19% ECR showed failure at the rupture node. Tests on zircaloy-4 with different controlled load rates and balloon shapes are planned to confirm their dependency of the fracture load
- LOCA transient test results with controlled axial load are comparable to earlier results on other LOCA equipment evaluated different mechanical test.
- The results of this study did not reveal any reason that new cladding designs with improved embrittlement performance observed in RCTs, or embrittlement limits developed from ring-compression testing at temperatures less than 1,200 degrees C, should not be applied in the balloon region
- This research was not extensive enough to develop any alternate metric, and pursuing an alternate metric, particularly for the ballooned and ruptured region of a fuel rod, is not recommended at this time.