U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
EBS PANEL MEETING

SUBJECT: ZIRCALOY CLADDING PERFORMANCE PREDICTION FOR DRY STORAGE

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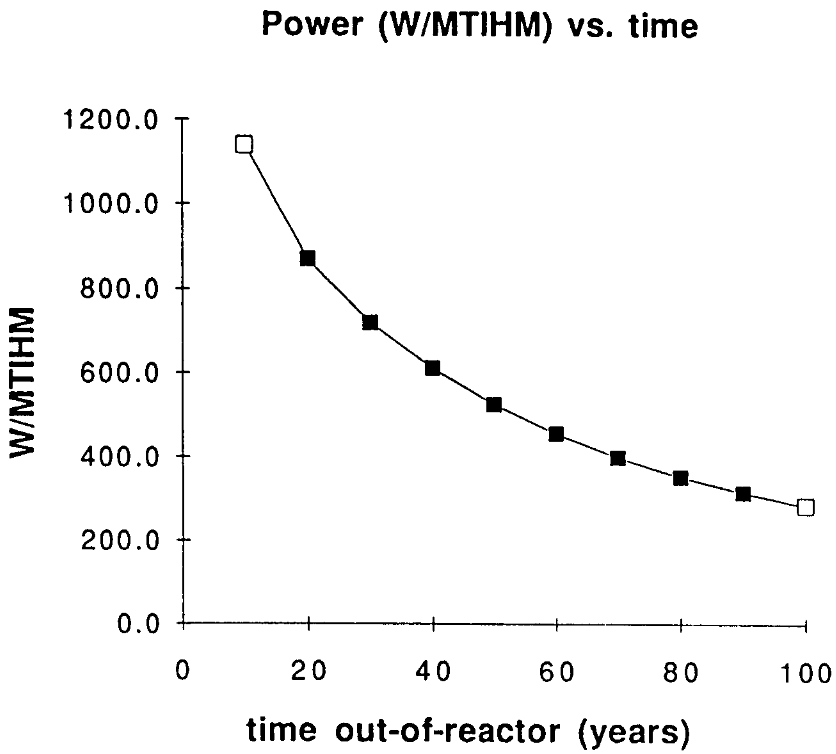
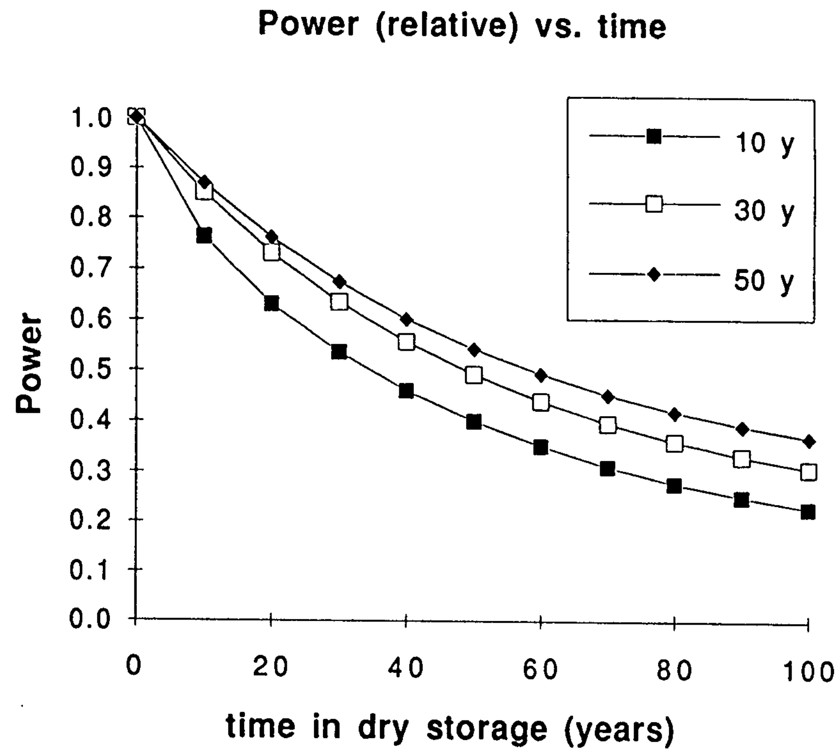
PLEASANTON, CALIFORNIA
MARCH 10-11, 1994

Cladding temperature and stress determine creep

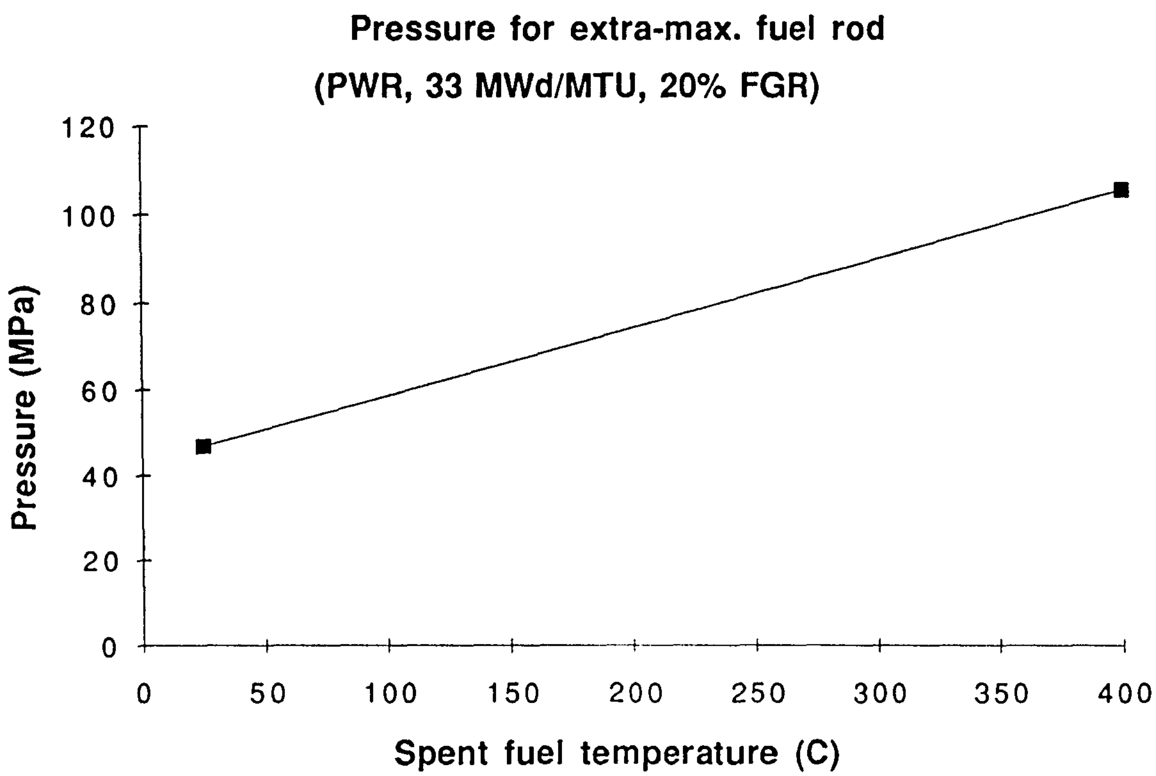




Temperature decline rate:

- Heat generation rate (t)
- Near-field heat capacity
- Thermal conductivity k(T)

Hoop stress depends on pressure p(T)



We have a dual interest in creep vs. temperature

- Yucca Mountain Project
  - Cladding performance during period of substantially complete containment (out to 300 to 1000 years) (Peak thermal period ~ 30 years, peak temperature ~ 350°C)
- Transportation risk assessment (sponsored by CRWMS M&O Transportation Division)
  - Cladding performance during severe fire accidents (considerably more severe than design basis accidents; frequency ~ 10-5 fraction of transportation accidents) (Cooldown period ~ 1 day, higher temperature threshold for damage)

Revisiting the factors in creep lifetime

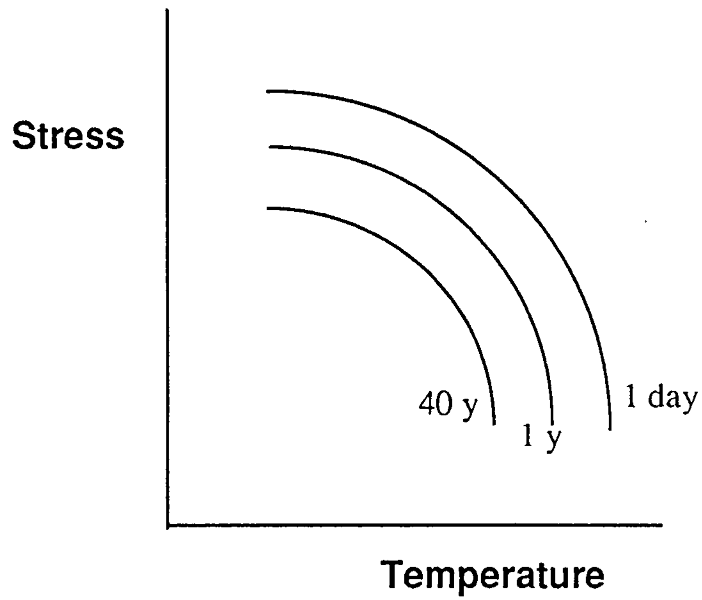
- Creep limit states, mechanisms for rupture
- Creep rates, mechanisms
- Stress
  - Preload gas and fission gas mass
  - Gas volume (vs. time)
- Statistical variability in material properties and in stress load

Points to make about creep data

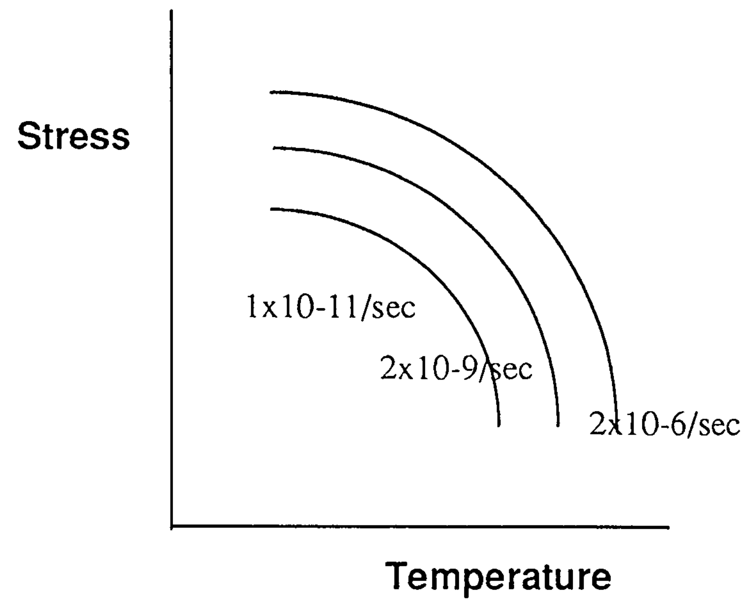
- Creep rate data are available for the (T,σ) region of most interest (320-400°C, 50-120 MPa)
- Creep *lifetime* data are not available for most of this region
- The data show a large variability
- Changing rates of dependence on T and on σ indicate different mechanisms in different (T,σ) regions

Long creep lifetimes mean long measurement times

Time to creep rupture



Creep rate



Single sets of data show consistency. Multiple sets of data show wide variations.

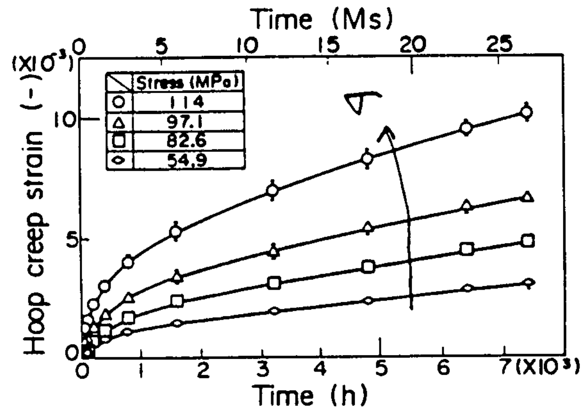


Fig. 3. Change in hoop creep strain with time at a test temperature of 626 K.

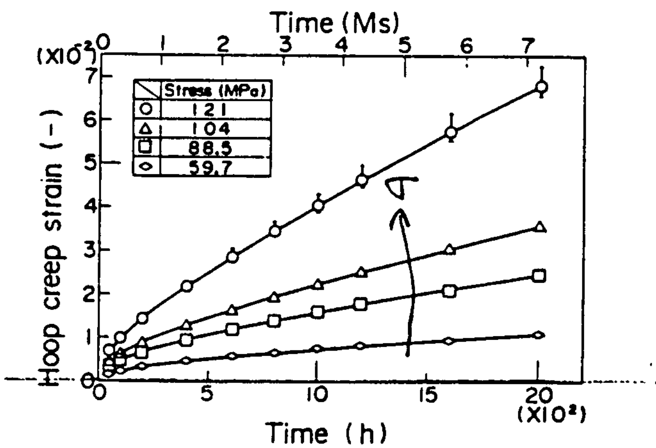
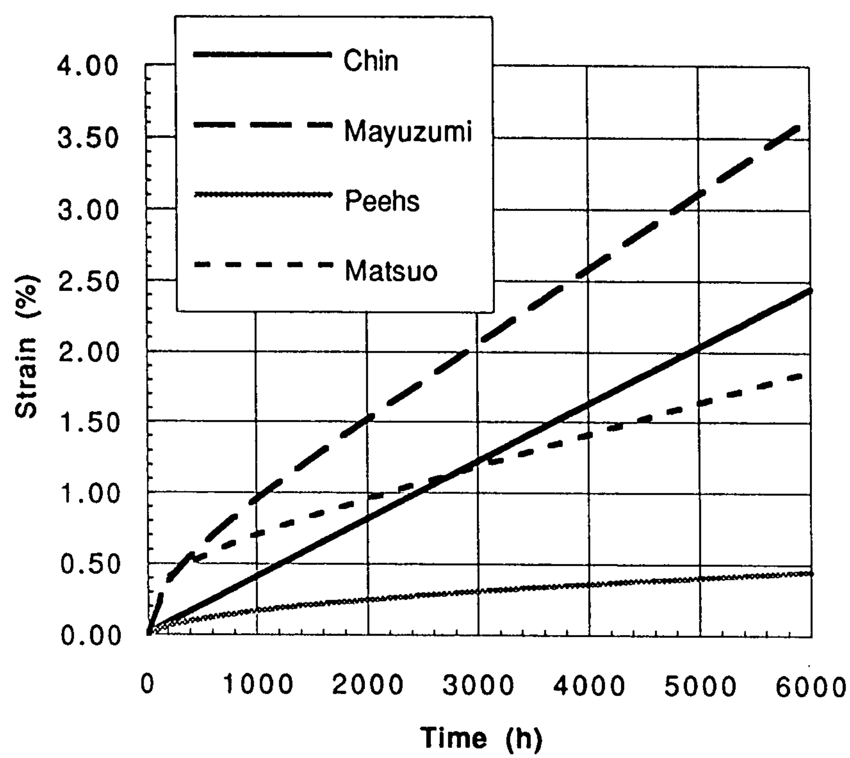


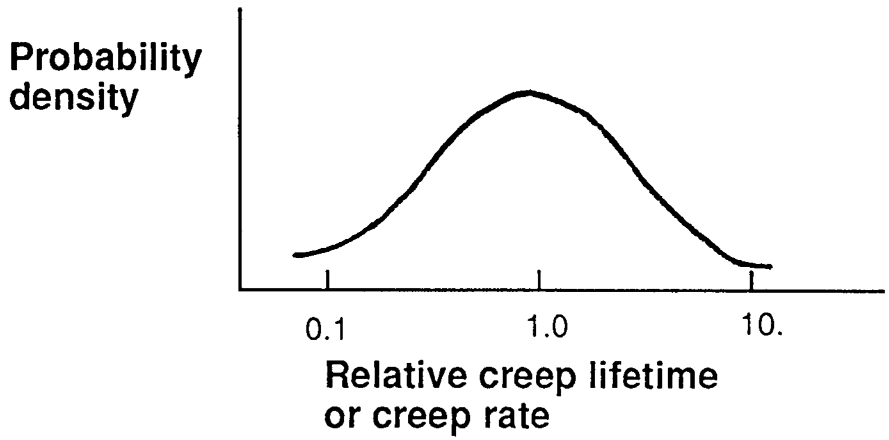
Fig. 4. Changes in hoop creep strain with time at a test temperature of 675 K.

(Mayuzumi 1990)

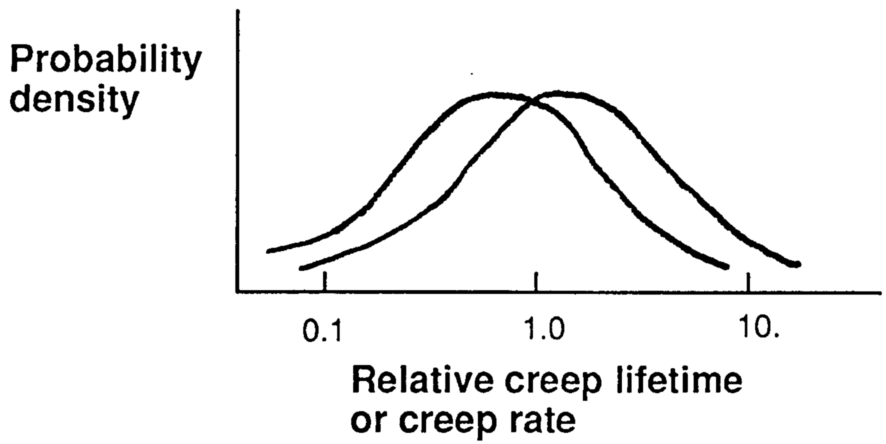


Peehs: Data to 6,000 hours
Mayuzumi: Data to 2,000 hours
Matsuo: Data to 500 and 1,000 hours

Summarizing cladding variability



Irradiated cladding typically has ~ a factor of two difference in creep rate.

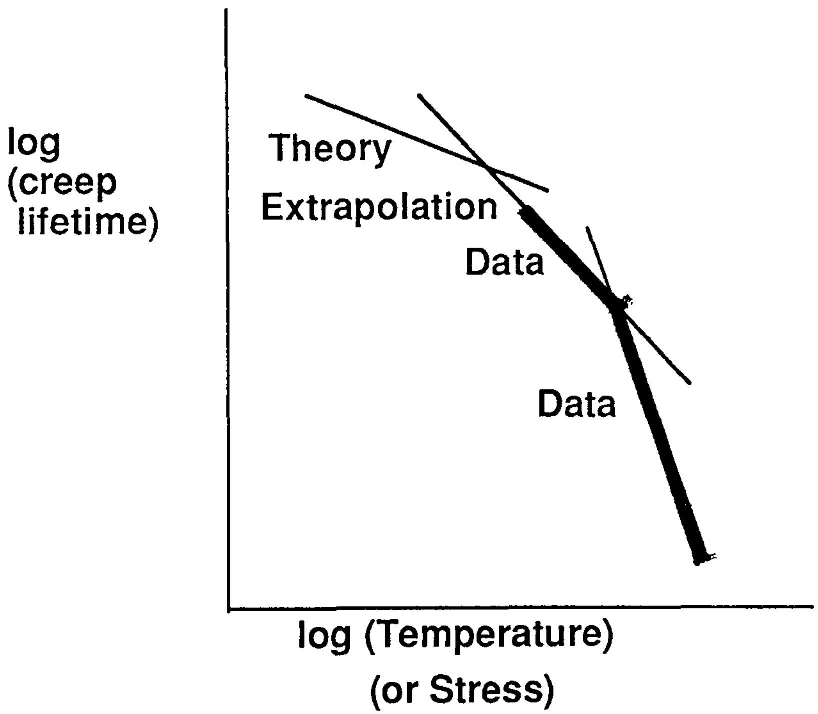


Creep lifetime may differ as well as creep rate.

Extrapolation plus theory are needed for creep lifetime at long lifetime values

- A relatively conservative theory is used.

The shortest-lifetime process controls in each region:



Performance criteria placed on cladding

- Interim dry storage

  NRC: The spent fuel cladding must be protected during dry storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during interim storage will not pose operational safety problems with respect to its removal from storage.

  Specific proposal (Chin and Gilbert 1989):
  Allow small through-wall breaches in < 0.5% of the spent fuel rods. A calculation method then determines a peak temperature limit.

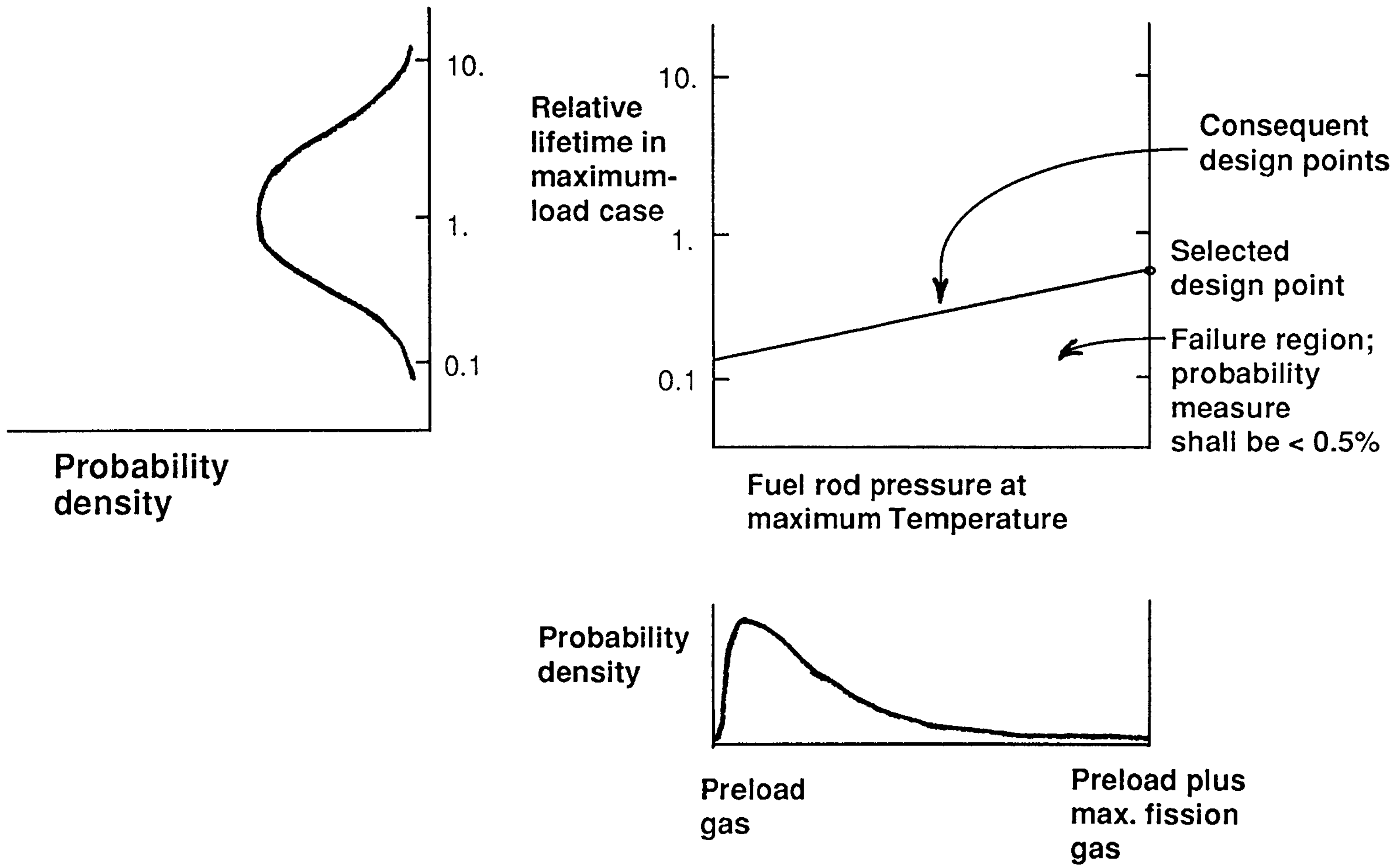
  NRC has acepted the calculation and associated temperature limit.

- Permanent disposal

  During the first 1,000 years, limit through-wall breaches of non-water-contacted spent fuel rods to < 2% of the spent fuel rods.
  After 1,000 years, no performance goal for cladding is set.

Probabilistic design approach accounts for variability

- **Component capacity > Applied load**
  for a large enough fraction of the cases.

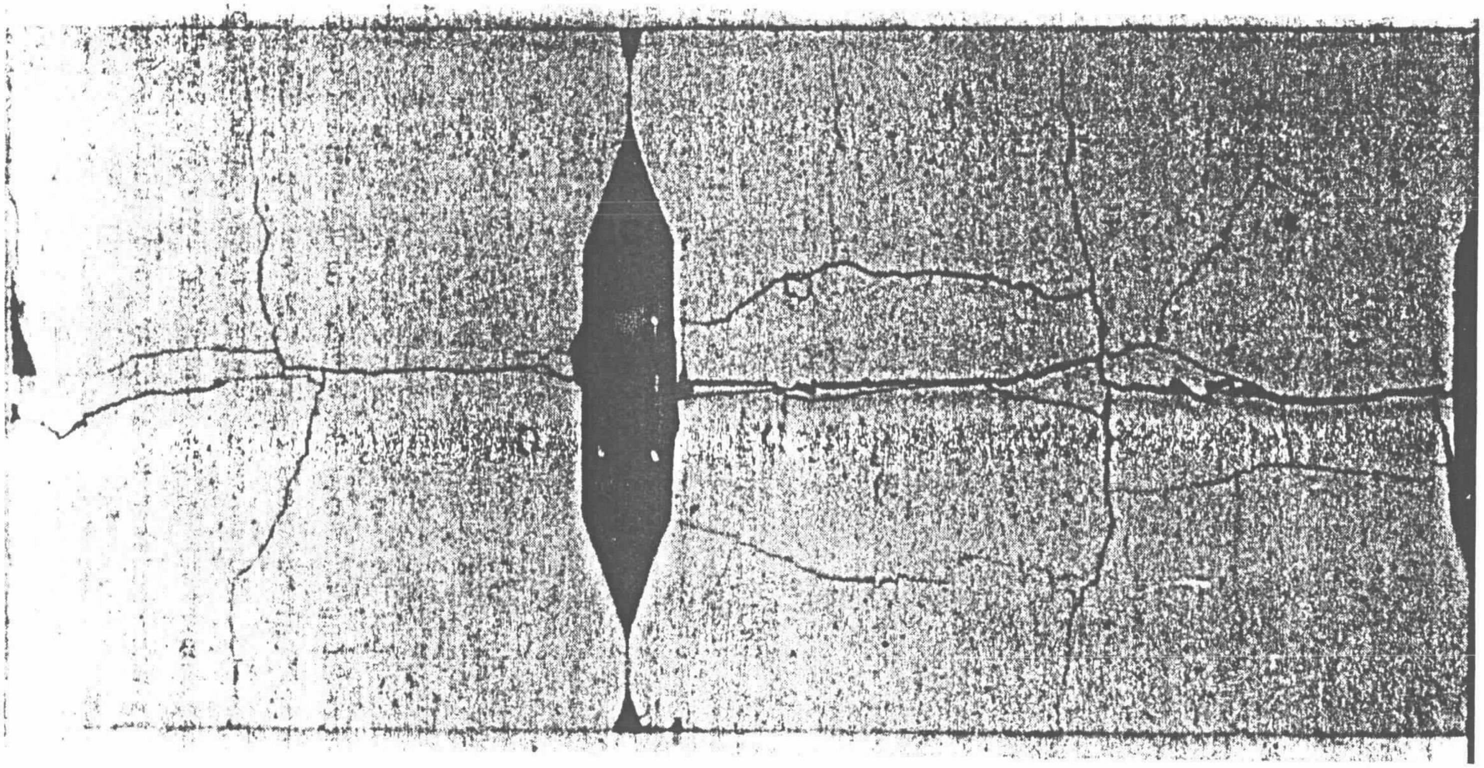


Gas volume vs. time

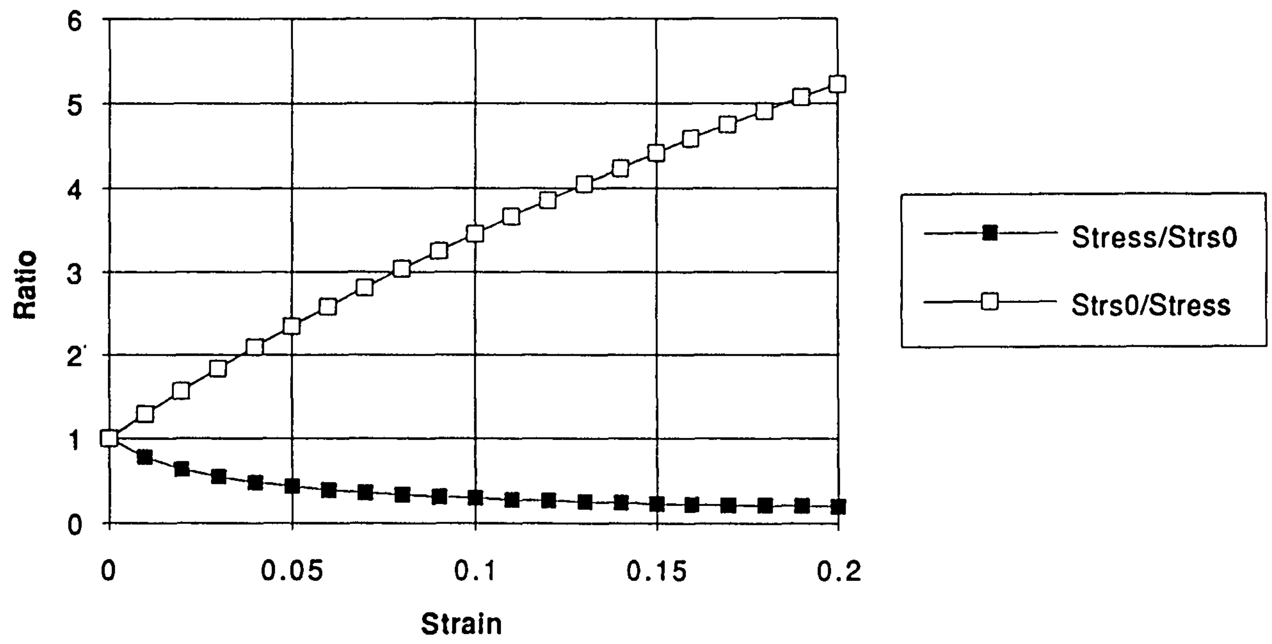
- Upon loading in dry storage or disposal setting:
  - Fuel pellet swelling from irradiation during reactor service
  - Fuel pellet cracks volume
  - Differential thermal expansion
- After some creep:
  - Increased gas volume from diametral creep of cladding

The fuel pellet swells during reactor service

- Cracks counterbalance part of the radial expansion.



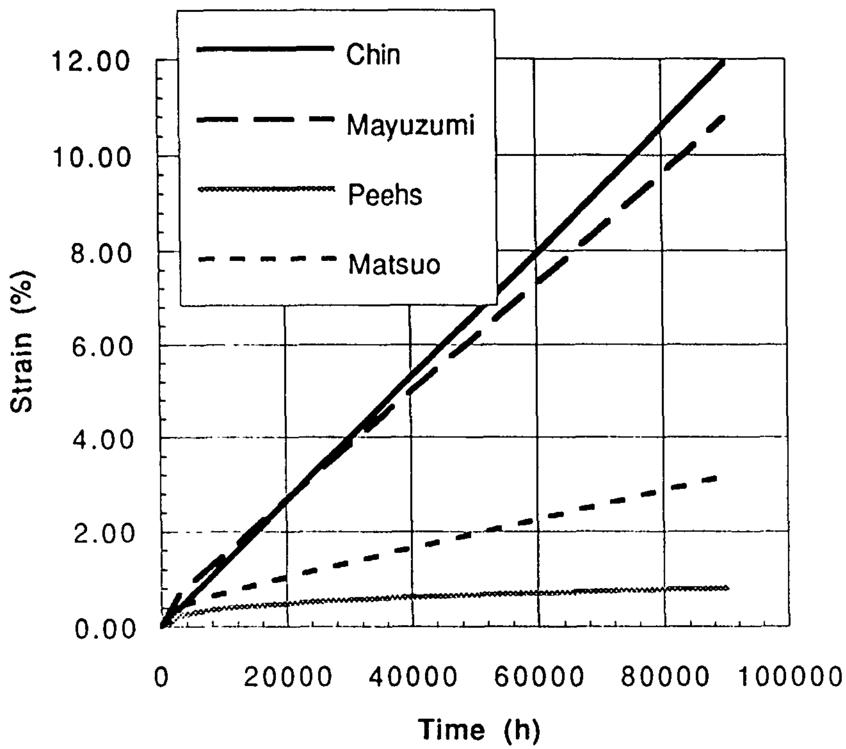
Creep expansion makes a big difference on a small initial volume



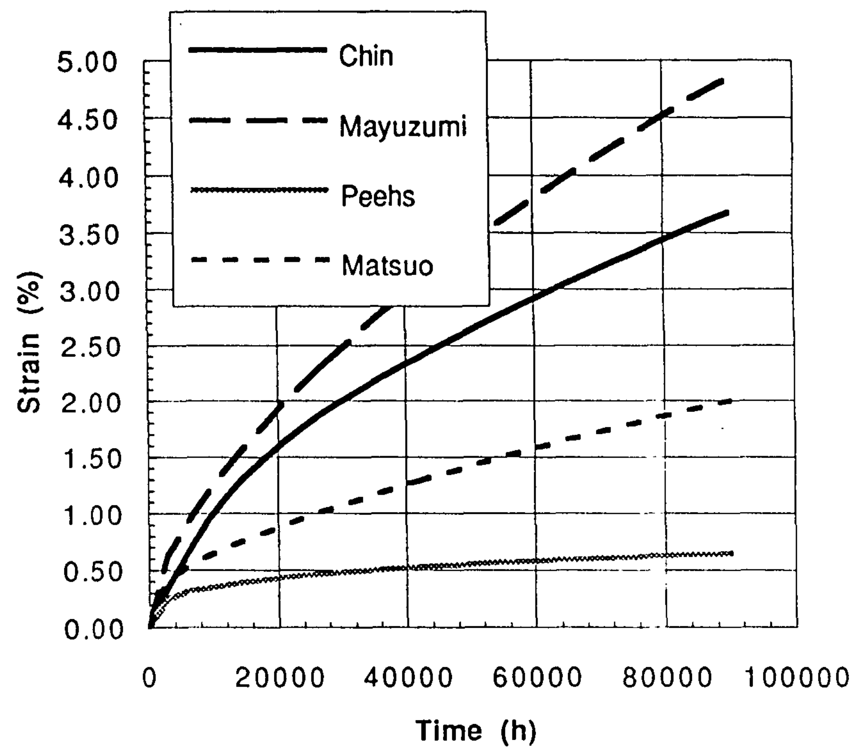
Accumulated creep is considerably dampened by increased volume and reduced pressure

- Effect is noticeable when creep approaches 2 to 3%.

360 °C, 99.4 MPa, Constant Volume



360 °C, 99.4 MPa, Varying Volume



Permanent-disposal performance of cladding from interim dry storage:

- The performance requirement accomodates a larger fraction of fuel rods breached
- The great majority of spent fuel rods from dry storage have less than maximal loading conditions.
  - Distribution of loads, properties
  - Center to edge of storage cask has temperature gradient
  - Many casks reach less than allowable peak temperatures because of fuel burnup, age at emplacement.

Experimental approaches to the long creep lifetime region

- Look for microscopic evidence for proposed or alternate creep damage mechanisms
  - Microscopic examination of flaws, grain shapes
  - Additional test procedures, e.g., independent multi-axial stress
- Correlate creep test results with material properties
- Examine actual dry storage performance
  - Sipping tests for any fraction failed
  - Creep dimensions
  - Fuel-rod gas mass by reactor history or by measurement

Summary

- To re-examine cladding performance, many factors must be checked.
- Creep *rate* data exist to check the creep-rate half of proposed mechanism theories.
- The link between creep and creep rupture needs further experiments, and further search for slow mechanisms.
- The great majority of spent fuel rods from dry storage will have had less than maximal allowed loading conditions.