Aqueous Corrosion

150-250°C

$7\,U + 6\,H_2O\,(g) \longrightarrow 3\,UO_2 + 4\,UH_3$

600-700°C

$U + 2H_2O \longrightarrow UO_2 + 2H_2$

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 U_3Si**
  Compounds

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*

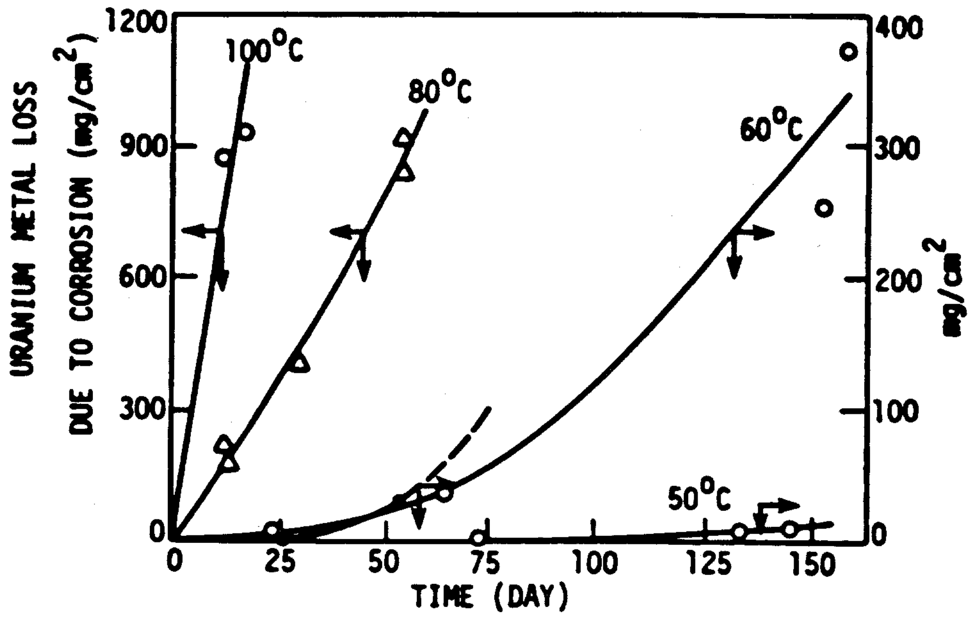


Fig. 6.6. Corrosion of standard uranium in aerated distilled water

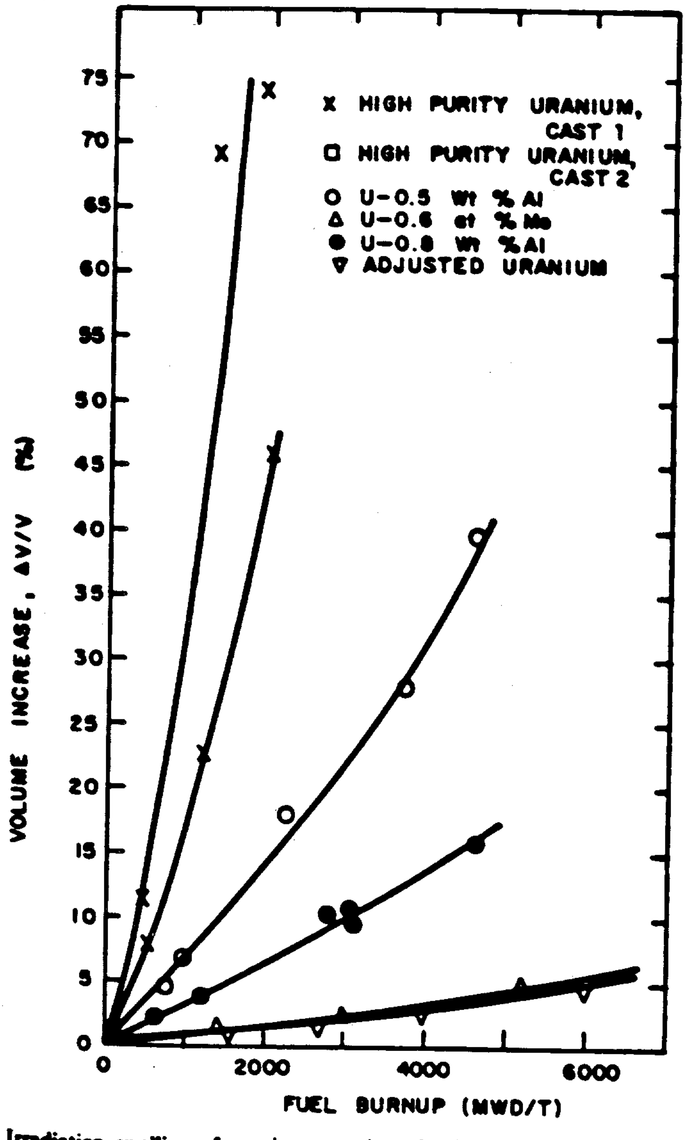


Fig. 6.19. Irradiation swelling of uranium, uranium-aluminum, and uranium-molybdenum alloys

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)**

[010] Elongation
[100] Contraction
[001] No Change

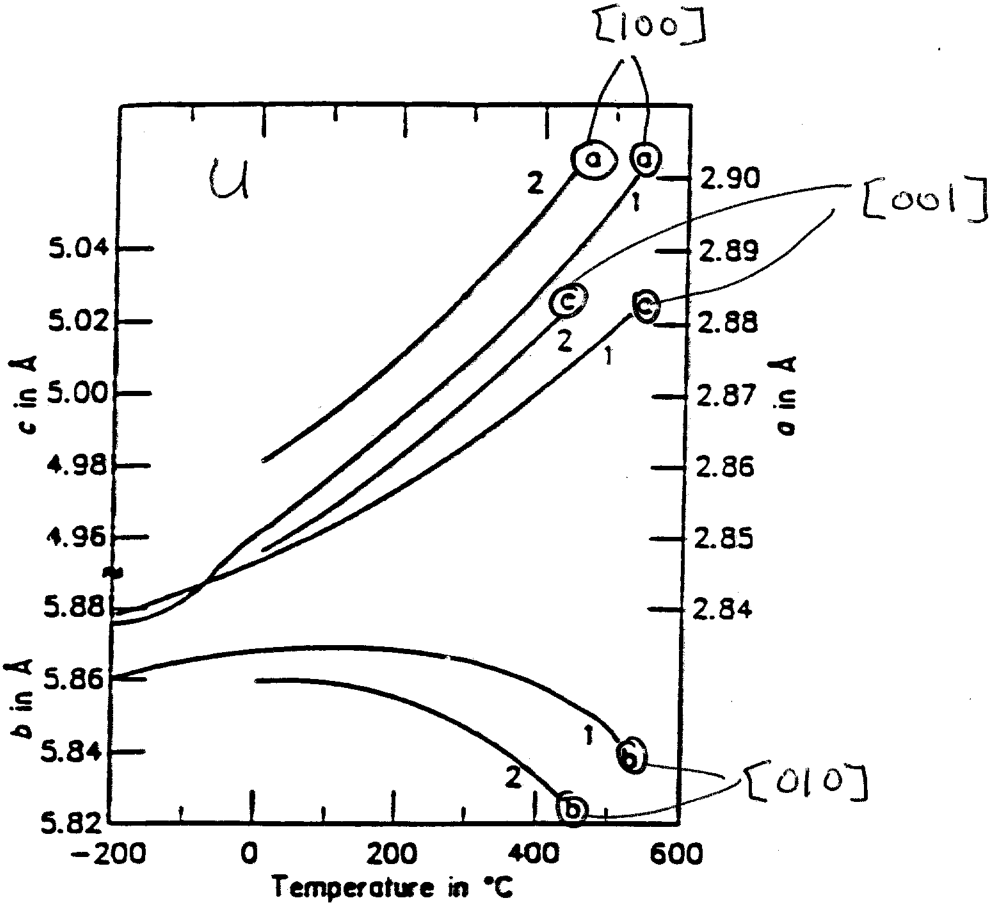
2.) Growth rate at any time depends on the length at that time rather than the initial length.

$$L = L_o e^{Gf}$$

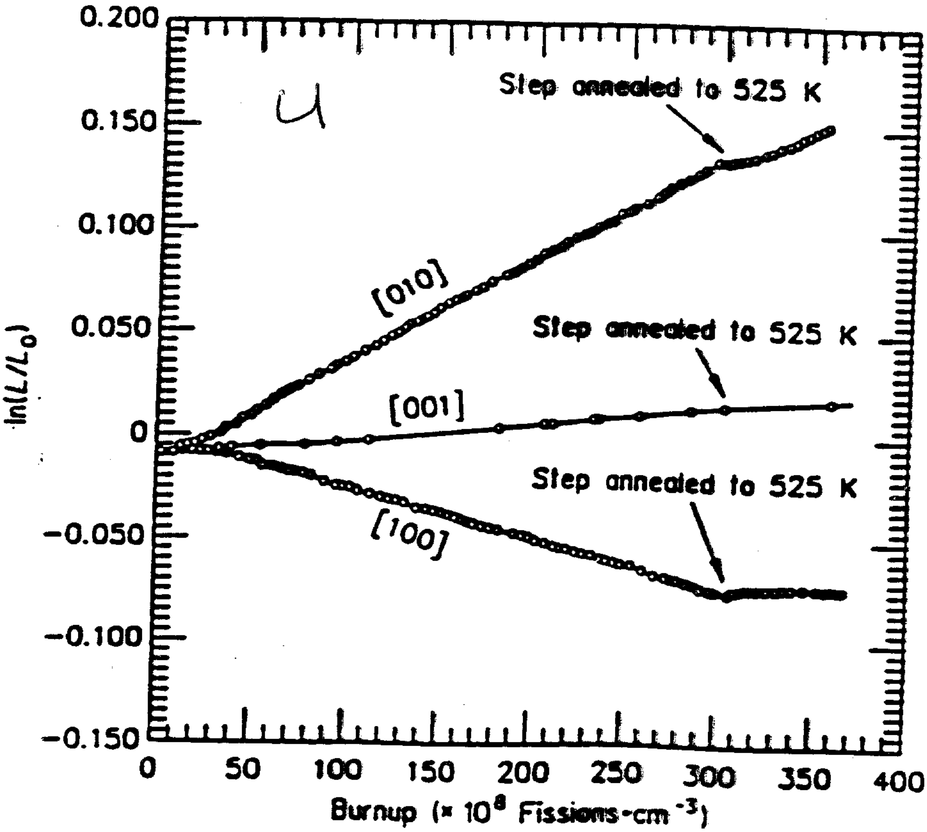
Where

G = growth const.
f = frac. of atoms that have fissioned

$$G = \frac{\ln\left(\frac{L}{L_o}\right)}{f}$$



[100]
[001]
[010]
U
c in Å
a in Å
b in Å
5.04
5.02
5.00
4.98
4.96
5.88
5.86
5.84
5.82
2.90
2.89
2.88
2.87
2.86
2.85
2.84
−200
0
200
400
600
Temperature in °C



U
Step annealed to 525 K
Step annealed to 525 K
Step annealed to 525 K
[010]
[001]
[100]
ln(L/L0)
0.200
0.150
0.100
0.050
0
−0.050
−0.100
−0.150
0
50
100
150
200
250
300
350
400
Burnup (× 10^8 Fissions-cm^-3)

normally report

$$\frac{\%\ \text{Growth}}{\%\text{Burnup}}$$

G is very temperature dependent (figure)

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

$$\frac{L}{L_o} \approx 2\text{-}3 \quad @\ 100^\circ C$$

Texture Effects

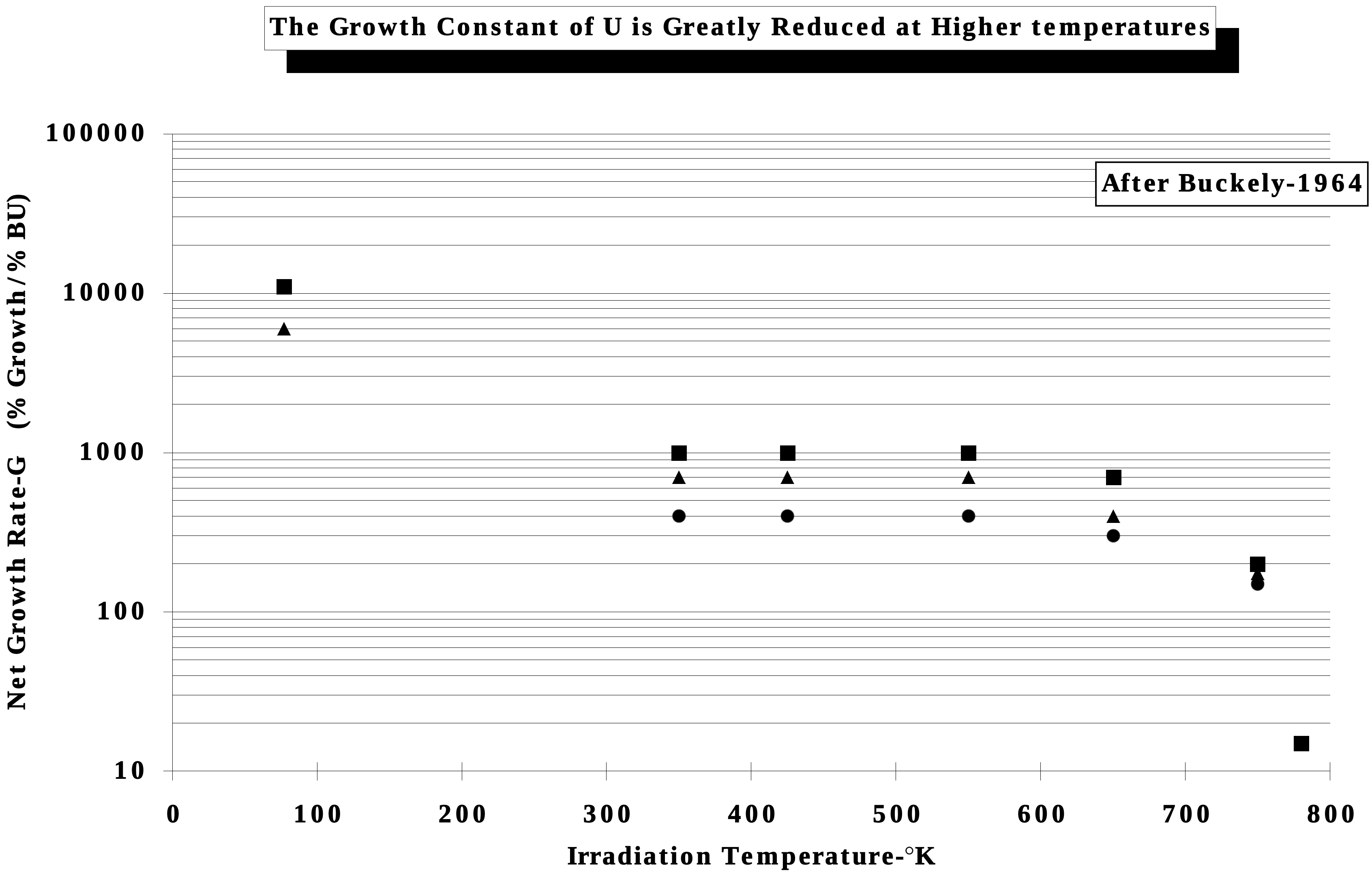
(figure)

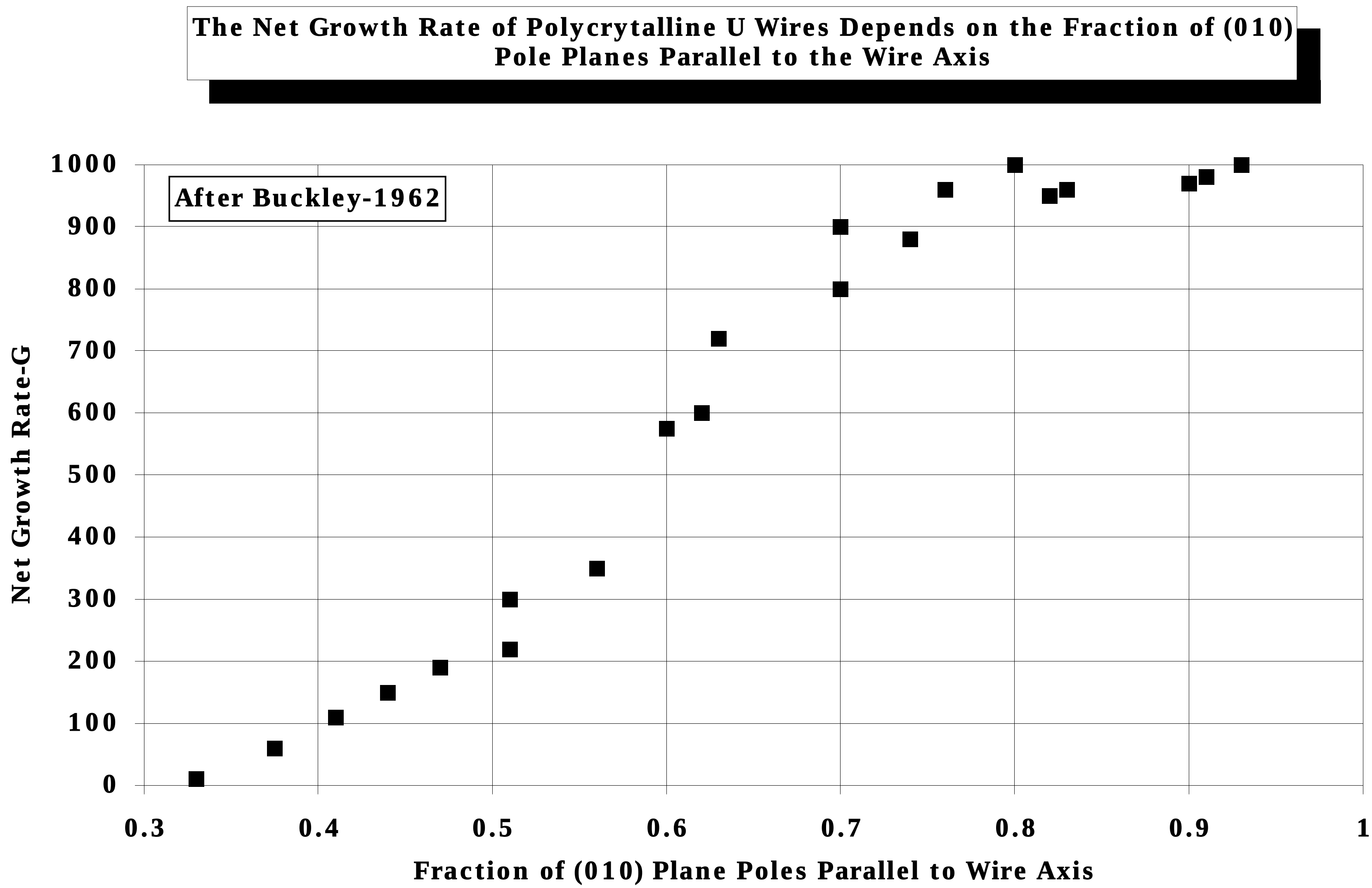
Elongated Rod (figure)

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**


The Growth Constant of U is Greatly Reduced at Higher temperatures
After Buckely-1964
100000
10000
1000
100
10
Net Growth Rate-G (% Growth/% BU)
0
100
200
300
400
500
600
700
800
Irradiation Temperature-°K



The Net Growth Rate of Polycrytalline U Wires Depends on the Fraction of (010) Pole Planes Parallel to the Wire Axis
After Buckley-1962
1000
900
800
700
600
500
400
300
200
100
0
Net Growth Rate-G
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Fraction of (010) Plane Poles Parallel to Wire Axis

Temperature Effects

- Low temperatures---> Random Loops (interstitials)
- Moderate Temp.---> Vacancy Loops Aligned (80-350 °C)
- Above 500°C -----> Loops anneal out

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 cavitational swelling by reducing grain size and increasing σ_y

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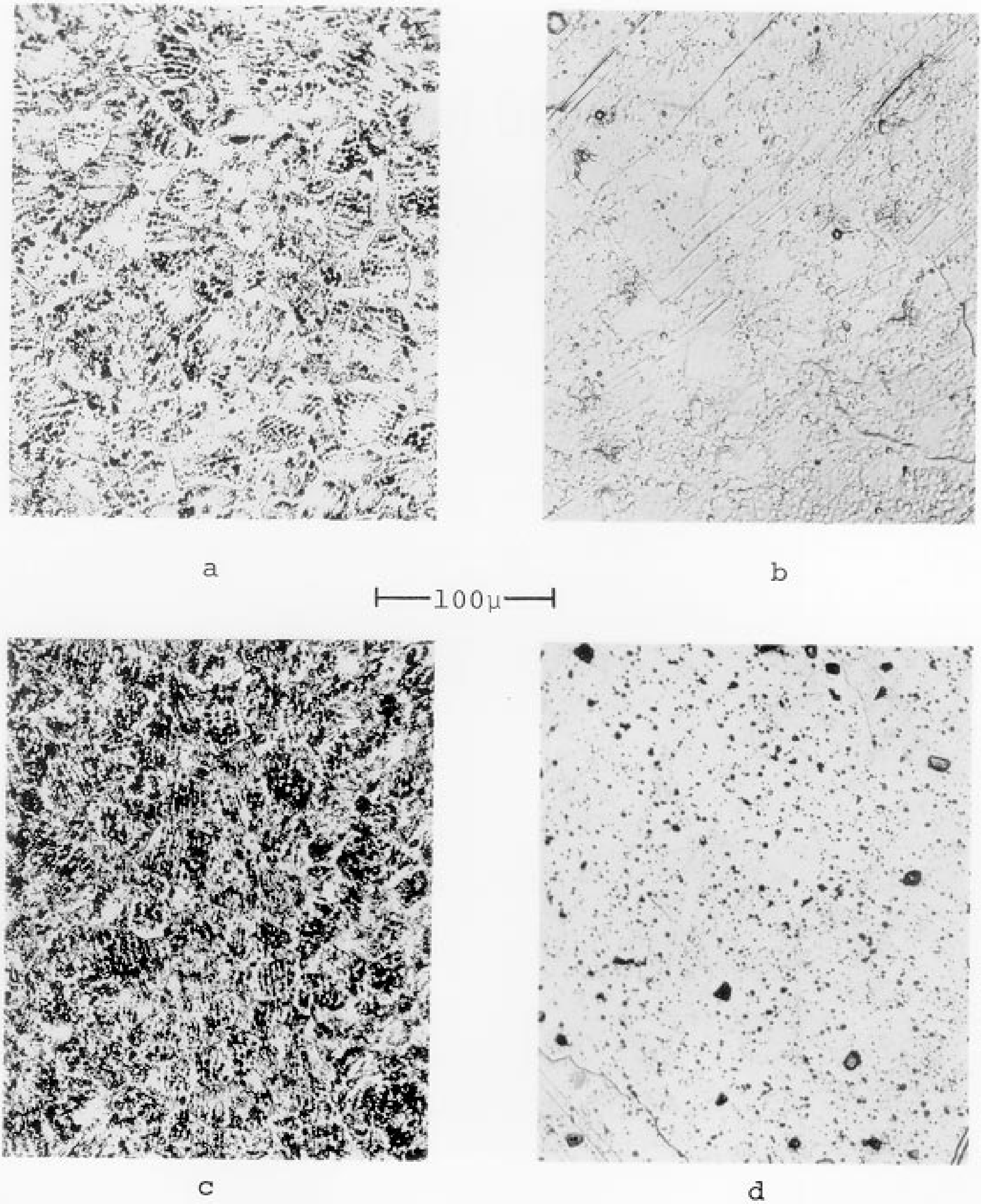
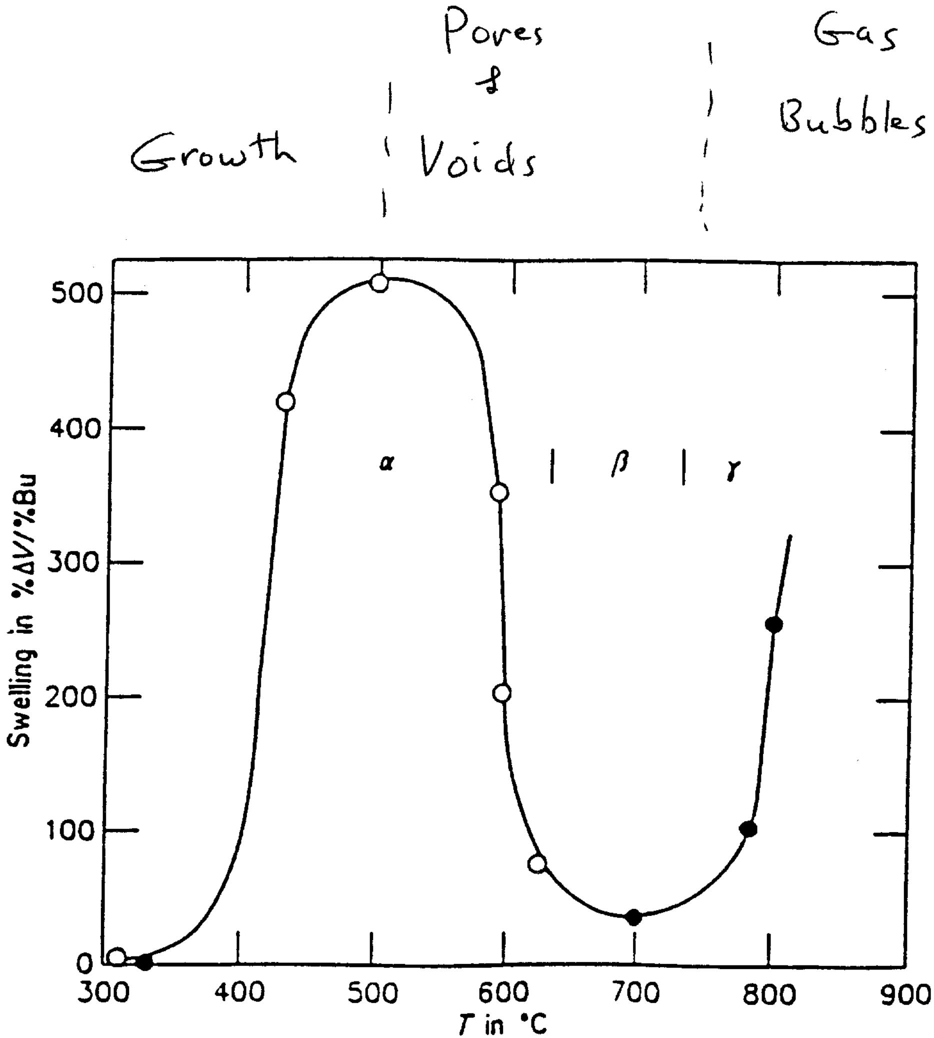
Breakaway Swelling *(Figure)*

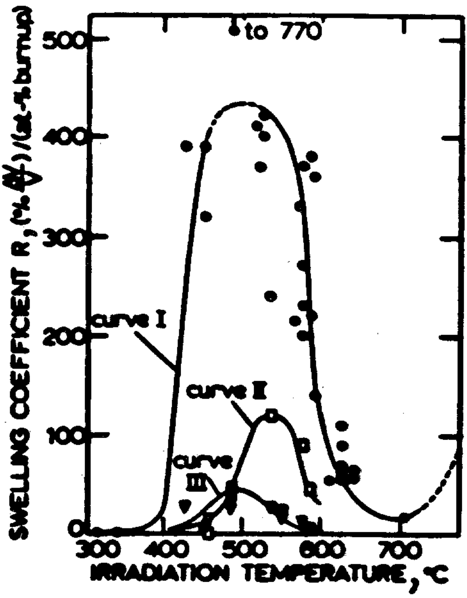


a) AFTER 0.15% B.U. AT 575°C-67 bar
b) SAMPLE IN a) AFTER 900°C-1000 bar ANNEAL
c) AFTER 0.16% B.U. AT 550°C-34 bar
d) SAMPLE IN c) AFTER 900°C-340 bar ANNEAL

FIGURE 1. PRESSURE EFFECT ON CAVITATIONAL SWELLING

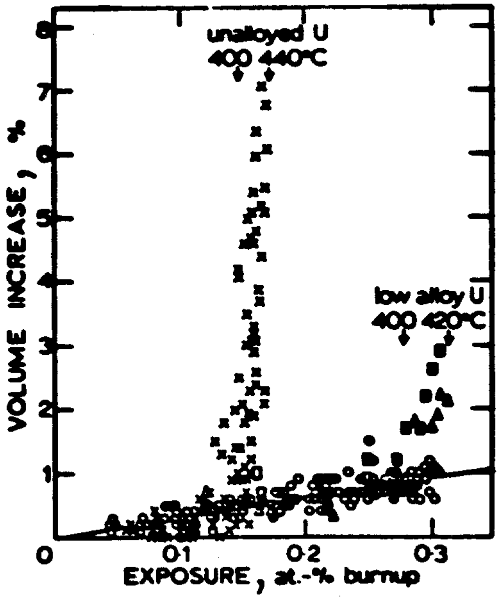


Growth
Pores
&
Voids
Gas
Bubbles
500
400
300
200
100
0
α
β
γ
Swelling in %ΔV/%Bu
300
400
500
600
700
800
900
T in °C



▲ high-purity U, 1000 lb/in²; ● high-purity U (5–86 ppm C), curve I; □ U (400 ppm C) +140 ppm Fe+95 ppm Si, curve II; ▽ U (500 ppm C) +400 ppm Fe+85 ppm Si+ 645 ppm Al, curve III

3 Temperature dependence of swelling in high-purity uranium and dilute uranium alloys



× unalloyed U; ○ 105 ppm avg Si; ■, ▲, ● 75–85 ppm Si; solid line depicts swelling due to fission products

4 Swelling of uranium and uranium–silicon alloys as a function of exposure (and concurrently varying temperature)[16]

Physical Properties of the Six Plutonium Allotropes

Phase	Crystal Lattice	Number of Atoms Per Unit Cell	Transition to Next Higher Phase, °C	Density gm/cm^3	Coeff. of Thermal Expansion x 10^{-6} per °C	Volume Change on Transformation, %
Alpha	Monoclinic	16	112	19.8	46.4	α->β, 8.9
Beta	Body centered Monoclinic	34	185	17.65	38.4	β-> γ, 2.4
Gamma	Face centered Othorhombic	8	316	17.2	34.7 (a=-19.7) (b= 39.5) (c = 83.4)	γ ->δ, 6.7
Delta	fcc	4	451	15.9	-8.8	δ->δ', -0.4
Delta Prime	body centered tetragonal	2	480	16.0	-116, (a=305) (c= -659)	δ'-> ε - 3.0
Epsilon	bcc	2	640	16.51	+36.5	

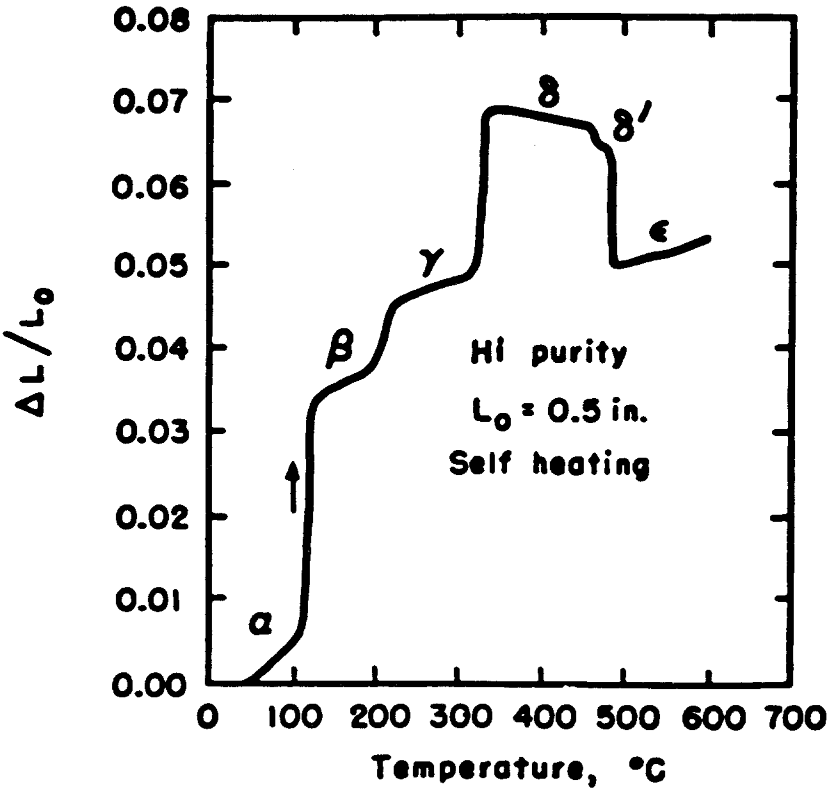


Fig. 12-2. Dilatometric curves for plutonium of normal purity and for plutonium of purity.