LOCA Criteria in Japan and Recent Test Results

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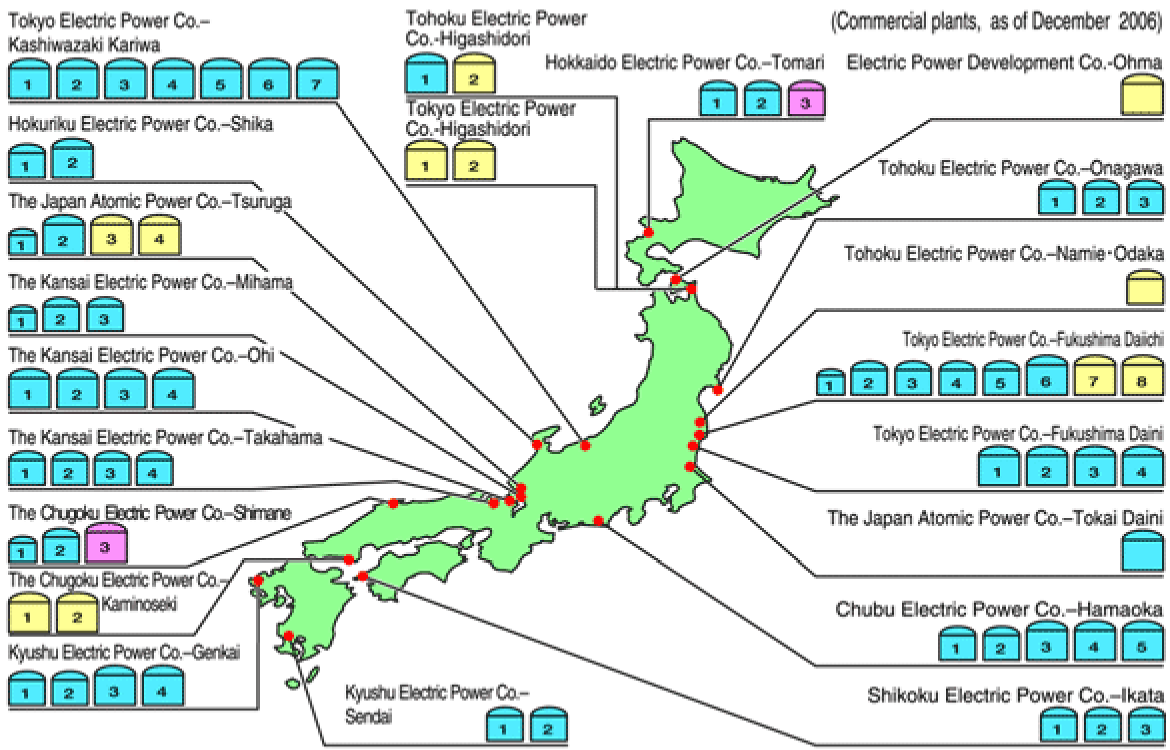
Nuclear Power Plants in Japan

(Commercial plants, as of December 2006)



Output scale: Under 500MW; Under 1,000MW; Over 1,000MW

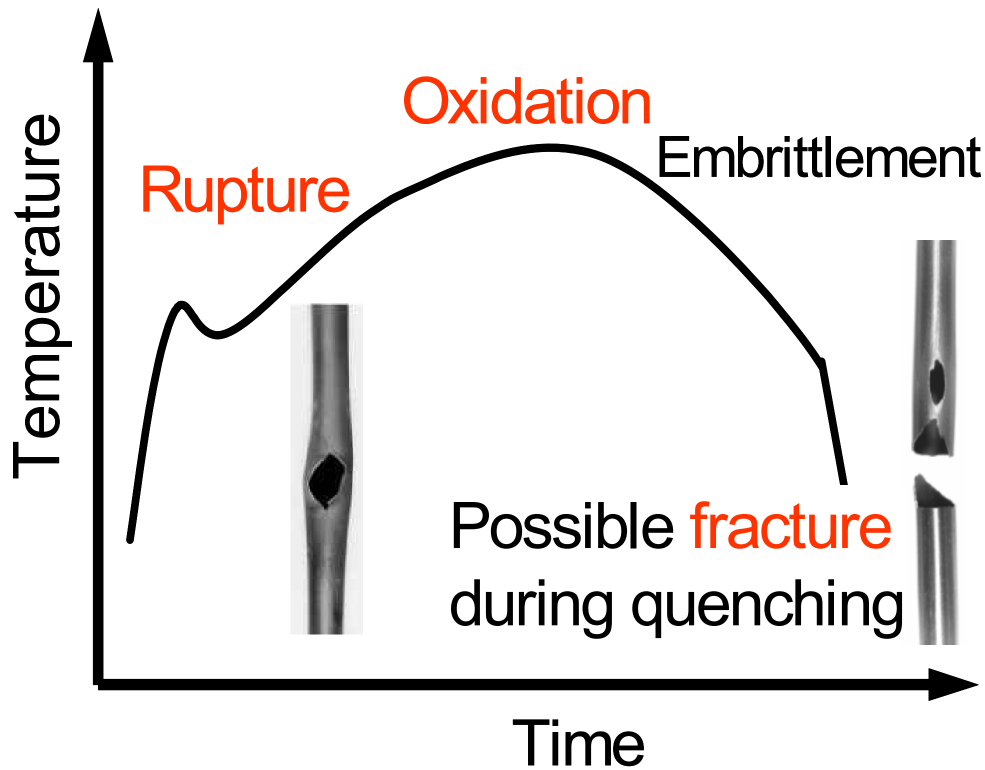
Operating; Under construction; Preparing for construction

	Number of Units	Total Output (MW)
In operation	55	49,580
Under construction	2	2,285
Preparing for construction	11	14,945
Total	68	66,810

55 NPPs in Japan; 32 BWRs and 23 PWRs

Gross capacity ; ~50 GWe

Cladding temperature change and main fuel behavior under LOCA conditions



ECCS (Emergency Core Cooling System)

Safety component of reactor to deal with a loss of coolant accident (LOCA) by providing massive backup sources of coolant

Criteria and recent concern

ECCS acceptance criteria

- Main objective is to maintain coolable geometry of core
- Cladding embrittlement criteria
  Max temperature <1200 deg C (2204 F)
  Max cladding oxidation <15% of thickness
- Established in 1970's based on experimental data with non-irradiated cladding

Recent concern

- Influence of high burnup on cladding embrittlement
- Applicability of the current ECCS acceptance criteria to high burnup fuel

History of LOCA criteria in Japan

1970 ········· 1980 ········· 2000 ·········

- Establishment of criteria ('75)
- Revision of criteria* ('81)

(Limits for cladding oxidation, 1200ºC and 15%)

Burnup extension

- Ring compression test of oxidized cladding

  ⇩

  Zero-ductility criteria

- Oxidation test of burst cladding

  ⇩

  Finding of "*Inner surface oxidation*" accompanied by significant hydrogen absorption

- Ring compression test of burst and oxidized cladding

  ⇩

  Cladding embrittlement enhanced by hydrogen absorption

- Integral thermal shock test
  - Fresh cladding
  - Ruptured, oxidized and quenched
  - Considering *axial restraint* during quench (Fully restrained)

  ⇩

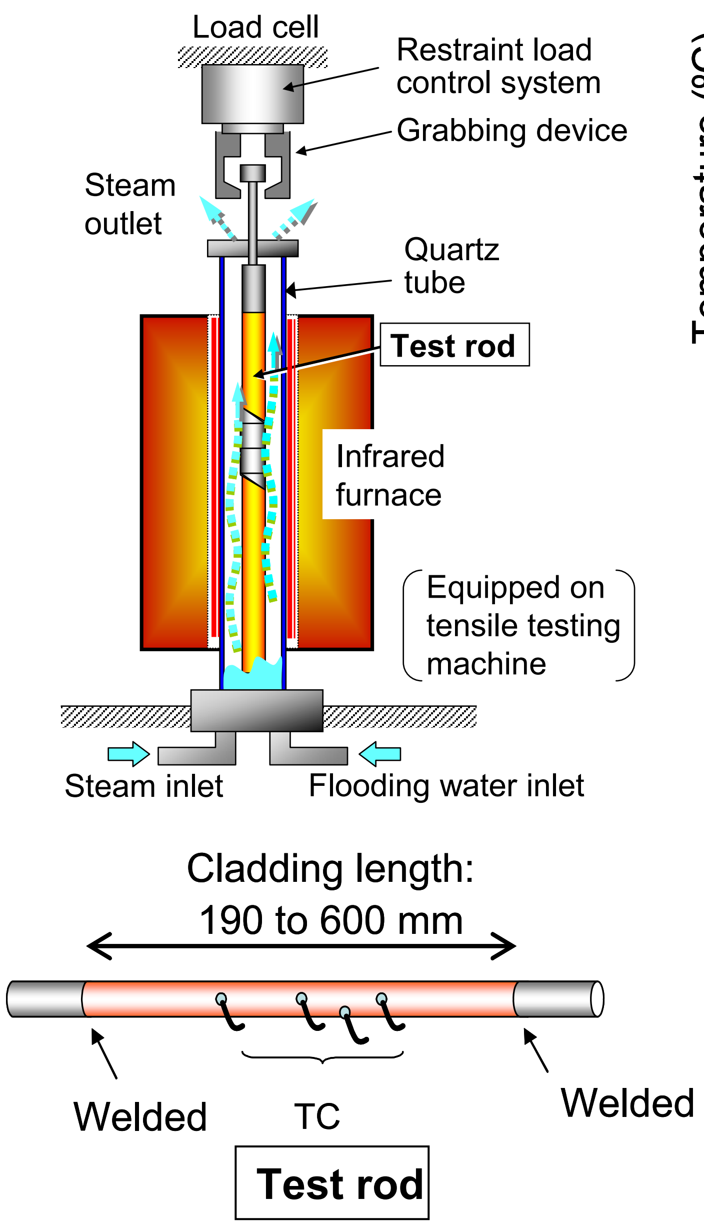
  Confirmed safety margin

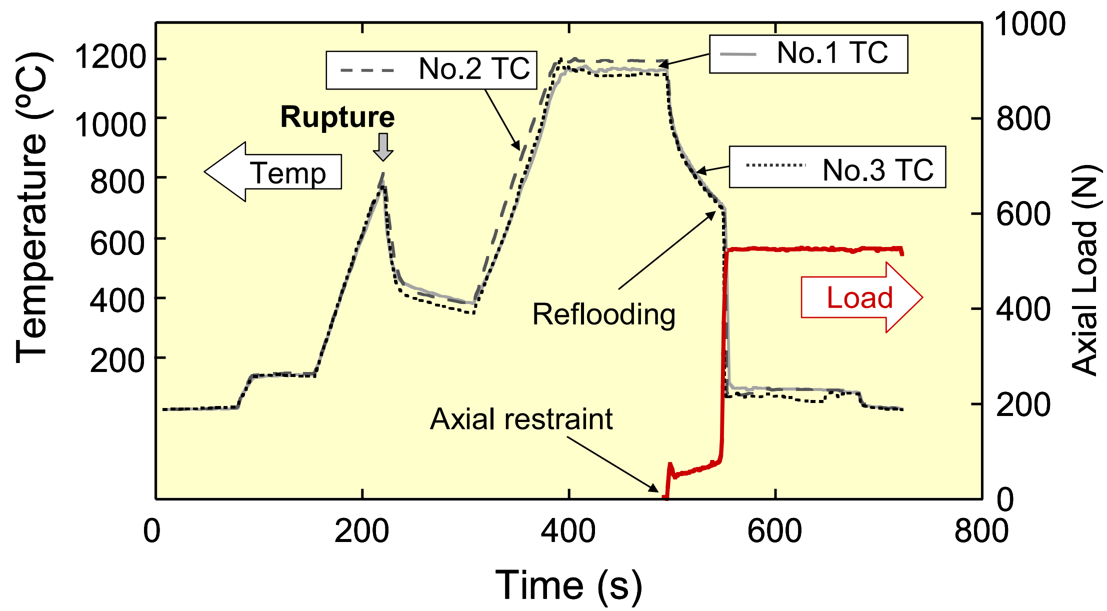
- Integral thermal shock test ('99-)
  - Pre-hydrided
  - High burnup cladding
  - Realistic restraint condition

The Japanese LOCA criteria are based on fracture/no-fracture condition of the fuel rod, which is experimentally determined

* Consequently, limits for cladding oxidation remained unchanged.

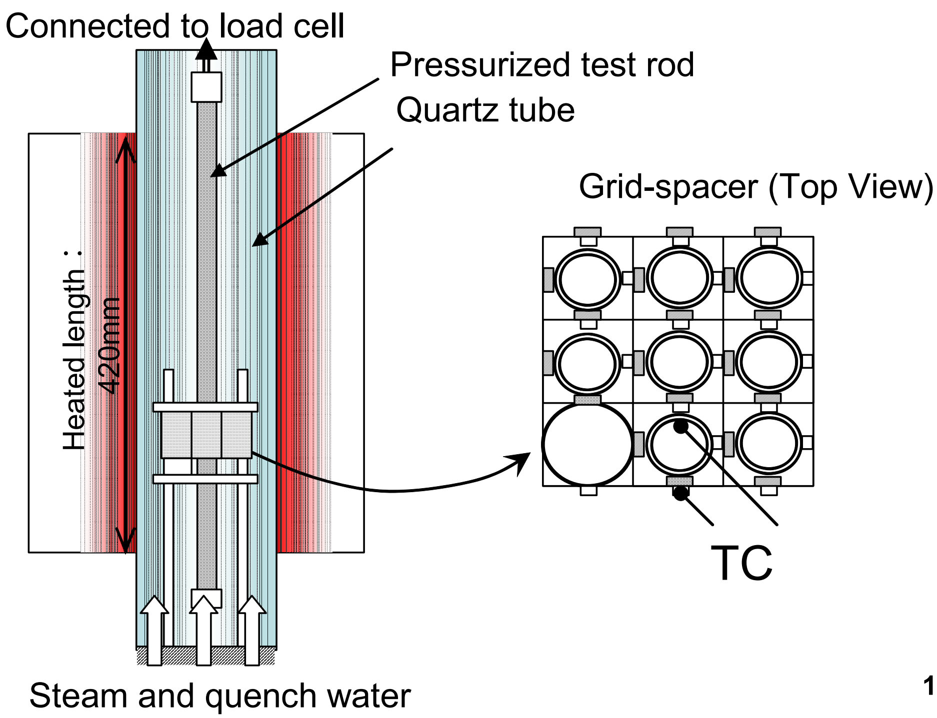
Integral LOCA test

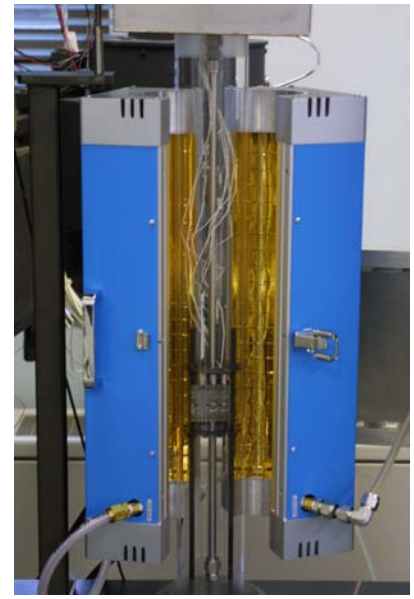


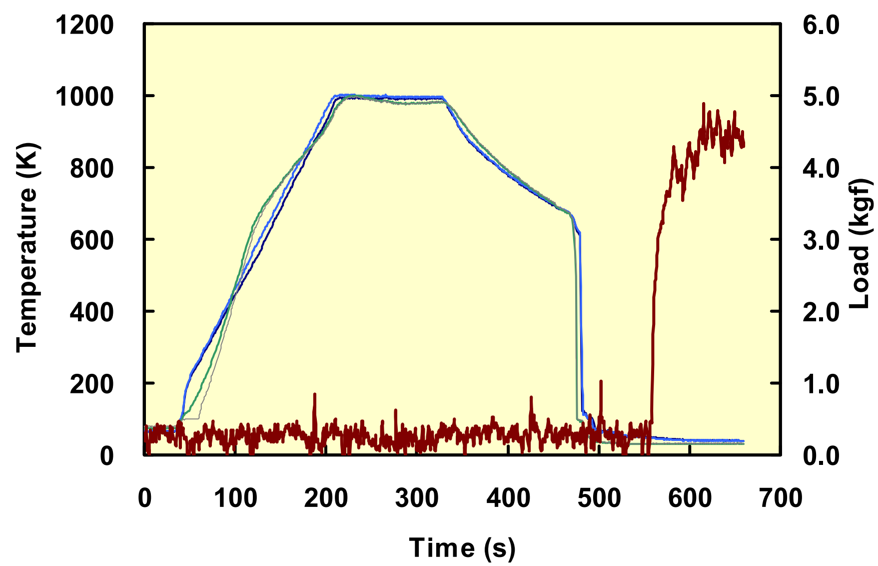


- ✓ Test rod experiences the whole process during a LOCA, ballooning and rupture, oxidation and hydrogen absorption at high temperature, and thermal shock at quenching.
- ✓ The rod is quenched with axial constraint to represent a possible condition of fuel rods between grid positions.
- ✓ The Japanese LOCA criteria are based on fracture/no-fracture boundary determined by the integral tests.

Test on axial loading during quench







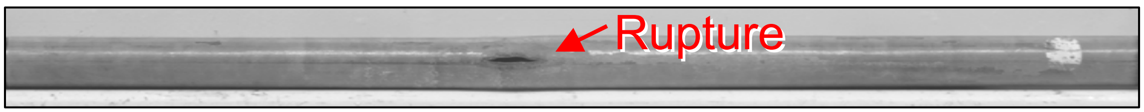
Test scheme

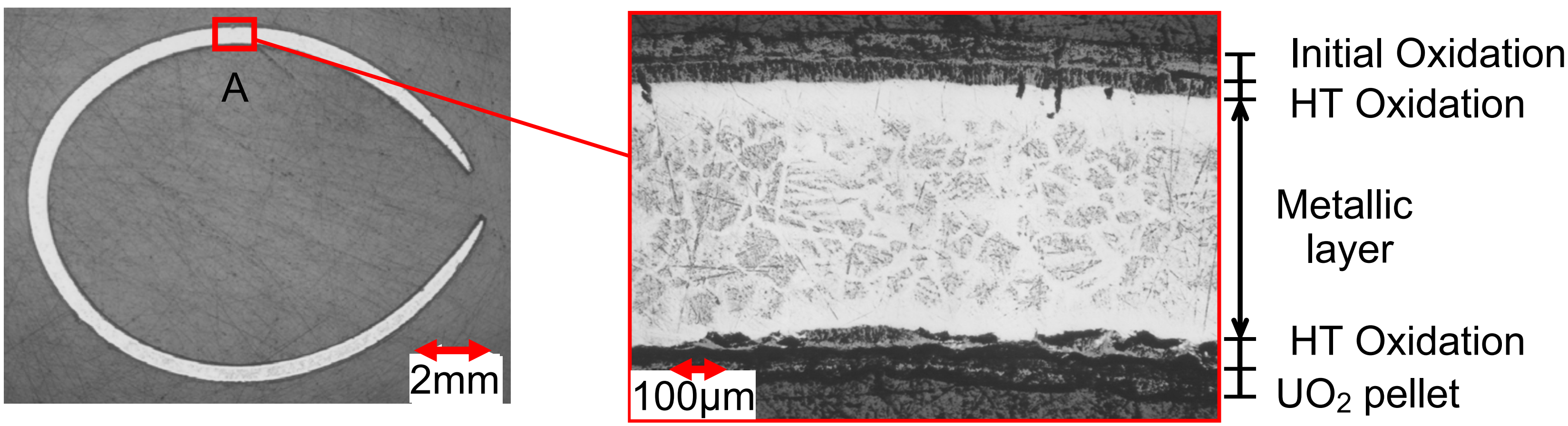
- Rupture and Oxidation ➡ Fix Grid to base ➡ Quench (Cladding shrinkage) ➡ Measure tensile load (generated when the cladding shrinkage is restrained by grid)
- Rupture and Oxidation ➡ Quench (without fixing grid) ➡ Fix grid ➡ Pull up test rod ➡ Measure tensile load

LOCA tests with high burnup PWR fuel cladding

ZIRLO	Vandellos	3 tests	
MDA	Vandellos	2 tests	Burnup up to ~75 GWd/t
M5	Ringhals	2 tests	

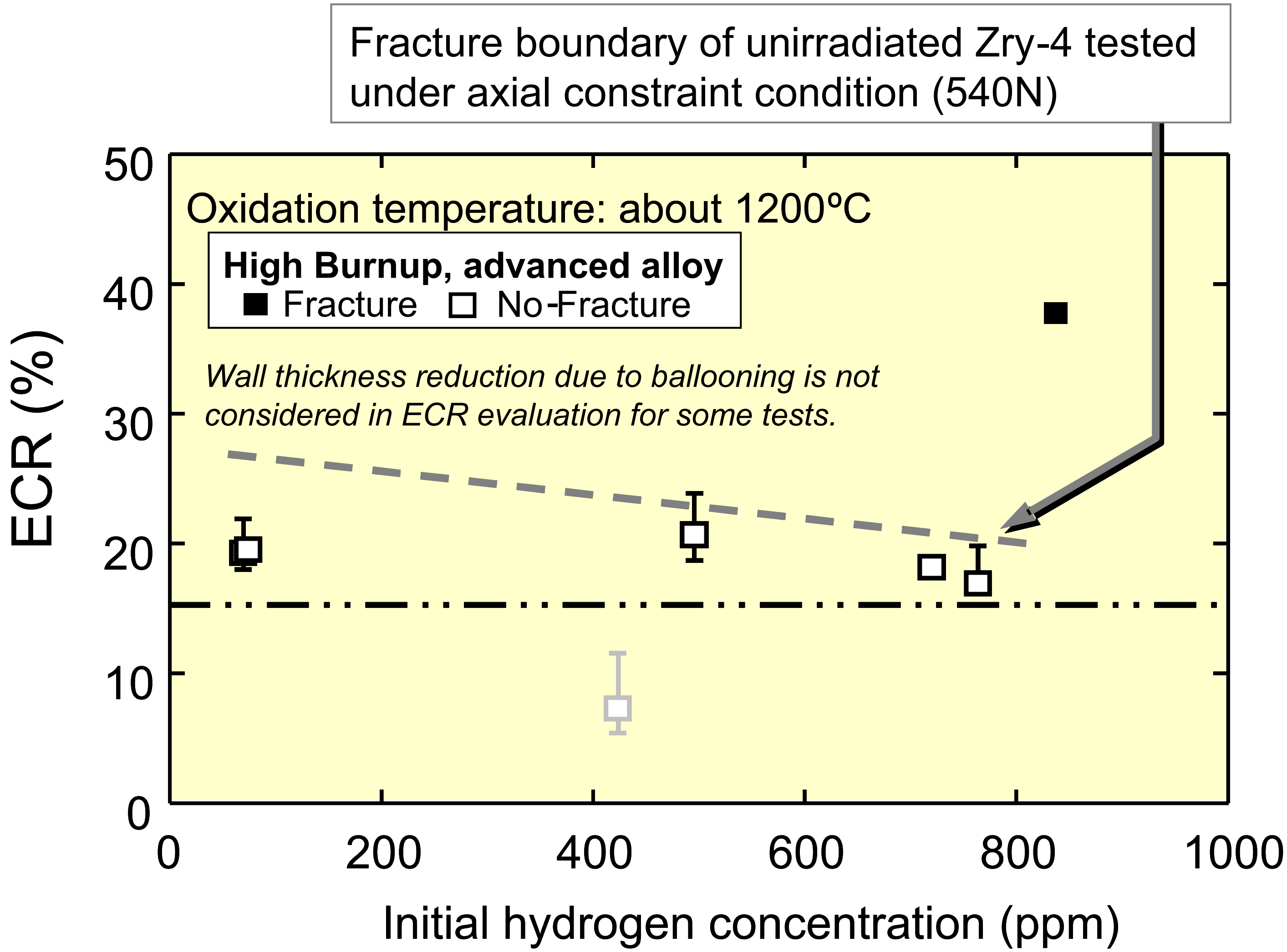
Oxidation temperature; ~1200 deg C (~2200 F)
Oxidation period; 120 to 720 s
ECR; 18% to 38%





✓ Oxide layers formed during the high temperature period. The oxide layer is not uniform inside the cladding, probably due to thin UO_2 layer.

Fracture map from the integral LOCA test



✓ Tests up to ~75 GWd/t ZIRLO, MDA and M5 cladding indicate that the current ECR limit has appreciable safety margin at high burnup.

Summary

- Ongoing tests use two methods:
  - Two-side steam oxidation + ring compression
    Criterion: “zero” ductility
  - Integral thermal shock test
    Criterion: rod fracturing (with axial constraint)

  The Japanese criterion was originally based on the “zero” ductility. However, it is currently based on fracture limit derived from the integral thermal shock tests.

- The thermal shock test method is an integral test covering all LOCA phases, i.e. heat-up, ballooning, oxidation and quenching, in as realistic as possible conditions. While “zero ductility” is sometime a complex notion to assess experimentally, the thermal shock tests criterion is based on a straightforward observation, i.e. on whether the cladding is fractured or not after testing.

- The burn-up effect on LOCA limit can be expressed as a function of the hydrogen pick up due to base corrosion. While tests with un-irradiated, artificially-hydrided Zry-4 specimens and ANL and CEA ductility tests indicated the effect of hydrogen, the current ECR limit has appreciable safety margin up to ~75 GWd/t, according to the JAEA thermal shock tests.