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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: ZIRCALOY CLADDING AS A DISPOSAL BARRIER

PRESENTER: KEVIN McCOY

PRESENTER'S TITLE AND ORGANIZATION: MANAGEMENT & OPERATING CONTRACTOR
B&W FUEL COMPANY

PRESENTER'S TELEPHONE NUMBER: (702) 794-1979

MARCH 10, 1994
PLEASANTON, CALIFORNIA

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OUTLINE

- Prognosis for cladding life
- Mechanisms for cladding degradation
- Creep rupture by diffusion-controlled cavity growth

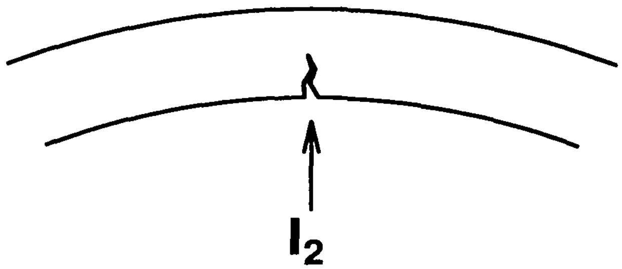
UNCERTAINTIES IN CLADDING LIFE

- Cladding life may be consumed before disposal
- Cladding is highly variable
- High burnups may damage cladding
- Characterizing cladding is expensive and time-consuming

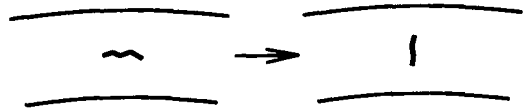
REASONS TO EXPECT SIGNIFICANT CLADDING PERFORMANCE

- More than 99% of fuel rods are intact at discharge
- Zircaloy is corrosion resistant
- Failures are usually microscopic
- Cladding is potentially important as a barrier to release
- Cladding serves as redundant barrier for containment

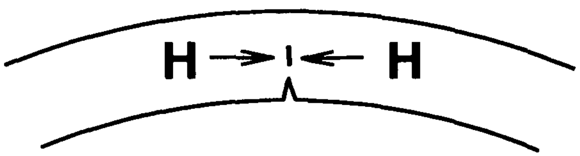
MECHANISMS FOR CLADDING DEGRADATION



Fuel-side Stress Corrosion Cracking



Hydride Reorientation

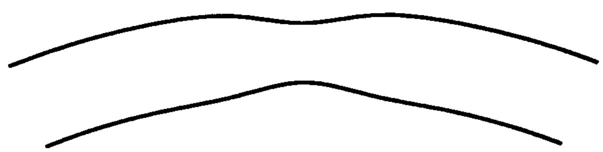


Delayed Hydride Cracking

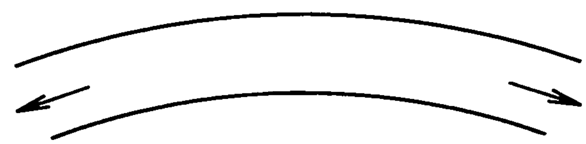
Axial Hydride Redistribution

MECHANISMS FOR CLADDING DEGRADATION

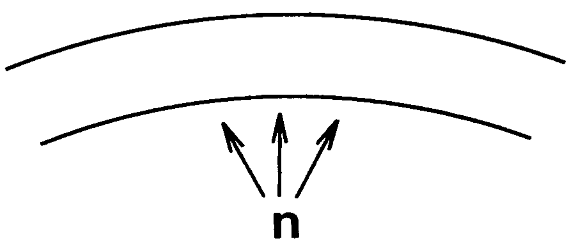
(CONTINUED)



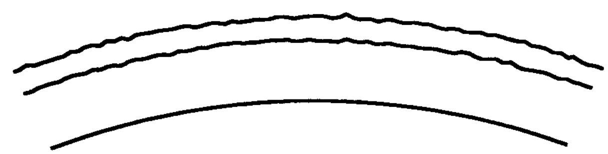
Creep Rupture



Strain Rate Embrittlement



Irradiation Embrittlement



Oxidation and Aqueous Corrosion

3-10TRB18.125.NWTRB/3-10-94

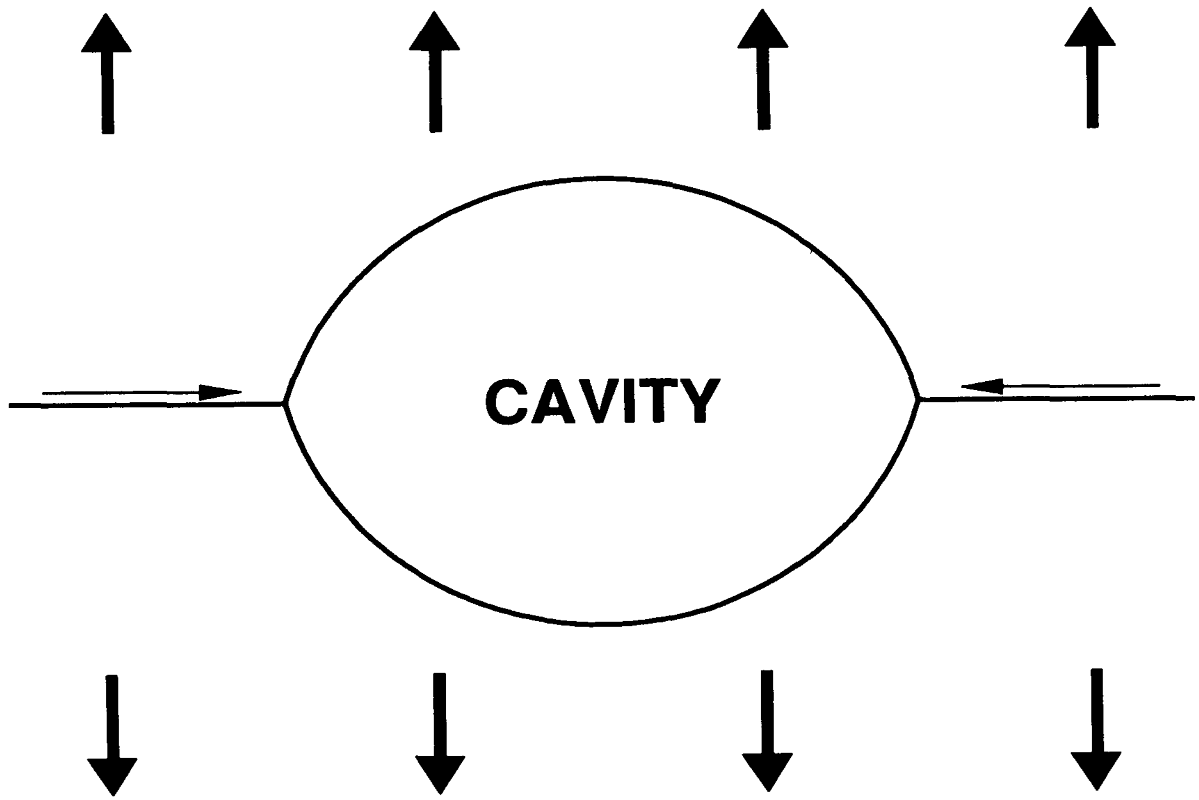
CREEP RUPTURE MECHANISMS

- Ductile transgranular fracture
- Triple-point cracking
- Power-law cavity growth
- Diffusion-controlled cavity growth (DCCG)

WHAT IS THE MOST IMPORTANT DEGRADATION MODE?

- NRC and PNL independently concluded that DCCG is the most important mode for dry storage
- Conditions for dry storage and disposal are similar
- DCCG is most important mode for disposal

SCHEMATIC OF CAVITY GROWTH IN DCCG



ACCUMULATED DAMAGE

$$D(t) = \int_0^t \frac{d\tau}{L(\tau)}$$

t = time

$D(t)$ = damage at time t

$L(\tau)$ = lifetime under conditions at time τ

PREDICTED LIFETIME

$$L = \frac{n\lambda^3 kT}{\delta D_{gb} \Omega \sigma m}$$

n = geometric/diffusional constant

λ = cavity spacing

k = Boltzmann's constant

T = temperature

δ = effective grain boundary thickness

D_{gb} = grain boundary diffusivity

Ω = atomic volume

σ = hoop stress

m = microstructural constant

DATA USED IN MODEL

n = 0.00226 (from NRC data, corrected as noted below)

λ = 10μm

k = 1.3807×10^{-23} J/K

T/σ = 643 K / 69.7 MPa

δ = 9.69×10^{-10} m

D_{gb} = $5.9 \times 10^{-6} \exp[(-131 \text{ kJ/mol})/RT]$ m^2/s

Ω = 2.334×10^{-29} m^3 (corrected)

α = 75° (dihedral half-angle at edge of cap) (corrected)

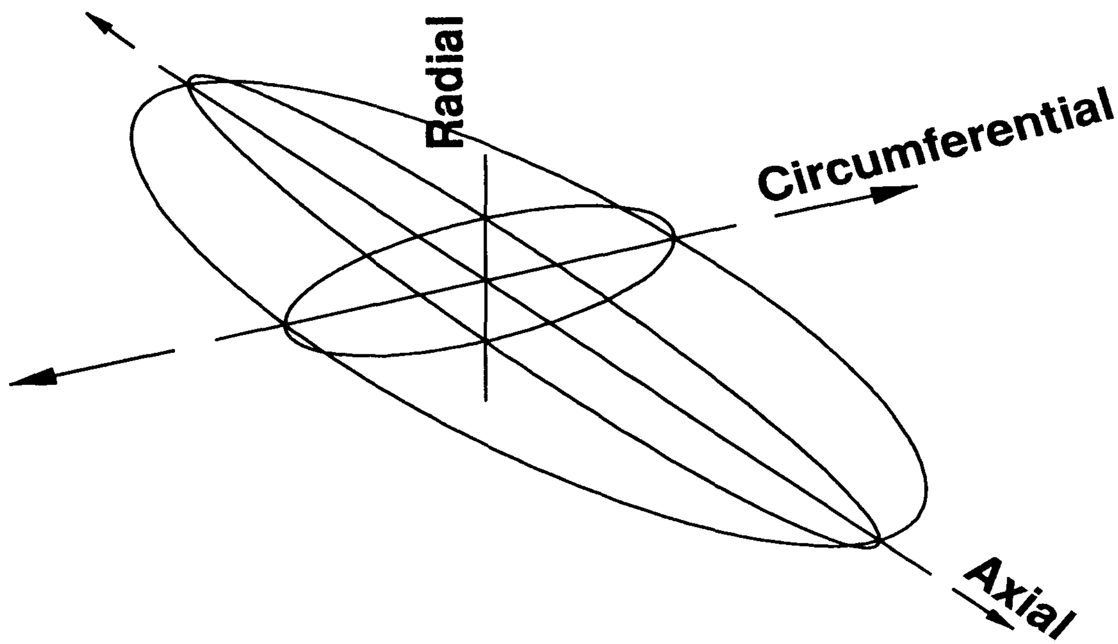
γ = 2 J/m^2 (surface energy) (no value given by NRC)

m = 0.165 (for grain aspect ratio 9 : 3 : 1
(axial : circumferential : radial))

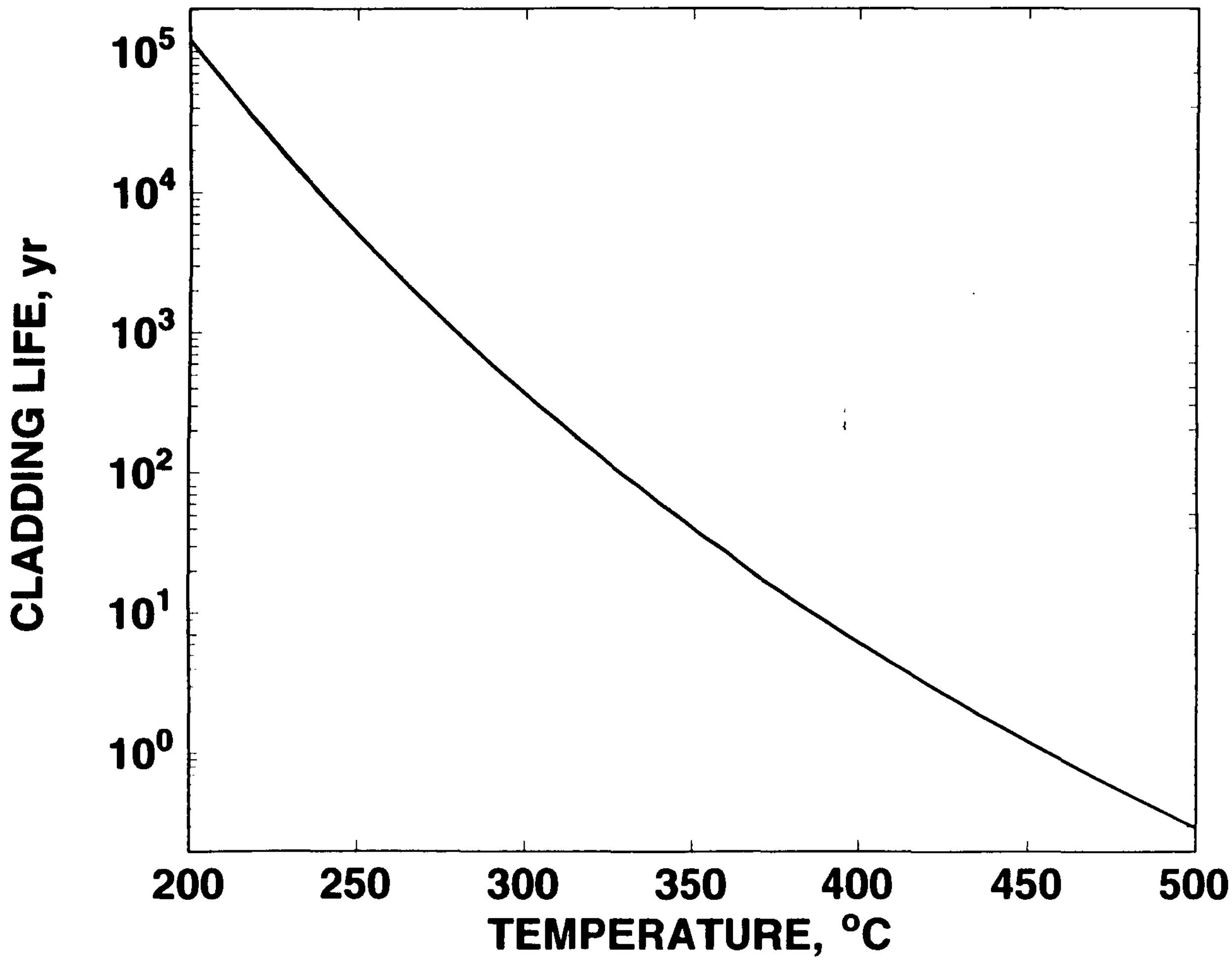
EFFECT OF MICROSTRUCTURE AND STRESS

- In fuel, most grain boundaries are oriented to resist DCCG
- Stress is σ in circumferential direction, $\sigma/2$ in axial direction, 0 in radial direction
- Represent grain as an ellipsoid, calculate average normal traction on surface
- Using realistic representation of microstructure and stress avoids excessive conservatism

MICROSTRUCTURE AND STRESS



PREDICTED CLADDING LIFE UNDER CONSTANT TEMPERATURE AND STRESS



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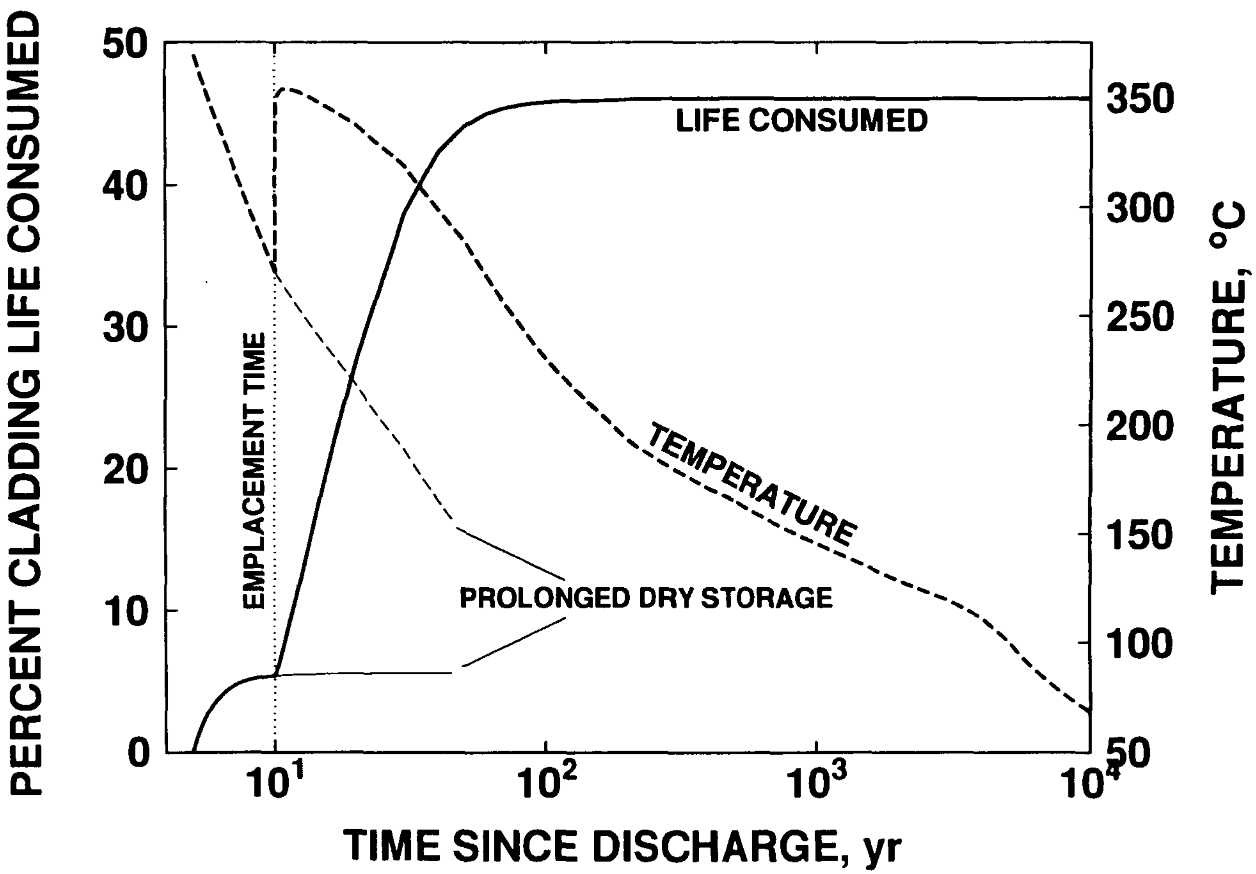
DAMAGE ACCUMULATION IN STORAGE AND DISPOSAL

Sample Calculation for Following Conditions:

- PWR Fuel With 40 GWd/MTU Burnup
- Stored in Fuel Pool for 5 Years
- Stored in CASTOR V/21 for 5 Years
- Disposal Without Backfill at 80 kW/acre, 21 Assemblies per Package

DAMAGE ACCUMULATION IN STORAGE AND DISPOSAL



CONCLUSIONS

- Cladding can potentially provide significant performance
- Obtaining cladding credit may be difficult
- Cladding can survive calculated temperatures for disposal for 10000 years

FUTURE STUDIES

Determine effects of

- Extended burnup
- Using other types of dry storage devices
- Different thermal loadings
- Backfill and resulting thermal spike