# *Storage of High Burnup Spent Fuel*

NRC-NEI Workshop

April 27, 2000

Albert Machiels

EPRI

# *Outline*

- Bottom Line
- Methodology for Allowable Peak Cladding Temperatures
- Failure Mode
- Creep/Strain Rate
- Rupture Strain
- In-Reactor Performance vs. Dry-Storage Performance

# *Bottom Line*

- Limiting mechanism for cladding integrity under dry storage conditions is cladding creep
- Reasonable to expect that failures from excessive creep would be "pin-hole equivalent," i.e., micron-size pin holes or narrow cracks (too small for release of fuel particles)

# *Bottom Line (cont.'d)*

- Creep/Strain rate for unirradiated claddings appropriately modified for:
  - Irradiation hardening, if appropriate
  - Hydrogen
  - Potentially others (example, fuel bonding)
  - Consideration of more mechanistic functional dependence of strain rates on hoop stress, temperature, back stress (strain hardening)
  - Limiting parameters (fission gas release, rod free volume, cladding wastage)
  - (Vacuum drying, recover, potential hydride re-orientation, limiting failure mechanisms)

# *Bottom Line (cont.'d)*

- Rupture Strain
  - Support of rupture strains >2%
  - Review of results available from burst testing
  - Strain rate dependence (from burst tests to short-term creep test to long-term creep tests)
  - (Consideration of alternate approaches such as the use of the strain energy density concept)

# *Treatment of Spent Fuel With Unusual Discharge Features*

- Statistical significance
  - "For each fuel type proposed for storage, the dry cask storage system should ensure a very low probability (e.g., 0.5 percent per fuel rod) of cladding breach during long-term storage" (NUREG-1536)
- Attributes
  - Fuel pushed beyond existing fuel specifications
  - Observation of conditions leading to the formation of hydride lenses (severe oxide de-lamination) -- Fuel Classification Protocol

# *Failure Mode*

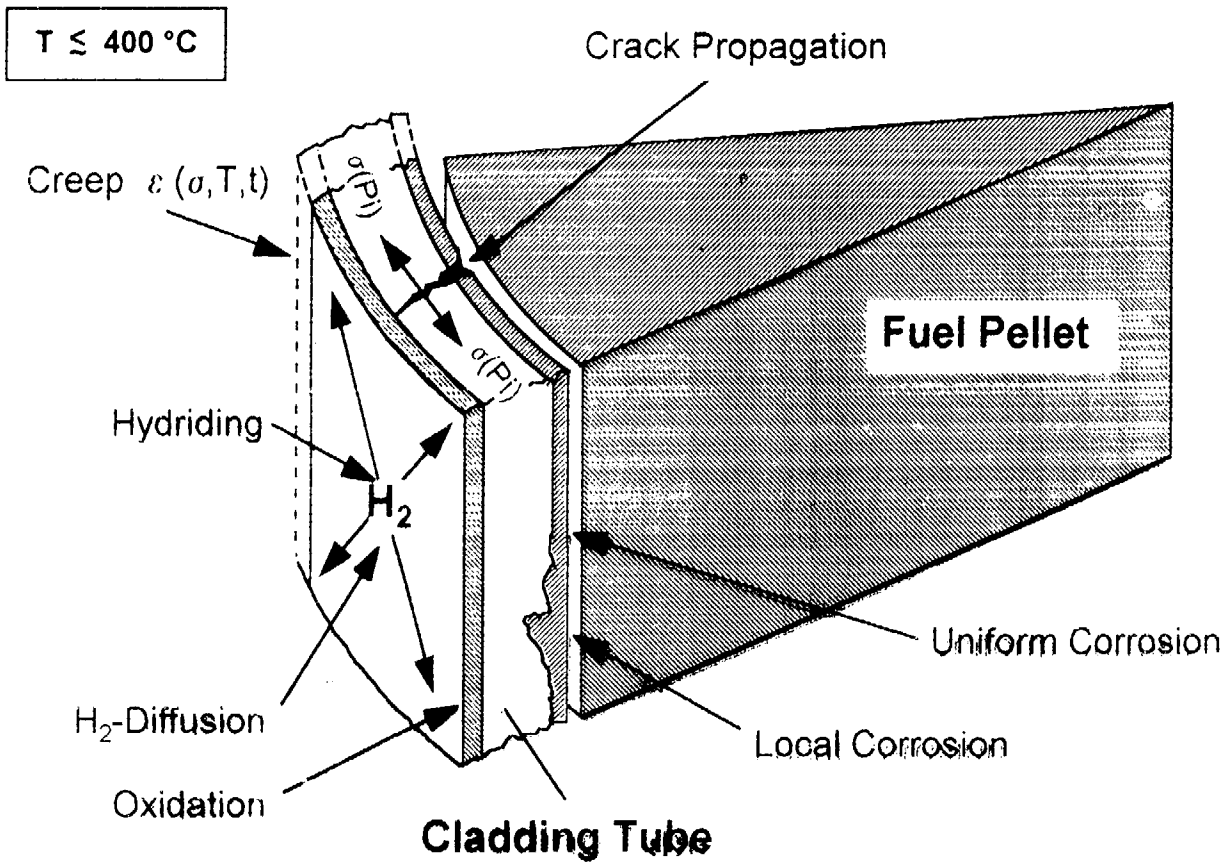
- "Pin hole" equivalence of defects resulting from excessive creep
  - PNL-4835
  - Others

# *Rupture Strain*

- Limiting Value of Hoop Strain
  - 1% is presently used in the German approach (Pending application for using 2%)
  - Data (burst and expanding ring tests, which use large driving forces and large strain rates, plus testing using slower strain rates ) obtained on irradiated claddings have been used to support these values, at least for the lower burnup range
  - Other concepts may be viable (e.g., strain energy density)

Kasper, et al. Ave. Unirrad. & Irrad. Data

# Mechanisms Affecting Spent Fuel Cladding Performance During Dry Storage.



# Comparison of creep strain of unirradiated and irradiated Zry-4 cladding

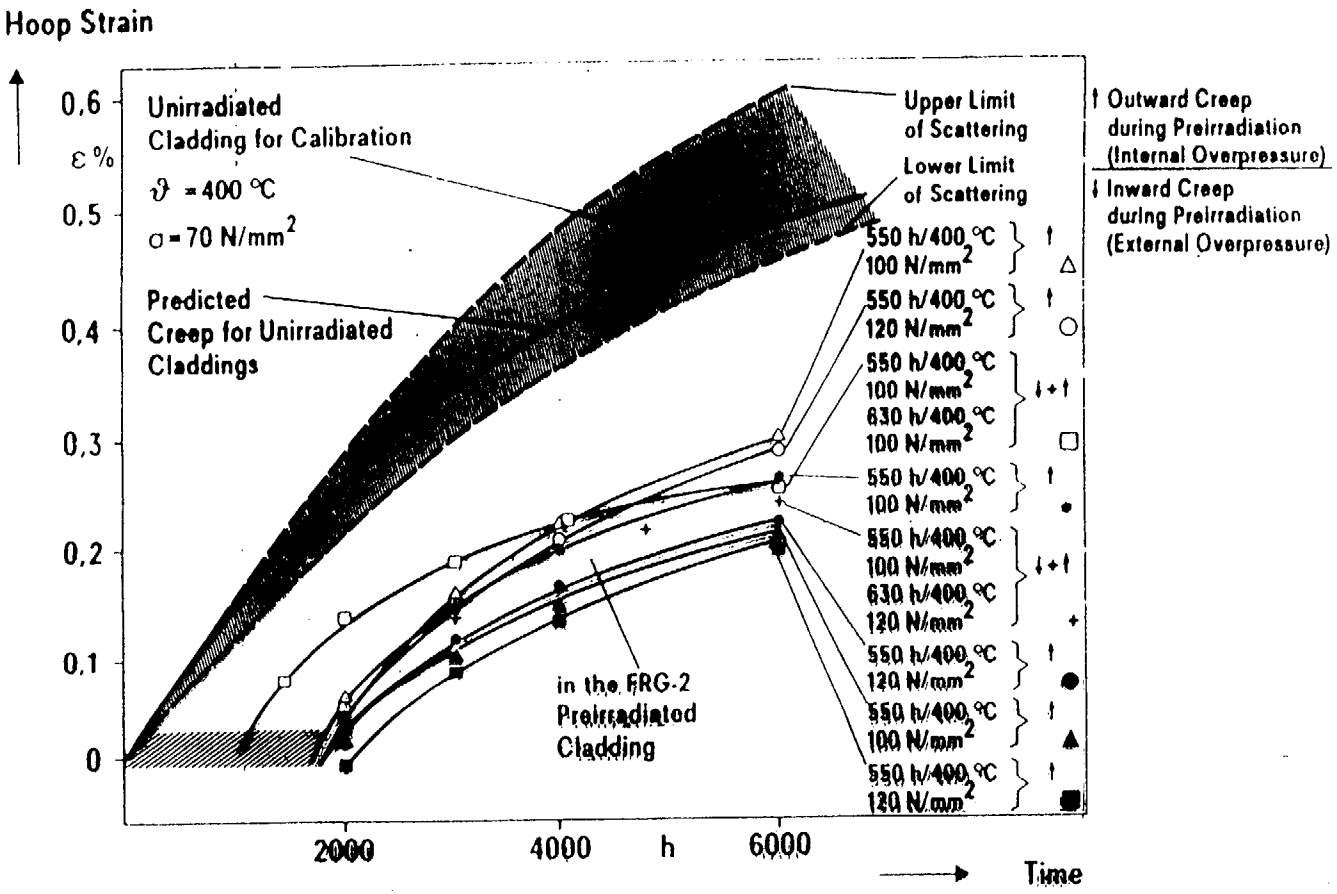


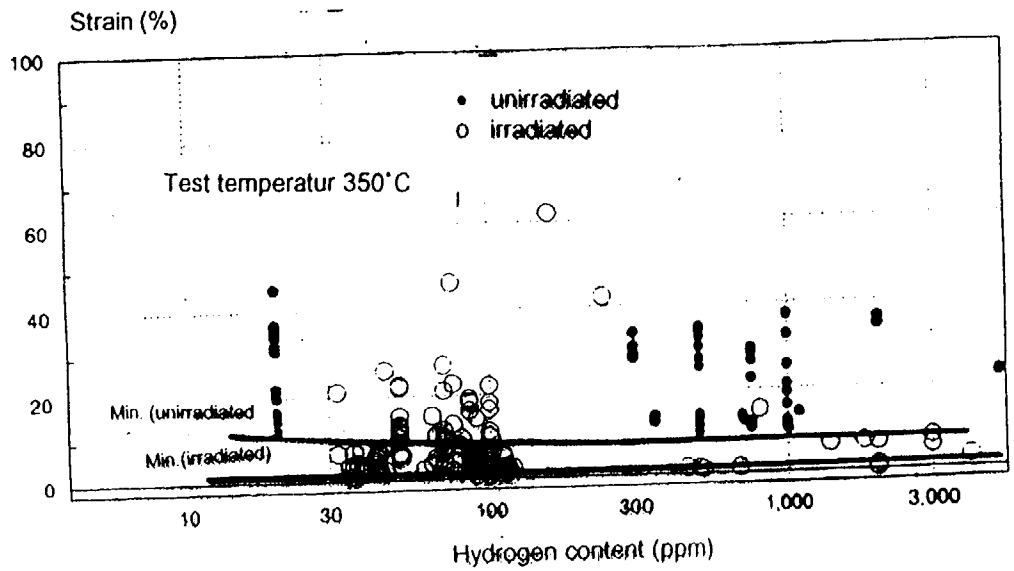

Figure 10



Dr. M. Peehs

# Burst strain data of Zry cladding in relation to its H-content

Burst tests provide due to its extremely high strain rates very conservative data.




Creep experiments with realistic strain rates will have an unrealistic duration of testing

Creep burst tests are an appropriate compromise if:

- the testing time is set to be about one week
- the stresses in the test are selected such as 1 - 5 % strain is expected

Figure 1/1

# HIGH-BURNUP LIMITS

NRC/NEI Meeting
April 27, 2000

Margaret S. Chatterton

# PRESENT STATUS

- Burnup limit of 62 GWD/MTU
  - Both BWRs and PWRs
  - Peak Rod Average
- Reviewing Requests for Higher Burnup
  - Limiting to 62GWD/MTU
- Oxide Thickness Limit of 100 Microns
  - Predicted
  - Best-Estimate Codes

# BURNUP EXTENSION

- NEI and Robust Fuel Program Proposing
  - 75 GWD/MTU for PWRs
  - 70 GWD/MTU
- 3-5 Year Time Frame

# BURNUP EXTENSION GUIDELINES

- Address Current Licensing Requirements including LOCA, ATWS and RIA
- Be Risk Informed
- Emphasis on Lead Test Assemblies
  - Prototypical
    - Power History
    - Type of Fuel and Cladding
    - Up to Requested Burnup
  - Near Limiting Locations
- Fuel Performance Monitoring Program

# BASIC APPROACH

- NRC Working With Industry to Develop a Strategy and a Plan
- Industry Will Develop the Plan
- Industry Will Do the Testing and Develop the Criteria
- NRC Will Review and Endorse it as a Regulatory Guide

**NEI High Burnup Dry Storage Workshop**
**Bethesda Hyatt Regency, Bethesda, MD**
**April 26 - 27, 2000**

The purpose of the workshop is to support development of practical approaches to dry storage and transportation of high burnup fuel (fuel with burnups in excess of 45 MWd/MTU).

**April 26, 2000**
1:00 PM - 4:30 PM, Congressional Room
Industry pre-meeting (NEI members)

**April 27, 2000**
Public meeting
7:30 AM - 4:30 PM registration
7:30 AM - 8:30 AM continental breakfast
8:30 AM - 4:30 PM, Cabinet/Judiciary Room

I. Opening Remarks and Welcome
NEI - Ralph Beedle, Chief Nuclear Officer
NRC - Bill Kane, Director NMSS
II. Trends in Reactor Operations/Designing Fuel to Meet Industry Needs

Duke Energy - Tracy Saville, Senior Engineer
Southern Nuclear - Bruce Hunt, Manager, Nuclear Fuel
NRC, Margaret Chatterton, Reactor Systems Branch, NRR

Industry Round Table Participants - Robert Beall BGE, Paul Crawley APS
Brian Hansen APS, Thomas Brookmire VA Power,
Lynnette Hendricks, Alan Nelson NEI
NRC Round Table Participants - William Brach, Wayne Hodges,
Susan Shankman, James Lyons, Earl Easton, Randy Hall,
Lawrence Kokajko, Chet Posluny, Farouk Eltawika, Sudhamay Basu
Kimberly Gruss

ABB Combustion Engineering - George P. Smith Consulting Engineer
Siemens Power Corporation - Charles Brown, Team Leader Mechanical Analysis Methods
Framatome Technologies - Joseph Sapyta, Project manager

10:00 AM - 10:15 Break

III. Storage and transportation of High Burnup Fuel - Considerations Supporting a Practical Regulatory Approach

EPRI – Albert Michiels, Program Manager

NRC - Kimberly Gruss, Materials Engineer, Spent Fuel Project Office, NMSS

Round Table Discussion – industry, NRC

11:45 AM – 1:00 PM, Lunch on your own

IV. Cask Designs for Storing High Burnup Fuel

Efforts are being made to design casks to meet industry dry storage high burnup needs. Several vendors have initiated applications and/or are planning to do so.

BFS – Rita Bowser, Manager, Strategic Planning
NAC – Willington Lee, VP Engineering and Chief Engineer
Holtec – Indresh Rampall, Sr. Fuel Project Manager

V. Practical Solutions

Round Table Discussion –industry, NRC

VI. Looking forward - Summary and Actions