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Graphite progress update

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Introduction

- POCO vs. “nuclear grade” graphite
  - HOPG as an example
- Environment = LBNE
  - 1 dpa
  - ≤300ºC
  - non-oxidising environment
- Neutron *c.f.* proton irradiation
- Continuous *c.f.* pulsed irradiation
- Some recommendations

POCO vs. "nuclear grade" graphite

- POCO chosen based upon
  - past experience (irradiation stability)
  - grain structure (isotropy)
  - high strength
- Similar (historical) conclusions in fission area
  - used as specimen holders, restraints etc.
  - manufacturing limits → restricted usage
- POCO different than nuclear grades
  - ultrafine grain size (1-5 μm *c.f.* ≥10 μm)
  - fine pore structure (0.3-0.8 μm *c.f.* ≥8 μm)
  - CTE near perfect (~8 $\times$ 10^{-6} K^{-1} *c.f.* ~4 $\times$ 10^{-6} K^{-1})

POCO vs. “nuclear grade” graphite

- POCO is probably a sintered material
  - previous differences
  - no visible “binder” phase
  - often no impregnation
- POCO can have a lower graphitisation temperature than standard (2800ºC) e.g.
  - AXF-Q1 = 2300ºC
  - ZXF-5Q = 2500ºC
  - AXF-8Q1 = 2800ºC
  - affects properties and irradiation behaviour

POCO AXF-8Q1

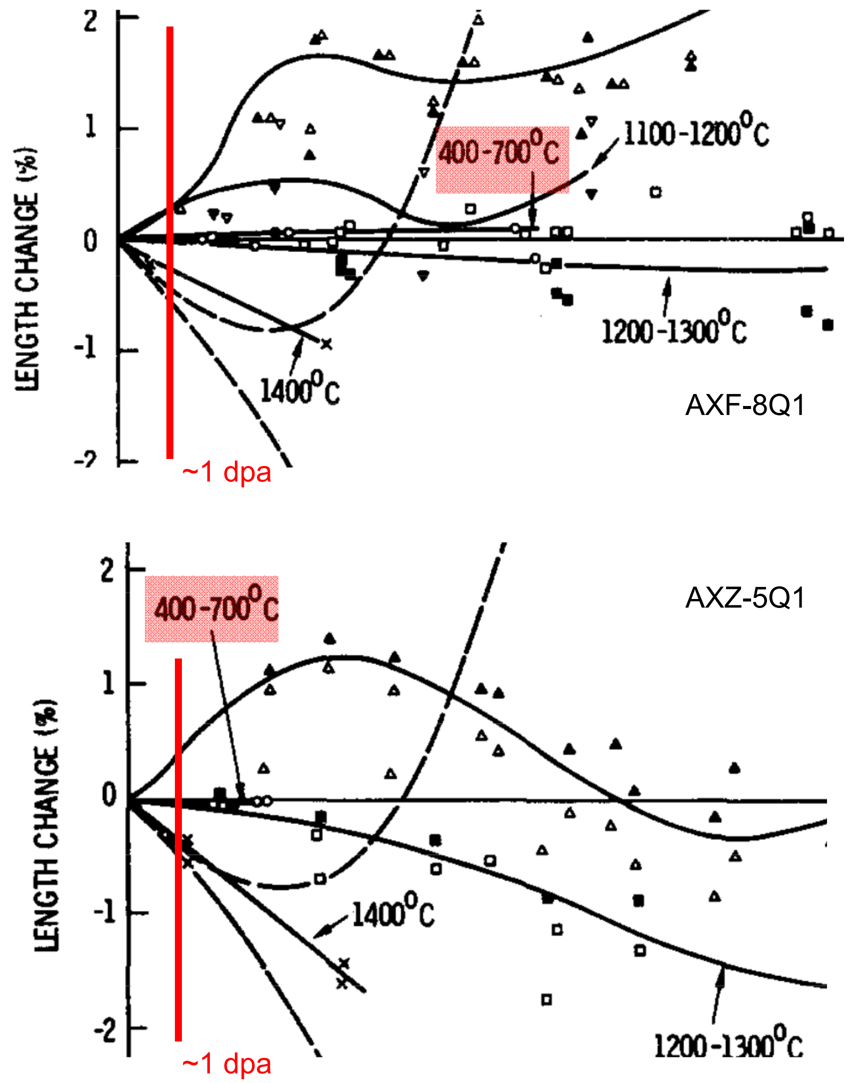
EGCR (nuclear grade)

Replica electron micrographs (Pitner, 1971)

Grade	ZXF-5Q	AXF-8Q1	AXZ-5Q	Gilsocarbon	IG-430	IG-110
Comment	candidate	historical experience (fission)	historical experience (fission)	historical experience (fission)	historical experience (fission) & similar to IG-43	historical experience (fission)
Particle size (µm)	1	5	5	500	10	20
Pore size (µm)	0.3	(0.3)	0.7	42	-	16
Density (g/cm^3)	1.78	1.80	1.66	1.81	1.82	1.77
Total porosity (% volume)	20	(20)	28	20	19	21
Open porosity (% of total)	80	(80)	90	55	65	58
Graphitisation temperature (ºC)	2500	2800	2500	≥2800	≥2800	≥2800

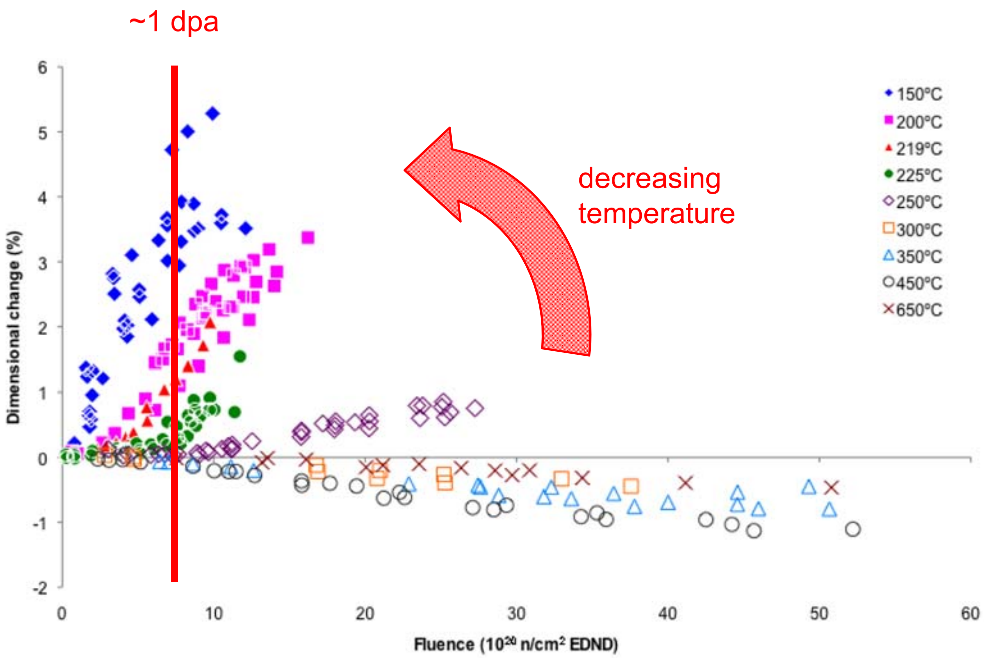
Dimensional change

- 400 to 700ºC
  - data on POCO grades
  - negligible dimensional changes
  - little data
  - nuclear grades shrink within this range
- ≤300ºC
  - no data on POCO grades
  - expect dimensional changes to be greater
    - possibly significant
  - lower temperature = greater the rate of change

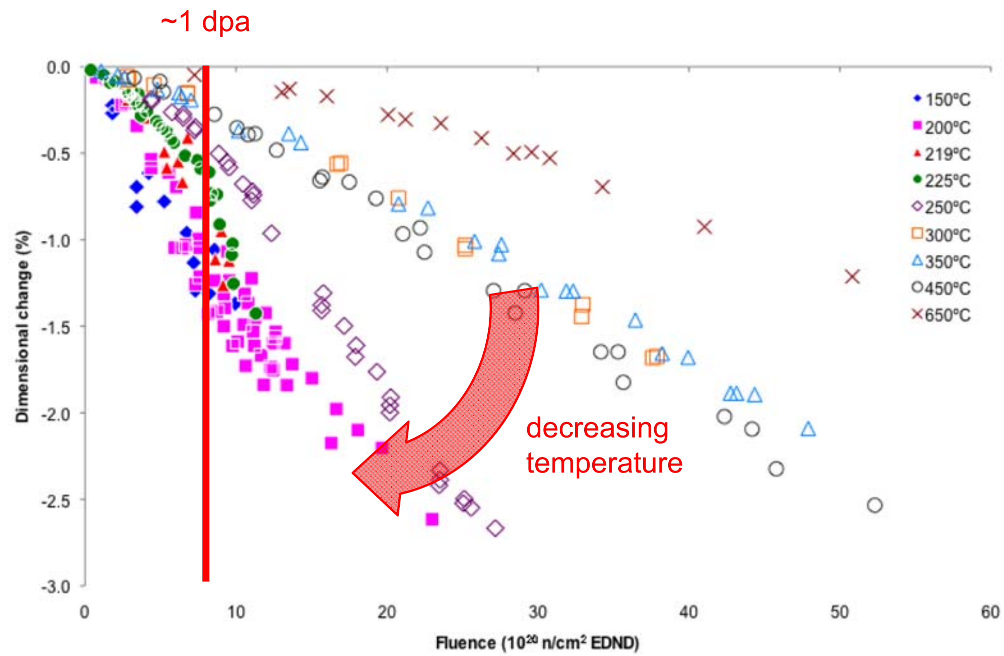


Dimensional changes (Pitner, 1971)

Dimensional change



against grain (AG)



with grain (WG)

Dimensional changes of Pile Grade A (PGA) graphite

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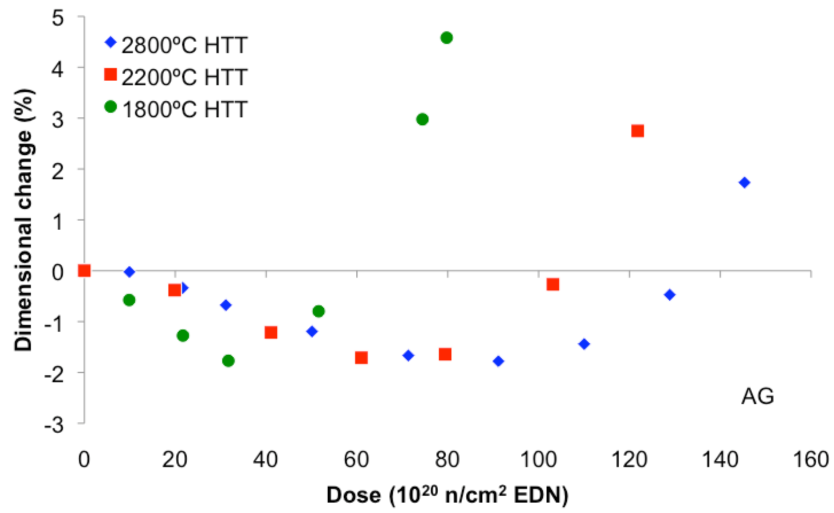
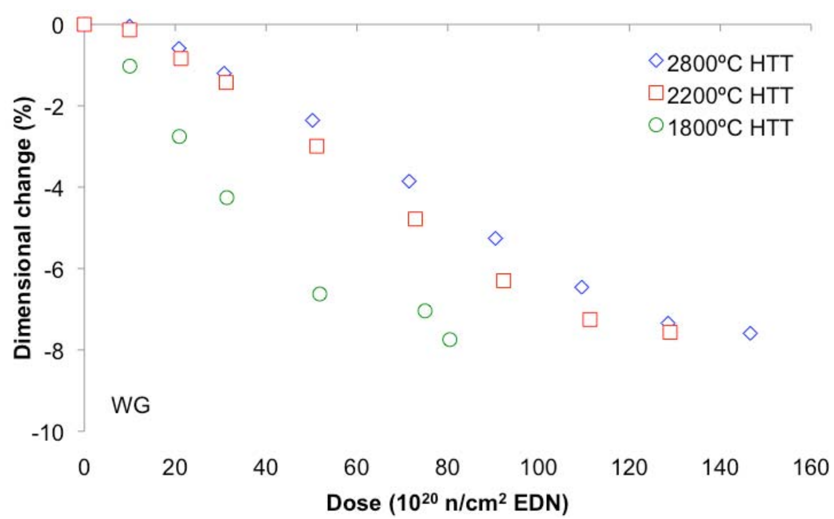
Dimensional change

- Decrease in graphitisation temperature = increase in dimensional change rate
  - at 1 dpa difference between 2500ºC and 2800ºC is likely to be negligible

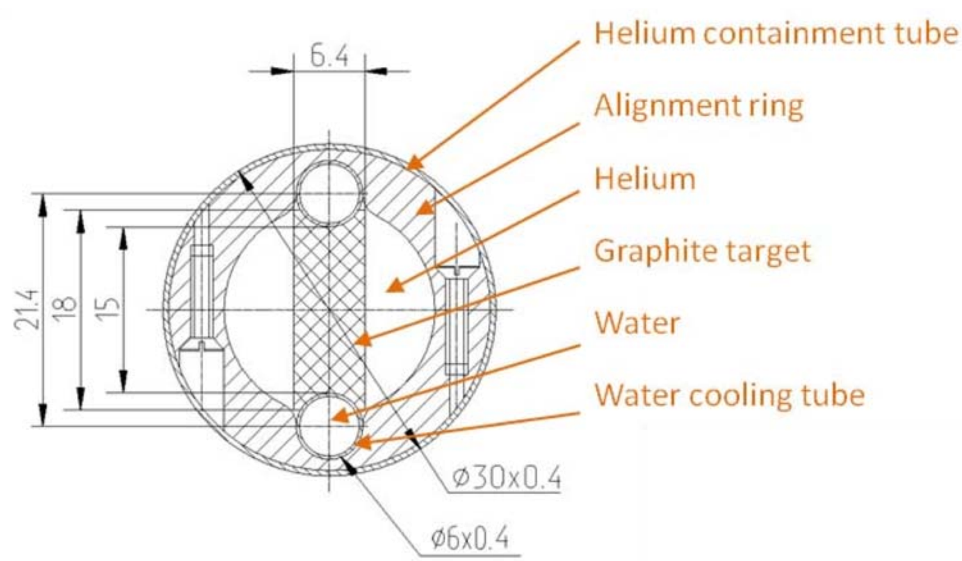




PGA graphitised to various temperatures and irradiated at 600ºC (Brocklehurst and Kelly, 1993)

Dimensional change

- Dimensional change under load
  - dimensional changes different due to irradiation creep
    - reduces stresses in graphite components
  - target under initial compressive load
    - shrinkage increases when already shrinking (≥300ºC)
    - assume expansion decreases when already expanding (<300ºC)
  - complex interaction in target
    - fluence distribution
    - temperature distribution
    - boundary conditions



Target for LBNE

Dimensional change

- Recommendations
  - keep graphite at higher temperatures (~300ºC)
  - graphitisation at 2500ºC should be ok
  - conduct stress analysis of target
    - realistic fluence and temperature distributions
- Additional recommendation
  - conduct experiments on POCO at temperatures of interest

Helium production

- Usually not considered in fission
  - negligible helium production
  - exception when graphite was doped with ^{10}B
- When helium production is not negligible
  - highly oriented pyrolytic graphite (HOPG) experiences increased dimensional changes and exfoliation/delamination/flaking of layers
    - helium trapped in cavities

HOPG doped with ^{10}B and irradiated 650ºC (Kelly and Mayer, 1969)

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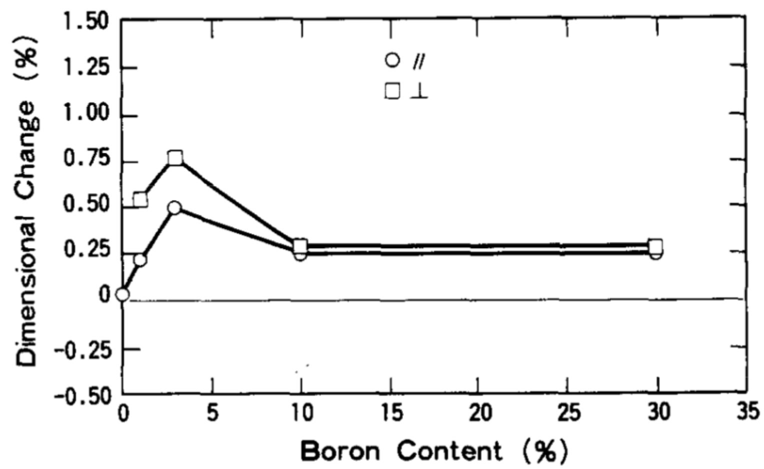
Helium production

- When helium production is not negligible
  - POCO and nuclear grade graphites have significant amounts of open porosity
    - some helium can escape
    - remainder could influence dimensional changes
      - helium effect secondary to effect of boron on nucleation of interstitial loops
- Recommendation
  - conduct further investigations and/or scoping calculations to determine relevance



Dimensional changes of boronised graphite irradiated to 0.13 dpa at 300ºC (Maruyama and Harayama, 1992)

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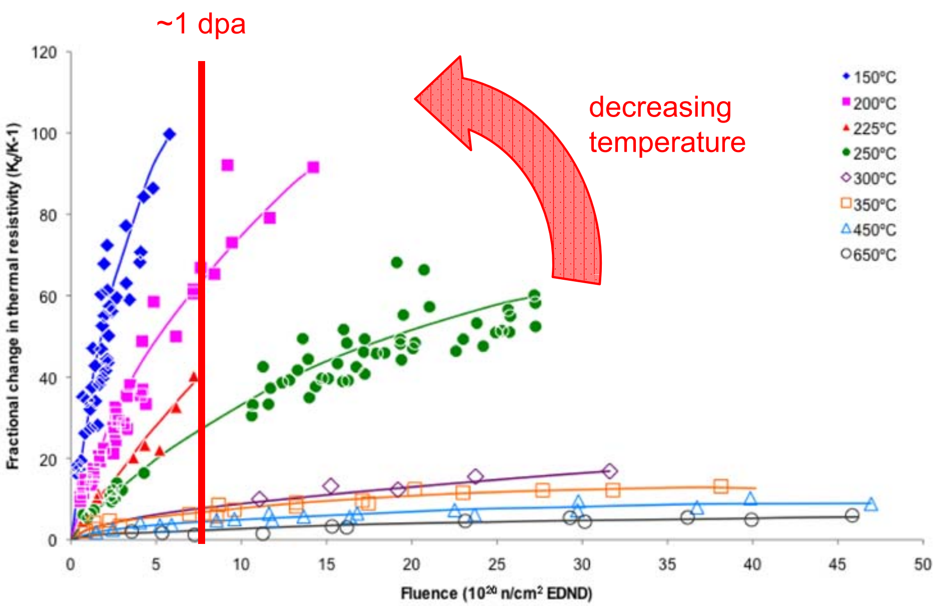
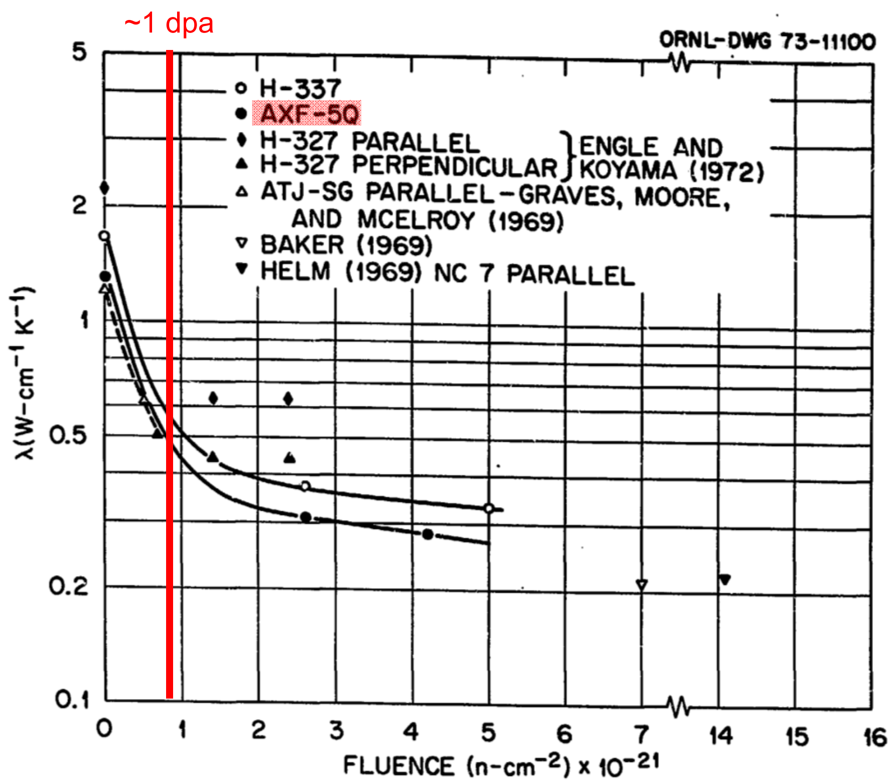
Thermal conductivity

- Rapid reduction in thermal conductivity with fluence
  - rate of decrease increases with decreasing temperature



Thermal conductivity of PGA irradiated at various temperatures (Birch and Brocklehurst, 1987)



Thermal conductivity of various irradiated graphites (Moore *et al*., 1973)