Aqueous Corrosion

150-250°C
7 U + 6 H₂O (g) ---> 3 UO₂ + 4 UH₃

600-700°C
U + 2H₂O ----> UO₂ + 2H₂

--------------------------------------------

Reduction of Corrosion in Water

- Metastable γ phase - U + 7% Mo
  or, U + 7% Nb

- Supersaturated - U + 3% Nb
  α phase
  U +1.5 % Nb + 5% Zr
  U + 3 % Nb + 0.7 Sn

- Intermetallic Compounds
  U₃Si
Irradiation Creep

• Thermal Creep -
  Plastic deformation of a solid at high temperatures while the stresses are below yield strength

• Irradiation Creep -
  Enhanced thermal creep, usually proportional to fission rate

First Russian Report of Accelerated Creep -

• English Version ≈ 1.5 -2 %
• Later Translation ≈ 1.5 to 2
• 1958 Conference ≈ 1.5 to 2 orders of magnitude
**Growth**

1.) First instability to be recognized

- 1955 - 1st UN Conf. on Peaceful Uses of Atomic Energy
- US, USSR, and UK found tremendous variations in the behavior of polycrystalline rods
- Found: (figure)

\[
\begin{align*}
&[010] \quad \text{Elongation} \\
&[100] \quad \text{Contraction} \\
&[001] \quad \text{No Change}
\end{align*}
\]

2.) Growth rate at any time depends on the length at that time rather than the initial length.

\[L = L_0 e^{Gf}\]

Where

- \(G\) = growth const.
- \(f\) = frac. of atoms that have fissioned

\[G = \ln\left(\frac{L}{L_0}\right) \div f\]
normally report

\[
\frac{\% \text{ Growth}}{\% \text{Burnup}}
\]

G is very temperature dependent (figure)

at 0.2% BU, (1850 MWd/tonne U)

\[
\frac{L}{L_0} \approx 2-3 \quad @ \quad 100^\circ C
\]

-----------------------------

Texture Effects
(figure)

-----------------------------

Elongated Rod  (figure)

-----------------------------

Explanation

• Fission fragments cause local heating
  • expansion-100, 001 (attracts vacancies)
  • contraction-010 (attracts interstitials)

• Defect migration produces
  • Vacancy loops on \{100\} planes
    (actually on \{110\})
  • Interstitial loops on \{010\} planes
Temperature Effects

- Low temperatures ---> Random Loops (interstitials)
- Moderate Temp. ---> Vacancy Loops (80-350 °C) Aligned
- Above 500°C  ---> Loops anneal out
The Net Growth Rate of Polycrystalline U Wires Depends on the Fraction of (010) Pole Planes Parallel to the Wire Axis

After Buckley-1962
The Growth Constant of U is Greatly Reduced at Higher temperatures

After Buckely-1964
## Physical Properties of the Six Plutonium Allotropes

<table>
<thead>
<tr>
<th>Phase</th>
<th>Crystal Lattice</th>
<th>Number of Atoms Per Unit Cell</th>
<th>Transition to Next Higher Phase, °C</th>
<th>Density gm/cm³</th>
<th>Coeff. of Thermal Expansion x 10⁻⁶ per °C</th>
<th>Volume Change on Transformation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>Monoclinic</td>
<td>16</td>
<td>112</td>
<td>19.8</td>
<td>46.4</td>
<td>α-&gt;β, 8.9</td>
</tr>
<tr>
<td>Beta</td>
<td>Body centered Monoclinic</td>
<td>34</td>
<td>185</td>
<td>17.65</td>
<td>38.4</td>
<td>β-&gt; γ, 2.4</td>
</tr>
<tr>
<td>Gamma</td>
<td>Face centered Orthorhombic</td>
<td>8</td>
<td>316</td>
<td>17.2</td>
<td>34.7 (a=-19.7) (b=39.5) (c=83.4)</td>
<td>γ -&gt; δ, 6.7</td>
</tr>
<tr>
<td>Delta</td>
<td>fcc</td>
<td>4</td>
<td>451</td>
<td>15.9</td>
<td>-8.8</td>
<td>δ-&gt; δ', -0.4</td>
</tr>
<tr>
<td>Delta Prime</td>
<td>body centered tetragonal</td>
<td>2</td>
<td>480</td>
<td>16.0</td>
<td>-116, (a=305) (c=-659)</td>
<td>δ'-&gt; ε -3.0</td>
</tr>
<tr>
<td>Epsilon</td>
<td>bcc</td>
<td>2</td>
<td>640</td>
<td>16.51</td>
<td>+36.5</td>
<td></td>
</tr>
</tbody>
</table>
Swelling

fission --> 2 atoms --> 3 times U vol.

*Early studies found much higher swelling rate*

(Figure)

-------------------------------------

Temperature Dependence

- 350-500 °C - Growth (tearing)
- 500-600 °C - Aligned pores/Voids
- > 600 °C - Gas Bubble Swelling

Al, Mg, and Fe reduce cavitation swelling by reducing grain size and increasing $\sigma_y$

-----------------------------------

Breakaway Swelling (Figure)