U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

Integral LOCA Tests at Argonne and Studsvik

Michelle Flanagan, Michael Billone, Harold Scott, Peter Askeljung

Enlarged Halden Program Meeting
Storefjell, Norway
March 14-19, 2010

Overview

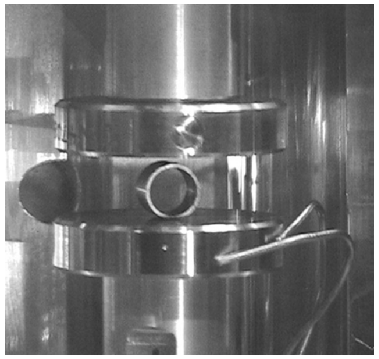
Today's Presentation will discuss:

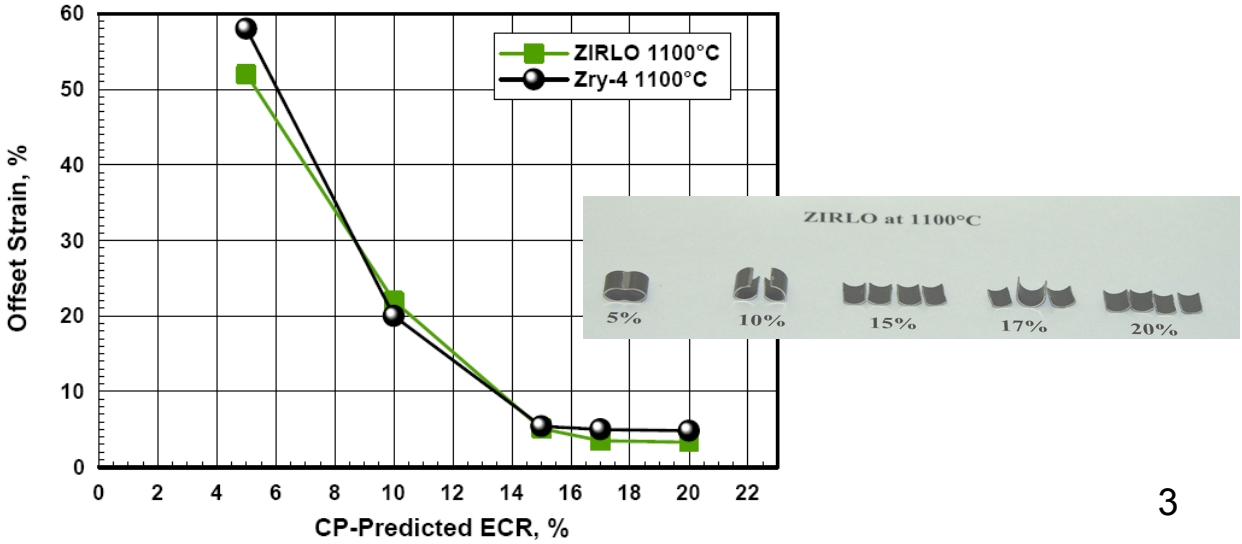
- Background: Ductility & the LOCA criteria
- Definition of planned investigation
- How results will contribute to further understanding of LOCA issues of interest

Background: Ductility & the LOCA criteria

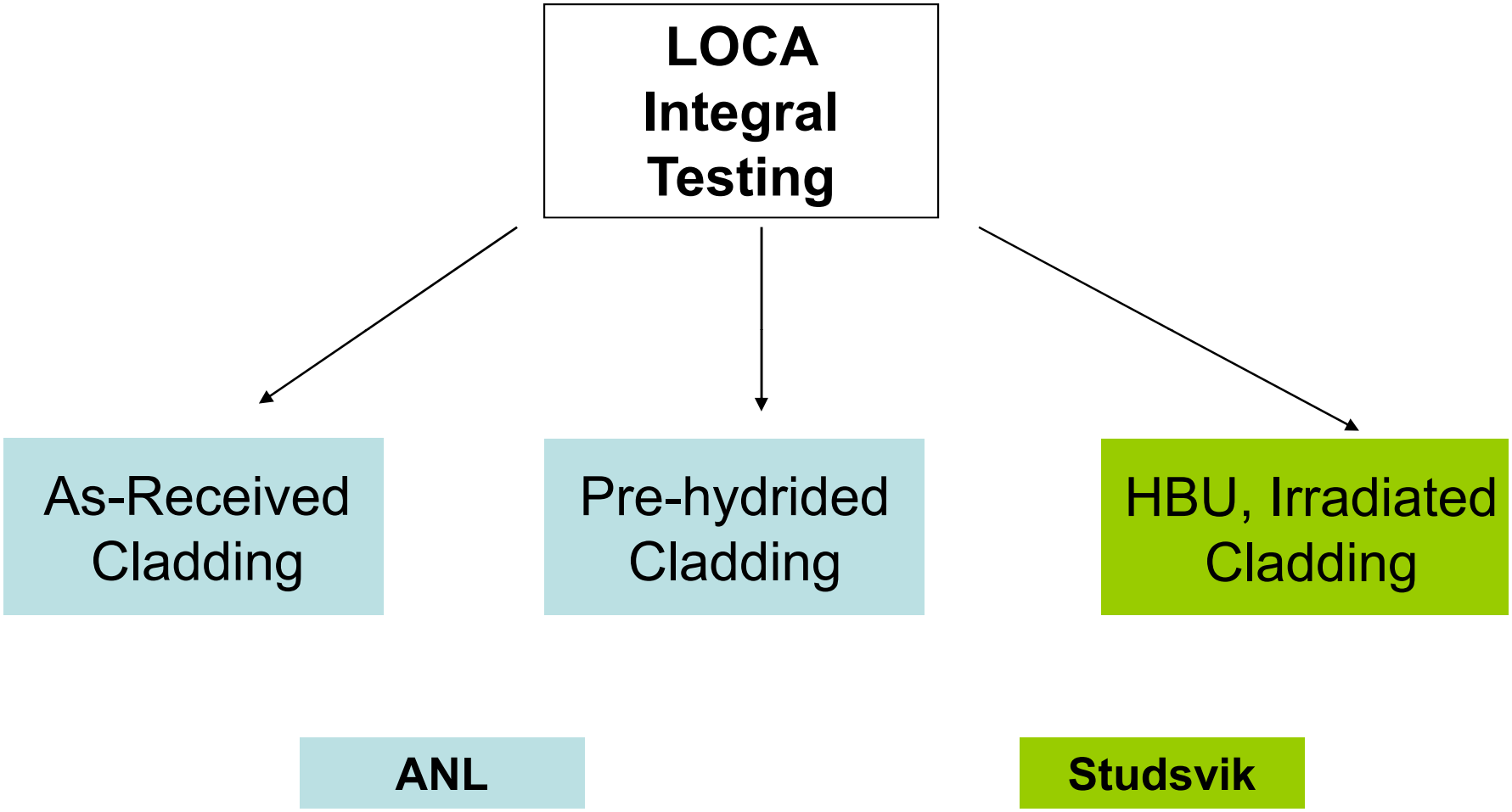
Measuring post quench ductility

Current U.S regulations are based on ring compression test data (among other experimental observations) to establish ductility thresholds. Rings are taken from near, but not in the ballooned region. We want to better understand the behavior of the cladding in the ballooned region.

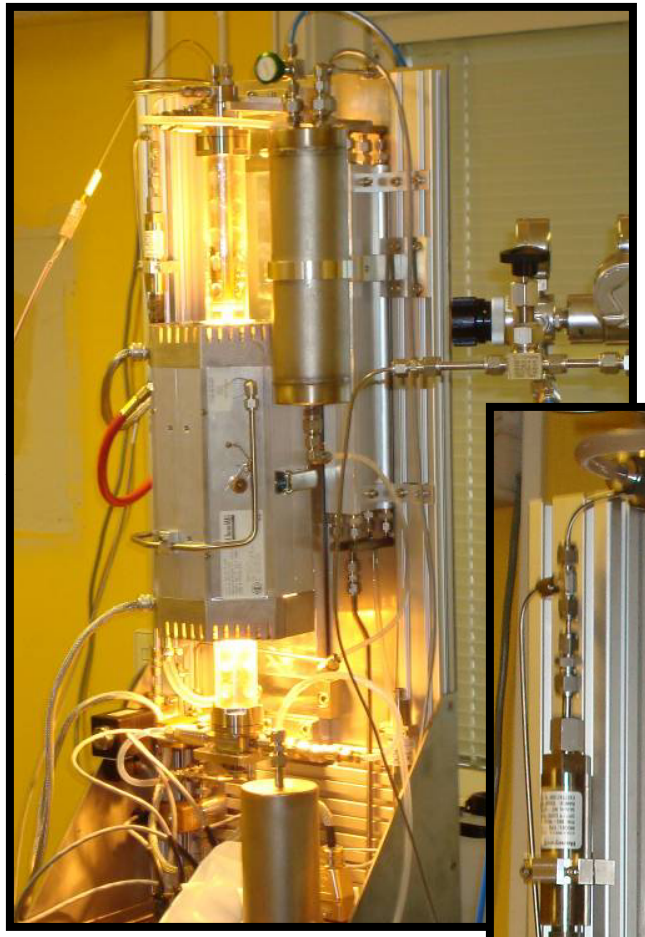




Planned Investigation



Planned Investigation



Sections of pressurized cladding, approximately 300 mm in length, will be ramped from 300°C at a rate of 5°C/sec. They will be pressurized at 300°C to induce ballooning and burst and to target balloon sizes within the range of 30% - 70% strain. They will be oxidized in steam to target oxidation levels (ECR), with consideration of the strain and hydrogen content.

The sections of cladding will undergo ballooning, burst and oxidation in a test train developed at ANL and now replicated at Studsvik. The test train, running at 1200°C at Studsvik is shown here. A similar test train already exists at ANL and is used for comparison tests.

Planned Investigation

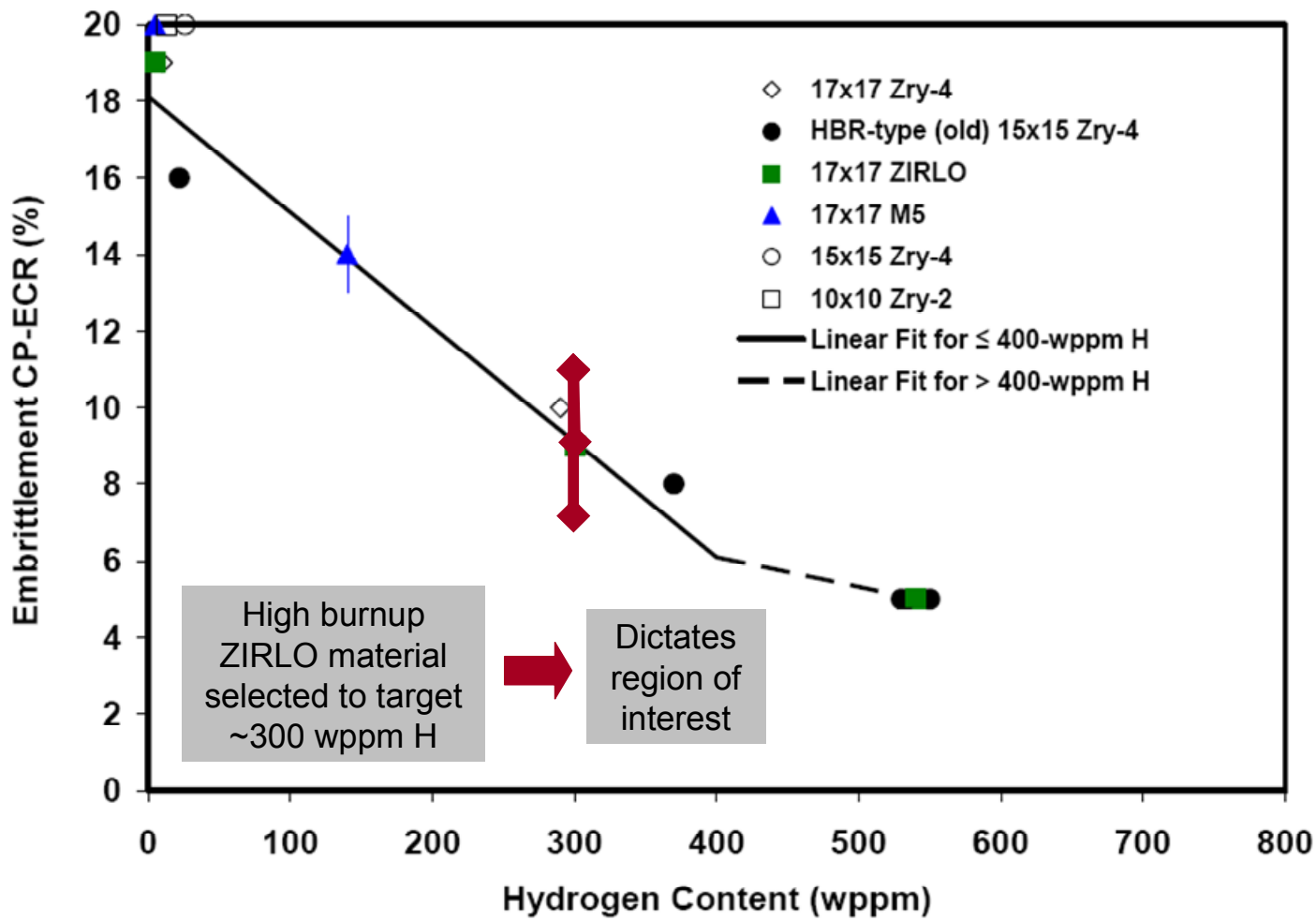
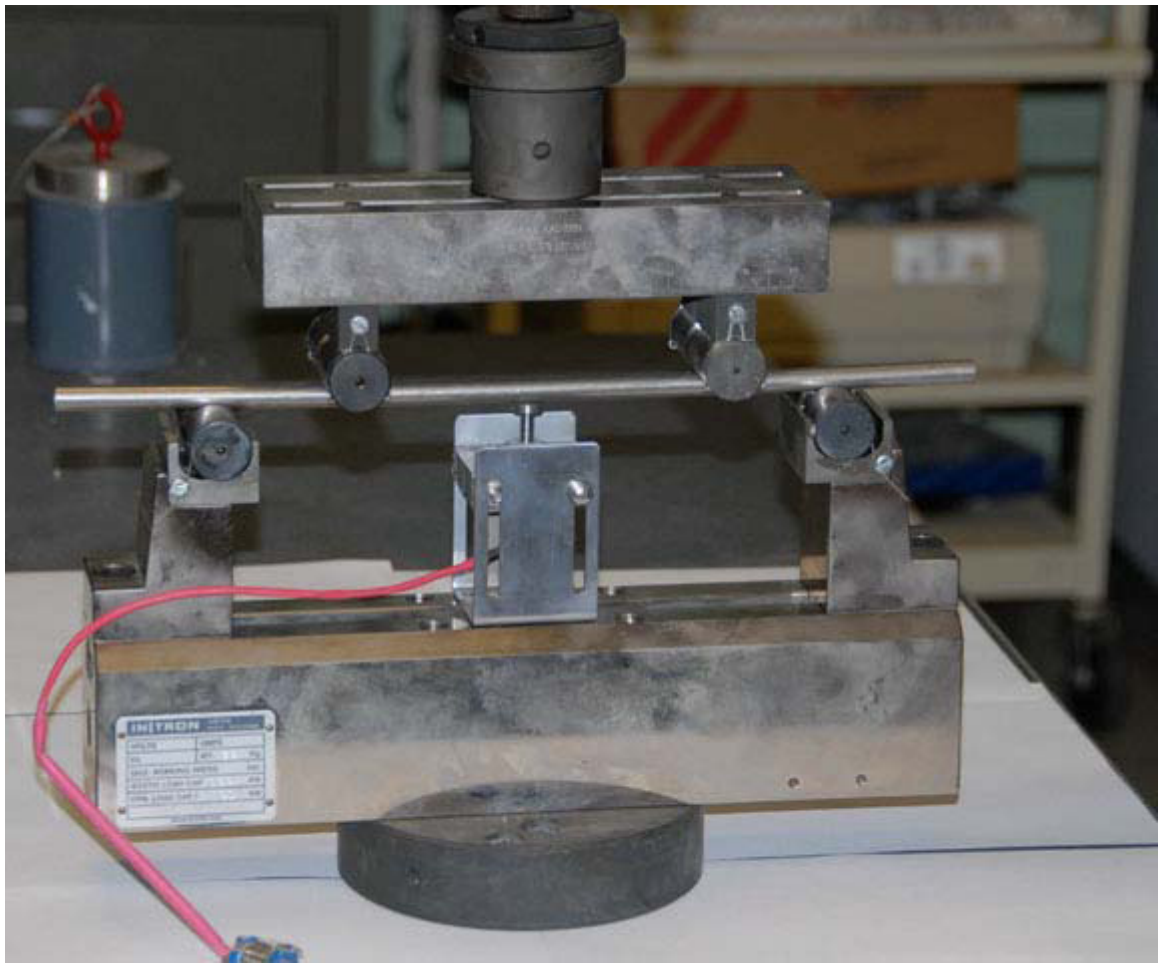


Figure 7 of Letter Report from Argonne National Lab, titled "Post-Quench Ductility Results for North Anna High Burnup 17x17 ZIRLO Cladding with Intermediate Hydrogen Content" Dated April 17th, 2009 (ML091200702)

Planned Investigation



The bend tests will be used to evaluate the oxidation limit ***in a mechanical test that includes the ballooned region***. The axial location and nature of fracture of fractured samples will be recorded. The observations of bend tests on irradiated material will be compared to bend test results on as-received and pre-hydrided ballooned and burst integral samples run at ANL.

Planned Investigation

- Bend each ballooned rod until it breaks or bends to a limit.
- Record the deflection and failure load.
- Observe condition of fracture. Is it clean or fragmented? Photograph the fracture surface.
- Hold upper part of rod vertically and shake it to see how much fuel falls out.
- Make all observations at each ECR level.

Bake it **Break it** **Shake it**

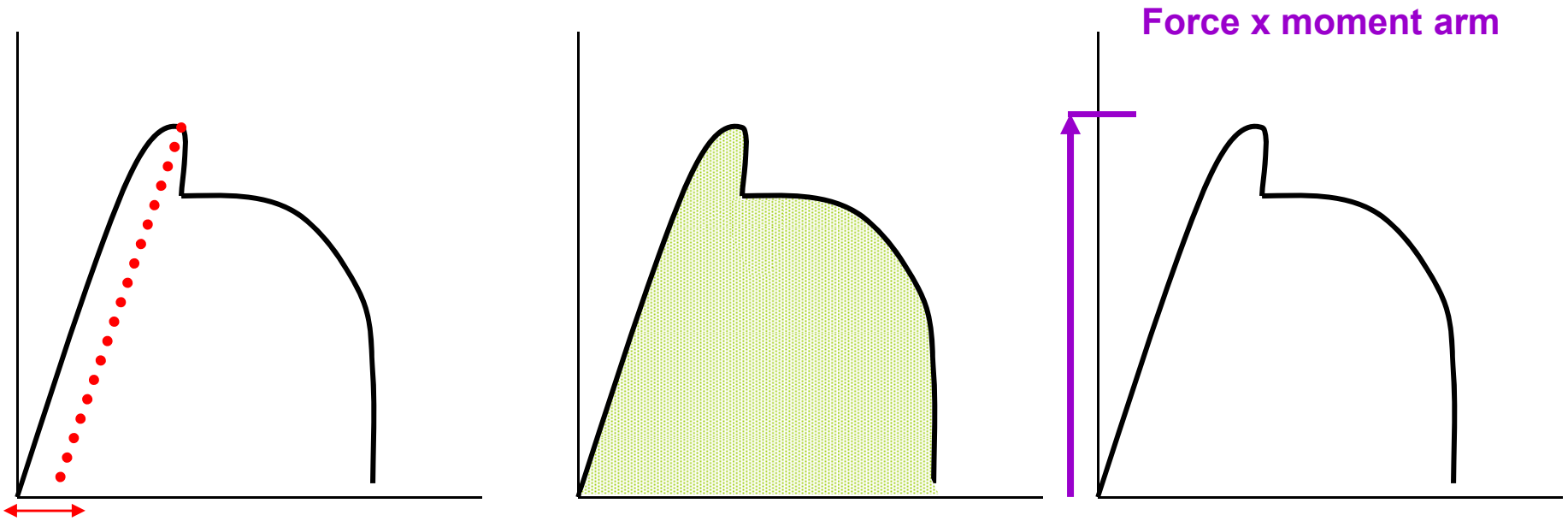
Planned Investigation

Data interpretation from the bend test

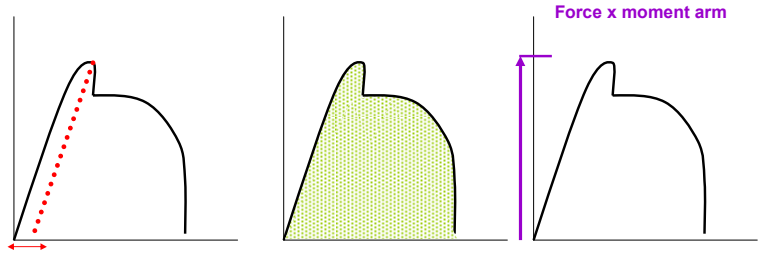
1. Maximum plastic displacement (measure of ductility)

2. Maximum applied energy (measure of toughness)

3. Maximum bending moment (measure of strength)



Planned Investigation



ANL

Studsvik

Investigate influence of:

- ✓ Accumulated ECR
- ✓ Irradiation
- ✓ Balloon size
- ✓ Bend test temperature
- ✓ Hydrogen content

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

LOCA issues of continued interest:

1. Mechanical Behavior of Balloon
2. Axial fuel relocation into a balloon
3. Loss of fuel particles through a rupture opening

ANL

Studsvik

Halden

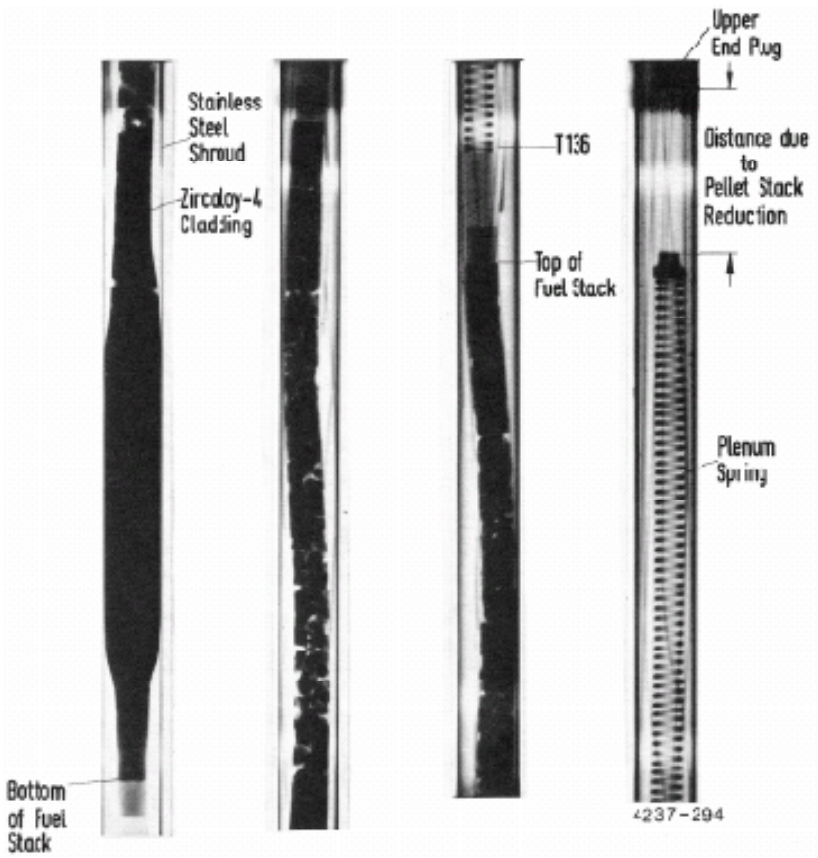
Mechanical Behavior of Balloon

Contribution of Integral LOCA program

- Balloons that occur in the cladding under LOCA conditions (1) reduce wall thickness and (2) lead to local regions becoming heavily oxidized and hydrided.
- Bend tests on ballooned and burst integral fuel samples will quantify residual properties in the balloon region.

Axial fuel relocation into a balloon

Contribution of Integral LOCA program



KfK 3346 - LWR Fuel Rod Behavior in the FR2 In-pile Tests Simulating the Heatup Phase of a LOCA, March 1983

Evidence for fuel relocation is available from the German FR2 tests. **Although some effort should be made to see if relocation occurred in the Studsvik LOCA integral tests**, these efforts should not interfere with other tests that are planned with these specimens. **Continued tests at Halden in the IFA-650 series which include extensive instrumentation and online monitoring will provide additional, quantitative results**

Loss of fuel particles

Contribution of Integral LOCA program

Fuel loss through the rupture opening was substantial in Halden LOCA test IFA-650.4 with fuel at 92 GWd/t. The observation has been confirmed by other tests in this series.

The LOCA apparatus for integral tests should collect any fuel that is lost through the rupture during our tests and characterize it to determine if significant fuel loss has occurred.

Continued tests at Halden in the IFA-650 series which include extensive instrumentation and online monitoring will provide additional, quantitative results.

Expectations of the Integral Test Program

From the results of the LOCA integral tests at Studsvik and ANL, the objective is to evaluate:

- The effect of ECR on mechanical integrity of the balloon region
- The use of embrittlement criteria developed from ductility measurements under ring compression for application in the ballooned region

Expectations of the Integral Test Program

Many additional phenomenon may effect cladding response and performance during a LOCA. These phenomenon will not be addressed by the planned program at Studsvik and ANL, but include:

- The effect of balloon shape and size on oxygen and hydrogen quantity and axial distribution
- Chemical effects (fission products) present in irradiated samples on inner surface oxidation and how they relate to inside oxidation
- The effect of hydrogen on balloon shape and strain
- The effect of irradiation on balloon shape and strain
- The effect of alloy on balloon shape and strain
- The effect of ramp rate on the balloon shape and strain
- And many others

Conclusions

- The integral test program at Studsvik and ANL will help to develop further understanding on the residual properties in the balloon region following a LOCA

- The program outlined here is only one part of developing a full understanding of the behavior of high burn up fuel during a LOCA