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POTENTIAL STRESS ON CLADDING IMPOSED BY THE MATRIX SWELLING FROM ALPHA DECAY IN HIGH BURNUP SPENT NUCLEAR FUEL

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DISCLAIMER

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Introduction

- **During long-term storage of spent nuclear fuel (SNF), the UO_2 matrix may undergo swelling due to alpha decays.**

- **The alpha decays introduce microstructure defects and He in the matrix.**
  This swelling may impose stress on cladding, especially if the gap between the cladding and the matrix is closed, as occurring for high burnup SNF (e.g., ~ 60 GWd/MTU).

- **If this stress is sufficiently high it may impact cladding integrity.**

- **This paper assesses using literature data:**

  - potential for matrix swelling and gap closure in SNF, and
  - potential stresses imposed on the cladding

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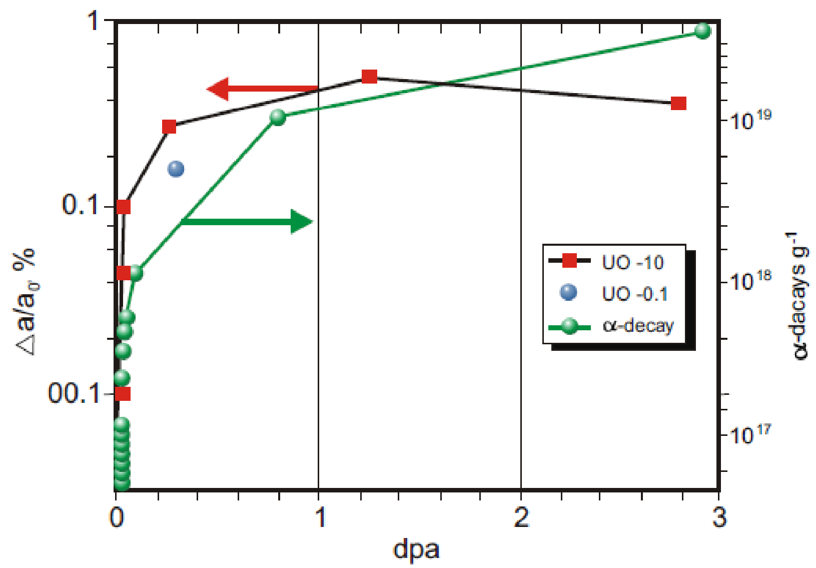
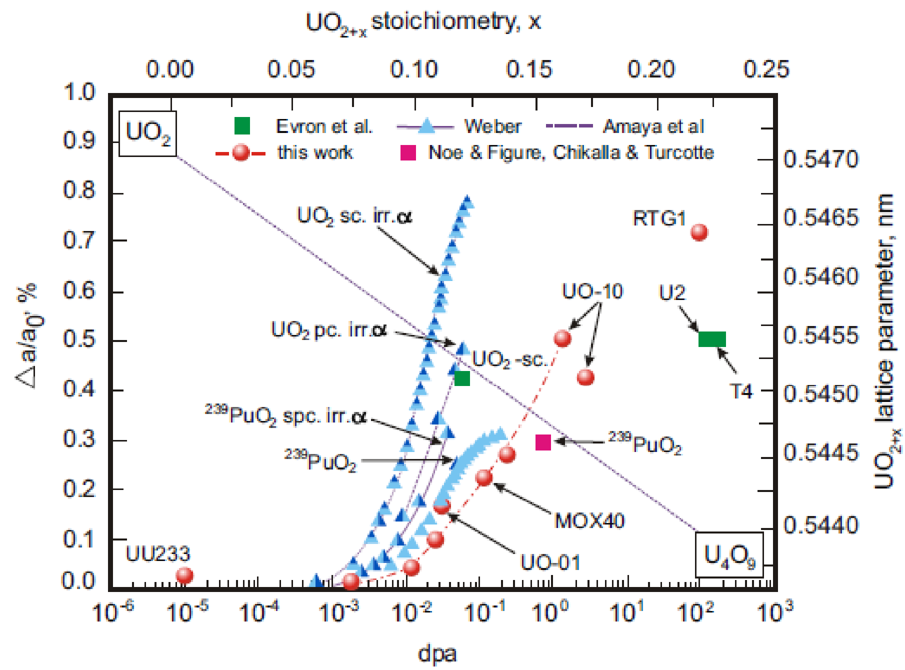
Outline

- **Introduction**
- **Experimental Test Methods and Data on UO_2 Matrix Swelling by Accelerated Irradiation**
- **Stress Analysis on Cladding by Thermal Expansion of UO_2 Matrix as an Indicator of Irradiation-Induced UO_2 Matrix Swelling**
- **Information and Assessment of Gap Size, and Stress on Cladding**
- **Summary**

Experimental Test Methods and Data on UO_2 Matrix Swelling by Accelerated Irradiation

Lattice Parameter Changes by Alpha Decays in UO_2 by Various Accelerated Test Methods





- **The Alpha Particle Damage Obtained by Doping with Alpha Emitter, Alpha-Particle Implantation, Recoil Atom Bombardment of UO_2, or by Direct Measurement of Lattice Parameter in Actinide Oxide Samples, or Natural Analogues (after Rondinella, et al., 2010)**

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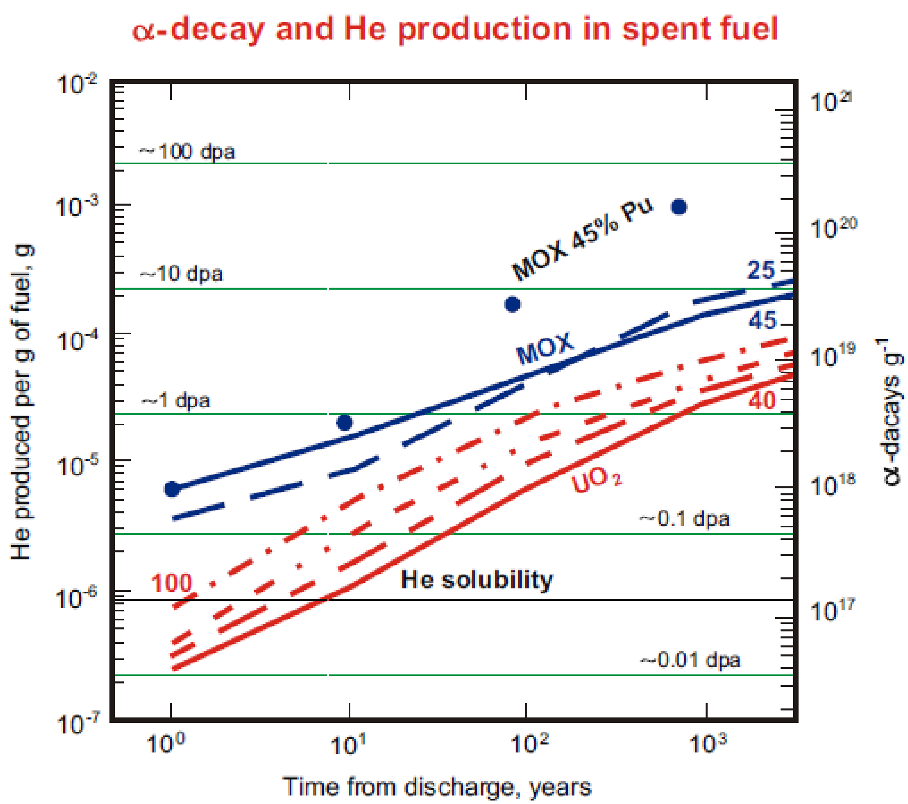
Experimental Test Methods and Data on UO_2 Matrix Swelling by Accelerated Irradiation (continued)

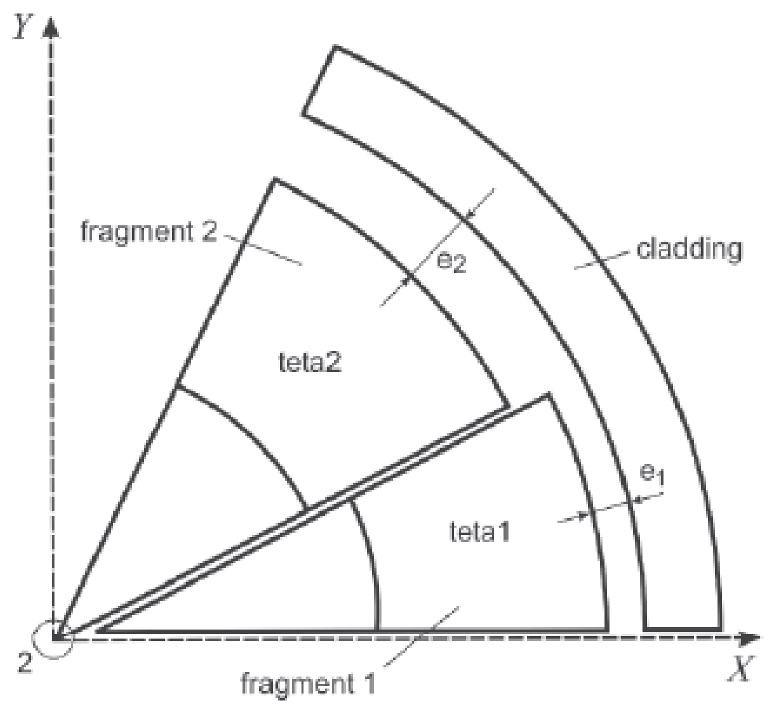
Alpha Particle Damage Accumulated during SNF Storage (after Rondinella, et al., 2012)



For 40 – 80 GWd/MTU, Doses Are 0.2 – 0.4 dpa in 100 Years. This Correspond to 0.2 – 0.5% Lattice Expansion for Doped UO_2 with Alpha Emitter in Previous Slides

Stress Analysis on Cladding by Thermal Expansion of UO_2 Matrix as an Indicator of Irradiation-Induced UO_2 Matrix Swelling

Model Used in the Calculation of Thermal Expansion of SNF by Retel, et al. (2004)



Stress Generated from Solid Matrix Swelling (Ahn, et al., 2007)

$$\sigma = E/(1 - 2\nu)\,[\Delta V/(3V)]$$

σ: stress developed
E: Young's modulus
ν: Poisson's ratio
V: volume
Δ: volume change

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Stress Analysis on Cladding by Thermal Expansion of UO_2 Matrix as an Indicator of Irradiation-Induced UO_2 Matrix Swelling (continued)

- **Cladding Hoop Stress and the UO_2 Matrix Displacement from Thermal Expansion Deduced from Retel, et al. (2004)**

Maximum Radial Displacement of teta1 and teta2, µm (µ inch)	Percentage of Displacement with respect to Rod Radius, 0.4096 cm (0.1613 inch)	Cladding Hoop Stress, MPa (ksi)
27.9 (11.0), 0 (0)	0.68	434 (62.9)
21.0 (8.3), 7 (2.8)	0.50	318 (46.1)
14.0 (5.5), 14.0 (5.5)	0.30	-34.8 (-5.1)
7.0 (2.8), 21.0 (8.3)	0.17	82.7 (12.0)

- **At a displacement of around 14.0 µm (5.5 µ inch), hoop stress disappears with 0.17 to 0.30% displacement**

- **The thermal expansion could be from a value between (0.17 to 0.30) and 0.68%, depending on cladding position.**

- **The hoop stress:**
  - 434 MPa (62.9 ksi) from [0.68 minus (0.17 to 0.30)%], average 0.45%
  - 318 MPa (46.1 ksi) from [0.50 minus (0.17 to 0.30)%], average 0.27%

(e.g., Ahn and Rondinella. 2011).

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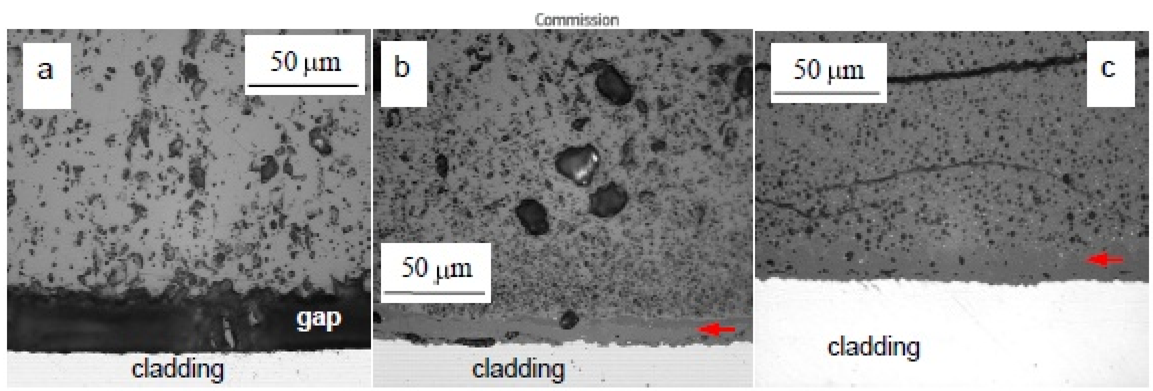
Information and Assessment of Gap Size and Stress on Cladding

- The magnitude of cladding stress: the initial gap and the matrix swelling during storage
- The gap closure routinely observed in the higher axial burnup regions of
- LWR SNF rods starting from above 40-45 GWd/MTU average rod burnup
- Ridge formation, crack pattern and inter-locking, and friction coefficients



LWR UO_2 Gap for (a) 20, (b) 47, and (c) 70 GWd/MTU

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Summary

- **The potential for stresses imposed by the SNF swelling depends on the extent of the swelling, the gap between cladding and the SNF matrix, and the crack pattern in SNF matrix.**

- **Data show the gap is closed for high burnup fuel after discharge from reactor.**

- **Non negligible stress on cladding by swelling from alpha decays is assessed in doped UO_2 with alpha emitter at accumulated dose levels corresponding to tens and hundreds of years of SNF storage.**